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Measuring the Maturity of a Technology: Guidance on Assigning a TRL

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Measuring the Maturity of a Technology: Guidance on Assigning a TRL

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Abstract

This report provides guidance on how to assign a technology readiness level (TRL). The method proposed assists in assigning TRLs through a series of questions that focus on a set of unambiguous maturation metrics. This method is slightly biased towards the environment and approach to technology maturation at Sandia National Laboratories where customers and suppliers are in very close proximity to one another, allowing for supplier-customer interactions at a very early stage in technology development.

The hope is that this report can serve as a practical guide to anyone trying to understand the maturity of a specific technology. Risk is reduced in system acquisition by selecting mature technologies for inclusion in system development. TRLs are used to assess the maturity of evolving technologies and therefore become part of an overall risk reduction strategy in system development.

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Contents

Introduction

Background

Technology readiness levels (TRL) are utilized by government agencies [1][2][3] to measure the maturity of evolving technologies prior to incorporating them in a system or subsystem. As part of a risk reduction strategy for system acquisition, technologies employed in system development should be mature before system development begins. In 2006, Sandia National Laboratories began to informally adopt the use of TRLs [4][5][6] and then more formally in 2007 with the introduction of a Corporate Business Rule [7].

This report is part of a strategy aimed at disseminating information on the use of TRLs at Sandia National Laboratories.

Using this Guide

A technology evolves and matures through a series of stages. The TRLs attempt to capture these stages in nine levels and through a series of brief descriptors. The lowest level of maturity is TRL 1 and the highest level of maturity is TRL 9.

To show that a technology is at a particular level of maturity it is necessary to have a set of maturity metrics associated with each level. In the approach utilized here, these metrics consist of a set of *yes/no* questions and associated required evidences. If a question is answered *yes*, then evidence is required to support that answer. The required evidence can be quite detailed and difficult to obtain, but it is necessary and part of rigorously demonstrating the readiness and maturity of a technology. In general, the supporting evidence must be evaluated by an independent third party who is also a subject matter expert. This last point is crucial.

Beginning on Page 11, a short **bold** descriptor and brief description of each TRL is given. Following the brief description, a sequential set of *yes/no* questions along with required evidence is presented. In general, it will not be possible to answer *yes* to all questions. Proceeding from the start, it becomes increasingly difficult to answer *yes* since succeeding questions also correspond with increasing technology maturity. For a technology to be assigned a particular TRL, it must be possible to answer *yes* to all questions in all levels leading up to and including the particular level in question. In most cases the maturity metrics will be completely satisfied up through a particular level and will be partially fulfilled for the next level up.

Assigning a TRL: Stakeholder Participation

It is recommended that all stake holders participate in the process of assigning a TRL. On a practical level, this means that customers, suppliers, and other stakeholders should meet and agree upon answers to the *yes/no* questions given in this guide. It may also be necessary to have third party subject matter experts evaluate supporting evidence.

Vocabulary and Semantics

Environment

The customer and supplier agree that the technology/product should logically be expected to meet requirements before, during, or after exposure to environments. The environments may be transient or indefinite in duration. Examples include such things as: product meets performance requirements during transient exposure to radiation environment; product is required to meet performance requirements after exposure to an extreme shock event; and product is expected to satisfy customer's needs when utilized on a particular computer platform and operating system. The environment can be physical (temperature, radiation, vibration, shock, etc), logical (platform: computer, operating system), context (frequency or extent of use), or any other setting the technology/product is integrated within or exposed to that may possibly degrade expected performance.

Key Elements

Key elements are components/pieces of a technology that are integrated logically so that the technology meets the agreed-upon customer/supplier requirements. Identification of key elements involves understanding functional aspects of a technology as well as how they will be developed. It is also important for the supplier to understand what level of granularity is useful and required in order to best communicate with the customer and to properly meet customers' needs. As an example, consider the AF&F. The AF&F includes at least three key elements that must be integrated: arming, firing, and fuzing.

Integration

There are two levels of integration: end-user integration and integration of key elements.

End-user integration

The technology is expected to integrate within the customer's system in order to solve a particular problem. The customer and supplier agree upon the nature and form of this integration so that requirements are met. In general this is an interface problem in which the supplier agrees to a particular interface within the customer's system. Common examples include mechanical and electrical integration, and software interfaces.

Integration of key elements

The pieces or components of a technology are integrated so that the technology meets the agreed-upon customer/supplier requirements. In contrast with end-user integration, integration of key elements relates to the internal workings of the technology. Key elements are integrated and assembled to form a functional unit that the customer utilizes. A simple list of the key elements of a car includes the engine, frame, drive shaft, body, axles, and wheels. The basic functionality of the car is realized once the key elements are integrated.

Disclaimer

Before proceeding it is necessary to give a disclaimer:

This document is only a guide and starting point for assigning a TRL to a technology. There is no perfect method or approach that can substitute for good judgment. The guidelines given may be utilized in a rigorous process for assigning TRLs to technologies.

TRL 1: Basic principles observed and reported

This is the first level of technology readiness and includes fundamental scientific research. At this level, basic scientific principles are being studied analytically and/or experimentally. Examples might include paper studies of a technology's basic properties. [7]

Question

►Is there a fundamental concept, innovation, or scientific principle that is key to the technology under study?

Evidence required

- List and describe the basic principles involved.
- List references (if any) that document the basic principles involved.
- Why is this interesting?

TRL 2: Concept and/or application formulated

Practical applications are beginning to be invented or identified. Applications are still speculative and there is no proof or detailed analysis to support assumptions. Examples might include applied research in a field of potential interest. [7]

Question

► Are there practical applications for this research and/or innovation?

Evidence required

- List examples of potential applications.
- Describe how applications would utilize the basic principles, concepts, or innovations under study.
- List references (if any) that link this research to potential applications.

TRL 3: Concepts demonstrated analytically or experimentally

Active research and development is initiated. This includes analytical and laboratory-based studies to physically validate analytical predictions of key elements of the technology. These studies and experiments should constitute "proof-of-concept" validation of the applications/concepts formulated at TRL 2. Examples include the study of separate elements of the technology that are not yet integrated or representative. [7]

Question

►Assuming the basic principles involved are sound, is there an intended application?

Evidence required

- Describe the key functionality of the intended application.
- Why would anyone be interested in this application?
- If a laboratory prototype were created, what would its key elements be?

Question

►Have laboratory prototypes been created that show "proof of concept" for key elements of the intended application? These elements are not necessarily integrated.

Evidence required

- Which key elements were demonstrated?
- What metrics were used to show "proof of concept?"

TRL 4: Key elements demonstrated in laboratory environment

The key elements must be integrated to establish that the pieces will work together. The validation should be consistent with the requirements of potential applications but is relatively low-fidelity when compared to a final product. Examples include integration of ad-hoc hardware or software in the laboratory such as breadboards, low fidelity development components, and rapid prototypes. [7]

Question

►Has a laboratory prototype been created that integrates all key elements necessary to address a particular problem or application?

Evidence required

- What problem does the prototype address?
- What key elements were integrated?
- Describe how the prototype integrates the key elements and solves the problem.

Question

►Has a laboratory demonstration been conducted that integrates all key elements necessary to solve a particular problem and shows functional aspects of the prototype operated according to what a customer would expect?

Evidence required

- Describe the demonstration.
- What key elements were part of the demonstration?
- What functionality was demonstrated with the prototype?
- What metrics were used to conclude that the prototype worked as expected?
- How does this demonstration correlate with what a customer of this technology would expect?

TRL 5: Key elements demonstrated in relevant environments

Fidelity of the key elements increases significantly. Key elements are integrated with realistic supporting elements so that the technology can be tested and demonstrated in simulated or actual environments. [7]

Question

►Is there an end-user customer for this technology?

Evidence required

- Who is the customer?

Question

►Is the customer working with the supplier to define functional and performance requirements?

Evidence required

- List and describe functional and performance requirements for the product.
- Describe how these requirements meet the customer's needs.

Question

►Is the supplier working with the customer to define integration and environmental requirements including abnormal or extrema events?

Evidence required

- Describe the integration requirements.
- Describe the plans for integrating the product within the customer's system.
- Describe the environmental requirements including abnormal or extrema events. What are the expectations for the product after exposure to abnormal environments?

Question

►Has a prototype been built and used to successfully demonstrate required functionality and performance before, during, and after exposure to the customer's environments?

Evidence required

- Describe the demonstration and discuss key elements integrated and included in the prototype.

Question

►Does the demonstration include all functionality and performance metrics the customer expects?

Evidence required

- List and describe the metrics used to conclude that the demonstration was a success.
- How do the metrics correlate with agreed-upon requirements for functionality, performance, and environmental exposure?

TRL 6: Representative of the deliverable demonstrated in relevant environments

Represents a major step in a technology's demonstrated readiness. Examples include testing a prototype or representative of a deliverable in a high fidelity laboratory environment or in a simulated operational environment. [7]

Question

►Have the supplier and the customer developed a set of requirements for the product?

Evidence required

- Please provide documentation of the requirements.

Question

►Has a prototype been created that is consistent with all of the agreed-upon requirements?

Evidence required

- Describe how the prototype meets form, fit, and function requirements.
- Describe how the prototype satisfies additional expectations/requirements that go beyond form, fit, or function.

Question

►Has the prototype been demonstrated successfully in the customer's required environments?

Evidence required

- Describe the demonstration.

Question

►Do the customer and supplier agree that the demonstration was representative of the customer's needs and that it was successful?

Evidence required

- How was the demonstration representative of the customer's specific needs?
- What metrics were used to conclude the demonstration was a success?

- How do the metrics correlate with the agreed-upon requirements?

TRL 7: Final development version of the deliverable demonstrated in operational environment

Development version of the deliverable is near or at the planned operational system. This represents a significant step beyond TRL 6 and requires the demonstration of an actual development version of the deliverable in the operational environment. Examples include integration and demonstration within the next assembly, and advanced concept technology demonstrations of integrated systems such as flight testing. [7]

Question

►Are the customer and supplier in full agreement that requirements are completely established and in final form?

Evidence required

- Please provide the final set of requirements.

Question

►Has a prototype been integrated within the customer's operational platform and demonstrated to function as expected in appropriate environments?

Evidence required

- Describe the demonstration and how the prototype integrates within the customer's system.

Question

►Are the customer and supplier in agreement that the demonstration was a success?

Evidence required

- List and describe all elements of functionality and performance that were demonstrated.
- What metrics were used to conclude the demonstration was a success?
- How do the metrics correlate with the agreed-upon requirements?

TRL 8: Actual deliverable qualified through test and demonstration

The technology has been proven to work in its final form under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the actual deliverable in its intended application to validate that it meets design specifications. [7]

Question

►Has a production unit (actual deliverable that is representative of that which can be created with acceptable cost, capacity, and schedule requirements) been created and integrated within the customer's system?

Evidence required

- Describe how this deliverable represents a production unit.
- Describe how the production unit integrates within the customer's system.

Question

►Has a production unit been qualified for final delivery to the customer?

Evidence required

- Describe the approach to qualification. List all tests and demonstrations utilized to qualify the production unit for final delivery.
- Link all elements of the qualification process back to agreed-upon requirements and demonstrate that through this qualification process the production unit is ready for final delivery.

Question

►Does the customer agree that the production unit is qualified and ready for final delivery?

Evidence required

- Describe the customer's approach to product acceptance.
- How does the customer's approach to product acceptance correlate with agreed-upon requirements?

TRL 9: Operational use of deliverable

Application of the technology in its final form and under mission conditions such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last bug fixing aspects of true system development. Examples include using the deliverable under operational mission conditions. This TRL does not include ongoing or planned product improvement of reusable systems. [7]

Question

►Has the customer accepted the product and placed it in service within their system?

Evidence required

- Describe the successful deployment of the product in terms of the customer's volume and frequency of use.
- What rate of success does the customer have using the product?

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