A TAILORED SYSTEMS ENGINEERING FRAMEWORK

FOR SCIENCE AND TECHNOLOGY PROJECTS

THESIS

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Abstract

As government and industry becomes subject to a wider range of technology initiatives, science and technology (S&T) research project leadership recognizes the need to incorporate more systems engineering (SE) rigor into their projects. The objective of this research is to develop a tailorable systems engineering framework for S&T project planning, execution, assessment and transition. The key deliverable is an Excel-based tool instantiating the SE framework for a wide range of S&T projects in technology development organizations. It includes a report with tailored methods based on programmatic discriminants.

To develop this framework, a comprehensive understanding of SE principles is applied to several case studies across government and supporting industry-sponsored S&T activities. This research followed a six-step approach: (1) Literature Review; (2) Formulate Taxonomy; (3) Prepare Data Gathering Approach; (4) Review Case Studies; (5) Develop Tailorable SE Framework for Technology Development and Transition; and (6) Validate Framework.

The framework allows S&T project leaders and engineers to customize a recommended set of SE processes, methods and tools for their specific project type, size, maturity, budget, and integration level. Recommendations for SE methods are made at a summary level, with additional details available for desired activities. References to established SE documentation is also included for further investigation of appropriate SE techniques.

Dedication

To our families and friends

AFIT/GSE/ENV/09-M02

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We are also appreciative to the members of the Air Force Research Laboratory Systems Engineering Council and the Case Study points of contact for their candid feedback and recommendations that allowed this research to produce a framework that can provide benefit to the Air Force.

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I. Introduction

The Air Force Research Laboratory (AFRL) has a long history of developing advanced technologies that ultimately deliver effects to the battlefield, whether in preparation, planning, or combat force. As research and development (R&D) dollars become subject to a wider range of technology initiatives, AFRL leadership recognizes the need to incorporate more systems engineering (SE) rigor into their projects. This chapter addresses the objective, scope, and approach of a research effort to help AFRL implement tailored SE to Science and Technology (S&T) projects.

Research Objective

The objective of this research thesis project is to develop a tailorable systems engineering framework for science and technology development planning, project planning, execution, assessment and transition. It provides recommendations to validate or improve existing SE practices within AFRL. The key deliverable is an SE framework, which includes a thesis with tailored methods and tools based on user-selected program discriminants. If implemented, it will facilitate use of SE principles by technology developers, project or program managers, decision makers, scientists, and engineers.

Research Scope

The team established several guidelines to help focus the research and establish a useful yet manageable scope. First, the ultimate goal is to deliver a product that will actually be utilized by the sponsor organization. The most realistic opportunity for this to occur is to deliver a framework for tailoring SE activities – something that can assist S&T managers implement the appropriate level of SE rigor for their specific project. One of the biggest impediments of SE application by the S&T community is the mindset that "big SE doesn't apply to my specific project." The detail of the SE tailoring tool is reflective of the research team's desire to overcome this mental obstacle by providing an easily navigated map indicating appropriate levels of SE rigor for the current state of a project.

Next, the research focuses on the deliberate and thoughtful application of SE processes, methods and tools to the S&T community rather than the larger systems acquisition genre. S&T projects may not meet milestone reviews, might not get detailed requirements flowed down from an operational user, and may not even be intended for actual use as developed. Basic research projects don't require the same depth of architecture definition that is critical to major weapons system development programs, nor do they necessarily have the resources to establish a comprehensive SE regimen. However, early SE is critical for subsequent transition of S&T products, whether to a larger integration effort or to the field as an Advanced Concept Technology Demonstrator (ACTD). Limiting the recommendation for SE implementation to only those activities required to ensure smart transition down the road helps S&T projects deliver better products without all of the resource-consuming SE rigor demanded of larger system acquisition activities.

Finally, this report takes a comprehensive look at candidate SE processes, methods and tools available to S&T projects based on academic and practical research. The authors of the report possess a knowledge base of SE principles based on dedicated coursework in an accredited academic program and are guided by multiple doctoral-level SE experts. This provides a foundation of academic SE insight which is bolstered by additional research into DoD and industry SE practices. The comprehensive understanding of SE principles is then applied to several case studies within DoD and in commercial research and development activities. The across-the-board look at SE applications allows incorporation of best practices by organizations not constrained by established DoD processes and whose S&T successes are the lifeblood of future capabilities.

During the initial thesis project planning activities, AFRL stakeholders made several suggestions as to how to best improve the SE application within the organization. Most of those who provided input claimed that culture was the primary inhibitor of true SE success. Others raised the issue that the division of responsibility for SE between government and contract personnel was a significant issue. While these observations are by no means inaccurate or unimportant, they are not the primary focus of this research. Rather, the intent is for the thesis deliverables to make desired SE benefits more tailorable, efficient and attainable.

Approach

This research followed a six-step approach that will be described in more detail in Chapters II – IV. These steps are:

1. Review Literature (Chapter II)

The research team conducted an extensive literature review including Air Force policy, guidance, and best practices at all levels (DoD, Air Force, Air Force Material Command, and Air Force Research Laboratory). The team reviewed existing S&T project taxonomies and processes within AFRL, and conducted interviews with relevant stakeholders. The team also reviewed systems engineering community publications from commercial, academic, and professional sources. Comparisons were made with previous studies that analyzed the subject of systems engineering in an S&T environment, ensuring the overlap with prior efforts did not render this activity redundant. The goal of this phase was to develop a current knowledge base with regard to theory, policy, guidance, best practices and shortfalls of SE application within S&T organizations.

2. Formulate Taxonomy (Chapter III)

The research team synthesized existing taxonomies and processes in order to tailor relevant SE processes, methods and tools to a wide range of S&T projects. Logical groupings of SE activities were defined. The team standardized a reference frame for S&T projects at various levels of maturity, given existing project taxonomies. Every effort was made to accommodate and/or relate terms to existing taxonomies. The goal of this phase was to establish common, manageable definitions of AFRL S&T project types and SE principles.

3. Prepare Data Gathering Approach (Chapter III)

   The research defined information needs based on where a technology development effort fit within the taxonomy. Information needs were defined to support decision making based on project objectives. The team also identified commonly used tools to accomplish specific SE activities. The goal of this phase was to establish the SE taxonomy, define questions to be asked and information to be gathered during the case study investigations.

4. Review Case Studies/Examples (Chapter IV)

   The research team examined projects and case studies to report on successful application of SE methods and gaps in SE execution. The review included active and historic AFRL projects and commercial projects. The goal of this phase was to extract lessons learned from a broad cross-section of S&T projects and make direct application to improve the SE framework delivered to AFRL.

5. Develop Tailorable SE Framework for Technology Development and Transition (Chapter IV)

   The research team analyzed lessons learned and developed a tailorable approach for applying SE within an S&T organization. The lessons learned from the research and case studies provided the basis for recommended SE practices and strengthened the tailoring of SE processes, methods and tools within the S&T framework for a given project state. The goal of this phase was to provide a framework and guidance for interested parties to add SE value to future S&T projects.

6. Validate Framework (Chapter IV)

   This research obtained feedback from the stakeholders as to the applicability of the SE framework. Interested and knowledgeable parties conducted an independent evaluation of the framework by evaluating typical and random sets of programmatic discriminants and incorporating recommended changes. The goal of this phase was to deliver a tailorable SE framework for S&T development planning, project planning, execution, assessment and transition.

The specific research is detailed in the remainder of this report. The background of SE within AFRL as well as a thorough literature review is described in Chapter II. Chapter III defines the research methodology, including descriptions of the taxonomies and information needs, as well as the process for conducting the case studies and validation of the SE framework. Relevant case study reviews and application of the extracted lessons learned to the tailorable SE framework development and validation comprise Chapter IV. Chapter V discusses the final results and recommendations of the research.

II. Background

This chapter addresses the resources utilized by the team for the information gathering phase, to include previous efforts to study and improve early application of SE, published policies, and documents from DoD, professional and academic communities. The information provides a baseline as to what has been done, and opens questions as to what more could be done. The SE history within AFRL, their current practices, and the obstacles to successful SE implementation within AFRL all provide the impetus for the SE tailoring framework developed by this thesis.

SE History within AFRL

Integrated Process and Project Development (IPPD) is a structured SE process including management principles, design philosophy, methodology, and tools which was formally instituted within AFRL in 2000 [IPPD, 2002: iv]. A primary assertion of the IPPD document with respect to SE is "The finished dish might be new, but the ingredients have been on the store shelves all along" [IPPD, 2002: 2]. IPPD aims to increase the amount of integration and SE activity by focusing on requirements, exit criteria, technology alternatives, and decision analysis. The IPPD approach proved effective in industry and is also adaptable to S&T to provide a map to implement SE methods for development projects.

Two significant reviews of SE application within AFRL lay out prior successes and opportunities for improvements that are being realized today. In 2004, the Air Force Institute of Technology's report on "Technology Transition and Program Formulation in

AFRL" called for "integration of technologies between technical directorates and the need for a firm grasp on system engineering principles." The two initial recommendations from this report are: 1) improve the application of SE principles, and 2) change the culture at AFRL [Coglitore et al, 2004: 2]. Following the implementation of IPPD, General Dynamics produced the Transformational Activities in Systems Engineering (TASE) Report to evaluate SE practices, to include IPPD implementation and effectiveness, for AFRL/XP in May 2007. One of the recommendations was, "AFRL should use the Defense Acquisition Guidebook (Chapter 4) as a framework for improving its systems engineering guidance because it is complete from a process viewpoint and is supported by DoD" [TASE, 2006: 1].

Current AFRL SE Practices

Subsequent to the TASE report, AFRL implemented two active governing instructions for SE policy. AFRL Instruction 61-104, "Science and Technology Systems Engineering" provides direction to ensure that SE is implemented on all S&T programs, although the application of SE to basic research programs is optional to the director of each technology directorate and the Air Force Office of Scientific Research (AFOSR) [S&T SE, 2008]. The instruction states that the level of SE effort is to be tailored to the needs of the individual S&T activity and customer expectations, and provides eight SE key questions to assess programs. The instruction also evaluates the 16 Defense Acquisition Guidebook (DAG) processes (8 Technical Processes, 8 Technical Management Processes) specific to the S&T activities, by re-writing the DAG processes in AFRL language and stating the importance of each [DAG, 2004]. This research took the importance of tailoring and addressing all 16 DAG processes into account. AFRL Instruction 61-202, "AFRL Laboratory Management Review (LMR) Process" provides a logical approach for laboratory reviews, to include an extensive listing of questions to assess each area of a project (technical, financial, schedule, contracting, deliverables, manning, and testing) [LMR, 2005]. These current practices introduce SE at the conceptual level but do not proscribe detailed or tailored SE regimens for all S&T projects.

A major AFRL initiative started in 2006 is the use of Focused Long-Term Challenges (FLTCs) to increase the S&T integration level across AFRL's Technology Directorates. S&T project integration across AFRL directorates is required to meet capability objectives established by combatant, operational, and development commands. The integration challenge is well-known to AFRL, as several studies, initiatives and policies (including the TASE Report, an AFIT research effort, and AFRLI 61-104) demanded stronger integration efforts in order to transition S&T project successes. The FLTC initiative organizes the majority of AFRL projects into one of eight Challenge categories, then further subdivides them into Problems, Capability Concepts, Products, and Programs. FLTCs are designed to produce integrated technology challenge baselines, taxonomies, and roadmaps to show how groups of separately managed products will deliver integrated capabilities [FLTC Briefing, 2006]. In Fall 2008, the FLTCs were evaluated by an Independent Review Team (IRT) headed by the Director of the Air Force's Center for Systems Engineering. An interview with the Director provided several recommendations about good project case study candidates. Some concerns were raised about FLTC's cross-directorate integration success, including lack of demonstrations at the integrated systems level, lack of structure and content in FLTC roadmaps, and disconnects in funding control between the Technology Directorates and FLTC managers [Mooney, 2008]. The IRT's final report executive summary from August 2008 stated,

> "the FLTC process was making some progress in tearing down … directorate stovepipes. Several testimonies from FLTC Team Leads illustrated how new relationships were formed among directorates only as a result of the FLTC construct. However, the IRT found that cross-directorate focus of the FLTCs was reduced by organizational structure challenges" [IRT, 2008: 3].

This assessment, along with the lack of clear definitions of each FLTC integration level, led the thesis team to consider the intent of the FLTCs, rather than the specific FLTC structure as a way to represent the desired integration level of a project for tailoring purposes.

AFRL also seeks to improve SE application across all of its directorates under the guidance of the Systems Engineering Council (SEC), which is comprised of senior engineers from every AFRL Technology Directorate. At the 12 August 2008 SEC Face to Face meeting, the head of the Council stated that the SEC's job was to tailor SE and articulate what that tailoring means in order to affect a culture shift at AFRL. He also said that "SE is not just the things you do at the beginning of a program to make your job easier … it's a mindset" [SEC Meeting, 2008]. These comments reinforced the need for a tailoring framework to make SE activities more accessible to research scientists and engineers. The SEC also provided guidance on the types of discriminators to be used in the project taxonomy, the approach to gathering case study candidates, and a recommendation to perform some validation on the final framework.

Discussions with AFRL/XP's policy staff provided additional insight on AFRL's strategic objectives, project structures, and SE policies. AFRL currently places emphasis on three Core Processes to differentiate management practices between long-term research (CP-1), Program Office transition projects (CP-2), and projects intended to transition urgent warfighter needs directly to operations (CP-3) [ERP CP2, 2008; ERP CP3, 2008]. These discussions also further explained how AFRL implements FLTCs as a project management and integration structure. Concern was raised over some technology managers erroneously reporting Technology Readiness Level (TRL) status, so a recommendation was made to not use it as a project discriminant for this project; however, the team found TRLs to be the best measure of technology maturity on S&T projects and chose to use them as a discriminant in the SE Framework. Finally, the XP staff provided several recommendations for good case study projects to evaluate in this research project [XP Meeting, 2008].

Recognizing the need to identify the criteria for transitioning a product, "The Manager's Guide to Technology Transition in an Evolutionary Acquisition Environment," was released in January 2003. Transitioning refers to a product being usable, producible, reliable, and affordable [Guide to TT, 2003]. The Guide identifies the usability criteria as nine distinct Technology Readiness Levels to assess technology maturity. The remaining criteria (producible, reliable, and affordable) are identified as five distinct Engineering and Manufacturing Readiness Levels (EMRLs or MRLs) (Table 1).

Table 1: TRL and EMRL Definitions and Mapping

Technology Readiness Level (TRL)	**Engineering Manufacturing Readiness Level (EMRL)**
1. Basic principles observed and reported.	Too Early
2. Technology concept and/or application formulated.	Too Early
3. Analytical and experimental critical function and/or characteristic proof of concept.	Too Early
4. Component and/or breadboard validation in laboratory environment.	1. System, component, or item validation in laboratory environment or initial relevant engineering application or breadboard, brass board development
5. Component and/or breadboard validation in relevant environment.	1. System, component, or item validation in laboratory environment or initial relevant engineering application or breadboard, brass board development
6. System/subsystem model or prototype demonstration in a relevant environment.	2. System or components in prototype demonstration beyond breadboard, brass board development.
7. System prototype demonstration in an operational environment.	3. System, component, or item in advanced development. Ready for low-rate initial production.
8. Actual system completed and qualified through test and demonstration.	4. Similar system, component, or item previously produced or in production. System, component, or item in low-rate initial production. Ready for full-rate production.
9. Actual system proven through successful mission operations.	5. Identical system, component, or item previously produced or in production. System, component, or item in full-rate production.
Source: Defense Acquisition Guidebook, Ch. 10.5.2, Technology Maturity and Technology Readiness Assessments	Source: Office of the Undersecretary of Defense, (AT&L), "Manager's Guide to Technology Transition in an Evolutionary Acquisition Environment", Version 1.0, January 31, 2003, Pg 2-22

The level of S&T project concept and technical maturity has a direct link to the budget. The DoD Financial Management Regulation Volume 2B, Chapter 5, July 2008, defines seven budget activities, to include: Basic Research, Applied Research, Advanced Technology Development (ATD), Advanced Component Development and Prototypes (ACD&P), System Development and Demonstration (SDD), RDT&E Management Support, and Operational System Development [Finance Management, 2008]. These activities serve as the basic structure for the various types of development project funding and are strictly controlled and monitored. The DoD research community (including AFRL) most commonly uses the 6.1 (basic research), 6.2 (applied research), and 6.3 (ATD) budget activity codes for funding S&T projects.

Obstacles to SE Success

While the recommendations, guidance and policies for increased SE and integration are in place, SE has not yet flourished within AFRL's working levels. Some project managers within AFRL resist this initiative, claiming that SE activities were developed for major acquisition programs and will "stifle the creativity" required for S&T projects. Others decry the "burden" on time and fiscal resources of implementing a comprehensive SE program for relatively "small" laboratory efforts. There exists a perception of projects being constrained by bureaucratic boundaries, whether organizational, funding type, or transition path. For project leaders in a "technology push" paradigm, performing systems engineering with only "soft requirements and changing customers" can appear to be a waste of time and money [TASE, 2006: 29].

A primary obstacle to proper implementation of SE within AFRL is cultural [Coglitore et al, 2004: 25]. The other major impediment to AFRL's comprehensive adoption of SE is the lack of "formal, specialized tools supporting systems engineering sub-disciplines" [TASE, 2006: 29]. AFRL's Materials and Manufacturing Directorate (AFRL/RX) recognized the tie between culture and tools and requested AFIT investigate how to encourage the use of SE processes, methods and tools within the directorate. The research identified that one of the cultural impediments to embracing SE was the overwhelming amount of recommended activity in typical SE documentation. After consulting with a senior systems engineer from AFRL/RX, the team determined that a tool or framework could be developed to tailor the large amount of generic SE practices to specific S&T projects at various levels of size and maturity, mitigating some of the cultural arguments against SE. Additionally, a tool could simplify the complex SE universe for those who desire to use SE but don't know where to start for their project, allowing SE implementation more pervasively within the labs. Based on direction from the SE Council, the delivered SE tailoring framework is intended for ubiquitous use by all of AFRL, not just one directorate. [SEC Meeting, 2008].

SE Policies/Directives and Best Practices

To provide a comprehensive SE framework, the research team needed to clearly understand the breadth and depth of SE activities. Thus began a detailed literature search, ranging from Air Force policies, to professional SE organization publications, to academic textbooks.

At the Air Force level, policies related to SE concepts and methods display the Air Force's understanding of the importance of SE. AFI 10-604, "Capability Based Planning (CBP)," requires a process to be analytically sound, repeatable, and traceable in order to identify, assess, and prioritize capability needs and potential tradespace study areas [Capabilities Based Planning, 2006: 3]. AFI 63-1201, "Acquisition, Life Cycle Systems Engineering" identifies the SE methods and management required to provide and sustain products/systems, to be cost-effective, operationally safe, and effective [Life Cycle SE, 2007: 1]. AFI 63-101, "Operations of Capabilities Based Acquisition System," is a guide to for a systematic framework approach when acquiring AF capabilities [Capabilities Based Acquisition, 2005: 1]. The Air Force also communicates best SE practices in manners other than policies. The SE Assessment Model (SEAM) describes a set of SE best practices tailored for use by Air Force programs and projects. The model facilitates self assessment and independent assessment of SE implementation on individual projects [SEAM, 2008].

Air Force Materiel Command (AFMC) documents further refine SE concepts and methods. AFMCI 61-102, "Advanced Technology Demonstration Technology Transition Planning" provides an outline of policy and organizational responsibilities for managing and transitioning Advanced Technology Demonstrations (ATDs) [ATD Planning, 2006: 1]. Additionally, the Technology Program Management Model (TPMM) provides a logical methodology to plan and develop programs via stage gates. TPMM is currently being implemented within AFMC and AFRL as the Developing & Sustaining Weapons Systems (D&SWS) initiative [Technology Transitions, 2008].

Non-policy documents utilized within the SE community include the DoD Defense Acquisition Guidebook (DAG), the Friedman-Sage Matrix, and the INCOSE Handbook. The DAG delineates 16 SE processes. The eight Technical Processes (TPs) include Requirements Development, Logical Analysis, Design Solution, Implementation, Integration, Verification, Validation, and Transition. The eight Technical Management Processes (TMPs) include Decision Analysis, Technical Planning, Technical Assessment, Requirements Management, Risk Management, Configuration Management, Technical Data Management, and Interface Management (Figure 1) [DAG, 2004]. The AF Center for Systems Engineering Case Studies include the Friedman-Sage Matrix, which illustrates nine key SE concept areas, representing phases in the systems engineering lifecycle and necessary process and systems management support [Friedman-Sage, 2005]. The International Council on Systems Engineering (INCOSE), a leading SE professional organization, published the INCOSE Systems Engineering Handbook in June 2006. This handbook provides key SE process activities at a detailed level, with the purpose of designing for affordability and performance. The handbook tends to focus on industry-related projects, in an input, control, output, mechanism (ICOM) format [INCOSE, 2006].

The 2008 AFRL Technology Maturity Conference was another information resource for the practice of SE in defense-related industry. A common theme at the conference was the use of various readiness levels to determine the ability of a product to transition. The conference provided awareness to the team of current practices to mature and transition

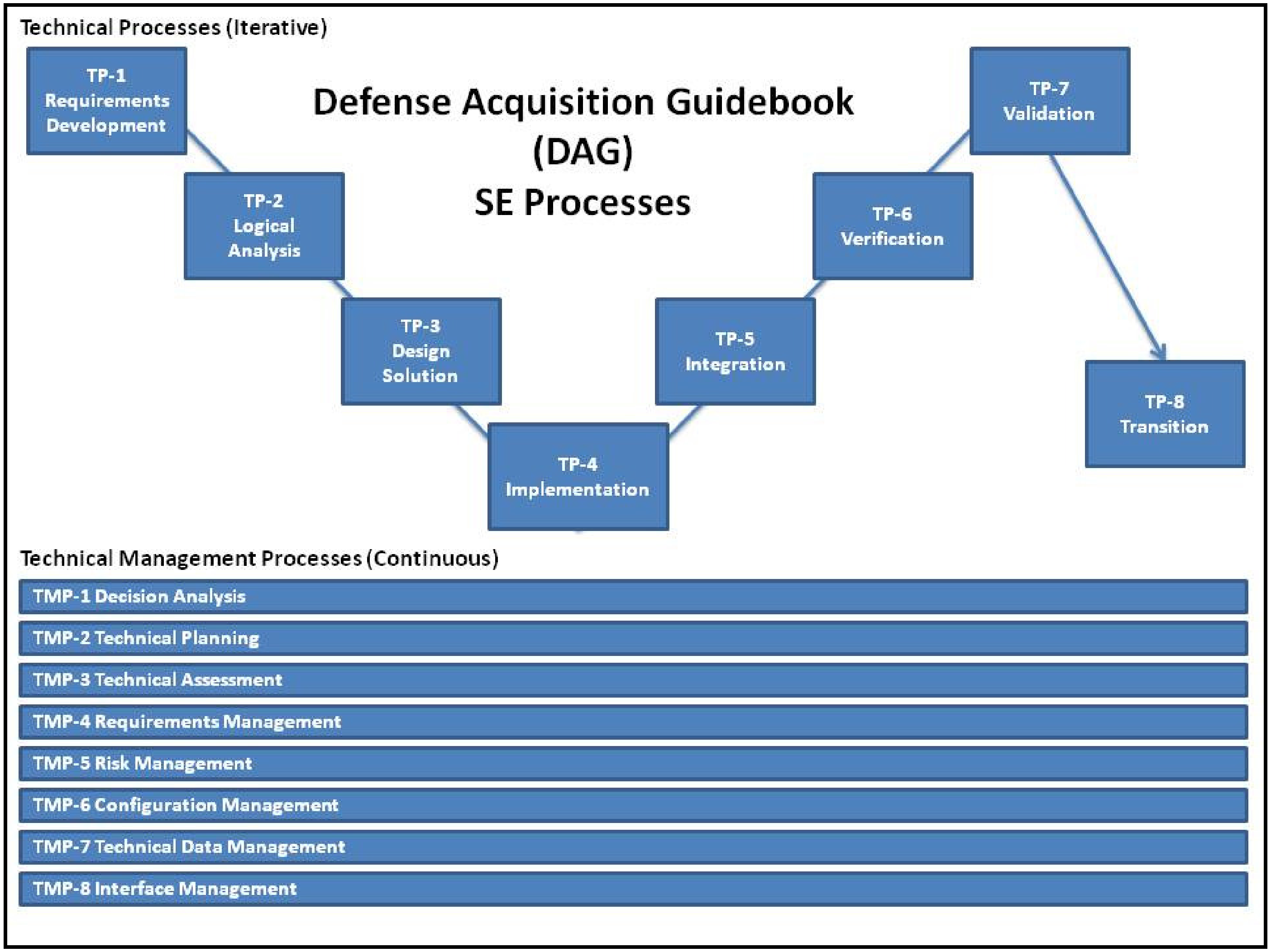


Figure 1: Defense Acquisition Guidebook Processes

"grown up" technologies to program offices. It also solidified the need for a tailored approach rather than defining a new discriminant by which to measure projects.

In addition to the contributions by the SE community as stated above, the academic community is also a significant resource. "The Engineering Design of Systems: Models and Methods" by Dennis Buede is a text utilized at the graduate level, and addresses methods for using models during the SE process [Buede, 1999]. This text is one of the two resources for the framework that provides SE methods at a detailed level; the other being the INCOSE Handbook. The team examined other academic contributions during the literature review, but settled on the Buede text as our primary reference. "Essentials of Project and Systems Engineering Management" by Howard Eisner, also a text utilized at the graduate level, provides an organization of 30 SE elements, which span the overall SE process over a system's life cycle [Eisner, 2002]. "Best Project Management and Systems Engineering Practices in the Pre-acquisition Phase for Federal Intelligence and Defense Agencies" by Steven R Meier, was published in Project Management Journal, in March 2008. Meier concludes that SE must be upfront and include an understanding of the interfaces, technology assessments, system trades, and risk management [Meier, 2008]. These documents helped the research team establish a SE knowledge base to proceed with building the tailoring framework.

Differences from Previous Efforts

Earlier activities looked at the topic of early application of SE in technology development and acquisition. While these studies addressed many of the same SE processes and methods as this thesis, the scope of applicable projects, intended implementation of the final results, and specific deliverables are different. The reports and presentations should all be considered when mapping out an SE program, but this thesis project does in fact stand alone as a comprehensive guide and tool to tailoring SE activities for S&T projects.

One of the primary studies that relates to this thesis topic area is the TASE report [TASE, 2006]. The TASE report focused on documenting the state of SE implementation within AFRL and recommending ways to improve its overall use on S&T projects. The report looked at consistent application of all SE processes to all projects, and while general tailoring was recommended, a specific tailoring framework was out of scope. This thesis delivers a specific model for tailoring SE activities to a range of S&T projects based on maturity, size, Core Process category, and funding source. The TASE report also focused primarily on Advanced Technology Demonstrations (ATDs), which are only a subset of the type of projects contained within AFRL's portfolio. This research looks at the entire range of AFRL projects. TASE used the 16 SE processes from the DAG, which is consistent with SE taxonomy approach used in this thesis. Both the TASE report and this thesis include a comprehensive review of existing AFRL SE policy and guidance, but the TASE report additionally focused on the cultural effects of implementing SE within AFRL – something this thesis does not specifically address. There are also many similarities in the methodologies between this thesis and the TASE report: literature review (including policies, guidance, and non-DoD SE practices), assessment of past and current AFRL projects, and recommendations of applicable SE processes, methods and tools. The research additionally reviews a non-DoD case study for an outside perspective on research and development activities. Finally, the deliverables between the two efforts differ, as TASE produced two reports (assessment and recommendations), while the research will deliver a single report along with an SE tailoring tool that can be immediately used by S&T project leaders to identify a recommended level of SE rigor for their specific project [TASE, 2006].

Another applicable study is the Commission on Pre-Milestone A (Pre-MS A) Systems Engineering report [Pre MS-A, 2008]. The Pre-MS A report addressed the effects of early implementation of SE on major acquisition programs but did not specifically address S&T projects. It placed emphasis on the Concept Refinement and Technology Development phases of the systems acquisition life cycle and defined a minimum level of early-phase SE activities for programs that follow this model. The report described "general policies and best practices for systems engineering in all phases," but while many of the policies and practices that the Pre-MS A report recommended are also applicable for S&T projects (which are usually smaller in size), it was not focused specifically on the AFRL project portfolio [Pre MS-A, 2008: 72]. The Pre-MS A report generically recommended tailoring, saying "Formal SE processes should be tailored to the application", but no specific tailoring recommendations were made [Pre MS-A, 2008: 7]. The Pre-MS A report also contained a thorough review of the training and experience of the Air Force's acquisition workforce, which is well outside of the scope of this thesis, but well within the realm of actions necessary within AFRL. Again, there were similarities in the Pre-MS A and AFIT methodologies, notably a review of previous SE reports and an emphasis on case studies to produce a report and recommendations. This thesis, however, looks at S&T and AFRL-specific policy and guidance in developing the analysis approach, where the Pre-MS A report looked primarily at prior review panel reports for its approach. The Pre-MS A Commission delivered a report that was centered on "trying to define a minimum set of systems engineering processes" as well as a list of 20 questions that should be asked on all programs prior to Milestone A [Pre MS-A, 2008: 1, 3]. The thesis deliverable covers many of these SE minimums and questions, but includes more SE detail and allows tailoring of those details based on the type of S&T project being considered.

During the course of this research project, AFRL/RX developed a streamlined approach using IPPD and AFRLI 61-104 for applying SE principles to their programs. The approach recommends AFRL/RX tailoring to the eight key questions, showing the amount of effort recommended for four project types (basic research, applied research, advanced research, and Advanced Technology Demonstrations) [Malas, 2008]. This streamlined SE approach, intended as a bottoms-up minimum set of activities, omitted many general and detailed SE activities. Although the streamlined approach and the thesis framework's purposes are similar in nature, the framework presents a much more detailed and comprehensive top-down approach, providing tailoring of a greater range of SE activities for the complete set of potential AFRL project states.

Purpose for Research

While this research clearly builds on the work done by previous studies, especially the TASE report, it stands on its own as a comprehensive review of all SE processes, methods, and tools as they apply to the wide range of S&T project types. Most importantly, it provides a useful tool for customizing the amount of rigor put into each of these SE principles. The intent of this deliverable is to not only make the case for increased focus on SE within AFRL, but to facilitate the implementation of select SE activities at a level appropriate for specific S&T projects.

III. Methodology

Methodology Overview

This chapter addresses the development and validation of the SE tailoring framework, comprised of a taxonomy of comprehensive SE activities and a separate taxonomy of relevant categories and domain values possible for S&T projects. This framework forms the basis of the tailoring tool discussed in Chapter IV. The SE taxonomy incorporates a broad set of recognized activities from academic, defense, and industry sources and organizes these activities according to the Defense Acquisition Guidebook's structure of Technical Processes (TPs) and Technical Management Processes (TMPs). The project taxonomy forms the basis for treating each project as a state problem, with unique project discriminants consisting of discrete domain values. Both taxonomies were developed independently and then matrixed into the SE framework. These groupings allow for specific tailoring as a function of unique project characteristics. The framework validation was accomplished by analyzing current and recently completed S&T projects as well as review by prominent systems engineers within AFRL.

SE Taxonomy Development

As described in Chapter II, a variety of approaches exist for implementing Systems Engineering in developmental and S&T projects; however, the team did not find a single literature source that included a sufficiently comprehensive and appropriate set of these activities for direct transfer into the desired SE taxonomy. The team determined that pulling from multiple literature sources would allow for a look at systems engineering from academic, defense, and industry perspectives and would provide the basis for generating a "superset" of activities that spanned all three realms of experience. Academic textbooks often address the SE process as a whole, but focus instruction on the author's specific areas of interest and communicate in the author's preferred terminology. Defense sources outline policy directives regarding SE activities for acquisition projects, but do not specifically state which activities are appropriate for various project types. Industry sources encompass accepted practices from a wide variety of business sectors and introduce a level of specificity not found in either academic or defense sources. In fact, no readily-available sources were found to address appropriate SE activities specifically for S&T projects. As all three literature categories showed promise for contribution to the "superset", the group selected a single source from each category to incorporate into the SE taxonomy. The selected sources from the literature review are "The Engineering Design of Systems: Models and Methods" by Dennis Buede [Buede, 1999], Chapter 4 from the Defense Acquisition Guidebook (DAG) [DAG, 2004], and the International Council for Systems Engineering (INCOSE) Handbook [INCOSE, 2006].

With sources identified, the research analyzed candidate organization schemes to determine the most appropriate construct for the SE taxonomy. These organization schemes included the Friedman-Sage Matrix [Friedman-Sage, 2005] used on multiple Air Force Center for Systems Engineering case studies, *The Thirty Elements of Systems Engineering* from Chapter 7 of the Eisner textbook referenced in Chapter II [Eisner, 2002: 191, 194], and the DAG TPs and TMPs [DAG, 2004]. As the direct application of the research effort is defense S&T, and to remain consistent with current AFRL policies and practices, the team determined that the DAG construct was most appropriate. An added benefit of the DAG construct is the inclusion of the systems engineering "Vee", an iterative approach to implementing TPs on a project, as well as the continuous implementation of TMPs on a project. The importance of using the SE "Vee" was noted by the AFRL FLTC Independent Review Team (IRT): "The IRT used the SE "Vee" from the Defense Acquisition Guidebook (DAG) as interpreted for tailored application to the science and technology environment in AFRLI 61-104 as the basis for evaluating FLTC SE processes" [IRT, 2008]. Additionally, AFRL currently bases their SE planning activities (AFRLI 61-104) around the DAG processes, providing a familiar taxonomy for users of the Tailored SE Framework (Figure 2) [S&T SE, 2008].

The team gathered systems engineering processes from each of the 3 literature references and compiled them into 16 lists according to the 8 TPs and 8 TMPs from the DAG. Once the data was gathered, each list was organized by functional hierarchy and chronological order, resulting in a completed "superset" of systems engineering processes in each of the 16 categories. Within each category, the SE activities were organized according to functional groupings, in chronological order (to the extent possible), and hierarchically according to five levels of increasing detail. The DAG processes comprise Level 1 of the SE taxonomy, functional groupings make up Level 2, and most of the executable activities reside at Level 3. Levels 4 and 5 contain details or variations of the Level 3 activities that can be selectively applied at the discretion of the project (Table 2). With the elements of the SE taxonomy established, the SE processes were organized into a single Excel worksheet to provide optimum visibility and management of the resulting

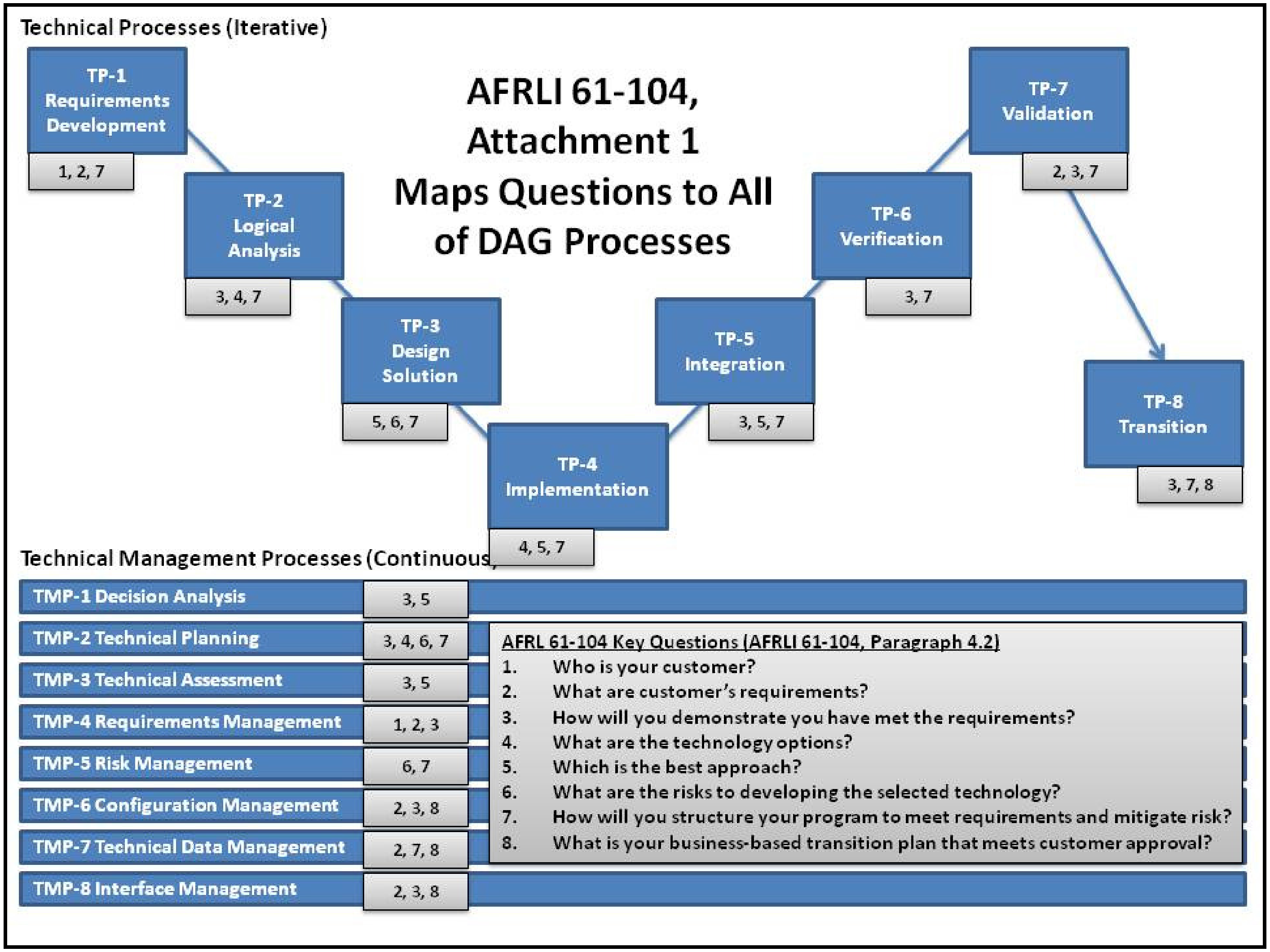


Figure 2: Mapping of AFRLI 61-104 Questions to Defense Acquisition Guidebook Processes

hierarchy, function and structure of the "superset" within the tool to be discussed in Chapter IV.

Table 2: SE Taxonomy Levels and Activities

SE Taxonomy Hierarchy	Description	# of SE Activities
Level 1	16 DAG Processes + Fundamental Principles	17
Level 2	Functional SE Activity Grouping	65
Level 3	Tailored SE Activities	350
Level 4	Detailed SE Activities	538
Level 5	Detailed SE Activities	161

During review of the 16 DAG processes, six common SE activities were discovered in multiple processes. These activities were all from the INCOSE Handbook and related to utilization of existing processes and practices within a larger enterprise management structure. Examples of these common activities are "utilize enterprise strategic plan" and "utilize enterprise infrastructure". Rather than leave these redundant activities buried within multiple categories, an additional category titled "Fundamental Principles" was created at Level 1, with a roll-up at Level 2 titled "Utilize Enterprise Capabilities".

Project Taxonomy Development

Similar to the SE framework, the research assessed multiple organization schemes to encompass the characteristics used by AFRL to discriminate between projects. Initial organization attempts to establish relationships between the individual project discriminants resulted in a layered matrix schema with project size and complexity along the vertical axis, project maturity along the horizontal axis, and the DAG's 16 processes forming the depth of the matrix. While this initial attempt provided an understanding of the relationships between the discriminants, it was not sufficient to capture the possible combinations of domain values within the discriminants in enough detail to adequately tailor the SE activities for a particular project. Discussions with thesis advisors regarding the multiple discriminants implemented by AFRL resulted in a decision to treat the project taxonomy as a state problem, with the project state being determined by the applicable domain values within each discriminant for the project. In essence, the desired tool should provide a transformation of the project state description into a set of systems engineering activities with recommended amounts of rigor to be applied to the project.

The project taxonomy initially included all established discriminants currently used by AFRL (Figure 3). The team conducted meetings in August 2008 with AFRL/XP and with the AFRL Systems Engineering Council to refine the potential list of discriminants

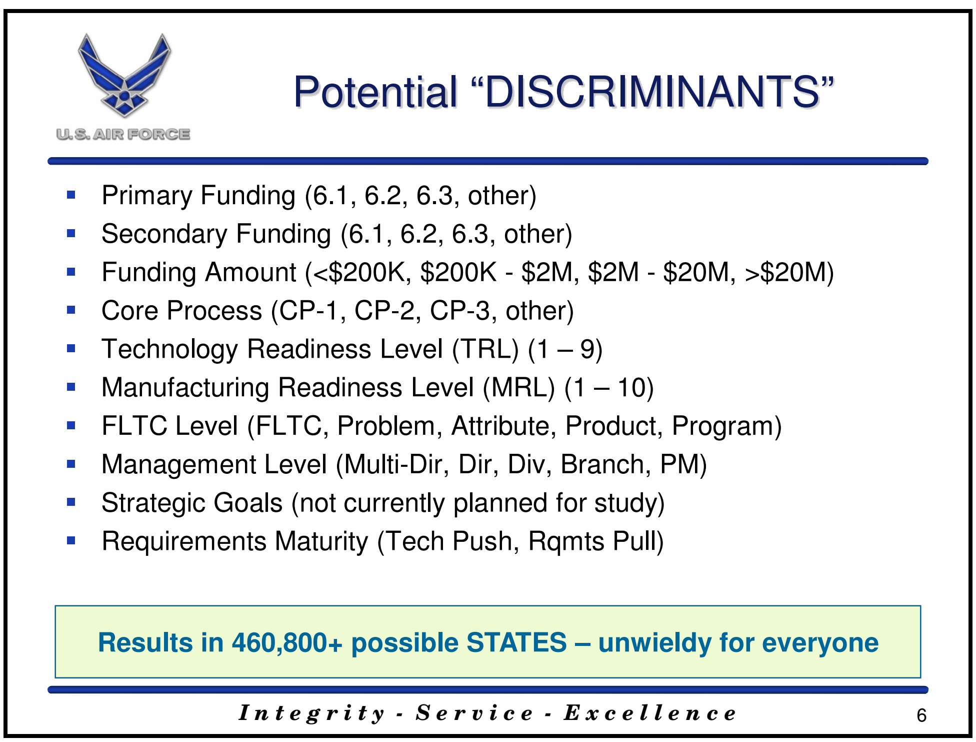


Figure 3: Potential Project Discriminants Presented to AFRL SE Council (Aug '08)

for the final project taxonomy and made further refinements during the taxonomy development process to ensure the final discriminants were reduced to a manageable set, were appropriate for S&T projects and contained discrete domain values for each discriminant. The SE Council recommended eliminating the "Secondary Funding", "Manufacturing Readiness Level (MRL)", "Management Level", and "Strategic Goals" discriminants, as well as the "other" domain value for the "Core Process" discriminant [SEC Meeting, 2008].

First, the "Secondary Funding" discriminant was initially included to account for multiple funding sources for a project, but was eliminated with guidance that a project should be tailored according to the "highest" level of funding. An example would be treating a project with funding from both 6.2 and 6.3 categories as a 6.3 project. Second, as the domain values (1-10) within the "Manufacturing Readiness Level (MRL)" discriminant have direct correlation with the domain values (1-9) of the "Technology Readiness Level (TRL)" discriminant, it was also eliminated. Next, the "Management Level" and "Strategic Goals" discriminants were initially included to account for projects spanning multiple directorates within AFRL, but were eliminated in favor of the "Focused Long Term Challenge (FLTC)" discriminant, which also incorporates dependencies between AFRL directorates associated with a particular project. Finally, the team eliminated the "other" domain value for the "Core Process" discriminant upon discovery that "CP-1", CP-2", and "CP-3" encompassed the entire domain.

With a refined set of discriminants in hand, the research defined each of the discriminants and associated domain values in the form of a questionnaire to be provided to projects during the Case Study phase of the thesis. Research into the definitions aided in the team's understanding of each discriminant and resulted in further refinements to the project taxonomy. The first refinement, eliminating the "other" domain value from the "Primary Funding" discriminant, resulted from further discussions with AFRL/XP regarding the expected funding sources for S&T projects. The second refinement modified the "FLTC" discriminant, partly due to a lack of a formal definition of the discrete qualifiers between the proposed domain values ("Challenge", "Problem", "Capability Concept", "Product" and "Program"), but more particularly to implement a more generic description of a project's "Integration Level" with the discrete domain values of "Subsystem Level Technology", "System Level Concept", and "Mission Level Concept". This change also makes the framework more accessible to S&T projects outside of AFRL. The last refinement to the project taxonomy consisted of a slight adjustment to the domain values of the "Funding Amount" discriminant, which occurred after the team spent considerable time "tailoring" the SE framework, and better encapsulates discrete funding breaks at which certain SE activities become appropriate for projects. The discriminant was renamed "Project Budget" with domain values of "Less than $500K", "$500K to $2M", and "Greater than $2M".

The final project questionnaire, provided as Appendix A to this thesis, provides definitions for each of the final 6 discriminants and 18 domain values (Figure 4) and seeks to define the particular "state" of the project to which the SE tailoring will be applied. The final discriminants and domain values result in over 648 possible project states, a significant reduction from the original discriminant set, which contained over 460,000 possible states. The need to address each of these potential states in the project taxonomy mandated that the delivered tool provide a simple interface with the flexibility to report results for any number of the project discriminants and domain values (which potentially increases the number of states above 648).

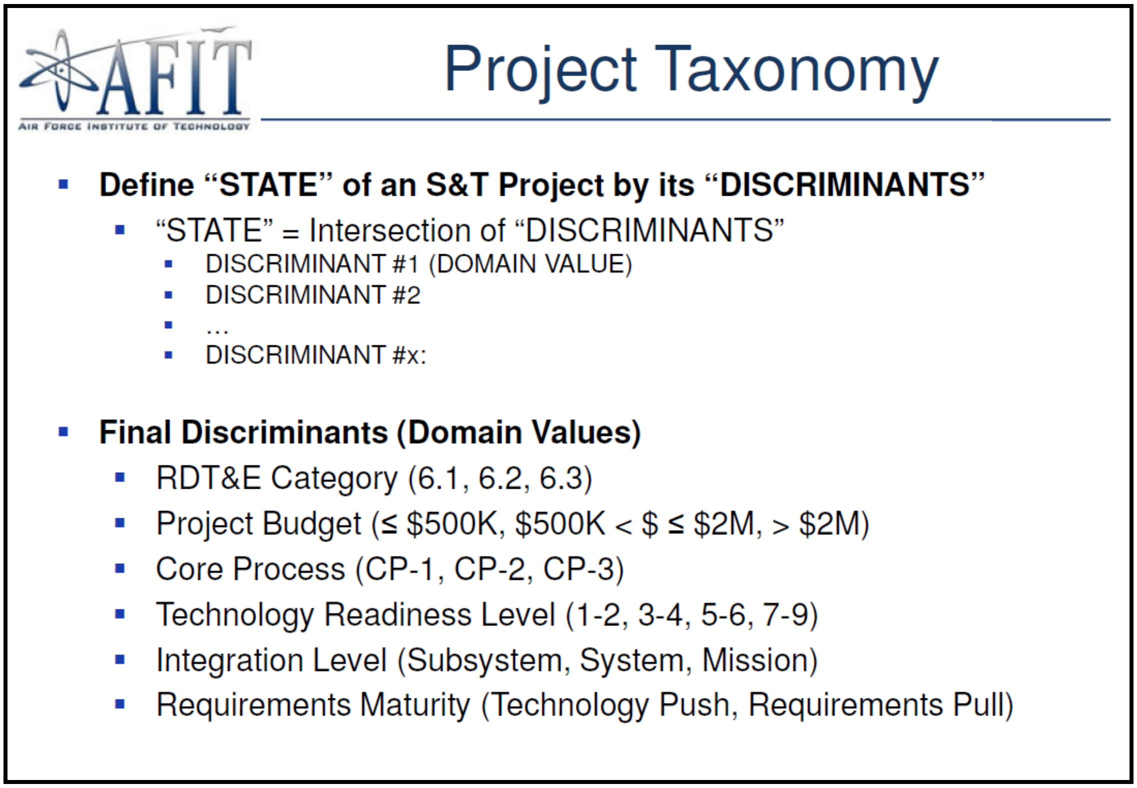


Figure 4: Discriminants and Domain Values (Project Taxonomy)

Systems Engineering "Tailoring"

The goal of the tailoring effort was to indicate the relative importance for each SE activity for a given project, based on the project's specific domain values. Returning to the previous state analogy, the tailoring process is the mechanism to transform the project state description to the recommended set of activities with associated rigor levels. The tailoring effort and implementation into the Excel tool, "Systems Engineering Tailoring Tool for Science & Technology Projects (SETT-STP)" followed a four step process: 1) Tailor at Level 3 of the SE Taxonomy, 2) Implement Discriminant Tailoring into the SE Framework, 3) Normalize SE Rigor Values (0-100% Scale), and 4) Apply Tailoring Factors to Gauge Impact of Various Schemes to SE Rigor.

First, the research looked at 350+ Level 3 SE activities, methods and tools listed in the SE taxonomy (Appendix F), and determined the applicability of each activity to the 18 project domain values. The research team created a table of SE activities for each TP and TMP, as well as for each discriminant category and domain value. Each SE activity at Level 3 of the SE taxonomy was evaluated independently against each domain value. For instance, if the research explored applicability of an activity for the 6.2 RDT&E Budget domain value, no assumptions were made as to the associated TRL, Core Process, or Integration Level. As a general guideline, the tailoring was more inclusive for larger, more expensive, and more mature S&T projects. Likewise, the evaluation tended to tailor out more activities for smaller, less expensive and immature projects. This tendency was utilized several times when there was debate over whether an activity was applicable or not for a given domain value. Specifically, a 6.3, $5 million, and TRL-8 project was found to require more SE rigor than a 6.1, $250 thousand, and TRL-3 project; the framework needed to reflect this in a quantitative manner. A sample tailoring table from TP-4 "Implementation" is shown in Table 3. At least two students reviewed each set of tables for each TP and TMP to ensure consistency. After several internal review and discussion sessions, the tables were submitted to the faculty advisor for review and

Table 3: Sample SE Tailoring Table for TP-4 "Implementation"

RDT&E Budget Category	6.1 Basic Research	6.2 Applied Research	6.3 Advanced Tech Dev
Generate Implementation Strategy	• Utilize design requirements • • Utilize terms and conditions of agreements • •	• Utilize design requirements • Utilize verification/validation criteria • Utilize terms and conditions of agreements • Utilize gov't and industry standards •	• Utilize design requirements • Utilize verification/validation criteria • Utilize terms and conditions of agreements • Utilize gov't and industry standards • Improve process control on design
Fabricate Hardware	• • • • • Define fabrication procedures	• Develop detailed drawings • • • • Define fabrication procedures	• Develop detailed drawings • Identify hardware configuration items for assembly • Identify implementation tolerances • Develop detailed material specifications • Define fabrication procedures
Code Software	• Identify software configuration items for compiling • • Develop detailed codes	• Identify software configuration items for compiling • Define coding procedures • Develop detailed codes	• Identify software configuration items for compiling • Define coding procedures • Develop detailed codes
Conduct Unit Testing	• • Inspect hardware and software for correct functionality • Test hardware and software for correct functionality •	• • Inspect hardware and software for correct functionality • Test hardware and software for correct functionality • Ensure sufficient hardware and software testing prior to integration	• Generate acceptance test procedures • Inspect hardware and software for correct functionality • Test hardware and software for correct functionality • Ensure sufficient hardware and software testing prior to integration
Conduct Training	• • • •	• • • •	• Establish initial staff of trained users • Establish initial staff of trained maintainers • Train initial operators • Train initial maintainers
Prepare for Integration	• • Refine integration constraints	• Supply system element for verification / validation • Refine integration constraints	• Supply system element for verification / validation • Refine integration constraints

comment. This review process resulted in changes to not only the tailoring, but also to the grouping and wording of the activities. A couple of noteworthy trends emerged as the tailoring effort progressed. Two of the discriminants, Integration Level and Requirements Maturity, did not lend themselves to significant tailoring between the respective domain values. For Integration Level, the research found that the same SE activities applied whether the product under development was a subsystem, a self-contained system, or part of a mission-level concept. The Requirements Maturity discriminant resulted in significant tailoring in TMP-4 (Requirements Management), but was largely consistent between the Technology Push and Requirements Pull domain values for the other processes in the SE Taxonomy. The team debated removing these discriminants, but decided that it was important to include them in the framework to build credibility with the wide range of projects that would potentially use the framework. An effort was made, though, to reduce the impact of these two discriminants on the reported output of SETT-STP through the Tailoring Factors, discussed in the third step of the tailoring process.

Another trend discovered in the tailoring process resulted in a change to the Project Budget discriminant, with initial domain values of “Less than $200K”, “$200K-$2M”, “$2M-$20M”, and “Greater than $20M”. In the first tailoring iteration, the only real effect of tailoring the Project Budget discriminant was observed in the “Less than $200K” category, as this was such a small budget level that not much formal systems engineering activity could be afforded without undercutting the S&T benefit. Additionally, the research team held numerous debates about the amount of tailoring appropriate for the "$200K - $2M" category, as a $250K project would apply SE much differently than a $1.9M project. The "$2M-$20M" and "Greater than $20M" domain values provided no difference in tailoring. Ultimately, the team decided that the $200K threshold was too low, and that the split between the "$2M-$20M" and "Greater than $20M" categories provided no value. These domain value categories were re-designated "Less than $500K", "$500K - $2M", and "Greater than $2M".

The second step of the tailoring activity involved implementing the Level 3 tailoring into the Excel-based tool. After the table-based review, the applicable activities were transposed into a series of Excel workbooks that scored the SE activities for each domain value. A binary system annotated the applicability of each domain value, with a "1" score indicating that the SE activity should be accomplished for a domain value, and a "0" indicating that the activity was not critical for the domain value. The binary scoring system allowed for a customizable weighting to be applied to a selected set of project discriminants, while simplifying the tailoring implementation within the Excel tool. A sample input to the Excel tool is shown in Figure 5. The team did consider an alternate scoring system for the domain values, where domain values would receive a fractional

TP-4 (Implementation)	6.1	6.2	6.3	<500K	500K-2M	>2M	CP1	CP2	CP3	1-2	3-4	5-6	7-9	Subsystem	System	Mission	Push	Pull
Generate Implementation Strategy																		
Utilize design requirements	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
Utilize verification criteria	0	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1
Utilize validation criteria	0	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1
Utilize terms and conditions of agreements	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Utilize government and industry standards	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1
Improve process control with Lean Design	0	0	1	0	0	1	0	1	1	0	0	1	1	1	1	1	1	1

Figure 5: Sample of Binary Tailoring Input to SETT-STP

score on a scale of zero to one; however, the degree of confidence in the binary system was not quantifiable to the point that implementing the fractional value system provided any additional benefit.

The third step in tailoring the SE activities required a summation and normalization of the scores on a 0-100% scale. For a given set of discriminants, the tailored weights revealed the relative level of SE rigor that should be applied to each activity for a specific project state. The intent behind this methodology was to give a user a relative indicator as to where they should apply resources. An activity with a 100% weight should be accomplished to a more formal and detailed level over an activity with a 60% weight. The team notionally interpreted the tailored percentages for SE rigor according to the descriptions in Table 4.

Table 4: Notional Interpretations for Reported SE Rigor

SE Rigor Percentage	Notional Interpretation
100%	REQUIRED: An activity should be accomplished to a complete and formal level of planning, coordination, and documentation
70%	RECOMMENDED: An activity should be considered for planning, coordination, and documentation
30%	WATCH LIST: An activity should be considered for informal planning, coordination, and documentation
0%	NOT APPLICABLE: An activity is probably not necessary to project success and requires little or no planning, coordination, and documentation

The fourth step of the tailoring activity applied tailoring factors to each of the Project Taxonomy discriminants to assess their impact on the normalized score of SE rigor. A detailed sensitivity analysis explored the impact of tailoring factors to reported SE rigor scores. A baseline case with equal weighting of the project discriminants was compared to two additional weighting methods. The second tailoring factor scheme attempted to capture the lack of tailoring discovered within the Integration Level and Requirements Maturity discriminants during the initial tailoring efforts. The third tailoring factor scheme further explored the impact of the Project Budget discriminant on the reported SE rigor. The sensitivity analysis results are contained in Chapter IV, and the complete sensitivity analysis is presented as Appendix C. Ultimately, the sensitivity analysis showed that the third tailoring factor scheme provided the greatest spread in tailoring scores and was adopted into SETT-STP's initial release.

Case Study Results & Feedback

A critical part of this research project is the intersection of student-derived tailoring with real-world S&T projects that utilized systems engineering principles. Much of the initial tailoring was accomplished by applying the team's academic knowledge and prior individual work experience, but that was not sufficient to definitively claim that the tailored SE Framework was accurate and applicable to potential users. The team sought out several current and recently completed S&T projects to fine tune the initial tailoring. The reviewed projects, treated as case studies, in some cases validated the framework, but more often drove important changes to the SE taxonomy's terminology, grouping, or weightings. The team developed an initial listing of potential case study candidates based on faculty advisor input and solicitation of the AFRL SE Council for applicable project candidates. The preliminary case study target list consisted of projects within AFRL/RX, but was expanded based on the recommendation from the SE Council that the tailorable

SE framework should be applicable to all directorates within AFRL. The research then formally solicited candidate projects from all of the SE Council representatives.

Basic systems engineering tenets are applicable to all complex projects, whether applicable to the defense department or not, and whether they are guided by DoD policy and guidance or not. Accordingly, the team also decided to pursue S&T projects from other governmental agencies (non-DoD), as well as from corporate research and development engineering organizations. Industry perspective is particularly important, as corporate livelihoods are often based on the successes of S&T projects as well as the appropriate application of systems engineering principles to ensure future development, integration, and transition activities are conducted in a cost-effective manner.

Upon receiving an S&T project point of contact, the research sent out an initial Case Study Pre-Survey Questionnaire (Appendix A). The questionnaire solicited contact information and asked the point of contact to indicate which of the project taxonomy discriminants applied to the candidate project. The points of contact received full definitions of each of the discriminants to ensure consistent understanding of the project taxonomy. After receiving the completed questionnaires, the team requested access to relevant, previously assembled case study project documents. The research reviewed all provided documentation and made notes against a project-specific tailored output from the SE tool using the cited domain values. After reviewing all documentation, the research formulated questions for the project point of contact to resolve all discrepancies and gaps. The ensuing interviews with the point of contacts were insightful and provided clarification of confusing terms and sequences in the SE framework, added background and understanding to formal documentation, and illustrated why certain SE processes, methods and tools were or were not used for the project. After each documentation review and personal interview, the research revised the tailored SE framework and documented trending information for further framework updates and conclusions.

Following the tool development and case study application, the SE framework tool was delivered to a group of prominent systems engineers both internal and external to AFRL with the goal of validating the results of the tool for various project states as well gathering impressions and feedback with respect to the tool's functionality and ease of navigation. The validators were asked to provide specific feedback in the following areas: Functionality, Activity Descriptions, Tailoring, References and Tools, and General Comments. Feedback from the validators added final refinements to the SE framework and is presented in Chapter IV.

IV. Analysis and Results

The SE and Project Taxonomies provided the foundation for an SE tailoring framework. The research team's goal of delivering an output that will be utilized by the S&T community drove the need for a validated, user-friendly tailoring tool, based on real-world projects that successfully applied SE principles. The initial tailoring effort used the case studies to correct any false assumptions and thought processes. The tool validation effort provided several independent views of the results and generated areas for immediate adjustment as well as future work.

SE Tailoring Tool Development

A simple user interface was deemed critical to the success of the tailoring tool. The team envisioned drop down boxes with selectable domain values, desired processes and detail levels, and easy to navigate controls. The course to this interface wandered through explorations into using Microsoft Access, Java, SQL, and Visual Basic. Ultimately, a simple solution was found in Excel itself, by creating an interface worksheet that allows users to select their project domain values, and then selecting the next worksheet for the tailoring results. This decision made the assumption that users would have access to Excel 2007 and would be familiar enough with Excel to click between worksheets and perform simple grouping and filtering functions (if desired). The number of SE activities (over 1,200) was still fairly cumbersome and intimidating, so the team implemented the grouping feature in Excel 2007, which uses a collapsible "+/-" system (similar to MS Project) to allow users to drill down to the desired detail level. Additionally, filtering is enabled on the worksheet to allow users to select only specific activities, detail levels, or even weight scores. The SE Tailoring Tool User's Guide at Appendix B contains specific details, operating instructions, and guidance to modify the tool.

Following the first case study (HELLTP, described in detail below), the team revised the tailored weight calculations. The HELLTP case study reinforced suspicions that the Integration Level and Requirements Maturity played a minor role in SE tailoring, and that Project Budget was the dominant discriminant in what SE activities a project lead would accomplish. Analysis of the tailored weight data (see Appendix C) backs up this assessment and bolsters the argument for using discriminant weight factors. To this point, the tailored weight calculation treated each discriminant as equal, so if all six discriminant categories were used, each discriminant would have a 16.67% factor in the tailoring score. The tailoring tool was changed to provide a weight factor for each discriminant. Project Budget was assigned a 30% factor, RDT&E Category, TRL, and Core Process were each assigned 20% factors, and Integration Level and Requirements Maturity were assigned 5% factors (for a total of 100%). This gives the tailoring tool a greater spread of weight values (as noted in case study feedback) and provides a more realistic view of how users should assess whether or not to apply specific SE activities. It is important to note that the discriminant weight factors can be easily changed if a specific tool user wishes to customize it in the future.

To accommodate projects that don't have a single identifiable domain value for each discriminants, the tool will maintain a 100% scale for tailoring recommendations for nonstandard program inputs. If no domain values are selected for a discriminant, that discriminant's weight factor will be proportionally distributed among the other discriminants that do apply. Alternately, if multiple domain values are selected for a given discriminants, that discriminant's weight factor is split equally between the number of selected domain values, so the other discriminants' weight factors do not change.

Tailored Weight Analysis

The SE Taxonomy resulted in 350 SE activities with tailored weights at Level 3. The team performed evaluations on the amount of tailoring for various project types, as well as the impact of the weight factors described above. Three distinct project types were evaluated for tailoring (Table 5).

Table 5: Project Domain Values for Statistical Analysis

Discriminant / Project #	RDT&E Category	Budget	Core Process	TRL	Integration Level	Rqmts Maturity
1	6.1	<$500K	CP-1	1-2	Subsystem	Tech Push
2	6.2	$500K - $2M	CP-2	3-4	System	Tech Push
3	6.3	>$2M	CP-3	7-9	Mission	Rqmts Pull

Additionally, each type of project was evaluated with three different weight factor schemes (Table 6).

Table 6: Weight Factor Schemes

Discriminant / Project #	RDT&E Category	Budget	Core Process	TRL	Integration Level	Rqmts Maturity
Current	20%	30%	20%	20%	5%	5%
Middle	20%	20%	20%	20%	10%	10%
Equal	16.66%	16.66%	16.66%	16.66%	16.66%	16.66%

Histograms of the Level 3 weights for each project type and weight factor are in Figures 6-8 below.

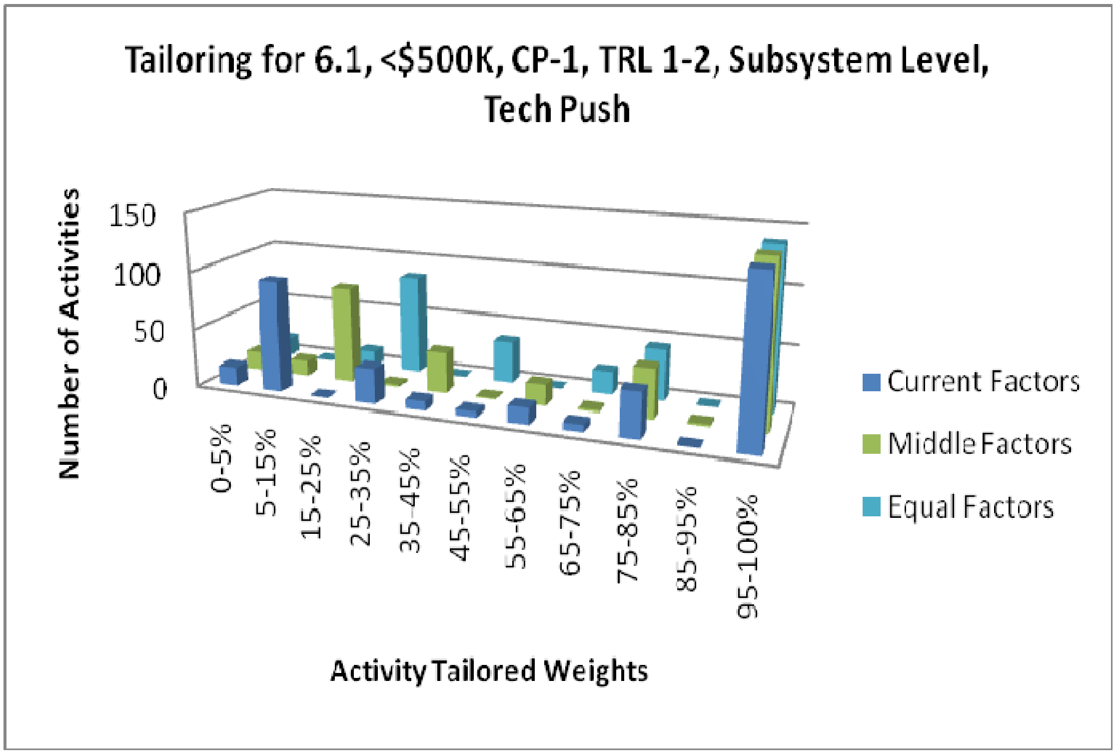


Figure 6: SE Activity Weight Histogram for Project 1

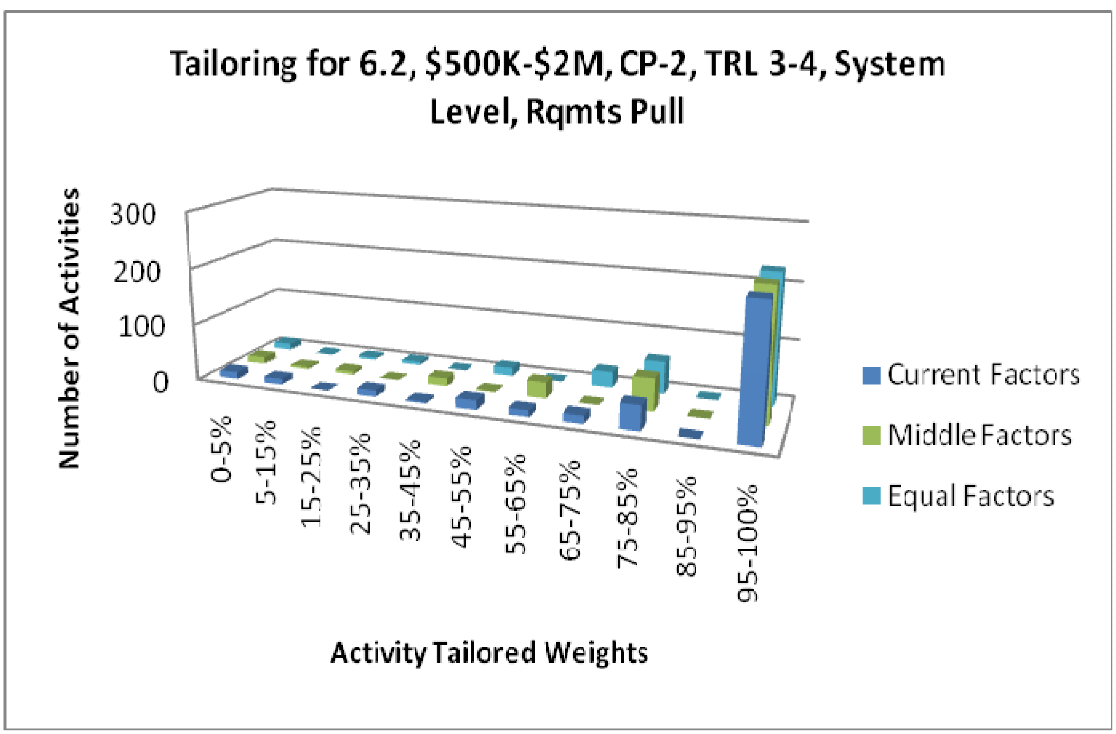


Figure 7: SE Activity Weight Histogram for Project 2

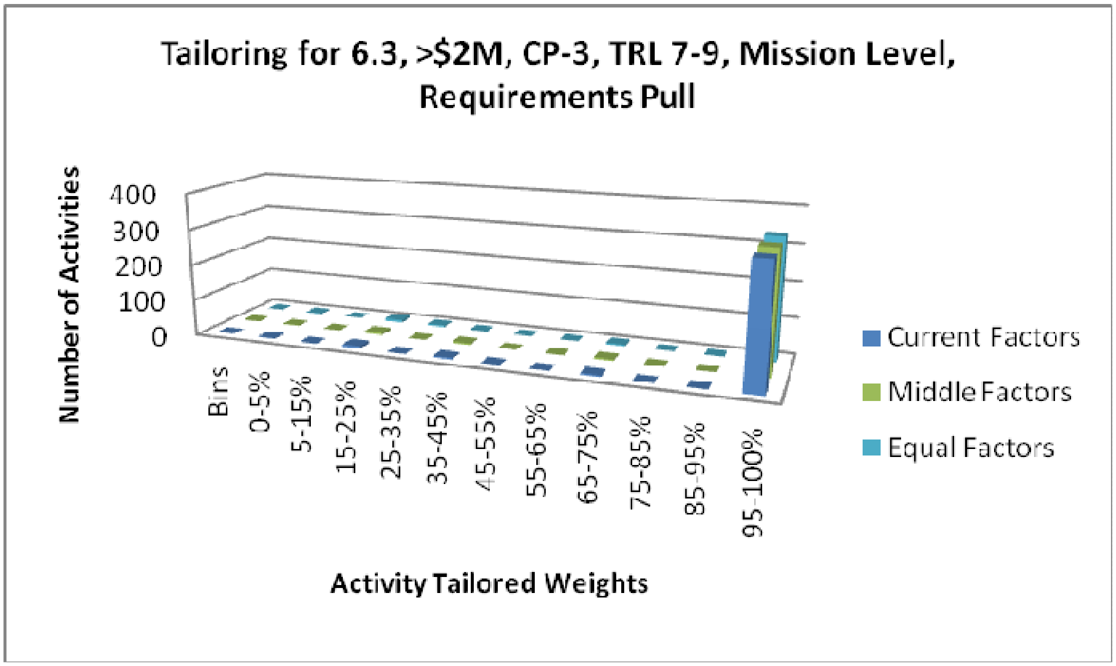


Figure 8: SE Activity Weight Histogram for Project 3

The data clearly shows that there is more tailoring for smaller, less mature projects than for larger, more mature projects. Only 39% of the activities in Project 1 carry 100% weights, while 65% of the activities in Project 2 and 95% of the activities in Project 3 carry 100% weights. The weight factors prove to have minimal impact on the tailoring for most, but not all projects. There is almost no impact from the various weight factors in Project 3 – only 3% of the activities changed weights using the different factors. The factor selection played a more prominent role in Project 1, where about 45% of the activities had their tailored weight scores affected by 10-20% based on the factor criteria.

Case Study Summaries

After completing the initial development of the tailored SE framework, the research investigated six case studies based on recent S&T projects that valued systems engineering principles. The research identified the case study projects by their domain values in the project taxonomy, reviewed documentation, and interviewed knowledgeable points of contact to resolve gaps and discrepancies in documentation. After the case study reviews, the tailored SE framework was updated to reflect the lessons learned. The case study reviews sought out only application and impact of SE processes, methods and tools. Though specific information about the project technology and operational use was often available, it was not the primary focus of this research and is not included in this report.

The research completed case study reviews by assembling a representative tailored SE framework output based on the applicable project domain values. The tailored output was at the "3" level to allow a comprehensive review of significant activities while not subjecting the participants to a 1,200+ item survey for each case study. The provided project documentation either did or did not support evidence of each SE activity, which was annotated on a review sheet. Any SE activities with an absence or conflicting documentation evidence were posed as interview questions for the point of contact for further clarification.

The initial list of potential case studies contained 10 candidate projects. Seven candidates came from across AFRL, two were independent research and development projects from defense contractors, and one was from NASA. Ultimately, six project points of contact were responsive enough to provide the team with a thorough case study opportunity (Table 4). The predominant case study findings identified the need to establish a project's context and time horizon, refined the SE taxonomy, improved the SETT-STP tool functionality, and most significantly, revealed a clear disconnect on SE terminology and applicability for 6.1 (Basic Research) projects. Summaries of each case study review follows.

Table 7: Mapping of Case Studies to Project Discriminants

Project	RDT&E			Budget			Core Process			TRL				Integration			Requirements	
	6.1	6.2	6.3	<$500K	500K-2M	>$2M	CP-1	CP-2	CP-3	1-2	3-4	5-6	7-9	Subsystem	System	Mission	Push	Pull
HELLTP		■				■		■			■	■		■				■
PLOCAAS			■			■		■					■		■		■	
Layered Sensing		■			■			■				■				■	■	
NGC-IRAD			■			■		■			■			■			■	
Deployed Energy		■		■					■		■	■	■	■	■			■
RXQ 6.1	■			■			■			■				■			■	

Case Study 1: High Energy Laser on a Large Tactical Platform (HELLTP)

The HELLTP project came to the team by recommendation from the AFRL Systems Engineering Council during the initial project briefing in September 2008. This multi-directorate systems engineering initiative implemented the IPPD process for the three-phased project, conducted from 2005 to 2008. In his response to the "Case Study Pre-Survey Questionnaire", the project subject matter expert provided the project discriminants for HELLTP as follows: RDT&E Category: 6.2, RDT&E Budget: Greater than $2M, Core Process: CP-2, TRL: 5-6, Integration Level: Subsystem, Requirements Maturity: Requirements Pull. Documentation review consisted of the "Task 1 Final Report" (September 2006), the "Thermal Management System Analysis for the Airborne Advanced Electrical Laser System" (March 2007), and the "Final Report for the Tactical Laser Characterization and Integration Study" (September 2008).

The research team combed through these documents to determine which SE processes within the SE taxonomy the HELLTP project implemented, and focused on annotating what was done on the project and not specifically on how well it was done. Results were recorded by labeling each of the Level 3 SE processes according to the "YES/NO/SOME/NO DATA" criteria established by the methodology. This review resulted in 38 project questions for the subsequent interview, as well as inconsistencies within the tool itself, such as areas where the tailoring inputs and calculations were incorrect or missing and where related tasks were weighted differently within the SE Framework output. The documentation review also highlighted the need to include a Level 3 task and associated weightings within TP-2 (Logical Analysis) to "identify training requirements" for a project. The team implemented these changes prior to the review of the next case study.

The follow-up interview covered the 38 questions from the documentation review and led into a discussion regarding the current interface and functionality. The questions focused on annotating the SE processes within the framework where supporting documentation was inconsistent or incomplete. Additional interview discussions highlighted the importance of correctly establishing a project context for the "state" determination and review process, as well as the importance of first-hand project knowledge in correctly identifying which SE tasks were accomplished. The interview also identified possible functionality improvements or changes to the tool itself.

Case Study 2: Powered Low Cost Autonomous Attack System (PLOCAAS)

The PLOCAAS project evaluated mission concepts, defined performance objectives, investigated environmental constraints, and evaluated candidate sensing technologies for a powered version of a low-cost searching weapon system. The project was conducted in the late 1990s by what was then known as the Munitions Directorate of AFRL. The subject matter expert was a former program manager for the project and served as the point of contact for the case study. He provided the project discriminants for PLOCAAS as follows: RDT&E Category: 6.3, RDT&E Budget: Greater than $2M, Core Process: CP-2, TRL: 7-9, Integration Level: System, Requirements Maturity: Technology Push.

PLOCAAS focused on early concept and technology development, and as such, applied a majority of its systems engineering effort on the early technical processes. To varying levels of formality, the project accomplished most of the activities in TP-1 through TP-7. The project did not transition to another developing or using organization, so most of the TP-8 activities did not apply to the project. The technical management processes were all addressed, but the program did not apply these activities robustly across the board. Significant diligence was applied in the decision analysis and technical assessment processes. The project applied minimal configuration management and thinly documented project requirements, risks, and interfaces. Other technical management processes were generally applied at a high level, but specific activities were omitted or accomplished informally [Jacques, 2008].

Following the documentation review, the team conducted a follow-up interview, according to the established process. The subject matter expert evaluation provided by the point of contact proved to be much more thorough than the student review given the scope and detail level of the documentation. The interview prompted several revisions to the SE framework, including taxonomy overhauls for many of the technical management processes. Some specific processes were merged (the definitions of threshold versus objective performance parameters) and reworded (the use of “interface architecture” preferred by Buede was changed to “interface control methods”.) Additionally, the team found it useful to insert comment boxes into the SE tool to provide definitions or clarifying statements to the SE activities.

Case Study 3: Layered Sensing

The Layered Sensing project is the second phase of a multi-directorate effort designed to “improve the quality and timeliness of acquiring, sorting, processing, and reporting information to improve effects based situation awareness” [Sensors Directorate, ii]. This phase of the project focused on identifying the requisite tools and measures for building an executable architecture designed to evaluate various sensor system combinations. The project subject matter expert, provided the project discriminants for Layered Sensing as follows: RDT&E Category: 6.2, RDT&E Budget: $200K - $2M, Core Process: CP-2, TRL: 5-6, Integration Level: Mission, Requirements Maturity: Technology Push. Documentation review consisted of the Phase II Study Plan and its associated annexes.

Similar to the previous projects, the team reviewed the documentation for indications of SE activities, processes, and tools. This review resulted in nine specific questions for the follow-up interview, but also left over 250 of the Level 3 activities unresolved, further justifying the conclusion from the HELLTP and PLOCAAS case studies to have a subject matter expert or project representative involved in determining which activities were accomplished. A thorough review of the SE tailoring tool output with the subject matter expert on 30 December 2008 reconciled the specific questions and resolved the gaps from the documents, but also pointed out inconsistencies in the level of detail within the SE taxonomy hierarchy, the need to further tailor activities in the “Project Budget” discriminant, and the desire to see a roll-up of the Level 3 tailored weights at Levels 1 and 2.

The primary inconsistency revolved around the level of detail for Level 3 activities between the TPs and the TMPs, where some of the TMP Level 3 activities were much more specific than those of the TPs. This feedback resulted in moving many of the TMP Level 3 tasks (particularly within TMP-2 “Technical Planning” and TMP-3 “Technical Assessment”) down to Level 4 in the SE taxonomy, simplifying the user interface for those processes. The case study review also uncovered a need to further tailor the Total Budget discriminant for the “$200K to $2M” domain value in TMP-6 “Configuration Management” and TMP-7 “Technical Data Management”, as many of these activities were given a “100%” weight, but seemed to be too heavily weighted for the scope of the project. The team reviewed the initial tailoring effort and made changes where appropriate, but left the tailoring intact where the activities seemed critical to project success. The final change to the SE tailoring tool was the addition of an indication at Levels 1 and 2 of the range of tailored weights for the subordinate Level 3 tasks.

Another critical result from this case study was the importance of framing the context of a project when selecting the discriminant domain values in the SE tailoring tool. As the Layered Sensing project consists of multiple phases, the total budget for the current phase does not correctly capture the scale of the overall project, thus potentially reducing the tailored weights for activities that would be valuable within the larger context. This was notable in the project interview, where the subject matter expert indicated that although certain SE activities were not accomplished on the current phase (largely concept exploration with little implementation), they would be beneficial in future phases of Layered Sensing.

Case Study 4: Northrop Grumman Internal Research and Development

The research sought insight into SE activities within a corporate project to determine whether the SE taxonomy was appropriate for an S&T environment outside of DoD, as well as to gain perspective on how SE was implemented when not constrained by government contract requirements. At the team's request, The Northrop Grumman (NG) Corporation's Integrated Systems Division provided an Internal Research and Development (IRAD) project for a case study review. While the project is ultimately targeted for fielding in the defense environment, it was not governed by a government contract and thus was not subject to government systems engineering control. For purposes of protecting Northrop Grumman's competitive interests, details of the project will not be provided in this report. However, the technical details are not important to the systems engineering analysis that was performed. The NG project fit the following domain values: 6.3, >$2 million, CP-2, TRL 5-6, Subsystem Level, and Technology Push.

Due to the sensitive nature of the NG project, the team did not receive project documentation. Instead, the team sent the latest draft of the SE Tailoring Framework to NG, who had their project team go through the activities in the SE taxonomy. The NG personnel indicated whether or not they performed each activity in the project's execution. They also made comments about the tailored weight levels and the tool's usability. After receiving NG's comments, the student team formulated a set of interview questions; nine about why activities were or were not performed, as well as six "big picture" questions about NG's internal SE processes. The NG interview resulted in several changes to the framework activity descriptions and SE Rigor scores, which were incorporated. The term "qualification" in TP-8 (Transition) was confusing, and ultimately changed to "deliverable" to clarify the meaning to be a transition item that would undergo certain transition activities. NG noted that no manufacturing process improvements were made under their IRAD project due to limitation of time and funding. In fact, NG's IRAD projects don't generally cross into the realm of manufacturing or producability; lab prototypes are used for product evaluations.

A few significant differences were noted between NG's IRAD and Contracted Research and Development (CRAD) efforts. IRAD projects don't usually solicit bids for various suppliers; rather, they pick the vendor that they know can supply a product. Under CRAD rules (which are inherent to government development activities), competition between vendors and suppliers is mandatory. Additionally, NG's IRAD projects typically apply rigorous and detailed SE practices, but they are often less formal, more streamlined, and more self-contained than for CRAD. The project leaders felt they applied the right amount of SE rigor, which resulted in a successfully tested prototype. Generally, NG indicated that they did execute most of the recommended SE activities listed in the framework.

Additional NG feedback indicated that the tailored weights did not always match with their assessment of required SE rigor. However, they said the framework was a good exercise to remind project managers and systems engineers to apply proper SE practices. NG suggested that applying inputs, outputs, constraints and sequencing to each SE activity would greatly increase the tool's value. This suggestion falls outside the scope of this research project and is recommended for follow-on work in Chapter V.

Case Study 5: Deployed Base Energy Study

The fifth case study is a project planning study to develop an investment strategy for creating more efficient methods of providing energy to deployed airbases. The Deployed Base Energy study was conducted by AFRL's Materials and Manufacturing Directorate (AFRL/RX). This case study was unique because it only focused on early SE processes associated with determining requirements, logical analysis, and making decisions about what technologies to pursue. This activity did not intend to deliver any capabilities, so it was a good test for the left-hand side of the systems engineering "Vee".

The project domain values for the Deployed Base Energy study were: 6.2, <$500K, CP-3, TRL 3-9, System and Subsystem Levels, and Requirements Pull.

The Deployed Base Energy study used a self-contained SE methodology, called Systems Engineering For Science and Technology (SETFST), which is a "multi-criteria analytical process for comparing alternatives" [SynGenics, 2008; 10]. The SETFST method encompasses similar activities to the early DAG technical and technical management processes. The five SETFST process steps are: 1. Assemble an Integrated Product Team; 2. Develop Desirements; 3. Generate Alternatives; 4. Evaluate Alternatives; and 5. Document. These easily map to TP-1 (Requirements Development), TP-2 (Logical Analysis), and TMP-1 (Decision Analysis). The study intended to evaluate possible design solutions, not deliver a specific design, so the rest of the DAG processes were not applicable for this phase of the project.

This case study review consisted of the point of contact's assessment of how the framework's recommended activities were accomplished via the mature SETFST process, followed by a personal interview. The review clearly demonstrated that the DAG TP-1, TP-2, and TMP-1 activities and weights were in line with the successful SETFST study results. The project subject matter expert also closely evaluated the rest of the processes, activities and weights in the tool and assessed that they were reasonable, based on his 20+ years of systems engineering experience. Specifically, he couldn't find justification to change any activities or weights within the framework. He suggested that the User's Guide should introduce the tailoring tool at a more basic level, but liked the flexibility of the framework. He also noted that the tool would be useful primarily to users who had a basic familiarity with systems engineering activities, but that the new user may struggle with some of the terminology and intent contained within the framework. This resulted in the addition of a Glossary tab in the tool.

Case Study 6: Basic Research RXQ Project

The sixth case study came as a direct result of the team traveling to Tyndall AFB, FL for the Systems Engineering Council Face-to-Face meeting to present project status and tool demonstration on 2-4 February 2009. Specifically, conversations with AFRL/RXQ during a side-session of the meeting presented an opportunity for the team to conduct this case study with the two project leads.

While presenting background information and the requirement for this thesis effort, the team outlined the 8 questions from AFRLI 61-104 (not currently required by the instruction for 6.1 projects). The points of contact quickly recognized the questions relating to AFRL Form 2913 (Sept 2002), required by AFRLI 61-202 "Laboratory Management Review (LMR)." When asked about the usefulness of these questions, the senior project lead stated that filling out the form was a burden until the new technical director helped them see that going through the LMR process actually helped them structure their projects, with the example of translating the goal of their basic research into the requirement for the project. An additional observation identified differences between basic research and systems engineering. His assertion was that SE drives design toward a known goal (i.e. system), while basic research is largely guided by the data presented from the experiment itself.

As the team began the case study review of “Characterization of the Nucleation and Binding Sites of Hen-Egg-White-Lysozyme to Silica”, the research team tried to get the project officers to give “Yes/No” answers to the Level 2 SE activities. It was quickly apparent that the project officers needed the team to translate each of the SE activities within the framework into vernacular more familiar to basic research scientists. In an attempt to overcome this obstacle, the team explained the Level 2 SE activities within the framework until the project officers understood the underlying value of the activity and replied with similar activities performed for basic research. This approach proved cumbersome, so the team elevated the interview goal to determining if the project officers understood the simple definition of the activity or if it needed translation. Ultimately, the time and effort involved for translation and explanation led the team to abandon a detailed review of the case study, with obvious conclusions in hand.

The team recognized that the framework will have limited usefulness for the 6.1 community as written. To make the framework applicable to basic research projects, the SE terminology must be translated and adapted to more closely represent existing scientific discovery methods. Additionally, an adjustment must be made to the framework to allow tailoring for a lower level in the Integration Level discriminant (for instance, “Component” or “Technology” for cases where a project with a single functional output is desired. These modifications, though critical to implementing the framework for the 6.1 community, were realized too late to be implemented under this research project. They are contained as follow-on project recommendations in Chapter V.

Validation

To validate the framework, the team provided a Beta version of the Systems Engineering Tailoring Tool for Science & Technology Projects (SETT-STP) framework to eight senior AFRL scientists and engineers with SE experience. The accompanying instructions asked the validators to review two out of four notional project types (Table 6.) A column in the tool allowed for specific comments for each SE activity and tailored level of SE Rigor, as well as general comments based on Functionality, Activity Descriptions, Tailoring, References and Tools, and General Comments. Six validation responses were received and grouped into several functional areas: SE Rigor; Terminology; Methodology; Tool Usability; CONOPS; and Follow-On Work. The predominant results are contained in the SE Rigor, CONOPS, and Follow-On Work areas. The team analyzed the responses for trends as well as incorporating specific recommendations where possible. Many recommendations were too large in scope or required major changes to the framework approach to be implemented prior to the

Table 8: Mapping of Validation Projects to Discriminants

Project	RDT&E			Budget			Core Process			TRL				Integration			Requirements	
	6.1	6.2	6.3	<$500K	500K-2M	>$2M	CP-1	CP-2	CP-3	1-2	3-4	5-6	7-9	Subsystem	System	Mission	Push	Pull
Project A		■			■			■			■				■			■
Project B	■			■			■			■				■			■	
Project C			■			■			■			■				■		■
Project D	Any Combination of Domain Values Selected by Validators																	

framework's release. These major recommendations are summarized in Chapter V for incorporation into future versions of the framework.

SE Rigor Comments

Most of the validation comments for the SE rigor percentages displayed in the tool were applicable to Project B. The validators recognized that many of the SE activities (as written in the framework) were not directly applicable to small, basic research projects and that the SE rigor values should be reduced, and in many cases even 0%. Although many specific changes were recommended, the team did not implement them in the tool, due to the previously recognized need to translate and adapt the SE framework for basic projects. Making detailed adjustments to the tailoring values would have little worth when an overhaul of the tool for 6.1 projects is a major recommendation from the validation effort.

The only other project to receive significant comments on the SE rigor values was Project C, where the validator agreed with the framework output, which tailors in nearly all SE activities at a formal level.

Terminology Comments

The two dominant overarching comments (and several detailed specific comments) from the validation phase reinforced conclusions drawn from the Basic Research case study. Specifically, the existing framework terminology for SE activities generally does not apply for 6.1 (Basic Research) projects. Additionally, a fourth domain value under the

Integration Level discriminant is required to describe single component or technology development activities. The research team strongly agrees with these comments, but was unable to implement them in the framework under the scope of this thesis. These changes are recommended in the follow-on work section in Chapter V.

Additional explanation is needed to instruct users that the selected TRL domain value should apply to the desired TRL end state for a given phase of a project. This change was made to the SETT-STP user guide and described in the methodology section of the thesis report.

Methodology Comments

The validation effort revealed suggestions about the number and nature of discriminant categories used in the project taxonomy that resulted in the activity tailoring results. One suggestion was to re-evaluate the discriminants to better define a fewer number of factors that are integral to recommending SE rigor for a project. The six discriminants that are in the framework were developed as a direct reflection of how AFRL manages its projects today. The student team considered an initial approach for the project taxonomy that used just two overarching discriminants (Project Complexity and Project Maturity). This approach was discarded, as it did not provide enough fidelity to capture the broad range of AFRL project types that could benefit from the tailoring framework. Note that a framework user can set up the tool to incorporate just one or two discriminants and still obtain proper tailoring recommendations.

A different suggestion was that using Core Processes as a discriminant might indicate that some customers deserve more SE than others. This is an accurate assessment based on the ability of the customer organization to add additional SE rigor to the ultimate end product. For instance, a CP-3 project delivers to an operational user who can't perform additional integration or data management planning, whereas a CP-2 project typically delivers to a Systems Program Office who will have formal SE processes in place to ensure the final deliverable is matured by the maximum possible level of SE rigor. Thus, an AFRL CP-3 project should apply more SE rigor than a CP-2 project. There should be no interpretation on the level of importance of one customer over another based on this distinction.

Another suggestion was that the RDT&E Budget Category discriminant should not affect the framework's recommended tailored SE rigor level. The team disagrees with this assessment, as the vast differences between a 6.1 project and a 6.3 project, as noted in the case studies, are enough to drive an overhaul to the terminology and application of SE principles based solely on the type of research project (6.1 vs. 6.2/6.3).

A fourth suggestion was that the Integration Level is a more important discriminator and driver of SE rigor than TRL. The tailoring results and accompanying sensitivity analysis contained in Appendix C show that Integration Level and Requirements Maturity had almost no effect on SE rigor tailoring values, so no changes were made based on this suggestion.

The final methodology suggestion was to include more than three Project Budget domain values. The project taxonomy originally included four Project Budget domain values, but was consolidated down to three due to a lack of difference in tailoring results between the top two categories. This approach would be useful if specific metrics could be captured on historic projects to provide additional tailoring insight.

Overall, none of the methodology comments resulted in changes to the final framework. However, some of the suggestions may be applicable to a follow-on tailoring effort.

Tool Usability Comments

Members of the AFRL SE Council provided usability feedback during individual and group presentations. Specific Council members and validators commented favorably on the tool's functionality and navigation ease, to the point of requesting the tool for their immediate use. Another comment praised the SE taxonomy, indicating the best use of the tool is in identifying a comprehensive set of SE activities to be accomplished by S&T projects.

CONOPS

Several suggestions were made as to how AFRL should apply the framework. None of these comments resulted in changes to the tool, but they are included for AFRL's future consideration. One suggestion was that the framework should be managed and implemented at the highest possible level within AFRL, thus increasing the chances of the tool improving SE coherence across Technology Directorates. The final comment re-iterated the thought that the framework, as currently written, does not cover the 6.1

(Basic Research) end of the S&T project spectrum, due to the challenges with relating SE concepts and terminology to the pure science community.

Follow-On Work Comments

Several comments recommended major changes to the SETT-STP framework that were not incorporated as part of this research. The need for a 6.1-specific translation and inclusion of a "component" value in the Integration Level discriminant were previously discussed.

A "high-medium-low" construct for SE rigor was recommended. The idea behind this is that ranges of tailored SE rigor percentages could be grouped into a simpler color-coded scheme that indicates whether the level of SE rigor should be high, medium, or low. This could also represent the recommended SE taxonomy activity detail level a project should follow. Notionally, "low" rigor activities should be limited to Level 2, "medium" will apply Level 3 activities, and "high" rigor categories should look at Levels 4 and 5. One concern with this is that not all Level 3 activities have subtended Level 4 and 5 activities. This construct was not implemented, but a description of SE rigor percentages and appropriate notional interpretations were included in Table 3 and in the User's Guide.

A suggestion was made to perform metrics collection on all AFRL projects that will validate future tailoring values and improve the framework for further utilization. This could possibly be implemented with an Excel macro to record parameter values and user comments. The research team applauds this suggestion but found that discerning specific, quantifiable metrics from historical and even existing projects was difficult. If this can be automated in the future, it will greatly assist AFRL in appropriately applying it resources toward successful SE.

Additional AFRL-specific information and tailoring for the “Tools” column in the tool would provide value to project leads. To accomplish this, a focused effort across AFRL will need to update the “Tools” column with AFRL-specific tools to augment the generally accepted tools that the research identified in the framework. Tailoring of specific tools to specific projects may require that the number of discriminants is reduced to ensure a feasible implementation.

V. Conclusions & Recommendations

The Air Force is continuing its efforts to implement systems engineering principles earlier in the life cycle of research and development projects. Proper systems engineering enables projects to meet cost, schedule, and performance objectives. Current guidance clearly states the need for early SE [Pre MS-A, 2008; DSB, 2008] and recent studies within the Air Force Research Laboratories [TASE, 2006; IRT, 2008] indicate isolated elements of successful SE. The recent implementation of the Focused Long Term Challenges (FLTCs) within AFRL provides a unique structure to further employ SE trades at the mission, system, and subsystem and component levels. Additionally, AFRL's current operating instructions take a critical first step towards challenging project managers, scientists, and engineers to consider SE principles for the execution of their projects. These principles, based on the eight Technical Processes (TPs) and eight Technical Management Processes (TMPs) from the Defense Acquisition Guidebook (DAG), are embodied in the eight questions in AFRLI 61-104. Additionally, it is clear that the AFRL Systems Engineering Council is making strides towards sharing and implementing SE best practices between the technology directorates. If additional gains towards cohesive SE within AFRL are to be achieved, subsequent updates to operating instructions must include a set of common and manageable practices and tools that take the existing eight questions to the next level of SE rigor. Implementing the SETT-STP Framework will take a large step toward AFRL realizing its goal of systems engineering excellence.

This research developed a framework which incorporates a taxonomy of the SE activities embodied in the DAG, the International Council for Systems Engineering (INCOSE) Handbook [INCOSE, 2006], and "The Engineering Design of Systems: Models and Methods" by Dennis Buede [Buede, 1999]. Although it was not a primary objective of the research, the SE Taxonomy was cited by several interested parties to be a valuable stand-alone by-product. The SE Taxonomy provides a comprehensive list of SE activities that are functionally and hierarchically organized, with the capability to sort to desired detail levels. Likewise, the Project Taxonomy sets the foundation for describing a project's state, and is not limited to DoD terminology. This taxonomy was refined through a rigorous evaluation of case studies and validation reviews. Additionally, the customizable nature of the Project Taxonomy allows it to be adapted to meet any S&T organization's needs.

The framework includes a methodology for tailoring the specific SE activities for a unique project state, based on common discriminants and domain values currently found within AFRL. The tailoring applies a combination of engineering assessment and numerical analysis that results in weight factors for each project discriminant as they affect an independent assessment of SE activity applicability. The product from this framework, the SETT-STP tool, is intended as guidance for the amount of relative SE rigor to apply for each SE activity on a given project. The tool uses accepted SE principles and is designed to augment existing AFRL policies and practices. If properly utilized, SETT-STP will allow scientists and engineers to simply input their project's state descriptors and receive as output a comprehensive set of SE activities and their recommended rigor that will enable a final deliverable product ready for successful transition to the project's customer (Figure 9).

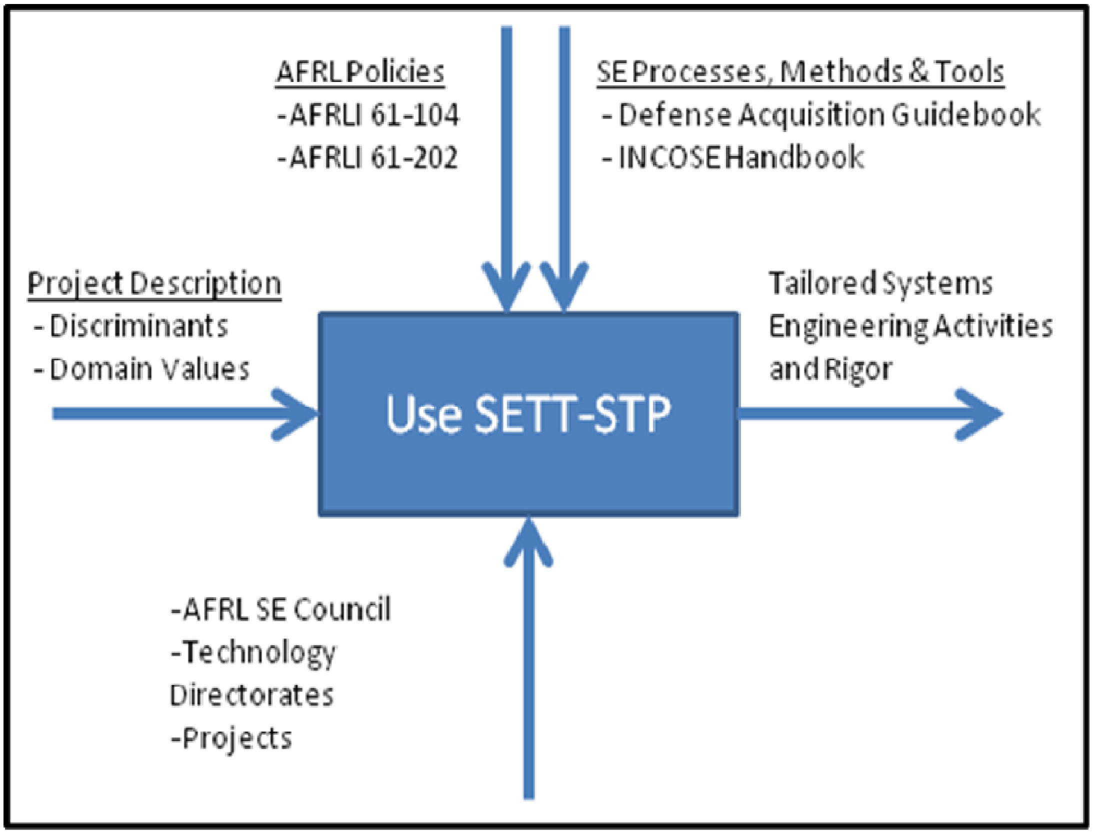


Figure 9: SETT-STP Functional Diagram

The onus is on each project manager within their specific management structure to interpret, adapt, and even modify the tailoring recommendations to best suit the needs of their project. The tailoring recommendations from SETT-STP must be evaluated within the project context and should not be taken as a directive for specific implementation. Heuristically, larger programs need to execute a greater number of SE activities to a greater level of formality and small projects are not relieved of their responsibility to apply appropriate SE rigor. Feedback from the case studies and interactions with the

AFRL SE Council indicate SETT-STP appropriately establishes a framework for approaching what SE activities are suitable. Specifically, the SE Taxonomy compiles proper SE activities for S&T projects in a hierarchical manner, which in turn facilitates the tailoring of those activities to a specific project state. Finally, SETT-STP is applicable to any development project (laboratories, program offices, and commercial developments, and maybe even humanity's grand challenges [NAE, 2008]) and allows scientists, technologists, engineers, and project managers the opportunity to drill down through the activities and consider whether they are appropriate for a specific project.

Specific Recommendations

The research revealed several opportunities for AFRL to consider in strengthening the SE program implementation.

1. **AFRL should continue to emphasize the utilization of the 16 DAG processes as a common reference.** AFRL made a critical step in this direction with the 8 questions in AFRLI 61-104, including a gross mapping to the DAG processes in Attachment 1 [S&T SE, 9-18]. Utilizing this established and widely recognized document, in conjunction with the SE Taxonomy hierarchy implemented in SETT-STP, provides the opportunity to mature the project question matrix and the AFRLI 61-104 Attachment 1 correlation to the DAG.

2. **AFRL should increase visibility of SE activities within the FLTC construct.** By tailoring reportable SE activities at the Challenge, Problem, Attribute, Product, and Program level, AFRL could bolster systems engineering implementation

within the FLTCs. While this visibility of SE activities may be perceived as an additional burden, standardizing the review process to highlight achievement of tailored activities within the FLTCs, Core Processes, and Technology Directorates (i.e. everyone reviewing the same criteria) will ultimately streamline the amount of reportable and inspectable information.

3. **AFRL should use training and mentorship to foster a culture of "Systems Thinking."** Scientists and engineers must be able to recognize systems engineering principles in order to correctly implement them. The SE case studies demonstrated that the thought process behind systems engineering occurs more than is commonly realized. Putting more formal and informal attention toward recognizing SE activities in everyday work will increase the acceptance of the "SE mindset" and promote a receptive culture that will lead to more proper and rigorous SE implementation.

4. **AFRL should consolidate and streamline its project management structure as well as systems engineering initiatives.** AFRL manages projects in several manners, as discussed when compiling the framework's Project Taxonomy. While each of the structures has merit and provides benefit to the project planning and execution process, the structures often interfere with each other and hamper systems engineering and integration success. Likewise, SE initiatives under the purview of individual technology directorates each provide some benefit, but result in a fractured and inefficient overall approach to improving SE across AFRL. Picking the best practices and expanding them in a smart, integrated manner will provide the most effective SE value for all S&T projects.

5. **AFRL should begin using the SETT-STP framework to guide SE efforts within the Technology Directorates.** This research was built on existing DoD and AFRL SE policy and guidance. It was validated by S&T projects with reported SE success. The case studies, incorporated primarily at the recommendation of the SE Council, spanned multiple directorates within AFRL, each with unique approaches and practices that validated the SE activities listed in the framework. As the SE Council continues to explore the benefits of various approaches to implement SE across the Technical Directorates, it should build upon existing practices to employ standardized processes, methods, and tools in the provided common tailorable framework.

Recommended Follow-On Work

The research revealed several opportunities for future work that was not within the scope of the research.

1. Further customization and tailoring of the framework, to translate/adapt to 6.1 projects, to include 6.1 specific tools, and to add the ability to tailor at the component or technology level within the "Integration Level" discriminant.

2. Incorporate AFRL specific "tools / best practices" not listed in the SETT-STP framework. The tool has application to every technology directorate, but there may be additional tailoring (additions or subtractions) needed for the SE activity list in SETT-STP. An example would be adding specific activities from the Rational Unified Process (RUP) used by AFRL/RI.

3. Validate the specific language within the SE Taxonomy activities to enable formal AFRL endorsement. A recommended avenue to accomplish this is to create an AFRL Integrated Dictionary for terms within the SE Taxonomy.

4. Determine which reference materials will be formally accepted within AFRL framework, as the INCOSE Handbook [INCOSE, 2006] and the Buede textbook [Buede, 1999] were utilized for the framework.

5. Provide specific guidance as to how to interpret the "SE Rigor" results from the framework. The research provides a recommended interpretation as a starting point.

6. Implement a level of standardization across directorates by providing instruction as to how to establish the context of the project being evaluated, whether it be a specific technology project or an FLTC designator at the Problem (X.X) or Capability (X.X.X) level. The SE activities should be applied to the same context (possibly add room on front page of tool to identify scope or the context of the project).

7. Add inputs, outputs, constraints, sequencing, and related activities for each SE activity. This will transform the SE taxonomy from just a list of (sequential) activities into a tool that incorporates project flow and emphasizes the relationships between the SE activities.

Appendix A. Case Study Pre-Survey Questionnaire

Your project has been identified for inclusion as a case study in the "Systems Engineering in a Science & Technology Environment" thesis project at the Air Force Institute of Technology. The following initial information regarding your project is requested in order to better approach interactions during the case study period of the thesis project:

Project Name:
Point of Contact:
AFRL Directorate:
Phone Number:
Email:

Please identify where your project falls with respect to the following areas. Choose a single best answer if possible. Descriptions are provided on the following pages:

1) **Primary RDT&E Budget Category**

   6.1 Basic Research
   6.2 Applied Research
   6.3 Advanced Technology Development

2) **Total S&T Project Budget**

   Budget$\leq$ \$500K
   \$500K < Budget $\leq$ \$5M
   Budget $\geq$ \$5M

3) **Core Processes**

   CP-1 CP-2 CP-3

4) **Technology Readiness Level**

   TRL 1-2 TRL 3-4 TRL 5-6 TRL 7-9

5) **Level of Integration / System Hierarchy**

   Subsystem Level Technology
   System Level Concept
   Mission Level Concept

6) **Requirements Maturity**

   Technology Push
   Requirements Pull

DISCRIMINANT #1: Research, Development, Test and Evaluation (RDT&E) Budget Category

Source: DoD Financial Management Regulation Volume 2B, Chapter 5, July 2008
Reference:
http://www.dtic.mil/descriptivesum/RDTE_Budget_Activies_Establishing_RDTE_Program_Elements.pdf

DOMAIN VALUE: Budget Activity 1, Basic Research. Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress. Basic research may lead to: (a) subsequent applied research and advanced technology developments in Defense-related technologies, and (b) new and improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials and structures, and personnel support. Program elements in this category involve pre-Milestone A efforts.

DOMAIN VALUE: Budget Activity 2, Applied Research. Applied research is systematic study to understand the means to meet a recognized and specific need. It is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. It may be oriented, ultimately, toward the design, development, and improvement of prototypes and new processes to meet general mission area requirements. Applied research may translate promising basic research into solutions for broadly defined military needs, short of system development. This type of effort may vary from systematic mission-directed research beyond that in Budget Activity 1 to sophisticated breadboard hardware, study, programming and planning efforts that establish the initial feasibility and practicality of proposed solutions to technological challenges. It includes studies, investigations, and non-system specific technology efforts. The dominant characteristic is that applied research is directed toward general military needs with a view toward developing and evaluating the feasibility and practicality of proposed solutions and determining their parameters. Applied Research precedes system specific technology investigations or development. Program control of the Applied Research program element is normally exercised by general level of effort. Program elements in this category involve pre-Milestone B efforts, also known as Concept and Technology Development phase tasks, such as concept exploration efforts and paper studies of alternative concepts for meeting a mission need.

DOMAIN VALUE: Budget Activity 3, Advanced Technology Development (ATD). This budget activity includes development of subsystems and components and efforts to integrate subsystems and components into system prototypes for field experiments and/or tests in a simulated environment. ATD includes concept and technology demonstrations of components and subsystems or system models. The models may be form, fit and function prototypes or scaled models that serve the same demonstration purpose. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility rather than the development of hardware for service use. Projects in this category have a direct relevance to identified military needs. Advanced Technology Development demonstrates the general military utility or cost reduction potential of technology when applied to different types of military equipment or techniques. Program elements in this category involve pre-Milestone B efforts, such as system concept demonstration, joint and Service-specific experiments or Technology Demonstrations and generally have Technology Readiness Levels of 4, 5, or 6. Projects in this category do not necessarily lead to subsequent development or procurement phases, but should have the goal of moving out of Science and Technology (S&T) and into the acquisition process within the future years defense program (FYDP). Upon successful completion of projects that have military utility, the technology should be available for transition.

DOMAIN VALUE: OTHER. This includes Budget Activity 4, Advanced Component Development and Prototypes (ACD&P); Budget Activity 5, System Development and Demonstration (SDD); Budget Activity 6, RDT&E Management Support; and Budget Activity 7, Operational System Development.

Budget Activity 4, Advanced Component Development and Prototypes (ACD&P). Efforts necessary to evaluate integrated technologies, representative modes or prototype systems in a high fidelity and realistic operating environment are funded in this budget activity. The ACD&P phase includes system specific efforts that help expedite technology transition from the laboratory to operational use. Emphasis is on proving component and subsystem maturity prior to integration in major and complex systems and may involve risk reduction initiatives. Program elements in this category involve efforts prior to Milestone B and are referred to as advanced component development activities and include technology demonstrations. Completion of Technology Readiness Levels 6 and 7 should be achieved for major programs. Program control is exercised at the program and project level. A logical progression of program phases and development and/or production funding must be evident in the FYDP.

Budget Activity 5, System Development and Demonstration (SDD). SDD programs have passed Milestone B approval and are conducting engineering and manufacturing development tasks aimed at meeting validated requirements prior to full-rate production. This budget activity is characterized by major line item projects and program control is exercised by review of individual programs and projects. Prototype performance is near or at planned operational system levels. Characteristics of this budget activity involve mature system development, integration and demonstration to support Milestone C decisions, and conducting live fire test and evaluation (LFT&E) and initial operational test and evaluation (IOT&E) of production representative articles. A logical progression of program phases and development and production funding must be evident in the FYDP consistent with the Department's full funding policy.

Budget Activity 6, RDT&E Management Support. This budget activity includes research, development, test and evaluation efforts and funds to sustain and/or modernize the installations or operations required for general research, development, test and evaluation. Test ranges, military construction, maintenance support of laboratories, operation and maintenance of test aircraft and ships, and studies and analyses in support of the RDT&E program are funded in this budget activity. Costs of laboratory personnel, either in-house or contractor operated, would be assigned to appropriate projects or as a line item in the Basic Research, Applied Research, or Advanced Technology Development program areas, as appropriate. Military construction costs directly related to major development programs are included.

Budget Activity 7, Operational System Development. This budget activity includes development efforts to upgrade systems that have been fielded or have received approval for full rate production and anticipate production funding in the current or subsequent fiscal year. All items are major line item projects that appear as RDT&E Costs of Weapon System Elements in other programs. Program control is exercised by review of individual projects. Programs in this category involve systems that have received Milestone C approval. A logical progression of program phases and development and production funding must be evident in the FYDP, consistent with the Department's full funding policy.

050202 Establishing RDT&E Program Elements

A. The program element is the primary data element in the Future Years Defense Program (FYDP) and is the major aggregation, at which RDT&E efforts are organized, budgeted and reviewed. All funding associated with a major system new start should be identified in a unique program element. Requests to establish program elements should be forwarded to OSD Program Analysis and Evaluation for coordination and approval. Instructions are contained in DoD 7045.7-H, "The FYDP Program Structure Handbook."

B. In general, the coding symbology identifies the RDT&E budget activity for the program element. Program elements in RDT&E budget activities 1 through 6 will have "06" in the first two positions; "06"indicates it is part of Major Force Program 6, Research and Development. The third and fourth position will identify the specific budget activity (e.g., 0602 is an RDT&E budget activity 2 program element). Program elements in RDT&E budget activity 7 reflect the Major Program of the fielded system in the first two positions (e.g., "01" indicates a strategic system).

DISCRIMINANT #2: Total S&T Project Budget

This descriminant captures the total funding size of the S&T project across fiscal years. As it is used to distinguish relative size of the project, the division of domain values was set to discriminate very small projects from very large projects such as an integrated Advanced Technology Demonstration. "Budget" refers to the estimated project costs for the lifetime of the science & technology program. It includes costs for the prior, current and planned future years of the project's research and/or demonstration phase (as opposed to full system development or production.)
Note: If the project is an integrated demonstration, do NOT include costs of subsystem or component-level projects being done under separate project budget authority.

DOMAIN VALUE: Budget ≤ $500K

DOMAIN VALUE: $500K < Budget ≤ $5M

DOMAIN VALUE: Budget ≥ $5M

DISCRIMINANT #3: Core Processes

DOMAIN VALUE: Core Process 1 (CP1)
Projects that address future technology concepts to senior Air Force leadership and/or advance a core technology that influences the broader S&T community are referred to CP1. Projects progressing through CP1 that have identified a transition customer are then referred to CP2 to continue maturation of the technology, ready for integration into an acquisition or sustainment program.

> **Source: AFRL Enterprise Process Management – Volume II: Core Process 2, Paragraph 4.1.1.1.1/2**

DOMAIN VALUE: Core Process 2 (CP2)
CP2 is the process that enables AFRL to identify and mature technologies needed to enhance or transform weapons systems and contribute to a successful technology transition process. It is designed to have strong ties to acquisition, sustainment, and industrial communities and to focus on product delivery – the emphasis is on developing and delivering affordable, timely, and transitionable technology options characterized by disciplined program management and systems engineering and heavily drawing upon the research from Core Process 1. Therefore, the primary outputs of CP2 are mature technologies ready for integration into an acquisition or sustainment program – technologies that shape today's Air Force.

> **Source: AFRL Enterprise Process Management – Volume II: Core Process 2, Paragraph 1.3**

DOMAIN VALUE: Core Process 3 (CP3)
Core Process 3 (CP3) addresses near-term warfighter technology needs through the rapid infusion, integration, and innovation of S&T-based solutions that capitalize on the breadth and depth of AFRL's expertise. CP3 is designed to tightly integrate AFRL S&T knowledge with operator knowledge to deliver solutions to the warfighter in 6-12 months. The solutions may utilize individual or focused technology application (in which case the process is usually executed at the TD level), or cross- and multi-discipline technology solutions (executed at the enterprise level). CP3 encompasses technology demonstrations and corporate efforts for consulting and prototyping to meet near term warfighter technology needs. CP3 requires a framework that tolerates risk-taking and innovative, unconventional (out-of-the-box) thinking, yet focuses on delivering viable solutions. To provide these attributes, CP3 requires the cultural, institutional, and business support systems needed to rapidly deliver innovative capability to Air Force and other AFRL customers and stakeholders.

> **Source: AFRL Enterprise Process Management – Volume III: Core Process 3, Paragraph 1.3**

DISCRIMINANT #4: Technology Readiness Level

Technology Readiness Levels are determined by a Technology Readiness Assessment (TRA), a "regulatory information requirement for all acquisition programs. It is a systematic, metrics-based process that establishes the maturity of critical technology elements. The TRA should be conducted concurrently with other technical reviews such as the Alternative Systems Review, System Requirements Review, or the Production Readiness Review. (Defense Acquisition Guidebook)

> **Source: Glossary of Defense Acquisition Acronyms & Terms, 12th Edition, July 2005.**
> **Reference: https://akss.dau.mil/jsp/glossary.pdf**

DOMAIN VALUE: TRL 1-2

TRL-1: Basic principles observed and reported.
Description: Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
TRL-2: Technology concept and/or application formulated.
Description: 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.

DOMAIN VALUE: TRL 3-4

TRL-3: Analytical and experimental critical function and/or characteristic proof of concept.
Description: Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
TRL-4: Component and/or breadboard validation in laboratory environment.
Description: Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.

DOMAIN VALUE: TRL 5-6

TRL-5: Component and/or breadboard validation in relevant environment.
Description: Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
TRL-6: System/subsystem model or prototype demonstration in a relevant environment.
Description: 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 simulated operational environment.

DOMAIN VALUE: TRL 7-9

TRL-7: System prototype demonstration in an operational environment.
Description: Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
TRL-8: Actual system completed and qualified through test and demonstration.
Description: Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
TRL-9: Actual system proven through successful mission operations.
Description: Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

DISCRIMINANT #5: Level of Integration / Demonstration –OR– System Hierarchy

The Air Force S&T Vision is "Anticipate, Find, Fix, Track, Target, Engage, and Assess – Anything, Anywhere, Anytime" (p.4). In order to realize this Vision, the Air Force Research Laboratory has divided their projects into Focused Long Term Challenges (FLTCs) in order to characterize the Air Force problem space and provide a framework for long term S&T planning. The FLTC framework facilitates a dialog with stakeholders of planning priorities and desired effects without prematurely dictating "solutions, platforms, or domain specific assumptions" (p.8) or the "type, source, or timing of potential technical solutions"(p.30). FLTCs are currently divided into the following categories: Technology Challenges, Problem Statements, Attributes, Products, and Programs.

Source: AFRL Capability Based S&T Strategy 2030, 31 July 2007.

In order to make the taxonomy more generic and applicable to the AFRL context as well as other government agency (OGA) and industry contexts, the following domain values describe the level of integration and/or demonstration of a concept or technology into an applicable system hierarchy:

Source: Student Defined

DOMAIN VALUE: Subsystem Level (or below) Technology
Target project/demonstration is at the subsystem level (or lower … i.e. component). A fully developed system concept may not yet exist. A wide range of external dependencies are possible, and may be only notionally defined. It is also possible that a target system/component is already identified.

DOMAIN VALUE: System Level Concept / Demonstration
Target project/demonstration is contained to a specific system and/or S&T project. Will generally integrate subsystem and/or component technologies within the system concept. Interfaces are well understood and within control of the project lead.

DOMAIN VALUE: Mission Level Concept / Demonstration
Target project/demonstration includes multiple independent systems and/or project interfaces and may require integration at levels beyond the control of the project lead, and will generally have dependencies external to the project.

DISCRIMINANT #6: Requirements Maturity

Source: AF 63-101 "Operations of Capability Based Acquisition Systems"

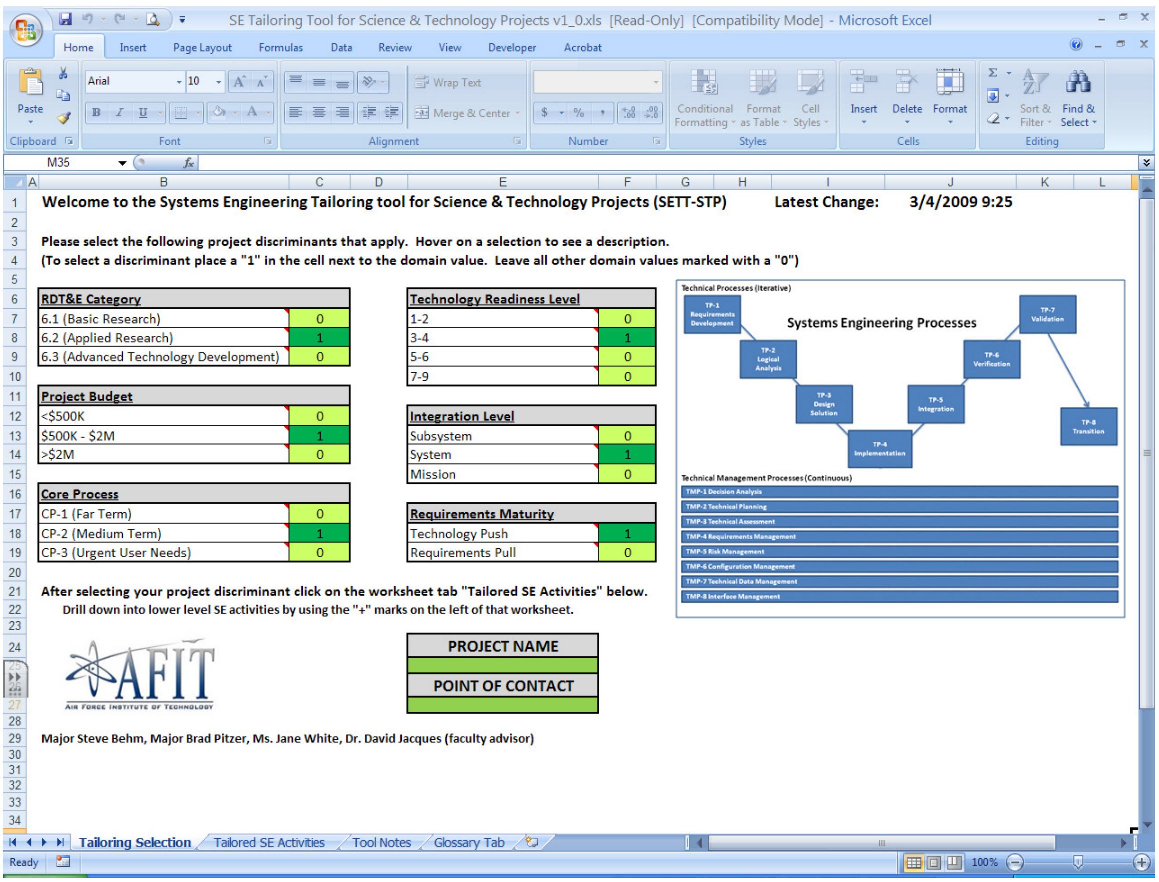
DOMAIN VALUE: Technology Push
Technology push is defined as technology that has the potential for new revolutionary warfighting capabilities (AF 63-101, 2.1.3).

DOMAIN VALUE: Requirements Pull
Requirements pull is defined as technology developed in response to documented operator needs (AF 63-101, 2.1.3).

Appendix B. SE Tailoring Tool User's Guide

Systems Engineering Tailoring Tool for S&T Projects

User's Guide (Version 1.0, 4 March 2009)



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Air Force Institute of Technology
March 2009

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Introduction

Systems engineering (SE) is essential to effectively developing and transitioning complex technical products, whether they transition to a higher Technology Readiness Level, to a more mature Science and Technology (S&T) effort, to a Systems Program Office, or to an operational user. However, executing the complete set of SE activities can be cumbersome, confusing, and not resource effective for the laboratory scientist.

This SE Tailoring Tool was developed to help S&T project managers decide which SE activities are either critical or of minimal importance for a certain type of project. It recognizes that all projects are not the same, and the maturity of the technology, the development lead-time, and even the project budget dictate the SE rigor that should be applied.

The tool provides a relative importance "weight" for over 350 individual SE activities based on the type of project. The results do not provide a "yes/no" checklist as to what to do and what not to do, but rather suggests a relative importance of activities to accomplish.

A few **Notes** before getting started:

- The tool is a starting point; not all projects will clearly fit the tailoring for the selected categories. Users may need to adjust their selections to adjoining domain values to get the tailoring that best suits their specific program.

- The tool describes WHAT to do, not necessarily HOW to do it. It assumes the user is familiar with basic SE terminology and principles and has access to more detailed information about specific tasks and suggested tools. The tool does provide ready references to defense, industry, and academic sources to aid the user on HOW to implement the activities.

- The tailoring tool can be an effective teaching aid, but it is not designed to be a self-contained SE training tool.

- Changes to the weighting can be made if one discriminant improperly dominates the weighting for a given project. See the "Advanced User Notes" section to adjust the weighting factors.

- Although users will be asked to select specific domain values for their project, the best results will be achieved if the user has a clearly defined context for the project as a sanity check on the results. For example, is the program a portion of a larger project effort, and what is the transition target for the program or project. Without the proper project context, the recommended SE activities will not provide the true systems engineering value to the project. All domain values should be based on the discriminant's desired end-state for the current phase of the project.

Getting Started

To start using the tool, open the file: _SE Tailoring Framework for S&T Projects v1_0.xls_ on a computer equipped with Excel 2007. Older versions of Excel will still fundamentally run the tool, but may lose some advanced functionality. The tool opens to the worksheet titled "Tailoring Section" and contains six blocks that describe the discriminants and domain values (see Figure 1). Each domain value has a definition embedded in the cell comment, so hovering over the red triangle in the upper right corner of the cell, or right clicking on "Show Comment" for a cell will display the definition. For a given project, the user should type a "1" in the appropriate block for each domain value that applies, and type a "0" for each value that does not apply. An optional space allows for saving the Project Name and Point of Contact.

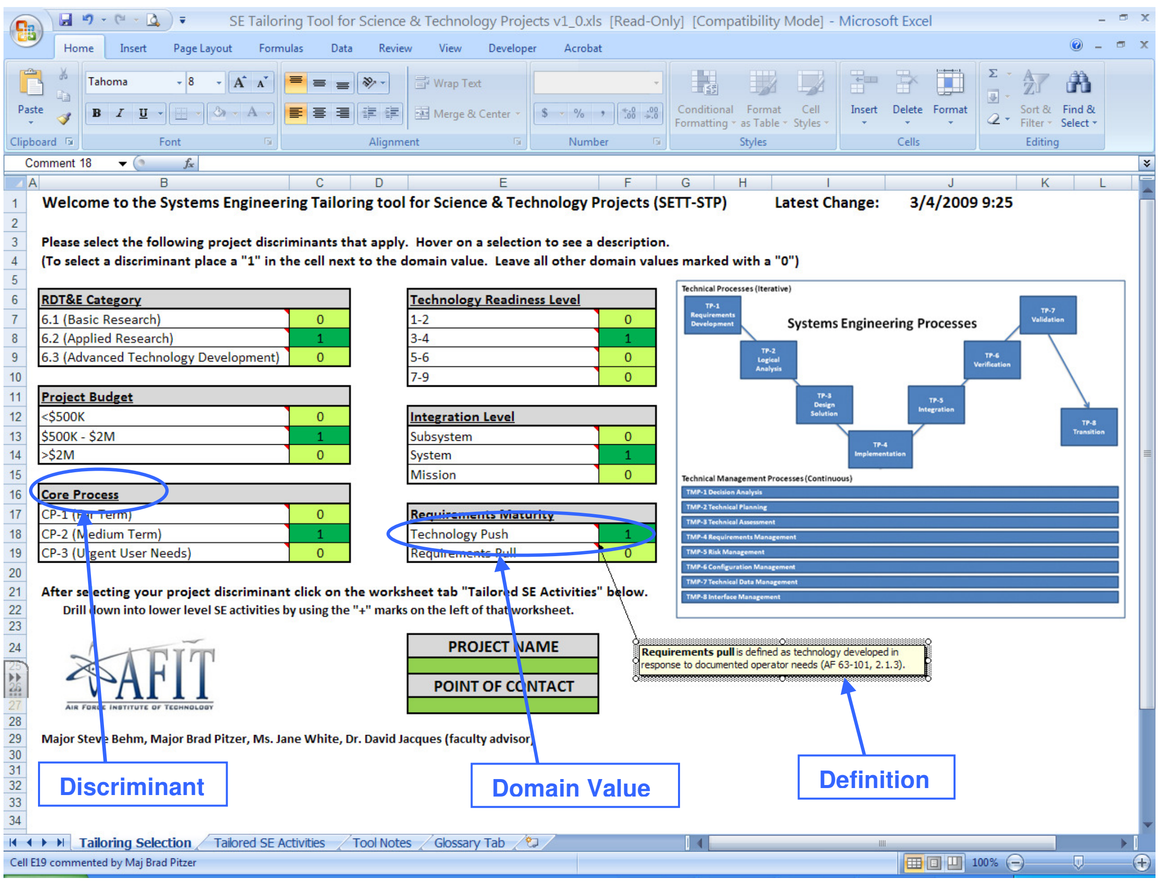


Figure 10: Tailoring Selection Screen

Note: The base file is "read only", so users will need to save the tailoring tool file for each set of project discriminants. This will ensure a common starting point for all projects, consistent display of results, and will maintain an unaltered version of the tool for later user.

Displaying Your Results

After the appropriate domain values are selected, click on the tab to select the "Tailored SE Activities" Worksheet (see Figure 2). The "Tailored SE Activities" screen contains the Defense Acquisition Guidebook's Technical Processes (TPs) and Technical Management Processes (TMPs), the activity detail level, the SE activity name, the literature source that the activity was derived from, the tools associated with the activity, and the tailored weight of that activity.

The tailoring weights are only directly applied to activities at level 3. The level 3 scores are rolled up for level 2 weights, which are represented by the highest and lowest activity weights from the subordinate level 3 activities. Likewise, the level 1 weights display the maximum and minimum weights from each of the level 2 categories. The scores will be in a range of 0% to 100%, with a 100% activity being critical to successful SE on the project, and 0% being of minimal impact. The default/initial display will show the roll-up weights associated with levels 1 and 2.

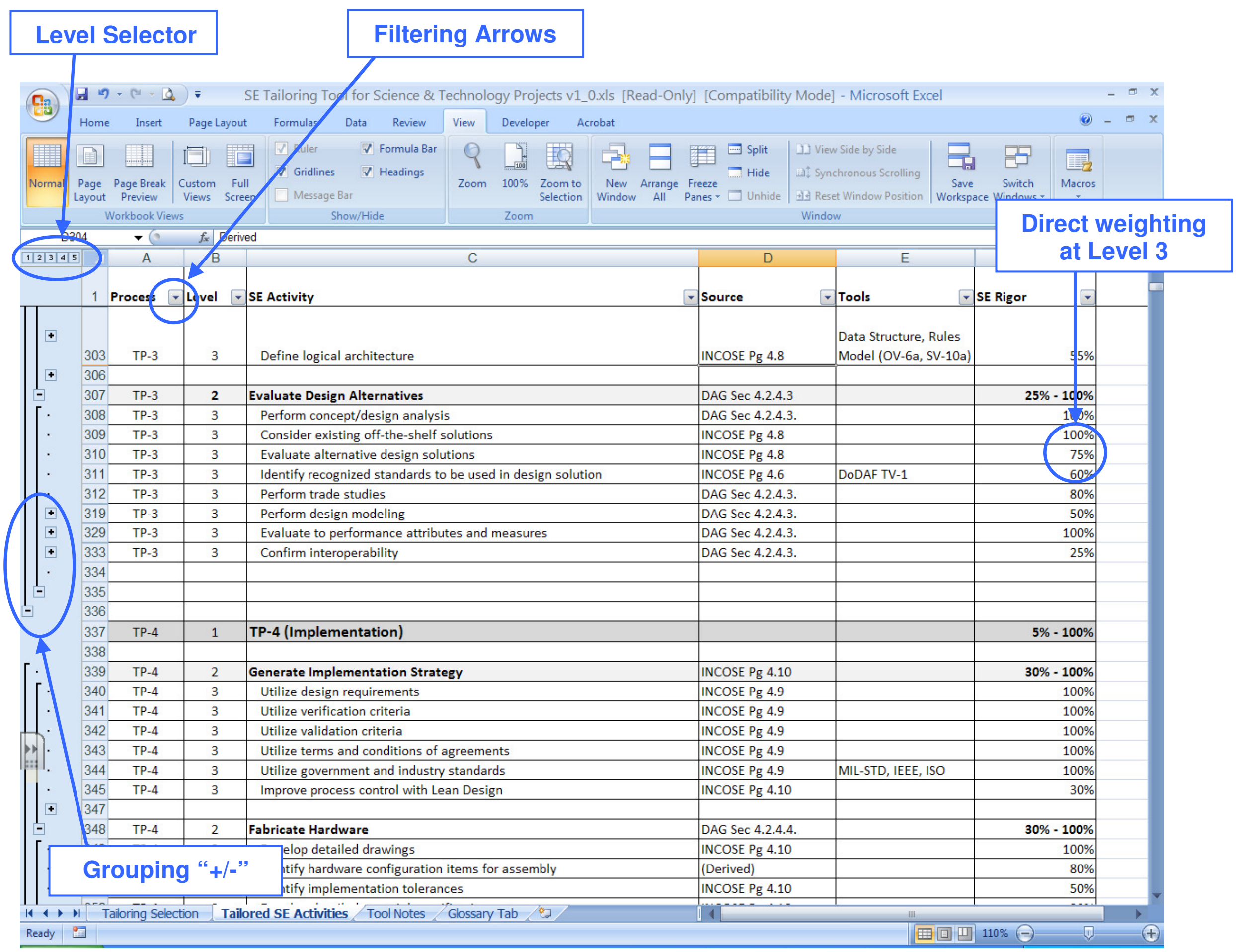


Figure 11: SE Tailoring Tool Activities Screen

Note: The tailoring weights for SE Activities will vary if something other than one domain value is selected for each project discriminant. For instance, if two values for Technology Readiness Level are selected, the weights will be different than if only one TRL value is selected. Likewise, if one discriminant is left with all "0" values selected, the weights will be different than if one domain value from each discriminant was selected. The tailored values will all still be based on a 0-100% weighting scale.

Grouping and Filtering

There is a "+" sign to the left of each activity. The "+" sign can be clicked for each process to drill down to the next level of SE activity grouping. This process can be repeated to expand activity details up to five levels, depending on the specific details included in the activity. Alternately, activity details can be expanded by clicking on the desired detail level (1, 2, 3, 4, or 5) from the upper left corner of the worksheet.

At the top of each data column, a dropdown box with a downward pointing arrow is displayed. These arrows allow for filtering on a specific piece of data within each column. For instance, if a user only wanted to display activities in TMP-5, the user would click on the dropdown box in column A "Process", then uncheck all boxes except for TMP-5.

Note: Users are encouraged to use the filtering for the "Process", "Level", and "Tailored Weight" data columns for displaying data. Use filtering for the "SE Activity", "Source", and "Tools" data columns only to find specific items, or use the search feature in Excel.

Note: The filtering will override the previously selected display grouping. The grouping can be restored for the filtered selection by clicking on the appropriate "+" or "-". Clicking on the grouping number boxes in the upper left corner will override the filtering selection.

Advanced User Notes

The SE activity weighting factor system is embedded and hidden in the tool. The base factors are:

RDT&E Category: 0.2
Project Budget: 0.3
Core Process: 0.2
Technology Readiness Level: 0.2
Integration Level: 0.05
Requirements Maturity: 0.05

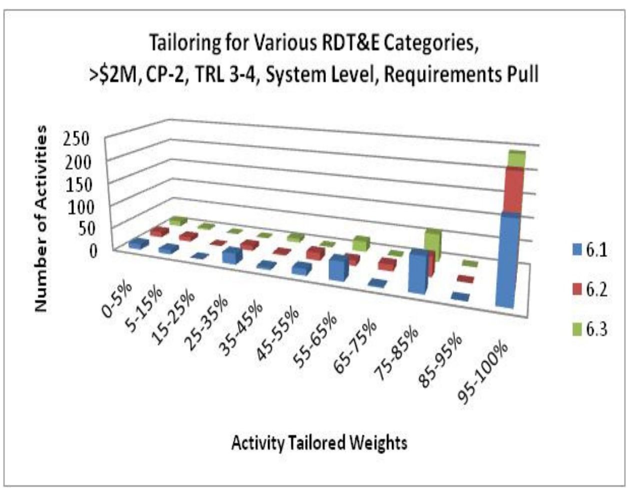
The factors can be changed, but it is necessary that the factors sum to 1.0 in order to keep the weighting scale at 0-100%. To access them, select columns "Y" through "AH", right click, and select "unhide". Make sure that all rows are displayed; this is best done by clicking on the "5" in the detail level selector in the upper left corner of the worksheet. The factors are located in column AE. Hide the factors by highlighting columns "Z", through "AG", right click, and select "hide". **DO NOT** change the other values in columns "Z" through "AF" or the tailoring weight calculations will be lost.

Activities can be added or deleted by inserting or deleting a selected row, respectively, within Excel. If an activity is added at Level 3, tailoring should be included for each possible domain value. To access the tailoring markings, select columns "E" through "Y", right click, and select "unhide". The discriminant categories and domain values are listed at the top of the spreadsheet. Place a "1" in the appropriate box if the activity is deemed necessary for successful completion of a project in that domain value; place a "0" in that box otherwise. To display the calculated weight, select the cell for weight of an adjoining level 3 activity, copy it, and paste it in the weight column of the new activity. Do NOT drag an adjoining weight into the new cell. Hide the tailoring values by highlighting columns "F", through "X", right click, and select "hide". After inserting or deleting an activity, that process' activities need to be re-grouped. Use the "group" and "ungroup" features on the "data" menu in Excel 2007.

Appendix C. Tailored Weight Statistical Analysis

The tailored weights were analyzed to understand the impact of each discriminant on the total tailored weight for each Level 3 activity. The baseline project type for the analysis is 6.2, $500K - $2M, CP-2, TRL 3-4, System Level, and Requirements Pull. From this baseline, each discriminant was modified to each contained domain value. For each domain value, the tailored weight was recorded for the 350 Level 3 activities. The tailored weights were then binned, with bin widths of 10%, to output total numbers of Level 3 activities that fall in each bin. It is important to note that weight factors were applied as follows: RDT&E Category: 0.2; Project Budget: 0.3; Core Process: 0.2; TRL: 0.2; Integration Level: 0.05; and Requirements Maturity: 0.05. The data and analysis for each varied discriminant follows.

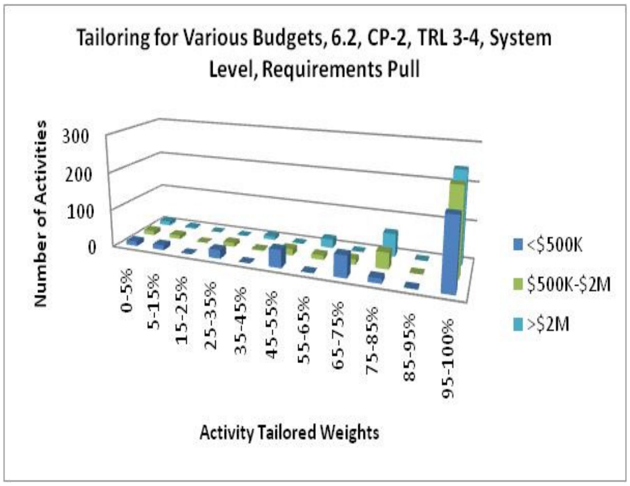
Various RDT&E Categories, $500K - $2M, CP-2, TRL 3-4, System Level, Rqmts Pull



Bins	6.1	6.2	6.3
0-5%	12	12	12
5-15%	10	10	4
15-25%	0	0	0
25-35%	24	11	0
35-45%	5	3	9
45-55%	14	17	0
55-65%	41	12	23
65-75%	2	14	0
75-85%	75	43	60
85-95%	0	0	0
95-100%	165	228	242

Analysis: This discriminant has a significant effect on the tailoring. The portions of 100% weights comprise 47% of all 6.1 activities, 65% of all 6.2 activities, and 69% of all 6.3 activities.

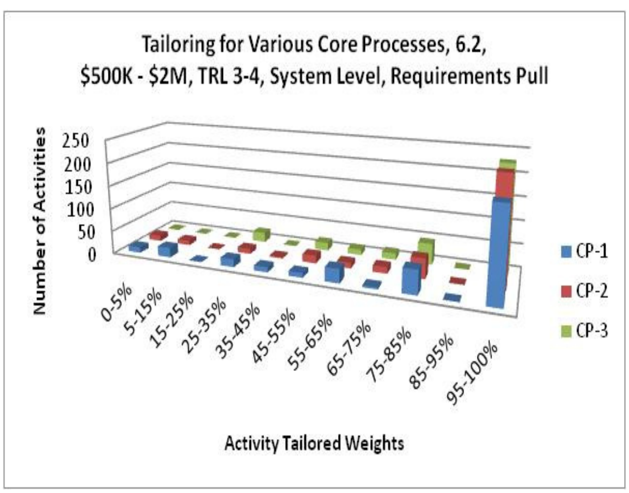
Various Budget, 6.2, CP-2, TRL 3-4, System Level, Rqmts Pull



Bins	<$500K	$500K-$2M	>$2M
0-5%	12	12	12
5-15%	13	10	4
15-25%	0	0	0
25-35%	23	11	0
35-45%	0	3	9
45-55%	47	17	0
55-65%	0	12	23
65-75%	57	14	0
75-85%	13	43	60
85-95%	0	0	0
95-100%	185	228	242

Analysis: This discriminant has a significant effect on the tailoring. The portions of 100% weights comprise 53% of all low budget activities, 65% of all middle budget activities, and 69% of all high budget activities. Additionally, the portions of weights below 55% comprise 27% of all <$500K activities, 15% of all $500K-$2M activities, and only 7% of >$2M activities.

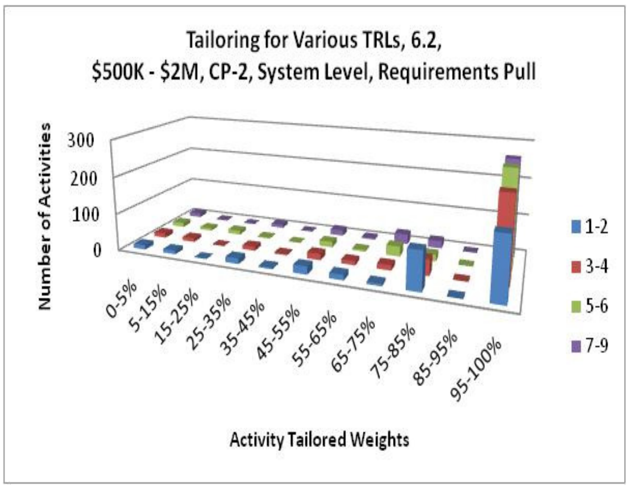
Various Core Process, 6.2, $500K-$2M, TRL 3-4, System Level, Rqmts Pull



Bins	CP-1	CP-2	CP-3
0-5%	12	12	1
5-15%	21	10	0
15-25%	0	0	0
25-35%	17	11	21
35-45%	11	3	0
45-55%	10	17	17
55-65%	30	12	12
65-75%	4	14	14
75-85%	51	43	45
85-95%	0	0	0
95-100%	194	228	228

Analysis: The Core Process discriminant affects some tailoring, but to a lesser extent than does RDT&E Category and Project Budget. The portion of 100% weighted activities is 55% for CP-1, and 65% for both CP-2 and CP-3. The tailoring stands out a bit more in the lower weighted regions, as the portions of activities with weights below 55% are 20% of CP-1, 15% of CP-2, and 11% of CP-3.

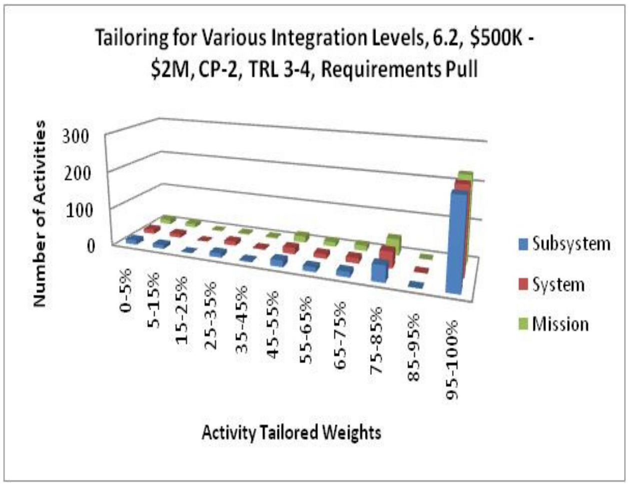
Various Technology Readiness Levels, 6.2, $500K-$2M, CP-2, System, Rqmts Pull



Bins	1-2	3-4	5-6	7-9
0-5%	12	12	12	12
5-15%	10	10	7	1
15-25%	0	0	11	0
25-35%	15	11	3	9
35-45%	4	3	0	0
45-55%	21	17	15	15
55-65%	14	11	5	4
65-75%	6	14	27	27
75-85%	102	43	18	20
85-95%	0	0	0	0
95-100%	165	228	262	262

Analysis: The TRL discriminant has a moderate effect on tailoring, especially at the lower domain values. The portions of 100% weights are 47% for TRL 1-2, 65% for TRL 3-4, and 75% for TRL 5-9. Additionally, the lower weights are reflective of this moderate effect on tailoring. The portions of activities weighted below 55% are 18% for TRL 1-2, 15% for TRL 3-4, 14% for TRL 5-6, and 11% for TRL 7-9.

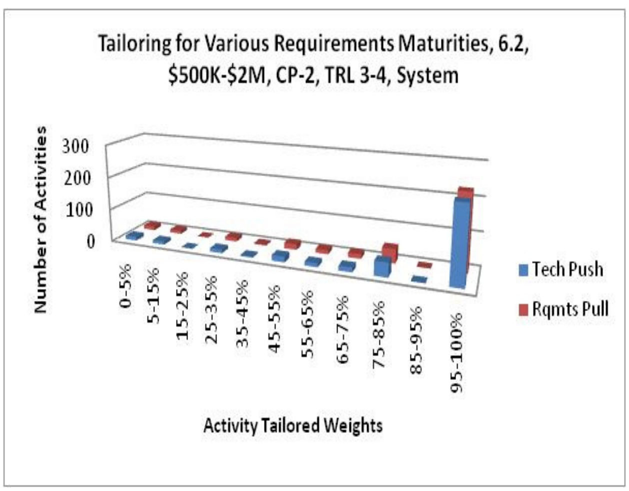
Various Integration Levels, 6.2, $500K-$2M, CP-2, TRL 3-4, Rqmts Pull



Bins	Subsystem	System	Mission
0-5%	12	12	12
5-15%	10	10	10
15-25%	0	0	0
25-35%	11	11	11
35-45%	3	3	3
45-55%	17	17	17
55-65%	12	12	12
65-75%	14	14	14
75-85%	43	43	43
85-95%	0	0	0
95-100%	228	228	228

Analysis: Integration Levels had no effect on the SE activity tailoring. All activities fell into the same weight bins for each integration level (mission, system, and subsystem). This supports the argument to apply a lower weight factor to this discriminant.

Various Requirement Maturity Levels, 6.2, $500K-$2M, CP-2, TRL 3-4, System



Bins	Tech Push	Rqmts Pull
0-5%	12	12
5-15%	10	10
15-25%	0	0
25-35%	11	11
35-45%	3	3
45-55%	17	17
55-65%	12	12
65-75%	14	14
75-85%	43	43
85-95%	0	0
95-100%	228	228

Analysis: Requirement Maturity Levels had no effect on the SE activity tailoring. All activities fell into the same weight bins for each requirement maturity level (Tech Push and Requirements Pull). This supports the argument to apply a lower weight factor to this discriminant.

Appendix D. Glossary

CASE STUDY
Current and recently completed S&T project reviewed by the team in order to refine the SE taxonomy's terminology, grouping, or tailoring values.

DISCRIMINANTS
Six categories utilized to identify various aspects of a project, to include: Primary RDT&E Budget Category, Total S&T Project Budget, Core Process, Technology Readiness Level, Level of Integration / System Hierarchy, and Requirements Maturity.

DOMAIN VALUES
Eighteen sub-categories of the discriminants, utilized to specify project information.

FILTERING
Tailoring tool feature to retrieve specific data within each column of the worksheet, as indicated by "down arrows" in the column title blocks.

FRAMEWORK
Comprised of a taxonomy of comprehensive SE activities and a separate taxonomy of relevant categories and domain values possible for S&T projects, and forming the basis for the tailoring tool.

GROUPING
Tailoring tool feature to display the SE activity details, up to five levels.

MATURITY
State of readiness to transition to the next level of development, implementation, or utilization.

PROJECT
Any planned effort with a specific end goal.

PROJECT TAXONOMY
Classifying a project by the six discriminants.

QUALIFICATION
The process of verifying and validating the system design and then obtaining the stakeholder's acceptance of the design, per Dennis Buede.

SE ACTIVITIES
Actions done in the nature of SE; and as a total form the SE taxonomy.

SE PROCESSES
A structured SE activity that may be accompanied by specific methods and/or tools. Not to be confused with the 16 DAG Technical and Technical Management Processes.

SE RIGOR
The amount of formal planning, coordination and documentation applied to a systems engineering activity.

SE TAXONOMY
Incorporate a broad set of recognized SE activities from academic, defense, and industry sources and organize these activities according to the Defense Acquisition Guidebook's structure of Technical Processes (TPs) and Technical Management Processes (TMPs).

SE TOOLS
Means to accomplish an SE activity.

STAKEHOLDERS
Persons with an invested interest in a situation, action or enterprise.

STATE
Set of designated discriminant domain values for a project.

SUPER SET
Compilation of SE activities from multiple literature sources to include: academic, defense, and industry perspectives.

TAILOR
Ability to select SE activities, based upon the domain values selected.

TAILORED WEIGHT
For a given set of SE activities, the scores were summed and normalized on a 0-100% scale, revealing the relative importance of each activity for a specific project state, to give a ranking on where resources should be applied.

TIME HORIZON
Factors include the end-state TRL level and total project budget, as opposed to the current state of the project. Critical to establishing the context of the project to which SE activities will be applied.

TOOL VALIDATION
Providing the tool to potential users for their evaluation, resulting in tool refinement for actual utilization.

TRANSITION
Movement of the project to the next level of development, implementation, or utilization.

WEIGHT FACTORS
Importance of the six discriminants, in relation to each other, as stated in percentages to equal 100%.

WORKBOOK
The total contents of a single Excel file. A workbook may consist of one or multiple worksheets.

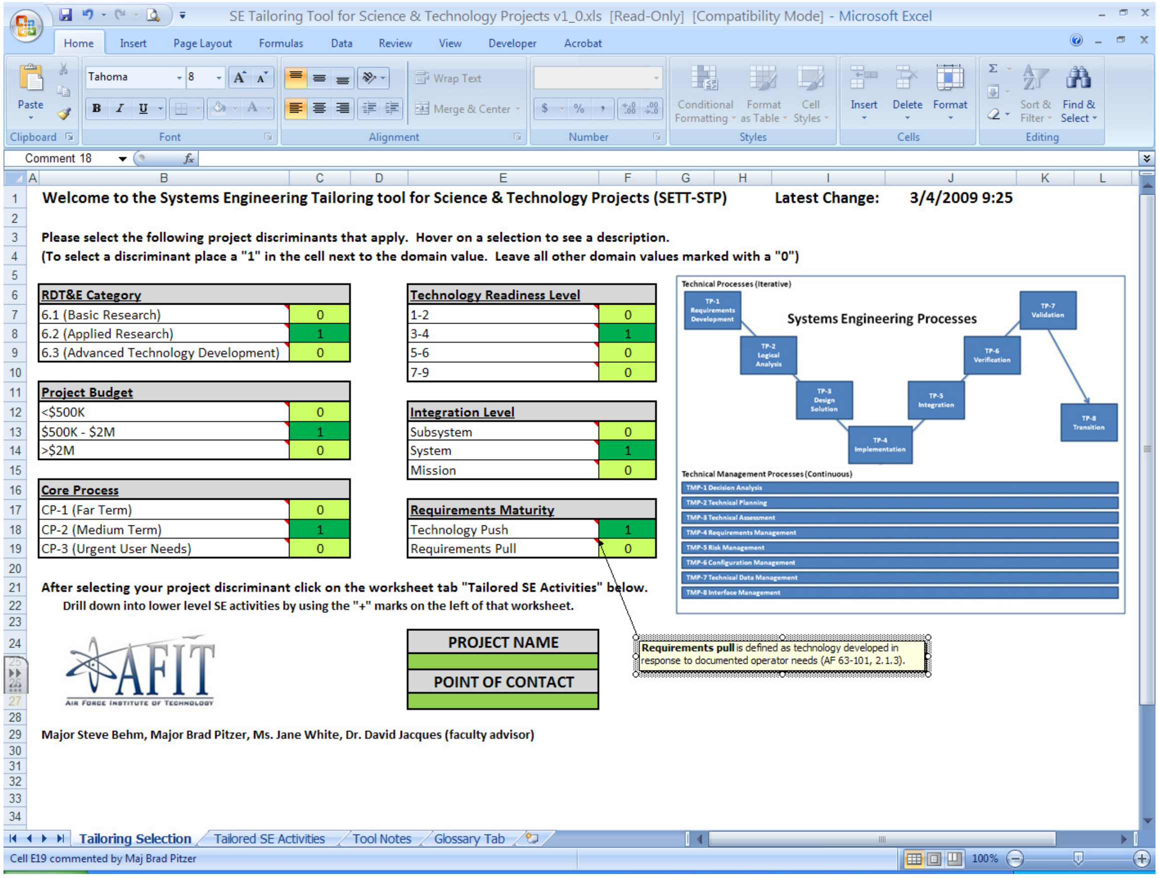
WORKSHEET
Individual tabs within the tailoring tool (an Excel file) to include Interface and Tailoring Results.

Appendix E. Acronyms

ACD&P	Advanced Component Development and Prototypes
ACTD	Advanced Concept Technology Demonstrator
AFI	Air Force Instruction
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFMCI	Air Force Materiel Command Instruction
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFRL/RX	Air Force Research Laboratory / Materials and Manufacturing Directorate
AFRL/XP	Air Force Research Laboratory / Plans and Programs
AFRLI	Air Force Research Laboratory Instruction
ATD	Advanced Technology Development
CBP	Capability Based Planning
CP	Core Process
D&SWS	Developing and Sustaining Weapons Systems
DAG	Defense Acquisition Guidebook
DoD	Department of Defense
EMRL	Engineering and Manufacturing Readiness Level
FLTC	Focused Long-Term Challenge
HELLTP	High Energy Laser on a Large Tactical Platform
ICOM	Input, Control, Output, Mechanism
IG	Inspector General
INCOSE	International Council on Systems Engineering
IPPD	Integrated Process and Project Development
IRT	Independent Review Team
LMR	Laboratory Management Review
MRL	Manufacturing Readiness Level
PLOCAAS	Powered Low Cost Autonomous Attack System
Pre-MS A	Commission on Pre-Milestone A Systems Engineering Report
R&D	Research and Development
RDT&E	Research and Development Test & Equipment

S&T	Science and Technology
SDD	System Development and Demonstration
SE	Systems Engineering
SEAM	System Engineering Assessment Model
SEC	Systems Engineering Council
TASE	Transformational Activities in Systems Engineering Report
TMP	Technical Management Process
TP	Technical Process
TPMM	Technology Program Management Model
TRL	Technology Readiness Level

Appendix F. Example SETT-STP Input & Output



Process	Level	SE Activity	Source	Tools	SE Rigor
TP-1	1	**TP-1 (Requirements Development)**			30% - 100%
TP-1	2	**Establish Communications with Stakeholders**	DAG Sec 4.2.4.1		30% - 100%
TP-1	3	Identify stakeholders	DAG Sec 4.2.4.1.; Buede Pg 23; INCOSE Pg 4.3, 4.4		100%
TP-1	3	Address customer needs	DAG Sec 4.2.4.1.; INCOSE Pg 4.2		100%
TP-1	4	Identify stakeholder requirements	INCOSE Pg 3.7		
TP-1	4	Clarify stakeholder requirements	INCOSE Pg 3.7		
TP-1	4	Document stakeholder requirements	INCOSE Pg 3.7		
TP-1	4	Negotiate modifications to resolve unrealizable requirements	INCOSE Pg 4.4		
TP-1	5	Avoid acceptance of unrealistic objectives	INCOSE Pg 4.4		
TP-1	5	Avoid acceptance of competing objectives	INCOSE Pg 4.4		
TP-1	3	Develop stakeholder agreements	INCOSE Pg 4.2-4	Memorandum of Agreement / Understanding	100%
TP-1	4	Establish good relationship with stakeholders	INCOSE Pg 4.4		
TP-1	4	Utilize terms and conditions of agreements	INCOSE Pg 4.2		
TP-1	3	Obtain stakeholder approval	INCOSE Pg 4.3		30%
TP-1	3	Identify transition partners and relevant applications	(Student Derived)		100%
TP-1	2	**Identify Project Constraints**	DAG Sec 4.2.4.1		50% - 100%
TP-1	3	Identify constraints from agreements	INCOSE Pg 4.3		100%
TP-1	3	Identify schedule constraints	DAG Sec 4.2.4.1.; Buede Pg 22; INCOSE Pg 4.2	Integrated Master Schedule	100%
TP-1	4	Identify schedule issues	Buede Pg 45		
TP-1	4	Identify development time period	Buede Pg 45, 131		
TP-1	4	Determine manufacturing time for each unit	Buede Pg 131		
TP-1	4	Determine training time to reach proficiency by category of user	Buede Pg 131		
TP-1	4	Determine deployment period	Buede Pg 131		
TP-1	4	Determine durability of system	Buede Pg 131		
TP-1	3	Identify cost constraints	DAG Sec 4.2.4.1.; Buede Pg 22, 45; INCOSE Pg 4.2	Cost Estimates	100%
TP-1	4	Identify cost trade-offs	Buede Pg 45		
TP-1	4	Determine affordability	Buede Pg 131		
TP-1	4	Determine development cost	Buede Pg 131		
TP-1	4	Determine production cost of system	Buede Pg 131		
TP-1	4	Determine decommissioning cost of system	Buede Pg 131		
TP-1	3	Identify technical constraints	DAG Sec 4.2.4.1.; Buede Pg 22; INCOSE Pg 4.2	Technology Readiness Assessment	100%
TP-1	4	Address market research	DAG Sec 4.2.4.1.		
TP-1	4	Identify technology to be incorporated	Buede Pg 45		
TP-1	3	Identify cost-performance trade-offs	Buede Pg 45		100%
TP-1	3	Identify external interface constraints	Buede Pg 45	IDEF0, DoDAF SV-1	50%
TP-1	2	**Determine Required Capabilities**	DAG Sec 4.2.4.1		30% - 100%
TP-1	3	Identify operational needs	DAG Sec 4.2.4.1.	Capabilities Review & Risk Assessment (CRRA), CONOPS, Use Cases	60%
TP-1	4	Identify derived requirements	Buede Pg 128		
TP-1	4	Identify implied requirements	Buede Pg 128		
TP-1	4	Identify emergent requirements	Buede Pg 128		
TP-1	4	Identify operational life	Buede Pg 45		
TP-1	4	Determine plan for disposal	INCOSE Pg 3.9, 4.3		
TP-1	5	Utilize scenarios to define disposal concept documents	INCOSE Pg 4.4		
TP-1	3	Identify capability gaps	DAG Sec 4.2.4.1.		60%
TP-1	3	Determine capabilities of system	INCOSE Pg 4.3		100%
TP-1	3	Determine concept of operations	INCOSE Pg 4.3	DoDAF OV-1, CONOPS, Scenarios	60%
TP-1	4	Utilize scenarios to define operations concept documents	INCOSE Pg 4.4		

TP-1	4	Determine response to undesired inputs	Buede Pg 131		
TP-1	4	Determine response to unexpected inputs	Buede Pg 131		
TP-1	4	Determine bounds on expected inputs	Buede Pg 131		
TP-1	4	Determine appropriate response on expected inputs	Buede Pg 131		
TP-1	3	Identify output requirements	Buede Pg 45	IDEF0, Use Cases	100%
TP-1	4	Identify how test data obtained for output reqs	Buede Pg 45		
TP-1	4	Determine accuracy of output	Buede Pg 131		
TP-1	4	Determine correctness of output	Buede Pg 131		
TP-1	4	Determine security/survivability of output	Buede Pg 131		
TP-1	4	Determine intensity/size of output	Buede Pg 131		
TP-1	4	Determine number per unit time of output	Buede Pg 131		
TP-1	4	Determine coverage of output	Buede Pg 131		
TP-1	4	Determine response time of output	Buede Pg 131		
TP-1	4	Determine update frequency of output	Buede Pg 131		
TP-1	4	Determine availability of output	Buede Pg 131		
TP-1	3	Determine verification criteria	Buede Pg 23; INCOSE Pg 3.4	System Requirements Document, Test & Evaluation Master Plan	30%
TP-1	4	Identify how test data determines system conforms to design	Buede Pg 45		
TP-1	4	Identify how test data determines system acceptable to stakeholders	Buede Pg 45		
TP-1	4	Identify how test data obtained for technology and system-wide reqs	Buede Pg 45		
TP-1	3	Determine validation criteria	Buede Pg 23; INCOSE Pg 4.3	System Requirements Validation Document, Test & Evaluation Master Plan	30%
TP-1	4	Identify how test data determine system complies with originating reqs	Buede Pg 45		
TP-1	4	Identify how test data determines system acceptable to stakeholders	Buede Pg 45		
TP-1	4	Identify how test data obtained for system-wide reqs	Buede Pg 45		
TP-2	1	**TP-2 (Logical Analysis)**			**5% - 100%**
TP-2	2	**Analysis Preparation**	DAG Sec 4.2.4.2.		**100% - 100%**
TP-2	3	Identify logical groupings of elements	DAG Sec 4.2.4.2.		100%
TP-2	2	**Perform Functional Analysis**	DAG Sec 4.2.4.2.	DoDAF OV-5, SV-5	**100% - 100%**
TP-2	3	Identify system boundaries	INCOSE Pg 4.6	Context Diagram	100%
TP-2	4	Identify functional boundaries	INCOSE Pg 4.6		
TP-2	3	Identify functional relationships (ICOMs)	DAG Sec 4.2.4.2.	CORE, System Architect	100%
TP-2	4	Identify Inputs of Functions	INCOSE Pg 4.5		
TP-2	5	Utilize stakeholder requirements	INCOSE Pg 4.5		
TP-2	5	Utilize cost constraints	INCOSE Pg 4.5		
TP-2	5	Utilize schedule constraints	INCOSE Pg 4.5		
TP-2	5	Utilize solution constraints	INCOSE Pg 4.5		
TP-2	5	Utilize traceability matrix	INCOSE Pg 4.5		
TP-2	4	Identify Controls of Functions	INCOSE Pg 4.5		
TP-2	5	Utilize terms and conditions of agreements	INCOSE Pg 4.5		
TP-2	5	Utilize project procedures and processes	INCOSE Pg 4.5		
TP-2	4	Identify Outputs of Functions	INCOSE Pg 4.5		
TP-2	5	Derive additional requirements	INCOSE Pg 4.5		
TP-2	5	Define functional boundaries	INCOSE Pg 4.5		
TP-2	5	Identify interfaces	INCOSE Pg 4.5		
TP-2	5	Identify information exchange requirements with systems external to functional boundaries	INCOSE Pg 4.4, 4.5		
TP-2	5	Determine functional requirements	DAG Sec 4.2.4.2.; INCOSE Pg 4.5		
TP-2	5	Determine performance requirements	DAG Sec 4.2.4.2.; INCOSE Pg 4.5		
TP-2	5	Determine non-functional requirements	DAG Sec 4.2.4.2.; INCOSE Pg 4.5		
TP-2	5	Determine architectural constraints	INCOSE Pg 4.5		
TP-2	4	Identify Mechanisms of Functions	INCOSE Pg 4.5		

TP-2	5	Identify physical design constraints	INCOSE Pg 4.6		
TP-2	5	Utilize enterprise infrastructure	INCOSE Pg 4.5		
TP-2	5	Utilize enterprise policies, procedures, and standards	INCOSE Pg 4.5	DoDAF TV-1 (Standards Profile), TV-2 (Standards Forecast)	
TP-2	3	Allocate functional requirements	DAG Sec 4.2.4.2.		100%
TP-2	4	Define functional performance	INCOSE Pg 4.6		
TP-2	5	Determine measures of performance	INCOSE Pg 4.6		
TP-2	5	Determine measures of effectiveness	INCOSE Pg 4.6		
TP-2	3	Allocate performance parameters	DAG Sec 4.2.4.2.		100%
TP-2	3	Allocate performance constraints	DAG Sec 4.2.4.2.		100%
TP-2	2	**Perform Behavioral Analysis**	DAG Sec 4.2.4.2.	DoDAF OV-6(a,b,c), SV-10(a,b,c)	**100% - 100%**
TP-2	3	Identify behavioral relationships	DAG Sec 4.2.4.2.	Data Flow Diagrams, UML	100%
TP-2	4	Perform data flow analysis	DAG Sec 4.2.4.2.		
TP-2	4	Perform object-oriented analysis	DAG Sec 4.2.4.2.		
TP-2	3	Identify temporal relationships	DAG Sec 4.2.4.2.	OV-6c	100%
TP-2	4	Perform timeline analysis	DAG Sec 4.2.4.2.		
TP-2	3	Identify key interfaces	DAG Sec 4.2.4.2.	External Systems Diagram	100%
TP-2	4	Identify functional interfaces	Student Derived		
TP-2	5	Identify functional interfaces to interacting systems	INCOSE Pg 4.6		
TP-2	5	Identify functional interfaces to interacting platforms	INCOSE Pg 4.6		
TP-2	5	Identify functional interfaces to interacting humans	INCOSE Pg 4.6		
TP-2	4	Identify design interfaces	Student Derived		
TP-2	5	Identify design interfaces to interacting systems	INCOSE Pg 4.6		
TP-2	5	Identify design interfaces to interacting platforms	INCOSE Pg 4.6		
TP-2	5	Identify design interfaces to interacting humans	INCOSE Pg 4.6		
TP-2	4	Define interfaces	DAG Sec 4.2.4.2.	Interface Control Document	
TP-2	2	**Perform Environmental Analysis**	DAG Sec 4.2.4.2.		**10% - 100%**
TP-2	3	Identify natural environmental factors	DAG Sec 4.2.4.2.		100%
TP-2	4	Identify natural environmental factors affecting system performance	INCOSE Pg 4.6		
TP-2	4	Identify natural environmental factors impacting human comfort	INCOSE Pg 4.6		
TP-2	4	Identify natural environmental factors impacting human safety	INCOSE Pg 4.6		
TP-2	4	Identify natural environmental factors causing human error	INCOSE Pg 4.6		
TP-2	3	Identify Induced environmental factors	DAG Sec 4.2.4.2.		100%
TP-2	4	Identify induced environmental factors affecting system performance	INCOSE Pg 4.6		
TP-2	4	Identify induced environmental factors impacting human comfort	INCOSE Pg 4.6		
TP-2	4	Identify induced environmental factors impacting human safety	INCOSE Pg 4.6		
TP-2	4	Identify induced environmental factors causing human error	INCOSE Pg 4.6		
TP-2	4	Identify potential environmental impact	INCOSE Pg 4.6		
TP-2	3	Identify training requirements	INCOSE Pg 4.10		10%
TP-2	3	Identify human systems integration requirements	INCOSE Pg 4.6		100%
TP-2	3	Identify system security requirements	INCOSE Pg 4.6		100%
TP-2	2	**Design Factors Analysis**	INCOSE Pg 4.6		**5% - 100%**
TP-2	3	Identify production design factors to facilitate efficient functions	INCOSE Pg 4.6		60%
TP-2	3	Identify deployment design factors to facilitate efficient functions	INCOSE Pg 4.6		30%
TP-2	3	Identify transition design factors to facilitate efficient functions	INCOSE Pg 4.6		100%
TP-2	3	Identify operation design factors to facilitate efficient functions	INCOSE Pg 4.6		60%
TP-2	3	Identify maintenance design factors to facilitate efficient functions	INCOSE Pg 4.6		30%
TP-2	3	Identify re-engineering design factors to facilitate efficient functions	INCOSE Pg 4.6		50%
TP-2	3	Identify disposal design factors to facilitate efficient functions	INCOSE Pg 4.6		5%
TP-2	2	**Develop Functional Architecture**	DAG Sec 4.2.4.2.		**50% - 100%**
TP-2	3	Document functional architecture	DAG Sec 4.2.4.2.	DoDAF OV-5, SV-4,5	100%
TP-2	3	Identify technology alternatives	DAG Sec 4.2.4.2.		100%
TP-2	3	Identify recognized standards to be used in functional architecture	DAG Sec 4.2.4.2.; INCOSE Pg 4.6		100%
TP-2	3	Maintain configuration control of functional architecture	INCOSE Pg 4.6		50%
TP-2	3	Define criteria to verify functional architecture	INCOSE Pg 4.6		100%

TP-3	1	**TP-3 (Design Solution)**			**30% - 100%**
TP-3	2	**Define Design Problem**	Buede Pg 31, 39		**50% - 100%**
TP-3	3	Utilize stakeholder inputs	Buede Pg 39, 40, 125		100%
TP-3	3	Utilize originating requirements	Buede Pg 39		100%
TP-3	4	Utilize system requirements	Buede Pg 39		
TP-3	3	Utilize operational concept	Buede Pg 39, 40		50%
TP-3	3	Utilize system inputs, controls, and outputs	Buede Pg 40		100%
TP-3	4	Utilize system inputs	Buede Pg 40		
TP-3	5	Utilize functional requirements	INCOSE Pg 4.7		
TP-3	5	Utilize performance requirements	INCOSE Pg 4.7		
TP-3	5	Utilize architectural constraints	INCOSE Pg 4.7		
TP-3	5	Utilize traceability matrix	INCOSE Pg 4.7		
TP-3	5	Utilize system solution constraints	INCOSE Pg 4.7		
TP-3	4	Utilize system controls	INCOSE Pg 4.7		
TP-3	5	Utilize natural and societal laws	INCOSE Pg 4.7		
TP-3	4	Utilize system outputs	Buede Pg 40		
TP-3	5	Determine system element detailed descriptions	Buede Pg 40		
TP-3	5	Assign requirements to system elements	Buede Pg 40		
TP-3	5	Document requirement assignment to system elements	Buede Pg 40		
TP-3	5	Determine interface requirements	Buede Pg 40		
TP-3	5	Establish plan for system integration	Buede Pg 40		
TP-3	5	Establish plan for verification strategy	Buede Pg 40		
TP-3	4	Utilize system mechanisms	Buede Pg 40		
TP-3	3	Utilize trade studies analysis tools	Buede Pg 40	Objectives Hierarchy; Quality Function Deployment/House of Quality, Influence Diagrams	50%
TP-3	4	Utilize SE team input	Buede Pg 40		
TP-3	3	Define system boundaries	Buede Pg 40	DoDAF SV-1	100%
TP-3	4	**Identify interfaces between system elements and external systems**			
TP-3	4	Utilize system boundaries	Buede Pg 40		
TP-3	3	Partition system requirements		DoDAF SV-4,5	80%
TP-3	4	Allocate system requirements to system elements			
TP-3	3	Define system integration strategy			80%
TP-3	2	**Generate Alternative Design Solutions**	Buede Pg 31, 39		**55% - 100%**
TP-3	3	Identify appropriate products	DAG Sec 4.2.4.3.		100%
TP-3	4	Identify products	DAG Sec 4.2.4.3.		
TP-3	4	Identify basis for work breakdown structures	DAG Sec 4.2.4.3.		
TP-3	4	Identify basis for baselines	DAG Sec 4.2.4.3.		
TP-3	3	Develop performance attributes and measures	DAG Sec 4.2.4.3.	Technical Performance Measures	100%
TP-3	4	Develop specifications	DAG Sec 4.2.4.3.		
TP-3	4	Identify basis for specifications	DAG Sec 4.2.4.3.		
TP-3	3	Develop physical baseline architecture	DAG Sec 4.2.4.3.; Buede Pg 31, 39		100%
TP-3	4	Develop functional architecture	Buede Pg 31, 39		
TP-3	4	Develop operational architecture	Buede Pg 31, 39		
TP-3	4	Address development system	Buede Pg 39		
TP-3	4	Address manufacturing system	Buede Pg 39		
TP-3	4	Address deployment system	Buede Pg 39		
TP-3	4	Address training system	Buede Pg 39		
TP-3	4	Address refinement system	Buede Pg 39		
TP-3	4	Address retirement system	Buede Pg 39		
TP-3	3	Utilize prototypes	INCOSE Pg 3.7		70%
TP-3	4	Utilize prototypes to verify concept feasibility	INCOSE Pg 3.7		
TP-3	4	Utilize prototypes to explore risks	INCOSE Pg 3.7		
TP-3	4	Utilize prototypes to explore opportunities	INCOSE Pg 3.7		
TP-3	4	Utilize prototypes to explore affordability assessment	INCOSE Pg 3.7		
TP-3	4	Utilize prototypes to explore environmental impact	INCOSE Pg 3.7		
TP-3	4	Utilize prototypes to explore opportunities	INCOSE Pg 3.7		
TP-3	4	Utilize prototypes to explore failure modes	INCOSE Pg 3.7		
TP-3	4	Utilize prototypes to explore hazard analysis	INCOSE Pg 3.7		
TP-3	4	Obtain confidence solution is achievable	INCOSE Pg 3.7		
TP-3	4	Identify potential component problems	INCOSE Pg 3.7		
TP-3	3	Provide design outputs	Buede Pg 40		100%
TP-3	4	Provide output: system boundaries	Buede Pg 40		

TP-3	4	Provide output: inputs	Buede Pg 40		
TP-3	4	Provide output: outputs	Buede Pg 40		
TP-3	4	Provide output: qualification plan	Buede Pg 39		
TP-3	4	Provide output: design documentation	Buede Pg 39		
TP-3	4	Provide output: operational concept	Buede Pg 40		
TP-3	4	Provide output: objectives hierarchy	Buede Pg 40		
TP-3	4	Provide output: originating requirements	Buede Pg 40		
TP-3	4	Provide output: system requirements	Buede Pg 40		
TP-3	4	Provide output: design feasibility	Buede Pg 40		
TP-3	4	Provide output: test requirements	Buede Pg 40		
TP-3	3	Define logical architecture	INCOSE Pg 4.8	Data Structure, Rules Model (OV-6a, SV-10a)	55%
TP-3	4	Define data structure	Student Derived		
TP-3	4	Define rules model	Student Derived		
TP-3	2	**Evaluate Design Alternatives**	DAG Sec 4.2.4.3		**30% - 100%**
TP-3	3	Perform concept/design analysis	DAG Sec 4.2.4.3.		100%
TP-3	3	Consider existing off-the-shelf solutions	INCOSE Pg 4.8		100%
TP-3	3	Evaluate alternative design solutions	INCOSE Pg 4.8		80%
TP-3	3	Identify recognized standards to be used in design solution	INCOSE Pg 4.6	DoDAF TV-1	60%
TP-3	3	Perform trade studies	DAG Sec 4.2.4.3.		80%
TP-3	4	Perform operational capabilities trade studies	DAG Sec 4.5.6		
TP-3	4	Perform functional trade studies	DAG Sec 4.5.6		
TP-3	4	Perform manufacturing trade studies	DAG Sec 4.5.6		
TP-3	4	Perform testing trade studies	DAG Sec 4.5.6		
TP-3	4	Perform support trade studies	DAG Sec 4.5.6		
TP-3	4	Perform lifecycle cost trade studies	DAG Sec 4.5.6		
TP-3	3	Perform design modeling	DAG Sec 4.2.4.3.		50%
TP-3	4	Develop environmental modeling view	Buede Pg 30		
TP-3	4	Develop data/informational modeling view	Buede Pg 30, INCOSE Pg 4.8	Core Architecture Data Model, SysML (Logical Architecture)	
TP-3	4	Develop process modeling view	Buede Pg 30		
TP-3	4	Develop behavior modeling view	Buede Pg 30		
TP-3	5	Consider feature interactions	INCOSE Pg 4.8		
TP-3	5	Consider emergent properties	INCOSE Pg 4.8		
TP-3	5	Consider human-machine interactions	INCOSE Pg 4.8		
TP-3	4	Develop implementation modeling view	Buede Pg 30		
TP-3	4	Validate simulations	INCOSE Pg 4.11		
TP-3	3	Evaluate to performance attributes and measures	DAG Sec 4.2.4.3.		100%
TP-3	4	Complete product analyses	INCOSE Pg 4.10		
TP-3	4	Complete process analyses	INCOSE Pg 4.10		
TP-3	4	Complete material analyses	INCOSE Pg 4.10		
TP-3	3	Confirm interoperability	DAG Sec 4.2.4.3.		30%
TP-4	1	**TP-4 (Implementation)**			**5% - 100%**
TP-4	2	**Generate Implementation Strategy**	INCOSE Pg 4.10		**30% - 100%**
TP-4	3	Utilize design requirements	INCOSE Pg 4.9		100%
TP-4	3	Utilize verification criteria	INCOSE Pg 4.9		100%
TP-4	3	Utilize validation criteria	INCOSE Pg 4.9		100%
TP-4	3	Utilize terms and conditions of agreements	INCOSE Pg 4.9		100%
TP-4	3	Utilize government and industry standards	INCOSE Pg 4.9	MIL-STD, IEEE, ISO	100%
TP-4	3	Improve process control with Lean Design	INCOSE Pg 4.10		30%
TP-4	4	Inspections are proactive way to build in quality	INCOSE Pg 4.10		
TP-4	2	**Fabricate Hardware**	DAG Sec 4.2.4.4.		**30% - 100%**
TP-4	3	Develop detailed drawings	INCOSE Pg 4.10		100%
TP-4	3	Identify hardware configuration items for assembly	(Student Derived)		80%
TP-4	3	Identify implementation tolerances	INCOSE Pg 4.10		50%
TP-4	3	Develop detailed material specifications	INCOSE Pg 4.10		30%
TP-4	3	Define fabrication procedures	INCOSE Pg 4.10		100%
TP-4	4	Identify tools	INCOSE Pg 4.10		
TP-4	4	Identify equipment	INCOSE Pg 4.10		
TP-4	4	Assure consistent and repeatable element production	INCOSE Pg 4.10		
TP-4	2	**Code Software**	DAG Sec 4.2.4.4.		**70% - 100%**
TP-4	3	Identify software configuration items for compiling	(Student Derived)		100%
TP-4	3	Define coding procedures	INCOSE Pg 4.10		70%

TP-4	3	Develop detailed codes	INCOSE Pg 4.10		100%
TP-4	2	**Conduct Unit Testing**	INCOSE Pg 4.10		**50% - 100%**
TP-4	3	Generate acceptance test procedures	DAG Sec 4.2.4.4.		60%
TP-4	3	Inspect hardware and software for correct functionality	INCOSE Pg 4.10	System Functionality Description (SV-4)	100%
TP-4	3	Test hardware and software for correct functionality	INCOSE Pg 4.10		100%
TP-4	4	Perform white box testing on software	INCOSE Pg 4.10		
TP-4	3	Ensure sufficient hardware and software testing prior to integration	INCOSE Pg 4.11		50%
TP-4	2	**Conduct Training**	INCOSE Pg 4.10		**5% - 5%**
TP-4	3	Establish initial staff of trained users	INCOSE Pg 4.10		5%
TP-4	3	Establish initial staff of trained maintainers	INCOSE Pg 4.10		5%
TP-4	3	Train initial operators	INCOSE Pg 4.10		5%
TP-4	3	Train initial maintainers	INCOSE Pg 4.10		5%
TP-4	2	**Prepare for Integration**	DAG Sec 4.2.4.4.		**80% - 100%**
TP-4	3	Supply system element for verification and validation	INCOSE Pg 4.10		80%
TP-4	3	Refine integration constraints	INCOSE Pg 4.10		100%
TP-5	1	**TP-5 (Integration)**			**10% - 100%**
TP-5	2	**Determine Integration Process**	Buede Pg 310		**100% - 100%**
TP-5	3	Execute assembly processes / procedures	DAG Sec 4.2.4.5.		100%
TP-5	4	Define integration strategy regarding availability of system elements	INCOSE Pg 4.12		
TP-5	4	Determine assembly sequence	DAG Sec 4.2.4.5.		
TP-5	4	Identify assembly constraints	DAG Sec 4.2.4.5.		
TP-5	4	Utilize top down process	Buede Pg 310		
TP-5	5	Select top level module, with simulated components	Buede Pg 310		
TP-5	5	Replace simulated components with actual, one at a time, to qualify top level module	Buede Pg 310		
TP-5	4	Utilize bottom up process	Buede Pg 310		
TP-5	5	Test components, individually	Buede Pg 310		
TP-5	5	Test assembled components until entire system assembled and tested	Buede Pg 310		
TP-5	4	Utilize big bang process	Buede Pg 310		
TP-5	5	Assemble untested components	Buede Pg 310		
TP-5	5	Test assembly	Buede Pg 310		
TP-5	3	Develop integration plan	INCOSE Pg 4.12		100%
TP-5	2	**Conduct Assembly / Integration of System**	INCOSE Pg 4.12		**10% - 100%**
TP-5	3	Utilize configuration item components	Buede Pg 42	Configuration Items	40%
TP-5	4	Utilize hardware configuration item components	(Student Derived)		
TP-5	4	Utilize software configuration item components	(Student Derived)		
TP-5	3	Utilize integration technology constraints	INCOSE Pg 4.12		10%
TP-5	3	Utilize architectural design requirements	INCOSE Pg 4.12		100%
TP-5	3	Assemble system elements according to integration plan	INCOSE Pg 4.12		100%
TP-5	4	Utilize integration tools	INCOSE Pg 4.12		
TP-5	5	Schedule integration testing tools	INCOSE Pg 4.12		
TP-5	4	Utilize integration facilities	INCOSE Pg 4.12		
TP-5	5	Schedule integration testing facilities	INCOSE Pg 4.12		
TP-5	4	Utilize integration test equipment	INCOSE Pg 4.12		
TP-5	3	Obtain subsystem / system ready for verification	INCOSE Pg 4.12		80%
TP-5	3	Conduct integration verification testing	Buede Pg 42		80%
TP-5	4	Utilize acceptance test plan	Buede Pg 42		
TP-5	4	Inspect to verification requirements	Buede Pg 32		
TP-5	3	Validate internal interfaces	INCOSE Pg 4.12	DoDAF SV-1	100%
TP-5	4	Validate internal interfaces through black box testing at each assembly level	INCOSE Pg 4.12		
TP-5	4	Confirm correct functionality of assembled products at each assembly level	INCOSE Pg 4.12		
TP-5	3	Conduct early evaluation against performance attributes	Buede Pg 42		100%
TP-5	4	Utilize stakeholder inputs	Buede Pg 42		
TP-5	4	Utilize operational concept	Buede Pg 42		
TP-5	4	Utilize originating requirements	Buede Pg 42		
TP-5	4	Utilize derived requirements	Buede Pg 42		
TP-5	3	Obtain integration test and analysis results	INCOSE Pg 4.12		100%
TP-5	3	Determine adjustments to system elements	DAG Sec 4.2.4.4.		100%

TP-5	2	**Relevant Environment**	DAG Sec 4.2.4.5.		**40% - 40%**
TP-5	3	Incorporate assembled system into relevant environment	DAG Sec 4.2.4.5.		40%
TP-6	1	**TP-6 (Verification)**			**80% - 100%**
TP-6	2	**Plan Verification**	Buede Pg 314		**80% - 100%**
TP-6	3	Review / utilize system objectives	Buede Pg 314; INCOSE Pg 4.13	System Requirements Document, Test & Evaluation Master Plan	100%
TP-6	3	Review / utilize allocated requirements to functional / physical / logical architectures	Buede Pg 314		100%
TP-6	4	Utilize functional architectures for verification components	Buede Pg 314		
TP-6	4	Utilize derived requirements to functional architectures	Buede Pg 314		
TP-6	4	Utilize functions to physical architectures	Buede Pg 314		
TP-6	3	Create master verification plan	Buede Pg 314		80%
TP-6	4	Create test scenarios	Buede Pg 314		
TP-6	4	Write activity level verification plans for each verification component	Buede Pg 314		
TP-6	5	Identify required simulation data for each activity	Buede Pg 314		
TP-6	3	Develop detailed derived verification procedures	Buede Pg 314; INCOSE Pg 4.14		80%
TP-6	4	Utilize verification criteria (to include pass/fail thresholds) and methods (analysis, inspection, demonstration, & testing)	Buede Pg 314; INCOSE Pg 4.13		
TP-6	4	Utilize verification criteria and method for system objectives	Buede Pg 314		
TP-6	4	Utilize verification criteria and method for operational concept	Buede Pg 314		
TP-6	4	Utilize acceptance test plan	Buede Pg 42		
TP-6	3	Write test procedures	Buede Pg 314		100%
TP-6	3	Write analysis procedures	Buede Pg 314		80%
TP-6	3	Assign verification responsibilities	Buede Pg 314		100%
TP-6	**4**	**Assign verification activities to organizations**	**Buede Pg 314**		
TP-6	4	Allocate verification activiities to resources	Buede Pg 314		
TP-6	2	**Execute Verification**	INCOSE Pg 4.14		**80% - 100%**
TP-6	3	Verify materials are safe	DAG Sec 4.2.4.6.		100%
TP-6	3	Demonstrate system	DAG Sec 4.2.4.6.; Buede Pg 50		100%
TP-6	4	Perform modeling & simulation	DAG Sec 4.2.4.6.; Buede Pg 50		
TP-6	4	Ensure interfaces operational when older component replaced with newer component	INCOSE Pg 2.5		
TP-6	3	Conduct verification testing	Buede Pg 42		100%
TP-6	4	Test to verification requirements	Buede Pg 32		
TP-6	4	Test at lowest system element level	DAG Sec 4.2.4.6.; Buede Pg 32; INCOSE Pg 4.13		
TP-6	4	Test to sub-system level	DAG Sec 4.2.4.6.; Buede Pg 42		
TP-6	5	Record evidence that system element satisfies requirements, or not	INCOSE Pg 4.14		
TP-6	4	Test to system level	DAG Sec 4.2.4.6.; Buede Pg 42		
TP-6	5	Record evidence that system satisfies requirements, or not	INCOSE Pg 4.14		
TP-6	4	Perform software component testing	DAG Sec 4.2.4.6.		
TP-6	3	Document verification testing	Buede Pg 42		100%
TP-6	4	Provide output: accepted system	Buede Pg 42		
TP-6	3	Inspect to verification requirements and tolerances	DAG Sec 4.2.4.6.; Buede Pg 32, 50		80%
TP-6	3	Identify deficiencies	Buede Pg 32		100%
TP-6	4	Record recommended corrective actions	INCOSE Pg 4.14		
TP-6	3	Correct deficiencies			100%
TP-6	4	Record corrective actions taken	INCOSE Pg 4.14		
TP-6	3	Document uncorrectable deficiencies	Buede Pg 32		100%
TP-6	3	Analyze test results	DAG Sec 4.2.4.6.		80%
TP-6	3	Document verification results	Buede Pg 42; INCOSE Pg 4.14		80%
TP-6	3	Provide output: verified components and system	Buede Pg 42		100%
TP-6	3	Transfer verified system to validation testing	Buede Pg 42		80%

TP-7	1	**TP-7 (Validation)**			80% - 100%
TP-7	2	**Plan Validation**	Buede Pg 314		80% - 100%
TP-7	3	Review / utilize system objectives	Buede Pg 314	System Requirements Document, Test & Evaluation Master Plan	100%
TP-7	4	Identify validation system objectives	Buede Pg 314		
TP-7	5	Utilize validation operational concept	Buede Pg 314		
TP-7	5	Utilize validation requirements	Buede Pg 314		
TP-7	5	Identify pass/fail thresholds	Buede Pg 314		
TP-7	3	Define validation architectures	Buede Pg 314		80%
TP-7	4	Define validation functional architecture	Buede Pg 314		
TP-7	5	Allocate requirements to functional architecture	Buede Pg 314		
TP-7	4	Define validation generic physical architecture	Buede Pg 314		
TP-7	5	Allocate functions to generic physical architecture	Buede Pg 314		
TP-7	4	Develop functional architectures for validation components	Buede Pg 314		
TP-7	5	Allocate derived requirements to functional architectures	Buede Pg 314		
TP-7	5	Allocate functions to physical architectures	Buede Pg 314		
TP-7	3	Create master validation plan	Buede Pg 314		80%
TP-7	4	Write activity level validation plans for each validation component	Buede Pg 314		
TP-7	5	Utilize validation criteria for stakeholder requirements	INCOSE Pg 4.17		
TP-7	4	Identify required simulation data for each activity	Buede Pg 314		
TP-7	4	Create test scenarios	Buede Pg 314		
TP-7	5	Utilize scenarios exercising all system modes	INCOSE Pg 4.17		
TP-7	3	Write test procedures	Buede Pg 314		100%
TP-7	**3**	**Write analysis procedures**	**Buede Pg 314**		**100%**
TP-7	4	Develop validation procedures to show system fit for its purpose	INCOSE Pg 4.17		
TP-7	4	Develop validation procedures to show system satisfies stakeholder's requirements	INCOSE Pg 4.17		
TP-7	3	Assign validation responsibilities	Buede Pg 314		100%
TP-7	4	Assign validation activities to organizations	Buede Pg 314		
TP-7	5	Test with ultimate users	DAG Sec 4.2.4.7.; Buede Pg 51		
TP-7	4	Allocate validation activities to resources	Buede Pg 314		
TP-7	5	Test in operational environment	DAG Sec 4.2.4.7.		
TP-7	2	**Execute Validation**	Buede Pg 51; INCOSE Pg 4.17		80% - 100%
TP-7	3	Utilize integrated system released for validation	Buede Pg 42; INCOSE Pg 4.17		80%
TP-7	4	Obtain approved system baseline	INCOSE Pg 4.17		
TP-7	3	Ensure system readiness to conduct validation	INCOSE Pg 4.17		100%
TP-7	4	Ensure enabling system readiness to conduct validation	INCOSE Pg 4.17		
TP-7	4	Ensure trained operator readiness to conduct validation	INCOSE Pg 4.17		
TP-7	3	Perform simulation	DAG Sec 4.2.4.7.		100%
TP-7	4	Prove-in with prototypes	DAG Sec 4.2.4.7.		
TP-7	4	Prove-in with mock-ups	DAG Sec 4.2.4.7.		
TP-7	4	Prove-in with modeling & simulation	DAG Sec 4.2.4.7.		
TP-7	3	Conduct system validation testing	Buede Pg 42		100%
TP-7	4	Demonstrate system level performance over entire operating regime	INCOSE Pg 4.17		
TP-7	4	Utilize results to correct performance deficiencies before implementation	INCOSE Pg 4.17		
TP-7	3	Analyze validation test results	INCOSE Pg 4.17		100%
TP-7	4	Obtain results of validation activities	INCOSE Pg 4.17		
TP-7	4	Detect trends in failure	INCOSE Pg 4.17		
TP-7	4	Find threats to system	INCOSE Pg 4.17		
TP-7	4	Find evidence of design errors	INCOSE Pg 4.17		
TP-7	3	Obtain design feedback	INCOSE Pg 4.17		80%
TP-7	4	Analyze for corrective actions, if anomolies detected	INCOSE Pg 4.17		
TP-7	3	Determine corrective actions	INCOSE Pg 4.17		100%
TP-7	4	Ensure interfaces operational when older component replaced with newer component	INCOSE Pg 2.5		

TP-7	3	Determine system meets stakeholder needs	Buede Pg 51		80%
TP-7	4	Utilize results to forcast success in meeting expectations of users	INCOSE Pg 4.17		
TP-7	3	Document validation results	(Student Derived)		100%
TP-7	3	Provide output: validated system	Buede Pg 42		80%
TP-8	1	**TP-8 (Transition)**			**0% - 100%**
TP-8	2	**Identify Transition Opportunities**	INCOSE Pg 3.2		**70% - 100%**
TP-8	3	Evaluate decision gates	INCOSE Pg 3.2		100%
TP-8	3	Determine if deliverable fulfills business case/mission	INCOSE Pg 3.2		100%
TP-8	3	Determine if affordable	INCOSE Pg 3.2		100%
TP-8	3	Determine if deliverable can be delivered when needed	INCOSE Pg 3.2		100%
TP-8	3	Identify required simulation data for each activity (ID DATA REQUIRED BY EACH TRANSITION OPPORTUNITY)	Buede Pg 314		70%
TP-8	2	**Qualify Production Item**	Buede Pg 314		**0% - 0%**
TP-8	3	Refine concept for qualification of Production Items	Buede Pg 314		0%
TP-8	3	Refine requirements for qualification of Production Items	Buede Pg 314		0%
TP-8	4	Identify qualification system objectives	Buede Pg 314		
TP-8	4	Identify pass/fail thresholds	Buede Pg 314		
TP-8	4	Develop detailed derived qualification requirements	Buede Pg 314		
TP-8	3	Refine functional architecture for qualification	Buede Pg 314		0%
TP-8	4	Develop functional architectures for qualification components	Buede Pg 314		
TP-8	4	Allocate derived requirements to functional architectures	Buede Pg 314		
TP-8	4	Define qualification generic physical architecture	Buede Pg 314		
TP-8	4	Allocate functions to physical architectures	Buede Pg 314		
TP-8	3	Create master qualification plan	Buede Pg 314		0%
TP-8	4	Write activity level qualification plans for each qualification component	Buede Pg 314		
TP-8	3	Assign qualification responsibilities	Buede Pg 314		0%
TP-8	4	Define qualification resources	Buede Pg 314		
TP-8	5	Allocate qualification activities to resources	Buede Pg 314		
TP-8	4	Define qualification organizations	Buede Pg 314		
TP-8	5	Assign qualification activities to organizations	Buede Pg 314		
TP-8	3	Develop qualification schedule, consistent with development schedule	Buede Pg 314		0%
TP-8	3	Perform qualification testing and analysis	(Student Derived)		0%
TP-8	2	**Execute Transition**	INCOSE 4.15		**80% - 100%**
TP-8	3	Receive authority to proceed	INCOSE Pg 3.3	Transition Readiness Assessment	100%
TP-8	3	Receive acceptance of project Production Item	INCOSE Pg 3.3		100%
TP-8	3	Install at user site	DAG Sec 4.2.4.8.; INCOSE Pg 4.15		100%
TP-8	4	Train system users	INCOSE Pg 4.15		
TP-8	4	Affirm users have knowledge and skills necessary to perform operation and maintenance activities	INCOSE Pg 4.15		
TP-8	3	Confirm system meets users needs	INCOSE Pg 4.15		100%
TP-8	3	Determine system acceptability	INCOSE Pg 4.15		80%
TP-8	3	Determine corrective actions for Production Item if discrepancies from acceptance criteria	INCOSE Pg 4.15		100%
TP-8	4	Document post-implementation problems that may lead to corrective actions or design changes	INCOSE Pg 4.16		
TP-8	3	Utilize validated system	Buede Pg 42		100%
TP-8	3	Provide output: validated operational concept	Buede Pg 42		100%
TMP-1	1	**TMP-1 (Decision Analysis)**			**100% - 100%**
TMP-1	2	**Identify Strategy for Making Decision**	INCOSE Pg 5.8		**100% - 100%**
TMP-1	3	Formulate problems that require decisions	INCOSE Pg 7.3	Utility Theory, Influence Diagrams, Decision Tree	100%
TMP-1	4	Frame problem context	INCOSE Pg 7.5		
TMP-1	5	Utilize history of prior decisions	INCOSE Pg 5.8		
TMP-1	5	Utilize assessments from all relevant persons	INCOSE Pg 5.8		
TMP-1	4	Frame problem scope	INCOSE Pg 7.5		
TMP-1	5	Understand business situation	INCOSE Pg 7.3		

TMP-1	5	Decompose problem into smaller more manageable problems	INCOSE Pg 7.3		
TMP-1	5	Identify experts	INCOSE Pg 7.3		
TMP-1	5	Identify modeling & simulations	DAG Sec 4.2.3.1.		
TMP-1	5	Identify supportability	DAG Sec 4.2.3.1.		
TMP-1	5	Identify level of repair	DAG Sec 4.2.3.1.		
TMP-1	5	Identify post fielding support	DAG Sec 4.2.3.1.		
TMP-1	5	Identify repair vs discard	DAG Sec 4.2.3.1.		
TMP-1	5	Identify cost parameters	DAG Sec 4.2.3.1.		
TMP-1	5	Augment with prototypes	DAG Sec 4.2.3.1.		
TMP-1	5	Identify transportability requirements	DAG Sec 4.2.3.1.		
TMP-1	5	Identify maintenance concept	DAG Sec 4.2.3.1.		
TMP-1	5	Determine affordability	DAG Sec 4.2.3.1.		
TMP-1	5	Determine reliability	DAG Sec 4.2.3.1.		
TMP-1	5	Determine availability	DAG Sec 4.2.3.1.		
TMP-1	5	Determine schedule	DAG Sec 4.2.3.1.		
TMP-1	5	Determine maintainability goals	DAG Sec 4.2.3.1.		
TMP-1	4	Frame problem constraints	INCOSE Pg 7.5		
TMP-1	5	Identify interoperability constraints	DAG Sec 4.2.3.1.		
TMP-1	3	Identify project decision	INCOSE Pg 5.8		100%
TMP-1	4	Identify all personnel with knowledge and experience relevant to decision	INCOSE Pg 5.8		
TMP-1	4	Utilize uncetainty as catalyst of future performance	INCOSE Pg 7.3		
TMP-1	4	Utilize systemic thinking to connect current to future situations	INCOSE Pg 7.3		
TMP-1	4	Utilize dialog to foster learning	INCOSE Pg 7.3		
TMP-1	4	Utilize dialog to clarify actions	INCOSE Pg 7.3		
TMP-1	3	Communicate decisions with stakeholders	INCOSE Pg 7.5		100%
TMP-1	4	Involve necessary disciplines in decision approval	INCOSE Pg 7.2		
TMP-1	4	Involve necessary stakeholders in decision approval	INCOSE Pg 7.2		
TMP-1	3	Establish clear objectives for project decisions	INCOSE Pg 7.3		100%
TMP-1	4	Determine entry/exit criteria for decision	INCOSE Pg 7.1		
TMP-1	4	Identify decision purpose	INCOSE Pg 7.2		
TMP-1	4	Identify decision support activities	INCOSE Pg 7.2		
TMP-1	5	Identify decision chairperson	INCOSE Pg 7.2		
TMP-1	5	Identify decision attendees	INCOSE Pg 7.2		
TMP-1	5	Identify decision location	INCOSE Pg 7.2		
TMP-1	5	Identify decision agenda	INCOSE Pg 7.2		
TMP-1	5	Identify decision method of conduct	INCOSE Pg 7.2		
TMP-1	5	Identify decision evidence to be evaluated	INCOSE Pg 7.2		
TMP-1	5	Identify decision actions	INCOSE Pg 7.2		
TMP-1	5	Identify decision method for closing review	INCOSE Pg 7.2		
TMP-1	2	**Execute Decision Making Strategy**	DAG 4.2.3.1		**100% - 100%**
TMP-1	3	Select decision criteria	DAG Sec 4.2.3.1.; INCOSE Pg 7.1	House of Quality, Utility Theory, Influence Diagrams, Decision Tree, Sensitivity Analysis	100%
TMP-1	4	Define evaluation criteria	INCOSE Pg 7.5		
TMP-1	5	Select criteria that are measurable	Buede Pg 149; INCOSE Pg 7.5		
TMP-1	5	Express criteria in understood units	Buede Pg 149		
TMP-1	5	Select criteria with demonstrable links to customer needs and system requirements	Buede Pg 148		
TMP-1	5	Maintain need-based balance among often-conflicting criteria	Buede Pg 148		
TMP-1	4	Define and assign value weights to criteria	Buede Pg 365; INCOSE Pg 7.5		
TMP-1	4	Coordinate criteria/value weights with stakeholders	INCOSE Pg 7.6		
TMP-1	3	Identify trade studies	DAG Sec 4.2.3.1.; INCOSE Pg 7.5		100%
TMP-1	4	Establish clear trade-offs	DAG Sec 4.2.3.1.; INCOSE Pg 7.3		
TMP-1	4	Develop creative and unique alternatives	INCOSE Pg 7.3		
TMP-1	5	Define alternatives	INCOSE Pg 7.5		
TMP-1	5	Use value creation lens for developing opportunities	INCOSE Pg 7.3		
TMP-1	5	Determine if requirements can be traded against constraints	INCOSE Pg 7.6		
TMP-1	5	Use trade-offs to show performance variations	Buede Pg 149		
TMP-1	5	Use trade-offs to show cost variations	Buede Pg 149		

TMP-1	5	Use trade-offs to show schedule variations	Buede Pg 149		
TMP-1	5	Use trade-offs to show risk impact variations	Buede Pg 149		
TMP-1	5	Determine if architecture features can be traded against dictated equipment	INCOSE Pg 7.6		
TMP-1	5	Determine if architecture features can be traded against interface requirements	INCOSE Pg 7.6		
TMP-1	5	Determine if alternative functional choices can be traded to determine an optimal configuration	INCOSE Pg 7.6		
TMP-1	5	Determine if alternative performance choices can be traded to determine an optimal configuration	INCOSE Pg 7.6		
TMP-1	4	Select analysis methods	DAG Sec 4.2.3.1.; INCOSE Pg 7.2		
TMP-1	5	Use simulation and experimental design to perform trade-offs	Buede Pg 149		
TMP-1	4	Define measures of merit	INCOSE Pg 7.5		
TMP-1	4	Select candidates for study	INCOSE Pg 7.5		
TMP-1	3	Evaluate alternatives	INCOSE Pg 7.5	House of Quality, Utility Theory, Influence Diagrams, Decision Tree, Sensitivity Analysis	100%
TMP-1	4	Determine probability of alternatives	Buede Pg 361		
TMP-1	4	Determine order of preferences	Buede Pg 361		
TMP-1	4	Determine acceptable substitutions	Buede Pg 361; INCOSE Pg 5.8		
TMP-1	5	Use value creation lens for evaluating opportunities	INCOSE Pg 7.3		
TMP-1	4	Analyze results	INCOSE Pg 7.5		
TMP-1	5	Gather meaningful and reliable data	INCOSE Pg 7.3		
TMP-1	5	Make value judgements of trade-offs by customer	Buede Pg 149		
TMP-1	5	Evaluate consequences of alternative choices	INCOSE Pg 5.8		
TMP-1	5	Avoid analysis paralysis	INCOSE Pg 7.3		
TMP-1	4	Review results with stakeholders	INCOSE Pg 7.5		
TMP-1	**5**	**Allow customer to modify requirements based on trade-offs**	**Buede Pg 149**		
TMP-1	5	Allow customer to participate in developing solution based on trade-offs	Buede Pg 149; INCOSE Pg 7.2		
TMP-1	4	Investigate consequences of implementation	INCOSE Pg 7.5		
TMP-1	4	Utilize scenario planning to test assumptions about future	INCOSE Pg 7.5		
TMP-1	4	Select best alternative	Buede Pg 361; INCOSE Pg 5.8 INCOSE Pg 7.5		
TMP-1	5	Delay commitment to last moment	INCOSE Pg 7.4		
TMP-1	4	Communicate new directions from decision	INCOSE Pg 5.8		
TMP-1	3	Document decision	INCOSE Pg 5.8		100%
TMP-1	4	Document approved decision	INCOSE Pg 5.8		
TMP-1	4	Document relevant data and supporting documentation	INCOSE Pg 5.8		
TMP-1	5	Document rationale	INCOSE Pg 5.8		
TMP-1	5	Document assumptions	INCOSE Pg 5.8		
TMP-1	5	Document constraints	INCOSE Pg 5.8		
TMP-1	5	Document supporting analysis	INCOSE Pg 5.8		
TMP-1	4	Maintain history of prior studies and decisions in case old questions reappear	INCOSE Pg 5.8	Decision Analysis Record	
TMP-2	1	**TMP-2 (Technical Planning)**			**0% - 100%**
TMP-2	2	**Plan Systems Engineering**	DAG Sec 4.2.3.2.		**0% - 100%**
TMP-2	3	Collaborate with project managers to develop project plan	INCOSE Pg 8.11	SE Plan	100%
TMP-2	4	Consider where past experiences and intuition have been a handicap, for architecture development	INCOSE Pg 8.3		
TMP-2	4	Consider developing architectural alternatives to meet stakeholder requirements	INCOSE Pg 8.2		
TMP-2	3	Address scope of technical effort	DAG Sec 4.2.3.2.		100%
TMP-2	3	Identify people	DAG Sec 4.2.4.3.	Integrated Product Team	100%
TMP-2	4	Use Integrated Product Team for analysis	INCOSE Pg 4.8		
TMP-2	3	Identify processes	DAG Sec 4.2.4.3.		100%
TMP-2	4	Determine program decision process	DAG Sec 4.2.4.3.		
TMP-2	3	Develop integration plan	INCOSE Pg 4.12		80%
TMP-2	3	Identify critical producability requirements	INCOSE Pg 8.4		80%

TMP-2	3	Establish contractual context and constraints	INCOSE Pg 8.1		100%
TMP-2	4	Examine implementation (TP 4) for constraints	DAG Sec 4.2.3.2.		
TMP-2	4	Examine integration (TP 5) for constraints	DAG Sec 4.2.3.2.		
TMP-2	4	Examine verification (TP 6) for constraints	DAG Sec 4.2.3.2.		
TMP-2	4	Examine validation (TP 7) for constraints	DAG Sec 4.2.3.2.		
TMP-2	4	Examine transition (TP 8) for constraints	DAG Sec 4.2.3.2.		
TMP-2	3	Assist project manager with contract negotiations	INCOSE Pg 8.1		100%
TMP-2	3	Address conformance with society expectations	INCOSE Pg 4.1		100%
TMP-2	3	Address conformance with legislative requirements	INCOSE Pg 4.1		100%
TMP-2	3	Establish quality management	INCOSE Pg 8.12		80%
TMP-2	3	Develop plan to qualify suppliers	DAG Sec 4.2.4.4.		100%
TMP-2	3	Develop receiving inspection plan	DAG Sec 4.2.4.4.		100%
TMP-2	3	Develop manufacturing system	DAG Sec 4.2.4.4.		0%
TMP-2	4	Develop manufacture processes	DAG Sec 4.2.4.4.		
TMP-2	4	Develop manufacture procedures	DAG Sec 4.2.4.4.		
TMP-2	4	Identify packaging	DAG Sec 4.2.4.4.		
TMP-2	4	Identify handling	DAG Sec 4.2.4.4.		
TMP-2	4	Identify storage	DAG Sec 4.2.4.4.		
TMP-2	4	Identify equipment maintainance program	DAG Sec 4.2.4.4.		
TMP-2	5	Identify criteria for refurb inspection	DAG Sec 4.2.4.4.		
TMP-2	3	Develop configuration management plan	INCOSE Pg 8.5		100%
TMP-2	3	Develop information management plan	INCOSE Pg 8.6		100%
TMP-2	3	Define test plans and schedule	Buede Pg 314		100%
TMP-2	4	Develop verification schedule, consistent with development schedule	Buede Pg 314		
TMP-2	4	Schedule verification enabling systems	INCOSE Pg 4.14		
TMP-2	4	Define analysis schedule	Buede Pg 314		
TMP-2	3	Prepare for verification	DAG Sec 4.2.4.4.; INCOSE Pg 8.15		100%
TMP-2	4	Identify tester calibration program	DAG Sec 4.2.4.4.		
TMP-2	4	Define verification organizations	Buede Pg 314		
TMP-2	4	Define verification resources	Buede Pg 314		
TMP-2	3	Prepare for validation	DAG Sec 4.2.4.4.; INCOSE Pg 8.15		100%
TMP-2	4	Define validation resources	Buede Pg 314		
TMP-2	4	Define validation organizations	Buede Pg 314		
TMP-2	3	Prepare transition strategy	INCOSE Pg 4.15		100%
TMP-2	4	Assess operational environment	INCOSE Pg 4.15		
TMP-2	4	Prepare operator training strategy	INCOSE Pg 4.15		
TMP-2	4	Prepare logistics support strategy	INCOSE Pg 4.15		
TMP-2	4	Develop installation procedure	INCOSE Pg 4.15		
TMP-2	4	Define operational concept for qualification of deliverables	Buede Pg 314		
TMP-2	4	Define requirements for qualification of deliverables	Buede Pg 314		
TMP-2	4	Define functional architecture for qualification	Buede Pg 314		
TMP-2	2	**Implement Technical Plan**	INCOSE Pg 8.1-13	Integrated Master Plan	**50% - 100%**
TMP-2	3	Utilize SE Plan (SEP) and Integrated Master Schedule (IMS)	INCOSE Pg 8.11		100%
TMP-2	3	Develop system architecture	INCOSE Pg 8.2	DoDAF System View	80%
TMP-2	3	Participate in process compliance reviews	INCOSE Pg 8.12		100%
TMP-2	3	Perform technical management activities (planning, scheduling, reviewing, and auditing to SE process)	INCOSE Pg 8.11		100%
TMP-2	3	Perform preliminary trade studies on cost, schedule, and technical performance	INCOSE Pg 8.1		100%
TMP-2	3	Perform interoperability analysis	INCOSE Pg 8.3		80%
TMP-2	3	Perform manufacturing and producibility analysis	INCOSE Pg 8.4		80%
TMP-2	3	Perform cost-effectiveness analysis	INCOSE Pg 8.8		50%
TMP-2	3	Perform life cycle-cost analysis	INCOSE Pg 8.9		100%
TMP-2	3	Maintain resource management	INCOSE Pg 8.13		100%
TMP-2	2	**Evaluate Plan to Address Needs**	INCOSE Pg 3.8-9		**0% - 0%**
TMP-2	3	Assess impacts of product modifications during production	INCOSE Pg 3.8		0%
TMP-2	3	Assess impacts of product modifications during usage	INCOSE Pg 3.8		0%
TMP-2	3	Assess impacts of product maintenance modifications during usage	INCOSE Pg 3.9		0%
TMP-3	1	**TMP-3 (Technical Assessment)**			**100% - 100%**
TMP-3	2	**Prepare for Technical Assessment**	DAG Sec 4.2.3.3.		**100% - 100%**
TMP-3	3	Develop review process	DAG Sec 4.2.3.3.		100%
TMP-3	4	Develop/utilize project plans	INCOSE Pg 5.5		

TMP-3	4	"What gets measured gets done"	INCOSE Pg 5.5		
TMP-3	4	Utilize prior project status	INCOSE Pg 5.5		
TMP-3	4	Utilize key personnel	INCOSE Pg 5.5		
TMP-3	4	Utilize key resources	INCOSE Pg 5.5		
TMP-3	3	Determine technical performance measures	INCOSE Pg 5.5	TPMs	100%
TMP-3	4	Determine project performance measures	INCOSE Pg 5.5		
TMP-3	3	Schedule frequent assessments	INCOSE Pg 5.6	IPT Meetings	100%
TMP-3	2	**Perform Technical Assessment**	INCOSE Pg 5.5		**100% - 100%**
TMP-3	3	Gain insight into contractor processes	DAG Sec 4.2.4.4.		100%
TMP-3	3	Monitor critical tasks	INCOSE Pg 5.5	Integrated Master Schedule	100%
TMP-3	3	Monitor new technologies	INCOSE Pg 5.5		100%
TMP-3	3	Conduct technical reviews	DAG Sec 4.2.3.3.; INCOSE Pg 5.5		100%
TMP-3	4	Evaluate hardware solutions	DAG Sec 4.2.4.4.		
TMP-3	4	Evaluate manufacturing solutions	DAG Sec 4.2.4.4.		
TMP-3	4	Evaluate software solutions	DAG Sec 4.2.4.4.		
TMP-3	4	Evaluate test results	DAG Sec 4.2.4.4.		
TMP-3	4	Analyze trade studies	Buede Pg 268		
TMP-3	4	Assess "ilities"			
TMP-3	5	Address reliability	Buede Pg 267		
TMP-3	5	Address availability	Buede Pg 267; INCOSE Pg 5.5		
TMP-3	5	Address maintainability	Buede Pg 267; INCOSE Pg 3.9		
TMP-3	5	Address usability	Buede Pg 267		
TMP-3	5	Address supportability	Buede Pg 267		
TMP-3	5	Address durability	Buede Pg 267		
TMP-3	5	Address affordability	Buede Pg 267; INCOSE Pg 5.5		
TMP-3	4	Assess concurrent engineering			
TMP-3	5	Address concurrent engineering issues to impact on manufacturing	Buede Pg 267; INCOSE Pg 3.8		
TMP-3	5	Address concurrent engineering issues to impact on deployment	Buede Pg 267		
TMP-3	5	Address concurrent engineering issues to impact on training	Buede Pg 267		
TMP-3	5	Address concurrent engineering issues to impact on disposal	Buede Pg 267; INCOSE Pg 3.9		
TMP-3	4	Assess product modifications	INCOSE Pg 3.8		
TMP-3	4	Assess resources			
TMP-3	4	Evaluate completion of required accomplishments	DAG Sec 4.2.3.3.; INCOSE Pg 5.5		
TMP-3	4	Determine deviations in project quality	INCOSE Pg 5.5		
TMP-3	3	Conduct peer reviews	INCOSE Pg 4.10		100%
TMP-3	3	Evaluate to exit criteria	DAG Sec 4.2.3.3.; INCOSE Pg 5.5		100%
TMP-3	4	Determine actual and projected cost against budget	INCOSE Pg 5.5		
TMP-3	4	Determine actual and projected time against schedule	INCOSE Pg 5.5		
TMP-3	4	Evaluate effectiveness of personnel	INCOSE Pg 5.5		
TMP-3	4	Evaluate adequacy of project infrastructure	INCOSE Pg 5.5		
TMP-3	4	Evaluate availability of project infrastructure	INCOSE Pg 5.5		
TMP-3	4	Evaluate project progress against established criteria	INCOSE Pg 5.5		
TMP-3	4	Evaluate project progress against established milestones	INCOSE Pg 5.5		
TMP-3	4	Conduct reviews to determine readiness to proceed to next milestone	INCOSE Pg 5.5		
TMP-3	3	Follow-through with results			100%
TMP-3	4	Determine recommendations for adjustments to project plans	INCOSE Pg 5.5		
TMP-3	5	Determine corrective actions for deficiencies	DAG Sec 4.2.3.3.; INCOSE Pg 5.5		
TMP-3	5	Make recommendations for adjustments to project plans	INCOSE Pg 5.5		
TMP-3	4	Make decision to proceeed or not to proceed, when assessment supports tollgate	INCOSE Pg 5.6		
TMP-3	4	Generate change requests	INCOSE Pg 5.5		
TMP-3	5	Establish changes to schedule to reflect actions taken	INCOSE Pg 5.6		
TMP-3	5	Establish work items to reflect actions taken	INCOSE Pg 5.6		
TMP-3	4	Implement corrective actions for deficiencies	DAG Sec 4.2.3.3.; INCOSE Pg 5.6		
TMP-3	5	Initiate corrective actions when assessment indicates deviation from approved plan	INCOSE Pg 5.6		
TMP-3	5	Initiate preventive actions when assessment indicates trend toward deviation	INCOSE Pg 5.6		

TMP-3	5	Initiate problem resolution when assessment indicates non-conformance with performance success criteria	INCOSE Pg 5.6		
TMP-3	4	Compile project performance measures assessment	INCOSE Pg 5.5		
TMP-3	4	Identify risk assessment situations	INCOSE Pg 5.5		
TMP-3	4	Develop effective feedback control system	INCOSE Pg 5.6		
TMP-3	4	Communicate status per agreements and policies	INCOSE Pg 5.5		
TMP-4	1	**TMP-4 (Requirements Management)**			10% - 100%
TMP-4	2	**Determine Roles/Responsibilities During Reqs Generation Process**	Buede Pg 129		100% - 100%
TMP-4	3	Identify stakeholders (customers, end-users, regulatory agencies, representation for future generations, etc.)	INCOSE Pg 7.7	INCOSE Tools Database: Working Group Database (INCOSE Pg 7.7)	100%
TMP-4	4	Identify who has right to have operational requirement	Buede Pg 129		
TMP-4	3	Establish means for stakeholder interaction	Buede Pg 129		100%
TMP-4	2	**Define System Capabilities and Performance Objectives**	INCOSE Pg 7.6-12		30% - 100%
TMP-4	3	Understand needs of stakeholders to support architecture design process	INCOSE Pg 7.10	Identify capability gaps & threatening systems	100%
TMP-4	3	Elicit and capture requirements	INCOSE Pg 7.6	DoDAF OV-1, Interviews, Focus Groups, Delphi Technique	100%
TMP-4	4	Collect requirements from all communications and negotiations	INCOSE Pg 7.6		
TMP-4	4	Capture source for each requirement	INCOSE Pg 7.6		
TMP-4	4	Capture rationale for each requirement	INCOSE Pg 4.4		
TMP-4	3	Address non-functional requirements (ilities) early	INCOSE Pg 7.9		30%
TMP-4	3	Develop technical performance measures for each requirement	INCOSE Pg 7.12		100%
			INCOSE Pg 7.12		
TMP-4	2	**Validate Requirements Development Process**	Buede Pg 41		50% - 50%
TMP-4	3	Generate operational analysis models to test concept and requirements validity	INCOSE Pg 7.9	DoDAF Operational Views	50%
TMP-4	4	Carry analysis to one level deeper than seems necessary	Buede Pg 158		
TMP-4	4	Carry analysis to one level broader than seems necessary	Buede Pg 158		
TMP-4	4	Determine how it is known that requirement is "right"	Buede Pg 129		
TMP-4	2	**Ensure Requirements Feasibility and Validity**	Buede Pg 40		10% - 100%
TMP-4	3	Ensure customer and consumers understand requirements	Buede Pg 158		100%
TMP-4	4	Identify scenarios	INCOSE Pg 7.8	interviews with opertors of current or similar systems, potential end users, and meetings with Interface Working Group	
TMP-4	4	Resolve uncertanties with requirements	INCOSE Pg 7.11		
TMP-4	3	Analyze requirements for clarity, completeness, and consistency	INCOSE Pg 4.4; DAG Sec 4.2.4.3.		80%
TMP-4	4	Analyze requirements against all communications and negotiations	INCOSE Pg 7.6		
TMP-4	4	Analyze impact of emerging technologies	DAG Sec 4.2.3.4.		
TMP-4	4	Analyze impact of current threats	DAG Sec 4.2.3.4.		
TMP-4	4	Utilize Failure Modes Effects and Criticality Analysis (FMECA) or Hazard Analysis to identify critical system level requirements	INCOSE Pg 4.6		
TMP-4	3	Analyze requirements for feasibility by interdisciplinary team	INCOSE Pg 7.11		10%
TMP-4	3	Validate requirements at all levels	INCOSE Pg 7.9		100%
TMP-4	4	Validate requirements to all communications and negotiations	INCOSE Pg 7.6		
TMP-4	3	Assess if requirements are verifiable	INCOSE Pg 7.11		70%
TMP-4	2	**Document Requirements**	INCOSE Pg 4.3, 4.4		30% - 100%
TMP-4	3	Develop concept document to capture implementation-free understanding of stakeholder's needs	INCOSE Pg 7.9	Initial Capabilities Document or equivalent; AFPD 10-28	100%
TMP-4	4	Develop concept document to capture behavioral characteristics of subsystems	INCOSE Pg 7.9	DoDAF OV-2	
TMP-4	4	Develop concept document to capture manner in which people will interact with system	INCOSE Pg 7.9	DoDAF OV-2	

TMP-4	4	Develop concept document to capture external system interaction	INCOSE Pg 7.9	CJCSI/M 3170; AFPD 10 28	
TMP-4	3	Create templates for constructing requirements statements	INCOSE Pg 4.6		80%
TMP-4	3	Write rationale for each requirement (often uncovers real requirement)	Buede Pg 158		80%
TMP-4	4	Establish basis for requirements to support system over its life	INCOSE Pg 7.9		
TMP-4	4	Establish basis for test planning, system test requirements, and environmental simulator requirements	INCOSE Pg 7.9		
TMP-4	4	Provide basis for computation of system capacity	INCOSE Pg 7.9		
TMP-4	3	Develop requirements diagram to capture hierarchies, derivation, satisfaction, and verification relationships	INCOSE Pg 7.8	DoDAF OV-5, SV-5	30%
TMP-4	3	Place established requirements under configuration control	INCOSE Pg 4.4		60%
TMP-4	3	Convey documented requirements to stakeholders	Buede Pg 129	Originating requirements document; Requirements Baseline	100%
TMP-4	2	**Ensure Traceability of Requirements**	DAG Sec 4.2.3.4.; Buede Pg 158; INCOSE Pg 3.10		**100% - 100%**
TMP-4	3	Determine traceability tool	Buede Pg 23; INCOSE Pg 4.4	Initial Capabilities Document, Excel Spreadsheet	100%
TMP-4	4	Develop requirements verification traceability matrix	INCOSE Pg 4.13		
TMP-4	3	Provide traceability from operational needs to requirements	INCOSE Pg 7.9		100%
TMP-4	4	Determine requirements traced to functions	Buede Pg 53; INCOSE Pg 4.8		
TMP-4	4	Determine requirements traced to components	Buede Pg 53; INCOSE Pg 4.9		
TMP-4	4	Determine requirements traced to inputs/outputs assigned to interfaces	Buede Pg 53; INCOSE Pg 4.11		
TMP-4	4	Enter data to traceability matrix	INCOSE Pg 4.17		
TMP-4	**3**	**Maintain traceability to requirements**	**INCOSE Pg 4.6**		**100%**
TMP-4	4	Confirm upward traceability of requirements	DAG Sec 4.2.4.3.		
TMP-4	4	Confirm downward traceability of requirements	DAG Sec 4.2.4.3.		
TMP-4	4	Continually verify technical parameters to monitor trend	INCOSE Pg 7.12		
TMP-4	4	Control external interfaces	Buede Pg 158		
TMP-4	4	Control internal interfaces	Buede Pg 158		
TMP-4	4	Input information to requirements verification traceability matrix	INCOSE Pg 4.14		
TMP-4	2	**Establish Process for Requirements Changes**	Buede Pg 129		**80% - 100%**
TMP-4	3	Establish plan to correct/change requirements	Buede Pg 158		100%
TMP-4	3	Establish process for evaluating impact of system modifications	Buede Pg 129		80%
TMP-4	3	Document requirements changes	DAG Sec 4.2.3.4.		100%
TMP-4	4	Record rationale for changes	DAG Sec 4.2.3.4.		
TMP-4	4	Record corrective actions	INCOSE Pg 4.14		
TMP-4	3	Assess product modifications	INCOSE Pg 3.8		80%
TMP-4	4	Record evidence that system element satisfies requirements, or not	INCOSE Pg 4.14		
TMP-4	4	Record evidence that system satisfies requirements, or not	INCOSE Pg 4.14		
TMP-5	1	**TMP-5 (Risk Management)**			**40% - 100%**
TMP-5	2	**Risk Planning**	DAG Sec 4.2.3.5	Risk Management Framework	0%
TMP-5	3	Establish risk management process	DAG Sec 4.2.3.5.; Buede Pg 382; INCOSE Pg 5.11	Reference Project Management Institute, and "Risk Management Standard" generated by Institute of Risk Management	100%
TMP-5	3	Coordinate risk management activities	DAG Sec 4.2.3.5.; INCOSE Pg 3.4		50%
TMP-5	4	Identify what should be done	DAG Sec 4.2.3.5.		
TMP-5	4	Establish schedule	DAG Sec 4.2.3.5.	Integrated Master Schedule	
TMP-5	4	Assign responsibilities	DAG Sec 4.2.3.5.		
TMP-5	3	Utilize project risk assessments	INCOSE Pg 5.10		100%

TMP-5	4	Utilize prior risk matrix	INCOSE Pg 5.10	Examine successes, failures, problems, and solutions of similar prior projects; expected value model (INCOSE Pg 7.15)	
TMP-5	4	Utilize project plans and performance	INCOSE Pg 5.10		
TMP-5	2	**Risk Identification**	DAG Sec 4.2.3.5.; Buede Pg 314; INCOSE Pg 5.10-5.11	Documentation Reviews; Information Gathering (Brainstorming, Delphi Technique, Interviews, SWOT (Strength-Weakness-Opportunity-Threat) Analysis)	**50% - 100%**
TMP-5	3	Identify cost risk	DAG Sec 4.2.3.5.; INCOSE Pg 7.14	Checklists	100%
TMP-5	3	Identify schedule risk	DAG Sec 4.2.3.5.; INCOSE Pg 7.14	Integrated Master Schedule, Critical Path Analysis, Assumption and Constraint Analysis	100%
TMP-5	3	Identify performance risk	DAG Sec 4.2.3.5.; INCOSE Pg 7.14	Diagramming Techniques (Cause-Effect Diagrams, Fault-Event Trees, System/Process Flow Charts, Influence Diagrams)	100%
TMP-5	3	Identify technology maturity risks	DAG Sec 4.2.3.5.	Graph of planned value of key parameter plotted against calendar time (INCOSE Pg 7.17)	100%
TMP-5	4	Identify root cause for technology maturity risks	DAG Sec 4.2.3.5.		
TMP-5	3	Identify supplier capability risks	DAG Sec 4.2.3.5.		80%
TMP-5	4	Identify root cause for supplier capability risks	DAG Sec 4.2.3.5.		
TMP-5	3	Identify design maturation risks	DAG Sec 4.2.3.5.		50%
TMP-5	4	Identify root cause for design maturation risks	DAG Sec 4.2.3.5.		
TMP-5	3	Review potential shortfalls against expectations	DAG Sec 4.2.3.5.		100%
TMP-5	2	**Risk Analysis (Qualitative & Quantitative)**	DAG Sec 4.2.3.5.; Buede Pg 382	ARENA, CORE, MATLAB State Flow Modeler, Crystal Ball (Excel add-in)	**100% - 100%**
TMP-5	3	Identify Areas for Analysis			100%
TMP-5	4	Analyze requirements	INCOSE Pg 7.18		
TMP-5	4	Analyze current / proposed staffing	DAG Sec 4.2.3.5.		
TMP-5	4	Analyze current / proposed process	DAG Sec 4.2.3.5.		
TMP-5	4	Analyze current / proposed design	DAG Sec 4.2.3.5.		
TMP-5	4	Analyze current / proposed supplier	DAG Sec 4.2.3.5.		
TMP-5	4	Analyze current / proposed operational employment	DAG Sec 4.2.3.5.		
TMP-5	4	Analyze current / proposed resources	DAG Sec 4.2.3.5.		
TMP-5	4	Analyze current / proposed dependancies	DAG Sec 4.2.3.5.		
TMP-5	4	Analyze negative trends	DAG Sec 4.2.3.5.		
TMP-5	4	Examine wide range of operational scenarios	Buede Pg 267		
TMP-5	3	Assess Probability	INCOSE Pg 5.10		100%
TMP-5	4	Identify probability of threats	DAG Sec 4.2.3.5.		
TMP-5	4	Identify probability of technology maturity risks	DAG Sec 4.2.3.5.		
TMP-5	4	Identify probability of supplier capability risks	DAG Sec 4.2.3.5.		
TMP-5	4	Identify probability of design maturation risks	DAG Sec 4.2.3.5.		
TMP-5	4	Identify probability of performance vs plan risks	DAG Sec 4.2.3.5.		
TMP-5	3	Assess Consequence	INCOSE Pg 5.10		100%
TMP-5	4	Identify consequence of threats	DAG Sec 4.2.3.5.		
TMP-5	4	Identify consequence of technology maturity risks	DAG Sec 4.2.3.5.		
TMP-5	4	Identify consequence of supplier capability risks	DAG Sec 4.2.3.5.		
TMP-5	4	Identify consequence of design maturation risks	DAG Sec 4.2.3.5.		
TMP-5	4	Identify consequence of performance vs plan risks	DAG Sec 4.2.3.5.		

TMP-5	2	**Risk Handling**	DAG Sec 4.2.3.5.; INCOSE Pg 5.11		**100% - 100%**
TMP-5	3	Establish risk handling approaches for moderate and high risk items	INCOSE Pg 7.17	Risk Management Plan	100%
TMP-5	4	Risk Mitigation	DAG Sec 4.2.3.5.; Buede Pg. 314		
TMP-5	5	Determine planning for risk mitigation	DAG Sec 4.2.3.5.		
TMP-5	5	Determine budget for risk mitigation	DAG Sec 4.2.3.5.		
TMP-5	5	Determine requirements for risk mitigation	DAG Sec 4.2.3.5.		
TMP-5	5	Determine contractual changes for risk mitigation	DAG Sec 4.2.3.5.		
TMP-5	5	Generate change requests to mitigate technical risk	INCOSE Pg 5.10		
TMP-5	5	Prioritize handling of risks	INCOSE Pg 5.10		
TMP-5	5	Generate plan of action for when risk threshold exceeds acceptable levels	INCOSE Pg 5.11		
TMP-5	5	Utilize measurements or statistics that help manage the risk	INCOSE Pg 5.11		
TMP-5	4	Risk Acceptance	DAG Sec 4.2.3.5.		
TMP-5	4	Risk Transference	DAG Sec 4.2.3.5.; Buede Pg 382		
TMP-5	4	Risk Avoidance	DAG Sec 4.2.3.5.; Buede Pg 382		
TMP-5	5	Avoid risks introduced by human error through training, teamwork, and morale	INCOSE Pg 7.18		
TMP-5	5	Avoid risks through early procurement, initiate parallel developments, implement extensive analysis and testing, and make contingency plans	INCOSE Pg 7.18		
TMP-5	3	Select most promising risk handling option	INCOSE Pg 7.18		100%
TMP-5	4	Beware of temptation to reduce verification activities due to budget or schedule overruns	INCOSE Pg 4.14		
TMP-5	4	Avoid conducting verification late in schedule	INCOSE Pg 4.14		
TMP-5	2	**Risk Monitoring**	DAG Sec 4.2.3.5.		**100% - 100%**
TMP-5	3	Communicate risks to stakeholders	DAG Sec 4.2.3.5.; INCOSE Pg 5.11		100%
TMP-5	4	Outline risk reporting requirements	DAG Sec 4.2.3.5.		
TMP-5	4	Communicate risk management activities	DAG Sec 4.2.3.5.		
TMP-5	4	Alert management for plans implement/change	DAG Sec 4.2.3.5.		
TMP-5	3	Monitor risk mitigation plans	DAG Sec 4.2.3.5.		100%
TMP-5	3	Review regular status updates	DAG Sec 4.2.3.5.		100%
TMP-5	4	Conduct periodic program management reviews	DAG Sec 4.2.3.5.		
TMP-5	4	Conduct periodic technical reviews	DAG Sec 4.2.3.5.		
TMP-5	3	Monitor test results	DAG Sec 4.2.3.5.		100%
TMP-5	2	**Risk Documentation**	DAG Sec 4.2.3.5.; INCOSE Pg 5.10		**40% - 100%**
TMP-5	3	Document risk management activities	DAG Sec 4.2.3.5.; INCOSE Pg 5.10		100%
TMP-5	3	Document change history	DAG Sec 4.2.3.5.		60%
TMP-5	3	Document program metrics	DAG Sec 4.2.3.5.		100%
TMP-5	3	Document technical reports	DAG Sec 4.2.3.5.		100%
TMP-5	3	Document earned value reports	DAG Sec 4.2.3.5.		80%
TMP-5	3	Document watch lists	DAG Sec 4.2.3.5.		40%
TMP-5	3	Document schedule performance reports	DAG Sec 4.2.3.5.		80%
TMP-5	3	Document technical review minutes	DAG Sec 4.2.3.5.		100%
TMP-5	3	Document critical risk process reports	DAG Sec 4.2.3.5.		100%
TMP-5	3	Maintain record of risk items and how they were handled	INCOSE Pg 5.11		100%
TMP-6	1	**TMP-6 (Configuration Management)**			**50% - 100%**
TMP-6	2	**Develop Configuration Baselines**	DAG Sec 4.2.3.6.; INCOSE Pg 4.17; INCOSE Pg 5.12		**70% - 100%**
TMP-6	3	Begin configuration management process in early phases of project	INCOSE Pg 5.13		100%
TMP-6	3	Establish configuration management responsibilities	INCOSE Pg 5.12	Configuration Control Board	70%
TMP-6	4	Identify gov/ctr systems engineering interaction	DAG Sec 4.2.3.6.		
TMP-6	4	Identify gov/ctr design engineering interaction	DAG Sec 4.2.3.6.		
TMP-6	4	Identify gov/ctr logistics interaction	DAG Sec 4.2.3.6.		
TMP-6	4	Identify gov/ctr contracting interaction	DAG Sec 4.2.3.6.		
TMP-6	4	Identify gov/ctr manufacturing interaction	DAG Sec 4.2.3.6.		

TMP-6	3	Establish structure for configuration identification	DAG Sec 4.2.3.6.		70%
TMP-6	3	Identify system elements to maintain under configuration control	INCOSE Pg 5.13	Configuration Items	70%
TMP-6	4	Assign unique identifier to each version of each system element	DAG Sec 4.2.3.6.; INCOSE Pg 8.5		
TMP-6	3	Establish architectural baseline	INCOSE Pg 4.8		100%
TMP-6	4	Ensure product functional characteristics are properly identified, documented, validated, and verified	INCOSE Pg 5.12		
TMP-6	4	Ensure product performance characteristics are properly identified, documented, validated, and verified	INCOSE Pg 5.12		
TMP-6	4	Document architectural design decisions	INCOSE Pg 4.8		
TMP-6	4	Obtain design approval	Buede Pg 31		
TMP-6	4	Document design approval	Buede Pg 31		
TMP-6	5	Provide substantiated justification	INCOSE Pg 3.7		
TMP-6	5	Obtain approval of documentation	Buede Pg 40		
TMP-6	3	Establish hardware baselines	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		100%
TMP-6	4	Ensure product physical characteristics are properly identified, documented, validated, and verified	INCOSE Pg 5.12		
TMP-6	4	Complete product specifications	INCOSE Pg 4.10		
TMP-6	4	Complete process specifications	INCOSE Pg 4.10		
TMP-6	4	Complete material specifications	INCOSE Pg 4.10		
TMP-6	4	Complete product assembly drawings	INCOSE Pg 4.12		
TMP-6	4	Complete manufacturing tool drawings	INCOSE Pg 4.12		
TMP-6	3	Establish software baselines	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		100%
TMP-6	2	**Establish Configuration Change Control Plan (Establish configuration control cycle that incorporates evaluation, approval, validation, and verification of change requests)**	DAG Sec 4.2.3.6.; INCOSE Pg 5.13		**50% - 50%**
TMP-6	3	Establish change request process	INCOSE Pg 5.12	Configuration Control Board	50%
TMP-6	4	Ensure changes identified	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		
TMP-6	4	Ensure changes recorded	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		
TMP-6	4	Ensure changes evaluated	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		
TMP-6	4	Ensure changes approved/disapproved	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		
TMP-6	4	Ensure changes incorporated	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		
TMP-6	4	Ensure changes verified	DAG Sec 4.2.3.6.; INCOSE Pg 5.12		
TMP-6	4	Establish configuration control board	INCOSE Pg 5.13		
TMP-6	3	Identify criteria and means for auditing element configuration to design documentaion	INCOSE Pg 4.10		50%
TMP-6	2	**Develop and Maintain Configuration Control Documentation**	INCOSE Pg 4.6 & 5.13		**50% - 50%**
TMP-6	3	Document status and impact of change request	DAG Sec 4.2.3.6.; INCOSE Pg 5.13	Change Request Database	50%
TMP-6	3	Identify and document characteristics of system elements to be unique and accessible	INCOSE Pg 8.5		50%
TMP-6	2	**Maintain Configuration Baselines**	DAG Sec 4.2.3.6.; INCOSE Pg 4.12 & 5.13		**50% - 100%**
TMP-6	3	Control and maintain architectural baselines	Student Derived		100%
TMP-6	3	Control, and maintain hardware baselines	INCOSE Pg 5.12		80%
TMP-6	3	Control, and maintain software baselines	INCOSE Pg 5.12		80%
TMP-6	3	Perform configuration audits associated with milestones and decision gates to validate baselines	DAG Sec 4.2.3.6.; INCOSE Pg 5.13		50%
TMP-6	4	Assure audit trail for decisions	DAG Sec 4.2.3.6.; INCOSE Pg 8.5		
TMP-6	4	Assure audit trail for design modifications	DAG Sec 4.2.3.6.; INCOSE Pg 8.5		
TMP-6	3	Update design documentation	INCOSE Pg 4.10		100%
TMP-6	3	Ensure consistent product versions	INCOSE Pg 8.5		100%

TMP-7	1	**TMP-7 (Technical Data Management)**			**10% - 100%**
TMP-7	2	**Develop Data Management Plan**	DAG Sec 4.2.3.7.; INCOSE Pg 5.15	Core Architecture Data Model	**70% - 100%**
TMP-7	3	Identify data management policies	DAG Sec 4.2.3.7.		70%
TMP-7	3	Identify data management systems	DAG Sec 4.2.3.7.		70%
TMP-7	3	Identify data management procedures	DAG Sec 4.2.3.7.		70%
TMP-7	3	Identify method of recording technical data	DAG Sec 4.2.3.7.		100%
TMP-7	4	Identify method of recording system development	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording modeling & sim	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording test development	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording test and evaluation	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording installation	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording spare parts	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording repair parts	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording product sustainment	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording supplier data	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording software documentation	DAG Sec 4.2.3.7.		
TMP-7	4	Identify method of recording management info	DAG Sec 4.2.3.7.		
TMP-7	3	Establish and maintain data dictionary	INCOSE Pg 5.15		70%
TMP-7	2	**Determine / Define System Relevant Information**	INCOSE Pg 5.15		**100% - 100%**
TMP-7	3	Identify data reqs for development	DAG Sec 4.2.3.7.		100%
TMP-7	4	Identify data reqs for modeling & simulation	DAG Sec 4.2.3.7.		
TMP-7	4	Identify data reqs for test development	DAG Sec 4.2.3.7.		
TMP-7	4	Identify data reqs for test and evaluation	DAG Sec 4.2.3.7.		
TMP-7	4	Identify data reqs for installation	DAG Sec 4.2.3.7.		
TMP-7	4	Identify data reqs for spare parts	DAG Sec 4.2.3.7.		
TMP-7	4	Identify data reqs for repair parts	DAG Sec 4.2.3.7.		
TMP-7	4	Identify data reqs for product sustainment	DAG Sec 4.2.3.7.		
TMP-7	4	Identify data reqs for supplier data	DAG Sec 4.2.3.7.		
TMP-7	3	Identify technical data to be recorded	DAG Sec 4.2.3.7.		100%
TMP-7	4	Identify software documentation to be recorded	DAG Sec 4.2.3.7.		
TMP-7	4	Identify management information to be recorded	DAG Sec 4.2.3.7.		
TMP-7	4	Identify valid sources of information and periodically obtain artifacts of information	INCOSE Pg 5.15		
TMP-7	3	Identify technical data to be communicated	DAG Sec 4.2.3.7.		100%
TMP-7	4	Identify software doc to be communicated	DAG Sec 4.2.3.7.		
TMP-7	4	Identify management info to be communicated	DAG Sec 4.2.3.7.		
TMP-7	2	**Identify System Data to Purchase**	DAG Sec 4.2.3.7.1.		**100% - 100%**
TMP-7	3	Identify cost of data delivery	DAG Sec 4.2.3.7.1.		100%
TMP-7	3	Identify technical data to purchase	DAG Sec 4.2.3.7.1.		100%
TMP-7	4	Identify circumstances for data to be more useful	DAG Sec 4.2.3.7.1.		
TMP-7	4	Identify circumstances for data to be updated	DAG Sec 4.2.3.7.1.		
TMP-7	4	Identify required format of delivered data	DAG Sec 4.2.3.7.1.		
TMP-7	2	**Determine Data Protection Requirements**	DAG Sec 4.2.3.7.2.		**100% - 100%**
TMP-7	3	Identify if data has restrictions	DAG Sec 4.2.3.7.2.		100%
TMP-7	3	Determine data marking / release	DAG Sec 4.2.3.7.2.		100%
TMP-7	3	Develop protection for critical technology info	DAG Sec 4.2.3.7.2.		100%
TMP-7	4	Reference ISO 17799 "Code of Practice for Information Security Management"	INCOSE Pg 5.15		
TMP-7	3	Establish distribution statements	DAG Sec 4.2.3.7.2.		100%
TMP-7	3	Assure proper handling of data	DAG Sec 4.2.3.7.2.		100%
TMP-7	4	Assure proprietary data properly handled	DAG Sec 4.2.3.7.2.		
TMP-7	4	Assure limited distribution data properly handled	DAG Sec 4.2.3.7.2.		
TMP-7	4	Assure intellectual property data properly handled	DAG Sec 4.2.3.7.2.		
TMP-7	2	**Address Long-term Data Storage Requirements**	DAG Sec 4.2.3.7.3.		**70% - 100%**
TMP-7	3	Identify artifacts for storage	INCOSE Pg 5.15		100%
TMP-7	4	Identify information rich artifacts and store for later use	INCOSE Pg 5.15		
TMP-7	3	Develop plan for digitizing information	DAG Sec 4.2.3.7.3.		70%
TMP-7	4	Develop plan for digitized data availability	DAG Sec 4.2.3.7.3.		
TMP-7	4	Develop plan for preserving digitized data	DAG Sec 4.2.3.7.3.		
TMP-7	4	Develop plan to migrate digitized data to new form	DAG Sec 4.2.3.7.3.		
TMP-7	3	Address retrieval of data	DAG Sec 4.2.3.7.3.		100%
TMP-7	2	**Record Program Data**	INCOSE Pg 4.10		**10% - 100%**
TMP-7	3	Complete specifications	INCOSE Pg 4.10		80%
TMP-7	4	Complete product specifications	INCOSE Pg 4.10		
TMP-7	4	Complete process specifications	INCOSE Pg 4.10		

TMP-7	4	Complete material specifications	INCOSE Pg 4.10		
TMP-7	3	Update design documentation	INCOSE Pg 4.10		100%
TMP-7	3	Document testing and analysis results	Buede Pg 42		100%
TMP-7	4	Document verification testing	Buede Pg 42		
TMP-7	4	Document validation testing	Buede Pg 42		
TMP-7	4	Document integration testing results	INCOSE Pg 4.12		
TMP-7	4	Document integration analysis results	INCOSE Pg 4.12		
TMP-7	4	Document data acceptance test report	DAG Sec 4.2.4.6.		
TMP-7	3	Document architecture	INCOSE Pg 4.12	All DoDAF Views	100%
TMP-7	3	Develop manuals	DAG Sec 4.2.4.4.		10%
TMP-7	4	Develop operations manuals	DAG Sec 4.2.4.4.; INCOSE Pg 4.10		
TMP-7	4	Develop maintenance manuals	DAG Sec 4.2.4.4.		
TMP-7	4	Develop installation manuals	DAG Sec 4.2.4.4.		
TMP-7	3	Draft training documentation	INCOSE Pg 4.10		10%
TMP-7	4	Draft training documentation for operating system components	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for operating subsystems	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for operating systems	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for conducting failure detection and isolation for system components	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for conducting failure detection and isolation for subsystems	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for conducting failure detection and isolation for systems	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for maintaining system components	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for maintaining subsystems	INCOSE Pg 4.10		
TMP-7	4	Draft training documentation for maintaining systems	INCOSE Pg 4.10		
TMP-7	3	Maintain safety critical product documentation	INCOSE Pg 3.10		100%
TMP-7	2	**Make Project Data Available**	INCOSE Pg 5.15		**70% - 100%**
TMP-7	3	Define information formats and media (capture, retention, transmission, and retrieval)	INCOSE Pg 5.15		70%
TMP-7	3	Define storage requirements, access priveledges, and duration of maintenance	INCOSE Pg 5.15		70%
TMP-7	4	Define access priveledges, and duration of maintenance	INCOSE Pg 5.15		
TMP-7	4	Archive designated information to comply with legal requirements	INCOSE Pg 5.15		
TMP-7	3	Publish current and valid system information	INCOSE Pg 5.15		100%
TMP-7	4	Make available for use and communication of all relevant system artifacts in timely, complete, valid, and confidential manner	INCOSE Pg 5.15		
TMP-7	3	Maintain information according to security requirements	INCOSE Pg 5.15		100%
TMP-7	3	Retrieve and distribute information as required	INCOSE Pg 5.15		100%
TMP-7	4	Provide access to contents of data repositories; Email, intranet, database	INCOSE Pg 5.15		
TMP-7	4	Reference ISO 10303 "Standard for the Exchange of Product Model Data"	INCOSE Pg 5.15		
TMP-7	3	Retire unwanted, invalid, or unverifiable information	INCOSE Pg 5.15		100%
TMP-8	1	**TMP-8 (Interface Management)**			**10% - 100%**
TMP-8	2	**Define Interface Requirements and Control Methods**	Buede Pg 294; INCOSE Pg 4.8		**100% - 100%**
TMP-8	3	Utilize operational concept and system architecture	Buede Pg 294	CONOPS, DoDAF	100%
TMP-8	3	Utilize system integration plan	INCOSE Pg 4.8		100%
TMP-8	3	Identify interface management approach	DAG Sec 4.2.4.5.		100%
TMP-8	3	Identify interoperability among systems and sub-systems	DAG Sec 4.2.4.1.; INCOSE Pg 4.8		100%
TMP-8	3	Identify related internal and external interfaces	DAG Sec 4.2.4.3. DAG Sec 4.2.4.5.; Buede Pg 294	External Systems Diagram	100%
TMP-8	4	Identify items to be transported by interface	Buede Pg 294		
TMP-8	3	Identify interface constraints	INCOSE Pg 4.3		100%
TMP-8	4	Identify interface constraints from interfaces with legacy systems	INCOSE Pg 4.3		
TMP-8	3	Write interface requirements	Buede Pg 294		100%
TMP-8	3	Coordinate interface requirements with stakeholders	DAG Sec 4.2.4.5.		100%
TMP-8	3	Select high-level interface control methods	Buede Pg 294		100%
TMP-8	4	Identify candidate control methods	Buede Pg 294	DoDAF	
TMP-8	4	Define trial interfaces for each candidate	Buede Pg 294		
TMP-8	4	Evaluate alternatives against requirements	Buede Pg 294		
TMP-8	4	Choose high-level interface control methods	Buede Pg 294		

TMP-8	3	Identify interface definition impacts	DAG Sec 4.2.3.8.		100%
TMP-8	4	Identify impacts to original defined capabilities	DAG Sec 4.2.3.8.		
TMP-8	4	Identify impacts to original defined interfaces	DAG Sec 4.2.3.8.		
TMP-8	4	Identify impacts to perform parameter thresholds	DAG Sec 4.2.3.8.		
TMP-8	4	Identify impacts to perform parameter objectives	DAG Sec 4.2.3.8.		
TMP-8	4	Identify impacts to system	DAG Sec 4.2.3.8.		
TMP-8	2	**Develop System Interface Control Methods**	DAG Sec 4.2.4.1. DAG Sec 4.2.3.8.; Buede Pg 50; INCOSE Pg 4.7		**60% - 100%**
TMP-8	3	Develop functional interface controls	Buede Pg 294	DoDAF SV-1	100%
TMP-8	4	Identify functions performed by interfaces	Buede Pg 50		
TMP-8	4	Specify functional decoposition	Buede Pg 294		
TMP-8	4	Add inputs and outputs	Buede Pg 250, 94		
TMP-8	5	Determined required format of inputs and outputs as defined by interface	Buede Pg 131		
TMP-8	5	Interface simulation drivers should be representative of tactical environments	INCOSE Pg 4.11		
TMP-8	4	Add fault detection	Buede Pg 294		
TMP-8	4	Add recovery functions	Buede Pg 294		
TMP-8	3	Develop physical interface controls	Buede Pg 294	DoDAF SV-1	100%
TMP-8	4	Identify physical form/fit of interface	Buede Pg 131		
TMP-8	4	Identify candidates based on high level architecture	Buede Pg 294		
TMP-8	4	Eliminate infeasible candidates	Buede Pg 294		
TMP-8	3	Develop operational interface controls	Buede Pg 294	DoDAF OV-2	80%
TMP-8	4	Identify timing constraints with interface	Buede Pg 131		
TMP-8	4	Allocate functions to components of interface	Buede Pg 294		
TMP-8	4	Analyze behavior of alternatives	Buede Pg 294		
TMP-8	4	Analyze performance of alternatives	Buede Pg 294		
TMP-8	4	Select alternative	Buede Pg 294		
TMP-4	3	Negotiate interfaces with affected engineering staff	Buede Pg 158		100%
TMP-8	3	Refine interfaces	DAG Sec 4.2.3.8.		60%
TMP-8	4	Refine internal interfaces from design phase	DAG Sec 4.2.3.8.		
TMP-8	4	Refine external interfaces from design phase	DAG Sec 4.2.3.8.		
TMP-8	4	Add functions to components connected to interface, as needed	Buede Pg 294		
TMP-8	4	Refine integration constraints	INCOSE Pg 4.10		
TMP-8	4	Update interface requirements specifications	INCOSE Pg 4.12		
TMP-8	2	**Generate Interface Control Documentation**	DAG Sec 4.2.3.8. DAG Sec 4.2.4.5.	DoDAF SV-1, Interface Control Document	**80% - 100%**
TMP-8	3	Document interfaces and integration plan	INCOSE Pg 4.8	Interface Control Working Group	100%
TMP-8	3	Establish interface management control measures	DAG Sec 4.2.3.8.		100%
TMP-8	3	Assure change communication	DAG Sec 4.2.3.8.		100%
TMP-8	3	Assure interface requirements available to IPT	DAG Sec 4.2.3.8.		100%
TMP-8	3	Document design	Buede Pg 294		100%
TMP-8	3	Obtain approval	Buede Pg 294		80%
TMP-8	2	**Utilize Interface Controls**	DAG Sec 4.2.3.8.; Buede Pg 39		**10% - 100%**
TMP-8	3	Use interface reqs to facilitate bids	DAG Sec 4.2.3.8.		10%
TMP-8	3	Use interface reqs to enable system integration	DAG Sec 4.2.3.8.		100%
TMP-8	3	Use interface reqs to support system maintenance	DAG Sec 4.2.3.8.		60%
TMP-8	3	Use interface reqs for upgrades	DAG Sec 4.2.3.8.		80%
ALL	1	**Fundamental Principles (Applicable to ALL PROCESSES)**			**100% - 100%**
ALL	2	**Utilize Enterprise Capabilities**	INCOSE Pg 4.12-13		**100% - 100%**
ALL	3	Utilize enterprise strategic plan	INCOSE Pg 5.10		100%
ALL	3	Utilize enterprise infrastructure	INCOSE Pg 4.12		100%
ALL	3	Utilize enterprise policies, procedures, and standards	INCOSE Pg 4.12		100%
ALL	3	Utilize Integrated Product Teams to bring together expertise	INCOSE Pg 4.6		100%
ALL	3	Utilize terms and conditions of agreements	INCOSE Pg 4.13		100%
ALL	3	Utilize project procedures and processes	INCOSE Pg 4.13		100%

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14. ABSTRACT

As government becomes subject to a wider range of technology initiatives, science and technology (S&T) research project leadership recognizes the need to incorporate more systems engineering (SE) rigor into their projects. The objective of this research is to develop a tailorable systems engineering framework for S&T project planning, execution, assessment and transition. The key deliverable is an SE framework, implemented as an Excel application, for use by S&T organizations. It includes a report with tailored methods based on programmatic discriminants. To develop this framework, a comprehensive understanding of SE principles is applied to several case studies across government and supporting industry-sponsored S&T activities. The framework allows S&T project leaders and engineers to customize a recommended set of SE processes, methods and tools for their specific project type, size, maturity, budget, and integration level.

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