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A CONTRASTIVE STUDY OF STANDARD SPECIFICATION FOR TECHNOLOGY READINESS ASSESSMENT

Wenyuan CHENG, Chenguang XING, Gang SONG

System Engineering Division, Aviation Industry Development Research Center of China (ADR) Beijing China 100029

Abstract

The standard specification released in recent five years was analyzed in this paper, including ISO 16290 TRL standard, DoD's TRA Deskbook, NASA's TRL definition, ESA's TRL handbook, and GAO's TRL guidance. The main update in TRL definition, applications, etc. and the purpose were summarized. Secondly, the application of TRL standard, including GJB 7688/7689 and GJB/Z173.X was analyzed about assessment object, TRL definition, the architecture of TRL assessment criteria and applications. Based on this, the contrastive study has been made and the short come for our TRL standard's application. Finally, some suggestions were given to establish and modify the national military standards.

Keywords: technology readiness level, technology readiness assessment, standard, specification

1. Introduction

Since NASA formally released the world's first standard relevant to Technology Readiness Levels (TRLs) in 1995 in form of a white paper, TRLs has been adopted as a tool to assess the risk of a new or advanced technology in one of products by the Defense Department, including Department of Defense (DoD), Department of Energy (DOE), Government Accountability office (GAO), Department of Homeland Security (DHS), Department of Transportation (DOT), etc. [1-9]. Nowadays, TRLs methodology has been adopted widely and become a standard tool in defense acquisition and scientific research management in major countries and institutions all over the world, such as the United States, Europe, Australia, and Asia, which has also released or published their own policies and standards. At present, the relevant standards and specifications related to Technology Readiness Assessment (TRA) commonly used include: NASA's TRL white paper [1], DoD's TRA Deskbook [2-3], GAO TRA guidance [6-7], International Standardization Organization (ISO) 16290 TRL Standard [10], ESA's TRL guidance [11], and European Cooperation for Space Standardization (ECSS)'s space system TRL guidelines [12]. These standards and specifications also promote the application of technology maturity evaluation methods in the research and management of high-tech systems or products. The European Association of Research and Technology Organization (EARTO) members were very active in National and European research, technology & innovation programs, and had used TRLs as a tool for decision making on Research and Development (R&D) investments at EU level [13], especially in Key enabling technology management in "Horizon 2020"[14-15]. In addition, Boeing, Lockheed Martin, General Electric, Pratt & Whitney, Rolls-Royce, Raytheon, Airbus, Bombardier, and SpaceX have all adopted technology maturity evaluation methods.

In 2009, the China national standard "General rules of science and technology research projects evaluation"(GB/T 22900-2009) classified and categorized scientific and technology research projects and gave the TRLs definition according to NASA's TRLs definition [16]. In order to guide the technology maturity evaluation of defense science and technology (S&T) project, the relevant department released the instruction for TRA in defense science and technology. In 2012-2014, two TRA standards (GJB 7688-2012 and GJB 7689-2012) and seven guidances (GJB/Z 173.x-2014) for materiel were released based on research achievements and practice experience in order to guide the evaluation activities in weapon systems [17-18]. These two standards respectively regulate the classification and definition of TRLs and procedures of TRA. These seven guidances issued as secondary standard have specified the technology maturity evaluation of ship, aircraft and helicopter, aero engine, and spacecraft system.

In this paper, the technology maturity evaluation standards and specifications released in past five years has been taken as main research object, the background, evaluation models, evaluation criteria, and evaluation procedures were compared and analyzed, especially focusing on latest changes and modification. Secondly, the application of GJB 7688-2012 series standards and guidance has been analyzed through questionnaires surveys, and some problems and suggestions have been given. Finally, the limitation and shortcoming in the GJB 7688-2012 series standards has been found out through comparative analysis, and some suggestions were given for implementation and revision in relevant national military standards.

2. Latest Modification on TRA Standard Specifications in Past Several Years

2.1 Summary of the Standards And Specifications For Technology Readiness Assessment

Since the NASA TRLs white paper published in1995, more than nine technology maturity evaluation related standards and/or specifications have developed to guide the technology readiness assessment activities in defense acquisition and research management. Among them, ISO 16290 standard, GAO's TRA guide, ECSS's TRL guidelines have been updated in the past five years. And the DOT's TRL guidebook is new one, as shown in table 1. This paper focuses on these first three standards, and analyzes the main content and the main changes compared with other standards.

Table 1 – Standard and Specification of Technology Readiness Assessment

No.	Organization	Standard or specification	Release time
1	NASA	Technology Readiness Levels White Paper	1995
2	DoD	Technology Readiness Assessment (TRA) Deskbook	2003 2005(updated) 2009(updated)
3	DoD	Technology Readiness Assessment (TRA) Guidance	2011
4	ESA	Technology Readiness Levels Handbook for Space Application	2008
5	DOE	Technology Readiness Assessment Guide	2009 2011(updated) 2015(updated)
6	ISO	Space systems-Definition of the technology Readiness Levels (TRLs) and their criteria of assessment	2013
7	GAO	Technology Readiness Assessment Guide (draft)—Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects	2016 2020(updated)
8	ECSS	Space engineering Technology readiness level (TRL) guidelines	2017
9	DOT	Technology readiness level guidebook	2017

2.2 ISO's 16290 TRL standard

The ISO 16290 TRL standard released in November 2013 is the first international standard related to technology maturity evaluation, which is organized by ESTEC under ESA. ISO standard is regulating the definition of the technology Readiness Levels (TRLs) and their criteria of assessment for space systems. This international standard was produced by taking due consideration of previous available documents on the subject, in particular including those from the National Aeronautics Space Administration (NASA), the US DoD and European space institutions (DLR, CNES and ESA). The TRL scale can be useful in many areas including, but not limited to the following examples [10]:

a) For early monitoring of basic or specific technology developments serving a given future mission or a family of future missions;

b) For providing a status on the technical readiness of a future project, as input to the project implementation decision process;

c) In some cases, for monitoring the technology progress throughout development.

The standard mainly describes the engineering terms and grade definitions from the mechanism, and is supplemented with examples to highlight the general applicability. The standard mainly includes scope of application, definition of terms and TRLs, and summary table. The 21 general terms, such as breadboard, critical function of an element, element, model, etc. have been described with common language. And the TRL descriptions are provided with examples, which in favor of user understands. Finally, The achievements that are requested for enabling the TRL assessment at each level are identified in the summary table, which could be used for evaluation quickly. The release of ISO 16290 standard indicates that the ideas and methods of technology maturity evaluation have been widely accepted worldwide.

2.3 GAO's TRA guide

In August 2016, the US GAO released a draft "Technology Readiness Assessment Guide" which is a companion to GAO's Cost Estimating and Assessment Guide and its Schedule Assessment Guide. With this Guide, GAO intends to establish a methodology based on best practices that can be used across the federal government for evaluating technology maturity, particularly as it relates to determining a program or project's readiness to move past key decision points that typically coincide with major commitments of resources. And provide TRA practitioners, program and technology managers, and governance bodies throughout the federal government a framework for better understanding technology maturity, conducting credible technology readiness assessments, and developing plans for technology maturation efforts [6].

In this guide, GAO mainly recommends a reliable process for conducting credible TRAs, which include six steps, as following:

a) Design the overall technology maturity assessment strategy for the program or project.

b) Define the individual TRA's purpose, develop a TRA plan, and assemble the assessment team.

c) Select critical technologies.

d) Evaluate critical technologies.

e) Prepare, coordinate and submit TRA report.

f) Using TRA results and developing a Technology Maturation Plan.

A five-step process presented in the latest GAO's TRA guide updated in January 2020, provides the frame work for planning, assessing, and reporting the TRA, as shown in figure 1. In comparison with the six-step process, the activities about designing the assessment strategy and defining the assessment purpose was eliminated [7].

Figure1 – Five Steps for Conducting a High-Quality Technology Readiness Assessment (TRA)

This guide also describes the definition and purpose of TRA and provides best practices for evaluating the readiness of technology for use in acquisition programs and projects with many case studies drawn from GAO reviews. And some interested issue such as technology maturity plan (TMP), TRAs and software development, and development of system-level readiness measures, was discussed.

2.4 ECSS's space engineering TRL guidelines

The ECSS's space engineering TRL guidelines released in March 2017 by ESA's requirements and standards division is one of the series of ECSS Documents intended to be used as supporting material for ECSS Standards in space projects and applications. The handbook provides guidelines on the way to assess the maturity of a technology of a product in a given environment, to use the TRL assessment outcome in the product development framework, and to introduce some further refinements for specific disciplines or products to which the TRL assessment methodology can be extended [12].

The handbook is divided into seven chapters including scope, references, terms, definitions and acronyms, the history and evolution of TRLs, TRA guidelines, project implementation, the link with model philosophy and technology demonstration and assessment, and 3 appendices including TRL considerations for software, electrical, electronic, and electromechanical components, materials and manufacturing processes.

2.5 Analysis of major changes

This paper focuses on latest modification and revision of the relevant standard specifications issued in the past several years as the research object, including DoD's TRA guidance updated in 2011, ISO 16290 standard released in 2013, GAO's TRA guidance updated in 2020, and ECSS's TRL guideline released in 2017. Here, although NASA's TRA research team report in 2016 [19] cannot be used as a formal standard specification, it is also listed as a comparative object as a supporting document for subsequent guidelines that NASA may issue. A comparative analysis is made from two aspects, the main purpose and the content of the changes, details as shown in table 2.

Table 2 – Development Analysis of Standard Specification for TRA in past several years

No.	Standard Specification	Purpose	Modifications and Changes
1	DoD TRA guidance （2011）	● With the widely use in defense acquisition management, the evaluation become more and more complex and expensive, which result in the decrease in effectiveness and efficiency. ● DoD needs improve the TRA effectiveness in coincidence with the better acquisition policy.	● Change the title from deskbook to guidance. ● Remain the overall requirement and process for TRA only, and delete the appendix. ● Remain the mandatory TRA assessment in MDAP milestone B only. ● Adjusted the organization, the S&T executive modified with PM.
2	ISO16290 standard （2013）	● Identify the difference between various TRLs standards, and construct a general architecture	● Giving the general definition to reducing the deviation in various standards from different aerospace institutes, especially

		and definition for TRL using a common ontology. ● ESA replaced internal TRL document with ISO16290 standard as official definition, while NASA still using TRL definition from NMI7100.	in terms. ● The 9-level TRL definition described and highlighted with specific technical examples on the basis of NASA's and DoD's definitions, and three case descriptions are added to each level to improve the understanding of definition description.
3	NASA-TRA report （2016）	● The investigation on the state of TRA implementation in NASA. ● Identify the problems in the current standards. ● Give some suggestion on strength the TRA process.	Some suggestions were given: ● Develop a Consolidated TRA Handbook. ● Independent TRA Validations. ● Update the TRL definition in NPR7123. ● Update the TRA process and NASA System Engineering handbook. ● TRA for Software.
4	GAO-TRA guide （2020）	● Introduce the general standard to reader for executing the efficient TRA in defense acquisition. ● Provide a tool to PM, technology developer and manager for risk management.	● Some suggestions on best practice in each step and cases were given. ● A general six or five step process is suggested. ● Adding the technology maturity plan in TRA process.
5	ECSS- TRL guidelines （2017）	● This Handbook supports the application of the TRL, and provides guidelines to its use in projects and its independent verification within each specific project context.	● The TRL definition is same as ISO16290; the critical factor in each level was described about element definition status, performance requirement status and V&V status. ● Some difference between NASA TRL and ISO16290 TRL is described.

3. Analysis on the Application of Domestic TRA Standards and Specifications

3.1 Questionnaire Survey

In order to find out the application of domestic TRA standards and specifications, i.e. two top-level standards (GJB 7688/7689) and seven second-level guidances (GJB/Z 173.X), a questionnaires were designed, including 17 questions focus on the application, development and revision of TRA standard, and research on TRA methodology, as shown in table 3.

Table 3 – Questionnaires for Technology Readiness Assessment

Category	Questionnaires lists
Application of TRA standar d	1. Have you regularly organized/participated in the training of the TRA standard? 2. Which types of major equipment research and development have you conducted technol ogy maturity evaluation? 3. When did you implement TRA process? 4. Do you refer to GJB7688 / 7689 standard and GJB / Z 173.X guidance when conduct T RA evaluation? 5. Which standard or guideline do you refer to in your TRA process? 6. Can the current 2 standards and 7 guidelines meet your TRA needs? 7. Have the current 2 standards and 7 guidelines support your TRA evaluation?
Development and/or revisio n of TRA stan dard	8. What problems do you think the current standards and guidelines have in the evaluation process? 9. What problems do you think the current standards and guidelines have in terms of TRL definition and criteria? 10. Regarding the revision of the existing standards and guidelines, which of the following do you think is more appropriate? 11. Which aspects will be focused on if the two standards (GJB7688 / 7689) revised?

	12. Which aspects will be focused on if the seven guidances (GJB/Z 173.X) revised? 13. What materiel do you recommend to if needs to supplement the guidance?
Research on TRA methodo logy	14. Does your organization establish a specialized team for TRA theory research and appli cation? 15. Have you organized or participated in writing the TRA relevant book? 16. Have you organized or participated in drafting TRA relevant standards or guidances? 17. Are you interested in participating in the revision of the current TRA standard?

In this questionnaire, the main survey content focus on three aspects:

1) The capability and experience of the research objects in the theoretical research and evaluation activities.

2) The commonly used standards in the research objects.

3) The challenges and suggestion on the usage and revision of current TRA standards and specifications.

In this investigation, the subjects are mainly related institutes engaged in weapon system development and management in national defense science and technology industry, including: institutes responsible for drafting standards and major contractors in various industries.

3.2 Findings and Discussions

In terms of technology maturity evaluation practice, it's not enough in training and promotion of standards in defense science and technology industries, with only 40% institutes investigated regularly organizing or participating in technology maturity evaluation related training. Almost all institutes are required to implement the TRA process in major weapon system development and have experience in evaluation. The timing of technology maturity evaluation mostly choose milestone decision gates, such as the initiation and acceptance, etc. and a large number of institutes will also do the TRA evaluate with annually inspection, as shown in figure 2. These standards and guidances have been adopted in the technology maturity evaluation in various institutes, especially in aviation, ship, electronics, etc., which can basically support the needs of each industry to carry out technology maturity evaluation.

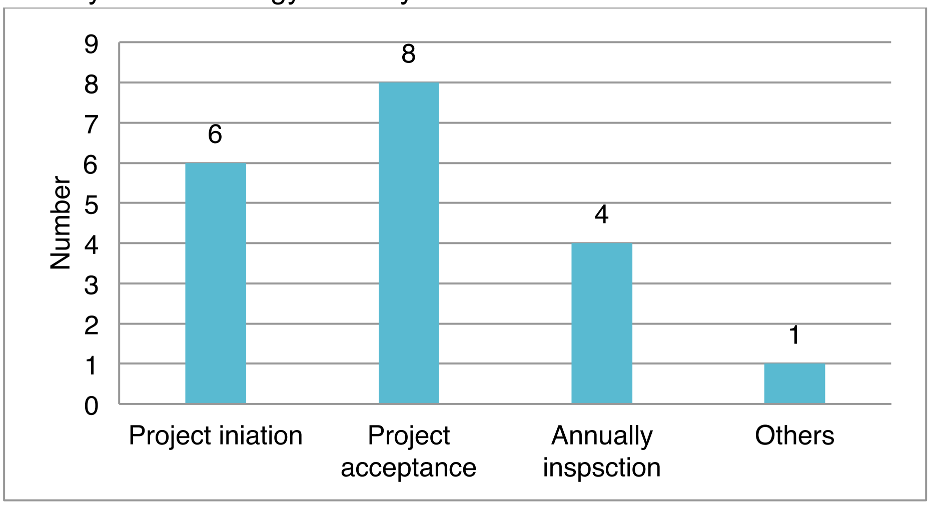

Figure 2 – Statistical overview for the timing of technology maturity evaluation

As for the TRLs definition and evaluation criteria, nearly 70% of the institutes pointed out that some evaluation criteria and engineering practices is mismatch. In term of the revision of existing standards, nearly 46% of the institutes suggested supplement new secondary guidance on the basis of two standards and seven guidances, nearly 27% suggested revise these seven guidances only, and nearly 27% suggested revise all these nine documents, as shown in figure 3.

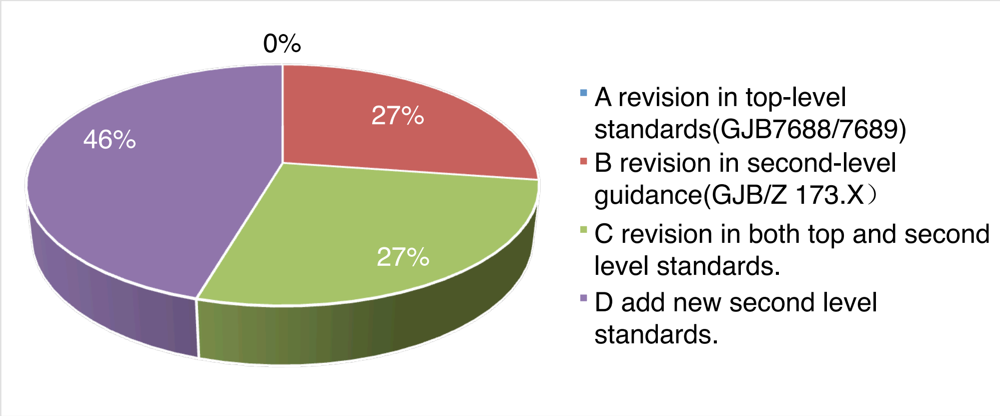

Figure 3 – Statistical overview for revision of existing standards and guidances

Anyway, whether the two top-level standards or the seven second-level guidances, the focus of revision is on the evaluation criteria, followed by the TRLs definition, evaluation procedures and evaluation templates, as shown in figure 4.

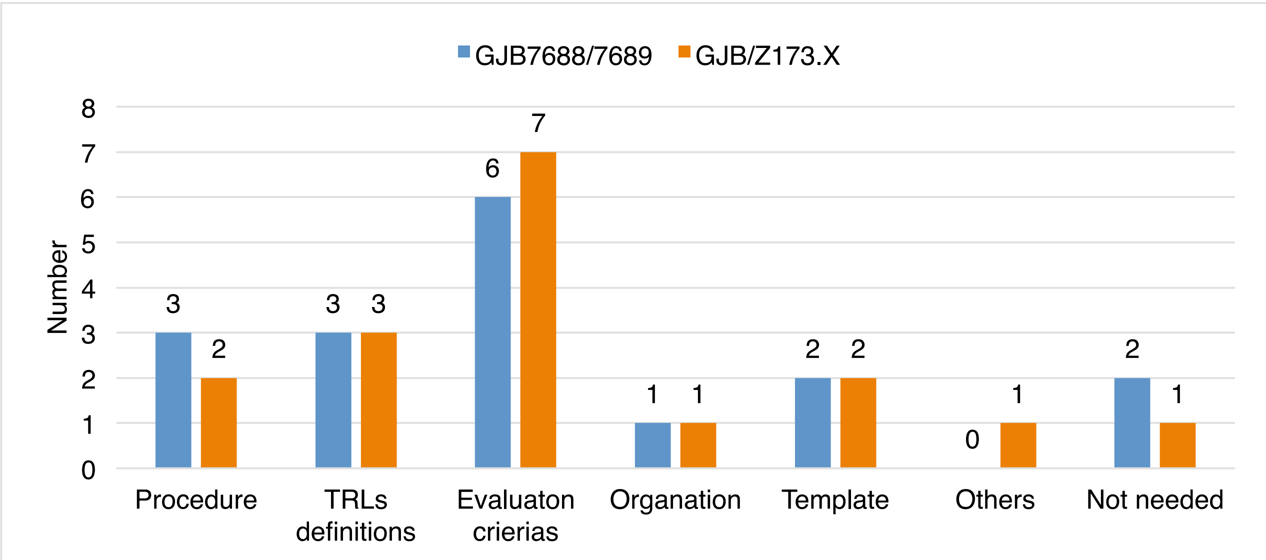

Figure 4 – Statistical overview for reversion content of existing standards

In terms of theoretical research on technology maturity evaluation methodology, aviation and aerospace related institutes have made more efforts rather than the others, and established an adaptive methodology suitable for their own evaluation requirement. Most institutes have participated in the drafting of standards and guidances.

Through the preliminary analysis, we found out that technology maturity evaluation has become a major decision-making management tool for major weapon system development including the S&T programs and projects, which has been widely used in various industries. However, there are still many problems in the promotion and application, which are mainly summarized as follows:

1) The existing technology maturity evaluation related standards and guidances is not sufficient to support the technical maturity evaluation of weapon system, needing supplement new guidance.

2) The effectiveness and outcomes of TRA activities is limited without the guidance from policy and regulations, supervision during evaluation implementation.

4. Contrastive Analyses of Technology Maturity Standards

This paper takes the TRL white paper published by NASA in 1995, the DoD's TRA manual (2009 edition), and the ESA's TRL manual as objects, and makes a comparative analysis from the definition of TRLs and terms, evaluation criteria, and evaluation processes.

4.1 TRL Definitions and Terminology

The five sets of TRL definitions and terms from NASA, ISO, DoD, ESA, GJB, etc. described in table 4. Among them, ESA directly adopted NASA's definition, GAO directly adopted DoD's definition; hence, the comparative analysis in this paper is mainly focus on NASA, DoD, ISO and GJB-7688 documents.

Table 4 – TRLs definition for different organization

TRL	NASA/ESA	DoD/GAO	ISO/ECSS	GJB-7688
1	Basic principles observed and reported	Basic principles observed and reported.	Basic principles observed and reported	Basic principles observed and reported.
2	Technology concept and/or application formulated	Technology concept and/or application formulated	Technology concept and/or application formulated	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Analytical and experimental critical function and/or characteristic proof of concept	Analytical and experimental critical function and/or characteristic proof-of-concept	Feasible proof of concept and application assumption
4	Component and/or breadboard validation in laboratory environment	Component and/or breadboard validation in a laboratory environment	Component and/or breadboard functional verification in laboratory environment	Component and/or breadboard validation in a laboratory environment
5	Component and/or breadboard validation in relevant environment	Component and/or breadboard validation in a relevant environment	Component and/or breadboard critical function verification in a relevant environment	Component and/or brassboard validation in a relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)	System/subsystem model or prototype demonstration in a relevant environment	Model demonstrating the critical functions of the element in a relevant environment	System/subsystem prototype demonstration in a relevant environment
7	System prototype demonstration in a space environment	System prototype demonstration in an operational environment	Model demonstrating the element performance for the operational environment	System prototype demonstration in an representative operational environment
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)	Actual system completed and qualified through test and demonstration	Actual system completed and accepted for flight ("flight qualified")	Actual system proven in operation environment
9	Actual system "flight proven" through successful mission operations	Actual system proven through successful mission operations.	Actual system "flight proven" through successful mission operations	Actual system proven through successful mission operations.

Through comparative analysis, we found that the definitions of TRL1 to TRL3 are exactly the same, and in TRL4 to TRL9, the main difference between those four definitions focus on technology form, verification and validation environment, etc.

1) In TRL4 and TRL5, the term “validation” is used to regulate the activities in these two levels by DoD, NASA, GJB-7688, which differs from the term “functional verification” by ISO. As for technology form, the term “breadboard” is used to describe low-fidelity breadboard in TRL4 and the term “brassboard” as medium-fidelity breadboard in TRL5 by GJB-7688 standard, and the others use “breadboard” in TRL4 and TRL5 only. No matter whatever term these standards used, the technology validation state is basically the same in TRL4 and TRL5.
2) In TRL6 and TRL7, the term “model” and “element” is used to describe technology form, which differs from the term “system/subsystem” and “model or prototype” by DoD, NASA and GJB-7688. As for the validation activities, ISO focus on the critical function demonstration in TRL6 and performance demonstration in TRL7, which differs from the other standards’ function and performance for prototype in TRL6 and TRL7. In environment, NASA used ground or space environment that suitable for its own engineering requirement, however, the others validate technology in the relevant environment usually may not be the operation environment in TRL6.
3) In TRL8 and TRL9, the “qualified” used in ISO, NASA and DoD to regulate the validation state, however, GJB-7688 used “proven”. NASA and ISO emphasize the flight activities both in TRL8 and TRL9; however, DoD and GJB-7688 emphasize the test and demonstration and operation only.

Compared with NASA's TRL definition, the ISO 16290 standard has undergone some changes: the NASA's TRL5 is split into two levels, corresponding to the ISO's TRL5 and TRL6, and the TRL7 is deleted. After adjustment, the ISO's TRL6 is equivalent to NASA's TRL5; TRL7 of ISO is equivalent to TRL6 of NASA, as shown in figure 5 [12].

	NASA 95 white paper		ISO 16290 standard
TRL1	Basic principles observed and reported	Equivalent	Basic principles observed and reported
TRL2	Technology concept and/or application formulated	Equivalent	Technology concept and/or application formulated
TRL3	Analytical and experimental critical function and/or characteristic proof-of concept	Equivalent	Analytical and experimental critical function and/or characteristic proof-of concept
TRL4	Component and/or breadboard ***validation*** in laboratory environment	Equivalent	Component and/or breadboard ***function verification*** in laboratory environment
TRL5	Component and/or breadboard ***validation*** in relevant environment	Split	Component and/or breadboard ***critical function verification*** in a relevant environment
TRL6	***System/subsystem*** model ***or prototype*** demonstration in a relevant environment ***(ground or space)***	Shifted	Model ***demonstrating the critical functions of the element*** in a relevant environment
TRL7	***System prototype demonstration in a space*** environment	Removed	***Model demonstrating the element performance for the operational*** environment
TRL8	Actual system completed and ***“flight qualified” through test and demonstration (ground or space)***	Equivalent	Actual system completed and ***accepted for flight (“flight qualified”)***
TRL9	Actual system “flight proven” through successful mission operations	Equivalent	Actual system “flight proven” through successful mission operations

Figure 5 – Illustration of differences between NASA and ISO 16290

Comparison with the NASA, DoD and ISO standards, the TRLs definition in GJB-7688 has some differences:

1) The distinguish between TRL4 and TRL5 is further defined by using breadboard and brassboard to describe the technology form, which help to understanding for engineers and managers.
2) The prototype demonstration activities are strengthened in TRL6 to reduce the risk before entering engineering and manufacture development phase.
3) The validation environment is defined in TRL8, which emphasizes the operational environment, however, the others standard only used “qualified” to regulate the validation environment implicitly.

4.2 TRL Assessment Criteria

In the United States, NASA, DOE, DHS have studied and formulated their own assessment criteria based on TRL calculator (version 2.2) developed by U.S Air force Research Laboratory (AFRL) [20], as shown in figure 6. In AFRL TRL calculator, there are 274 questions design for evaluate the hardware (H) or software (S) technology development state of each level category with technology (T), manufacturing (M) and programmatic (P), by the way, here, in the figure, “B” means both for hardware and software.

Both	Catgry	% Complete		TRL 6 (Check all that apply or use sliders)
B	T	100	☑	Cross technology issue measurement and performance characteristic validations completed
H	M	100	☑	Quality and reliability levels established
B	M	100	☑	Frequent design changes occur
H	P	100	☑	Draft design drawings are nearly complete
B	T	100	☑	Operating environment for eventual system known
B	P	100	☑	Collection of actual maintainability, reliability, and supportability data has been started
B	P	100	☑	Design to cost goals identified
H	M	100	☑	Investment needs for process and tooling determined
B	T	100	☑	M&S used to simulate system performance in an operational environment
B	P	100	☑	Final Test & Evaluation Master Plan (TEMP)
H	T	100	☑	Factory acceptance testing of laboratory system in laboratory setting
B	T	100	☑	Representative model / prototype tested in high-fidelity lab / simulated operational environment
B	T	100	☑	Realistic environment outside the lab, but not the eventual operating environment
B	P	100	☑	Final Systems Engineering Master Plan (SEMP)

Figure 6 – AFRL TRL calculator questions

The top-level decision process for calculating the overall TRL [20], as shown in figure 7, the qualifying algorithm looks at the number of questions checked and the color of the previous TRL, except for TRL1, which has no previous. Checking the previous color keeps the calculator from displaying a green TRL at a higher level than a red or yellow, and keeps a yellow from appearing higher than a red.

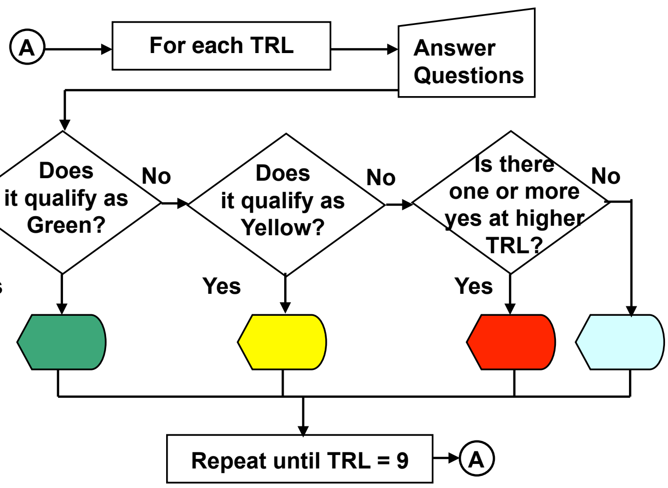

Figure 7 – Decision process flowchart in AFRL TRL calculator

Although the specific content and the number of terms are different, the architecture is the same. With the publication of version 3.6, the criteria show a trend of simplification. Focusing on the assessment criteria of the four standards, through comparative analysis, it is found that: In Europe, ESA has developed its own assessment criteria referred AFRL's TRL calculator, but ISO16290 regards the milestones and work achievement in each level as criteria, which is consistent with early principle in NASA and DoD. In comparison with the other organization, the universality was chosen as the first principle in the ISO standard. As for domestic standards, the assessment criteria in GJB-7688 standard also derived from AFRL's TRL calculator. The second-level guideline (GJB/Z 173.X) has improved the adaptability by considering different weapon system types and characteristics.

4.3 TRL Assessment Process

Each origination has developed its own assessment process defined in related standards and guidances; for example, GAO has recommended six or five step process in way of best practice. The following is each organization's evaluation process. NASA recommends assessment process including 11 steps, while the ESA's assessment process comprises 6 steps, as shown in figure 8.

NASA's assessment process:

1) Define terminology.
2) Perform gap analysis to ID technology needs.
3) Establish process for periodic assessment.
4) Perform initial assessment of new technologies.
5) Use "weakest link" roll-up.
6) Depth of detail expands as project progresses.
7) Identify CTEs.
8) Assessment of heritage elements.
9) AD2 (risk quantification).
10) Develop maturation plan.
11) Annually assess progress.

ESA/ECSS assessment process:

1) Formal definition of the terms of reference for the assessment (including timing, technology data collecting, and the detailed criteria)
2) Identification of key supporting data (e.g., operating environment and expected system applications).
3) Identification of TRA Participants (including appropriate involvement of technologists and/or systems program participants).
4) Development and delivery of technology data to the TRA (often including preparatory meetings and/or studies by members of the technology community involved).
5) Implementation of the TRA itself (often involving meetings of a formal review committee).
6) Development of a TRA report.

Figure 8 – TRA assessment process of NASA and ESA

Department of Defense (DoD) TRA Process includes 5 steps, as following:

1) Establish TRA plan and schedule.
2) Form SME team.
3) Identify technologies to be assessed.
4) Collect evidence of maturity.
5) Assess technology maturity:
    a. SME team assessments.
    b. Prepare, coordinate, and submit TRA report.
    c. Assistant Secretary of Defense (Research & Evaluation) to review and evaluate.

Taking the DoD, GAO, NASA, ISO and domestic technology maturity evaluation processes as examples for comparative analysis, it is not difficult to find:

1) The technology maturity evaluation process of major US institutions represented by NASA, DoD, GAO, focusing on technology risk identification and evaluation. The evaluation process mainly includes: making plans, identifying critical technologies, evaluating critical technologies, and preparing reports. And NASA and GAO added the technology maturity plan (TMP) after the evaluation and NASA also developed the Advancement Degree of Difficulty (AD2) evaluation in order to better formulate TMPs.

2) The European technology maturity evaluation process represented by ESA, ISO, and ECSS, which is relatively simplified, lacking of identification of critical technologies, emphasizing on single technology evaluation from four aspects of description, demand, verification and feasibility. Item analysis.

3) The domestic technology maturity evaluation process follows DoD's assessment process, but compared to the US institutions, it lacks AD2 evaluation and TMP part is not emphasized.

In summary, the evaluation process in the United States is more standardized, emphasizing the evaluation of high-tech risk sources in weapon system development, focusing on the major risk only; the evaluation process in Europe is relatively simplified, and the lack of identifying critical technical phase, emphasizing evaluation for single technology element.

5. Conclusions

In this paper, through investigations and surveys on domestic standards in defense science and research industry, as well as comparative analysis on technology maturity evaluation related standards and specifications focusing on TRLs definitions and terms, assessment criteria and assessment process, some enlightenment and suggestions for the implementation of domestic TRLs related standards drafting and revisions has obtained, as the following.

(1) The standardization and institutionalization of technology maturity methods is the basis for rapid widely adopted in the world. The top-level regulations are programmatic documents that standardize and guide the implementing technology maturity evaluation that in favor of defense science and technology research management. In the process of implementing technology maturity evaluation in the international organization from the United States and Europe, the top-level regulations specify evaluation timing, evaluation requirements, and application of evaluation results. Meanwhile, the standards provides the guidelines for TRLs definitions, assessment criteria, assessment process, etc., which is a supplementary for regulations.

(2) Carrying out continuous theoretical research and revision of standards and specifications is the guarantee of supporting technology maturity evaluation in defense acquisition. In the past several years, the United States and Europe have continuously revised and improved top-level regulations and standards related to technology maturity evaluation, in order to better play the role of technology maturity in defense science and technology evaluation. Ongoing research on theories and methods related to technology maturity is the basis for formulating and revising the technical maturity evaluation standards of various countries, and it is a guarantee to support efficient evaluation and ensure the evaluation effect.

(3) Regular training and computer-aided platform are important to implement technology maturity evaluation management. Through regular training in Defense Acquisition University (DAU) from the United States and ECSS from Europe, engineers and managers can better understand the evaluation method, including the TRL definitions, assessment process, etc. In the other hand, some evaluation and management tools, such as TRLs calculator by AFRL, TPMM software by US Army, and AD2 software by NASA, have been developed to solidify the assessment process and standards, and helped to improve the evaluation efficiency.

In summary, the technology maturity evaluation has become a regular method and tool for defense science and technology management all over the world. In the past ten years, domestic methodology related to technology maturity evaluation has been developed and applied in many areas through theoretical research, pilot evaluation, standard drafting and regulation research. With the release of domestic standards and guidances since 2012, technology maturity evaluation played an important role in decision-making management and improved the efficiency of defense science and technology management. However, we also face with some challenges from the standards, such as insufficient guidance for different industries, mismatch with engineering practice in TRLs definitions and assessment criteria, etc., hence, there is urgent need to revise the current domestic standards.

6. Contact Author Email Address

mailto: iace_chwy@163.com

7. Copyright Statement

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