SAND2016-7250C

Incorporating Human Readiness Levels at Sandia National Laboratories

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***Abstract*—*Since 2010, the concept of human readiness levels (HRL) has been under development as a possible supplement to the existing technology readiness level (TRL) scale. The intent is to provide a mechanism to address safety and performance risks associated with the human component in a system that parallels the TRL structure already familiar to the systems engineering community. Sandia National Laboratories in Albuquerque, New Mexico, initiated a study in 2015 to evaluate options to incorporate human readiness planning for Sandia processes and products. The study team is baselining current development processes and collecting feedback on the viability of potential options for human readiness planning. The utility of identified solutions will be assessed in one or more test cases.*

***Keywords*—*human readiness level; technology readiness level; human systems integration*

I. Introduction

Technology readiness levels (TRL) represent a common tool to measure technology maturity that provides consistency within and across programs. The TRL concept can be traced back as early as 1969, and the first published description appeared in 1989 [1]. At that time, the U.S. National Space Policy directed a broader role for NASA in the technology maturation process to drive technology advances for future mission capabilities. Development of the initial seven-level TRL scale was prompted by NASA's realization that the differences between success and failure in the past were directly attributable to the adequacy of technology readiness. The explicitly defined readiness levels in the TRL scale provided a precise means of describing the maturity of a technology and its readiness for operational use.

The Department of Defense (DOD) fully adopted TRLs in 1999 when the Government Accounting Office (GAO) concluded that demonstrating high maturity before including new technologies in development programs increases the chances of success [2]. TRLs are now widely accepted and used throughout the DOD, other U.S. government agencies such as the Department of Energy, and many companies worldwide. At Sandia National Laboratories, Realize Product Procedure #22 describes the process and rationale for assessing a product's TRL.

The current TRL scale has nine levels that describe various stages of technology maturity, beginning with the initial stages of scientific investigation at TRL 1 and culminating in successful use of the final system at TRL 9. In general, all sites use the same basic descriptors for each of the nine TRL levels (Sandia's descriptions appear in Table 1), but may supplement them with more specific descriptions tailored to their products and missions. Each level of the scale has associated exit criteria describing the conditions that must be met before the technology can advance to the next level.

II. Limitations of Technology Readiness Levels

The TRL scale offers many benefits. It provides a simple indicator of a technology's maturity that is readily understood. It can be used to gauge progress throughout development and manage program risks. However, the TRL scale does have limitations. Namely, the TRL definitions combine several different aspects of technology readiness into a single metric; in effect, the scale represents technology maturity as a single dimension. Such limitations have spawned the development of multiple other types of readiness level scales to fill the gaps—manufacturing, design, integration, and system readiness levels.

TABLE I. TRL DESCRIPTIONS

TRL	Description
9	Operational use of deliverable
8	Actual deliverable qualified through test and demonstration
7	Final development version of the deliverable demonstrated in operational environment
6	Representative of the deliverable demonstrated in relevant environments
5	Key elements demonstrated in relevant environment
4	Key elements demonstrated in laboratory environment
3	Concepts demonstrated analytically or experimentally
2	Concept and application formulated
1	Basic principles observed and reported

Another gap that has been identified in the TRL scale is its inability to capture the human-related aspects of technology development and their critical role in the readiness of a technology for operational use. A system is comprised of both technologies and people who must interact successfully within the environment in order to achieve system effectiveness. Failures originating from any one component of the system can negatively impact overall system effectiveness. While the TRL scale provides assurance that the technological components of the system will function as intended, it does not address the interactions between the technologies and the humans in the system that are necessary for success. That is, a technology may be mature in a strictly technical sense; however, if it is not ready for people to use effectively, then its overall readiness for deployment could be much lower.

Along with this recognition of a gap in the TRL scale is the growing realization that most of the problems in engineered systems stem from the people in the system, not the technologies. Human error is said to be a major causative factor in many domains—up to 45% of nuclear power plant accidents, 60% of aircraft accidents, and 90% of road traffic accidents are attributable to human error [3]. People typically make 3 to 7 errors per hour under normal conditions and up to 15 errors per hour in stressful, emergency, or unusual conditions (up to 15 million errors per million hours) [4]. By contrast, a toggle switch fails once per million hours [5].

To complicate matters, most current systems engineering approaches for product development "forget" the human—the largest error-generating component—in the system [6]. That is, the role of people in the system and their interfaces with the technological components receive little to no attention throughout the development lifecycle. More commonly, the human component is not considered until the system is fielded and human errors start to occur. Given that costs to fix errors escalate exponentially over the product lifecycle, it can be 30 to 1500 times more costly to correct the error at the operations and maintenance phase as compared to a design flaw detected and corrected early in the development process [7].

III. HUMAN READINESS LEVELS

In an effort to address these concerns, several researchers have been exploring the utility of supplementing TRLs with another type of readiness scale—human readiness levels (HRL) [8, 9, 10, 11]. The intent is to give equal weight to the technologies and the humans within the system and to "remember" the human early and often throughout the lifecycle. The central question underlying HRLs is whether the technology is ready for human use. In other words, have the features necessary for usability and operator effectiveness been engineered into the design as early as possible?

Dr. Hector Acosta first introduced the concept of a human readiness level scale during a panel discussion at the Aerospace Medical Association annual meeting in Phoenix [12]. Afterwards, he served as an advisor for a Naval Postgraduate School thesis in which a framework for a nine-level HRL scale was formally developed [11]. Dr. Mica Endsley, former Chief Scientist of the Air Force, began advocating the nine-level HRL scale and maintained that it should be as much of a requirement as the TRL scale for system development [8]. Table 2 shows the proposed HRL scale that Dr. Endsley presented at the National Defense Industrial Association (NDIA) Human Systems Conference in 2015 [13].

The HRL scale has been intentionally designed to parallel the TRL structure familiar to the systems engineering community to facilitate integration into current approaches for product development. While there has been interest and continued effort in developing the HRL concept, the scale has yet to be formally adopted and used. One issue is current DOD feedback, which suggests reluctance to introduce yet another readiness scale. As a result, more recent DOD efforts have begun to explore options that retain the critical concepts embedded in an HRL scale, but focus more heavily on tools to support performance- and risk-based assessments of human readiness [14]. Human systems integration (HSI) risk tools are intended to facilitate communications regarding the program risks stemming from low human readiness as well as the consequences if those risks are not addressed during development (e.g., degraded system performance, safety, cost, schedule). Suggested mitigation strategies to address the identified risks are also incorporated. A standard risk matrix illustrating the likelihood and consequences of each risk may be used to facilitate communications with program managers.

IV. SANDIA STUDY SCOPE

Sandia National Laboratories initiated a study in 2015 to evaluate options to incorporate human readiness planning tailored to Sandia processes and products. The study capitalizes on previous DOD research by using the lessons that have already been learned to facilitate a study approach. The scope of the Sandia study includes an initial baseline assessment to understand in detail how various organizations within the labs conduct product development now. The baseline assessment is currently underway to explore the requirements that guide development, the resources that are used (e.g., documents and subject matter experts), and the extent to which the human component of the system is addressed at present. The study team is working with multiple groups at Sandia to represent the range of development activities at the labs.

TABLE II. HRL DESCRIPTIONS

HRL	Description
9	Post deployment and sustainment of human performance capability
8	Human performance using system fully tested, validated, and approved in mission operations
7	HSI requirements verified through development test and evaluation in representative environment
6	System design fully matured by human performance analyses, metrics, and prototyping
5	HSI demonstration and early user evaluation of initial prototypes to inform design
4	Modeling and analysis of human performance conducted and applied within system concept
3	Mapping of human interactions and application of standards to proof of concept
2	Human capabilities & limitations and system affordances & constraints applied to preliminary designs
1	Human focused concept of operations defined

Once the baseline assessment is complete, the study team will begin gauging staff views of various options that might be implemented to prompt human readiness assessments. To date, use of a separate HRL scale is an option that will continue to be explored in the study to determine its viability for Sandia—DOD reservations about another readiness scale may or may not be reflected at Sandia. Other options that will be explored include an HSI risk tool similar to Stohr's proposed tool and a "modified TRL" scale that incorporates human readiness directly into the definition of technology maturity. The study team will also explore additional alternatives suggested by participants throughout the study. To assess the utility of the most promising options, the study team will conduct up to three test cases. The test cases will help identify and refine the optimal approach that will be recommended to Sandia management as a path forward to achieve systematic and comprehensive human readiness planning, regardless of the specific program or product.

V. CONCLUSIONS

Sandia National Laboratories has identified a need for an approach to bridge the gap between the current technology-centric systems engineering approach and the desired end state of full incorporation of the human component throughout the product lifecycle. Sandia will use DOD research and lessons learned in this arena to inform a study approach, recognizing that solutions that work for the DOD may not be optimal for Sandia's mission. The objective is to provide a recommended path forward to ensure a balanced systems engineering approach that gives equal weight to the technologies and the humans in the system throughout the product lifecycle.

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