A Brief Discussion on Technology Readiness Levels

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ABSTRACT:

Technology Readiness Levels (TRLs) are a methodical and often used way to gauge how mature a technology or invention is. TRLs provide a standardised framework that allows academics, engineers, and decision-makers to assess a technology's suitability and potential for real-world use. An overview of Technology Readiness Levels and their importance in determining a technology's development stage are provided in this abstract. From fundamental research (TRL 1) through fully operational deployment (TRL 9), TRLs are divided into nine stages. Each level denotes a distinct development stage for the technology and offers information on its readiness, dangers, and likelihood of being successfully implemented. The summary emphasises the primary issues and problems at each stage of technology development while highlighting the major traits and criteria associated with each TRL level. It examines how TRLs are used in a variety of fields, including information technology, energy, aerospace, and defence.

KEYWORDS:

Readiness Levels, Standardised Framework, Systems Engineers, Technology Readiness.

I. INTRODUCTION

System engineers utilise Technology Readiness Levels (TRLs), a structured set of criteria, to evaluate the maturity and readiness of a given technology or system. TRLs provide a standardised framework for assessing and conveying a technology's state of development across the course of its life cycle. Engineers and decision-makers may assess a technology's development, make knowledgeable choices, allocate resources efficiently, and reduce risks by giving it a TRL [1], [2].

TRLs were first introduced by the US Department of Defence (DoD) and have subsequently gained widespread use in a number of sectors, including information technology, aerospace, defence, and energy. The TRL framework has nine levels, each of which corresponds to a distinct stage in the evolution of technology:

1. **TRL 1:** Fundamental Concepts Observed: This level denotes the formulation of a technology idea and the existence of some technical or scientific proof supporting the notion's viability.
2. **TRL 2:** Technology idea verified: At this stage, tests or analytical investigations have verified the technology idea, proving its potential feasibility.
3. **TRL 3:** Established Proof of Concept: A simple experimental prototype or analytical demonstration has been created to demonstrate the usefulness of the technology, which shows how far it has come.
4. **TRL 4:** Technology Validated in Lab Environment: The technology has undergone testing and validation in a lab setting, demonstrating its effectiveness under simulated circumstances.
5. **TRL 5:** Technology Validated in Relevant Environment: The technology has been examined and validated in a setting that is appropriate and representative of real-world use cases.
6. **TRL 6:** System Model or Prototype Demonstrated in Applicable Environment: A prototype system successfully demonstrated in the intended operational environment.
7. **TRL 7:** System Prototype Demonstrated in Operational Environment: The performance and functionality of the system prototype have been shown off in an operational setting.
8. Actual System Completed and Qualified at TRL 8: The system has been created and certified for its intended usage, and the technology has achieved its final design configuration.
9. **TRL 9:** Real-World System Demonstrated by Successful Operations: Successful operational deployments or missions have validated the technology's dependability, efficacy, and performance.

TRLs help stakeholders communicate in a single language and get a common understanding of the maturity of the technology. They aid decision-makers in weighing the advantages and disadvantages of adopting or investing

in a certain technology. The move from early-stage ideas to fully functional systems is facilitated by TRLs, which also serve as a roadmap for technological progress. TRLs enable the planning and administration of research and development operations. Technology Readiness Levels (TRLs) provide a standardised framework for evaluating the maturity and readiness of technologies or systems in system engineering, in conclusion. Throughout the technology development life cycle, they make decision-making, resource allocation, risk reduction, and planning more successful [3], [4].

II. DISCUSSION

Technology Readiness Levels (TRL) are a technique for gauging and evaluating the development of a certain technology. They provide project staff, managers, and engineers with a constant point of reference for understanding how a technology is evolving. Technology Readiness Levels (TRL) are used to gauge how mature a system's technological components are. The assessment enables project staff to comprehend how much more work has to be done before a certain technology can be put to use. A TRL grade aids in tracking a project's development [5], [6].

Scale for Technology Readiness (TRL)

The TRL scale ranges from 1 to 9, with 9 being the most advanced technology. TRLs make it possible to discuss technological maturity across several technologies in a consistent, standardised manner. When evaluating programme risk, decision authorities will take the suggested TRLs into account.

Technology Readiness Level for Systems Engineering (TRL)

Before moving on to an end-item design or Milestone B, the primary systems engineering objective is to acquire the necessary technical knowledge to develop the program's System Requirements Document (SRD) and to confirm that the system solution(s) required technology is sufficiently mature, has a TRL 6 or above. Before moving on to Milestone B, a programme must develop its CTE, which is covered in the Technology Development Strategy (TDS). After Milestone B, the Engineering and Manufacturing Development (EMD) Phase Acquisition Strategy should include a technology maturation plan or strategy for those CTE that need greater concurrency and technical development to reach a higher TRL [7], [8].

Technology Readiness Levels (TRLs) are often used in systems engineering to evaluate the maturity and readiness of technologies in the context of a system development project. TRLs provide guidance for decision-making throughout the project lifecycle and assist in assessing the technical risks connected to integrating new or developing technologies into a system.

TRLs are used in systems engineering in a number of ways:

Technology Assessment

TRLs help in assessing various technologies for possible system integration. Systems engineers may decide if a technology is at an appropriate degree of maturity to be taken into consideration for inclusion by evaluating the TRL of each technology. Higher TRL technologies are often favoured since they have shown more substantial advancement, lowering the hazards involved.

Risk Management

TRLs are a tool for risk management since they show the dangers of using a certain technology. Since the technology has evolved through many development stages and shown its viability, higher TRLs suggest a reduced degree of risk. TRLs are a tool that systems engineers may use to identify and reduce risks associated with technical uncertainty [9], [10].

Analysis of Requirements

TRLs assist Systems Engineers in comprehending the effects of technological decisions on system requirements. For instance, if a crucial system need is dependent on a technology with a low TRL, it means that more resources and effort may be needed to advance the technology to a mature stage where it can provide the appropriate degree of functionality.

Technology Roadmapping and Long-Term Planning

TRLs support the creation of long-term technology roadmaps. TRLs may be used by systems engineers to evaluate the status of technologies now and project how far they will progress in the future. With the use of this

knowledge, system improvements, possible technology transitions, and technology insertion may all be strategically planned.

Collaboration and Communication

TRLs provide a common language for stakeholders participating in system development initiatives to communicate. They make it possible for Systems Engineers, project managers, academics, funding organisations, and industry partners to communicate effectively, assuring a common understanding of technological maturity and development advancement. Project teams may make wise judgements, efficiently manage risks, align technology choices with system requirements, and streamline the entire system development process by integrating TRL evaluations into Systems Engineering practices.

Technology Readiness Levels (TRL) Assessment of Technology Readiness

Technology Readiness Levels (TRL) are the primary metrics used in a Technology Readiness Assessment (TRA) to evaluate each technology, although an assessment is more than simply a snapshot in time or a single number. It is a collection of lower-level evaluations that, depending on the development's complexity and the program's timeline, may take many years.

Evaluations may uncover possible issues for decision-makers during purchases, provide programme planning information, and assist measure the status of technological advancement. Prior to risks being carried into the later, costlier stages of system development, prospective issues may be identified by regularly conducting TRAs at the early phases of development.

By offering a consistent vocabulary for talking about technological readiness and associated technical risks, TRAs may help simplify communication between technology developers, programme managers, and acquisition authorities throughout development and at crucial decision points. The findings of TRA may also be used to inform other evaluations and planning processes, including cost and schedule projections, risk evaluations, and plans for the maturity of new technologies.

The most reliable source of TRL information is Appendix C of the Technology Readiness Assessment Deskbook. It includes:

1. A description of TRL
2. Hardware Critical Technology Elements (CTE) Assessment
3. Software Critical Technology Elements (CTE) Evaluation

Difference Between Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL)

The readiness assessment frameworks Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) are both utilised at various phases of the development and deployment of a system or technology. TRL focuses on the growth and maturity of technology, while MRL explicitly assesses the readiness of manufacturing processes and capacities. The following are the main variations between TRL and MRL:

1. Scope:

TRL: TRL evaluates a system's or technology's technical elements, functionality, and performance in order to determine how mature and ready it is.

MRL: MRL assesses if the manufacturing procedures, infrastructure, tools, and resources are prepared to create a technology or system at the necessary volume and calibre. It includes production planning, supply chain management, manufacturing processes, and other manufacturing-related elements.

2. Focus:

TRL: TRL places a strong emphasis on technical advancement, showing the viability and efficacy of a system or technology via experiments, prototypes, and testing in supervised settings.

MRL: MRL focuses on manufacturing capabilities, making sure that the required infrastructure, resources, and manufacturing processes are in place to create a technology or system effectively, consistently, and in a volume that is appropriate.

3. Assessment Standards:

TRL: TRLs often take the shape of a scale from 1 to 9, with each level denoting distinct benchmarks and requirements relating to technology development, performance validation, and deployment readiness.

MRL: MRLs often evaluate manufacturing readiness using a comparable scale or a distinct set of levels. Criteria including process validation, manufacturing cost estimate, production rate capacity, supplier preparedness, and quality control procedures may be included in these levels.

4. Purpose:

TRL: TRLs are used to evaluate the hazards posed by new or developing technologies when included into a system. During the system development process, they serve as a guide for decision-making, risk management, and technology selection.

MRL: MRLs concentrate on identifying and controlling risks related to the manufacturing process itself. In order to enable efficient and economical production, quality control, and supply chain management, they make sure that the manufacturing capabilities match the system's needs.

5. Timing:

TRL evaluations: Starting with the conceptual stage and moving through design, prototyping, and testing, TRL assessments are often carried out in the early phases of technology development. TRLs provide an overview of the maturity of a technology at various phases of development.

MRL: Evaluations of the MRL are carried out when the technology moves closer to manufacture and production. MRL evaluations, which may be carried out concurrently with TRL assessments, guarantee that manufacturing procedures are prepared to support the production of the technology or system.

In the end, MRL evaluates the readiness of manufacturing processes and capabilities whereas TRL concentrates on technological maturity and deployment readiness. While MRL looks at the manufacturing-related elements required for effective and dependable production, TRL assesses the technical aspects of the technology. In evaluating many facets of the development and deployment process of a system, both frameworks serve complimentary roles.

III. CONCLUSION

Systems engineering and the development of new technologies heavily rely on Technology Readiness Levels (TRLs). They provide a standardised framework for evaluating technologies at various phases of their development lifecycles for maturity, readiness, and related hazards. During the system development process, stakeholders may use TRLs to manage risks, distribute resources wisely, and make informed choices. TRLs make it easier to assess and choose technologies for system integration while taking into account their state of development and viability. They support successful risk management strategies by assisting in the identification of the risks and uncertainties related to implementing new or developing technology. By exposing the effects of technological choices on the functionality and performance of systems, TRLs also aid requirements research.

TRLs also assist in long-term technology planning and roadmap creation by offering perceptions into the condition of technologies now and their potential for development in the future. This knowledge helps in making strategic choices about the introduction of new technologies, system updates, and technological changes throughout time. TRLs also promote successful stakeholder communication and cooperation by creating a shared vocabulary and understanding of technological maturity and readiness. This encourages cooperation among project managers, academics, funding organizations, and business partners engaged in system development.

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