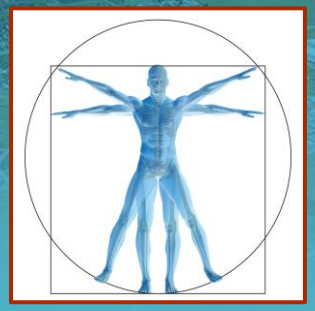
Applying the Human Readiness Level (HRL) Scale in the Systems Engineering Process



INCOSE Enchantment Chapter Meeting

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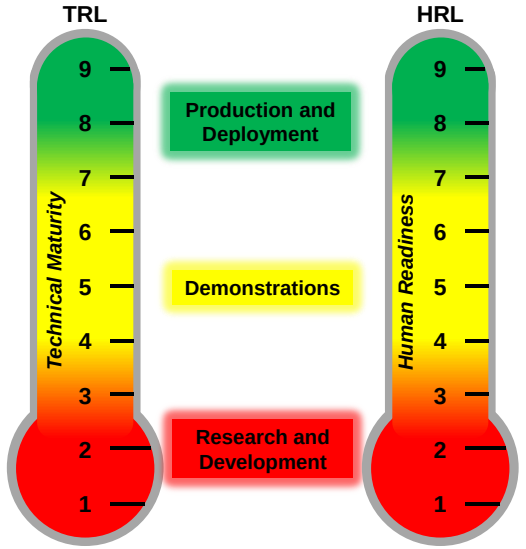
What are Human Readiness Levels?

A novel leading-edge technique to enable decisive action promoting technology usability and suitability

- Simple nine-level scale that mirrors existing Technology Readiness Level (TRL) scale
- Designed to evaluate, track, and communicate ***readiness of a technology for human use***
- Fully incorporates human element throughout entire system lifecycle
- Maturity = readiness of a technology for people to use

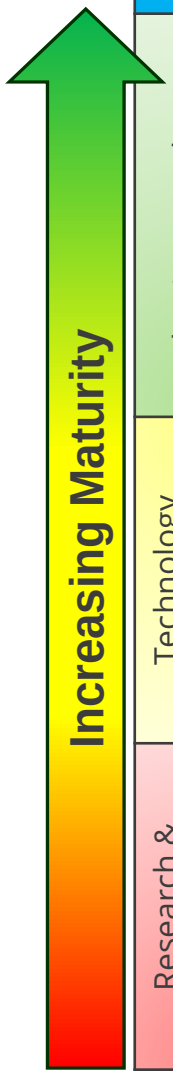
Provide Assurance That:	
TRL	Technology will function as intended
HRL	Human is able to use the technology as intended



HRL scale is intended to capture and mitigate human systems issues early in the design phase to reduce human error in fielded systems.

HRL Scale Complements and Supplements TRL Scale

HRL scale provides a single number to communicate readiness for human use to decision makers



Level		Technology Readiness Level	Human Readiness Level
Production / Deployment	9	Operational use of deliverable	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance
	8	Actual deliverable qualified through test and demonstration	Human systems design fully, tested, verified, and approved in mission operations, using completed system hardware and software and representative users
	7	Final development version of the deliverable demonstrated in operational environment	Human systems design fully tested and verified in operational environment with system hardware and software and representative users
Technology Demonstration	6	Representative of the deliverable demonstrated in relevant environments	Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment
	5	Key elements demonstrated in relevant environments	Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design
	4	Key elements demonstrated in laboratory environment	Modeling, part-task testing, and trade studies of human systems design concepts and applications completed
Research & Development	3	Concepts demonstrated analytically or experimentally	Human-centered requirements to support human performance and human-technology interactions established
	2	Concept and application formulated	Human-centered concepts, applications, and guidelines defined
	1	Basic principles observed and reported	Basic principles for human characteristics, performance, and behavior observed and reported

Need for HRLs

Neglecting human readiness increases the likelihood of system failures due to human error

- Many systems engineering approaches are technology-centric
  - "Forget" humans in the system until after fielding, when human error occurs
  - Evaluate *technical* maturity using TRL scale
  - TRL scale does not address readiness of technology for people
- Most problems in engineered systems are linked to humans in the system
  - Up to 45% of nuclear power plant accidents
  - 60% of aircraft accidents
  - 80% of NASA mishaps

Makes 3 to 7 errors/hour normally

Up to 15 in unusual situations

(Farris & Richards, 2009)

Fails once per million hours

(Smith, 2005)

Inattention to people → **Poor interface designs** → **Human error and system failures**

HRLs shift focus from lagging indicators (human error in fielded systems) to leading indicators (evidence-based measures of usability readiness).

NASA = National Aeronautics and Space Administration

Understanding HRLs

Fielding is too late to discover humans cannot use the technology as intended

- HRLs augment existing TRLs by focusing on human element of the system
- Contributions of HRL concept can be understood by examining consequences of neglecting human readiness during development
- Initial fielding of U.S. Army Stinger Missile in early 1980s (Booher, 2003; Tully, 1986)
  - Fielded at TRL 9
  - Designed for specific kill probably
  - Actual kill probability was reduced by half once operators were in the loop
  - Designers assumed human performance would be perfect
  - Soldiers found missile difficult to use
    - Too complicated
    - 18 separate steps to fire it

If an HRL scale had been used for the Stinger Missile, human performance issues would have been recognized and mitigated earlier in development before fielding.

Benefits of HRL Scale

Benefits of applying the HRL scale mirror those found in TRL scale

TRL Scale *Demonstrating high maturity for new technologies increases chances of program success*	HRL Scale *Demonstrating human readiness for new technologies increases chances of program success*
• Provides common language across diverse programs and organizations	
• Promotes testing and verification	
• Gauges progress to plan future level of effort	
• Manages schedule and cost risks	
• Provides proactive cradle-to-grave planning framework	
• Provides assurance that technology functions and can be used as intended	

- Current HRL scale emphasizes both **progress** and **performance**
  - Human systems evaluations *progress* from basic conceptual design phases through prototype demonstrations and final qualification and fielding
  - Human *performance* must be deemed satisfactory by qualified experts before advancement to next HRL level can occur

HRL Scale Supports Human Systems Evaluations

HRL scale provides multiple opportunities to detect human systems issues throughout lifecycle

Evaluation Activity	HRL 3	HRL 4	HRL 5	HRL 6	HRL 7	HRL 8
Usage scenarios	✓	✓	✓	✓	✓	✓
Human performance metrics	✓	✓	✓	✓	✓	✓
Human-machine allocations	✓	✓	✓	✓	✓	✓
Human factors engineering	✓	✓	✓	✓	✓	✓
Safety and occupational health	✓	✓	✓	✓	✓	✓
Manpower, personnel, training	✓	✓	✓	✓	✓	✓
Environment	✓	✓	✓	✓	✓	✓
Other relevant HSI domains	✓	✓	✓	✓	✓	✓
Maintenance and sustainment	✓	✓	✓	✓	✓	✓
Strategies for human use	✓	✓	✓	✓	✓	✓
Conformance to guidelines and principles		✓	✓	✓	✓	✓
User procedures and other manuals		✓	✓	✓	✓	✓
Issue tracking system				✓	✓	✓

HRL scale supports iterative evaluation of all HSI domains and other core human-centered topics as technical maturity progresses.

HRL Scale Evolution

Inputs, maturation, and reviews came from a diverse human systems community

Rigor

- Concept first proposed in 2010 (Acosta, 2010)
- Concept elaborated in two Naval Postgraduate School (NPS) master's theses
  - Produced first nine-level HRL scale (Phillips, 2010)
  - Proposed framework to standardize HSI throughout development (O'Neil, 2014)
- Matured via two different working groups
  - 2015 working group led by DOD (Phillips, 2015)
  - 2019 working group led by SNL (Salazar, See, Handley, & Craft, 2021)
    - Matured HRL scale
    - Assessed utility in three diverse real-world scenarios (historical)
      - Human systems issues detected as early as Level 1
      - HRL scale deemed effective and usable

Number of Members

Organization	#
Air Force	2
Army	1
Navy	4
DOE	10
FAA	1
NASA	4
Industry	10
Academia	6
Total	**38**

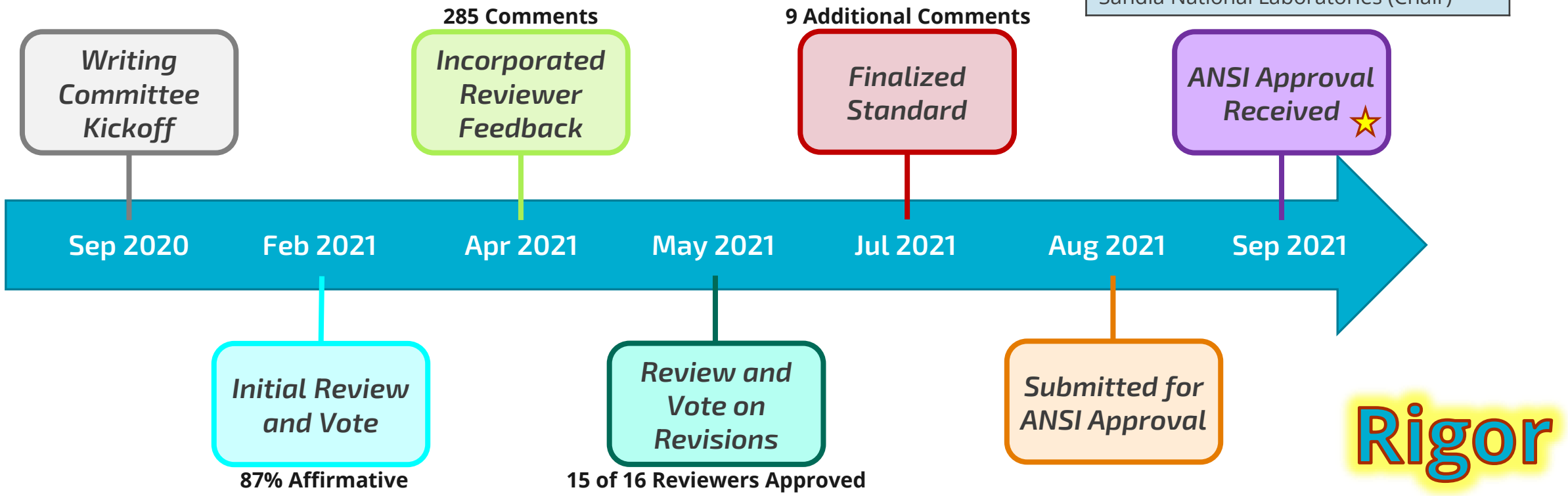
DOD = Department of Defense; DOE = Department of Energy; FAA = Federal Aviation Administration; NASA = National Aeronautics and Space Administration

ANSI/HFES 400-2021 Development

Rigorous one-year process for development, external review, and ANSI approval

- Diverse 10-member writing committee and 23 external peer reviewers
- Final, approved standard available free of charge at https://www.hfes.org/Publications/Technical-Standards

HRL Writing Committee
Federal Aviation Administration
General Motors Company
Human Factors and Ergonomics Society
Johns Hopkins University Applied Physics Laboratory
Navy Expeditionary Combat Command
Northrop Grumman
Old Dominion University
SA Technologies
Sandia National Laboratories (Chair)

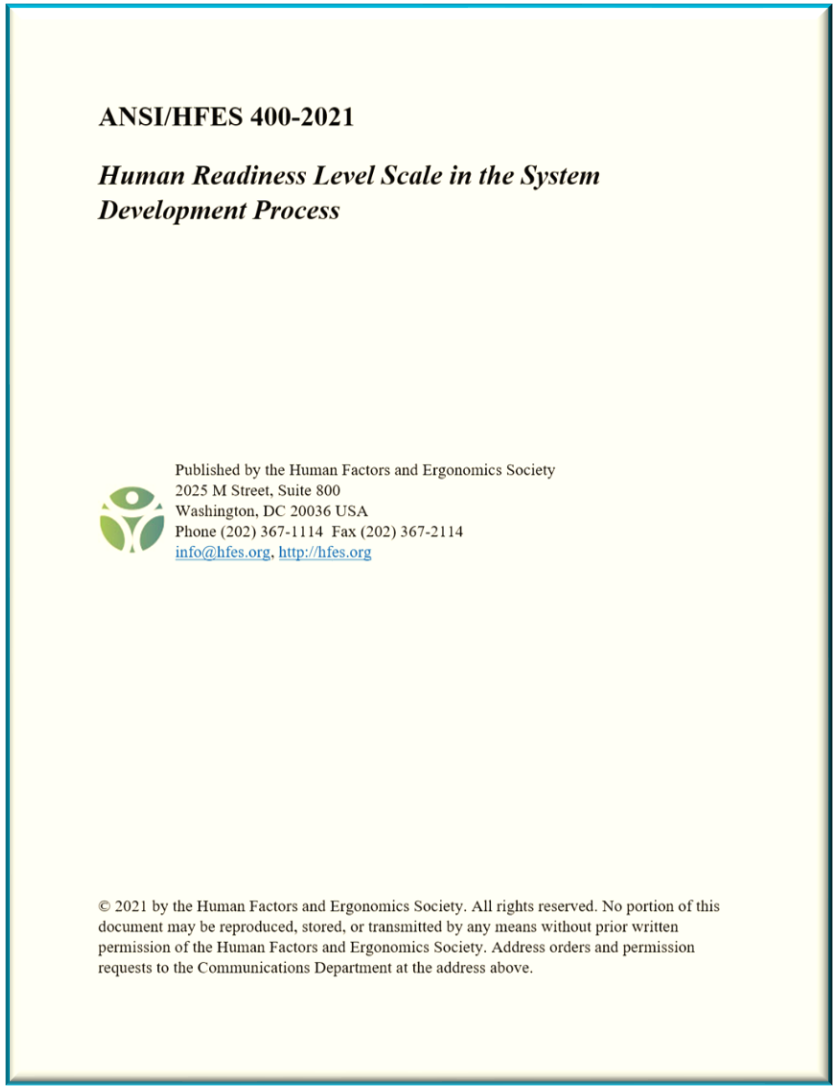


ANSI = American National Standards Institute; HFES = Human Factors and Ergonomics Society

ANSI/HFES 400-2021 Contents

Section 7.0 provides an overview designed for nonpractitioner understanding

- **Main body**
  - 1.0 Purpose and background
  - 2.0 Scope
  - 3.0 Related standards and documents
  - 4.0 Human readiness level scale
  - 5.0 Relationship between HRL and TRL scales
  - 6.0 Mapping the HRL scale to acquisition frameworks
  - **7.0 Applying the human readiness level scale**
  - 8.0 References
- **Appendices**
  - Appendix A: DOD budget activities
  - Appendix B: HRL-AAF mapping
  - **Appendix C: HRL guidance**
  - Appendix D: Application examples
  - Appendix E: Process considerations



ANSI/HFES 400-2021

Human Readiness Level Scale in the System Development Process

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AAF = Adaptive Acquisition Framework

HFES 400-2021 Appendix C: HRL Guidance

Appendix C identifies recommended questions to be addressed at each HRL level

HRL Level 1

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

1. Have key human behaviors, capabilities, and limitations been identified?
2. Have preliminary usage scenarios for potential users been identified?
3. Have potential key human performance issues and risks been identified and concomitant basic research conducted?
4. Has basic human research relevant to a developing concept or application been conducted?

Additional Description for Each Question

At this very early conceptual stage, key human-centered issues requiring further investment in research and development may be identified. Exploring potential human-centered issues and risks provides an opportunity to consider each HSI domain with respect to possible implications for technologies, systems, operations, concepts, and support. The intent is to highlight areas that may warrant in-depth attention from a human systems perspective and begin planning approaches to mitigate or prevent those issues and risks.

HRL scale questions serve as triggers to consider applicability of multiple HSI topics throughout design and development.

HFES 400-2021 Appendix C: HRL Guidance

Appendix C provides additional guidance and specifies exit criteria and supporting evidence

- Guidance and considerations for each HRL level to further clarify trigger questions

HRL Level 1 Guidance and Considerations

Basic human research begins and may continue through Levels 2 and 3 as additional information about the proposed technology becomes available

- Basic research on human characteristics, behaviors, and limitations in general or relevant to a developing concept is conducted at HRL 1
- Human systems experts can begin addressing human involvement at a very high level to start identifying the characteristics of people who might use the concept and how
- Human systems experts should learn about developing technology concepts to understand the technological component and potential impacts on human users and lifecycle concepts
- Involving human systems experts at HRL 1 may enhance technical discovery efforts at TRL 1 and help guide a preliminary concept toward a tangible solution

- Exit criteria and supporting evidence

Human involvement relevant to the developing concept or proposed application should be identified and characterized at a basic level.

- Document key human characteristics, performance, and behaviors
- Document potential technology or concept usage scenarios at a high level
- List potential key human performance issues and risks
- Document basic human research findings

Using the HRL Scale and ANSI/HFES 400-2021

Minimizes uncertainty regarding suitability of developing technology for intended human operators

- HRLs apply broadly across diverse technologies and organizations
  - Primary question is whether technology is ready for human use
  - Have suitability and usability for human use been evaluated?
  - Questions are generic in nature to capture key human systems activities and evaluations
- Qualified human systems experts must be involved throughout lifecycle
  - Apply HRL scale and complete appropriate human systems activities
  - Estimate HRL rating at key milestones
  - Communicate significance of HRL rating

HRL scale does not prescribe how to design a technology. It helps determine if all options to design a system ready for people to use have been effectively addressed.

Using the HRL Scale in Systems Engineering Processes (1 of 3)

HRLs align with systems engineering focus on the user

From Wasson (2016)

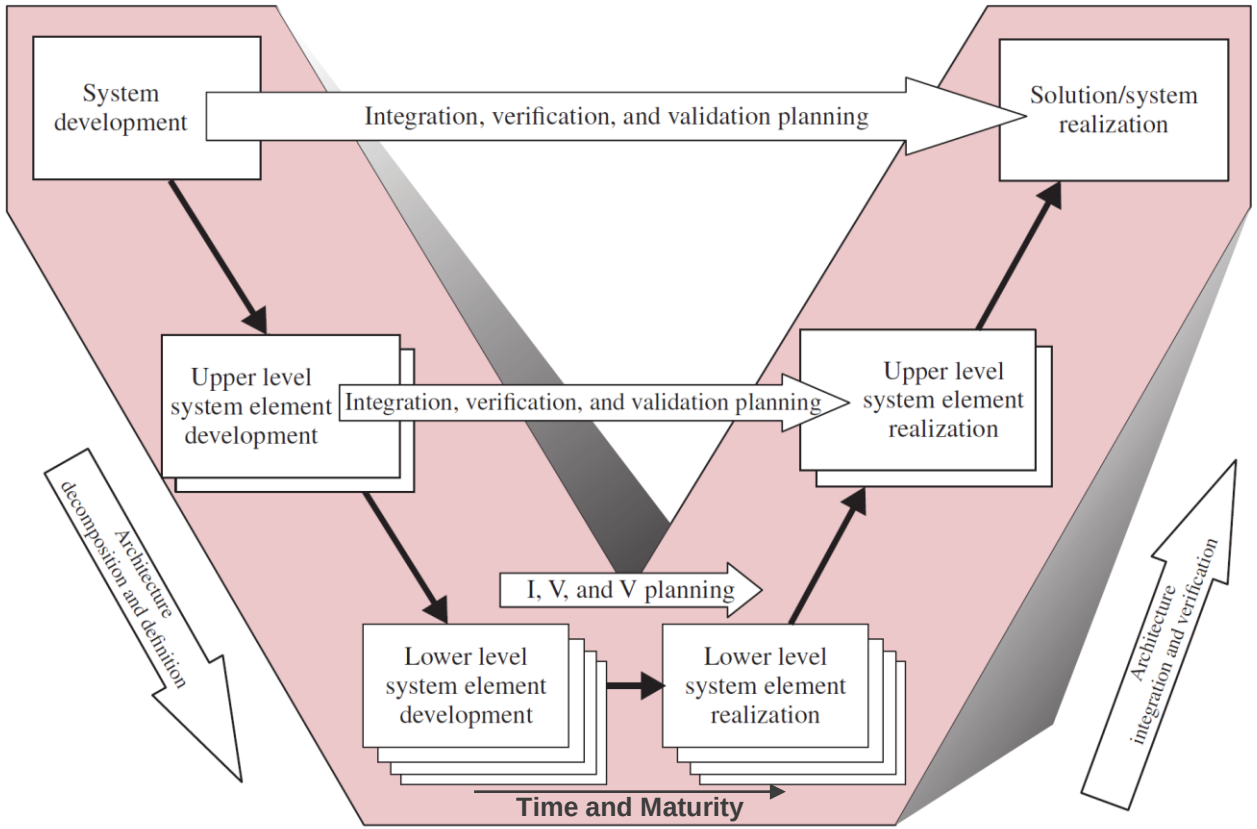
- Systems engineering begins and ends with users of a system, product, or service
  - Understand user jobs or missions that support successful system use
  - Consider user roles throughout deployment, operations, maintenance, sustainment, retirement, and disposal

Effective consideration of users helps prevents ambiguities like these

SE = Systems Engineering

Using the HRL Scale in Systems Engineering Processes (2 of 3)

Vee model illustrates key systems engineering activities during the lifecycle



From *INCOSE Systems Engineering Handbook* (2015)

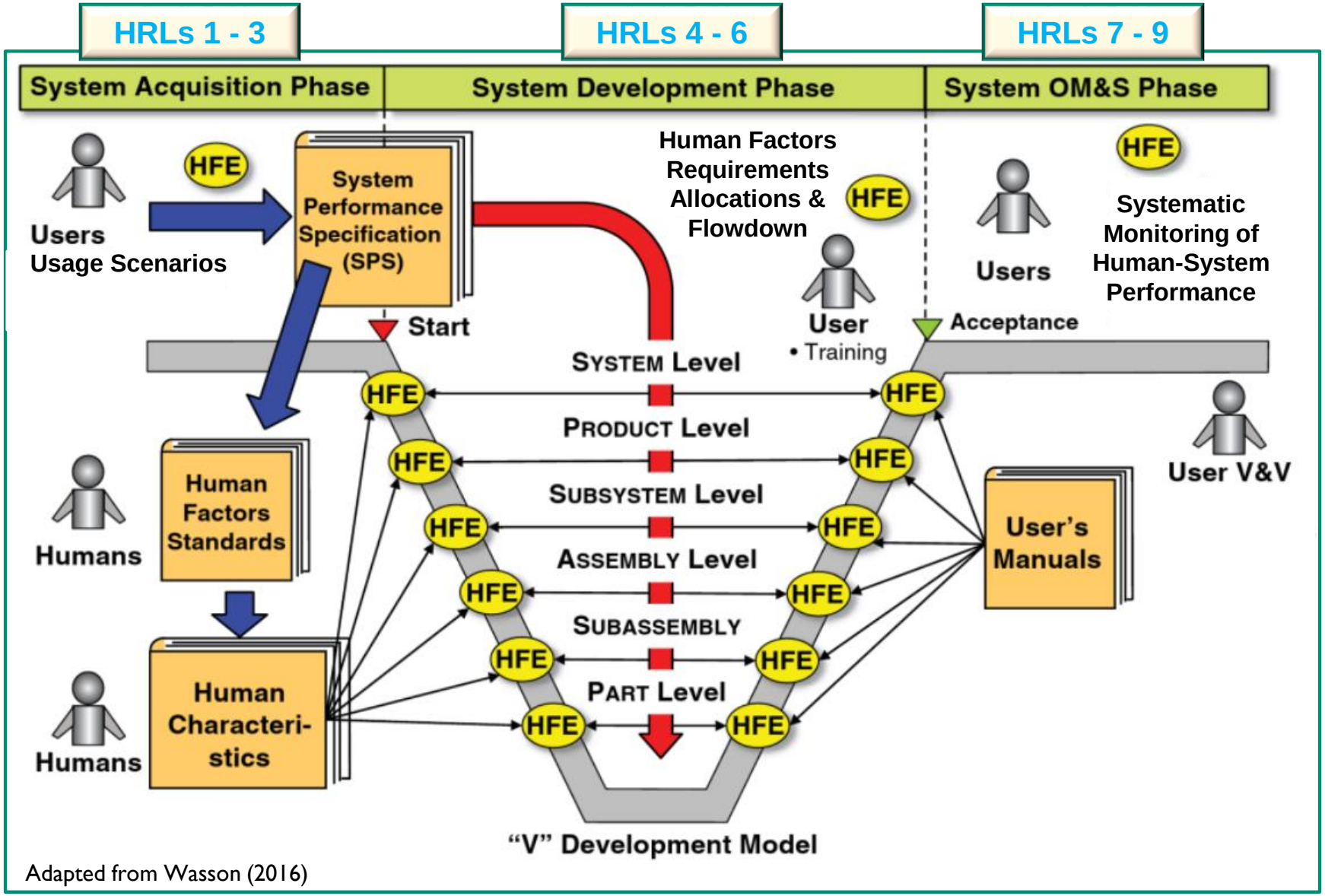
- Highlights need for continuous validation
- Emphasizes verification planning during requirements development
- Assesses risk and opportunity continuously

HRL scale objectives align very well with Vee model purpose.

I, V, and V = Integration, Verification, and Validation

Using the HRL Scale in Systems Engineering Processes (3 of 3)

HRL scale and its human systems considerations apply throughout Vee model



HFE = Human Factors Engineering; OM&S = Operations, Maintenance, and Sustainment; V&V = Verification and Validation

General Approach to Apply ANSI/HFES 400-2021

HRL scale provides a single human readiness number to support decision making

- HRL rating supports decision making at key milestones
  - Future program direction
  - Investment of time and resources

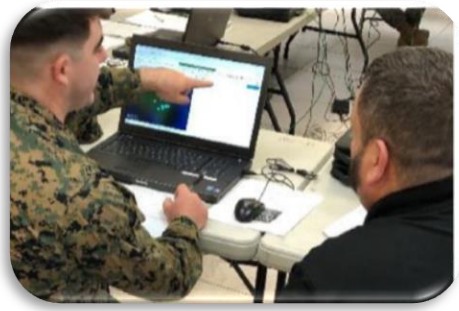
TRL Rating		HRL Rating	
2	Technology concept and application formulated	2	Human-centered concepts, applications, and guidelines defined
✓	• Very low level of maturity • TRL and HRL activities are well aligned		
6	System/subsystem model or prototype demonstration in a relevant environment	1	Basic principles for human characteristics, performance, and behavior observed and reported
✗	• Technical maturity has advanced • HRL lags behind TRL by 5 levels		
7	System prototype demonstration in an operational environment	7	Human systems design fully tested and verified in operational environment with system hardware and software and representative users
✓	• High level of maturity • TRL and HRL activities are well aligned		

Current Applications

ANSI/HFES 400-2021 is currently being applied in multiple venues

- **Joint HSI Steering Committee under OUSD**
  - Currently developing proposed path forward for DOD adoption
  - Specifying DOD-centric considerations for application

- **U.S. Army Combat Capabilities Development Command**
  - Retrospective case study of AFATDS command and control system (Savage-Knepshield, Hernandez, & Sines, 2021)
    - Recode 30-year-old software to improve usability and implement embedded training
    - HRL scale provides framework to support user-centered design evaluation and reporting
  - Application to similar current Army software modernization efforts



- **Airspace modernization efforts**
  - Coordination between U.S. FAA and European Organization for the Safety of Air Navigation (Eurocontrol)
  - Application to U.S. Next Generation Air Transportation System (NextGen) and European SESAR Joint Undertaking
    - Implement major new technologies and procedures
    - Increase levels of automation
    - Enhance cybersecurity for data sharing and connectivity in air traffic management

AFATDS = Advanced Field Artillery Tactical Data System; OUSD = Office of the Under Secretary of Defense

ANSI/HFES 400-2021 Significance

HRL scale can transform human systems integration in system development and operations

- Integrates seamlessly with existing TRL and systems engineering processes
- Assures equal consideration of human and technological components
- Shifts attention from lagging to leading indicators
- Provides a standardized approach to HSI
- Facilitates communication with high-level decision makers

- **Lagging Indicators:** human error in fielded systems
- **Leading Indicators:** evidence-based measures of usability readiness

HRL standard provides a framework for consistent evaluation and incorporation of human usability and safety across multiple diverse organizations and technologies.

Questions?

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References

1. Acosta, H. (2010, May). *Human readiness levels: Implementing HSI – Connecting some dots* [Panel discussion]. 81st Annual Scientific Meeting of the Aerospace Medical Association, Phoenix, AZ, United States.
2. Booher, H. R. (2003). *Handbook of human systems integration.* John Wiley & Sons, Inc.
3. Farris, R., & Richards, B. (2009, August). *Human performance and organizational resilience* [Tutorial]. 2nd International Symposium on Resilient Control Systems, Idaho Falls, ID, United States.
4. INCOSE (2015). *Systems engineering handbook: A guide for system life cycle processes and activities* (4th ed.). John Wiley & Sons, Inc.
5. O'Neil, M. P. (2014). *Development of a human systems integration framework for Coast Guard acquisition* (Unpublished master's thesis). Naval Postgraduate School. https://apps.dtic.mil/dtic/tr/fulltext/u2/a608012.pdf
6. Phillips, E. L. (2010). *The development and initial evaluation of the human readiness level framework* (Unpublished master's thesis). Naval Postgraduate School. https://apps.dtic.mil/sti/pdfs/ADA525365.pdf
7. Phillips, H. (2015, May 4-8). *DOD HFE TAG: Human readiness level (HRL) working group.* [Paper presentation]. DOD HFE TAG 69th Meeting, Orlando, FL, United States.
8. Salazar, G., See, J. E., Handley, H. A. H., & Craft, R. (2021). Understanding human readiness levels. *Proceedings of the 2020 Human Factors and Ergonomics Society 64th Annual Meeting, 64*(1), 1765-1769. https://doi.org/177/10.1071181320641427
9. Savage-Knepshield, P. A., Hernandez, C. L., & Sines, S. O. (2021). Exploring the synergy between human systems integration and human readiness levels: A retrospective analysis. *Ergonomics in Design, 29*(4), 16-24. https://doi.org/10.1177/10648046211009718
10. Smith, J. (2005). *Reliability, maintainability, and risk: Practical methods for engineers including reliability centered maintenance and safety-related systems (7th ed.).* Butterworth-Heinemann.
11. Tully, A. (1986, September 4). Army finds Stinger too complex. *Reading Eagle.* https://news.google.com/newspapers?nid=1955&dat=19860904&id=Rh0iAAAAIBAJ&sjid=4KYFAAAAIBAJ&pg=2122,1746233&hl=en
12. Wasson, C. S. (2016). *System engineering, analysis, design, and development: Concepts, principles, and practices* (2nd ed.). John Wiley & Sons, Inc.