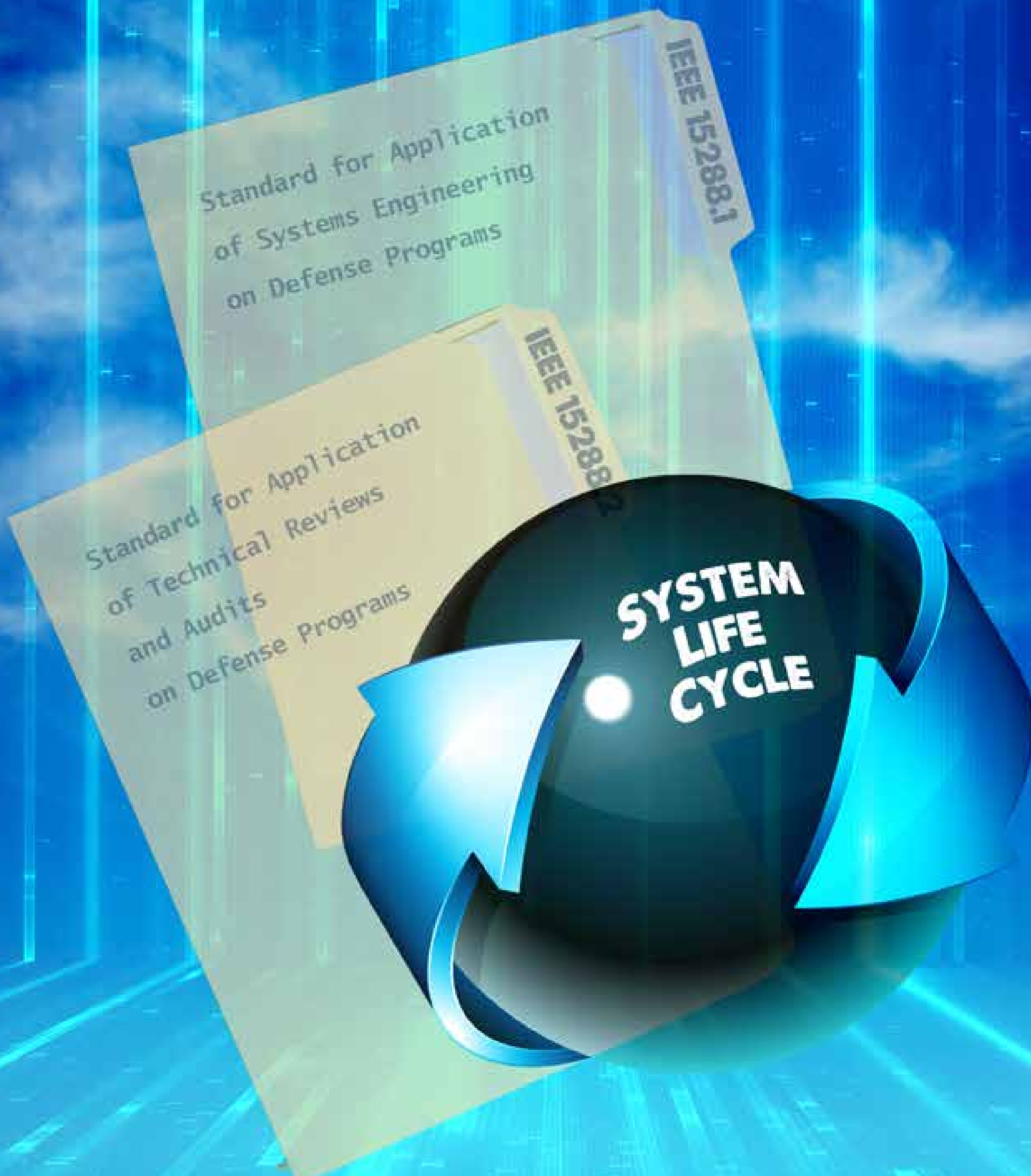
Extending Industry Standards to Meet the Systems Engineering Needs of Defense Programs

By Garry Roedler, Brian Shaw, and David Davis



Acquisition reform in the 1990s left gaps in the standardization of systems engineering (SE) for defense programs. However, over the past few years, DoD has defined the gaps and taken action to work collaboratively with industry, academia, and the standards development organizations (SDOs) to deal with the gaps. As a result, two new industry consensus standards—IEEE 15288.1, "Standard for Application of Systems Engineering on Defense Programs," and IEEE 15288.2, "Standard for Application of Technical Reviews and Audits on Defense Programs"—have been developed to address the defense-specific needs for SE processes and technical reviews and audits (TR&As), while leveraging the industry knowledge base.

Background and Objectives

Engineering standards can be used for bringing consistency to processes and the life-cycle management of systems or products. Processes are standardized to implement standard practices that facilitate engineering effectiveness based on best practices derived from academic/applied research and lessons learned. Stephen Welby, Deputy Assistant Secretary of Defense for Systems Engineering, DASD(SE), and chairman of the Defense Standardization Council (DSC), clearly expressed the current DoD position when he wrote, "Technical standards provide the corporate process memory needed for a disciplined systems engineering approach and help ensure that the government and its contractors understand the critical processes and practices necessary to take a system from design to production, and through sustainment."[1]

The 1994 acquisition reform drove the reduction of military standards to a fraction of what was in place in the 1980s.[2] As acquisition reform was implemented, many gaps were identified that needed to be addressed. The gaps include the absence of requirements and the conversion of previous standards into handbooks whose format prohibits use as contractual compliance documents. Industry responded to acquisition reform by establishing internal practices, often based on the military standards that have been in use for years. The non-governmental standards organizations also reacted by either converting canceled military standards into non-governmental standards or by developing new industry consensus standards to fill critical voids. These newer types of documents became part of the basis for contractors' "total system performance" responsibility in this new era of government contracting where buzzwords like "faster, better, cheaper" became the mantra for other buzzwords like "doing more for less." Whatever the mantra or buzzword, this new era of acquisition was characterized by tight budgets and high levels of competition yet a continued need for industry to meet the government's requirements.

In the military space sector, the 1990s brought several dramatic launch failures (including Titan IV[3] and Delta III[4]) that resulted in an unanticipated waste of millions of dollars. One of the attributes of a launch failure is that not only is the launch vehicle lost in such a mishap, but so too is the payload comprising a very expensive and potentially mission-critical satellite. Even when the launch goes well, there are great risks for the space vehicle. Once a satellite is off the ground, it is largely unmaintainable. On-orbit failures can transform a satellite performing a critical mission into a useless piece of space junk, and preventing that is quite a feat considering that a satellite operational life may be 15 years in a rather hostile environment.

When space system failures happen, extensive investigations are undertaken to determine the root cause of the failure and identify countermeasures to ensure future success. These investigations addressed failure to implement critical engineering standards as contributory to the launch mishaps.

The Air Force Space and Missile Systems Center (SMC), the primary military space acqusition agency, bucked the trend and, in 2003, reinstituted a collection of high-value standards as a routine part of space system acquisitions. The back-to-basics approach at SMC included not just reviving a formal standards program but focusing on effective implementation of basic SE practices that can contribute to mission assurance and mission success. Ultimately, SMC put into place a set of 68 standards and the infrastructure associated with maintaining and implementing the standards. These standards were selected considering prior failures and known best practices to ensure achievement of system/mission needs. SMC included all types of standards: interfaces, design criteria, manufacturing processes, standard practices, and test methods. It also used the best available source of standard: military, industry consensus, and locally written standards when justified.

SMC used four core principles of standards development, selection, and use. Specifically, the standards needed to (1) be the right size, not a gold standard but what is really needed to accomplish the objective; (2) be tailorable for scalability to individual acquisitions and to better describe the government's intent; (3) be clearly written, with requirements balanced against associated cost and schedule issues; and (4) use technical practices that have been optimized based on data and proven experience. Unlike some of the prior generation of standards, these newer standards focused on what needs to be done rather than specific how-to mandates. This addressed interest expressed by industry to be allowed to propose cost-effective alternatives that may be more efficient and lower cost yet meet the same mission need and design criteria.

In the SMC collection of standards were two locally developed standards: SMC-S-001, "Systems Engineering Requirements and Products," and SMC-S-021, "Technical Reviews and Audits for Systems, Equipment and Computer Software." These were initially released in 2008 and 2009 and used on SMC contracts.

Concurrent with SMC's standards revival was industry's recognition that SE capabilities had been lost in the cancellation of key standards such as MIL-STD-499, "System Engineering Management," and MIL-STD-1521, "Technical Reviews and Audits for Systems, Equipments, and Computer Software."

Notable in the effort to address SE needs was the National Defense Industrial Association's (NDIA's) Systems Engineering Division, which hosts an annual conference to foster government-industry technical interchange on this topic. These meetings crystalized several thoughts: all DoD services share the same SE need and have experienced similar degradation of SE capabilities/services, and both government and industry see value in standardization. Government benefits from having clearly stated requirements in a contractually compliant form, and industry benefits from having clearly stated requirements that they can bid against to ensure bidding sufficient resources to fulfill those requirements.

In 2011, DSC initiated a joint services activity, led by DASD(SE), to revive several key canceled standards, including SE, TR&As, manufacturing management, and configuration management. The goal of the gap analysis phase was fourfold:

- Identify need. Collect service inputs on problems resulting from the lack of specifications and standards.
- Determine gaps, for example, existence of industry SE standards that are not amenable for use on contracts and lack of industry technical review standards.
- Analyze alternative approaches.
- Recommend a way ahead to the DSC. The way-ahead recommendation was to revive and reinstate standards for SE and TR&As using the SMC standards as a starting point.

DSC's direction was to collaborate with industry and work toward industry consensus standards that would be suitable for use by DoD on contracts in these areas.

In 2012, a source selection phase was initiated for the joint service team to clarify its specific requirements for such a standard and to explore potential non-governmental SDOs for partnership. To support the government's assessment of capability and approach to developing standards suitable for use by DoD on contracts in these specific technical areas, the team held informal discussions and issued a formal request for information to the SDOs, NDIA, and Aerospace Industries Association. Key factors discussed included current involvement in the technical domain area, ability to coordinate a well-rounded and representative government-industry team, internal SDO process continuity from standards development through distribution and maintenance, and proven experience in developing effective standards whose use can be contractually compliant. For the SE and TR&A effort, the IEEE Computer Society (IEEE-CS) was selected on the basis of its proven history with the development and maintenance of ISO/IEC/IEEE 15288, "Systems and Software Engineering—System Life Cycle Processes," and harmonization of the SE document suite with related standards and DoD guidance.

Approach and Scope of the Standardization

In 2013, IEEE formed the Joint Working Group for DoD Systems Engineering Standardization under the IEEE-CS. The working group was chartered to address two separate, but related projects, the SE standard, IEEE 15288.1, and the TR&A standard, IEEE 15288.2. The specific goals of these standards were to meet both the government and industry needs by being

- tailorable for different domains and contracting environments,
- consistent with the DoD technical and contracting approach, and
- conformant with established, overarching industry process standards and practices.

The working group's leadership comprised an industry chairperson, a government vice-chair, a secretary, and editors for each of the documents. Membership comprised members of DoD (7 organizations, including each service branch), defense contractors (15 organizations representing about 80 percent of U.S. defense spending), industry associations (6 organizations), and academia from the DoD Systems Engineering Research Center. As the projects progressed, the representatives from each organization reached back to their respective organizations to capitalize on the breadth of requirements needs and experience during document development and formal balloting. Initially, it was conceived that each project would be developed separately, but in practice, the members of each project overlapped almost entirely, so the working group worked both projects simultaneously.

Since SE has interfaces with other standards being developed under DSC's auspices, specific efforts were made to establish relationships with the working groups chartered under other SDOs, like SAE International's G-33, which is responsible for EIA-649-1, "Configuration Management Requirements for Defense Contracts," and SAE G-23, which is responsible for SAE AS6500, "Manufacturing Management."

The working group operated in accordance with the American National Standards Institute–accredited IEEE standards development process. The standards development process ensures an open consensus process in which all interested stakeholders can participate. This facilitates open discussion and resolution of concerns, issues, and varied approaches with documented decision making. The balloting process was formally conducted by IEEE at both the working group and IEEE sponsor levels. IEEE also provided editorial and legal review prior to publication.

IEEE 15288.1 provides a standard with the defense-specific language and terminology to ensure the correct application of acquirer-supplier requirements for defense programs. The scope of the standard is focused on the system life-cycle processes, activities, and tasks of ISO/IEC/IEEE 15288 for use on any defense system and across the entire system life cycle. This standard was authored as an addendum that implements ISO/IEC/IEEE 15288 for use by DoD organizations and other defense agencies in acquiring systems or SE support. As an addendum rather than a standalone standard, IEEE 15288.1 does not repeat processes and information in 15288. IEEE 15288.1 used SMC-S-001 as a government requirements basis and incorporated best practices from the leading government and industry sources, including the *Defense Acquisition Guidebook*, International Council on Systems Engineering (INCOSE) *Systems Engineering Handbook* (SEH), *Guide to the Systems Engineering Body of Knowledge* (SEBoK), and others.

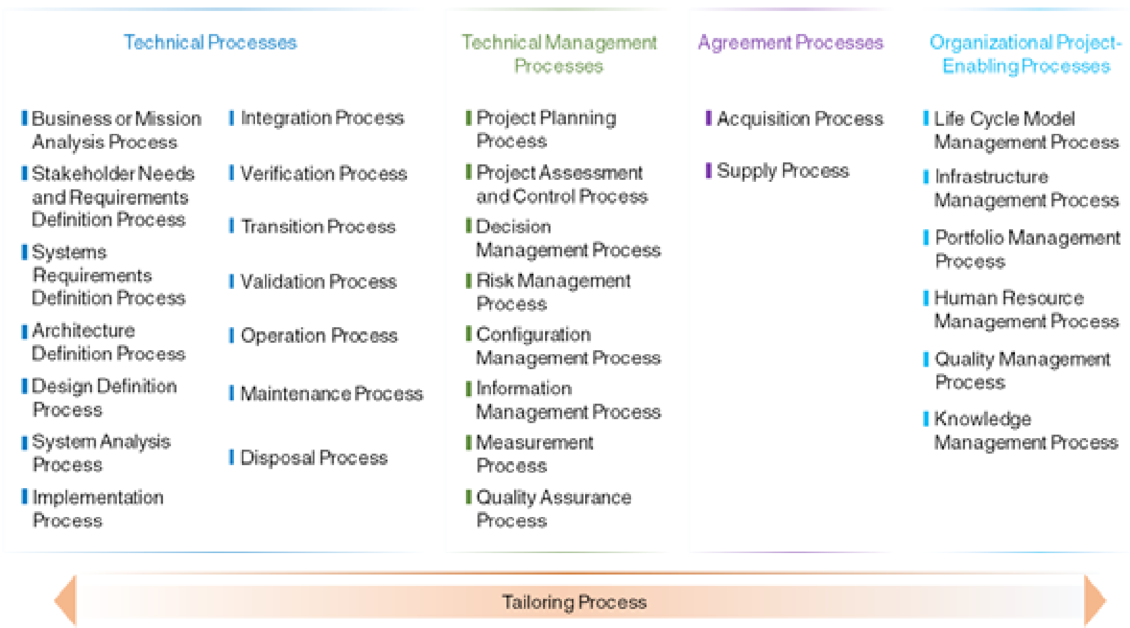
IEEE 15288.2 establishes the requirements for TR&As to be performed throughout the acquisition life cycle for DoD and other defense agencies. Since no current military or industry standard exists for TR&As, this standard amplifies ISO/IEC/IEEE 15288, Clause 6.3.2.3.a for selection, negotiation, agreement, and performance of the necessary TR&As, while allowing tailoring flexibility for the variety of acquisition situations and environments when the technical reviews or audits are conducted. IEEE 15288.2 elaborates on the activities and tasks related to TR&As, including defense-specific language and terminology, the criteria for reviews and audits, expected/required outcomes and products of reviews and audits, as well as a limited amount of essential explanation and guidance.

The development of the two standards spanned approximately 1 year of effort, including the authoring/review and balloting in preparation for final approval and release. Both projects executed by the IEEE Joint Working Group for DoD Systems Engineering Standardization resulted in standards that express a government-industry consensus and are suitable for use on DoD contracts, as did the related SAE efforts.

Summary of the Content

The base document used for this standardization effort is ISO/IEC/IEEE 15288, which provides a common, comprehensive, and integrated framework for describing and managing the full life cycle of systems. It is applicable to all size organizations, most domains, and any life-cycle model. This standard defines a set of processes, concepts, and associated terminology that can be applied at any level in the structure of a system across its life cycle. The processes are organized into four groups: technical processes, technical management processes, agreement processes, and organizational project-enabling processes. Figure 1 identifies the processes within each group.

Figure 1. Process Structure in ISO/IEC/IEEE 15288:2015



Adopted from ISO/IEC/IEEE 15288: 2015.

Processes in 15288 cover the full life cycle and are intended to be applied as needed and tailored for the specific program characteristics and needs. They are not intended to applied in a one-size-fits-all, sequential, and linear approach. They focus on "what" is expected, not "how" to achieve it, thus allowing for a variety of methods, techniques, and tools. The expectation for appropriate tailoring is reinforced by the processes in each of the four process groups:

- *Technical processes*. The 14 processes in this group "are used to define the requirements for a system, to transform the requirements into an effective product, to permit consistent reproduction of the product where necessary, to use the product to provide the required services, to sustain the provision of those services and to dispose of the product" and any waste during its life cycle or when it is retired from service.
- *Technical management processes*. The 8 processes in this group "are used to establish and evolve plans, to execute the plans, to assess actual achievement and progress against the plans and to control execution" throughout the life cycle.

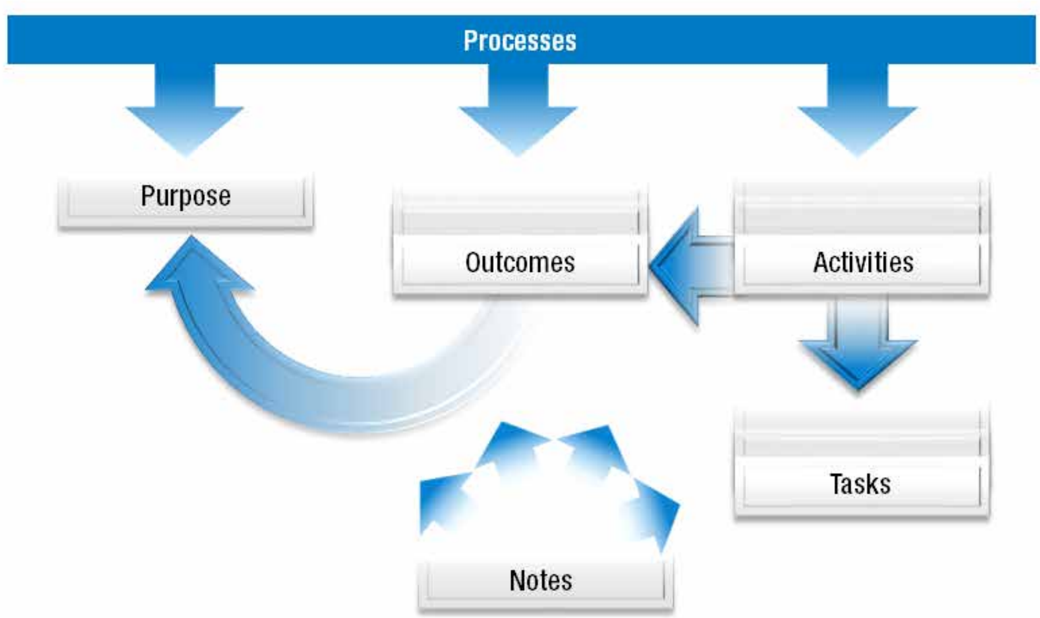
- *Agreement processes*. The 2 processes in this group define the expected interactions and parameters of an acquisition and supply relationship and "the activities necessary to establish an agreement between two organizations."
- *Organizational project-enabling processes*. The 6 processes in this group "ensure the organization's capability to acquire and supply products or services through the initiation, support and control of projects. They provide resources and infrastructure necessary to support projects." These processes focus on the interfaces with the organization that are necessary to enable to successful execution of projects.

As shown in Figure 2, each of the 15288 processes has five elements:

- *Purpose* states the overall objective of performing the process.
- *Outcomes* describe the most significant observable results of the successful achievement of the purpose.
- *Activities* provide the first level of actions to perform and generally provide a "binning" of the related lower-level elements called tasks.
- *Tasks* are performed to achieve the intent of the activities.
- *Notes* can be associated with any of the process elements to provide better understanding of expectations, relevant considerations, and other information to aid the planning and execution of the processes.

All of the processes in ISO/IEC/IEEE 15288 were determined to be relevant for application to defense programs. After gap analysis, the working group determined that additional processes were not necessary to cover the breadth of SE.

Figure 2. ISO/IEC/IEEE 15288:2015 Process Elements



IEEE 15288.1

IEEE 15288.1 is an addendum to the base standard providing tailoring and additional requirements to address defense application of the standard. Because IEEE 15288.1 was developed as an addendum to ISO/IEC/IEEE 15288, it includes only modifications, additions, or deletions to the process elements for each process. The structure of IEEE 15288.1 is the same as the structure of 15288, but does not repeat the base process information, since the two standards are intended to be used together. For each clause and process, IEEE 15288.1 identifies what information from the base standard applies, what does not apply, and what is changed or new. In addition to the changes to the process elements, IEEE 15288.1 also adds the expected outputs for each process. The outputs are stated in a way that attempts to avoid any specific structure, format, or technique. The requirements are kept to the "what" level rather than the "how" level.

IEEE 15288.2

IEEE 15288.2 is linked to the base standard through the planning process and the assessment and control process. However, the conduct of the processes also will invoke many other technical management processes, such as risk management and measurement. This standard is developed as a full content standard for TR&As. It is organized with one clause that provides an overview of TR&As and three clauses that provide the requirements and guidance for planning and executing TR&As:

- Clause 4 provides an overview of the reviews and their application in the life cycle, including the roles that are involved. Although this clause contains no requirements, it has useful information about planning the application of the reviews and audits.
- Clause 5 provides the requirements for each technical review and audit. The requirements include the purpose (why perform this technical review or audit); description (what system properties does the review or audit address); timing (when in the system life cycle or contract performance does the review or audit occur); and entry criteria, content, and exit criteria.
- Clause 6 provides the detailed criteria to be addressed in each review and audit. Specifically, for each review and audit, this clause contains four tables, which address (1) acceptability criteria, (2) preparation actions, (3) conduct elements, and (4) closure actions. These detailed criteria are expected to be tailored for the specific program.
- Clause 7 provides guidance for each TR&A for applying the detailed criteria identified in Clause 6. This clause does not contain normative (required) tasks, but does identify lessons learned or best practice information that should be considered.

IEEE 15288.2 includes the reviews and audits that the working group determined to be the most widely applicable to most defense programs. A specific type of program may find additional reviews useful and should consider them during planning. The standard's annexes identify and describe a few additional reviews. The intent is for the program to tailor the reviews and audits, determining which TR&As to include to best meet the program's needs and mitigate the program's risks.

Expected Usage in Requests for Proposals and Contracts

The intent of the standards is to provide a tool for the government to use to establish the acquirer-supplier agreement in a contract.[5,6] Specifically, the government intends to cite these standards in requests for proposals (RFPs) and evaluate contractor proposals for compliance, including the proposed execution of the technical practices, planned outputs from the engineering efforts, and the resourcing for those activities.

The government intends the standards to be appropriately tailored, as indicated in the standards. Tailoring by the government as part of the RFP development process is an established best practice to ensure that the government's requirements are focused on the specific domain and system being addressed in the procurement. When standards are specified in an RFP for contractual compliance, they will be identified in the statement of work, including initial government tailoring.

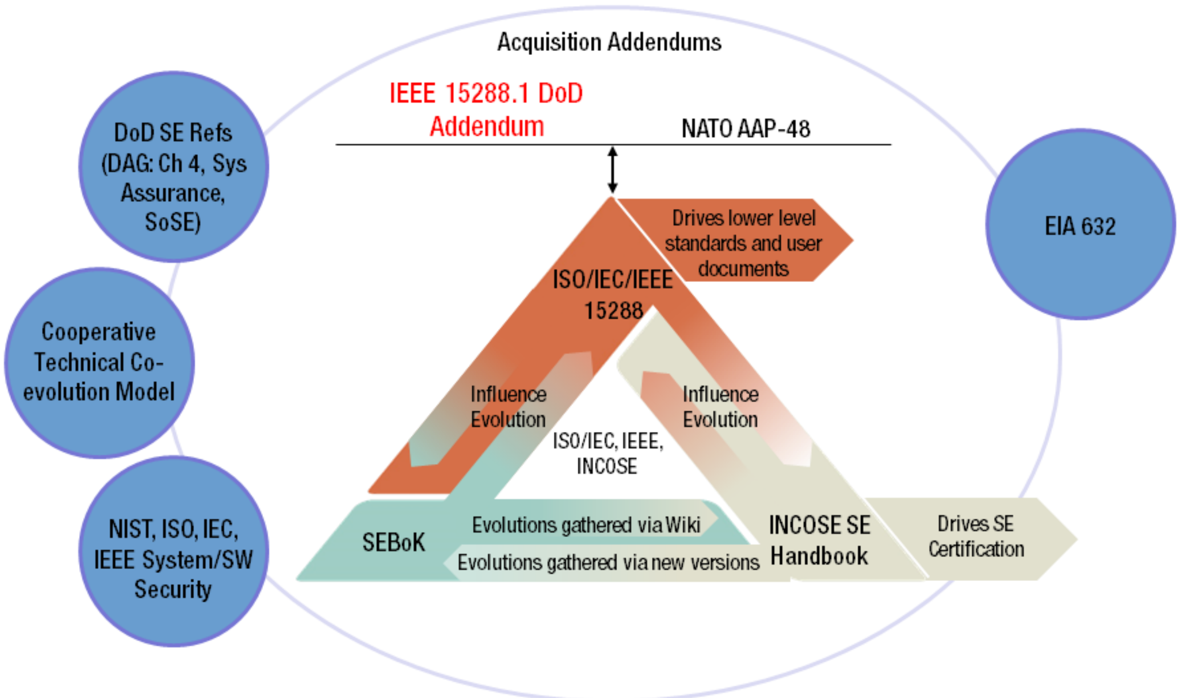
Further tailoring by industry as part of the proposal submission is also anticipated as a critical aspect of establishing an acquirer-supplier agreement.[7] All proposed tailoring will need to include the rationale and evidence that it will add value. Such tailoring may further refine the government's initial tailoring to address additional insights into the nature/needs of the specific procurement, or it may represent an alternative approach that meets the intent of the specified standard and represents a best-value alternative that will benefit the acquisition.[8]

A collaborative DoD and industry team are working on implementation guidance for the two standards. The team, led by the NDIA's Systems Engineering Division, plans to develop recommended RFP language, tailoring guidance based on program characteristics, and conformance guidance.

Relationship to Other Key SE Resources

The completion of this effort falls in line with other industry efforts to harmonize SE standards and guidance. The industry effort started with the initial publication of ISO/IEC/IEEE 15288, which quickly gained adoption and usage. Over the past several years, there has been a cooperative evolution of the key technical resources, including those shown in Figure 3.

Figure 3. Alignment of Key SE Resources—An Example for Cooperative Technical Coevolution



As this evolution has progressed, there has been voluntary cooperation by a number of industry associations and SDOs. For example, the developers of the SEBoK used ISO/IEC/IEEE 15288 and the INCOSE SEH as primary source documents. In turn, information included in the published SEBoK was later adopted in the recent revisions of ISO/IEC/IEEE 15288 and the INCOSE SEH. As these have evolved together, addendums to 15288 have been developed for application in specific domains, such as the NATO addendum AAP-48. In addition, a large number of lower level process elaboration standards have expanded on the processes in 15288 and are fully harmonized with the higher level standard. Finally, the 15288 process framework has been adopted in other engineering resources for security, system-of-systems, and testing.

IEEE 15288.1 and IEEE 15288.2 fill recognized gaps. For example, IEEE 15288.1 fills the need to have a domain-specific addendum for application of the system life-cycle processes for defense programs, similar to what the NATO addendum does for NATO programs. IEEE 15288.2 fills the need for a standard for TR&As, which has not existed for the past decade. And by ensuring it links to the system life-cycle processes, it ensures compatibility with the other standards for concurrent usage.

In developing these two new standards, the working group maintained close collaboration with the groups working on EIA-649-1 and AS6500. The chairs from both working groups were included in ongoing discussions and invited to participate as part of the SE working group to ensure consistency in concepts, terminology, and requirements. As a result, the configuration management process requirements and links to reviews and audits are consistent and aligned in EIA-649-1, IEEE 15288.1, and IEEE 15288.2. Similar consistency has been maintained with AS6500.

Conclusion

The development of IEEE 15288.1 and IEEE 15288.2 fills gaps that have been in place for nearly two decades. These standardization projects are a good example of collaboration between DoD, industry, academia, and the SDOs to fill the void, while leveraging the industry knowledge base. In doing this work, the team has continued to build toward the evolving harmonization of SE resources that has been seen in the past several years. The next step is to effectively apply the two standards.

Additional Reading

Systems Engineering

ISO/IEC/IEEE 15288:2015, "Systems and Software Engineering—System Life Cycle Processes."

ISO/IEC/IEEE 15289:2011, "Systems and Software Engineering—Content of Life-Cycle Information Products (Documentation)."

SMC-S-001, "Systems Engineering Requirements and Products," July 2013.

DoD Instruction (DoDI) 5000.02, "Operation of the Defense Acquisition System," January 2015.

NATO AAP-48, "NATO System Life Cycle Processes, July 2012 (Addendum Standard to 15288; focused on NATO Armament Systems)."

Defense Acquisition Guidebook, Chapter 4, "Systems Engineering," 2013.

INCOSE, *Systems Engineering Handbook*, V4.0.

INCOSE, *Guide to the Systems Engineering Body of Knowledge*.

EIA-632a, "Engineering of a System" (draft revision).

ISO/IEC TR 24748-1:2009, "Guide for Life Cycle Management."

ISO/IEC TR 24748-2:2011, "Guide to the Application of ISO/IEC 15288 (System Life Cycle Processes)."

ISO/IEC/IEEE 24748-4, "Systems and Software Engineering—Life Cycle Management—Part 4: Systems Engineering Planning" (draft).

Technical Reviews and Audits

Naval Sea Systems Command (NAVSEA), "Instruction and Policy 5000-009 for Systems Engineering Technical Reviews."

ISO/IEC/IEEE 15288:2015, "Systems and Software Engineering—System Life Cycle Processes."

DoDI 5000.02, "Operation of the Defense Acquisition System," January 2015.

SMC-S-021, "Technical Reviews and Audits for Systems, Equipment and Computer Software," Volume 1, September 2009.

NAVSEAINST 5009.9, *Naval Systems Engineering Technical Review Handbook*, July 2009.

Naval Air Systems Command (NAVAIR), *Systems Engineering Technical Review Process Handbook* (initial release).

NAVAIRINST 4355.19E, "Systems Engineering Technical Review Process."

Defense Acquisition Guidebook, Chapter 4.

[1] Guest Editorial, *M&S Journal*, Vol. 8, No. 1 (Spring 2013), Modeling and Simulation Coordination Office, Alexandria, VA (http://www.dtic.mil/ndia/2013system/TH15992_Konwin.pdf, chart 3).

[2] See https://dap.dau.mil/policy/Documents/Policy/Acquistion%20Reform%20a%20Mandate%20for%20Change.pdf.

[3] See http://www.spaceflightnow.com/news/9912/02usafreport/index.html; http://www.spacedaily.com/news/titan-99a.html.

[4] See http://www.cnn.com/TECH/space/9808/27/rocket.blast2/; http://www.spacelaunchreport.com/delta3.html.

[5] Federal Acquisition Regulation, Subpart 11.1, Selecting and Developing Requirements Documents.

[6] Federal Acquisition Regulation, Subpart 11.2, Using and Maintaining Requirements Documents.

[7] Federal Acquisition Regulation, Subpart 11.103, Market Acceptance. (Section 11103 refers to "items." Items may include engineering services as specified by standards associated with hardware, software, and systems.)

[8] Federal Acquisition Regulation, Subpart 2.1, Definitions.

About the Authors

Garry Roedler is a fellow at Lockheed Martin Corporation. He is also an INCOSE fellow and has leadership roles in many technical organizations, including past chair of the INCOSE Corporate Advisory Board, member of the INCOSE Board of Directors, steering group member for NDIA's Systems Engineering Division, working group chair for the IEEE Joint Working Group for DoD Systems Engineering Standardization, project editor of ISO/IEC/IEEE 15288 and several other standards, and key editorial roles in the development of the SEBoK and the INCOSE SEH. This unique set of roles has enabled Mr. Roedler to influence the technical co-evolution and consistency of these key SE resources.

Brian Shaw is a senior project leader at The Aerospace Corporation, currently supporting the SMC Engineering Directorate. He has been involved in various aspects of standardization throughout his career, including basic/applied research and standards writing in both military and commercial settings and application of standards on government contracts.

David Davis is the chief system engineer at SMC. He is the visionary behind the reintroduction of standards as a key part of the technical baseline for space system acquisition. He is a recipient of the NDIA's Lt Gen Thomas R. Ferguson, Jr., Systems Engineering Excellence Award, recognizing his role as an acknowledged leader in both the development and application of standards.