AFRL-RY-WP-TR-2022-0152

TECHNOLOGY MATURITY ASSESSMENT PROCESS RECOMMENDATIONS VERSION 1.0

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MAY 2022
Final Report

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AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

REPORT DOCUMENTATION PAGE

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED START DATE	3. DATES COVERED END DATE
May 2022	Final	26 April 2022	26 April 2022

4. TITLE AND SUBTITLE
TECHNOLOGY MATURITY ASSESSMENT PROCESS
RECOMMENDATIONS VERSION 1.0

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER
FA8650-19-C-1941	N/A	63270F/63203F/25219F
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**
3720/665A/5212	N/A	N/A

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)		8. PERFORMING ORGANIZATION REPORT NUMBER
Plans Branch Sensors Plans & Advanced Programs Division (AFRL/RYZC) & Advanced Programs Branch Sensors Plans & Advanced Programs Division (AFRL/RYZT) Air Force Research Laboratory, Sensors Directorate Wright-Patterson Air Force Base, OH 45433-7320 Air Force Materiel Command, United States Air Forces	AFRL/EN ACAP Leidos Inc. 3745 Pentagon Blvd Beavercreek, OH 45431	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'SREPORT NUMBER(S)
Air Force Research Laboratory, Sensors Directorate Wright-Patterson Air Force Base, OH 45433-7320 Air Force Materiel Command, United States Air Forces	AFRL/RYZC	AFRL-RY-WP-TR-2022-0152

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
PAO case number AFRL-2022-1967, Clearance Date 26 April 2022. The U.S. Government is joint author of this work and has the right to use, modify, reproduce, release, perform, display, or disclose the work. Report contains color.

14. ABSTRACT
This report details a tailored RY process for technical readiness assessment developed in reference to other DoD processes.

15. SUBJECT TERMS
process development

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	C. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
Unclassified	Unclassified	Unclassified	SAR	53

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PREVIOUS EDITION IS OBSOLETE.
STANDARD FORM 298 (REV. 5/2020)
Prescribed by ANSI Std. Z39.18

Technology Maturity Assessment Process Recommendations

Version 1.0

28 March 2022

Contract #: FA8650-19-C-1941

Prime Contractor: Leidos

Distribution Statement [DISTRIBUTION STATEMENT A]: [Approved for public release; distribution is unlimited.]

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Document creation date:	28 March 2022

Please forward any suggestions, comments, or questions regarding this document to the authoring activity.

The official version of this document shall be the latest revision that contains approval signatures by all parties involved as indicated below. Interim releases for review with most recent changes may be published with a higher revision number than the official version. These review drafts will not establish consensus until all approval signatures are obtained.

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Revision History

Date	Revision Description	CR #	Pages Affected
20220324	1.0 – Initial Version / Base Document	N/A	All

Table of Contents

1. Background

One of the primary goals for the Air Force Research Laboratory (AFRL) in technology development is to transition technology to a "customer" to address a capability need. This transition can be within AFRL, to industry, to a System Program Office (SPO), or directly to the Warfighter. Each of these "customer" categories describes a potential "transition partner." The technology development can occur in support of customer-requested maturation ("tech pull") where the customer outlines their need (a "requirement") and AFRL responds with technology development tailored to satisfy the need. The technology development can also occur absent specific requirements when AFRL develops new technology or finds a new use for older technology based on its role as the Science and Technology (S&T) lead for critical technology areas. Known as "tech push," this occurs when the basic and/or applied scientific research conducted by AFRL scientists reveals the potential for previously unknown military capabilities. Both "tech pull" and "tech push" projects can *change the art of the possible* for other AFRL programs, industry, a SPO, or the warfighter, creating potentially disruptive capabilities that are extremely hard for adversaries to counter without equivalent S&T research activities. The challenge for any transition is that the value of the technology may not be well understood by the wider community, nor, in the case of new technology, *by the scientists conducting the research.*

Too often, discussions between scientists and potential transition partners fail to accurately ascertain the maturity level of a technology, the potential military uses, and a reasonable and reliable timeline for operational employment of a technology. In both "tech pull" and "tech push" situations, an accurate description of technology maturity is necessary to inform both S&T leadership and potential transition partners as to progress on development. The maturity level, commonly known as a Technology Readiness Level (TRL), is a snapshot in time that describes the characteristics of the demonstration or testing environment under which a given technology was successfully tested. The Department of Defense (DoD) has a standard definition of TRLs, from 1 to 9, spanning the scope of basic principles to an actual system proven in actual mission operations.[1] Historically, official TRL assessments are only systematically assigned during formal acquisition processes, yet requests for technology maturity assessments are commonly requested at all levels of AFRL program development.

There is currently a lack of a systematic approach to assess AFRL technologies and an absence of documented verification of any assessments. While not causal to the lack of transition, a methodical, accurate, and verifiable process for TRL assessment helps establish the foundation for multiple other processes; supports meaningful engagements with fellow S&T professionals, governance bodies, and potential transition partners; and supports increasing the probability of transition of AFRL technologies. These other processes include Technology Maturation Plans (TMPs), Advancement Degree of Difficulty (AD2), Manufacturing Readiness Levels (MRLs), Integration Readiness Levels (IRLs), System Readiness Assessments and Levels (SRAs and SRLs), Air Force Futures (HAF/A57, formally Air Force Warfighter Integration Capability (AFWIC)) Technology, Mission, Resources, Organization (TMRO) methodology, AFRL Transition Metric (ATM) and Program Management Reviews (PMRs).

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[1] (Department of Defense, 2009) (Department of Defense, 2011)

A TRL can be derived by various means but is commonly determined through a Technology Readiness Assessment (TRA). A TRA establishes a TRL based on the demonstration of a technology in incrementally higher levels of fidelity in terms of its form, level of integration with other parts of a system, and its operating environment. A TRA is a systematic, evidence-based process that evaluates the maturity of Critical Technology Elements (CTEs), which can be hardware, software, a process, or a combination thereof. A technology element is "critical" if the system being acquired depends on this technology element to meet operational requirements (within acceptable cost and schedule limits) *and* if the technology element or its application is either a new technology, uses older/updated technology in a new way, or the technology element or its application is used in an area that poses major technological risk during detailed design or demonstration.[2] Formal TRAs are most often used to support defined phases of an acquisition program, such as the requirement detailed in 10 United States Code 2366b[3] that a program must have been demonstrated in a relevant environment prior to Milestone B approval; however, informal, or "knowledge-building TRAs," may also be used to assess the technology maturity and provide developers, program managers, governance bodies, and potential transition partners with useful information to more effectively mature critical technologies, determine a technology's readiness and manage and address current and future developmental risk.[4]

Today, the National Defense Strategy and our own Chief of Staff of the Air Force and Chief of Space Operations demand that we accelerate technology development and get capability into the hands to of the Warfighter faster.[5] A credible, repeatable assessment of technology maturity is key to follow on and simultaneous processes and methodologies, such as TMPs, AD2, MRLs, IRLs, SRAs and SRLs, TMRO, ATM, and PMRs, and establishes a foundation to support rapid transition activities internal to AFRL, to industry, to a SPO or directly to the Warfighter once the technology is proven to an appropriate level. This study presents recommended processes and tools to conduct those TRAs.

2. Study Objectives

The primary objective of this study is to identify and recommend a rigorous, standardized, repeatable process and supporting tools to conduct TRAs that increase the credibility of available technology solutions from a transition partner perspective and support increasing the probability of transition for successful technologies. As such, this study will:

- Identify a tailored, rigorous, standardized, repeatable TRA process for conducting credible TRAs, along with supporting tools that support process execution

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[2] (Department of Defense, 2009)
[3] (10 U.S.C. § 2366b, 2021)
[4] (United States Government Accountability Office, 2020)
[5] (Department of Defense, 2018) (Brown, 2020) (Raymond, 2020)

Sub-objectives include:

- Systemize the process to evaluate when to conduct a TRA, what to do with the results, and how to determine the next steps
- Detail a systematic approach to identify CTEs
- Produce a tailorable TRA template, including characteristics essential to credibility and objectivity
- Identify RY capabilities that support technology maturation and TRL assessment
- Methodize inclusion of technology elements into Modeling Simulation and Analysis (MS&A)
- Identify data artifacts and repositories to evidence the TRL assigned

3. Literature Review

Much research has been conducted on the topic of technology assessment, in addition to other assessments that support technology transition. This section reviews both research and authoritative DoD guidebooks on the topic to help shape a tailored process that achieves objectives while minimizing additional administrative burden. Additionally, as Senior Leaders have emphasized the need to deliver performance at the speed of relevance,[6] streamline approaches from development to fielding,[7] and conceive, develop and field inside competitors' timeline,[8] various other methodologies or processes have been developed to assist in both determining what to invest in (TMRO methodology) [9] and how to assess progress during development (ATM).[10] These will also be reviewed for their relationships to TRAs and TRLs.

3.1 Government Accounting Office (GAO) Technology Readiness Assessment Guide (2020)[11]

For two decades, the GAO has shown that effective management practices and processes to assess technology maturation are fundamental to evaluating integration readiness and risk management in major acquisition systems. These practices, processes and tenets are applicable throughout the development lifecycle of large and small elements or programs. This guide provides a framework for better understanding technical maturity and describes best practices for conducting high quality assessments. It has two stated objectives: 1) describe generally accepted best practices, and 2) provide technology developers, program managers, and governance bodies with useful information to more effectively mature critical technologies, determine a technology's readiness and manage and address risk.

Technology experts agree that disciplined, repeatable processes which focus on end user technology employment and that rely on sufficient evidence to produce a useful TRA report

6 (Department of Defense, 2018)
7 (Department of Defense, 2018)
8 (Brown, 2020)
9 (TMRO Methodology Presentation)
10 (Gary Scalzi, 2020)
11 (United States Government Accountability Office, 2020)

place Program Managers (PMs), technology developers, and governance bodies in a better position to make informed decisions. It arms them with information for making technical and resource allocation decisions such as whether to move technologies to the next stage, allocate time and effort for more development in the current stage, discontinue the effort or reconsider alternate technologies.

Additionally, high quality assessments provide a common framework to discuss transition issues with stakeholders, solidify stakeholder commitments, and identify concerns that may require additional scrutiny or a need to develop risk mitigation plans.

Furthermore, the process of executing the TRA "requires practitioners to cross organizational, professional, and managerial boundaries to establish lines of communication, exchange information, and keep scientists, systems engineers, acquisition officials, and others informed throughout the development of a program or project. These activities increase knowledge and facilitate an understanding of how technologies interact with one another and with the larger systems or programs that integrate them. They may increase awareness of changes that could affect other elements and systems, while eliciting involvement and participation of the test and evaluation communities to ensure that maturity demonstrations adequately stress technologies appropriate to the expected relevant or operational environment."

3.1.1 What is a TRA?

A TRA is:

- A systematic, evidence-based process that evaluates the maturity of critical technologies (hardware, software, process, or combination thereof) vital to the performance of a larger system or the fulfillment of the key objectives of an acquisition program, including cost and schedule
- A maturity assessment (TRL) at a given point in time
- Used statutorily for acquisition programs, but can also be used to inform technology developers, program managers, and governance bodies of technology development progress and assist in identifying/managing risk

A TRA does NOT:

- Assess risk
- Detail technology maturation efforts
- Assess integration readiness, system readiness or technology advancement difficulty (what it takes to get to the next TRL level)

3.1.2 Types of TRAs

There are effectively two types of TRAs: Formal and Informal (knowledge-building). It is critical to identify the "customer" who will receive the TRA and what the assessment is to be used for in order to determine the type of TRA to accomplish. Formal TRAs may be governed by statutory or organizational requirements; informal TRAs can be modified so as to meet the intent for accomplishing the TRA, but should still follow best practices to ensure credibility.

8

Formal TRAs:

- Provide evidence that technology development is progressing as desired and mature enough to meet the requirements of the assessed TRL
- Provide a comprehensive assessment of the CTEs needed for a decision point or stage gate review for a governance body

Informal (knowledge-building) TRAs can:

- Be used as project self-assessments to support activities such as:
    - Determining whether technologies are ready to transition to new or existing acquisition programs or larger systems
    - Deciding whether CTEs are ready for a TRA to be conducted for governance bodies at an upcoming decision point
    - Identifying gaps in maturity or specific areas that may be challenging
    - Identifying potential concerns and risks
    - Understanding the transition risks when maturing technologies
- Calculate progress toward achieving technical performance goals for a specific technology or group of technologies
- Gather evidence to support continuing development efforts or initiating steps toward using an alternative or backup technology
- Demonstrate the performance of technologies or prototypes that can be fielded

Both types of TRAs can:

- Be used to illuminate potential area of concern or risk
- Facilitate discussions between PMs and customers during development
- Complement risk reduction efforts

3.1.3 Characteristics of a High-Quality TRA

High-quality TRAs are credible, objective, reliable, and useful. They rely upon artifacts and information to determine the TRL. These can include requirement documents, analysis, and test reports. How much and of what type is dependent on the phase of technology development and should be determined when planning a TRA.

- **Credible:** conducted with an understanding of the requirements that guide development of the CTEs and system, the relevant or operational environment in which it will function, and its integration or interaction with other technologies.

- **Objective:** are based on objective, relevant, and trustworthy data, analysis, and information; and the judgements, decisions, and actions for planning and executing the assessment are free from internal and external bias or influence.

- **Reliable:** follow a disciplined process that facilitates repeatability, consistency, and regularity in planning, executing, and reporting the assessment.

- **Useful:** provide information that has sufficient detail, is timely and can be acted upon in accordance with the intent for conducting the TRA.

3.1.4 TRA Five-Step Process

The GAO TRA Guide offers a five-step process framework for conducting TRAs. It represents a standardized, repeatable methodology based on government and industry best practices.

1. Prepare the TRA plan and identify the TRA team
    a. The plan:
        i. Has a comprehensive assessment approach and includes all the key information (Credible)
        ii. Identifies the recipient or recipients of the TRA report (Useful)
        iii. Identifies the expertise needed to conduct the assessment, and other characteristics of the TRA team (Credible)
    b. The team:
        i. Has members that are independent and objective (Objective)
        ii. Reviews the initial TRA plan to ensure it has all the essential information (Reliable)
        iii. Has the time and resources to execute the plan (Reliable)
        iv. Obtains all the key information to conduct the assessment, such as the program master schedule, budget documents, test plans, and technical baseline description of the program's purpose, system, performance characteristics, and system configuration (Objective)
    c. The level of detail for the TRA is consistent with the level of detail (evidence) available for the program (Objective)
2. Identify the Critical Technology Elements
    a. Select via a reliable, disciplined, and repeatable process (Reliable)
    b. Select based on consideration of the newness or novelty of technologies and how they will be used (Credible)
    c. Select based on consideration of the operational performance requirements and potential cost and schedule drivers (Credible)
    d. Derive a relevant environment for each CTE from those aspects of the operational environment determined to be a risk for the successful operation of that technology (Credible)
    e. Explicate potential adverse interactions with other systems with which the technology being developed will interface as part of the determination to select CTEs (Credible)
    f. Select the CTEs based on solid analysis using the work breakdown structure (WBS), technical baseline description, process flow diagram, or other key program documents (Objective)
    g. Continue to confirm the selection of CTEs, using more specific questions and requirements that pertain to the platform, program, or system in which they will operate (Objective)
    h. Select CTEs during early development and update as required throughout the development lifecycle (Credible)
    i. Ensure CTEs are defined at a testable level, including any software needed to demonstrate their functionality (Credible)
    j. Document the reasons why technologies are selected as critical, including reasons why other technologies are not selected as critical (Reliable)

3. Evaluate Critical Technologies
    a. TRA team confirms the TRL measure and definitions selected in Step 1 are appropriate and reaches agreement with the program manager on the kinds of evidence needed to demonstrate that a TRA goal or objective has been met (Reliable)
    b. TRA team verifies that the test article and the relevant or operational environment used for testing are acceptable and the results are sufficient (Objective)
    c. TRA team assigns a TRL rating for each CTE based on credible and verifiable evidence, such as test and analytical reports, requirements documents, schematics, and other key documents (Objective)

4. Prepare the TRA Report (see Appendix D for the GAO TRA Report template)
    a. Policy or guidance details how TRA reports should be prepared, including a template that identifies the elements to report; process for submission, review and approval; how the TRA report results should be communicated; and who should be involved (Reliable)
    b. TRA report includes all of the key information as determined in the plan (Reliable)
    c. Management checks the factual accuracy of the TRA report (Objective)
    d. TRA report includes management's written response to the TRL rating (Reliable)

5. Use the TRA Report Findings
    a. TRA report is used for its stated purpose (Useful)
    b. For CTEs assessed as immature, identify follow on actions (Useful)
    c. Submit TRA reports used for governance purposes in advance of a decision point or stage gate (Useful)
    d. TRA report documents lessons learned and recommendations for follow on TRAs (Reliable)

3.1.5 TRA Report

TRA reports can be used to:

- Inform the Test & Evaluation (T&E) community about technology maturity demonstration needs
- Support TMP preparation as part of a maturity roadmap for CTEs prior to a decision point
- Provide a basis for modifying requirements if technological risks are too high
- Support refinement of technology development strategies or similar planning documents used in the systems engineering process
- Support establishment of technology transition agreements to articulate external dependencies on technology base projects and to define specific technologies, technology demonstration events, and exit criteria for the technology to transition into the acquisition program

11

- Augment knowledge building and continuous improvement as an important part of an evolving TRA process and identify lessons learned that benefit future TRAs and/or technology development projects that should be identified during the TRA process
- For technologies assessed as immature, support:
    - Consideration of alternative technology
    - Development of a technology maturation plan
    - Updates to the program's risk management plan
    - Revision of cost or schedule risk assessments

3.2 DoD TRA Deskbook (2009)[12]

The DoD TRA Deskbook was created to provide guidance for conducting TRAs from the Director, Research Directorate (DRD), in the office of the Director of Defense Research and Engineering (DDR&E) [now the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) based on organizational changes].[13] As with the GAO TRA Guide, this document focuses mainly on formal TRAs, but the best practices and guidance are relevant to any type of technology readiness assessment process. The document touches on early evaluations of technology maturity conducted prior to Milestone A and describes how these early assessments would be beneficial to the development of a Technology Development Strategy (TDS) [this is no longer used, but does provide a useful case study of a documented approach to address technology development/maturation in terms of cost, schedule and performance]. The TRA Deskbook guidance was designed to be generic and non-prescriptive, and organizations are encouraged to develop processes to meet local requirements. The emphasis is on procedures based upon key principles, guidance, and recommended best practices.

Specifically in this document, the definition of a CTE was expanded to include technologies that may experience integration, design, or demonstration complexity risk, not just the technology itself. As stated in the definition: *A technology element is "critical" if the system being acquired depends on this technology element to meet operational requirements (within acceptable cost and schedule limits) and if the technology element or its application is either new or novel or in an area that poses major technological risk during detailed design or demonstration.*

The Deskbook states that PMs have found the TRA assessment process useful in managing technology maturity. Methodically executing the process highlights critical technologies and other potential technology risk areas that might require either specific oversight or active management by a PM. The TRA can help identify immature and important components and track the maturity development of those components through multiple iterations of technology maturity assessment. While the TRA is not a risk assessment, the results of the TRA are used as an important part of risk assessment in overall program management.

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[12] (Department of Defense, 2009)
[13] (Department of Defense, 2011)

These assessments of technology readiness, or TRA-like activities, take place throughout the acquisition lifecycle, as depicted in the figure below.

Table 3-1. Basis of Technology Maturity Assessments Throughout Acquisition

	Milestone A	Milestone B	Milestone C
Basis of CTE Identification	Early evaluation of technology maturity	Current level of design and CDD requirements	Planned LRIP article (or limited deployment version of an IT system), prior TRAs, and final design
CTE Identification Status	Potential CTEs	CTEs – actual technologies in a preliminary design	CTEs of planned LRIP articles (or limited deployment version of an IT system)
Assessment Method	Evaluated in early evaluations of technology maturity and TMPs	Assessed in Milestone B TRA	Assessed in Milestone C TRA
Documentation	Informal submission to DRD and corresponding updates to TDS appendix	Milestone B TRA	Milestone C TRA

3.2.1 Early Evaluations of Technology Maturity

In the Materiel Solution Analysis (MSA) phase, an Analysis of Alternatives (AoA) is conducted to identify potential materiel solutions. Through this identification of potential solutions, candidate CTEs are identified. The AoA, early systems engineering, and early TRL assessments form the basis of the TDS, which shows how the technology will be demonstrated in a relevant environment prior to key acquisition milestones.

As a best practice, early evaluation of technology maturity (TRL) provides the foundation for both early decisions and other processes that use TRLs as part of process execution. Specifically, these assessments can result in the following actions:

- Modify requirements if the technology development is too risky based on cost/performance/schedule and technology interdependencies
- Support development of the TMP
- Refine the TDS
- Inform the T&E community about T&E needs for both assessment and maturation activities

- Ensure all potential CTEs are included in the risk management plan
- Establish Technology Transition Agreements (TTAs) to articulate external dependencies on technology base projects
- Define the specific technologies, technology demonstration events, and exit criteria for the technology to transition into the acquisition program

3.2.2 Key Player and Roles and Responsibilities

Key Players	Roles and Responsibilities
Program Manager (PM)	• Stakeholder • Plans, funds, and designates responsibility for activities in support of the TRA • Prepares draft schedule • Identifies recommended CTEs • Suggests Subject Matter Experts (SMEs) needed for TRA • Provides evidence of technology maturity to the IRT • Provides technical expertise in support of the IRT
Component S&T Executive	• Stakeholder • Directs the conduct of the TRA • Coordinates the TRA schedule • Nominates SMEs • Trains IRT members in the TRA process • Reviews the TRA report and provides a cover memorandum for the report
Component Acquisition Executive (CAE)	• Stakeholder • Approves the final TRA report and forwards to DRD
Independent Review Team (IRT)	• Conducts the TRA • Develops a list of CTEs • Informs stakeholders/governance entities of TRA progress • Assesses TRLs for all CTEs • Prepares the TRA report
DRD	• As the governance/oversight body, concurs with the proposed schedule, IRT members, and CTE list • Oversees the TRA process • Reviews and evaluates the TRA report • Provides certification recommendation to the acquisition decision authority

3.2.3 CTE Identification Guidance and Best Practices

In order to conduct a TRA, CTEs must be identified. The Deskbook focuses extensively on both guidance and best practices for identifying CTEs as they are the foundation for the TRA and the items that must be assessed. If a CTE is overlooked and is not brought to the required maturity level, the overall program may be jeopardized. One must, however, balance the need to identify the right CTEs and not become so conservative that every element of a program is considered a CTE. An overly conservative approach minimizes the importance of actual critical elements and unnecessarily allocates emphasis and resources, potentially diverting them from what is needed to bring a program to a desired level of maturity.

As stated previously, a CTE is *"critical" if the system being acquired depends on this technology element to meet operational requirements (within acceptable cost and schedule limits)* ***and*** *if the technology element or its application is either new or novel or in an area that poses major technological risk during detailed design or demonstration*. This also includes old technology that may be used in a new way or when old technology is used in conjunction with new technology and may induce complications due to predicted obsolescence or when demanded performance exceeds previous development levels. CTE identification is not a one-time effort but should be a continuing part of every program.

Additionally, CTE identification is integral to a Systems Engineering (SE) approach. SE is "an interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and total lifecycle balanced set of system, people, and process solutions that satisfy customer needs. Systems engineering is the integrating mechanism across the technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for systems and their life cycle processes."

SE Approach, Architectures, and Products

The SE process and approach is the sensible place to identify CTEs and to understand their maturity (i.e., their readiness for application to the system design). There are two outcomes of the systems engineering approach:

- A functional architecture:
  - Allocates functional and technical performance requirements
  - Provides the well-defined framework around which the physical architecture is conceived and designed
  - Basis against which the system and its various sub-elements are tested

- A physical architecture (design):
  - Shows the system design broken down into all its constituent elements (i.e., subsystems and components)
  - Represents the software and hardware "products" necessary to realize the concept
  - Forms the basis for design definition documentation (e.g., specifications, baselines, the system and software architectures, and the technical work breakdown structure (WBS)).

The technical WBS has several beneficial attributes for identifying CTEs:

- It is readily available when system-engineering practices are used
- It evolves with the system concept and design and supports continual CTE identification
- It is composed of all products that constitute a system and, thus, is an apt means to identify all the technologies used by a system
- It relates to the functional architecture and, therefore, to the environment in which the system is intended to be employed
- It reflects the system design/architecture and the environment and performance envelope for each product in the system
- It increases in specificity during development, thereby allowing old CTEs to be updated and new CTEs to be identified

The DoD Architecture Framework (DoDAF) defines a common approach for DoD architecture description, development, presentation, and integration. It describes three related views of architecture:

- Operational View (OV): identifies what needs to be accomplished and who does it
- Systems View (SV): relates systems and characteristics to operational needs
- Technical Standards View (TV): TV prescribes standards and conventions

CTE Identification

A TRA is an assessment of CTEs. The recommended CTE identification process is:

1. Create an initial list of possible CTEs (led by the PM, government program office, and system contractors). Questionable technology should be identified as a possible CTE until determined otherwise.
2. Develop a list of CTE candidates (led by the IRT designated by the Component S&T Executive). Additions to the list may include any technologies that warrant the rigor of the formal TRA process.
3. Approve the list of CTEs for assessment.

As a best practice, the IRT, with the requisite technical knowledge and the independence needed to make a good judgment, should guide the actual set of questions asked for each candidate CTE.

Further development and approval of candidate CTEs rely on a series of questions to test whether the CTE definition applies:

1. Does the technology have a significant impact on an operational requirement, cost, or schedule?

   AND

2. Does the technology pose a major development or demonstration risk?
3. Is the technology new or older technology used in a new way?
4. Has the technology been modified from prior successful use?

5. Has the technology been repackaged such that a new relevant environment is applicable?
6. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

To be considered a CTE, the answer must be "YES" to Question 1, and "YES" to one or more of Questions 2-6. Through this method, even a perceived "high TRL" technology may be assessed as a CTE.

Identification of the Relevant Environment

As part of the TRA process, a CTE is assessed under a specific testing environment. For TRL 6, it must be demonstrated in a relevant environment; for TRL 7, it must be demonstrated in an operational environment. The environment includes both the *external* or *imposed* environment and the *internal* or *realized* environment. Both must be considered in determining relevant test gates for the assessment of TRLs. The SE process, and architecture and WBS development are key to refining the characteristics of the environment. Environments may include, but are not limited to, the following:

- Physical environment:
  - Mechanical components, processors, servers, and electronics
  - Kinetic and kinematic
  - Thermal and heat transfer
  - Electrical and electromagnetic
  - Threat (e.g., jammers)
  - Climatic – weather, temperature, particulate
  - Network infrastructure
- Logical environment
  - Software interfaces
  - Security interfaces
  - Web-enablement
  - Operating systems
  - Service-oriented architecture(s)
  - Communication protocols
  - Layers of abstraction
  - Virtualization
  - Coalition, federation, and backward compatibility
- Data environment
  - Data formats, structures, models, schemas, and databases
  - Anticipated data rates latency, jitter, transit loss, synchronization, and throughput
  - Data packaging and framing
- Security environment
  - Connection to firewalls
  - Security protocols and appliqués
  - Nature of the cyber adversary
  - Methods of attack, and trust establishment
  - Security domains

- User and use environment
    - Scalability
    - Ability to be upgraded
    - User training and behavior adjustments
    - User interfaces
    - Organizational change/realignments with system impacts
    - Implementation plan

Key questions that can help guide the definition of the environment, and subsequent T&E requirements, for the CTE candidates might include the following:

- Is the physical/logical/data/security environment in which this CTE has been demonstrated similar to the intended environment? If not, how is it different?
- Is the CTE going to be operating at or outside its usual performance envelope? Do the design specifications address the behavior of the CTE under these conditions? What is unique or different about this proposed operations environment?
- Do test data, reports, or analyses that compare the demonstrated environment to the intended environment exist? If modeling and simulation (M&S) are important aspects of that comparison, are the analysis techniques common and generally accepted?

3.2.4 Technology Maturity Assessment Guidance and Best Practices (aka, Cats and Dogs)

TRLs

TRLs:

- Are NOT a measure of design validity
- DO NOT indicate the difficulty in achieving the next TRL level
- ARE an indication of a level of maturity at the time of CTE measurement

TRL hardware definitions involve several characteristics:

- **Scale of the application:** It ranges from device to component, subsystem, and system
- **Environment:** It includes the laboratory, mathematical models, physical simulations, field tests, and operational use
- **Performance levels:** Are demonstrated by increasingly more representative tests across these characteristics

DoD TRL definitions (hardware and software) are located in Appendix C.

CTEs

CTEs should be identified and assessed under the assumption that the design—developed as part of the systems engineering approach—is adequate for the performance of the required functions. To support TRL 5 or higher, a precise knowledge of how a technology will actually be used is needed to define the relevant environment. Should the design be determined inadequate or flawed, the CTE assessment process should be re-accomplished.

CTEs must also be assessed in an integrated way. A CTE may appear to be mature in isolation; however, this assessment may change when, for example, the combined effects of size, weight, and power (SWaP) are considered.

Environments and Testing Legitimacy

A *relevant* environment is a set of stressing conditions, representative of the full spectrum of intended operational employments, which are applied to a CTE as part of a component (TRL 5) or system/subsystem (TRL 6) to identify whether any design changes to support the required (threshold) functionality are needed.

Testing will not likely include actual accomplishment of the full range of required operational employments. Therefore, there must be a body of data or accepted theory to support, with confidence, that the efficacy of a technology, though demonstrated only in some useful environment, can be extended to the full spectrum of employments.

Demonstration of a CTE as part of a component or system/subsystem in a relevant environment requires successful trial testing that either (1) Shows that the CTE satisfies the required functionality across the full spectrum of intended operational employments, or, (2) Shows that the CTE satisfies the functional need for some important, intended operational employment(s) and then uses accepted analytical techniques to extend confidence in supporting the required functionality over all the required, intended operational employments.

An *operational* environment is a set of operational conditions, representative of the full spectrum of operational employments, which are applied to a CTE as part of a system prototype (TRL 7) or actual system (TRL 8) in order to identify whether any previously unknown or undiscovered design problems might impact required (threshold) functionality.

Demonstration of a CTE as part of a system prototype in an operational environment requires successful testing that either (1) Shows that the CTE satisfies the required functionality across the full spectrum of operational employments, or, (2) Shows that the CTE satisfies the functional need for important, operational employment(s) and then uses accepted analytical techniques to extend confidence in supporting the required functionality over all the required operational employments.

3.2.5 Nuances of Software TRAs

Original DoD TRL definitions were developed for performance-related hardware technologies. As systems have evolved, a need has emerged to look at software separate from hardware in both CTE identification and TRL assessments. While the definitions are similar, the examples, characteristics, and documentation needed to support assessments has changed. The process, concepts, best practices, etc. from both the Deskbook and GAO Guide, however, remain valid. The Air Force uses a set of definitions also used by the Navy and Army, and approved by the Information Technology TRL Working Group. They are located in Appendix C.

In assessing software CTEs, the application level are values of algorithms, software components, software programs, and software packages. The environment includes integration, laboratory user environment, logical relationship, data environment, security environment, and, possibly, interface issues. Dimensions, such as obsolescence, scalability, and throughput are usually expressed in terms of system-wide requirements, but can also be described in terms of software elements. Additionally, hardware components often contribute to meeting these requirements. CTEs may need to be illuminated as both elements of hardware and software, and assessed separately. The combination of these dimensions determines any TRL.

To properly assess software's technical readiness, one must be aware of the characteristics of the *relevant environment* and *operational environment*. Technical readiness in a relevant environment (TRL 5 or higher) requires a detailed architecture that fully exposes all components and elements affecting the operation of the critical software element. Technical readiness in an end-to-end relevant environment (TRL 6 or higher) requires evidence of performance on full-scale, realistic problems. Technical readiness in an operational environment (TRL 7 or higher) requires evidence of the acceptable performance of the software element under operational factors, including issues such as system loading, user interaction, security, and realistic communications environment (e.g., bandwidth, latency, jitter).

3.2.6 Conclusion

The Deskbook emphasizes the need for a high quality, credible TRA process, including IRT selection, CTE identification, CTE assessment, and report preparation. In short, the recommended TRA process is:

1. Establish TRA Schedule
2. Form an Independent Review Team (IRT)
3. Identify Candidate CTEs
4. Finalize CTEs Through Coordination
5. Collect Evidence of CTE Maturity
6. Assess CTE Maturity
7. Prepare, Coordinate, and Submit the TRA Report
8. Oversight Organization Review and Evaluate Report

3.3 DoD TRA Guidance (2011)[14]

The 2011 TRA Guidance is a minor alteration on information detailed in the 2009 TRA Deskbook. Specifically, there are adjustments on key players and roles, and should be referenced in support of future official TRAs, but the core of TRA execution guidance should be derived from the GAO TRA Guide and the DoD TRA Deskbook. The TRA Guidance provides a template for the TRA report (see Appendix D) and descriptions of DoD TRL definitions.

[14] (Department of Defense, 2011)

3.4 Air Force Futures (HAF/A57) TMRO Methodology[15]

At its most basic, the AF Futures TMRO methodology is intended as a decision support tool to advance an operational concept and decide what to invest in. The method systematically characterizes and addresses uncertainty, and identifies activities needed in order to learn and refine concepts. Ultimately, it helps determine where the AF should allocate resources to advance capabilities. The four elements of TMRO are:

- **T: Technology.** It is based on standard TRLs. Will the technology advance on a relevant timeline? Is it a point/proprietary solution or does it incorporate open architectures/standards that should simplify integration challenges and modification/updates?
- **M: Mission.** It assesses the technology in relation to mission accomplishment. Does the technology solution solve the problem/accomplish the mission? Does it make a measurable difference compared to other potential solutions? Are there undesirable (or desirable) 2^{nd} and 3^{rd} order effects? Is it vulnerable to countermeasures and would it require additional technology development/integration to implement?
- **R: Resource.** Are there resources available and is the solution affordable on a relevant timeline? Does the Force have the necessary skills and competencies to implement the technology solution?
- **O: Organization.** Is the Force structured to execute the solution or do new processes need to be developed? Does the solution align with core missions and competencies and is it in alignment with the future force design? Is the solution acceptable within organization culture and Service/Department policies?

The process works on a Discover – Incubate – Accelerate model, incorporating the four elements above. See Appendix E for the metric matrix. Its assessment of TRL is close, but not exact, to the standard DoD TRL assessment matrix.

3.5 AFRL Transition Metric (ATM) Process[16]

The AFRL Transition Metric (ATM) was developed in response to a SAF/AQR tasking to answer the question: "How do I know my AFRL programs will successfully transition?" This tasking was broken down into two questions: 1) which development programs will the AF invest in? (supported by the AF Futures HAF/A57 TMRO process detailed in the previous section), and 2) how does AFRL know their development programs are successful, executing well, and will lead to a successful outcome (transition)?

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15 (TMRO Methodology Presentation)
16 (Gary Scalzi, 2020)

The second question is the motivation for creating the ATM Process. It is a methodical way to assess the health of a program, drive PM behavior in starting early discussions with potential transition partners (including alignment of technology to stakeholder requirements), identify roadblocks to transition, and provide objective and quantifiable data for decision makers. It applies to products, such as CTEs, and not programs (which may be comprised of multiple CTEs and other technologies), and may have multiple transition paths and/or partners. It measures transition risk, but uses snapshots in time as defined by TRL and MRL assessments. ATMs are geared more towards transition paths to SPOs or directly to the Warfighter, but contains elements that are relevant to all transitions, in general.

As ATM is a *metric*, it requires key characteristics of an effective metric: strategic, simple, owned, actionable, timely, referenceable, accurate, correlated, game-proof, aligned, standardized, and relevant. Of note, many of these characteristics are similar and complementary to those detailed in a good TRA. The metric must be quantifiable, documented and validated with artifacts. Again, similar to the TRA.

The ATM is comprised of four elements, using a TMRO methodology. This is slightly different than the TMRO methodology in the previous section (which may be confusing, depending on the audience) and is more relevant to the second derived question. This iteration of TMRO encompasses the following elements and the supporting key questions and/or recommendations:

- **T: Technology.** TRAs establishes a TRL.
  - Recommends using the Missile Defense Agency (MDA) TRA questionnaire to assist in determining the TRL
- **M: Manufacturing.** Manufacturing Readiness Assessment (MRA) establishes a MRL.
  - Recommends engaging with AFRL/RXM for MRAs
- **R: Resource Availability.** This encompasses an acquisition partner's resourcing status.
  - Is the PM talking with the Program Executive Officer (PEO)/acquisition partner early and often?
- **O: Organizational Suitability.** This details alignment to a requirements owner (likely the end-user/Warfighter) and the actions taken to incorporate the CTE into operations.
  - Is the PM talking with the MAJCOM/User/Warfighter/Requirements Source early and often?

The ATM process is designed to measure the health of the technology transition process (evaluate transition risk) and drives consistent conversation with the transition stakeholders. It is structured to provide decision-quality information to senior leaders. The matrix can be seen in Appendix F.

3.6 TRL as Related to Other Processes

As mentioned in the overview, TRLs provide a snapshot in time that describe the characteristics of the demonstration or testing environment under which a given technology was successfully tested. More importantly, TRLs are foundational elements for follow on or simultaneous processes and assessments that would be irrelevant or incomplete without an accurate and credible TRL assessment. A few of those processes are summarized below.

22

- **Technology Maturation Plan (TMP)**: The TMP is a management planning tool to mature CTEs that have been assessed as immature for the stage desired. The TMP lays out steps, actions, and resources needed to mature CTEs and ***uses the TRA report findings*** and other key information to establish a road map with the necessary engineering activities. It provides an accurate gauge of the overall progress for maturing technology and serves as a key reference document at a decision point or stage gate to verify that progress has been made in closing the maturity gaps.
- **Advancement Degree of Difficulty (AD2)**: A predictive method that provides information on ***what is required to move from one TRL to another***. Provides technology developers, program managers, and others with risk information in the form of likelihood of occurrence of an adverse event, impact cost to ensure that such an event does not occur, and the time required to implement the necessary action.
- **Manufacturing Readiness Level (MRL)**: ***Used in conjunction with TRLs***, MRLs are key measures that define risk when a technology or process is matured and transitioned to a system. It is common for manufacturing readiness to be paced by technology readiness or design stability. Manufacturing processes will not be able to mature until the product technology and product designs are stable. MRLs can also be used to define manufacturing readiness and risk at the system or subsystem level. For those reasons, the MRL criteria were designed to include a nominal level of technology readiness as a prerequisite for each level of manufacturing readiness.
- **Integration Readiness Level (IRL)**: Similar to TRLs, the IRL is defined as a series of levels that articulate the key maturation milestones for integration activities. Introducing an IRL to an assessment provides not only a check as to where a technology is on an integration readiness scale but also a direction for improving integration with other technologies. ***Just as the TRL is used to assess the risk associated with developing technologies, the IRL is designed to assess the risk associated with integrating these technologies.***
- **System Readiness Assessment / System Readiness Level (SRA/SRL)**:[17] Presented in 2006 by the Systems Development and Maturity Laboratory at Stevens Institute of Technology, SRL was designed to give a holistic picture of the readiness of complex systems by characterizing the effect of technology and integration maturity on an SE effort. The ***method was proposed because TRLs measure the maturity of an individual technology but do not provide insight into integration between technologies or the maturity of the whole system. The SRL incorporates the current TRL scale and uses IRL to calculate the SRL***.
- **HAF/A57 Futures TMRO Methodology:** A HAF/A57 Futures process intended as a decision support tool to advance an operational concept and decide what to invest in. It uses ***Technology (TRL)***, Mission, Resource, and Organization (TMRO) assessments to characterize and address uncertainty, and identify activities needed to learn and refine concepts.

[17] (Sauser, Verma, Ramirez-Marquez, & Gove, 2006)

- **AFRL Transition Metric (ATM):** An AFRL process designed to assess the health of a program, drive PM communications with potential transition partners, identify roadblocks to transition, and provide objective and quantifiable data for decision makers. It uses ***Technology (TRL)***, Manufacturing (MRL), Resource Availability, and Organizational Suitability (TRMO) assessments to identify transition risk.
- **AFRL/RY Information-Driven Decision Making:** An AFRL/RY nascent effort to formalize development, integration, and use of data sources to inform decision making that supports (and is supported by) the TRA recommendations presented in this study.

4. AFRL and RY Current Processes and Capabilities

4.1 AFRL Support to SAF/AQRE TRAs[18]

AFRL Guidance memo (63-01-08, 2008) describes the process by which AFRL SMEs are detailed to support formal TRA Independent Review Panels (IRPs). In this role, AFRL SMEs support acquisition program offices in evaluating CTEs for major defense acquisition programs.

4.2 AFRL Program Management

AFRL Instruction (AFRLI) 61-108, Management and Control of Technology Development for AFRL,[19] was released in January 2022 and supersedes and expands on the April 2021 Guidance Memorandum[20] on program management. This instruction establishes the structure and procedures for development, management and review of Research and Development (R&D) programs in the AFRL enterprise. It details program management and oversight functions to ensure the establishment, monitoring, and annual review of program progress, and details roles and responsibilities across the enterprise. It also identifies a suite of digital applications to support Research and Development Program Managers (R&DPMs) and outlines tailored SE approaches in support of R&D efforts.

An AFRL R&D program is a finite endeavor that expends manpower and/or funding to mature technology and deliver (*transition*) scientific or technology products that increase future warfighting capability. There are three types of R&D programs: R&D-1, R&D-2, and R&D-3, which dictate approval and reporting authority. R&D-1 and -2 programs have clearly defined and measurable objectives with products intended for transition in support of DoD capability development. They are among AFRL's largest and most high-visibility investments and only really differ in the Technical Approval Authority (TAA). Both should include upfront formal or informal technology transition planning. R&D-3 programs are everything else and are quite varied in maturity, investment, acquisition methodology and type of transition products, to include knowledge products.

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[18] (AFRL/CA, 2008)
[19] (Air Force Research Laboratory, 2022)
[20] (AFRL/CC, 2021)

A program progresses through seven phases during its lifecycle with key activities and documents (information) associated with each phase. This framework provides a methodical structure to guide conceptualization, organization, programming and execution of R&D programs. These phases (and key tasks) are:

- **Ideation:** identify, mature, and preliminarily refine conceptual R&D solutions based on best available information
    - Execute initial MS&A to establish technical approach and articulate feasibility, risk and military utility
    - Develop a preliminary transition strategy
    - Develop a basic program plan
- **Pre-Planning:** update the basic program plan and develop an acquisition structure
    - Identify stakeholders and appropriate program management cohort
    - Develop a WBS, schedule, risk assessment, and cost estimate
    - Define a transition strategy, which may include a Technology Transition Plan (TTP)
- **Budgeting:** develop program budget recommendations based on mission organization priorities
    - Develop Program Objective Memorandum (POM) program recommendations
    - Gain an approved program budget decision
- **Pre-Execution:** develop detailed program, SE, test, execution, spend, risk management, cybersecurity, and configuration plans (and any others required based on specific program requirements)
    - Mature the program plan
- **Execution:** begins once the program's cost, schedule, and performance baseline is approved by the TAA, upon successful completion of the initial PMR, and when in receipt of funding
    - While not detailed anywhere else, it is assumed that the program baseline is created and refined in the previous steps as all future assessments are measured against this baseline
- **Retirement:** finalize documentation and dispose of equipment and property
- **Program End:** administratively closeout the program, complete all reporting and archive all data in accordance with the program's Data Management Plan

During each of these phases, processes are executed, information is created, and plans are developed. Of interest for this study on TRAs are the program plan, program baseline, and PMRs.

The **program plan** is not a standardized "product" and may vary based on numerous factors. It evolves over the lifecycle of the program but will eventually contain the following elements:

- Program goals and technical objectives
- Statement of customer need
- Identification of delivered technical product(s) with corresponding Technical Performance Measures (TPMs)
- Constraints, assumptions, and scope limitations
- Documentation of technology alternatives

- Initial MS&A analysis and program MS&A, T&E, and/or facility requirements
- Detailed WBS and associated cost estimate
- Preliminary risk management plan
- Preliminary transition strategy
- Initial and refined cost, schedule and performance baseline
- Acquisition Strategy documentation (ASP)
- Data Management Plan (DMP)
- Program security and S&T protection plans
- Exit criteria
- Additional documentation/plans, as needed

The **Program Baseline** is the fundamental agreement between the program's TAA and the R&DPM that documents cost, schedule and performance, and clearly defines a reference point to measure progress. It contains the following minimum items:

- Program Scope
    - Program Overview
    - Desired Operational Capability
    - Program Objectives
    - Description of Products
    - Product KPPs, TPMs, and/or Measures of Performance (MOPs)
    - Technical Performance Breach Criteria
- Program Schedule
    - Level I WBS and Associated Schedule
    - Level II WBS and Associated Schedule
    - Description of Major Program Milestones
    - Schedule Breach Criteria
- Program Cost
    - Program Cost Estimate
    - Allocated Budget by WBS
    - Required Resources (Personnel and Facilities)
    - Cost Breach Criteria

The **PMR** is an annual requirement to ensure program objectives and technical measures remain current and achievable with current cost, schedule, and performance parameters. Additional content may be required based on specific requirements, but, at a minimum, the following elements are required in each PMR:

- A review of the program's technical objectives and program deliverables including any technical products, major program milestones, activities requiring airworthiness certification and other details as determined significant by the delegated TAA
- An assessment of the program's cost and schedule to ensure adequacy of resources to achieve the program's objectives
- A review of the program's financial execution history to ensure expedient execution of appropriated resources

- An assessment of the program's technical progression toward the program objectives to include consideration of TPMs, achievement of significant milestones and other factors as appropriate
- An evaluation of the program's risk management process as appropriate

There are four different types of PMRs: Initial, Periodic, Re-Baseline, and Closeout.

- **Initial**: An initial PMR is conducted after detailed planning is complete and a program baseline is drafted. This PMR reviews and approves these plans and is a pre-cursor to the "execution" phase of a program.
- **Periodic**: A periodic PMR reviews the program against the baseline. This is required at least annually for all programs.
- **Re-Baseline**: A re-baseline PMR is conducted to address any program breach(es).
- **Closeout**: A closeout PMR is conducted to review the final state of the program, either program completion or transition.

In support of AFRL's drive to digitize and integrate planning, programming, budgeting, and execution data across the enterprise, the Digital Enterprise R&D Management Suite (DEMS) has been deployed. It includes DoD-, DAF-, other government organization-, and AFRL-specific applications. AFRL's S&T Information Technology Collaboration Hub (STiTCH) R&D Management Apps (STiTCH M-suite) contains two applications seemingly most applicable to this study on TRAs. These are the PM app and the Work Unit (WU) app. These (along with other existing applications supporting program management) should be further explored to identify the best way to support both the execution and data management for documentation of TRAs. This includes identifying appropriate locations for data artifacts and information repositories to evidence assigned TRLs, and the development of specific apps to support future TRA processes.

4.3 AFRL/RY Information-Driven Decision Making Process

AFRL's digital transformation initiative has resulted in many directorate-level efforts. RY is formalizing the development, integration, and use of data sources to inform decision making in support of identifying needed capabilities and promising sensor technologies to address those needs. This facilitates acquisition processes and the fielding of sensor technologies that integrate into dominant weapon systems for the warfighter. This process is supported by utilizing virtual environments to prototype, experiment, and test decisions for RY programs as well as the upward integration of RY technologies into sub-systems and platforms. While still in its nascent stages, it will mature over time and supports (and is supported by) the TRA recommendations presented in this study.

4.4 AFRL/RY Maturation, Experimentation and Demonstration Capabilities

AFRL/RY organizations and laboratories perform essential test, maturation, integration and assessment of systems in various environments, which ultimately supports transition of capability to the warfighter. These efforts include Planning and Pre-Integration; Virtual Integration and Interoperability; and Physical Integration and Demonstration.

In Planning and Pre-Integration activities, MS&A is used to identify disparate technologies being developed across RY that can, or should, be integrated together or used within the battlespace to inform/influence the fight in Mission- and Campaign-level modeling and simulation. The MS&A can identify short-comings in the models from lower levels of the MS&A chain, allowing for modification and improvement to support higher level MS&A. Additionally, the analysis can guide roadmap development and identify areas where physics and phenomenology levels need to be developed in support of the MS&A pipeline.

Virtual Integration and Interoperability include both MS&A and the piecing together of aspects of individual sensors in the virtual environment. The MS&A covers everything from a systems engineering level to the campaign level, and informs requirements and parameter generation for follow-on physical integration and ground/flight demonstrations. The piecing together of aspects of individual sensors focuses on communications, command and control (C2), and data paths for how a sensor phenomenology can be packaged *within* a capability and packaged *for* other capabilities. The virtual integration process illustrates all digital aspects of the system for integration, and using Open Architectures (OAs) and standards reduces integration costs and timelines.

AFRL/RYZT (Blue Guardian) uses a 5 Pillar construct to support Physical Integration and Demonstration, which includes:

- Research and Development that focuses on the "rapid" aspects of demonstration, including implementing OAs and other Government Reference Architectures (GRAs), supporting development of the AgilePod® Series, and developing Cross Security Domain solutions to enable rapid integration and demonstration
- Yearly Combat Lancer demonstrations of capability across numerous Core Technical Competency structures
- Integration and demonstration support for Directorate-level programs such as Integrated Capability Demonstrations and multi-year/multi-campaign programs
- AFRL-level 6.3+ program integration and demonstration
- Integration and demonstration of technology for external customers and transition partners of AFRL

Specific laboratory capabilities are described in the AFRL Sensors Directorate Facilities guide[21] and the AFRL C4ISR 2020 Technology Program Plan.[22]

5. Discussion

A credible assessment process is not only necessary to assign a credible TRL, it is also essential to support a multitude of concurrent and related processes that rely on an accurate TRL determination. The tenets of the TRA are applicable across other, similar processes, such as MRAs and SRAs, as these other processes are also systematic methods to review and assess

[21] (Air Force Research Laboratory Sensors Directorate, 2022)
[22] (Air Force Research Laboratory, 2020)

programs to understand their development maturity, make informed risk assessments, and provide decision quality information to decision-makers at all levels.

A methodical, repeatable process can be used to identify problems, hopefully early. If based on standard definitions and best practices, it facilitates more precise communication between individuals and organizations, both in content and in follow-on implications, such as accurately projecting timelines to deliver and/or incorporate capability. Appendix C contains current DoD definitions of both hardware and software TRLs.

As an organization, AFRL must be able to move faster and deliver capability faster. An accurate assessment of a TRL will not, in itself, wholly accomplish that feat, but it supports increasing the probably of effective transitions, especially if synchronized with other processes. An accurate TRL does not eliminate risk, but it provides a systematic way to view a program's progression and make more informed risk assessments. If done consistently, it can provide the quality of information that enables earlier, data-informed decisions that influence effective resource allocation, more accurate programmatic decisions, and earlier identification of interface and integration issues.

AFRL operates primarily in the early phases of technology development. Often, the technology does not yet have an envisioned home and is not yet part of an established acquisition program. As such, formal TRAs, as described by the GAO report, may be overkill and not produce the data expected of such a labor-intensive process. GAO-described "informal TRAs," on the other hand, appear to be a better model for AFRL to pattern off of for early technology assessments, based on the ability to be tailored to the technology and level of maturity and on the "return on investment" of effort versus use of the information. For AFRL, "tailored TRAs" are more aligned with the kinds of decisions made in the laboratory environment and support future decisions as capability proves out.

Tailored TRAs:

- Support decisions on whether technology is ready for transition or integration
- Assist in clearly identifying CTEs and TPMs for entry/exit from various TRLs
- Identify the environments in which technologies may be subject
- Identify future MS&A and T&E requirements for CTE assessment
- Help identify concerns and risks with technologies, integration, and final form factors
- Provide evidence to support either continuing or terminating efforts or decisions to transitions to alternate technologies
- Better assess the use of older technologies in new ways through the CTE identification process
- Provide a clear path to technology demonstration in support of TRL assessment

There is no appetite, or, for that matter, extra resources in manpower, funding, and time, to add on yet another process that will take away from the important work of technology development. ***Under that assumption, there are few key takeaway items from the literature review.***

- Use a standardized, repeatable process
    - GAO[23] recommends the 5-step TRA process
    - DoD TRA Deskbook[24] recommends a methodology for CTE and relevant environment identification
    - AFRL Management and Control of Technology Development guidance [25] drives specific documentation and activities based on program designation
    - TMRO/ATM[26] methodologies use the information in a systematic way to make decisions
- Ensure the processes contain the key elements of high quality[27]
    - Credible – transparent determination and documentation of key elements with the ability to modify throughout the lifecycle as more information is gained
    - Objective – data supports assessments, and the assessors are free from internal and external bias (even if they are from within the program)
    - Reliable – repeatable, consistent process execution
    - Useful – results contain actionable information and drive documented decisions

The following section details the recommended "tailored" TRA process, modeled off the GAO-described "informal" TRA, which could support AFRL needs.

6. Proposed Tailored TRA Process

DoDI 5000.02[28] describes a move toward tailoring each process to be relevant; in other words, don't try to jam the square TRA process into a round assessment requirement. Rather, "tailor in" the information requirements used to assist the management of the program and support concurrent or follow-on processes. Under this directive, the intent is to weave in TRA elements into current processes, and to tailor the TRA to reflect the purpose of the TRA, the maturity of the technology, and how the knowledge gained from the TRA supports data-informed decision making across the enterprise at all levels. This does not preclude requiring or executing TRAs at other times or in support of other decision-making events. The value added of establishing an integrated and methodical process is that each TRA can leverage current processes, build on previous assessments and provide updated information through the progression (or non-progression) of programs. The information gathered, developed and assessed during each stage of technology maturity supports follow-on assessments.

[23] (United States Government Accountability Office, 2020)
[24] (Department of Defense, 2009)
[25] (Air Force Research Laboratory, 2022)
[26] (TMRO Methodology Presentation); (Gary Scalzi, 2020)
[27] (United States Government Accountability Office, 2020)
[28] (Department of Defense, 2020)

New AFRL Management and Control of Technology Development[29] was released in Jan 2022 and contains a practical framework for methodically executing TRAs. There are three key products that can be modified to incorporate requisite elements of the TRA process and best practices as detailed in the literature review – specifically, the program plan, program baseline, and the PMR. While the descriptions below detail the total requirements for each product, not all elements are present at each stage of a technology's lifecycle. As such, these products and recommendations need to be *tailored* based on what is appropriate at each stage. At various times throughout the lifecycle of the program, a TRA could be accomplished in support of a PMR at the specificity needed commensurate with the maturity of the program. Additionally, by including requisite elements in the below documents and processes, a TRA can more easily be accomplished when requested or desired outside a normal PMR timeline.

6.1 Program Plan Modifications

The **program plan** evolves (and is modified) over the lifecycle of the technology development program and will eventually contain the below elements. Accordingly, the proposed additional information should be relevant to the maturity of the technology, and should be updated as the technology development progresses and information changes. Proposed TRA elements that can be included to support follow on program assessments are shown in RED:

- Program goals and technical objectives
- Statement of customer need
- Identification of delivered technical product(s) with corresponding TPMs
    - [Added] Identify **CTEs**. Reference the TRA process in section 6.4 for CTE identification recommendations.
    - [Added] List known interdependencies between CTEs of this program and others. Identify any critical path/integration dependencies.
    - [Added] Identify the **Environment** that the CTEs will be subject to (at the appropriate level of technology maturity and knowledge). Reference section 6.4 below for CTE environment development recommendations.
- Constraints, assumptions, and scope limitations
- Documentation of technology alternatives
- Initial MS&A analysis and program MS&A, T&E, and/or facility requirements
    - [Added] Identify MS&A and T&E requirements for future CTE assessment. Update as required as technology matures.
    - [Added] Identify demonstration environments. Technologies must be developed sufficiently to satisfy systems requirements AND be able to be inserted into a system. Early engagement with the transition partner helps define that environment.
- Detailed WBS and associated cost estimate
- Preliminary risk management plan
- Preliminary transition strategy

[29] (Air Force Research Laboratory, 2022)

- Initial and refined cost, schedule and performance baseline
- ASP
- Data Management Plan
- Program security and S&T protection plans
- Exit criteria
- Additional documentation/plans, as needed

6.2 Program Baseline Modifications

The **Program Baseline** requires specific elements, dependent on the level of technology maturity. Recommended additional elements are detailed in RED:

- Program Scope
  - Program Overview
  - Desired Operational Capability (not required for R&D-3 programs)
  - Program Objectives
  - Description of Products
    - [Added] List CTEs as determined in the program plan. Update as technology matures.
  - Product KPPs, TPMs, and/or MOPs
    - [Added] List TPMs tied to CTEs for assessment.
    - [Added] Identify members who can support a Review Team (derived from the IRT from the DoD TRA Deskbook or the TRA Team from the GAO report). SMEs may need to come from within the program, but must be free to exercise objective assessments.
  - Technical Performance Breach Criteria
- Program Schedule
  - Level I WBS and Associated Schedule
  - Level II WBS and Associated Schedule
  - Description of Major Program Milestones
    - [Added] Identify projected TRAs.
  - Schedule Breach Criteria
- Program Cost
  - Program Cost Estimate
  - Allocated Budget by WBS
  - Required Resources (Personnel and Facilities)
  - Cost Breach Criteria

6.3 Program Management Review Modifications

The **PMR** requires specific minimum elements. The level of detail is commensurate with the level of technology maturity. Additional content may be required based on specific PMR requirements. PMRs will evolve over the lifecycle of a technology. Accordingly, the proposed additional information should be relevant to the maturity of the technology, and should be updated as the program progresses and information changes. Recommended additional elements are detailed in RED:

- A review of the program's technical objectives and program deliverables, including any technical products, major program milestones, activities requiring airworthiness certification and other details as determined significant by the delegated TAA
- An assessment of the program's cost and schedule to ensure adequacy of resources to achieve the program's objectives
- A review of the program's financial execution history to ensure expedient execution of appropriated resources
- An assessment of the program's technical progression toward the program objectives to include consideration of TPMs, achievement of significant milestones and other factors as appropriate
    - [Added] TRA (modeling the GAO 5-step process, detailed in section 6.4)
        - Prepare the TRA Plan and establish the Review Team
        - Update and approve CTEs identified in the program plan as the basis for the assessment; detail the environment for assessment
        - Assess CTEs using TPMs and the AFRL TRL Assessment Checklist
        - Prepare the report using the AFRL template
        - Use the findings to support the PMR process
- An evaluation of the Program's risk management process as appropriate

TRAs can be conducted outside the PMR when requested by decision making bodies; in support of AFLCMC acquisition processes; and/or when required for submissions for programs such as JCTDs, RDERs, and other programs. Including TRA elements in other AFRL documents and processes makes executing the TRA simpler and less time-consuming. In addition, including these data points throughout the lifecycle support subsequent TRA activities, either in the same program at different TRLs or as technology element(s) transition to other programs and are part of follow-on TRAs.

6.4 TRA 5-Step Process:

6.4.1 Prepare the TRA plan and Establish the TRA Team

The first step of the TRA process is creating a plan for assessment and assembling the team that will do the assessment.

- The plan:
    - Develop a comprehensive approach that includes all key information and assesses all relevant CTEs. This plan should detail the appropriate level of specificity for both the CTE and the required artifacts to prove a TRL, based on the technology maturity being assessed.
    - Identify the recipient(s) of the TRA report and the purpose of the TRA.
    - Identify the expertise needed to conduct the assessment, and other characteristics of the TRA team.

33

- The team:
  - Identify members.
    - List organizations and areas of expertise of each member.
    - Ensure members have the ability to be independent and objective, even if within the assessed organization/program.
    - Member are approved by the Certification Authority (IAW AFRL TRL Assessment Checklist).
  - Review the TRA plan to ensure it has all the essential information and is tailored to both the technology maturity level and the purpose of the TRA.
  - Ensure timeline and resources are sufficient to execute the TRA.
  - Obtain all the key information to conduct the assessment, such as the program master schedule, budget documents, test plans, and technical baseline description of the program's purpose, system, performance characteristics, system configuration, and anticipated environment.
- Confirm the level of detail for the TRA is consistent with the level of detail (evidence) available for the program, appropriate to the technology maturity level being assessed and sufficient for the purpose of the TRA.

6.4.2 Identify Critical Technology Elements and the Assessment Environment

Identify Critical Technology Elements

An element is **critical** if the system being acquired depends on this technology element to meet operational requirements (within acceptable cost and schedule limits) **AND** if the technology element or its application is either new or novel or in an area that poses major technological risk during detailed design or demonstrations. This includes old technology that may be used in a new way; when old technology is used in conjunction with new technology and may induce complications due to predicted obsolescence; or when demanded performance exceeds previous development levels. A CTE can be hardware, software, a process, or a combination thereof.

CTEs should be selected via a reliable, disciplined, and repeatable process. GAO and DoD best practices call out various system engineering processes that support CTE identification. Select the CTEs based on solid analysis using the WBS, technical baseline description, process flow diagram, or other key program documents. The AFRL SEPM group develops, promotes, and updates policy, processes, tools, and training for the PM workforce. This group should help guide early CTE identification for AFRL programs through systems engineering practices. There are three stages of CTE identification – initial, update, and approval.

- **Initial**: Create an initial list of possible CTEs. *This should be done by the R&DPM during program plan development.* Questionable technology should be identified as a possible CTE until determined otherwise.
  - Answer the following list of questions to help identify CTEs:

1. Does the technology have a significant impact on an operational requirement, cost, or schedule?

   AND

2. Does the technology pose a major development or demonstration risk?
3. Is the technology new or older technology used in a new way?
4. Has the technology been modified from prior successful use?
5. Has the technology been repackaged such that a new relevant environment is applicable?
6. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

To be a CTE, the answer to the first question must be YES and at least one more YES in response to questions 2-6.

- Update and confirm the list of CTEs throughout the development lifecycle, using more specific questions and requirements that pertain to the platform, program, or system in which they will operate. This means that CTEs can be updated, removed, or new CTEs may be developed at all stages of a technology's maturity.
- Define CTEs at a testable level, including any software needed to demonstrate their functionality. Inform the MS&A and T&E communities of future testing requirements to support maturation activities and assessments.
- Document the reasons why technologies are selected as critical, including reasons why other technologies are not selected as critical.
- Explicate potential adverse interactions with other systems with which the technology being developed will interface as part of the determination to select CTEs.

- **Update**: Determine a list of CTE candidates for assessment. *This is accomplished by the TRA review team and is a refinement of the initial list created by the R&DPM, including the modification of, removal of, or addition of CTEs.* Include any technologies that warrant the rigor of the formal TRA process.
- **Approval**: Approve the list of CTEs for assessment. *This is coordinated on by the TRA review team, the R&DPM, and the Certification Authority per the AFRL TRA Assessment Checklist.*

Identify Relevant Assessment Environment

During the CTE identification, there should be concurrent development of the anticipated environment for upcoming technology assessment, at the level commensurate with the proposed technology maturity. The AFRL TRL Assessment Checklist (as maintained by AFRL/EN) details the appropriate assessment environment associated with each TRL. As such:

- Derive the relevant environment for each CTE from those aspects of the operational environment determined to be a risk for the successful operation of that technology. The environment includes both the external or imposed environment and the internal or realized environment.

35

- Determine characteristics of the appropriate environment (examples below, but not limited to):
  - o Physical environment:
    - Mechanical components, processors, servers, and electronics
    - Kinetic and kinematic
    - Thermal and heat transfer
    - Electrical and electromagnetic
    - Threat (e.g., jammers)
    - Climatic – weather, temperature, particulate
    - Network infrastructure
  - o Logical environment
    - Software interfaces
    - Security interfaces
    - Web-enablement
    - Operating systems
    - Service-oriented architecture(s)
    - Communication protocols
    - Layers of abstraction
    - Virtualization
    - Coalition, federation, and backward compatibility
  - o Data environment
    - Data formats, structures, models, schemas, and databases
    - Anticipated data rates latency, jitter, transit loss, synchronization, and throughput
    - Data packaging and framing
  - o Security environment
    - Connection to firewalls
    - Security protocols and appliqués
    - Nature of the cyber adversary
    - Methods of attack, and trust establishment
    - Security domains
  - o User and use environment
    - Scalability
    - Ability to be upgraded
    - User training and behavior adjustments
    - User interfaces
    - Organizational change/realignments with system impacts
    - Implementation plan
- Is the physical/logical/data/security environment in which this CTE has been demonstrated similar to the intended environment? If not, how is it different?
- Is the CTE going to be operating at or outside its usual performance envelope? Do the design specifications address the behavior of the CTE under these conditions? What is unique or different about this proposed operations environment?

- Do test data, reports, or analyses that compare the demonstrated environment to the intended environment exist? If modeling and simulation (M&S) are important aspects of that comparison, are the analysis techniques common and generally accepted?
- CTEs should be identified and assessed under the assumption that the design—developed as part of the systems engineering approach—is adequate for the performance of the required functions. To support TRL 5 or higher, a precise knowledge of how a technology will actually be used is needed to define the relevant environment. Should the design be determined inadequate or flawed, the CTE assessment process should be re-accomplished.
- CTEs must also be assessed in an integrated way. A CTE may appear to be mature in isolation; however, this assessment may change when, for example, the combined effects of SWaP are considered.
- For TRL 6, it must be demonstrated in a relevant environment; for TRL 7, it must be demonstrated in an operational environment.

6.4.3 Evaluate Critical Technologies

- Utilize the AFRL TRL Assessment Checklist [as maintained by AFRL/EN].
- TRA team confirms the TRL measure, ensures definitions selected are appropriate and reaches agreement with the R&DPM on the kinds of evidence needed to demonstrate a TRA goal or objective has been met. *A total program TRL assignment should not exceed the lowest TRL assessment of any of the individual CTEs.*
- TRA team verifies that the test article and the relevant or operational environment used for testing are acceptable and the results are sufficient.
- TRA team assigns a TRL rating for each CTE based on credible and verifiable evidence, such as test and analytical reports, requirements documents, schematics, and other key documents.
    - Environment essentials:
        - A **relevant environment** is a set of stressing conditions, representative of the full spectrum of intended operational employments, which are applied to a CTE as part of a component (TRL 5) or system/subsystem (TRL 6) to identify whether any design changes to support the required (threshold) functionality are needed.
        - An **operational environment** is a set of operational conditions, representative of the full spectrum of operational employments, which are applied to a CTE as part of a system prototype (TRL 7) or actual system (TRL 8) in order to identify whether any previously unknown or undiscovered design problems might impact required (threshold) functionality.
        - Testing will not likely include actual accomplishment of the full range of required operational employments. Therefore, there must be a body of data or accepted theory to support, with confidence, that the efficacy of a technology,

though demonstrated only in some useful environment, can be extended to the full spectrum of employments.

- Demonstration of a CTE as part of a component or system/subsystem in a relevant environment or as part of a system prototype in an operational environment requires successful trial testing that either:
    - Shows that the CTE satisfies the required functionality across the full spectrum of intended operational employments, **or**
    - Shows that the CTE satisfies the functional need for some important, intended operational employment(s) and then uses accepted analytical techniques to extend confidence in supporting the required functionality over all the required, intended operational employments.

- Software CTE and environment nuances:
    - In assessing software CTEs, the application level are values of algorithms, software components, software programs, and software packages.
    - The environment includes integration issues, laboratory user environment issues, logical relationship issues, data environment issues, security environment issues, and possibly interface issues.
    - Dimensions, such as obsolescence, scalability, and throughput are usually expressed in terms of system-wide requirements, but can also be described in terms of software elements.
    - Hardware components often contribute to meeting these requirements. CTEs may need to be illuminated as both elements of hardware and software, and assessed separately. The combination of these dimensions determines any TRL.
    - To properly assess software's technical readiness, one must be aware of the characteristics of the relevant environment and operational environment.
        - Technical readiness in a **relevant environment** (TRL 5 or higher) requires a detailed architecture that fully exposes all components and elements affecting the operation of the critical software element.
        - Technical readiness in an **end-to-end relevant environment** (TRL 6 or higher) requires evidence of performance on full-scale, realistic problems.
        - Technical readiness in an **operational environment** (TRL 7 or higher) requires evidence of the acceptable performance of the software element under operational factors, including issues such as system loading, user interaction, security, and realistic communications environment (e.g., bandwidth, latency, jitter).

38

6.4.4 Prepare the TRA Report

- Prepare the report using AFRL guidance and requirements for the level of TRA
- Include all key information as determined in the plan
- Submit the report for review and approval
- Certification Authority (per the AFRL TRL Assessment Checklist maintained by AFRL/EN) provides a written response to the TRL rating
- Process the final report, including archiving and any electronic data management practices

6.4.5 Use the TRA Report Findings

- Use the report for the stated purpose, as established in the first step
- For CTEs that are assessed as immature, identify follow on actions
    - Consider alternative technology
    - Develop a technology maturation plan
    - Update the program's risk management plan
    - Revise cost or schedule risk assessments
- Submit TRA reports used for governance purposes in advance of a decision point or stage gate
- Input data generated into the appropriate program management data application suite and manage data in accordance with the established program DMP
- Document lessons learned and recommendations for follow on TRAs

7. Conclusions and Recommendations

This study reviewed guidance and best practices on TRAs, reviewed current AFRL and AFRL/RY processes and capabilities, and offered a framework for a tailored TRA process for AFRL/RY organizations that addresses the current lack of a systematic, documented approach to assess technologies. The recommended framework is derived from the established guidance and best practices, is integrated into current AFRL processes for program management, and offers up a flexible (tailorable) means to credibly execute a TRA on AFRL technologies. This credible assessment sets the foundation for many other concurrent and follow-on processes, supports meaningful engagements with other S&T professionals and transition partners, and supports increasing the probability of transition of AFRL technologies.

To support implementation of this proposed process, this study recommends the following:

- Execute the AFRL/RY Tailored TRA process on a subset of AFRL technology activities, such as those selected for the AFRL/RYZT 2022 Combat Lancer demonstration series
    - Use the AFRL TRL Assessment Checklist (as maintained by AFRL/EN)
    - Used the proposed AFRL TRA Report Template to write the TRA report

    - Provide feedback on the process, to include time/difficulty to implement additional activities in normal program management, ease of CTE identification and documentation, and template/checklist refinement to support follow-on TRAs
- Provide the report for management review and feedback
- Refine the process, checklist, and templates based on the feedback from the R&DPM and management
- Review current AFRL data management resources to support methodical TRA execution and as a repository for data artifacts
    - Identify current app modifications or new app development

Upon completion of testing of this process, update this study to ensure alignment with AFRL management and control of technology development, AFRL digital transformation initiatives, best practices that support engagement with transition partners, and overall guidance from Senior Leaders to accelerate technology development and get capabilities into the hands of the Warfighter faster.

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41

Appendix B. Acronym List

AD2	Advancement Degree of Difficulty
AF	Air Force
AFLCMC	Air Force Life Cycle Management Center
AFRL	Air Force Research Laboratory
AFRLI	Air Force Research Laboratory Instruction
AFWIC	Air Force Warfighting Integration Capability
AoA	Analysis of Alternatives
ASD (R&E)	Assistant Secretary of Defense for Research & Engineering
ASP	Acquisition Strategy Plan
ATM	AFRL Transition Metric
C2	Command and Control
CAE	Component Acquisition Executive
CTE	Critical Technology Element
DAF	Department of the Air Force
DDR&E	Director of Defense Research and Engineering (DoD Organization)
DEMS	Digital Enterprise R&D Management Suite
DMP	Data Management Plan
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DRD	Director, Research Directorate (DoD Organization)
GAO	Government Accounting Office
GRA	Government Reference Architecture
IRL	Integration Readiness Level
IRP	Independent Review Panel
IRT	Independent Review Team
JCTD	Joint Capability Technology Demonstration
MAJCOM	Major Command
MDA	Missile Defense Agency
MOP	Measure of Performance
MRA	Manufacturing Readiness Assessment
MRL	Manufacturing Readiness Level
MS&A	Modeling, Simulation & Analysis
MSA	Material Solution Analysis
OA	Open Architecture
OV	Operational View
PEO	Program Executive Office
PM	Program Manager

42

PMR	Program Management Review
POM	Program Objective Memorandum
R&D	Research & Development
R&DPM	Research & Development Program Manager
RDER	Rapid Defense Experimentation Reserve
S&T	Science & Technology
SE	Systems Engineering
SEPM	Systems Engineering and Program Management (Group)
SME	Subject Matter Expert
SPO	System Program Office
SRA	System Readiness Assessment
SRL	System Readiness Level
STiTCH	S&T information Technology Collaboration Hub
SV	System View
SWaP	Size, Weight and Power
T&E	Test & Evaluation
TAA	Technical Approval Authority
TDS	Technology Development Strategy
TMP	Technology Maturation Plan
TMRO	Technology, Manufacturing, Resource, Organization / Technology, Mission, Resource, Organization
TPM	Technical Performance Measures
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TTA	Technology Transition Agreement
TTP	Technology Transition Plan
TV	Technical standards View
WBS	Work Breakdown Structure
WU	Work Unit

Appendix C. Technology Readiness Levels[30]

Hardware and Software Technology Readiness Levels (TRLs)

Hardware TRL Definitions, Descriptions, and Supporting Information			Software TRL Definitions, Descriptions, and Supporting Information		
TRL Definition	**Description**	**Supporting Information**	**TRL Definition**	**Description**	**Supporting Information**
1 *Basic principles observed and reported.*	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.	**1** *Basic principles observed and reported.*	Lowest level of software technology readiness. A new software domain is being investigated by the basic research community. This level extends to the development of basic use, basic properties of software architecture, mathematical formulations, and general algorithms.	Basic research activities, research articles, peer-reviewed white papers, point papers, early lab model of basic concept may be useful for substantiating the TRL.
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.	Publications or other references that outline the application being considered and that provide analysis to support the concept.	**2** *Technology concept and/or application formulated.*	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 using synthetic data.	Applied research activities, analytic studies, small code units, and papers comparing competing technologies.
3 *Analytical and experimental critical function and/or characteristic proof of concept.*	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.	**3** *Analytical and experimental critical function and/or characteristic proof of concept.*	Active R&D is initiated. The level at which scientific feasibility is demonstrated through analytical and laboratory studies. This level extends to the development of limited functionality environments to validate critical properties and analytical predictions using non-integrated software components and partially representative data.	Algorithms run on a surrogate processor in a laboratory environment, instrumented components operating in a laboratory environment, laboratory results showing validation of critical properties.
4 *Component and/or breadboard validation in a laboratory environment.*	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.	**4** *Module and/or subsystem validation in a laboratory environment (i.e., software prototype development environment).*	Basic software components are integrated to establish that they will work together. They are relatively primitive with regard to efficiency and robustness compared with the eventual system. Architecture development initiated to include interoperability, reliability, maintainability, extensibility, scalability, and security issues. Emulation with current/legacy elements as appropriate. Prototypes developed to demonstrate different aspects of eventual system.	Advanced technology development, stand-alone prototype solving a synthetic full-scale problem, or standalone prototype processing fully representative data sets.
5 *Component and/or breadboard validation in a relevant environment.*	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?	**5** *Module and/or subsystem validation in a relevant environment.*	Level at which software technology is ready to start integration with existing systems. The prototype implementations conform to target environment/interfaces. Experiments with realistic problems. Simulated interfaces to existing systems. System software architecture established. Algorithms run on a processor(s) with characteristics expected in the operational environment.	System architecture diagram around technology element with critical performance requirements defined. Processor selection analysis, Simulation/Stimulation (Sim/Stim) Laboratory buildup plan. Software placed under configuration management. Commercial-of-the-shelf/government-off-the-shelf (COTS/GOTS) components in the system software architecture are identified.
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.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?	**6** *Module and/or subsystem validation in a relevant end-to-end environment.*	Level at which the engineering feasibility of a software technology is demonstrated. This level extends to laboratory prototype implementations on full-scale realistic problems in which the software technology is partially integrated with existing hardware/software systems.	Results from laboratory testing of a prototype package that is near the desired configuration in terms of performance, including physical, logical, data, and security interfaces. Comparisons between tested environment and operational environment analytically understood. Analysis and test measurements quantifying contribution to system-wide requirements such as throughput, scalability, and reliability. Analysis of human-computer (user environment) begun.
7 *System prototype demonstration in an operational environment.*	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?	**7** *System prototype demonstration in an operational high-fidelity environment.*	Level at which the program feasibility of a software technology is demonstrated. This level extends to operational environment prototype implementations, where critical technical risk functionality is available for demonstration and a test in which the software technology is well integrated with operational hardware/software systems.	Critical technological properties are measured against requirements in an operational environment.
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 (DT&E) of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?	**8** *Actual system completed and mission qualified through test and demonstration in an operational environment.*	Level at which a software technology is fully integrated with operational hardware and software systems. Software development documentation is complete. All functionality tested in simulated and operational scenarios.	Published documentation and product technology refresh build schedule. Software resource reserve measured and tracked.
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 (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.	**9** *Actual system proven through successful mission-proven operational capabilities.*	Level at which a software technology is readily repeatable and reusable. The software based on the technology is fully integrated with operational hardware/software systems. All software documentation verified. Successful operational experience. Sustaining software engineering support in place. Actual system.	Production configuration management reports. Technology integrated into a reuse "wizard."

[30] (Department of Defense, 2009)

Appendix D. TRA Report Template Examples

GAO TRA Report Template[31]

TRA REPORT TEMPLATE

EXECUTIVE SUMMARY

Briefly state who requested the Technology Readiness Assessment (TRA), what organization was responsible for conducting the TRA, what technology was assessed. Provide a summary table of the critical technologies and corresponding Technology Readiness Levels (TRL) rating determination made by the TRA team for each.

INTRODUCTION

Background

Provide project/program overview and background information (i.e., general description of the program and the technology system, including the critical technologies to be assessed).

Purpose and Scope of the TRA

Provide an explanation of why the TRA was conducted (i.e. program management's review for maturing technologies, TRA required for a decision point, etc.), and scope of the assessment. Reference applicable decision memos and planning documents.

TRA Process

Provide an overview, and plan of actions and milestones to conduct the TRA. Reference planning documents.

RESULTS

Provide the following for each critical technology assessed:

- Technology Reviewed: Provide a detailed description of the technology that was assessed. The level of detail can vary depending on the phase of development, design characteristics, and scope of review. Organizations should strive to provide a sufficient amount of information to facilitate an understanding of the technology assessed.
- Function: Describe the functions of the critical technologies.
- Relationship to Other Systems: Describe how the critical technologies interface with other systems.
- Development History and Status: Summarize pertinent development activities that have occurred to date on the critical technology.
- Relevant Environment: Describe relevant parameters inherent to the critical technology or the function it performs as it relates to the intended operational environment.
- Comparison of the Relevant Environment and the Demonstrated Environment

Describe differences and similarities between the environment in which the critical technology has been tested and the intended environment when fully operational. The demonstrated environment must correspond to the identified relevant environment for the TRL to be justified.

- Technology Readiness Level Determination

State the TRL determined for the critical technology and provide the basis justification for the TRL.

- Operational Requirement: Describe the required/traceable system functional performance and enabling features for the critical technology elements.
- Test Results: describe the analytical reports, test reports, or other information that was used to test the readiness, and functionality of the critical technology.

EXECUTIVE APPROVAL

- Provide statement or memo that shows executive management review and approval of the TRA report.

ATTACHMENTS

Include the following planning documents:

- TRA Plan
- Supporting documentation for identification of critical technologies
- Completed tables: TRL Questions for critical technologies
- List of support documentation for TRL determination
- TRL Summary table
- Lessons Learned
- Team biographies

Source: GAO analysis of agency documents. | GAO-20-48G

[31] (United States Government Accountability Office, 2020)

<u>DoD TRA Deskbook TRA Report Template (2009)</u>[32]

The following outline is an annotated version of the TRA report template.

1.0 Purpose of This Document

Provides a short introduction that includes the program name, the system name if different from the program name, and the milestone or other decision point for which the TRA was performed. For example, "This document presents an independent TRA for the UH-60M helicopter program in support of the Milestone B decision. The TRA was performed at the direction of the Army S&T Executive."

2.0 Program Overview

2.1 Program Objective

States what the program is trying to achieve (e.g., new capability, improved capability, lower procurement cost, reduced maintenance or manning, and so forth). Refers to the Capability Development Document (CDD) (for Milestone B) or the Capability Production Document (CPD) (for Milestone C) that details the program objectives.

2.2 Program Description

Briefly describes the program or program approach—not the system. Does the program provide a new system or a modification to an existing operational system? Is it an evolutionary acquisition program? If so, what capabilities will be realized by increment? When is the Initial Operational Capability (IOC)? Does it have multiple competing prime contractors? Into what architecture does it fit? Does its success depend on the success of other acquisition programs? Also, explicitly identifies the increments covered by the TRA, if relevant.

2.3 System Description

Describes the overall system, the major subsystems, and components to give an understanding of what is being developed and to show what is new, unique, or special about them. This information should include the systems, components, and technologies that will later be declared CTEs. Describes how the system works (if this is not obvious).

3.0 Technology Readiness Assessment (TRA)

3.1 Process Description

Tells who led the TRA and what organizations or individuals were included as part of the Independent Review Team (IRT). Identifies the special expertise of these participating organizations or individuals. This information should establish the subject matter expertise and the independence of the IRT. Members should be experts in relevant fields and should be sufficiently independent of the developers (government or industry) as to not be unduly influenced by their opinions or have any actual or perceived biases. To avoid being influenced by the program manager (PM), an IRT member should not be directly working for or matrixed to the program. Usually, the PM will provide most of the data and other information

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[32] (Department of Defense, 2009)

that form the basis of a TRA. Nevertheless, the *assessment* should be *independent* of the PM.

Tells how CTEs were identified (i.e., the process and criteria used and who identified them). States what analyses and investigations were performed when making the assessment (e.g., examination of test setups, discussions with test personnel, analysis of test data, review of related technology, and so forth). This is only a broad description of the process. Paragraph 3.3 presents an opportunity to include more detail.

3.2 Critical Technology Elements (CTEs)

Shows the technical work breakdown structure (WBS) or systems architecture and software architecture and the CTEs. Lists the technologies included in the TRA. Explains the criterion for technologies that were included on the list of CTEs. Describes the environment that surrounds each CTE. Can include a table that lists the technology name and includes a few words that describe the technology, its function, and the environment in which it will operate. The names of these CTEs should be used consistently throughout the document. Includes any additional technology elements that the Component S&T Executive considers critical.

3.3 Assessment of Maturity

3.3.1 First CTE or Category of Technology

Describes the technology (subsystem, component, or technology). Describes the function it performs and, if needed, how it relates to other parts of the system. Provides a synopsis of development history and status. This synopsis can include facts about related uses of the same or similar technology, numbers or hours breadboards were tested, numbers of prototypes built and tested, relevance of the test conditions, and results achieved. Describes the environment in which the technology has been demonstrated. Provides a brief analysis of the similarities between the demonstrated environment and the intended operational environment. Applies the criteria for Technology Readiness Levels (TRLs) and assigns a readiness level to the technology. States the readiness level (e.g., TRL 6) and the rationale for choosing this readiness level. Describes differing opinions for arriving at a particular TRL and the method of adjudication. Provides extensive references to papers, presentations, data, and facts that support the assessments. Includes data tables and graphs that illustrate the appropriateness of key facts. These references/tables/graphs can be included as an appendix. If the CTEs presented are in categories (e.g., airframe or sensors), the information specified in the previous paragraph (e.g., describing the technology, describing the function it performs, and so forth) should be provided for each CTE within a category.

3.3.2 Next CTE or Category of Technology

For the other CTEs, this paragraph and the following paragraphs (e.g., 3.3.3, 3.3.4, and so forth) present the same type of information that was presented in paragraph 3.3.1.

4.0 Summary

Includes a table that lists the CTEs and presents the assigned TRL and a short explanation (one sentence or a list of factors).

DoD TRA Guidance TRA Report Template (2011)[33]

The following outline is an annotated version of the TRA report template.

1.0 Purpose of This Document (One Paragraph)

Provides a short introduction that includes the program name, the system name if different from the program name, and the Milestone or other decision point for which the TRA was performed. For example, "This document presents an independent TRA for the UH-60M helicopter program in support of the MS B decision. The TRA was performed at the direction of the UH-60M Program Manager."

2.0 Executive Summary (One Page)

3.0 Program Overview

3.1 Program Objective (One Paragraph)

States what the program is trying to achieve (e.g., new capability, improved capability, lower procurement cost, reduced maintenance or manning, and so forth). For MS B, refers to the Capability Development Document (CDD) that details the program objectives.

3.2 Program Description (One Page or Less)

Briefly describes the program or program approach—not the system. Does the program provide a new system or a modification to an existing operational system? Is it an evolutionary acquisition program? If so, what capabilities will be realized by increment? When is the Initial Operational Capability (IOC)? Does it have multiple competing prime contractors? Into what architecture does it fit? Does its success depend on the success of other acquisition programs? Also, explicitly identifies the program increments or spirals covered by the TRA, if relevant.

3.3 System Description (Nominally 5 Pages)

Describes the overall system, the major subsystems, and components to give an understanding of what is being developed and to show what is new, unique, or special about them. This information should include the systems, components, and technologies to be assessed. Describes how the system works (if this is not obvious).

4.0 Program Technology Risks Summary and Readiness Assessment

4.1 Process Description (Nominally 2 Pages)

Tells the composition of the SME team and what organizations or individuals were included. Identifies the special expertise of these participating organizations or individuals. This information should establish the subject matter expertise and the independence of the SME team. Members should be experts in relevant fields. Usually, the PM will provide most of the data and other information that form the basis of a TRA. Tells how technologies to be assessed were identified (i.e., the process and criteria used and who identified them). States what analyses and investigations were performed when making the assessment.

4.2 Identification of Technologies Assessed (as Needed)

Lists the technologies included in the TRA and why they were selected as critical. Describes the relevant environment in which each technology was assessed. Normally, this would be the operational environment in which the system is intended

[33] (Department of Defense, 2011)

to perform; however, this can be adjusted if the technology's environment will be controlled while it operates in the system in question. Includes a table that lists the technology name and includes a few words that describe the technology, its function, and the environment in which it will operate. The names of these technologies should be used consistently throughout the document. Includes any technologies that the SME team considers critical and that have not been included in previously fielded systems that will operate in similar environments. Note that the technologies of interest here are not routine engineering or integration risk elements. They are items that require more than the normal engineering development that would occur in design for production as opposed to technology maturation programs.

4.3 PM's and SME Team's Assessments of Technology Risk and Technology Demonstration in a Relevant Environment (as needed)

4.3.1 First Technology

Describes the technology. Describes the function it performs and, if needed, how it relates to other parts of the system. Provides a synopsis of development history and status. If necessary, this synopsis can include facts about related uses of the same or similar technology, numbers of hours breadboards were tested, numbers of prototypes built and tested, relevance of the test conditions, and results achieved.

Describes the environment in which the technology has been demonstrated. Provides a brief analysis of the similarities between the demonstrated environment and the intended operational environment. States whether the assessed technology has been demonstrated in a relevant environment or not.

Provides data, including references to papers, presentations, data tables, and facts that support the assessments as needed. These references/tables/graphs can be included as an appendix.

Provides a summary of planned risk-mitigation activities showing how those activities will reduce the risk of the technology to acceptable levels.

Provides the SME team's concurrence or non-concurrence and the rationale therefore, and the SME team's assessment of the adequacy of proposed risk mitigation plans.

4.3.2 Next Technology

For the other technologies assessed, this paragraph and the following paragraphs (e.g., 4.3.3, 4.3.4, and so forth) present the same type of information that was presented in paragraph 4.3.1.

5.0 Summary (One Page)

Includes a table that lists the technologies that were assessed, the degree of risk associated with each, recommended mitigation measures if any, and whether each was demonstrated in a relevant environment. Summarizes any technologies for which the PM and the SME team are in disagreement as to the degree of risk or whether the technology has been demonstrated in a relevant environment.

49

Appendix E. TMRO (HAF/A57)[34]

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Total Capability Readiness Levels – TMRO

	Phase	RL	Technical	Mission	Resource	Organization
DISCOVERY	PRE	0	Basic principles observed and reported	Industry and Operational Trends	CFT charter and CFT resource plan developed	Fit with future force design confirmed
DISCOVERY	EARLY	1	Technology concept and/or application formulated	Mission attractiveness and operational value potential assessed	Early partnering options and project responsibilities identified	Opportunity alignment with technology or operating domains
DISCOVERY	MID	2	Key S&T Challenges identified and risk reduction plan developed	Operational application possibilities and employment options identified	Capability development resources identified	Strategy and stakeholder communication plan developed
DISCOVERY	LATE	3	Validation of key S&T. Initial technical concept and strategy developed	Mission vision and value proposition identified	Initial capability development strategy completed	Initial stakeholder advocacy with concept completed
INCUBATION	EARLY Learning Loop	4	Initial learning prototype validated in relevant environment (e.g. virtual prototype)	Initial Warfighting CONEMP developed and critical uncertainties evaluated	Early incubation resources in place and collaboration partners confirmed	Needed organizational structural and process alignment identified
INCUBATION	MID Learning Loop	5	Learning prototype iteration (e.g. hybrid or field experiment with non-fieldable prototype)	Mission application probing, concept option testing and competitive solution scoping	Capability development resources mapped to near, mid and far term (e.g. planning/programming inputs)	Initial DOTmLPF consideration activities completed
INCUBATION	FINAL Learning Loop	6	Demo product prototype with validated technical specifications (e.g. KPPs, AoA)	Update CONEMP, operational requirement developed (e.g. CDD)	Program of record identified. Initial lifecycle cost estimate (ready for MDD to MS B)	Full DOTmLPF-P development strategy and plan completed
ACCELERATE	EARLY	7	Product prototype demonstration in a development environment	Stakeholder engagement complete; operational requirement drafted	Operational deployment lifecycle resource plan developed	Organizational structure for product/solution ramp up in place
ACCELERATE	MID	8	Actual product completed and qualified through test and demo (expected operational conditions)	Military concept and initial operational deployment strategy validated	Resource transition from ramp up to full scale operational deployment	Final operations model selected (supply chain, assembly, distribution, etc.)
ACCELERATE	LATE	9	Actual product proven through successful application	Successful deployment of first application with plan for follow on applications and/or deployments	On-going product/solution resources in place, including partners	Organizational home assumes ops and sustainment; organize, train, and equip functions

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34 (TMRO Methodology Presentation)

Appendix F. ATM[35]

AFRL Transition Metric Version 2.0

AFRL Transition Metric v2.0													
Phase		**Technical Feasibility**	**Potential Info Sources**	**T**	**Manufacturability**	**Potential Info Sources**	**M**	**Resource Availability**	**Potential Info Sources**	**R**	**Organization Suitability**	**Potential Info Sources**	**O**
Screening		Is it technically realizable?	AFRL	0	Is it materially realizable?	AFRL	0	Is the concept aligned to a customers needs?	AFRL	0	What is the benefit to the warfighter?	AFRL	0
Discover / Create / Conceptualize	**Early**	Basic Principles Observed and Reported (TRL 1)?	AFRL	1	Implications on manufacturing identified (MRL 1)?	AFRL	1	Has an acquisition organization been identified? Is the acquisition organizations technology intake process known?	AFRL	1	Who (MAJCOM, User Org, etc.) would use this? Has a the customer organization been identified?	AFRL	1
	Mid	Technology Concept and/or Application Formulated Invention begun (TRL 2)?	AFRL	2	Manufacturing concepts identified (MRL 2)?	AFRL, Industry	2	Has the acquisition organization been contacted and are they open to engaging their intake process? Has a draft cost estimate and schedule for transition been developed?	AFRL, AFWIC, SDPE, Acq Partner	2	What is the projected impact on/change to the Users current practices? Has the individual within the customer organization been identified and an engagement strategy been developed? Has a draft conops been developed?	AFRL, Customer/ User	2
	Late	Analytical and experimental critical function and/or characteristic proof of concept (TRL 3)?	AFRL	3	Manufacturing proof of concept developed (MRL 3)?	AFRL, Industry	3	Is there an IP Management / Data Rights Plan? Are partnership agreements in place (e.g. OEM/performer)?	AFRL, AFWIC, SDPE, Acq Partner	3	Have initial meetings with stakeholders occurred? Does the customer accept that the technology meets a user requirement? Has system performance impact been validated through MS&A?	AFRL, AFWIC, SDPE, Customer/ User	3
Incubate / Learn / Experiment	**Early**	Component and/or breadboard validated in a laboratory environment (TRL 4)?	AFRL, SDPE	4	Is technology being produced in a laboratory environment (MRL 4)?	AFRL, Industry	4	Are funds identified in an integrated capability roadmap? Have procurement funds been programmed and submitted by user as part of President's budget?	AFWIC, SDPE, Acq Partner	4	Do you have a customer champion/advocate who can make the decision to integrate/transition the technology? Is there existing doctrine supporting this capability, or is new doctrine under development? Do units need to be restructured/organized to support the new capability? Is the customer organization involved in prototype demonstrations?	AFWIC, SDPE, Customer	4
	Mid	Component and/or breadboard validation in a relevant environment (TRL 5)?	AFRL, SDPE	5	Are prototype components being produced in a production relevant environment (MRL 5)?	AFRL, Industry	5	Does the system have a formal Acquisition Strategy? Is the customer including the technology in roadmaps/spiral development plans?	AFRL, AFWIC, SDPE, Acq Partner, User	5	Have use case scenarios been written and measures of effectiveness been identified? Have the warfighting benefits been validated through simulations? Has AFWIC integrated the technical capability in its mission analysis? Has customer identified, and is implementing, the changes required to incorporate the new capability? Has the CONOPS been wargamed and evaluated via simulation in user defined scenarios?	AFWIC, SDPE, Customer, User	5
	Late	System/subsystem model or prototype demonstration in a relevant environment (TRL 6)?	AFRL, SDPE, AFWIC	6	Is the prototype system or subsystem being produced in a production relevant environment (MRL 6)?	AFRL, SDPE, Industry	6	Is Initial resourcing of support equipment and prototypes completed? Are test facilities and initial training in place? Has funding been received via President's budget?	AFRL, AFWIC, Acq Partner, User	6	Have organizational strategic alignment and stakeholder expectations been identified and documented? Is a signed Technology Transition Plan in place? Has there been a formal recognition of the requirement? Has the organizational home assumed ownership?	AFWIC, SDPE, Customer, User	6
Accelerate / Adopt / Field	**Early**	System prototype demonstration in an operational environment (TRL 7)?	AFRL, AFWIC, Acq Partner	7	Is the system or subsystem being produced in a production representative environment (MRL 7)?	AFRL, Acq Partner, Industry	7	Has a mission delivery lifecycle resource plan been developed? Have operational facilities being developed and a personnel pipeline established?	Acq Partner, User	7	Has the capability been integrated into war planning?	AFWIC, Customer, User	7
	Mid	Actual system completed and qualified through test and demonstration (TRL 8)?	AFWIC, Acq Partner	8	Has the pilot line been demonstrated and is company ready for low rate initial production (LRIP) (MRL 8)?	Acq Partner, Industry	8	Have resources transitioned from ramp up to standard mission delivery?	Acq Partner, User	8	Has there been a successful mission launch of first application with plan for follow on applications? Are there special personnel/facilities required for this technology and, if so, is there a plan?	AFWIC, Customer, User	8
	Late	Actual system proven through successful mission operations (TRL 9)?	Acq Partner	9	Has LRIP been demonstrated and is the capability in place to begin full rate production (FRP) (MRL 9)?	Acq Partner, Industry	9	Are on-going product/solution resources in place, including partners? Is maintenance support in place?	Acq Partner, User	9	Operational Test & Evaluation performed with preliminary results?	AFWIC, Customer, User	9

[35] (Gary Scalzi, 2020)