Technology Readiness Level (TRL) as the foundation of Human Readiness Level (HRL)

Understanding the TRLs as the foundation of Human Readiness Level (HRL)

FEATURE AT A GLANCE:
Communication of the maturity of technology through the program/product life cycles is very important. Currently, many organizations use the Technology Readiness Level (TRL) as a simple metric to indicate the maturity of technology. This article will discuss the TRL history, define the TRL levels show how the TRL relates to the technology life cycle, and how the TRL framework contributes to the Human Readiness Level (HRL) structure. Through the TRL advantages and disadvantages, this article will show how the TRL falls short in numerous areas of engineering, including the integration readiness of system/subsystem components and assessment of the readiness of the technology to operate within the human capabilities and limitations. Yet, the article also shows how TRL serves as the foundation for HRL.

KEYWORDS:
Technology Readiness Level, Human Readiness Level, Human Systems Integration, Technology Maturity

Introduction

The Technology Readiness Levels (TRL) have served as an important assessment tool to innovators, engineers, managers, patent attorneys, and many others to understand the transition of technologies and allocation of resources. The purpose of the TRL is to understand the technological maturity measurements of performance, reliability, durability, and operating experience in the expected environment. Low TRLs, or low technology maturity, correlate with development risk. Overall, technologies have shown to be riskier on the earlier levels of TRLs than the later TRL levels. TRL can be assigned at the system, subsystem, or component level. Each level has an establish criteria in terms of test and analysis that help to determine if the technology is ready to mature to the next level. Though many variants of TRL such as integration and systems readiness level have been introduced, none have addressed the human-centric readiness level.

In fact, many systems engineering approaches are technology-centric and overlook the human in the system until a human error occurs. The TRL scale does not address the readiness of technology for the human. It lags in understanding the human performance that could be detected with evidence-based measures of usability readiness. The goals of this article are to provide an overview of the TRL as a foundation of the human readiness levels, facilitate understanding of the advantages of the TRL and how the HRL helps overcomes some of its limitations.

Understanding the human and technology relationship is imperative, especially in complex systems that could end the human life or end the mission. When the TRL was initially developed,it was because NASA saw its space programs becoming more complex and therefore needed a means of defining a methodological way to evaluate the maturity of technologies for spacecraft design for risk assessment that could affect technical, cost and schedule. NASA first saw that infusing technology into NASA programs required some means to assess technology maturity like flight readiness for a mission. Hence, a technology readiness level scale was developed in the mid-70s by a NASA researcher and later formally defined in 1989 (Sadin et al., 1989). It was not until 1995 that a refined TRL scale was introduced--increasing the scale from seven to nine levels. The NASA Systems Engineering handbook (NASA, 2017) provides guidance of TRL assessment for space systems. Table 1 shows the updated NASA TRL scale.

Leve l	Technology Readiness Levels
9	Actual system “flight-proven” through successful mission operations
8	Actual system completed and “flight qualified” through test and demonstration (ground or space)
7	System prototype demonstration in a space environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
5	Component and/or breadboard validation in the relevant environment
4	Component and/or breadboard validation in the laboratory environment
3	Analytical and experimental critical function and/or characteristics proof-of-concept
2	Technology concept and/or application formulated
1	Basic principles observed and reported
1	Basic principles observed and reported

Table 1. Technology Readiness Levels (NASA: Dumbar, 2017)

Need for Human Readiness Level

Since the TRL was developed, some organizations (such as the United States Department of Defense, Department of Energy, and Navy) have adapted and tailored the TRLs for assessments of technology (Department of Defense, 2002; Carter, 2017; See, Craft, and Morris, 2019). The adoption of the TRLs has many advantages. It provides a common understanding of the technology status, which facilitates communication. The TRLs help to enhance risk management from the early stages of product development. By understanding the technology maturity, managers can have an adequate understanding of potential risk and be better prepared for negotiations. The understanding of the different levels helps to aid decision-making on research and development actions and innovation actions. It facilitates decisions related to technology funding and understanding of the transition of technology. TRLs promotes testing and verification of the technology components. The TRL also gauges technical progress to plan future level of effort needed to achieve technology maturity.

Even though the TRL has shown many advantages to identify the maturity of technology levels, significant accidents are due to technological factors (Alvarenga, Frutuoso, Melo, and Fonseca, 2014). Karthick, Robert, and Kumar (2020) explained that human error contributes to over 90% of failures in the nuclear industry, over 80% of failures in the chemical and petrochemical industries, over 75% of marine casualties, over 70% of aviation accidents and over 75% of failures in drinking water distribution and hygiene (p. 16577), and contribute to an increase in the cybersecurity risks and challenges of at least 80% (O’Driscoll, 2020; CISOMAG, 2020).

The TRL scale does not address readiness of a technology for human support, human performance, ease of use, and user satisfaction. Researchers (See et al., 2019) have found that in systems that highly used the TRL for system analysis and decision support, have fallen short to incorporate the human component systematically or comprehensively across programs. There are several well-accepted Human Readiness Level frameworks (Garcia, Ganey, and Wilbert, 2017). Big government organizations, such as NASA uses the TRL with many different reviews that take place across the product or program life cycle (NASA, 2015; 2017; 2020). However, there is not guidance to understand whether the technology is human-ready. Each project and program may incorporate solutions across the development cycle. Although, the TRL levels are defined across organizations, currently, there are no guidelines on how to mature to the different TRL levels.

The Human Readiness Levels (HRLs) are used to identify the level of readiness or maturity of a given technology as it relates to its usability and its refinement to be used by a human(s) (Phillips, 2010). See and Handley (2019) refers to the current status of the HRL based on the development life cycle of technology (Table 2). As shown in the table, the HRL is based on the foundation of TRL through the mirroring of the nine levels to, like TRL, simplify the communications of human readiness to the management and engineering community. The authors explain that the HRL focuses on the human element of the system. The HRL aims to support technology to become human-centric, which is well known to improve human performance, enhance safety, and user satisfaction. See et al., (2019) noted that the HRL should not be used by itself, but be a counterpart of the TRL.

Table 1: Human Readiness Level (HRL) by See and Handley (2019)

Human Readiness Level	
Production and Deployment	
9	Post-development and sustainment of human performance capability
8	Human System Integration related requirements qualified and verified through test and demonstration in a representative environment
7	Human performance using system equipment fully tested, validated
Technology Demonstration	
6	System design fully matured as influenced by human performance analysis, metrics, and prototyping
5	Human System Integration demonstration and early user evaluation of initial and/or preliminary prototype to inform preliminary design
4	Modeling and analysis of human performance conducted and applied within system concept
Research and development	
3	Mapping of human interaction and application of standards to proof of concept
2	Human capabilities and limitations and system affordances and constraints applied to preliminary conceptual designs
1	Human-focused concept of operations (Human use scenario) defined)

The TRL readiness does not necessarily fit with appropriateness. For instance, a mature product may pose a greater or lesser degree of readiness for use in a system context than one of lower maturity. In other words, technology maturity does not always mean that the system is easy to use, enhance performance, and improve safety. A classic example of where technology was matured but not necessarily the human integrated into the system was the Three Mile Island incident that occurred in 1979. Lack of appropriate system status to the user-led to human error and consequently the accident (Malone, Kirkpatrick, Johnson, 1979).

Technology maturity only means that the product maturity has evolved. Human research helps to provide evidence of when the system is ready for the human use. There are different types of user research that can be used during the product life cycle to identify opportunities from the early stages of the design-for example, workload and usability assessment-as a gauge to see how mature the technology and human readiness are.

There are no requirements that dictate how to perform a TRL assessment. Although it is well defined, interpretation is up to the project. It does not explain how to do it or how to get to the different levels. Project planning sometimes lacks planning on an assessment of the maturity of the technology. For example, during the first level of the TRL, which is the most important level of the research and development of the technology: basic principles are observed and reported. For example, let's say that you want to develop a smart artificial skin to facilitate hand movements when suited on a pressurized suit for space exploration. This artificial skin could decrease the amount of force required by the crew within the suit environment or on harsh environments when mobility maybe constraint (e.g., lack of movement given the body changes in space and pressure of gravitational forces). In this example, this artificial skin will allow a crew member to control objects in any environment. The TRL does not provide guidance on how to make this concept a human-centric concept. In the first level of the TRL, developers will be working with biologists and engineers and perhaps find a nano-compound and sensors/actuators that can be combined and report results. This will define the draft key performance parameters are identified. It is unknown how it will be used, how the human will make the transition to the different gravitational forces, and how the system itself limits the crew response to the technology. For instance, it will be important to understand the concept of operations, scenarios where the crew will be using this skin. Without knowing how it will be used the first level for research and development could miss important factors that could affect the user performance. The technology may have merit, but if could tremendously affect user performance, ease of use, and safety.

The TRL levels are limited to an operational environment and product-system architecture. Product or program success is driven by the understanding of the user, and the factors that could influence how the user uses the product or system. The TRL maturity does not help to identify the characteristic that will empower the user. Because it does not account for the different factors that affect the use. For example, in the second TRL level concept and application is formulated. There is a tendency among machine-centered designers to reason that if 80% or more of accidents or unwanted events are the result of human error, all those errors will go away if the human in the system can be automated (Guastello, 2014). Following our pretend example, during the TRL 2, the skin compound will define possible sensors and actuators needed during the gravitational environment. Basic engineering/scientific principles support the concept. The TRL does not define the human capabilities and limitations, and it does not support how the human expectation of the automated environment will affect the human mental model to respond and use the technology. It is possible that the technology shows at level 3 that the analytical and laboratory studies of elasticity, flammability, conductivity, permeability, strength, etc., show if the technology is viable. However, this level does not map the human interactions and applications that should have been developed from the initial stage of the definition of the concept of operations.

During the 4 TRL, the technology demonstration starts. Laboratory testing of the smart skin product characteristics shows the compound behaviors in basic functional and critical test environments. Performance expectancy of the patch is defined for the operating environment. However, mechanical achievements do not always translate to the understanding of the human performance, the TRL misses the opportunity to demonstrate how it can support the human performance on applied concepts.

During the 5 TRL level, there may be laboratory testing of the integrated compound. The compound is made into an artificial skin patch and tested on a robotic hand. Researchers test mobility, accuracy, and time. At this level, the technology could be assessed as an early prototype to gather preliminary feedback that will shape the final product. The TRL level refers to the key elements of the hardware and software, but not the human.

A TRL level 6, will have a representative deliverable for the relevant environments. There will be a documented test performance demonstrating agreement with analytical predictions. However, the level of technological development is not driven by predictions on human performance.

Overall, TRLs do not provide integration readiness of the technology into an operational system. It declares that the system is ready, but only in terms of hardware and software without integrating the human element. During the production and development stage (TRL 7 to 9), there is a documented test performance demonstrating agreement with analytical predictions, test performance verifying analytical predictions, and the final product is successfully operated in an actual mission. The TRL allows the developer to get to the production and development stage without gathering user feedback. Human performance using the actual technology could identify opportunities to validate the system is ready for operations. The test and demonstration of the human in the system on a representative environment could identify potential factors that could affect the crew and the mission. Furthermore, the last level of the TRL tell us that the technology is ready for operational use but does not inform about opportunities for improvement and to understand how any changes on the environment could affect the human performance capabilities.

When the TRL and HRL are used to support technology development, there are sound benefits. However, the HRL by itself will not provide all the means that will be needed to help technology evolve. See, Craft, and Morris (2019) explain that there is not a one-to-one mapping between the TRL and HRL. For example, a TRL level 4, can sometimes mean that the HRL is at the levels of research and development. Going back to the smart skin path example provided earlier, a TRL level 4, may have completed all the laboratory testing of the product characteristics, shown the compound behaviors in basic functional, critical test environments, and achieve the performance expectancy of the patch material, but at at TRL level 4, it may not have completed the analysis of human performance of the patch. The HRL does not specify the activities that need to be completed at each level of the HRL. Because of this, interpretation and level of expertise on the HRL team will play an important role. For example, to understand if the system is fully mature and influence by the human performance metric, the right metrics need to be defined, and the right methodology need to be selected to get the adequate outcomes that will demonstrate a technology is human ready. Many times, individuals in the developing teams think that the system is ready because they are humans and they understand it and can use it. This could really affect the how user centric is the product, Therefore, the selection of personnel with the human research knowledge who can select sound methodologies and approaches is a key factor to successfully use the HRL.

Conclusion

The TRL currently has 9 levels. Since it was developed, the assessment tool has been adapted to different industries and government agencies. The TRL provides a way of conveying to management in a simplistic way the maturity of technology in the development process. However, the TRL major limitation is that the technology evolution is technology centric, and not user centric. Therefore, the HRL was founded on the TRL framework. This article provided an overview the TRL advantages, and limitations. The limitations introduce the need to understand technology maturity as an integrated part of human readiness. Several products and systems developed with TRL basis have shown human decrement in performance. This is an indicator that technologies need to become more user centric. Using the TRL and the HRL together, would help technology developers identify opportunities to address issues early in the design. This article shows how some of the TRL limitation can be overcome when the TRL is used with a HRL. It may serve to improve acceptance of the HRL to the technical and management community.

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