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***Human Readiness Level Scale in the System
Development Process***



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ACRONYMS

AAF	Adaptive Acquisition Framework
AAMI	Association for the Advancement of Medical Instrumentation
ANSI	American National Standards Institute
APA	American Psychological Association
ASTM	American Society for Testing and Materials
BA	Budget Activity
BCPE	Board of Certification in Professional Ergonomics
DAU	Defense Acquisition University
DBS	Defense Business Systems
DOD	Department of Defense
DOE	Department of Energy
GPS	Global Positioning System
GUI	Graphical User Interface
HF	Human Factors
HFACS	Human Factors Analysis and Classification System
HFACS-MA	Human Factors Analysis and Classification System for Maritime Accidents
HFES	Human Factors and Ergonomics Society
HIDP	Human Integration Design Processes
HMD	Helmet-Mounted Display
HOF	Human and Organizational Factors
HRL	Human Readiness Level
HSI	Human Systems Integration
IMPRINT	Improved Performance and Research Integration Tool
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
KPP	Key Performance Parameter
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
NUREG	Nuclear Regulation
O&M	Operations and Maintenance
PICMET	Portland International Joint Conference on Management of Engineering and Technology
PPE	Personal Protective Equipment
RDT&E	Research, Development, Test, and Evaluation
SAE	Society of Automotive Engineers
SHERPA	Systematic Human Error Reduction and Prediction Approach
STD	Standard
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level

DEFINITIONS

Disuse: Neglect or underutilization of technology features intended to effectively support mission accomplishment.

Environment: The external context in which the technology under design will function. Depending on the organization, environment may be one domain used in human systems integration. The Department of Defense and all its Service components no longer manage environment as a human systems integration domain. Further, in some organizations, environment is combined with the safety and occupational health domain. Activities within this domain address interactions between the technology and humans within the anticipated operational conditions. The scope varies significantly according to the system definition and may include physical, cyber, geopolitical, social, market, and organizational considerations. The scope nearly always includes human use environments characterized in terms of the visual, auditory, tactile, motion, and climatic environments in which tasks will occur (e.g., luminance, glare, ambient noise, vibration, weather, and environmental hazards).

Ergonomics: The International Ergonomics Association and the Human Factors and Ergonomics Society define ergonomics as the scientific discipline concerned with understanding interactions among humans and other elements of a system and the profession that applies theory, principles, data, and methods to design in order to optimize human wellbeing and overall system performance. Key goals of ergonomics are to decrease the risks of musculoskeletal injuries, illness, and work discomfort while improving the quality of work life and worker performance. The term is frequently used synonymously with human factors engineering.

Graphical User Interface: The use of direct manipulation and icons or other graphical symbols on a display to interact with a computer (Stramler, 1993).

Habitability: Habitability is one domain within human systems integration. Activities in this domain focus on living and working conditions necessary to sustain the morale, safety, health, quality of life, quality of work, and comfort of the target population. Habitability considerations can include the physical environment (space, lighting, and ventilation), the cultural environment (beliefs, customs, and behaviors), the social environment (relationships, interactions, and support networks), personal services (religious and medical), and living conditions (breathing and personal hygiene).

High-Fidelity Simulation: A functioning and realistic approximation of the intended final system with respect to form, fit, and function as well as the operational environment in which it functions. Simulations may involve hardware, software, or both.

Human Capabilities and Limitations: Traits and states that define what humans can and cannot do or do well. Key areas of consideration for human capabilities and limitations include sensation/perception (vision, audition, touch, taste, olfaction, vestibulation, proprioception, and interoception), information processing (cognitive functions such as reading, interpretation, attention, memory, and decision making), and action (anthropometrics, biomechanics, physiological capacity, motor skills, and reaction times). Capabilities and limitations are typically described in terms of statistically defined ranges of performance for basic tasks across people and conditions. Capabilities and limitations can be situationally dependent; i.e., a

capability in one context (the ability to read text on a computer screen) can become a limitation if the computer screen is located one mile away.

Human-Centered Evaluation: Systematic data collection and analysis of human interactions within a system to assess relevant and applicable elements of human performance and to determine the extent to which specified criteria have been met. Methods may include instrumented measurement, observations, interviews, and surveys to collect objective data and subjective user feedback.

Human-Centered Guidelines: Established principles, standards, and guidance to inform human systems designs and promote efficient human-technology interactions. Example guidelines include designing for simplicity and consistency, minimizing memory requirements, enhancing system transparency to users, incorporating redundancy, using feedback to improve learning, optimizing human-system function allocations, and designing for fail-safe operations.

Human Factors Engineering: Human factors engineering is one domain within human systems integration. Human factors is based on a body of knowledge about human abilities, limitations, and other characteristics relevant to system design. Human factors engineering is the application of human factors knowledge to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use. Human factors engineering is a multidisciplinary field that encompasses aspects of ergonomics; anthropometry; biomechanics; human-computer interaction; user experience; cognitive engineering; industrial engineering; and organizational, cognitive, and experimental psychology.

Human-Machine Function Allocation: Strategies for distributing system functions and tasks across people and technology in order to maximize performance and optimize user workload. Function allocations may be static, or they may vary dynamically over time.

Human Performance: All observable and measurable properties of individual or team behaviors that may impact the quality of system or mission accomplishment, as expressed through various metrics. Common human performance metrics include accuracy, response and completion times, error types and frequency, workload, situation awareness, user satisfaction, usability, fatigue, strain, risk of injury, reach, fit, layout, comfort, accessibility, learning rate, training demands, and manpower and personnel impacts.

Human Performance Issue: A human characteristic or state that may result in a performance risk or adverse condition in a system or operation. For example, if effective use of a proposed system involves monitoring and interpretation of visual displays, then characteristics of human visual acuity, the perceptibility of alternative display technologies, and the ability to process display information for a given design represent potential human performance issues. If users cannot adequately see the displays or cannot interpret and use the information in the displays, they may not be able to effectively perform required tasks.

Human Performance Modeling: Approaches and tools for representing and analyzing human performance and human systems designs via analytic and computer-based models. Examples include the ACT-R cognitive modeling tool, the Jack modeling software and simulation tool for ergonomics, the Improved Performance and Research Integration Tool (IMPRINT) tool for

simulation and modeling of human workload, and the 3D Static Strength Prediction Program for predicting static strength requirements for various tasks.

Human Readiness: Readiness of a technology for use by the intended human users in the specified intended operational environment. In this standard, human readiness does not refer to the physical or mental readiness of human operators who will use the technology in order to accomplish their mission work.

Human-System Interface: Any region or point at which humans interact with other system components such as hardware, software, procedures, environment, and other humans (Stramler, 1993).

Human Systems Design: The design of the technology or system with respect to all interactions with human users of all types. Human systems design includes design of the physical system, software interface, perceptual features, interaction methods, functionality, automation interaction, processes and procedures, task flows, and training. It includes a consideration of the broader organizational system, culture, and environment of which the system is a part. It also includes the design of technologies and concepts for fostering human performance augmentation (e.g., human-centered concepts and applications).

Human Systems Experts: Professionals with extensive training and experience in human factors engineering, human systems integration, or related field who ensure that human systems considerations are adequately identified and addressed. Human systems experts typically have advanced degrees or certificates in human factors, human systems integration, industrial engineering, safety, psychology, physiology, or a related field. Practitioners may also obtain professional certification in ergonomics, human factors, or user experience through the Board of Certification in Professional Ergonomics (BCPE). Human systems experts may be practitioners specializing in a particular human systems integration domain (e.g., human factors engineer, safety engineer, training system developer, or manpower planner).

Human Systems Integration: The Department of Defense Joint Human Systems Integration Working Group defines human systems integration as a disciplined, unified, and interactive approach integrating human considerations into system design in order to optimize total system performance and minimize lifecycle costs. Human systems integration addresses multiple human domains of a system. The specific domains used are organization-dependent, but they typically include human factors engineering; safety and occupational health; manpower, personnel, and training; environment; habitability; and survivability. These domains are highly interrelated and often overlap.

Human Systems Mapping: Linking human needs, capabilities, limitations, and characteristics directly to expected operational and system demands to understand human performance implications, identify requirements to support human performance, and mitigate likely scenarios for human error.

Manpower, Personnel, and Training: Manpower, personnel, and training are three related human systems integration domains that are frequently considered concurrently because a change in strategy for one domain typically impacts one or both of the other domains. Manpower

considers the number and type (military, civilians, and contractors) of qualified people required to operate, maintain, train, and support a system. Personnel considers the knowledge, skills, abilities, and limitations of system users. Training considers instruction, education, and on-the-job training as well as training systems and methods needed to provide personnel with the specific knowledge, skills, and abilities required to successfully perform system tasks. Training ensures consistency between the training material and the knowledge, skills, and abilities needed on the job.

Mission: A specific task or objective of an individual or team.

Mission-Relevant Simulation: Tools that represent key aspects of the system and mission environment, including relevant tasks and conditions. Computerized tools for simulation are often used, including realistic displays of system information and environmental conditions on large-screen displays or virtual reality devices. Simulations may occur within the laboratory or other environment using part-task or full-mission simulators, or they may involve exercises in actual environments.

Misuse: Improper interaction with technology features in ways other than intended, resulting in reduced mission effectiveness, mission failure, personnel injury or casualty, or other undesired effect. Such interactions can be unintentional occurrences or intentional violations.

Operational Envelope: The set of limits and conditions within which a system may be operated to ensure conformance with its safety analysis.

Operational Environment: The comprehensive set of factors that can directly or indirectly affect system operations and mission accomplishment. Such factors include the physical environment, organizational structures, climate, requirements, rules, procedures, and the socio-political environment.

Operational/System Demands: Requirements imposed on human users in order to accomplish task goals in both normal and non-normal conditions.

Operational Use Conditions: Operational and system demands impacting expected conditions such as number of users, mobility, pace of operations, stress, fatigue, and time of use for a system.

Part-Task Testing: The act of decomposing whole tasks into smaller parts that are more amenable to testing and demonstration. These parts may not always be tested or demonstrated in consecutive order.

Proof of Concept: Initial rough and incomplete demonstration of new functionality. Key elements of the technology or system are not yet integrated or representative. A proof of concept builds confidence in a design plan by showing that intended functionality is possible, given further development.

Prototype: Representation of all or part of a proposed system that transforms a concept into physical or virtual form, offering aspects of the features, the functionality, or performance expected in the final configuration. Key elements can be used to support analysis, design, and evaluation; but the prototype may be limited in some way (e.g., ad hoc hardware, mock

materials, or only portions of hardware or software). Prototypes can range from simple paper and pencil efforts to complex full-fidelity simulators and must be commensurate with the current level of development and the level of testing required.

Qualified System: A system that has been verified, validated, and approved as suitable for its intended mission in accordance with an established qualification process.

Representative Users: Individuals who have the range of relevant characteristics for the intended user population. Representative users may or may not be the final end users of the fielded system. Representative users may include individuals in roles such as operations, logistics, maintenance, sustainability, security, support, and training.

Safety and Occupational Health: Safety and occupational health is one domain within human systems integration (depending on the organization, it may be separated into two domains). Activities within this domain focus on addressing hazards to minimize the risk of death, injury, acute or chronic illness, or disability to humans.

States: Temporary conditions experienced for a short period of time, depending on circumstances (e.g., anxiety before taking a test required to pass a training course). States can refer to systems or to users.

Survivability: Survivability is one domain within human systems integration that facilitates system operation and personnel safety during exposure to hostile situations or environments. Some organizations, such as the Department of Defense, refer to this domain as force protection and survivability. Activities in this domain focus on mitigating hostile actions and enabling personnel to avoid or withstand hostile environments, while accomplishing their mission. The survivability hierarchy for threats is to avoid detection, avoid engagement, avoid or absorb damage/injury, and avoid destruction/death. In a broader sense, survivability refers to the ability to maintain functionality or to remain robust after a natural or human-caused disturbance, accident, or failure. Survivability is a subset of resilience.

System: An integrated collection of facilities, parts, equipment, tools, materials, software, personnel, or techniques that produce an organized whole capable of performing or supporting some function (Stramler, 1993). A system can be physical or conceptual or a combination of both. An engineered system is designed to interact with an anticipated physical and operational environment to achieve specific goals.

Technology: Techniques, tools, and machines created by humans to accomplish a specific purpose. Technologies include material technologies such as equipment and software as well as non-material technologies such as training techniques and operational concepts.

Trade Studies: Research to identify viable options(s) and analyze the alternatives by applying specific decision criteria.

Traits: Stable and enduring human characteristics and patterns of behavior manifested consistently across a wide range of circumstances (e.g., introversion versus extraversion).

Usability: The extent to which a system, product, or service can be used by the intended users to achieve specified goals with effectiveness, efficiency, and satisfaction in a given context of use (ISO 9241-220).

Usage Scenario: Scenario designed to demonstrate and test aspects of the human systems design throughout development. Usage scenarios can be derived from larger mission scenarios for the broader system, but they may need to be tailored to address specific areas of concern for user performance (e.g., automation failures and high-tempo events). In other cases, appropriate scenarios in which to conduct human systems testing may not exist at all and must therefore be developed by human systems experts. As such, some usage scenarios may be standalone scenarios separate from existing mission scenarios.

Use: Interaction with a technology in the intended manner for which it was designed or in ways that can reasonably be foreseen to occur (e.g., projected misuse or errors that may occur during technology interaction).

User: Any person who interacts with a system, product, or service. Users of a system, product, or service include people who operate the system, people who use the output of the system, and people who support the system (ISO 9241-220). Support roles may involve logistics, maintenance, sustainability, security, cyber, and other roles dictated by system context.

User Needs: Prerequisites identified as necessary for human users to accomplish the tasks within their assigned roles and achieve intended outcomes (ISO 9241-220). Human user needs may be functional, task, cognitive, physical, or operational.

User Satisfaction: The extent to which the user's physical, cognitive, and emotional responses that result from interaction with a system, product, or service meet user needs and expectations (ISO 9241-220).

Validation: The set of activities ensuring and gaining confidence that a system is able to accomplish its intended use, goals, and objectives (i.e., meet stakeholder requirements) in the intended operational environment. Validation determines whether the right system was built (ISO/IEC/IEEE 15288: 2015). Successful validation typically signifies approval to begin full-rate production and fielding.

Verification: The set of activities that compares a system or system element against the required characteristics. Activities include, but are not limited, specified requirements, design description, and the system itself. Verification determines whether the system was built right (ISO/IEC/IEEE 15288: 2015).

FOREWORD

This standard was developed by the Human Factors and Ergonomics Society (HFES), using the rules and procedures of the American National Standards Institute (ANSI). This edition is the first revision of the *Human Readiness Level Scale in the System Development Process*.

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1.0 PURPOSE AND BACKGROUND

1.1 Purpose

The purpose of this standard is to define the nine levels of a Human Readiness Level (HRL) scale and provide guidance for their application. The purpose of the HRL scale is to provide a mechanism to evaluate, track, and communicate the readiness of a technology or system for safe and effective human use that can be applied in the context of existing systems engineering and human systems integration (HSI) processes. This standard pertains to any organization involved in the design and development of technologies and systems for multiple classes of intended human users. It is applicable to any type of technology under development in the military, government, federal agencies, industry, and academia. The HRL scale is designed to be applied by trained and experienced human systems experts to ensure that the elements of human readiness in this standard are satisfactorily addressed.

1.2 Background

Proper attention to human systems design during the development of technological systems is a significant factor in minimizing or preventing human error, which can account for 60% to 90% of accidents and incidents across a wide range of systems (Chen, Wall, Davies, Yang, Wang, & Chou, 2013; Ghasemi, Nasleseraji, Hoseinabadi, & Zare, 2013; Shappell, Detwiler, & Boquet, 2006; Vaurio, 2009). In addition, costs associated with system training, operations, and maintenance; which account for 35% to 70% of overall system costs; can be reduced when the human component of the system is addressed early and often throughout design and development (Balut, Gordon, Bishop, Cann, & Collins, 1999). A recent review indicated that operations and support costs account for 63% of total lifecycle costs for major air, land, and sea systems in the Department of Defense (DOD), with significant increases in costs over the past 20 years (Boito, Conley, Fleming, Ramos, & Anania, 2018). However, many system development programs have been deficient in applying established and scientifically-based HSI processes, tools, guidance, and standards, resulting in suboptimal systems that degrade mission performance (Pew & Mavor, 2007). Approximately 70% of lifecycle costs are committed by the time the detailed design phase occurs, with costs of system modifications up to 60 to 100 times higher once the system design has been finalized (Gawron, Dennison, & Biferno, 1996; Pressman, 1992). Consequently, it is critical that human systems design issues be considered early during system design in order to reduce subsequent operations and maintenance costs, minimize accidents and incidents that negatively impact safety and costs, and improve the effectiveness of the combined human-system for achieving mission outcomes.

2.0 SCOPE

This standard defines the HRL scale and provides the guidance necessary for human systems experts to apply it. This standard uses the term *human readiness* to refer to the readiness of a technology for use by the intended human users in the specified intended operational environment. Addressing the current physical or mental readiness of human operators who will use the technology in order to accomplish their mission work is outside the scope of this standard. Further, although the HRL scale is applied in the context of existing systems

engineering and HSI processes, this standard does not provide a detailed process for conducting HSI assessments. Existing human systems engineering practices, processes, and tools are critical to provide the foundation from which HRL ratings can be derived; however, the purpose of the HRL scale is not to dictate the processes and tools that should be used or how they should be used. This type of information resides in standards such as SAE6906 *Standard Practice for Human Systems Integration* and in organization-specific HSI handbooks and guidance. For example, SAE6906 provides detailed requirements specifying how to integrate HSI processes within the overall systems engineering approach throughout the system lifecycle.

3.0 RELATED STANDARDS AND DOCUMENTS

This standard may be applied with other industry, national, and international standards and handbooks.

- ANSI/AAMI HE75:2009 *Human Factors Engineering: Design of Medical Devices*
- ANSI/HFES 100-2007 *Human Factors Engineering of Computer Workstations*
- *APA Handbook of Human Systems Integration* (2015)
- ASTM E2350-19 *Standard Guide for Integration of Ergonomics/Human Factors into New Occupational Systems*
- ASTM F1337-10(2015) *Standard Practice for Human Systems Integration Program Requirements for Ships and Marine Systems, Equipment, and Facilities*
- HF-STD-001B *Human Factors Design Standard* (Federal Aviation Administration)
- HFES 200-2008 *Human Factors Engineering of Software User Interfaces*
- HFES 300-2004 *Guidelines for Using Anthropometric Data in Product Design*
- ISO 9241-220 *Ergonomics of Human-System Interaction Part 220: Processes for Enabling, Executing and Assessing Human-Centred Design within Organizations*
- Mil-Std-1472H *Department of Defense Design Criteria Standard: Human Engineering*
- Mil-Std-882E *Department of Defense Standard Practice: System Safety*
- NASA-STD-3001, Volumes 1 and 2, *NASA Space Flight Human System Standards*
- NASA/TP-2014-218556 *Human Integration Design Processes (HIDP)*
- NUREG-0700 *Human-System Interface Design Review Guidelines*
- SAE6906 *Standard Practice for Human Systems Integration*

4.0 HUMAN READINESS LEVEL SCALE

4.1 Overview

The HRL scale is a simple nine-level scale developed as an adjunct to complement and supplement the existing Technology Readiness Level (TRL) scale widely accepted and used throughout government and industry (Department of Defense, 2017; Government Accountability Office, 2020; Nolte, 2008; Olechowski, Eppinger, and Joglekar, 2015). The HRL scale is further designed to mirror many features that have proven successful for the TRL scale. Some HRL level names were intentionally chosen to reflect names in the TRL scale for ease of translation and comparison between the two scales. Like the TRL scale, the HRL scale provides a common terminology to communicate status within and among diverse organizations. The HRL scale is

also structured to actively implement demonstration, testing, and verification that repeatedly address human readiness, enabling design teams to effectively plan anticipated levels of effort remaining to achieve the desired level of human readiness. Like the TRL scale, the HRL scale provides a mechanism to prevent integrating technologies before they are ready, supporting management of program schedule and cost risks. The HRL scale also fills a gap in the current TRL scale. Specifically, the TRL scale does not capture the human-related aspects of technology development and their critical role in the readiness of a technology for operational use.

While the TRL scale focuses on technical maturity, the HRL scale emphasizes the readiness of a developing technology for safe and effective human use (see Table 4-1). The HRL scale is intended to fully incorporate the human element of the system so that human systems issues can be captured and mitigated as early as possible during design and development when relevant decisions are being made (e.g., functionality, form, weight, layout, and automation). Early and proactive attention to the human element in the system design process significantly minimizes the cost and disruption associated with supporting human use, ultimately reducing human error in operational systems and promoting safe and effective human-system performance.

Table 4-1. Nine Levels of the HRL Scale

Phase	HRL Level
Basic Research and Development Scientific research, analysis, and preliminary development on paper and in the laboratory occur. This phase culminates in a validated proof of concept that addresses human needs, capabilities, limitations, and characteristics.	HRL 1: Basic principles for human characteristics, performance, and behavior observed and reported HRL 2: Human-centered concepts, applications, and guidelines defined HRL 3: Human-centered requirements to support human performance and human-technology interactions established
Technology Demonstrations The technology is demonstrated at increasing levels of fidelity, first in the laboratory and later in relevant environments. This phase concludes with demonstration of a representative system in a high-fidelity simulation or actual environment, with evaluation of human systems designs provided by representative users.	HRL 4: Modeling, part-task testing, and trade studies of human systems design concepts and applications completed HRL 5: Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design HRL 6: Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment
Full-Scale Testing, Production, and Deployment Final testing, verification, validation, and qualification occur, with human performance evaluations based on representative users. This phase concludes with operational use of the system and continued systematic monitoring of human-system performance.	HRL 7: Human systems design fully tested and verified in operational environment with system hardware and software and representative users HRL 8: Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users HRL 9: System successfully used in operations across the operational envelope with systematic monitoring of human-system performance

The HRL scale provides organization and program management with a simple rating (ranging from 1 to 9) of the level of maturity of a technology with respect to its readiness for human use. The HRL scale focuses on the degree to which human systems evaluation activities and processes have been completed to demonstrate that a relevant technology or system achieves the level of human readiness needed to meet desired mission objectives. The goal of the HRL scale is to support managers and decision makers in balancing time and resource investments necessary to maximize a technology or system's readiness for human use.

4.2 HRL Scale Descriptions

Table 4-2 provides additional details to describe the primary intent for the evaluations that occur at each of the nine levels in the HRL scale. Like the TRL scale, the HRL scale begins at a basic exploratory level and concludes with operational use of the system by its intended users.

Table 4-2. Descriptions for Each HRL Level

HRL Level	Description
HRL 1: Basic principles for human characteristics, performance, and behavior observed and reported	This first level of human readiness observes and reports basic principles for human characteristics, performance, and behavior. It is a broad, high-level exploration of human capabilities and limitations and basic human-centered issues and risks relevant to a developing concept or proposed application.
HRL 2: Human-centered concepts, applications, and guidelines defined	As practical applications are being invented or identified, implications for human involvement are analyzed concurrently. Relevant human-centered concepts, applications, and guidelines are developed to begin identifying human use requirements and provide inputs for preliminary conceptual designs. Human systems experts begin establishing objective and subjective metrics that will signal accomplishment of successful human performance for the developing technology. While HRL 2 focuses on applied research, basic human research begun at HRL 1 may continue.
HRL 3: Human-centered requirements to support human performance and human-technology interactions established	Critical characteristics and functions of the initial proof of concept are demonstrated analytically or experimentally; however, individual components are not yet integrated or representative. Analyses of human operational, environmental, functional, cognitive, and physical needs to understand requirements for supporting human user roles and meeting expected operational and system demands have been completed.
HRL 4: Modeling, part-task testing, and trade studies of human systems design concepts and applications completed	Human systems design concepts and applications are evaluated in basic laboratory environments or controlled field settings, using ad hoc modeling and part-task testing with low-fidelity prototypes and mockups that begin integrating key elements. Trade studies to analyze and identify viable human systems design options have been completed.
HRL 5: Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design	Human performance is evaluated via prototypes in mission-relevant part-task simulations or actual environments. The fidelity of key elements has increased significantly, and users participating in testing are independent from the design team and more representative of the target population. HRL 5 is the latest level to begin engaging more representative users during testing.
HRL 6: Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment	Human performance is evaluated with objective metrics in relevant high-fidelity simulated or actual environments, with a functional prototype and representative users. HRL 6 represents a major step up in demonstrated human readiness. The human-centered design is essentially finished, though minor modifications may still be made at subsequent levels.
HRL 7: Human systems design fully tested and verified in operational environment with system hardware and software and representative users	Human performance is evaluated for the full range of usage scenarios and tasks with the final development system in an operational environment. Recommended strategies to support human use and resolve human performance issues have been satisfactorily incorporated. The final development system conforms to key human-centered guidance and requirements.

Table 4-2. Descriptions for Each HRL Level

HRL Level	Description
HRL 8: Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users	Human performance is verified with the production system in a representative environment before full-rate production and final system fielding. HRL 8 represents the final opportunity to identify and incorporate elements to support human readiness before fielding and operational use. Any remaining human use issues are satisfactorily resolved.
HRL 9: System successfully used in operations across the operational envelope with systematic monitoring of human-system performance	The qualified system is fielded in the operational environment and operated by the intended users. Human systems experts continue to monitor the fielded system and resolve emerging issues. Human performance issues, errors, and accidents are systematically analyzed to identify enhancements.

Because the HRL scale focuses on readiness for human use, the role of human users at each level becomes a much more relevant consideration as compared to the TRL scale. As stated in Table 4-2, HRL 5 is the latest level to begin engaging representative users during demonstration and testing. While it is desirable to incorporate representative users whenever possible, human systems experts may consult and collect data from any types of users who are available at any time throughout the process. Samples of convenience (e.g., college students, members of the design team, and retired operators) may be a practical option to facilitate data collection in the early phases of design and development. If representative users are available to participate, they can and should be used at any HRL level. For instance, representative users of legacy systems might be interviewed at HRL 1 and HRL 2 to understand key human-technology interactions, potential sources of human error and misuse, and potential human performance issues and risks. By HRL 5, however, it is no longer acceptable to continue using samples of convenience. Representative users must be involved at HRL 5 and above.

5.0 RELATIONSHIP BETWEEN HRL AND TRL SCALES

5.1 Mapping the HRL Scale to the TRL Scale

The HRL scale has been intentionally designed to complement and supplement the existing TRL scale to address human readiness concurrently with technical maturity. Accordingly, the nine levels in the HRL scale align directly with the nine levels in the TRL scale. The alignment is primarily attributable to the need for human systems design and evaluation activities to keep pace with design and evaluation of the rest of the technological system, when critical decisions regarding provision of hardware, software, and functionality that impact human performance are made. Delays in the conduct of activities at each HRL level can result in suboptimal technology design decisions that can undermine later human interactions in the completed system.

Table 5-1 illustrates how the nine HRL levels map to the nine TRL levels used in the DOD TRL scale. In relation to the TRL scale, the HRL scale primarily focuses on a technology's maturity with respect to human systems integration. At lower TRLs, basic principles are discovered and early applications are considered. At TRL 4 and above, the focus shifts to assessing the integration of the technology within its intended system application. Elements of the HRL scale are worded in such a way to match this technology-to-system progression seen in the TRL scale.

Table 5-1. Mapping the HRL Scale to the DOD TRL Scale

Level	HRL	TRL
1	Basic principles for human characteristics, performance, and behavior observed and reported	Basic principles observed and reported
2	Human-centered concepts, applications, and guidelines defined	Technology concept and/or application formulated
3	Human-centered requirements to support human performance and human-technology interactions established	Analytical and experimental critical function and/or characteristic proof of concept
4	Modeling, part-task testing, and trade studies of human systems design concepts and applications completed	Component and/or breadboard validation in laboratory environment
5	Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design	Component and/or breadboard validation in relevant environment
6	Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment	System/subsystem model or prototype demonstration in a relevant environment
7	Human systems design fully tested and verified in operational environment with system hardware and software and representative users	System prototype demonstration in an operational environment
8	Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users	Actual system completed and qualified through test and demonstration
9	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance	Actual system proven through successful mission operations

5.2 Assessing Program Risk Due to HRL-TRL Misalignment

Ideally, design and development activities occur such that the TRL and HRL levels remain aligned. That is, the human systems work on a given program should be conducted in parallel with the technical work focused on maturing the technology. Misalignment between the TRL and HRL ratings may generate varying levels of program risk, depending on the phase of development and the extent of the discrepancy. To minimize program risks impacting cost, schedule, and performance as well as risk to the system's human users of fielding a technology that is not ready for human use, progression through the HRL scale should closely mirror progression through the TRL scale, as shown by alignment between the TRL and HRL scales in Table 5-1. In practice, however, one of two situations can potentially occur: (1) the HRL rating lags the TRL rating, or (2) the TRL rating lags the HRL rating.

Figure 5-1 depicts a program risk matrix that takes these considerations into account. As shown in the figure, five levels of risk associated with discrepancies between HRL and TRL ratings are defined:

- **Not Applicable (N/A):** This combination is not possible because it is precluded by the HRL definitions
- **Low:** Low likelihood of inadequate human-system performance with minor impacts on mission performance
- **Moderate:** Moderate likelihood of inadequate human-system performance with moderate impacts on mission performance
- **High:** High likelihood of inadequate human-system performance with major impacts on mission performance
- **Very High:** Very high likelihood of inadequate human-system performance with severe or catastrophic impacts on mission performance

		TRL Rating								
		1	2	3	4	5	6	7	8	9
HRL Rating	1	L	M	H	VH	VH	VH	VH	VH	VH
	2	L	L	M	H	VH	VH	VH	VH	VH
	3	M	L	L	M	H	VH	VH	VH	VH
	4	H	L	L	L	M	H	VH	VH	VH
	5	VH	M	L	L	L	M	H	VH	VH
	6	VH	H	H	M	L	L	H	VH	VH
	7	N/A	N/A	N/A	N/A	N/A	N/A	L	H	VH
	8	N/A	N/A	N/A	N/A	N/A	N/A	M	L	H
	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M	L

 N/A
  Low
  Medium
  High
  Very High

Level of Risk

Figure 5-1. Program Risk Due to HRL-TRL Misalignment

HRL Rating Lags TRL Rating. In the first situation, the HRL rating lags the TRL rating (the portion of Figure 5-1 above the diagonal). In this case, risk always increases whenever a discrepancy is present. Historically, when human systems work is neglected until the end of a program, human use requirements cannot be properly addressed because many technical constraints are in place that make required changes too expensive or leave insufficient time in the

schedule for the necessary rework. To properly address human systems needs, these human use requirements must be built into the system design from the beginning and thoroughly tested throughout the development process.

As illustrated in Figure 5-1, provided the HRL and TRL ratings are aligned, program risk due to improper human systems integration is minimized and is considered to be at a low (L) level (the top-to-bottom diagonal in the figure). At lower TRLs up through Level 5, program risk varies in the following manner, depending on the extent of the HRL lag:

- Risk is moderate (M, yellow) if the HRL rating lags the TRL rating by one level
- Risk is high (H, red) if the HRL rating lags the TRL rating by two levels
- Risk is very high (VH, dark red) if the HRL rating lags the TRL rating by three or more levels

Beginning at TRL 6, program risk becomes more pronounced if the HRL rating lags the TRL rating. In particular, a lag by a single level becomes a high risk (H, red), whereas a lag by two or more levels becomes a very high risk (VH, dark red). The rationale for this shift is a need to prepare at TRL/HRL 6 for the change in program focus that occurs at TRL 7. Namely, completion of TRL/HRL 7 satisfies entry criteria for the production and deployment phase and typically signals the end of development. The engineering design is essentially frozen at this level as the technology transitions from demonstrations focused on identifying further improvements to full-scale testing, production, and deployment. Therefore, program risk increases significantly if the HRL lags the TRL by this point.

TRL Rating Lags HRL Rating. In the second situation, the TRL rating may lag the HRL rating (the portion of Figure 5-1 below the diagonal). This occurrence does not necessarily represent program risk, particularly if there is good communication within the design team. In some cases, human systems work may safely precede technology development efforts. For example, basic human research may be conducted at HRL 1 with no immediate goals to invent practical applications or technological solutions (for an example, see the Rotorcraft Pilot's Associate program, Befort & Baker, 2015). Basic research is designed to expand the scientific knowledge base in a given area, advance theoretical foundations, or enhance understanding of human behavior and other phenomena. As another example, in software development, prototypes and other proxies may be used in place of fully functional technology to advance human systems testing through HRLs 4 and 5, providing inputs that inform maturation of system requirements and concept development for software that is still at TRL Levels 2 and 3. In this case, the HRL rating may safely exceed the TRL rating by one or two levels in the early stages of development.

Generally, however, it will not be possible for HRL ratings to advance more than two levels ahead of technology development. For example, in the case where an existing user interface with a previously established high HRL level is to be used in a new application, the HRL level for the new application resets to HRL 1. The interface can rarely be used directly "as is" in the new application, and it will be necessary to complete all HRL levels again to ensure assumptions remain valid and no changes are needed for the new hardware in which the interface will be

embedded. For lower TRL levels in hardware-intensive development programs, it is illogical for a technology to have an HRL rating more than two levels ahead of the TRL rating because it presumes the technology is ready for human use at a point in development when the hardware solution does not exist or exists only in very preliminary form. Further, by definition, the HRL rating can never progress to Level 7 or higher without the presence of operational hardware and software, indicating the TRL rating must be at Level 7 at that point (gray N/A blocks in Figure 5-1). In the later TRL stages (7 to 9), the HRL rating may not safely exceed the TRL rating due to the need to incorporate fully functional operational hardware and software during human systems testing and evaluations. Accordingly, program risk increases to at least a moderate level at this point if the HRL rating is deemed completed on the basis of system hardware and software that is not sufficiently mature.

6.0 MAPPING THE HRL SCALE TO ACQUISITION FRAMEWORKS

6.1 Traditional Acquisition Processes

The HRL scale aligns directly to the TRL scale. This alignment can be illustrated in the context of existing frameworks that map the TRL scale to the acquisition process. In effect, HRL ratings can be represented in established mappings simply by aligning them directly with existing TRL ratings. Along these lines, Figure 6-1 shows a mapping to the traditional DOD acquisition process, and Figure 6-2 shows a mapping to the Department of Energy (DOE) acquisition process (Department of Defense, 2012; National Nuclear Security Administration, 2018). The DOD and DOE acquisition processes are similar with respect to the overall progression of activities during the development lifecycle from initial concept development through full quantity production and operations. However, they differ with respect to the terminology used.

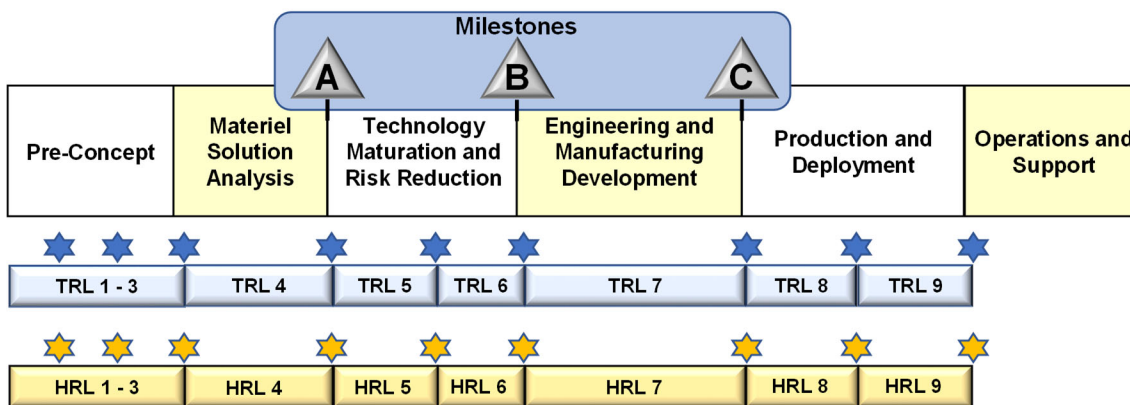


Figure 6-1. Mapping the HRL and TRL Scales to the DOD Systems Acquisition Framework
(users of this standard should consult up-to-date DOD sources for the most recent version of this acquisition framework)

As illustrated in Figure 6-1, the DOD requires TRL 4 by Milestone A, TRL 6 by Milestone B, and TRL 7 by Milestone C (Department of Defense, 2009). It should be noted that this mapping represents implementation of TRL ratings in accordance with requirements in the cited DOD resources; exact alignments observed in practice may vary. Further, the examples in Figure 6-1

and Figure 6-2 convey how the TRLs and HRLs map to mature development processes that are widely used. Specific system development processes may vary across organizations and commercial entities. Appendix A provides additional information regarding DOD budget activity (BA) categories used to fund DOD research, development, test, and evaluation (RDT&E) and their mapping to TRLs and HRLs.

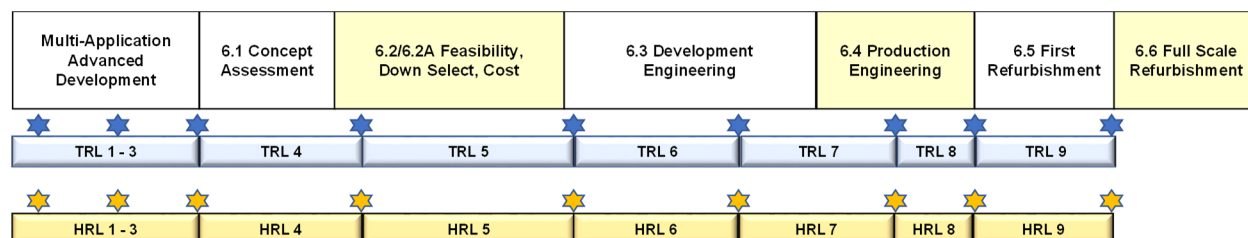


Figure 6-2. Mapping the HRL and TRL Scales to the DOE Systems Acquisition Framework
(users of this standard should consult up-to-date DOE sources for the most recent version of this acquisition framework)

6.2 Adaptive Acquisition Framework Pathways

With the release of the updated DOD Instruction 5000.02 in January 2020, the Department of Defense restructured the traditional acquisition process to include five additional acquisition pathways that provide opportunities to match acquisition strategies and processes to the characteristics of the capability being acquired (Department of Defense, 2020b). Appendix B of this document maps the HRL scale to each of the alternative acquisition pathways described in the Adaptive Acquisition Framework (AAF). Given that the DOD instruction constitutes new guidance, detailed information pertaining to applications of each of the individual pathways is not yet available. Therefore, the HRL guidance in Appendix B is inherently preliminary in nature and will be revised as the standard is updated to incorporate additional information regarding the new pathways. HRL guidance for the new pathways is being included in this standard because human readiness is a critical element applicable to all acquisition pathways.

7.0 APPLYING THE HUMAN READINESS LEVEL SCALE

The purpose of this section of the standard is to provide an overview of the actions that human systems experts take to effectively apply the HRL scale throughout the acquisition lifecycle. Detailed recommendations to guide application of the HRL scale are provided in Appendix C, including suggested evaluation activities at each of the nine levels in order to determine whether human systems activities for the developing technology have been satisfactorily accomplished. Recommendations regarding the criteria and supporting evidence needed to exit each HRL level are also described in Appendix C. The guidance in Appendix C may be tailored to accommodate unique mission purposes (e.g., reuse of legacy technologies for different purposes), provided the intent of the HRL definition at each level remains intact. Further, human systems experts may tailor the guidance by determining which of the recommended questions apply to the current effort and must be addressed. Applications of the HRL scale to examples representing both material and non-material solutions and both federal and non-federal acquisitions are covered in Appendix D. Additional guidance to consider when tailoring an organization-specific process for

application of the HRL scale within existing systems engineering and HSI processes is described in Appendix E.

7.1 HRL 1

Basic principles for human characteristics, performance, and behavior observed and reported.

As with TRL 1, work at this first level of human readiness is very conceptual, consisting of a broad, high-level exploration, primarily in the laboratory and on paper. HRL 1 focuses on observing and reporting basic human principles. At HRL 1, basic human-centered research promotes improved understanding of human capabilities, limitations, performance, and behavior to expand the scientific knowledge base, advance theoretical foundations, or enhance understanding of human behavior and other phenomena. Research is also aimed at understanding potential concepts for enhancing human performance; developing methods, models, and measures related to aspects of human performance; and conducting initial identification of potential human interactions and human-related issues and risks relevant to a newly developing concept or proposed practical application. Human systems experts begin exploring human involvement for the developing concept or idea, identifying important characteristics of the people who might use this concept, and thinking about preliminary usage scenarios. HRL 1 research encompasses all the varieties of users who may potentially be part of an eventual system (e.g., decision makers, leaders, trainers, trainees, operators, maintainers, monitors, and inspectors) and may be focused on people as individuals or teams. Human systems experts also learn as much as possible about newly developing concepts and technologies to understand potential roles and impacts on human users and lifecycle concepts.

7.2 HRL 2

Human-centered concepts, applications, and guidelines defined.

HRL 2 activities are intended to occur in conjunction with TRL 2 activities, which emphasize invention of practical applications for the developing concept or idea. Basic human research begun at HRL 1 is transformed into applied research concepts that are more fully explored as additional information about proposed technologies and their application becomes available. As practical applications are identified, human systems experts analyze the implications for human involvement. Basic research is transformed into a determination of technology characteristics to support effective human use. Relevant human capabilities and limitations identified in HRL 1 may be further defined, based on improved knowledge of developing practical applications and use environments. In addition, potential user roles and tasks begin to be identified at HRL 2. Concepts, applications, and roles are still speculative at this point, and there may be no proof or detailed analysis to support the assumptions. However, preliminary task descriptions developed at HRL 2 serve as a basis for task analyses and human-machine function allocation decisions at higher HRL levels.

Guidelines for the design of systems and technologies to support safe and effective human interactions are developed, based on human characteristics, capabilities, and limitations

discovered in HRL 1. Such guidelines provide the basis for establishing human-centered use requirements as well as inputs for preliminary conceptual designs. Human-centered principles, standards, and guidance may be used to create an overarching human systems interaction standard to establish consistency throughout later design and development.

Human performance analyses are a critical human-centered activity at HRL 2. First, human performance on legacy or comparable systems is analyzed to understand key human-technology interactions and potential sources of human error and misuse. Along these lines, relevant human performance data may be collected by interviewing current users for inputs or observing them complete key tasks with comparable systems. Historical documentation such as issue reports, HSI assessments, and domain assessments may also be analyzed; and highly controlled human-centered experiments may be conducted. Analysis of potential human errors and misuses at this early stage permits mitigation or prevention through identification of necessary design features.

Second, human systems experts begin identifying objective and subjective metrics that will signal the accomplishment of successful human performance for the proposed practical application. Human performance metrics encompass all relevant elements of human behavior that impact overall human-system performance, goal achievement, and mission accomplishment. Metrics may include accuracy, response and completion times, error types and frequency, workload, situation awareness, user satisfaction, usability, fatigue, strain, risk of injury, reach, fit, layout, comfort, accessibility, learning rate, training demands, and manpower and personnel impacts. These metrics are initiated at HRL 2 for use in applied research so their feasibility can be addressed; they are later applied once an initial proof of concept is available at HRL 3. Metrics will be continuously reviewed and updated during testing and evaluation at higher HRL levels as programs mature.

7.3 HRL 3

Human-centered requirements to support human performance and human-technology interactions established.

HRL 3 activities are meant to coincide with TRL 3. At this level, critical characteristics and functions of the concepts that have been under development are examined analytically or experimentally in laboratory studies. Relevant analyses to establish human use requirements for developing concepts and applications are completed (e.g., function analyses, task analyses, cognitive task analyses, operational use analyses, training needs analyses, safety analyses, and other HSI domain analyses). Critical human performance issues for a developing technology or system are identified, and requirements for supporting human use in the developing system are determined, based on research, guidelines, and standards established in HRLs 1 and 2.

An initial proof of concept for developing human-centered concepts and applications via further study and experimentation may be created. The proof of concept is sufficient to support active contextualized human research and development such as analytical human-centered studies, limited complexity human-focused laboratory studies, and field observations to generate a

broader understanding of human performance in complex systems. Human systems experts can use the proof of concept to begin understanding the demands the developing technology will impose on human users and to analyze human operational, environmental, functional, cognitive, and physical needs as well as their goals, strategies, and challenges. Human needs, capabilities, limitations, and characteristics are then mapped to the expected operational and system demands to establish perceptual, information, and decision requirements to support human user roles. With increased maturity of technology concepts, human systems experts can begin considering candidate human-machine function allocations to optimize performance. As part of updating usage scenarios and task descriptions, they are able to use the proof of concept to identify critical human performance issues that may impact achieving system goals and may therefore require additional rigor in the analysis.

With increased knowledge gained through the availability of a rough prototype, activities for each HSI domain relevant to the given effort begin at HRL 3. These domains may include human factors engineering; safety and occupational health; manpower, personnel, and training; environment; habitability; and survivability. For each relevant domain, preliminary requirements, risks, and implications are captured. In addition, possible tradeoffs among domains are evaluated to effectively support human users and system lifecycle concepts within the trade space characterized by schedule, costs, and performance. For example, design features that simplify operations may be recommended to minimize future cost and schedule resources required for manpower and training. Along the same lines, maintenance and sustainment analyses are conducted to support early consideration of design features that will optimize human interactions during future maintenance and repair activities.

All of the HRL 3 analyses described above serve to guide development of specific human-centered requirements at HRL 3 that are flowed into higher-level system requirements in the system design process. In addition, the proof of concept can be used to evaluate feasibility and sufficiency of the metrics developed at HRL 2. Specific key performance parameters (KPP) to support successful human performance and lifecycle concepts are identified. Finally, human systems experts use all of the information gained to date to recommend preliminary design features that accommodate the capabilities, limitations, and needs of human users. An overarching human systems plan is completed at HRL 3 and incorporated into the broader system plan. Human systems experts with requisite expertise in specific areas are identified and engaged to support execution of the plan. The number of human systems experts and their specialties will vary, depending on the exact nature of the design and development effort. A test plan for subsequent modeling and part-task testing with mockups at HRL 4 is begun.

7.4 HRL 4

Modeling, part-task testing, and trade studies of human systems design concepts and applications completed.

HRL 4 activities are intended to be completed concurrently with TRL 4 activities. Beginning at this level and continuing through Level 6, demonstrations and tests occur at increasing levels of

fidelity, first in the laboratory and later in relevant environments. Fidelity of all key elements increases progressively over time—the technology, the environment, and the users. At this level, human systems experts use prototypes, analytical tools, and mockups to support modeling and part-task testing of human-centered design and lifecycle concepts and strive to conduct these activities with representative users. Analytical tools and models may be used to better understand particular aspects of human tasks or human systems interactions such as physical reach/fit for a new workstation, workload over different task and environmental conditions, time to complete tasks, and potential errors. Part-task testing of human systems designs provides human-centered evaluations in laboratory or controlled field settings. At HRL 4, these tests may include only partial mission complexity, parts of the technology, or limited elements of human systems interactions. Mockups may be simple static versions of displays or simple hardware replicas. Outcomes of these efforts inform trade-based comparisons of different human systems design concepts and features to identify the most viable options to pursue. In addition, study outcomes are used to optimize development of procedures and other manuals for human use. All of these activities serve as a basis to identify and recommend various strategies to support human use and lifecycle concepts, minimize human error, and optimize mission outcomes. Such strategies include the full range of engineered solutions, training, personnel selection, procedures, organizational and administrative solutions, and personal protective equipment (PPE) controls.

Key activities begun at HRL 3 continue during HRL 4. Namely, evaluations of each HSI domain and HSI domain tradeoffs continue in order to refine previous analyses, based on information gained through demonstrations of rapid prototypes, modeling, part-task testing, and trade studies. The preliminary human-machine function allocations and task analyses developed at HRL 3 are updated to incorporate emerging information and to optimize task flow and sequencing. Strategies to address human interactions during maintenance and sustainment are refined. Human systems experts collect and evaluate human performance data during modeling and part-task testing to determine whether human performance metrics and requirements are successfully met. Human performance results may be compared against data from existing comparable systems to gauge the extent of any improvements or degradations and determine whether additional modifications are necessary. Human systems experts verify whether preliminary designs conform to human-centered guidelines and requirements established at earlier HRL levels. Finally, human systems experts finalize the test plan, document results, and generate a test report for human systems modeling and part-task testing activities completed at HRL 4. The test report includes recommended system design features and modifications. In addition, a draft test plan for subsequent human systems testing associated with HRL 5 activities is begun.

7.5 HRL 5

Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design.

At HRL 5, human systems design prototypes are developed or updated based on HRL 4 results. By HRL/TRL 5, the fidelity of key elements of the technology has increased significantly. Design and simulation of key user interface components and capabilities of the system, with

realistic supporting elements, are sufficient for testing and demonstration in mission-relevant part-task simulations or actual environments. Portions of relevant missions are simulated to exercise the system and provide realistic user tasks and use conditions. Further, at this level, users participating in human-centered testing are independent from the design team. During earlier HRLs, human systems experts may work with various types of users, including surrogates and samples of convenience such as college students, non-experts, other members of the design team, colleagues, and retired subject matter experts. Representative users must be engaged no later than HRL 5 to interact with the technology during testing. They may not be fully representative of the intended target population, but they are much more similar in terms of basic characteristics and skills. Thus, at HRL 5, part-task evaluations of higher-fidelity prototypes in mission-relevant simulations by more representative users provide a basis for refined design recommendations. All of the evaluation activities completed at HRL 4, including those across all relevant HSI domains, are repeated at HRL 5 under these more representative conditions with the refined human systems design concept. Human systems experts finalize the HRL 5 test plan, document results, and generate a test report for human systems activities completed at HRL 5 that includes recommended system modifications. In addition, a draft test plan for subsequent HRL 6 human systems testing is begun.

7.6 HRL 6

Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment.

At HRL 6, human systems design prototypes are updated based on HRL 5 results. HRL 6 activities occur in conjunction with TRL 6, which represents a major step in a technology's demonstrated readiness and the final demonstration before verification and validation activities begin. At this level, a prototype that is representative of the system is demonstrated in relevant environments such as a high-fidelity simulation or the actual environment with mission-level complexity. High-fidelity simulations used at this stage provide realistic approximations of the intended final system with respect to form, fit, and function and with respect to user equipment and the clothing to be worn in the actual environment. Further, users participating in human-centered testing are fully representative of the target population with respect to the range of characteristics (e.g., gender, anthropometry, and required knowledge, skills, and abilities) identified as relevant for the given technology. Human-centered testing encompasses the full range of usage scenarios and tasks, including emergency and non-normal events. Although subjective metrics continue to be informative at this level, testing emphasizes collection of objective metrics related to human performance and lifecycle concepts.

The evaluation activities completed at HRL 5, including those across all relevant HSI domains, are repeated at HRL 6 under these more representative conditions in high-fidelity simulations or actual environments with the evolved design concepts. Beginning at HRL 6, human systems experts also evaluate the effectiveness of a system designed to track and resolve human systems issues after fielding. This human systems issue tracking system may be an extension of an

existing, broader issue tracking system or a completely new and separate system devoted solely to human systems issues.

At the completion of HRL 6, the majority of the human-centered design is essentially finished; however, modifications are still possible if critical issues or risks are identified during subsequent verification and validation testing in the production and deployment phase. The expectation is that any changes after TRL/HRL 6 should be more minor in extent than at previous levels. Human systems experts finalize the HRL 6 test plan, document results, and generate a test report for human systems activities completed at HRL 6 that includes recommended system modifications. In addition, a draft test plan for subsequent human systems testing associated with HRL 7 activities is begun.

7.7 HRL 7

Human systems design fully tested and verified in operational environment with system hardware and software and representative users.

Completion of HRL/TRL 7 satisfies entry criteria for the production and deployment phase and typically signals the end of development. At this time, the engineering design is essentially frozen, though modifications are still possible. The final development system is evaluated in an operational environment with system hardware and software and representative users, providing a high-fidelity representation of the final operational fielded system. Human-centered testing during HRL/TRL 7 demonstrations encompasses the full range of usage scenarios and tasks, including emergency and non-normal events and the proposed system to track, prioritize, and resolve human systems issues after fielding.

The evaluation activities completed at HRL 6, including those across all relevant HSI domains, are repeated at HRL 7, using the final development system in an operational environment. However, by this level, the primary task of human systems experts shifts from identification and recommendation of mitigation strategies to evaluation and verification that key recommended strategies have been successfully incorporated and work as intended to satisfactorily support the humans in the system. The presence of realistic environmental conditions in which the final fielded system will be operated permits more thorough evaluation of the impacts of factors such as lighting, noise, vibration, stress, safety, and anomalous situations on human performance and behavior. Effectiveness of near-final user procedures, training approaches, and training manuals can also be evaluated at this level. Human systems experts verify whether (1) key human performance metrics and requirements established in earlier HRLs have been successfully met, (2) recommended strategies to support human use and lifecycle concepts have been satisfactorily incorporated in the final development system, and (3) the final development system conforms to key human-centered principles, standards, and guidance established at HRL 2. Human systems experts collaborate with systems engineering and design teams to resolve any remaining high-priority issues.

Human systems experts finalize the HRL 7 test plan and document HRL 7 verification results, including recommended system modifications. In addition, a draft test plan for subsequent human systems testing associated with HRL 8 activities is begun.

7.8 HRL 8

Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users.

During HRL/TRL 8, the completed system hardware and software are fully tested with representative users in mission operations, using full-mission scenarios representative of the operational environment, for final verification and validation. If verification and validation are successful, the system is qualified and approved for full-rate production and fielding. For the DOD, TRL/HRL 8 testing activities may occur as part of developmental test and evaluation. HRL 8 represents the final opportunity to identify and incorporate elements to support human readiness before fielding and operational use. Therefore, human-centered testing during HRL/TRL 8 demonstrations encompasses the full range of usage scenarios and tasks, and all of the evaluation activities completed at HRL 7 are repeated at HRL 8, using the production system in mission operations. Effectiveness of the strategies used to address each HSI domain is evaluated with the production system. At this point, any remaining human systems issues should have been identified and satisfactorily resolved. If any high-priority items or KPPs have not been satisfactorily addressed, human systems experts collaborate with the systems engineering and design teams to coordinate a mutually agreeable path forward. As a final check, conformance of the final production system to key human-centered principles, standards, and guidance identified as relevant at HRL 2 and requirements identified in HRL 3 is verified.

Human systems experts finalize the HRL 8 test plan, document results, and generate a test report for human systems activities completed at HRL 8. In addition, a draft plan for subsequent human systems evaluations at HRL 9 may be produced if testing such as operational test and evaluation is expected to occur. An overarching program report for the entire human systems program is also started and will be completed at this level if no additional formal testing is planned. If applicable, human systems experts monitor any other field experience with the system and participate in problem analysis, resolution, and implementation of solutions.

7.9 HRL 9

System successfully used in operations across the operational envelope with systematic monitoring of human-system performance.

HRL 9 activities are intended to occur at the same time as TRL 9, which involves successful mission operations with the actual system. Accordingly, during this final level of human readiness, intended users operate the qualified system, as fielded in the operational environment. For the DOD, TRL 9 may occur during operational test and evaluation. Upon fielding, human systems experts systematically monitor the system to ensure the demonstrated human performance capability and lifecycle concepts are maintained. A critical aspect of continued

monitoring is detection and resolution of emerging human systems issues, which may involve hardware, software, or process modifications. Systematic monitoring encompasses the comprehensive set of tasks and conditions comprising the intended mission, including training, operations, maintenance, and abnormal environments. Key elements for data collection and analysis at HRL 9 consist of human performance issues, errors, accidents, costs attributable to HSI concepts, and training effectiveness. Human systems experts may collect data via automated data collection, service databases, field observation, surveys, interviews, issue tracking systems, and error/accident reports. Lessons learned pertaining to both successes and failures are documented to support current and future applications. Finally, human systems experts participate during any planned system upgrades to evaluate human-system impacts and verify upgrades continue to support effective human performance and lifecycle concepts. Impacts of changes in user knowledge, skills, and abilities are also evaluated at this HRL level. Human systems experts finalize the HRL 9 plan, document results, and generate a test report, if applicable. If not accomplished during HRL 8, the overarching program report for the entire human systems program is finished.

8.0 REFERENCES

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APPENDIX A: DOD BUDGET ACTIVITIES (INFORMATIVE)

The DOD originally established seven budget activity (BA) codes ranging from 6.1 to 6.7 to support funding of research, development, test, and evaluation (RDT&E) work. Currently, an eighth category is being added to the list to fund software and digital technology pilot programs (Sargent, 2020). The new funding mechanism is intended to remove challenges program managers encounter when attempting to apply modern software development techniques like agile development (Department of Defense, 2020a).

Brief descriptions of the eight BA codes are provided in Table A-1 (Sargent, 2020). The DOD refers to funding in the BA 6.1 to 6.3 codes as the science and technology budget. The BA 6.4, 6.5, and 6.7 codes address funding for application of scientific and technical knowledge to meet current or near-term operational needs. BA 6.6 funds are for RDT&E management and may support work in any of the RDT&E budget accounts.

Table A-1. DOD RDT&E Budget Activity Codes

BA Code		Description
6.1	Basic Research	Systematic scientific study and experimentation to achieve greater knowledge or understanding of fundamental aspects of phenomena without specific applications or products in mind.
6.2	Applied Research	Systematic study to understand the means to meet a recognized and specific need by developing useful materials, devices, systems, or methods.
6.3	Advanced Technology Development	Development of subsystems and components and efforts to integrate them into prototypes for field experiments or tests in simulated environments. This effort provides proof of technological feasibility.
6.4	Advanced Component Development and Prototypes	Evaluation of integrated technologies, representative modes, or prototypes in high-fidelity and realistic operating environments. Efforts help expedite technology transition from the laboratory to operational use.
6.5	System Development and Demonstration	Engineering and manufacturing development tasks designed to meet validated requirements before full-rate production. Prototype performance is at or near planned operational system levels.
6.6	RDT&E Management Support	Management support and funds to sustain or modernize installations or operations required for general RDT&E.
6.7	Operational System Development	Development efforts to upgrade systems that have been fielded or have received approval for full-rate production (with the expectation that production funding will be received in the current fiscal year or next).
6.8	Software and Digital Technology Pilot Programs	Funding to cover agile development, test and evaluation, procurement and modification, and the operation and maintenance of pilot initiatives for software and digital technology.

Summarized from Sargent (2020)

Various interpretations of how the BA codes map to the TRLs exist. There are inconsistencies in the interpretations across different organizations, and overlaps between different BA codes may occur. Further, program managers directly control budgets, which may or may not align with established mappings. Figure A-1 represents one mapping between BA codes and TRLs (Atchison, 2013). In this view, RDT&E funding (BA 6.1 through 6.7 codes) ends at the conclusion of TRL 7 (Milestone C), at which time the engineering design is frozen, signaling the end of development. In this mapping, the BA 6.2 code does not begin until TRL 3. Defense Acquisition University (DAU) mappings, on the other hand, show RDT&E funding ending partway through TRL 9 with the BA 6.5 code (Figure A-2). In addition, the BA 6.2 code begins at the start of TRL 3 and extends midway through TRL 4 (Defense Acquisition University, 2018).

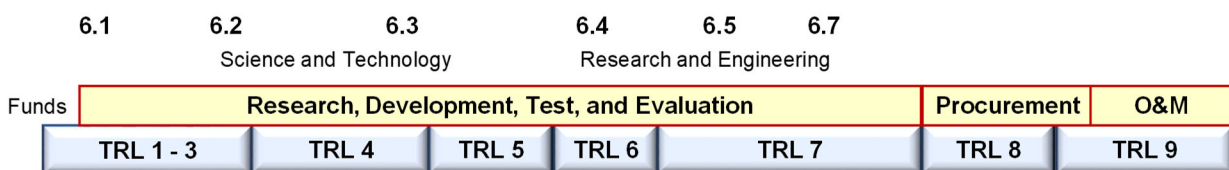


Figure A-1. One DOD Interpretation of a TRL-BA Mapping

(redrawn from Atchison, 2013)

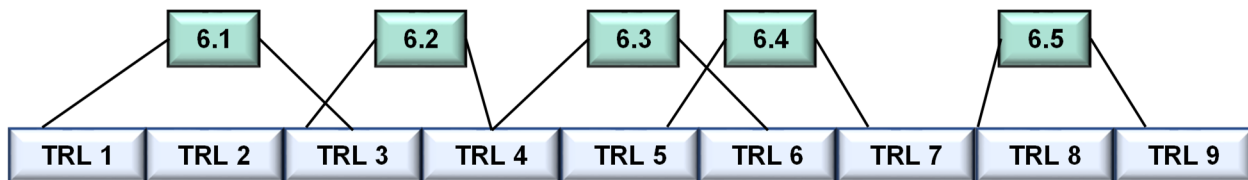


Figure A-2. One DAU Interpretation of a TRL-BA Mapping

(redrawn from Defense Manufacturing Management Guide for Program Managers, 2018)

Figure A-3 illustrates the TRL-HRL-BA mapping used in this standard. This mapping combines elements of existing TRL-BA mappings and aligns with the DOD and DOE systems acquisition framework mappings illustrated in Section 6.0 of this document. Existing TRL-BA mappings are readily extended to the HRL scale, given the intended direct alignment between TRLs and HRLs. Again, it should be emphasized that program managers directly control budgets. If an organization does not provide funding for required human systems activities, the HRL of a given technology or system may fall significantly behind the TRL, resulting in increased program risk.

- **BA 6.1 (basic research)** begins at TRL/HRL 1, during which basic research occurs in the laboratory and on paper. At this first level for technology/human readiness, fundamental scientific research occurs via analysis, observation, and experimentation. Examples include paper studies of a technology's basic properties and research investigating models of basic human capabilities, limitations, characteristics, and behaviors.

- **BA 6.2 (applied research)** begins at TRL/HRL 2 to coincide with the invention of practical applications and their implications for human involvement. Activities at TRL/HRL 2 move beyond basic research into applications and solutions. However, basic research elements of BA 6.1 activities may continue through TRL/HRL 2. Further, concepts, applications, and potential human roles are speculative at this point; there may not yet be proof or detailed analysis to support assumptions.
- **BA 6.3 (advanced technology development)** spans TRL/HRL 4 through TRL/HRL 6. These TRL and HRL levels emphasize repeated demonstration of the developing technology at increasing degrees of fidelity and user representativeness, first in the laboratory and later in simulations or actual environments. In accordance with BA 6.3, it is during these levels that true technology development occurs. Demonstration of the technology with increasingly realistic environments and users facilitates identification and implementation of additional design improvements throughout these TRL/HRL levels. By TRL/HRL 5 in particular, prototype development has progressed sufficiently to support participation of more representative users.
- **BA 6.4 (advanced component development and prototypes)** begins at TRL/HRL 5 and overlaps with both BA 6.3 and BA 6.5. BA 6.4 is viewed as beginning at TRL/HRL 5 when the fidelity and integration of key elements under development increases significantly, with demonstration in high-fidelity simulated or actual environments. During HRL 6, the human systems design is fully matured in preparation for follow-on verification, validation, and qualification activities.
- **BA 6.5 (system development and demonstration)** begins at TRL/HRL 7 at the start of the production and deployment phase of the lifecycle and continues through the initial stages of TRL/HRL 9. By TRL/HRL 7, the development version of the system is at or near the planned operational system, in preparation for final verification and validation tests funded at BA 6.5. At TRL/HRL 9, the qualified system is successfully used in operations across the operational envelope by the intended users.

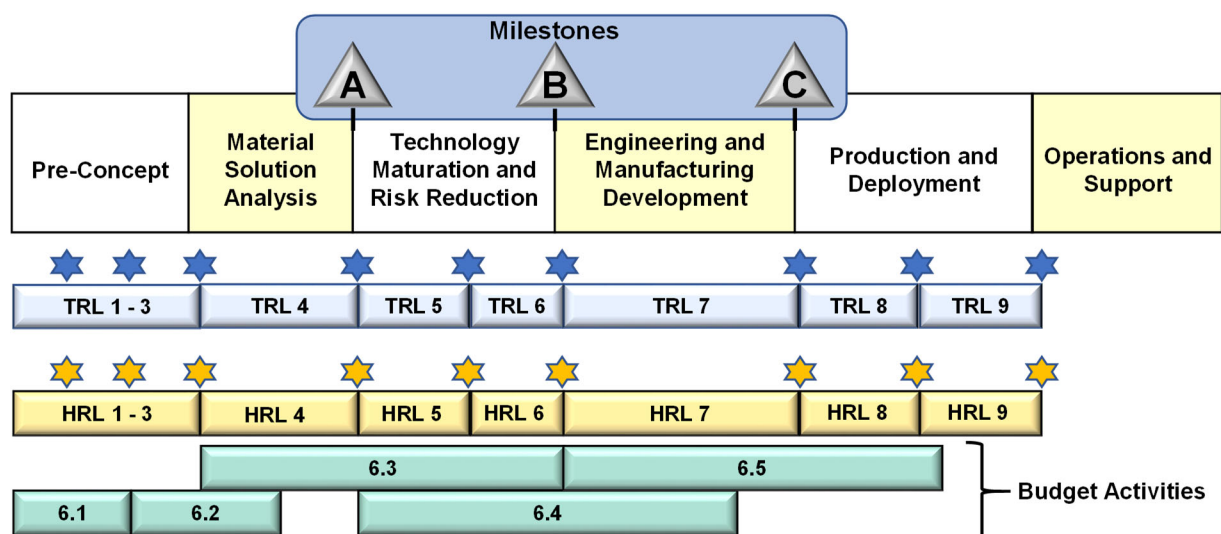


Figure A-3. TRL-HRL-BA Mapping Used in this Standard