Using the Technology Readiness Levels Scale to Support Technology Management in the DoD's ATD/STO Environments

A Findings and Recommendations Report Conducted for Army CECOM

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Suzanne Garcia
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Peter J. Van Syckle, U.S. Army CECOM RDEC STCD

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Software Engineering Process Management Program

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Abstract

In early 2002, the Communications Electronics Command (CECOM) Manager of the Army Tactical Wireless Network Assurance (TWNA) Science and Technology Objective (STO) FY03-07, hereafter referred to as STO, requested assistance from the Software Engineering Institute (SEI) in improving STO methods for assessing the maturity of new information-assurance technologies. The STO was seeking to use technology maturity, as measured by the Technology Readiness Levels (TRLs) scale, as a metric in its decision-making process for selecting new technologies for STO development and maturation, technologies that would eventually be transitioned to Army tactical programs. This report describes the results of the SEI study of the feasibility of (*a*) using TRLs in STO technology screening, (*b*) developing or acquiring a TRL tool, and (*c*) implementing a TRL tool.

1 Project Overview

1.1 Objectives

The objective of the project documented in this report was to assess the feasibility of developing an information assurance (IA) technology readiness level (TRL) assessment method (or equivalent) for technologies at various TRLs. The purpose of such an assessment method is to assist the Communications Electronics Command (CECOM) Manager of the Army Tactical Wireless Network Assurance (TWNA) Science and Technology Objective (STO), and others in the S&T community, in identifying technologies in basic research and applied research categories that would benefit the Army and other services.[1] Effective use of TRLs can reduce the risk associated with investing in immature technologies.

1.2 Background

In early 2002, the CECOM Manager of the Army TWNA STO FY03-07, hereafter referred to as STO, requested the Software Engineering Institute's (SEI's) assistance in improving their methods for assessing and identifying the maturity of new IA technologies. The premise was that technology maturity is a useful metric in the decision-making process of selecting new technologies for development and maturation within an advanced technology demonstration (ATD) or STO environment, technologies that will eventually be transitioned to Army tactical programs. The SEI and the Manager of the STO developed a plan for three phases of work, the first of which, a feasibility study, began in February 2002 and is the subject of this report.

The overall goal of the project (the cumulative result of all three phases) is to provide the STO with an IA TRL assessment method, or an equivalent, to support their decision-making process in selecting new technologies for investment. Recent DoD regulations (see Appendix A: Technology Readiness Levels) have put an emphasis on the use of TRLs to improve the ability of acquisition programs to select mature technologies for inclusion in their programs. The STO is seeking to apply this same or, at a minimum, a compatible approach to aid their investment decisions, which occur early in a technology's life cycle. The difference between the two domains is that the STO (or, likewise, an ATD) generally seeks to invest in technologies at TRL 4 or so, while acquisition program managers generally seek technologies at TRL 6 or higher. One of the goals of the STO (and ATD) is to mature technologies that are TRL 4

[1] Calendar Year 2002 Work Plan for the Tactical Information Assurance STO FY03-07, PWS 4-357, Version 2.1, Software Engineering Institute.

or below to at least a TRL 6, making the technologies more mature and thus more “ready” for insertion into acquisition programs.

STO is expected to mature new information assurance technologies to DoD TRL 6 in no more than four to five years after project start. The lower the maturity, or readiness, of an incoming technology (the technology selected by STO for maturation), the more time and money will likely be needed to mature that technology to TRL 6. Thus, STO considers a TRL 4 or 5 to be the minimum acceptable readiness level for an incoming technology that will enable them to satisfy their program constraints. STO is looking for consistent, repeatable methods to evaluate technology readiness as part of their investment decision-making process, to self-assess their own technology, and to help filter all the possible technologies down to the most promising ones. CECOM has an ongoing task to weed through the many programs to find ones relevant to their mission. Once identified as relevant to the mission, a TRL estimate can help reduce the risk of investing in a technology that is “too immature.”

While the DoD has issued new regulations stating that new major programs must utilize TRLs or a yet-to-be-identified equivalent, there has apparently been no top-level guidance on *how* to determine a TRL (our interviews with several TRL users from the General Accounting Office (GAO), Air Force Research Lab (AFRL), and Defense Advanced Research Projects Agency (DARPA) indicated this indeed to be the case). This project is an attempt to provide some of this missing guidance, specifically for support of STO needs, by understanding what methods, tools, or techniques others are currently using to estimate the TRL of a given technology.

1.3 Approach

This feasibility study sought to answer this question:

> *Is it feasible to develop (or acquire if available) a TRL (or equivalent) tool (such as a checklist or software package) that enables the Army STO Manager to assess the maturity of new IA technologies?*

The detailed project plan is provided in Appendix C. In general, our approach included identifying the needs of the STO regarding TRL use, assessing the state of the practice of other TRL users, and synthesizing the results into the following categories of findings, which are detailed in the Findings section of this report:

- Conceptual Feasibility: Is it feasible for TRLs (or an equivalent) to support or improve the STO Manager’s decision-making process in selecting new IA technologies for ATD investment?
- Development Feasibility: What resources would be needed for the development of such a tool if it does not already exist, or for its adaptation for use by the STO if such a tool does exist?

- TRL Tool Implementation Feasibility: What resources are needed to employ such a tool in the Army STO and DARPA S&T communities?

1.4 Scope and Constraints

A feasibility study can range in scope from a few months to more than a year, depending on the complexity of the issues being studied. To limit the duration and budget of this study, the following project constraints were agreed to at the project kickoff meeting in February 2002:

- Concentrate on assessing the technology's readiness coming into the STO (i.e., is it ready for the STO to take?), rather than the readiness of the technology going out of the STO (i.e., is it ready for the STO to transition to product developers?). However, the outbound technology readiness is a closely related issue and much of what is discussed herein applies in that case as well.
- If the feasibility study identifies potential alternatives to the TRLs, they can be reported. However, because of the Army's interest and emphasis on TRLs as they are currently defined, it would require some "sales and negotiation" to convince others that there is a better way. If an alternative looks more suitable, the practical approach would be to map to or package it in TRL terms.

1.5 Challenges

One of the main challenges of providing a readiness assessment method to support the STO is tied to their relationship with DARPA. DARPA is a major source of new IA technologies for STO, with a significant number of IA projects currently underway. While the STO personnel that we interviewed[2] stated that they have a good rapport with DARPA Program Managers (PMs) and some of the Principal Investigators (PIs), it would be challenging indeed to meet with roughly 50 DARPA PIs (the typical number of projects annually evaluated by STO) doing research for DARPA on a regular basis to discuss the readiness of each technology. Two STO interviewees[2] verified this, stating that it is difficult to get on the DARPA PIs' calendars. To facilitate awareness and understanding of their technologies, DARPA holds conferences throughout the year. According to the STO interviewees, about 15 technologies are described in presentations, about 15 are demonstrated, and the rest are reflected in document form. Even in this venue, however, the STO interviewees said they find it labor-intensive to assess technology readiness because that metric is not consistently expressed in research and therefore must be somehow extracted or formulated from the information PIs provide. The DARPA PMs we interviewed for this report,[3] however, stated that the information presented at these meetings generally doesn't contain sufficient detail for estimating TRLs.

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2 Conversations with Robert J. Schenk, U.S. Army CECOM RDEC Space and Terrestrial Communications Directorate, TWNA STO and Peter Van Syckle, U.S. Army CECOM RDEC Space and Terrestrial Communications Directorate, TWNA STO.

3 Conversations with Doug Maughan, DARPA and Jay Lala, DARPA.

In summary, the challenges to providing a readiness assessment method to support the STO technology selection process include the following:

- Regular face-to-face meetings between STO personnel and DARPA PIs are limited, creating reliance on the conference materials for determining a TRL.
- The technology information that DARPA provides comes in several forms (presentations, demonstrations, papers) but generally does not contain sufficient information to allow STO to determine TRLs just from the materials.
- Consistent DoD guidance on how to assess TRLs is lacking, thus putting STO in the position of defining a consistent method for this type of assessment.

As a result, STO will be breaking new ground in including TRL information in their decision-making process that may hopefully help others in the S&T community.

2 Findings

2.1 A Note About TRLs

TRLs are described in the DoD 5000.2-R document (see Appendix A) from a systems perspective, and thus are intended to be appropriate for both hardware *and* software. The document also states "DoD Components may provide additional clarifications for software." The Army, for example, has developed a mapping of the TRLs to software (see Appendix B), and the Army Medical Research and Materiel Command is working on defining corollaries for biomedical TRLs.[4] Thus, TRLs are meant to be overarching definitions for any technology, while interpretations or amplifications for specific technologies are left to the experts in that technology domain.

2.2 Conceptual Feasibility

This section of the report provides our findings in response to this question (see Section 1.3):

> *Is it feasible for TRLs (or an equivalent) to support or improve the STO Manager's decision-making process in selecting new IA technologies for investment?*

Currently, TRLs are being used successfully at the completion of an ATD or STO when getting ready to transition, i.e., when briefing progress to the Army sponsor, rather than as a screening approach for selecting new technologies. Most of the literature on TRLs that the SEI team surveyed is limited to the context of using TRLs to improve the timing of transitioning or inserting a technology *from* an ATD-like environment to a product development program (acquisition program). We found no literature describing the use of TRLs at the front end of an ATD, i.e., in the ATD technology-selection process. We note that the results of this project may also help refine the readiness assessment process at the TRL 6 stage as well. The GAO states that a major purpose of TRLs is to "reveal the gap between a technology's maturity and the maturity demanded for successful inclusion in the intended product" [GAO/NSIAD 99]. TRL-related requirements are integrated into the ATD/STO exit requirements. Meeting these requirements automatically satisfies a "TRL 6." TRLs are not the only exit criteria, of course. Domain-specific requirements, such as preventing or detecting network security events a certain percentage of the time, are obviously critical.

4 "Biomedical Technology Readiness Levels (TRLs)," a working paper provided to the SEI by the U.S. Army Medical Research and Materiel Command, but not approved for public release.

While the literature we surveyed and the TRL users we talked to are heavily oriented to using TRLs in the product development phase (assessing the risks of including a technology in product development), the GAO's 1999 report [GAO/NSIAD 99] cites the AFRL as having adapted and using TRLs "to measure the key steps in the progression of technology from initial concept to proven performance," thus indicating the use of TRLs throughout a technology development cycle. Conversations with William Nolte at AFRL confirm this statement. AFRL is currently using TRLs on a DARPA project (Medusa), which is being managed by AFRL.

At the front end of the STO technology management life cycle, current practice for selecting new technologies involves a variety of parameters, though generally not yet TRLs. Some of the parameters factored into a new technology selection include

- *the applicability of the technology to the ATD and STO program.* Obviously, only technologies that satisfy the mission of the program are suitable candidates.
- *availability of the technology developers*. Having the support of the basic and applied research and technology developers available to the STO developers throughout the STO project can be critical, and in some cases can be a deal-breaker if the STO developers are not confident that such support will be present. Access to the primary research staff is considered a critical success factor in preparing the technologies for product development use. As a result, the selection process generally rejects technologies that are no longer being actively developed. Once a project has closed down, the researchers go on to other work and are not available to support their original findings.
- *The skills of the technology lead*. A technology lead with experience in the technology domain, good human interaction skills, and a sincere interest in continuing the maturation of his or her technology (via the ATD/STO process) is an important factor in the technology's ultimate success. Thus, the skills of the technology lead are taken into account in the ATD/STO selection process.
- *Consistency of project funding*. Technology projects with consistent and sufficient funding are more likely to be objective with their TRL estimates and not be tempted to use them as a sales vehicle to secure funding.

So, what are the perceived benefits of using TRLs in STO or ATD technology selection? ATD personnel we interviewed[5] estimated that TRLs may address approximately 30% of the factors that they need to pay attention to in making their technology selections. They serve as a risk-reduction measure. Domain-related issues, requirements that are derived by CECOM, and ATD exit criteria, make up the majority of the selection criteria. If this estimate is accurate, TRLs can be said to bring value to the STO or ATD technology-selection process, though they should be considered as only one of numerous critical decision criteria. In addition, one of our interviewees[6] told us that the use of TRLs across the research and development community encourages the ATD to build from existing, though immature, technologies

5 Conversations with Robert Serenelli and Frank Geck, KeyWay Security.

6 Conversation with Peter Van Syckle, U.S. Army CECOM RDEC Space and Terrestrial Communications Directorate, Tactical Wireless Network Assurance (TWNA) Science and Technology Objective (STO).

from universities or research labs (e.g., Army Research Lab, Naval Research Lab) and evolve them, rather than developing new technologies themselves from scratch. Thus, the use of TRLs is not only being "strongly encouraged" by senior Army and DoD officials, it also shows merit for use in the ATD/STO technology-selection process.

What about equivalent measures of technology readiness and their value in the STO technology selection process? A survey of more than 30 articles in the field of new product development and portfolio management in industry provided little in the way of equivalencies at the level of detail at which TRLs are currently defined. The closest was a six-level scale of technology maturity, with the highest level of maturity denoting commercialization [TRECC 01]. That scale's purpose is to identify commercial technologies for potential adoption by the DoD. The literature also highlighted the fact that technology maturity (which TRLs are intended to help measure) is only one of numerous critical factors used by industry to select and prioritize technology projects. Our interviews with ATD personnel (detailed above) confirmed a similar perception of the value of TRLs in the overall technology selection process. One article [Heslop 01] listed more than 50 factors contributing to the successful transition of technologies from research universities and other R&D sources into commercial use.

Another issue to consider is that TRLs are currently defined for system technologies (see Appendices A and B) but not for non-system technologies, such as processes, methods, algorithms, or architectures. Based on the SEI's experience in transitioning new software engineering practices (an example of a non-system technology), we believe that the TRLs should be extended to include new corollaries for these kinds of technologies. However, the Army STO Manager informed us that the majority of IA technologies they are currently evaluating are software. Thus, TRLs for software (or a derivative) should be sufficient for many of the technologies they evaluate.

With the above information, what is our answer to our conceptual feasibility study: *Is it feasible for TRLs (or an equivalent) to support or improve the STO Manager's decision-making process in selecting new IA technologies for investment?*

Yes, it is feasible for TRLs (or an equivalent) to support or add value to the decision-making process. However, it is only one of several critical factors in the decision-making process, and, as currently defined for system technologies, it is insufficient for use with non-system technologies such as processes, methods, algorithms, and architectures.

With this affirmative result, we now turn to our findings on developing a tool to facilitate TRL assessments.

2.3 Development Feasibility

This section details our findings in response to the Development Feasibility question: *What resources are needed to develop a TRL tool or adapt an existing TRL tool for STO use?*

We investigated this question by talking with users of TRLs from the GAO, AFRL, and DARPA to discover how they have implemented TRLs. The findings are interesting. The range of implementation approaches is broad, ranging from a formal software tool, i.e., the “TRL Calculator” developed at AFRL, to more informal face-to-face discussions between the stakeholders.

AFRL has been using TRLs for about three years.[7] The GAO has also been involved in TRL assessments since the release of their Best Practices report [GAO/NSIAD 99] in 1999. Two DARPA Program Managers we interviewed[8] had used TRLs on more than seventy IA projects. The major findings from our interviews with AFRL, GAO, and DARPA personnel[9] who have used TRLs are as follows:

- Some of the interviewees suggested that the greatest value from using TRLs comes from the discussions between the stakeholders that go into negotiating a TRL value.
- TRLs provide a common language between the technology developers, program office, and engineers who will adopt/use the technology.
- An objective observer adds to the TRL accuracy and thus to its utility.
- Currently, there is no standard or commonly used approach for implementing TRLs.
  - The AFRL personnel we interviewed use either the TRL Calculator tool to conduct their assessments or hold discussions between the technology stakeholders.
  - The GAO personnel we interviewed generally gather the stakeholders in a room where they jointly work through the TRL descriptions, and jointly arrive at a TRL decision (a process that sometimes takes up to two days).
  - The DARPA PMs we interviewed use small teams of three to four personnel including the PI. Estimates by each team member are generally done independently of each other and differences are reconciled to arrive at a consensus.
  - CECOM RDEC personnel gather the STO management team to collectively assess maturity based on task progress and laboratory and field test results.
- William Nolte at AFRL has developed a TRL Calculator for both hardware and software that has been made available to STO.

The last item deserves special attention, since the STO Manager is ultimately seeking a tool of some form to facilitate STO TRL assessment. The only TRL tool found in this investigation was the TRL Calculator (for hardware and for software) developed by Mr. Nolte at AFRL. Mr. Nolte released an alpha version of the TRL Calculator (it is a Microsoft Excel

7 Conversation with Jim Harris, AFRL/WSPT.

8 Conversations with Doug Maughan, DARPA and Jay Lala, DARPA.

9 Conversations with Mathew Lea, GAO; Jim Harris, AFRL/WSPT; William Nolte, AFRL; Doug Maughan, DARPA; Jay Lala, DARPA.

application) in January 2002. Further refinements led to a beta release (v1.0) in March 2002, and, most recently, version 1.1, released in August 2002. According to Mr. Nolte, the TRL Calculator for hardware is based on NASA’s TRL definitions, which AFRL adopted three years ago. Figure 1 shows a screen capture from the TRL Calculator (v1.0) page of questions.

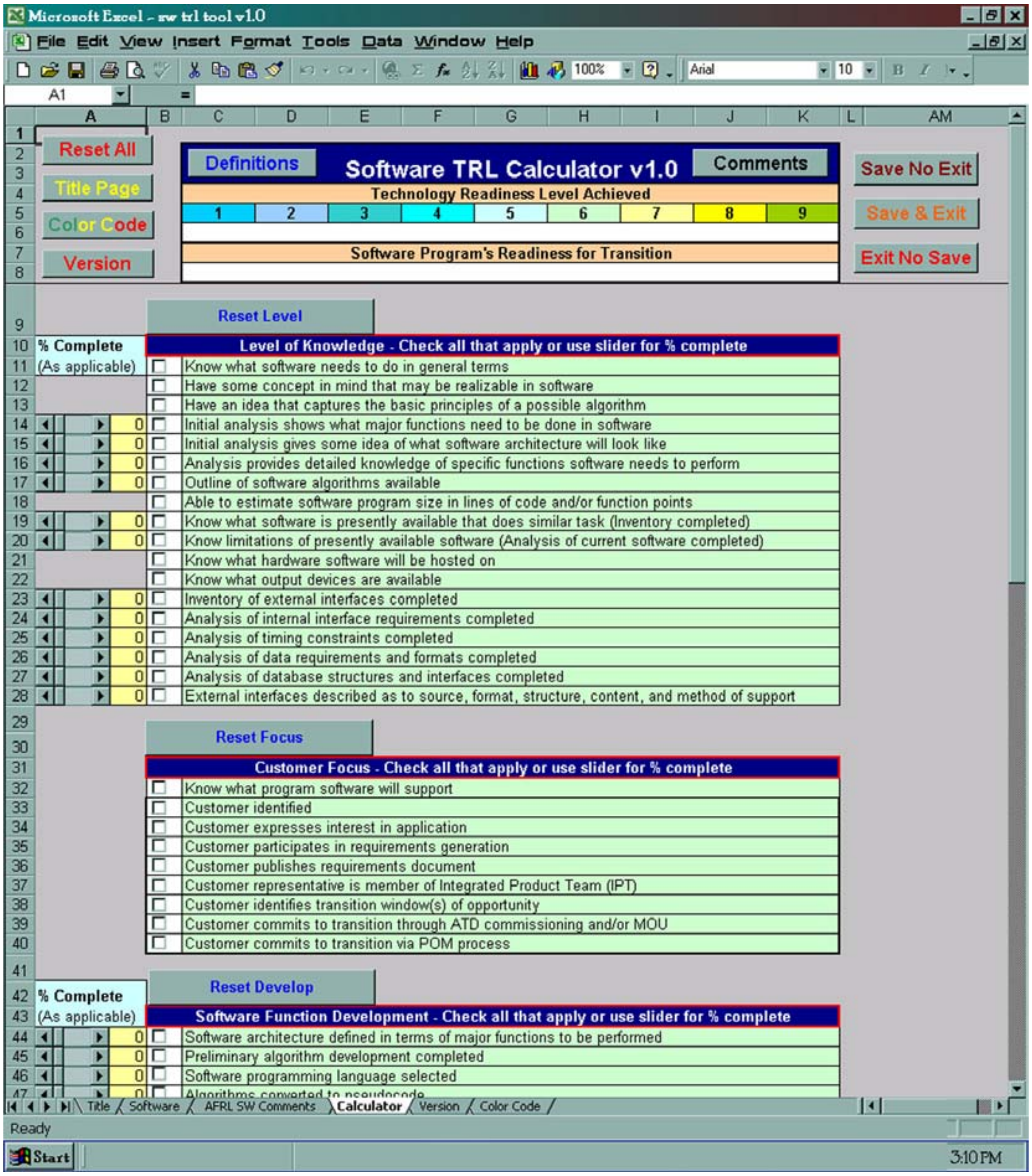

Figure 1:   A Screen Image from the Software TRL Calculator V1.0

The TRL Calculator for software is based on the Army’s software TRL definitions, with some modifications. While the tool has not undergone formal verification and validation, it is being used within AFRL and has demonstrated success (meaning the calculations are producing TRL values that the stakeholders agree with), according to Mr. Nolte. Because of the latter, Mr. Nolte estimates the tool is itself reflecting a TRL 7. The software TRL calculator is based on the Army’s TRL definitions for software. The STO Manager has expressed concern that some members of the software community view the Army's TRL definitions for software as too restrictive, particularly with regard to the verification and validation requirements. Based on a similar perspective, Mr. Nolte developed the Software TRL Calculator with modifications to the TRL definitions for software.

An independent evaluation of the tool and its relevance to the STO context is beyond the scope of this project. However, to allow STO personnel to evaluate the tool for themselves, the tool was given to the STO Manager in May 2002 by the authors of this report, with Mr. Nolte's permission.

Our literature survey uncovered one variation to the TRLs, written by DARPA PM Douglass Gage. PM Gage suggests the following refinements to the TRL scale:

TRL 3.5	Characterize target functionality, performance, costs—use as input to a decision to pursue serious technology development
TRL 5.5	Validation/development/refinement evaluation, decision refinement/ integration—use as input to a decision to integrate the technology into a system
TRL 8.5	Production/deployment

The interesting aspect of this adaptation of TRLs is not so much the definitions, but that this is a sign that others are picking up on the TRL idea and adapting it to their needs. A community of practice built around the use of TRLs would be an interesting and useful way to accelerate the sharing of this kind of information. Communities of practice are groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis [Wenger 02].

Based on the above findings, what is the answer to our Development Feasibility question, W*hat resources are needed to develop a TRL tool or adapt an existing TRL tool for STO use?*

The only TRL tool found in this investigation is the TRL Calculator (one for hardware and one for software) developed by Mr. Nolte at AFRL. STO is currently evaluating this tool. If the tool proves useful to STO, then extending it to account for non-system technologies such as processes, methods, algorithms, and architectures should be considered. This would first require establishing equivalent TRL definitions for these types of technologies, and then, if desired, incorporating those into the TRL Calculator tool. Mr. Nolte has expressed interest in working with STO to apply his technology in their domain.

A less sophisticated "tool" that could prove useful would be to define and develop a systematic, repeatable approach (i.e., a process) for determining TRLs based on the STO. We found no such defined process in our investigations. If desired, the TRL Calculator could enhance the process by facilitating the consensus-building steps in a TRL process. For example, the tool asks detailed questions to calculate a TRL. Comparing the answers between process par-

ticipants can highlight differences of opinion and allow the TRL process lead to focus on addressing those differences. This has the potential to make the TRL process more efficient, consistent, and reliable.

2.4 TRL Tool Implementation Feasibility

This section details our findings in response to the Transition Feasibility question: *What resources are needed to employ such a tool in the Army STO and DARPA S&T community?*

We investigated several approaches to getting a TRL tool into use in ways that satisfy the overall STO objective of gaining visibility into the TRLs of the many (approximately 50) IA technologies under development in DARPA each year. These include:

- In the case of RFPs, require the submitters to include a TRL estimate in their proposal. This may require additional guidance in the RFP on *how* to determine a TRL. And again, to address non-system technologies such as processes, methods, architectures, and algorithms, TRL corollaries for those types of technologies should be developed. In some circles (Army) this is occurring in the form of Technology Readiness Assessments (TRAs), but without the aid of a tool.
- Establish a team, or work with an independent organization, to regularly assess the TRLs of DARPA technologies. This report has already shown that TRLs are a subjective measure, sometimes involving lengthy discussions and negotiations between the interested parties in order to come to consensus on a TRL value, and that an objective observer helps to get accurate values. One of the challenges that CECOM has is that the need to evaluate so many technologies can result in excessive time spent in discussions with the technology developers and the CECOM engineers to arrive at a TRL consensus. A team with the primary responsibility of evaluating TRLs can provide the labor to do this. They would also have the responsibility to continually refine the process by which TRLs are agreed on.
- Have STO personnel use the TRL Calculator at the DARPA PI meetings and conferences where technologies are reviewed and answer the questions in the tool as they listen to the presentations, view the demos, or read the papers. This turns out not to be a reasonable option since, as previously stated, these meetings may not provide sufficient detail for each technology to be able to answer the TRL Calculator questions.
- Work with DARPA to get them to include TRL estimates in the documents and other materials they provide at the PI meetings and conferences. This sounds simpler than it is. Our interviews with two DARPA program managers led us to the conclusion that, at least in the near term, only a DARPA policy mandate will result in regular application of TRLs by DARPA PMs and PIs and regular inclusion of that information in DARPA technology materials. The two DARPA managers that we interviewed used TRLs with more than 70 of their technologies and found them useful, but said they would not likely use them again because of the level of effort expended in their already tight schedules. Senior DARPA officials mandated the first use of TRLs. Thus, organizations like STO that would like to have TRL data provided in the information package from DARPA will probably not see that in the near future.

3 Recommendations

We can summarize the findings from the Conceptual Feasibility study, the Development Feasibility study, and the Transition Feasibility study as follows:

- The TRL scale provides utility as one of several critical factors in the ATD/STO technology selection process. It is best to view TRLs as a risk-reduction measure in conjunction with the other criteria.
- As currently defined for system components, the TRLs could be much better defined to account for the uniqueness of non-system technologies, such as processes, methods, algorithms, or architecture. This was recognized and mentioned by several of the interviewees.
- The only TRL tool found in this investigation is the TRL Calculator (one for hardware and one for software) developed by Mr. Nolte at AFRL. A less sophisticated “tool” would be a systematic, repeatable process for determining TRLs (though we found no such defined process in our investigations). The TRL Calculator could be a support tool in such a process.
- It is unlikely that DARPA personnel will include TRL information in their technology documents (briefings, papers, etc.) in the near future, unless it is mandated from senior DARPA officials. This could aid in engaging early maturity technologies, but in the more exploratory stages of research, i.e., lower TRLs, the estimate may be somewhat subjective.
- While the TRL Calculator provides a repeatable set of questions for determining a TRL, it is the negotiation of the answers that is labor intensive. Thus, a good consensus-building and conflict-resolution process is also needed.
- Much of the value of TRLs comes from the discussions between the stakeholders that go into negotiating the TRL value.

Based on these findings we offer the following recommendations:

- Include relevant technology stakeholders in TRL negotiations.
- Develop an efficient process for negotiating TRLs with the relevant technology stakeholders. Use the TRL Calculator tool to support the process (if the STO evaluations currently underway report favorably on the tool for their context).
- Extend the utility of TRLs by developing corollaries for non-system IA technologies, such as processes, methods, architectures, and algorithms.
- Include TRL language in RFPs and provide guidance on how to calculate a TRL.

Appendix A Technology Readiness Levels

In their work on best business practices in the last few years, the GAO studied a number of commercial firms to determine key factors in successful product development. They reported that one such key factor is maturing a new technology far enough to get it into the right size, weight, and configuration needed for the intended product. After this is demonstrated, the technology is said to be at an acceptable level for product development. According to the GAO [GAO 01], “organizations that use best practices recognize that delaying the resolution of technology problems until product development—analogous to the engineering and manufacturing development phase—can result in at least a ten-fold cost increase; delaying the resolution until after the start of production could increase costs by a hundred-fold.” To illustrate their point, the same report cites an assessment of the readiness of critical technologies for the Joint Strike Fighter program and makes a comparison between the success of the Joint Direct Attack Munition and the Comanche helicopter programs.

> “For example, the Joint Direct Attack Munition (JDAM) used modified variants of proven components for guidance and global positioning. It also used mature, existing components from other proven manufacturing processes for its own system for controlling tail fin movements. The munition was touted for its performance in Kosovo and was purchased for less than half of its expected unit cost. However, the Comanche helicopter program began with critical technologies such as the engine, rotor, and integrated avionics at TRL levels of 5 or below. That program has seen 101 percent cost growth and 120-percent schedule slippage as a result of these low maturity levels and other factors.”

To improve the ability of programs to select mature technologies for inclusion in their programs, the GAO recommended the use of Technology Readiness Levels (TRL). TRLs were pioneered by the National Aeronautics and Space Administration and adopted by the Air Force Research Laboratory (AFRL), which promotes them as a means of evaluating the readiness of technologies to be incorporated into a weapon or other type of system. TRLs are being promoted as a gap assessment between a technology’s current maturity and the maturity needed for successful inclusion. The AFRL judges a technology to be low risk for the engineering and manufacturing development stage when (*a*) a prototype of that technology has been developed that includes all of its critical components in approximately the same size and weight, and (*b*) that prototype has been demonstrated to work in an environment similar to that of the planned operational system [GAO 01].

TRLs follow a scale from 1 (lowest level of readiness) to 9 (mature development). For example, a technology assessed at TRL 1 is by definition at the lowest level of technology readiness, “where scientific research begins to be translated into applied research and development” [GAO/NSIAD 99]. By the time the technology has reached a TRL 9, the technology has progressed through formulation of an initial concept for application, proof of concept, demonstration in a laboratory environment and realistic environment, and integration into a system, and has been “flight qualified” and then “flight proven.” This last state of development, where the technology is operating under mission conditions, is TRL 9. The AFRL considers TRL 7 to be an acceptable risk for starting the engineering and manufacturing development phase.

In a July 15 2001 memorandum, the Deputy Under Secretary of Defense (Science and Technology) officially endorsed the use of TRLs in new major programs. New DoD regulations require that the military services’ science and technology executives conduct a technology readiness level assessment for critical technologies identified in major weapon systems programs prior to the start of engineering and manufacturing development and production. The memorandum notes that technology readiness levels are the preferred approach for all new major programs unless the Deputy Under Secretary approves an equivalent assessment method.

Table 1 is an excerpt from the DoD 5000.2-R document [DoD 02], which specifies TRLs from a systems approach. TRLs thus are intended to be appropriate for both hardware *and* software. The document also states “DoD Components may provide additional clarifications for software.”

Table 1: TRL Descriptions

Technology Readiness Level	**Description**
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology’s basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in labora-	Basic technological components are integrated to establish that they will work together. This is relatively “low

Technology Readiness Level	Description
tory environment	fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Definitions

Breadboard: Integrated components that provide a representation of a system/subsystem and that can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.

High fidelity: Addresses form, fit, and function. High-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.

Low fidelity: A representative of the component or system that has limited ability to provide anything but first order information about the end product. Low-fidelity assessments are used to provide trend analysis.

Model: A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

Operational environment: Environment that addresses all of the operational requirements and specifications required of the final system, including platform/packaging.

Prototype: A physical or virtual model used to evaluate the technical or manufacturing feasibility or military utility of a particular technology or process, concept, end item, or system.

Relevant environment: Testing environment that simulates the key aspects of the operational environment.

Simulated operational environment: Either (*a*) a real environment that can simulate all of the operational requirements and specifications required of the final system, or (*b*) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.

Appendix B Army Draft of TRLs for Software

Table 2 contains an excerpt from a document provided by Mathew Lea of the GAO. Mr. Lea's information came from CECOM Research Development and Engineering Center. For each TRL, descriptions are given for hardware/subsystems (HW/S), and software (SW).

Table 2: TRL Descriptions for Hardware/Subsystems and Software

Technology Readiness Level	Description
1. Basic principles observed and reported	**HW/S:** Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties. **SW:** Lowest level of software readiness. Basic research begins to be translated into applied research and development. Examples might include a concept that can be implemented in software or analytic studies of an algorithm's basic properties.
2. Technology concept and/or application formulated	**HW/S/SW**: Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	**HW/S**: Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. **SW:** Active research and development is initiated. This includes analytical studies to produce code that validates analytical predictions of separate software elements of the technology. Examples include software components that are not yet integrated or representative but satisfy an operational need. Algorithms run on a surrogate processor in a laboratory environment.
4. Component and/or breadboard validation in laboratory environment	**HW/S**: Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of ad hoc hardware in the labora-

Technology Readiness Level	Description
	tory. **SW**: Basic software components are integrated to establish that they will work together. They are relatively primitive with regard to efficiency and reliability compared to the eventual system. System software architecture development initiated to include interoperability, reliability, maintainability, extensibility, scalability, and security issues. Software integrated with simulated current/legacy elements as appropriate.
5. Component and/or breadboard validation in relevant environment	**HW/S**: Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components. **SW**: Reliability of software ensemble increases significantly. The basic software components are integrated with reasonably realistic supporting elements so that it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of software components. System software architecture established. Algorithms run on a processor(s) with characteristics expected in the operational environment. Software releases are "Alpha" versions and configuration control is initiated. Verification, Validation, and Accreditation (VV&A) initiated.
6. System/subsystem model or prototype demonstration in a relevant environment	**HW/S**: Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment. **SW**: Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in software-demonstrated readiness. Examples include testing a prototype in a live/virtual experiment or in a simulated operational environment. Algorithms run on processor of the operational environment are integrated with actual external entities. Software releases are "Beta" versions and configuration controlled. Software support structure is in development. VV&A is in process.
7. System prototype demonstration in an operational environment	**HW/S**: Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Exam-

Technology Readiness Level	Description
	ples include testing the prototype in a test bed aircraft. **SW**: Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in a command post or air/ground vehicle. Algorithms run on processor of the operational environment are integrated with actual external entities. Software support structure is in place. Software releases are in distinct versions. Frequency and severity of software deficiency reports do not significantly degrade functionality or performance. VV&A completed.
8. Actual system completed and qualified through test and demonstration	**HW/S**: Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications. **SW**: Software has been demonstrated to work in its final form and under expected conditions. In most cases, this TRL represents the end of system development. Examples include test and evaluation of the software in its intended system to determine if it meets design specifications. Software releases are production versions and configuration controlled, in a secure environment. Software deficiencies are rapidly resolved through support infrastructure.
9. Actual system proven through successful mission operations	**HW/S**: Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions. **SW**: Actual application of the software 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 the system development. Examples include using the system under operational mission conditions. Software releases are production versions and configuration controlled. Frequency and severity of software deficiencies are at a minimum.

Appendix C Project Plan

The work statement for this project includes three phases of work:

Phase 1: Feasibility Study

The SEI, in collaboration with the Manager of STO, will determine the feasibility of developing an IA TRL assessment method (or equivalent) for technologies at various TRLs. This will assist the Manager of the STO in identifying technologies in basic research and applied research categories that would benefit the Army. If determined to be feasible, the SEI will collaborate with the STO in Phases 2 and 3 to develop and transition the method or tool into use.

Phase 2: Assessment Method Development

The particular assessment method to be developed will be based on the findings from the feasibility study. However, it is important that the development be a collaborative effort between SEI, STO, and selected DARPA personnel who are involved in the development of a technology that may eventually be transitioned into the Army.

Phase 3: Implementation Support

We expect that the implementation of a new technology readiness assessment method will include a focused effort on the planning and managing of its transition into use. The SEI will collaborate with STO to establish and implement a transition plan and management approach that will address both common technology adoption issues and those specific to the new assessment method and the organizations that will be adopting it. The level of effort for this task for the SEI and the adopting organizations will be determined at the conclusion of the feasibility study.

The plan for Phase 1 Feasibility Study consisted of three major tasks: (1) assess the state of the TRL practice through interviews with TRL users and a literature survey, (2) identify the needs of the STO with regard to TRL use, and (3) synthesize the results into a report of findings and recommendations. The status of each of these activities is provided in Table 3.

Table 3: Feasibility Study Activities

Activity	Progress Status
1. Assess the state of the practice 1.1 Literature Survey • DoD Web sites and literature • Army Web sites and literature • Navy Web sites and literature • Air Force Web sites and literature • GAO Web sites and literature • Articles from the field of new product development 1.2 Interviews with TRL users • GAO / Matt Lea • AFRL / Jim Harris • ARFL / Bill Nolte • DARPA / Jay Lala • DARPA / Doug Maughan	Activity 1 completed
2. Assess the needs of the STO • Interview current ATD developers • Compile interview notes • Interviewees review and comment on notes	Activity 2 completed
3. Synthesize Findings into Report 3.1 Preliminary Report • Draft preliminary findings and recommendations report • Bob, Peter, SEI team discuss preliminary report and next steps 3.2 Final Report • Formulate draft of final report • Bob, Peter, SEI team discuss final report draft • Refine Final Report draft • Deliver Final Report to Bob and Peter	Activity 3 completed

References

[Cooper 01] Cooper, R. G.; Edgett, S. J.; & Kleinschmidt, E. J. “Portfolio Management for New Product Development: Results of an Industry Practices Study.” Product Development Institute, July 2001. <http://www.prod-dev.com/research.shtml>.

[DoD 02] DoD 5000.2-R, “Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information Systems (MAIS) Acquisition Programs,” 5 April 2002.

[GAO 01] GAO. “Joint Strike Fighter Acquisition—Mature Critical Technologies Needed to Reduce Risks.” GAO-02-39, October 2001.

[GAO/NSIAD 99] “Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes.” GAO/NSIAD-99-162, July 30, 1999.

[Heslop 01] Heslop, L.; McGregor, E.; & Griffith, M. “Development of a Technology Readiness Assessment Measure: The Cloverleaf Model of Technology Transfer.” *Journal of Technology Transfer 26*, 4 (October 2001): 369–384.

[TRECC 01] Technology Research, Education and Commercialization Center. “Definitions of Technology Levels.” <http://www.trecc.org/html/tech_definitions.html> (2001).

[Wenger 02] Wenger, E.; McDermott, R.; & Snyder, W. M. *Cultivating Communities of Practice: A Guide to Managing Knowledge*. Boston: Harvard Business School Press, 2002.

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Caroline P. Graettinger, Suzanne Garcia, Jeannine Siviy, Robert J. Schenk, U.S. Army CECOM RDEC STCD, Peter J. Van Syckle, U.S. Army CECOM RDEC STCD

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Carnegie Mellon University
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13. ABSTRACT (MAXIMUM 200 WORDS)

In early 2002, the Communications Electronics Command (CECOM) Manager of the Army Tactical Wireless Network Assurance (TWNA) Science and Technology Objective (STO) FY03-07, hereafter referred to as STO, requested assistance from the Software Engineering Institute (SEI) in improving STO methods for assessing the maturity of new information-assurance technologies. The STO was seeking to use technology maturity, as measured by the Technology Readiness Levels (TRLs) scale, as a metric in its decision-making process for selecting new technologies for STO development and maturation, technologies that would eventually be transitioned to Army tactical programs. This report describes the results of the SEI study of the feasibility of (*a*) using TRLs in STO technology screening, (*b*) developing or acquiring a TRL tool, and (*c*) implementing a TRL tool.

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