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

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

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FEATURE AT A GLANCE:
In the world of complex system development, a common frame of reference in a project is to communicate the maturity of technology, its progress, its risks, and infusion readiness in terms of technology readiness. The method to estimate the maturity of technologies called Technology Readiness Level (TRL) has shown to play an important role in different project life cycles. The TRLs currently has 9 levels. Each level defines whether the technologies are ready to evolve. This article will discuss the TRL history, define the TRL levels, provide examples, show how the TRL relates to the technology life cycle, and describe the advantages and disadvantages. It will provide the groundwork to understand why the TRL, though a simple metric to indicate the maturity of technology, falls short in numerous areas of engineering including the integration readiness of system/subsystem components that may have different TRLs. Also, TRL lacks the capability to assess the readiness of the technology to operate within the human capabilities and limitations, and to enhance the user experience.

KEYWORDS:
Technology readiness level, human readiness level, human systems integration

Origin of the TRL

As space programs became more complex, it became evident to NASA that a means of defining a methodological way to evaluate the maturity of technologies for spacecraft design was needed 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 seven-point technology readiness level scale was developed in the mid-70s by a NASA researcher and later formally defined in 1989 (Sadin et al., 1989) that comprised of seven levels (See Table 1). These levels provided a definitive meaning of what complexity a research and technology development program should be followed. NASA recognized the approach as a useful way of an effective assessment of, and communication regarding the maturity of new technologies, using a simplistic figure of merit, the state of maturity of a technology-particularly, critical technology necessary to meet a mission/application objective.

Table 1. Original Seven-level Technology Readiness level Scale

1	Basic principles observed and reported
2	Potential application validated
3	Proof-of-concept demonstrated, analytically and/or experimentally
4	Component and/or breadboard laboratory validated
5	Component and/or breadboard validated in simulation or real space environment

6	System adequacy validated in a simulated environment
7	System adequacy validated in space

Though the seven-level TRL was a good start towards providing a common understanding of technology status and support management decisions about development, funding, and life-cycle phases transition, it had its shortcomings. These levels were intended to define the depth and research effort in pursuit of technology maturing-basic research, feasibility, development, and demonstration. The latter descriptions—levels 6 and 7—caused a bit of confusion between management and researchers (Sadin et al., 1989). It was not until 1995 that a refined TRL scale was introduced-increasing the scale from seven to nine. Figure 1 shows the updated NASA TRL scale.

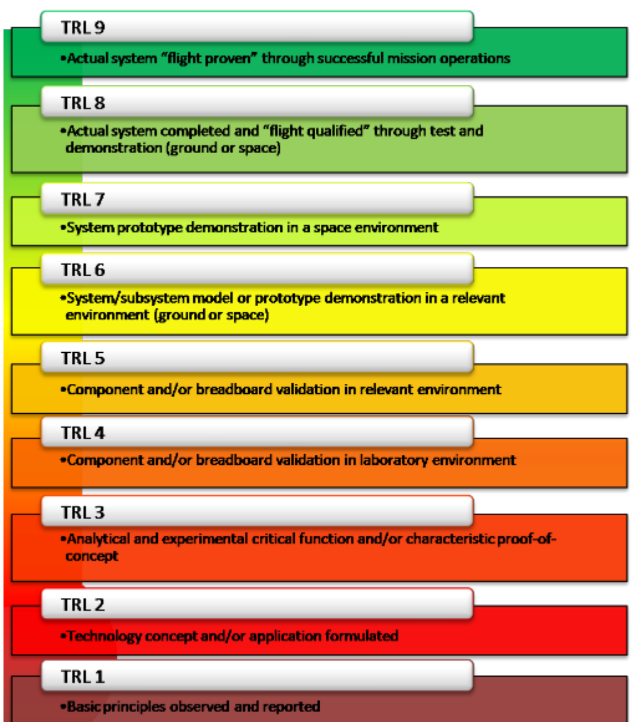

Figure 1. Technology Readiness Levels (NASA: Dunbar, 2017)

TRL Usage

Since the TRL was originated, some organizations (such as the United States Department of Defense (DoD), Department of Energy, and NAVY) have adapted the TRLs for assessments of technology. The DoD (Carter, 2017) and the NAVY tailored the level nine of the TRL by removing the word "flight." The US Department of Energy tailored the levels 4 to 9. The newly added language specifies the type of prototype, whether it is a component or a system, and whether it is for pre-commercial demonstration (U.S. Department of Energy, nd).

The TRLs 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 measured 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 that helps to determine if the technology is ready to mature to the next level.

Use of TRL in a program or project

Planning a project such as a space-related project represents important challenges-particularly, a complex project involving new technology. If technology infusion is not done properly, schedule slips, cost overruns, and potential project cancellation or failures can occur. A major influence in new technology insertion challenge is the degree of uncertainty and lack of understanding risks in terms of cost and schedule margins and reserves necessary to mature the technology with a high degree of confidence. Though risks and uncertainly (especially in high tech projects) cannot be eliminated, it can be considerably reduced through the early application of good systems engineering practices focused on understanding the technological requirements; the maturity of the required technology; and the technological advancement required to meet program/project goals, objectives, and requirements.

This section will provide a high-level example of the use of TRL in a project. TRLs are not used in a vacuum but rather are part of a series of elements to help the project planning for technology insertion. The example relates to a NASA project including the lifecycle and systems engineering planning. Much of the information that follows comes from the NASA Systems Engineering Handbook (NASA, 2017).

Planning a project

During project planning, a Technology Development Plan (TDP) is prepared when new technology development efforts are identified. The new technology may be a Critical Technology Element (CTE) such as a system, subsystem, or component comprised of hardware and/or software. A CTE is identified by the criticality of the technology element's importance in meeting functional and operational requirements and is either new or novel that poses cost, schedule, safety, or technical risks to the project or program. As part of the TDP, a roadmap is developed to support the development path forward to increase the maturity of the CTE in question. As a minimum, the roadmap should focus on:

- Resources to mature the technology
- Key decision points along with the evaluation criteria(e.g., testing) and metrics that will allow for clear identification of gaps and shortfalls in performance
- Risks and burndown of risks
- Show how TRL maturity will be performed such as modeling, analysis, and testing

Project Execution

The project execution is done through the NASA Systems Engineering Process as defined in the 7123.1C-NASA Systems Engineering Processes and Requirements (NASA, 2020). Figure 2 shows the NASA life-cycle phases of a project or program along with major formal design review milestones and the TRL maturity evolution. For a flight project, the key milestone on the CTE TRL is the preliminary design review (PDR). At PDR, per the NASA 7123.1C (NASA, 2020), the TRL for the CTE should be at 6 to ensure the readiness of the CTE for the integration process. After PDR, the next milestone is the critical design review (CDR) where the details of the selected design are reviewed and agreed upon by all stakeholders before the production of the actual flight system. After CDR, various reviews occur in preparation for flight: System Integration Review (SIR), Test Readiness Review (TRR), System Acceptance Review (SAR), Operational Readiness Review (ORR), and Flight Readiness Review (FRR).

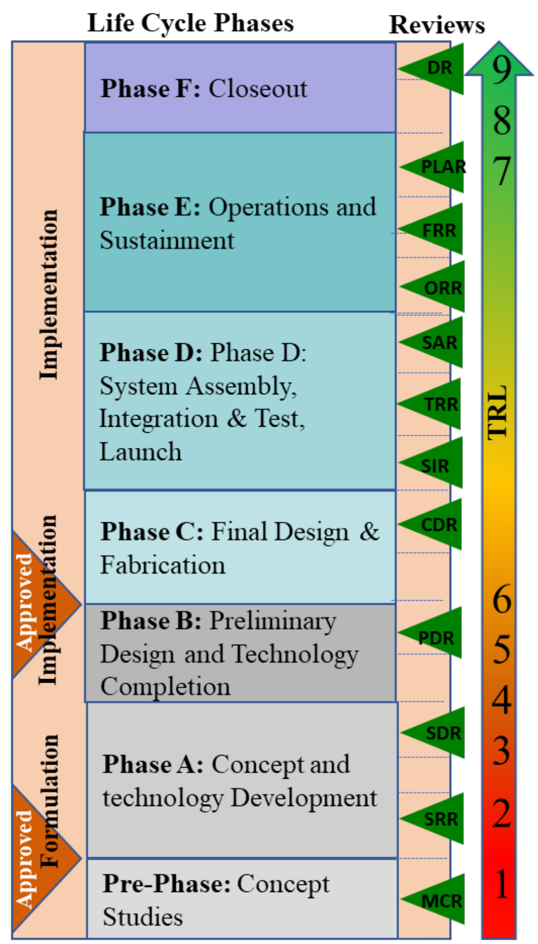

Figure 2. NASA life cycle phases. Note: DR: Design Review; PLAT: Post-Launch Assessment Review; FRR: flight readiness review; ORR: Operational Readiness Review; SAR: System Acceptance Review; TRR: Test Readiness Review; SIR: System Integration Review; CDR: critical design review; PDR: preliminary design review; SDR: system definition review; SRR: System Requirements Review; MCR: Mission Concept Review.

Most maturing of the CTE occurs during the Formulation stage-up to PDR. As part of the systems engineering process, during phases, A and B, requirements and architecture options are being developed along with candidate CTEs that are being evolved and evaluated. At system definition review (SDR), a candidate CTE is picked to mature to TRL 6. During the implementation stage phases C and D, the CTE is being realized and integrated with the final review occurring at flight readiness review (FRR). Continued maturing occurs at phase E where the Post-Launch Assessment Review (PLAR) occurs to assess the readiness to proceed to full routine operations.

Technology Readiness Level Assessment

The last section covered a high-level overview of a NASA project execution using the system engineering process and where TRL is used to make decisions. This section will look at a notional TRL assessment that determines whether a CTE should be matured to the next level or not.

As been mentioned, many agencies and organizations have adopted the TRL scale-tailoring to their particular application and needs. As shown in Figure 1, the scale and TRL descriptions look straight forward. Yet, difficulty in assigning levels arise with terminology and success criteria for the assessment. Breadboard and relevant environment may mean something different to different people. Therefore, the first step taken in the TRL assessment is to define the terms in the scale based on the CTE in question. Once the agreement is reached, experienced well-balanced, and diverse engineers that include human factors personnel should be part of the assessment team. Establishing the TRL success criteria for each level is important as well such as what testing (e.g., radiation, thermal vacuum etc,) is required and what facility to use.

The assessment should include a series of questions to answer including the evidence (hardware or software, analysis, testing, etc.) that supports the assessment level. The agency/organization can develop its own set of criteria or use the Air Force Research Lab TRL calculator (Nolte et al., 2003) developed using the NASA/DoD TRL scale. Note that a CTE cannot be promoted to the next TRL in the scale until it has satisfied its current TRL assessment. Also, note that if the CTE qualified for the mission changes in design or a new environment for future missions or applications, the CTE TRL drops to a lower level-typically TRL 5.

TRL Advantages

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

TRL Limitations

Readiness does not necessarily fit with appropriateness or technology maturity. 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.

Levels are limited to an operational environment and product-system architecture.

TRLs lack of representation of the 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.

Olechowski et al. (2015) studied seven different organizations (NASA, Raytheon, BP, Bombardier, John Deere, Alstom, and google) and examined documentation collected from industry standards and organizational guidelines related to technology development and demonstration. The authors found 15 TRL's challenges that fit into 3 main categories. These included system complexities (e.g., integration and connectivity), planning and review (e.g., backup plans and product road mapping), and validity of assessment (Subjectivity of the assessment and impression scale).

Conclusion

The TRL currently has 9 levels. Since it was developed, the assessment tool has been adapted to different industries. This article provides an overview of the history of the development of the TRL, it provides an example of the usage of the TRL in the NASA life cycle and lists specific advantages and limitations of this assessment tool.

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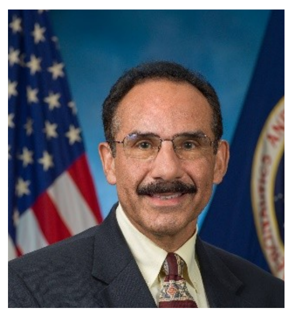

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