Creating a Mission Architecture Step to Inform the System Engineering Process

by

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A dissertation submitted to the Graduate Faculty of
Auburn University
In partial fulfillment of the
Requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
December 10, 2016

Keywords: Systems Engineering, Mission Analysis, Functional Decomposition, Functional Element, Mission Functions, Mission Architecture

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Abstract

The purpose of this research is to develop a structured engineering mechanism that allows decision makers to have confidence in data at any given point of design and development for complex defense systems. The research findings result in the establishment of an additional step that initiates the systems engineering process and permeates throughout the design and development of the acquisition product. The added step, described herein as the Mission Architecture Step, is initiated early in the mission operational requirements phase and defines the mission in terms of functions. These functions are then decomposed during a Mission Analysis so as to produce specific, quantifiable, measurable points that are captured in a Mission Analysis Plan. The primary benefit to this early identification is that it provides a basis for developing consistent assessment tools. Consistency in evaluation tools, tests and data analysis is key to understanding a system or component performance.

Application of this new process is demonstrated using a generic missile defense system composed of kill chain functions – command and control, sensor operation, target negation. All data used is open source information and therefore not controlled as sensitive. The direct implementation of the Mission Architecture Step provides a program manager/decision maker the necessary information to better manage and control resources.

Acknowledgments

The author wants to dedicate this work to the most important people in my life:

My son, Mr. Derek Gore, who is my greatest joy and pride and who is excelling in his own pursuit of educational merit.

My parents, Mr. and Mrs. Jesse B. Allen, who instilled a life-long love of learning, the commitment to hard work, and the will and determination to succeed.

The author would like to thank each of the professors and advisors in the Auburn University Industrial and Systems Engineering Department and the Computer Engineering Department for their time, guidance and encouragement especially during coursework. Sincere thanks go to my many colleagues who gave their time willingly and unselfishly. The author would like to provide a special thanks to my mentor and technical advisor, Dr. Rodney Robertson. Your continuous support and advice has been invaluable.

The author expresses deep gratitude and appreciation to the following individuals who provided support and assistance above and beyond during my extensive time away from home:

Ms. Lisa Laurendine ensured my home and employment responsibilities were completed in addition to being a great friend.

Mr. Keith Englander and Mrs. Deborah Frear made everything possible for this educational journey and were my biggest cheerleaders.

My wonderful friends who continuously provided support and encouragement and a nice break when needed.

Last but not least, my new Auburn family. My journey in Auburn holds cherished memories and I will always consider Auburn home.

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Chapter 1

Introduction and Background

Decision makers in defense acquisition face many challenges today. Budgets are limited and continually shrinking. The acquisition community is asked to do more with less and expected to accomplish this feat without the benefit of more time or personnel. Fortunately, technological advancements in day-to-day operations, increased computing power, and communication exchanges grant the ability to accomplish much more than one could a decade ago. However, decisions are continuing to be made with data that lacks the benefit of structured engineering basis.

Technology is constantly innovating, thus long acquisition schedules yield the risk of fielding products that are obsolete and require immediate upgrades. This is especially true for software intensive systems, and large complex defense systems. Since 1960, the average defense acquisition cycle time, the time a program takes to get from inception to initial operational capability, has been 132 months [1]. The Department of Defense (DoD) suggests limiting the system development to about five years, less than half the average duration. The DoD asserts that, "Time-defined constraints such as this are important because they serve to limit the initial product's requirements, allow for more frequent assimilation of new technologies into weapon systems, and speed new capabilities to the warfighter [2]. " Between 2001 and 2008, however, only 32 percent of the programs started completed their cycle time in less than five years [2]. A 2008 General Accountability Office audit concluded, "Current programs are experiencing a 21-month delay in delivering initial capabilities to the warfighter – often forcing DoD to spend additional funds on maintaining legacy systems" [3]. In 2007, the total acquisition cost for DoD's programs increased 26 percent and Research, Development, Test and Evaluation costs increased by 40 percent. Each of these increases was calculated based on each program's first estimate and these cost increases run converse to the downward pressure on real budgets and customer requirements [3].

One constant that plagues program managers is the lack of good data at the right time in order to make acquisition decisions. Decision makers are faced with making numerous difficult decisions on requirements changes, development advancement, funding prioritization, and program office personnel alignment. These decisions ultimately involve funding, schedule and product performance. It is imperative for the manager(s) to have the most accurate data as well as the most applicable data for the decision at hand. Focusing on the program technical perspective and the data that is needed for decision points, there are two critical program activities that must be detailed to provide any insight into the technical program health. First, the user requirements must be clearly understood in order to efficiently execute a desired product solution. The only way to do this is for the developer and the user to have full communication and clear understanding of what is really needed. The requirements must be fully defined and clearly organized to constitute their full intent. Requirements growth, also known as requirements creep, must be held to a minimum. Next, the program manager (PM) must develop a comprehensive engineering plan that completely devolves the requirements into measurable parameters. From this, the PM develops the blueprint for a comprehensive modeling and simulation program that not only assists in the system development but also provides data for system assessment. The PM must also develop an integrated testing program that is interchangeable with the modeling and simulation program so that test data feeds system validation. This allows the system to be evaluated within a constrained, measurable scope and facilitates a plan for all the tools and resources necessary to assess the system development against user requirements at any point of system maturity. The process for accomplishing these two major objectives is the systems engineering process. Defense Acquisition University defines the systems engineering process as, " … a technical management and problem-solving process applied through all stages of development to transform needs and requirements into a set of system product and process descriptions (adding value and detail with each level of development) [4]."

Numerous congressional reviews of program delays and cost overruns have identified failures in the systems engineering process. A 2008 Government Accounting Office (GAO) audit identified systemic engineering problems as both strategic and programmatic. Their report stated, "At the strategic level, DoD's processes for identifying warfighter needs, allocating resources, and developing and procuring weapon systems are fragmented and broken. At the program level, weapon system programs are initiated without sufficient knowledge about system requirements, technology and design maturity [3]."

Another GAO report on the Airlift and Tanker Programs cited specific issues of decisions being made "based on incomplete data and inadequate modeling and metrics that did not fully measure stress on the transportation system [5].” Decision makers chose to put into production four airlift programs that GAO found to have failed the basic systems engineering practices, the primary of which was to “achieve a stable design before beginning system demonstration and demonstrating the aircraft would work as required before making large production investments [5].”

In May 2009, Congress passed the Weapon Systems Acquisition Reform (WSAR) Act. It came in response to the 2008 GAO report on Assessment of Selected Weapon Programs, the Defense Science Board Task Force on Developmental Test and Evaluation, and other congressional reviews of defense acquisition program delays and cost overruns. The GAO found that schedule slippages and cost growth were “rooted in the use of immature technology, the impact of poorly defined requirements and requirements ”creep”, poor or ineffective design, and a lack of systems engineering processes which included disciplined software management and reliability growth programs [6].” The Defense Science Board Task Force principle finding was that “the high suitability failure rates were caused by the lack of a disciplined systems engineering process, including a robust reliability growth program, during system development [7].” The WSAR Act attempts to address these problems by requiring DoD to: “(1) assess the extent to which the Department has in place the systems engineering capabilities needed to ensure that key acquisition decisions are supported by a rigorous systems analysis and systems engineering process; and (2) establish organizations and develop skilled employees needed to fill any gaps in such capabilities [8].” In addition, the WSAR Act increased program reporting in the early developmental stages and increased emphasis on program developmental testing by requiring DoD to re-establish the position of Director for Test and Evaluation with a review of all military Test and Evaluation organizations.

The oversight implemented by the WSAR Act increases awareness and addresses part of the strategic issues of program systems engineering. However, there is more work required at both the strategic and program levels in the fundamental areas of system requirements definition, implementation, integration and system analysis verification. All of these are key components of the systems engineering process. Figure 1.1 provides the strategic view of the DoD systems engineering process model.

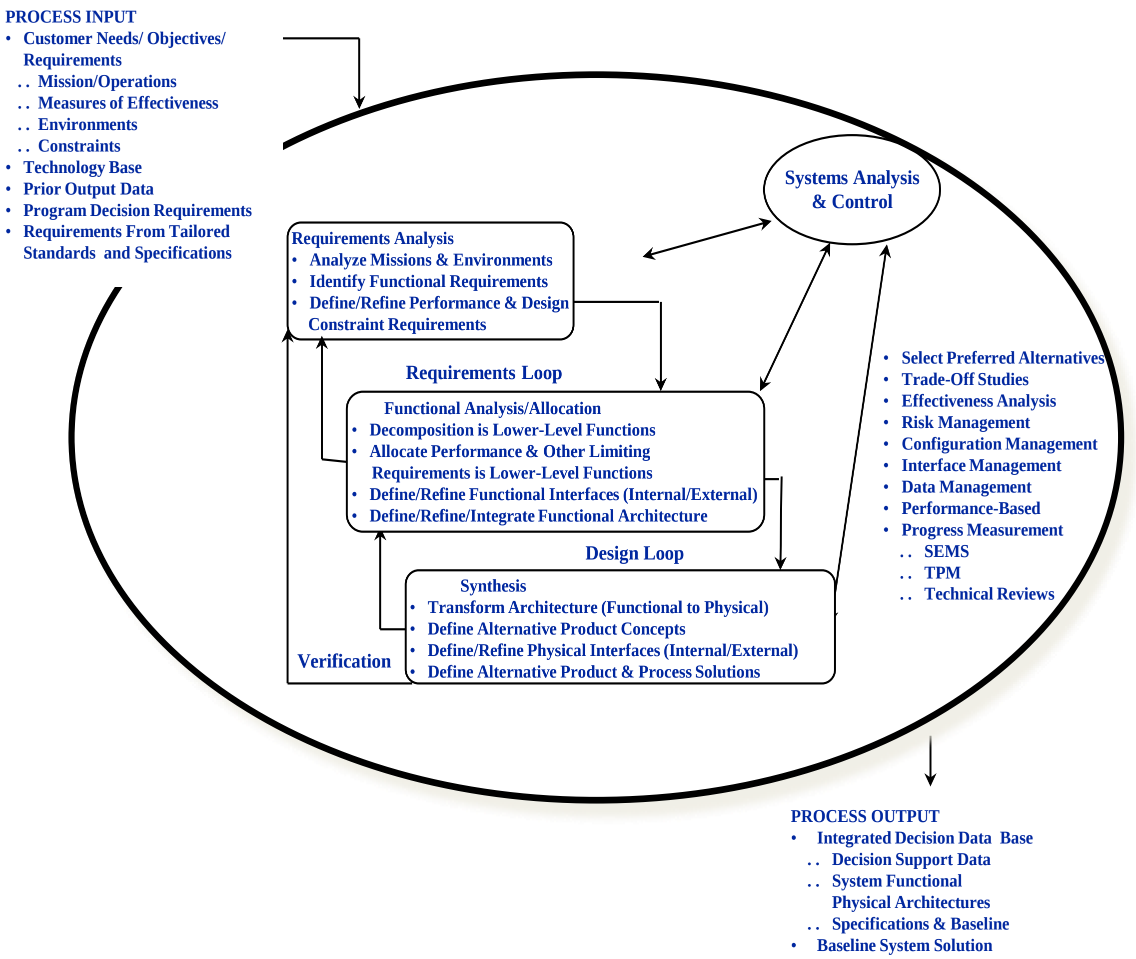


Figure 1.1 Systems Engineering Process [9]

Figure 1.2 visualizes the accepted industry standard for the systems engineering process. Both figures basically represent the same information depicted in a different format.

The DoD Deputy for System Engineering commissioned a study by the National Defense Industrial Association (NDIA) to identify the top five issues in systems engineering (SE). The original study was conducted in 2003 and it was updated in 2006 and again in 2010. The latest study reviews the issues in the previous studies and provides an updated status. Table 1.1 is a summary of the status update. As noted in the status update, the WSAR Act provided a path to some improvement, however issues continue to persist. Four of the five issues identified relate to disconnects with implementation of the systems engineering process and the lack of applicable tools to provide valid data.

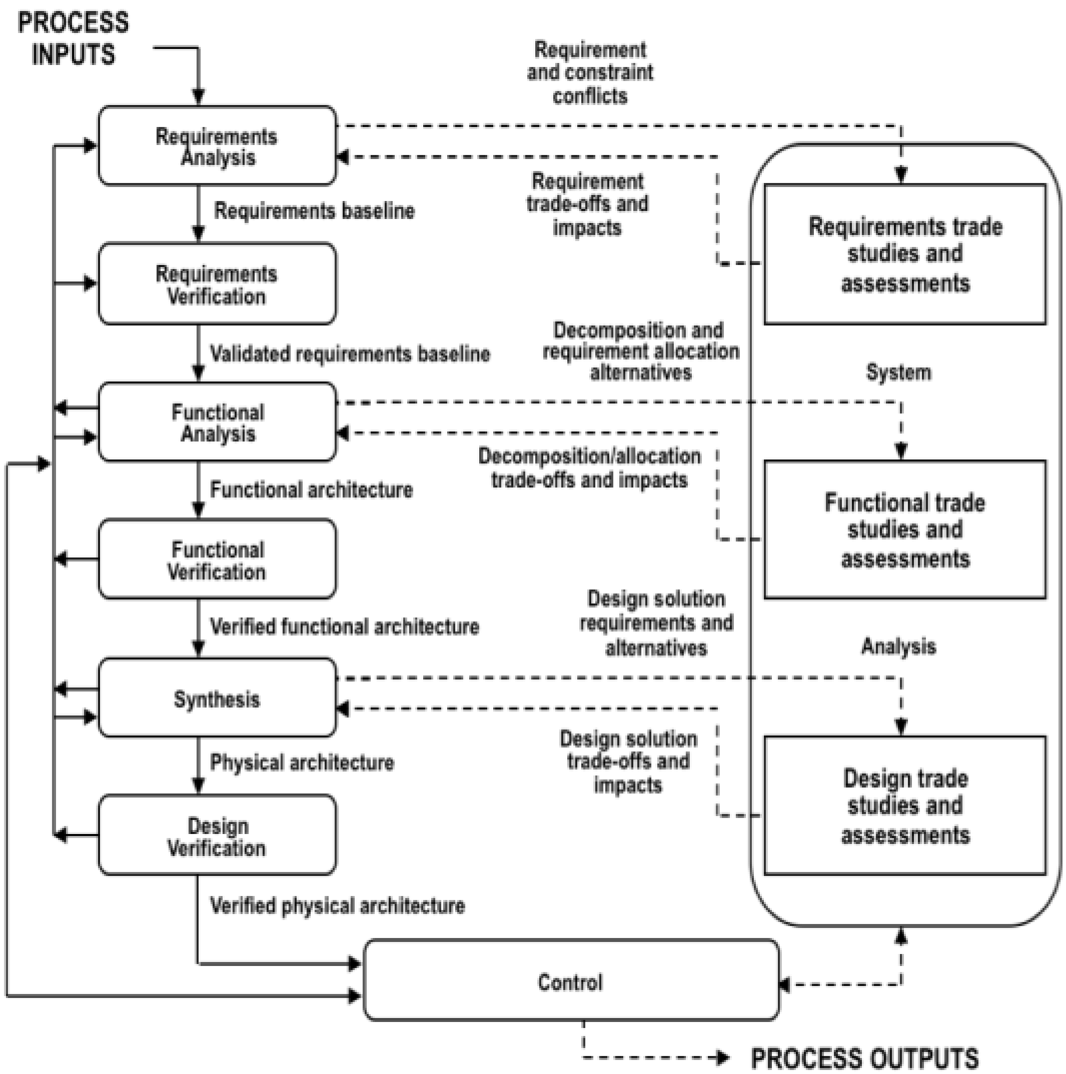


Figure 1.2 IEEE Standard for Application and Management of Systems Engineering [10]

Status of Activities against the Top Systems Engineering Issues for 2006

	2006 Issues	2010 Status
1	Key systems engineering practices known to be effective are not consistently applied across all phases of the program life cycle.	• Institutionalization of practices has shown value when adopted, but adoption tends to be spotty • Determination of proficiency in applying practices appears to be problematic
2	Insufficient systems engineering is applied early in the program life cycle, compromising the foundation for initial requirements and architecture development.	• Improving by necessity in complex systems • Policy updates (5000.2, competitive prototyping and earlier decisions) imply SE engagement, but are not explicit (subsequent revisions may have already addressed this or are in work)
3	Requirements are not always well-managed, including the effective translation from capability statements into executable requirements to achieve successful acquisition programs.	• WSAR Act requirements for development planning are believed to be an improvement • Variability in approaches to requirements definition, validation and consolidation continue
4	The quantity and quality of systems engineering expertise is insufficient to meet the demands of the government and the defense industry.	• Resource issues persist in government and industry. • Shortages: leadership, domain, architects, systems engineers • Initiatives: acquisition workforce, STEM, cross- training • Value of having experience to enhance educated workforce is better understood
5	Collaborative environments, including SE tools, are inadequate to effectively execute SE at the joint capability, system of systems (SoS), and system levels.	• State of the practice techniques not widely utilized • Multiple tools are available but little guidance on preferences exists. • Emphasis on SoS seems to have diminished

Table 1.1 Top Systems Engineering Issues in US Defense Industry [11]

The NDIA study also identifies and correlates additional information, including data from its study, into a new top five issues list [11]. It includes:

1. Increasingly urgent demands of the warfighter are requiring effective capabilities to be fielded more rapidly than the conventional acquisition processes and development methodologies allow.
2. The quantity and quality of systems engineering expertise is insufficient to meet the demands of the government and defense industry.
3. Systems engineering practices known to be effective are not consistently applied or properly resourced to enable early system definition.
4. Technical decision makers do not have the right information & insight at the right time to support informed and proactive decision making or may not act on all the technical information available to ensure effective & efficient program planning, management and execution.
5. Lack of technical authority can impact the integrity of a developed system and result in cost/schedule/system performance impacts as the technical solution is iterated and reworked in later stages of the development. [11]

The first issue covers both the strategic level and the detailed level of systems engineering. At the strategic level, this issue identifies the inability to quickly respond to urgent mission operational needs. The requirement to follow the Defense Acquisition System process and the lack of engagement by the functional stakeholders in the integrated system engineering teams is the primary causes of this issue. A strong systems engineering capability is crucial to making effective trades on technical approaches and maintaining a stable architecture so that decision makers can design, develop and deploy systems with minimal risk.

Issue two is focused on system engineering personnel and is not covered in this research. Issues three, four and five cover the more specific inadequacies of systems engineering practices. Inconsistent application of the disciplined systems engineering process and methods prevent proper information from being available to decision makers. Because of this incomplete or inadequate data, program managers make decisions with high risk because they do not know what information they lack. Stated briefly, "Programs do not always start with good requirements or capture evolving requirements adequately [11]." The system technical baseline is not established before field-testing. Data presented to decision makers does not fully convey potential impacts. Incomplete application of the SE process yields the inability to identify all the key technical parameters and critical technical issues that need to be used for assessing program technical health. All of these issues results in excessive rework and therefore higher program cost and schedule delay. Inconsistent application of the engineering practices, methods, and approaches often causes decision makers to lack confidence in the data available to them.

Problems such as these could be addressed, however, with an additional step inserted at the beginning of the systems engineering process. This dissertation asserts that the addition of this new step, a Mission Architecture Step (MAS), could substantially reduce cost and schedule overruns and streamline the acquisition process. This step would fully decompose the mission into its constituent functional attributes. The MAS can then serve as a touchstone throughout the SE process and help maintain a functional requirements baseline. The MAS would have two components, the Mission Analysis (MA) and the Mission Analysis Plan (MAP). One can think of these as strategic guides that set the overall direction for the requirements definition and design process. The benefits of adding a Mission Architecture Step include elimination of unneeded requirements definition, reduction or elimination of extraneous features in the solution, and reduction of unnecessary or mis-specified analysis tools, analyses and tests. The insertion of such a tool at the beginning of the systems engineering process could virtually eliminate the types of unnecessary cost and schedule delays the General Accountability Office, the National Defense Industrial Association (NDIA) for Systems Engineering and other government observers are targeting.

Chapter 2

Research Objectives and the Systems Engineering Process

Systems engineering is a big topic. There are numerous books written on the subject and its applications. Defense Acquisition University teaches a series of courses and awards a Defense Acquisition Certification after completion of each level. Many colleges and universities offer degrees in systems engineering (SE). With this abundance of information and training available on the subject, it is questionable why there are so many issues being found and attributed to failures in systems engineering and the implementation of the SE process. The prevalence of these failures suggests a fundamental flaw in the SE process as it is currently envisioned – either in its formulation, education, or application. The objective and goals of this research are to address and resolve the following questions:

1. Are there multiple systems engineering processes? If so, are there conflicts between the processes?
2. Is the systems engineering process broken or incomplete?
3. What can be done to improve the SE process?

Industry best practices are the primary source for DoD acquisition contract requirements regarding systems engineering. Overall, the SE processes taught and utilized by most contracts are based on the same principles, requirements definition, requirements synthesis and requirements analysis. The actual implementations of the process is tailored for each program and usually in accordance with the prime contractor practices. This tailoring of the SE process is a source of inconsistencies and disconnects and can lead to opportunities for failures. The NDIA report recognizes "How to perform disciplined SE is known, while its consistent application is not [11]."

2.1 The Systems Engineering Process

The Institute of Electrical and Electronic Engineers (IEEE), Software and Systems Engineering Subcommittee has combined industry's best practices and documented them in the Standard for Application and Management of the Systems Engineering Process, IEEE 1220. This standard was developed in collaboration with the International Organization for Standards that led to the international debut of ISO/IEC 26702:2007(E). There are key similarities between IEEE Std 1220-2005 and ISO/IEC 15288:202, however the IEEE standard prescribes more detailed systems engineering and management requirements and is intended to complement and extend the ISO standard. In contrast, the ISO/IEC document provides additional process definition and guidance with respect to life-cycle model definition and to the application of the systems engineering process. The IEEE standard "defines the requirements for an enterprise's total technical effort related to development of products (including computers and software) and processes that will provide life cycle support (sustain and evolve) for the products. It prescribes an integrated technical approach to engineering a system and requires the application and management of the systems engineering process throughout a product life cycle. The systems engineering process is applied recursively to the development or incremental improvement of a product to satisfy market requirements and to simultaneously provide related life-cycle processes for product development, manufacturing, test, distribution, operation, support, training and disposal [9].”

The IEEE Standard 1220 addresses the end-to-end system life cycle, including elements and element integration, and the various supporting products and processes. The system life cycle spans user needs, initial concept, development and operations through disposal. The standard defines the interdisciplinary tasks to develop, integrate, and operate a system solution that accommodates stakeholder needs, requirements, and constraints. The systems engineering process is both applicable to new products and incremental evolution of existing products. It is also applicable to specialty products and commodity products. Depending on the scale of the problem to be solved, it is reasonable to view a system as an element of a larger system. Thus it is essential to comprehend the boundaries of the system, and the relationships, interfaces, and interactions between it and other systems. IEEE Standard 1220-2005 focuses on product-oriented systems. In general, systems consist of elements and their interfaces. In this context, subsystems and components can be considered elements. Many elements can be considered systems in their own right, but are demoted to subsystems within the hierarchy of a larger system. Each of these elements has its own life cycle processes, which are a hierarchy within the parent system. The elements also include the people required to execute the processes and effectuate the products that comprise an element. The numbers of levels of hierarchy are not fixed, but depend upon the complexity of the system under development.

As previously stated, a life cycle is spans from the beginning stages of a product development to its operational end. The stages in the life cycle are defined as:

- Development
- Manufacturing
- Test
- Distribution
- Operations
- Support
- Training
- Disposal

Each stage is composed of sub-process and functions and include the human elements that govern the conduct of the systems engineering process. The IEEE document also provides directions for additional activities to include in the functions and processes such as built-in test, fault isolation test, failure mode and effects analysis, integrated product team, systems engineering master schedule, systems engineering process (SEP), and technical performance measures (TPM) to name a few.

The systems engineering process is an integrated technical effort "to develop a total system solution that is responsive to market opportunities, specified stakeholder requirements, enterprise objectives and external constraints [9]." The process is generic, accommodates or features iteration, and "provides the mechanisms for identifying and evolving the product and process definitions of a system [9]." Figure 2-1 depicts the systems engineering process. As depicted, the process is inherently iterative. The primary flow of the process features requirements analysis and validation, functional analysis and verification, and design synthesis and verification, all anchored to the functional then physical architecture. The process features an ancillary sequence of trade studies and assessments, beginning with requirements, then functions and then design.

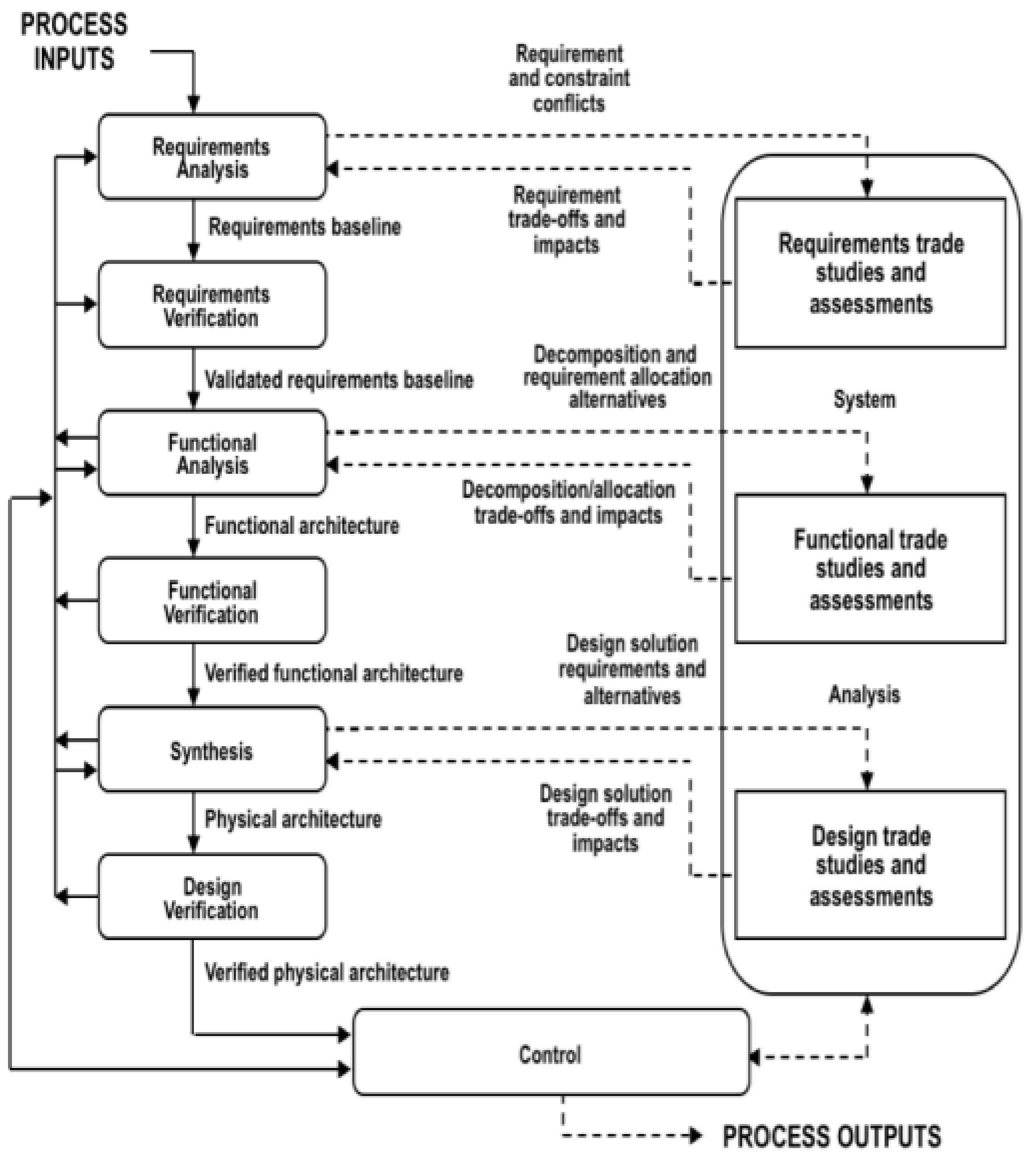


Figure 2-1 Systems Engineering Process [9]

The IEEE standard defines the requirement for the preparation and implementation of all technical plans and schedules that are required to guide the project to successful conclusion, which entails meeting objectives. The document recommends an engineering plan, a master schedule and detailed schedules. The engineering plan is the primary planning document for all technical efforts. The master schedule should be event-based, and the detailed schedule should be calendar-based but derived from the master schedule. The engineering plan "shall be prepared and updated throughout the system life cycle to guide and control the technical efforts of the project [9]." This is especially important for the success of an evolutionary or incremental development strategy, including the downstream task of inserting any incremental capability and /or technology enhancements. Technical plans are prepared to support the engineering plan. These plans are in engineering and technical specialty areas including "risk management, configuration management, technical reviews, verifications, computer resources, manufacturing, maintenance, training, security and human systems engineering [9]."

Requirements analysis culminates in a requirements baseline that guides the remaining activities of the systems engineering process. The culminating results define the problem to be solved. Implicitly then, there is connectivity between the requirements analysis subprocess and all of the other subprocesses as identified in Figure 2-1. A balanced requirements baseline is a desirable objective and trade-off analyses are beneficial for resolving conflicts and attaining the desired balance. Conflicts may arise from cost, schedule, and performance risks in achieving this balance. As the systems engineering process is applied to lower levels of the system hierarchy, upper level requirements are refined as appropriate, even as the lower level requirements are being defined. The requirements baseline addresses three perspectives: operational view, functional view and design view. The system requirements must be considered from both the functional and the performance perspective in order for the requirements to be considered complete, consistent and verifiable.

- Functional - applies to what the system should be able to do.
- Performance - applies to how well the functions must be executed.

During the requirements analysis process, technical performance measures (TPMs) and a special case of measures of performance (MOPs) are defined. These performance measures are critical and "if not met, put the project at cost, schedule and performance risk [9]."

Requirements Validation begins after completion of the requirements baseline. Figure 2-2 depicts this process. The requirements baseline is evaluated to ensure representation of shareholder expectations and overall constraints, and is assessed with respect to system operations and life cycle support. Iterative cycles are repeated as needed to refine validity of the requirements baseline, which is to be documented in the integrated repository and used as a critical input to the functional analysis sub process. In addition to validating the requirements against stakeholder expectations and identifying enterprise and project constraints, this process also has a task that identifies variances and conflicts, which provides an iterative feedback path to the predecessor requirements analysis subprocess. When the iterative cycles have been completed to satisfaction, the primary product is the validated requirements baseline, which goes into the integrated repository, and feeds forward to the functional analysis subprocess.

The Functional Analysis task has two primary objectives: 1) Describe in clearer detail the problem previously defined by requirements analysis and 2) Decompose system functions to lower-level functions at the element level. A key focus is to translate the validated requirements baseline into a functional architecture, which "describes the functional arrangements and sequencing of sub-functions [9]." The functional analysis

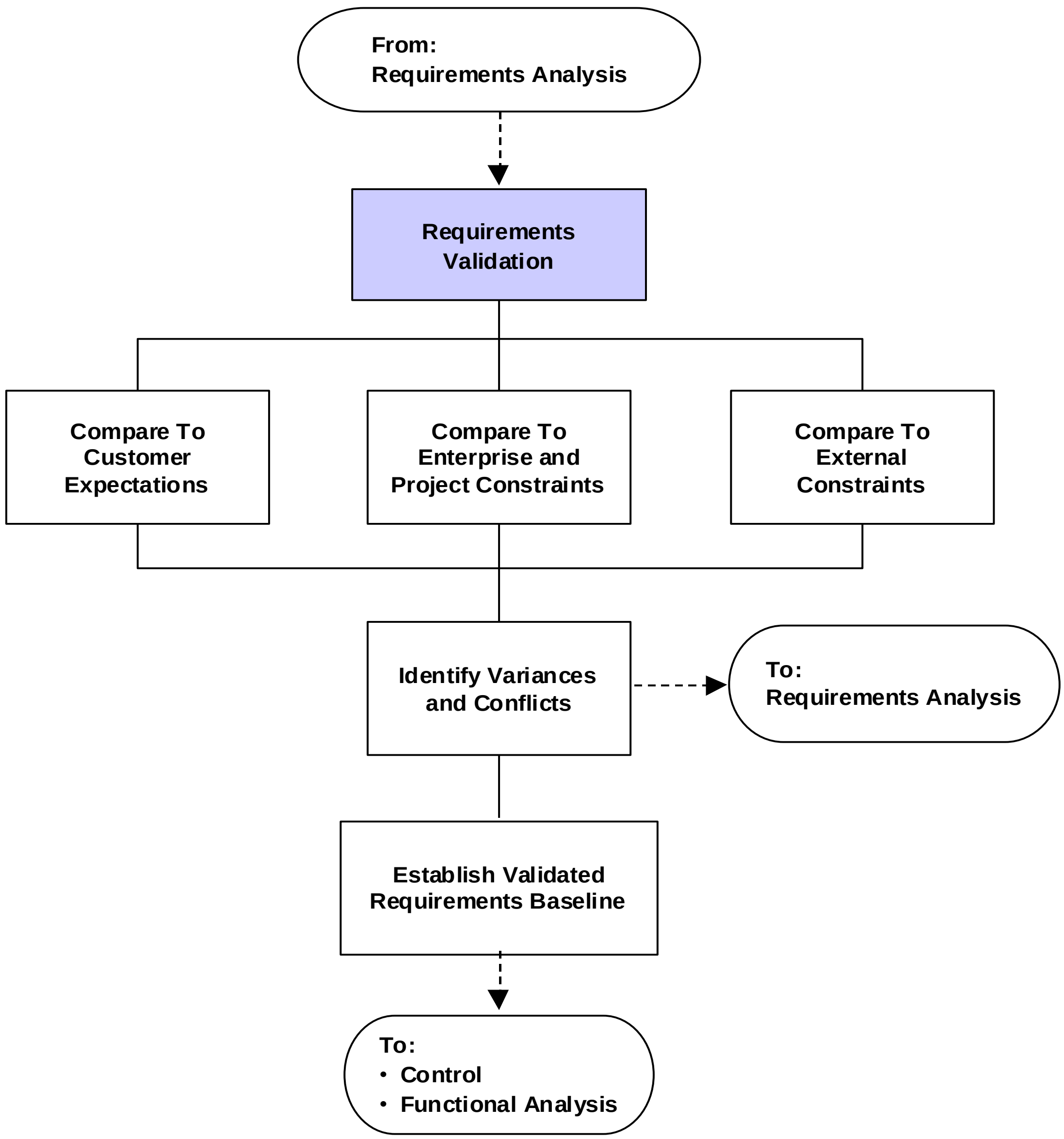


Figure 2-2 Requirements Validation Process [9]

sub-process must be executed without consideration for a design solution.

Figure 2-3 identifies three tasks, and a number of subtasks, that comprise the functional analysis sub-process of the systems engineering process. The overall functional analysis sub-process receives inputs from functional verification (implicitly via iterative feedback) and from design verification (implicitly via iterative feedback). The first task is functional context analysis, and is partitioned into three subtasks. It receives input from requirements analysis. The three subtasks appear to be staged in parallel. The second task is functional decomposition. It is partitioned into six subtasks, and receives input from requirements validation. Two of the subtasks appear to be staged in parallel, preparatory to the other four, which appear also to be staged in parallel. The third task is titled Establish Functional Architecture. The resultant functional architecture is the primary product of the functional analysis sub-process.

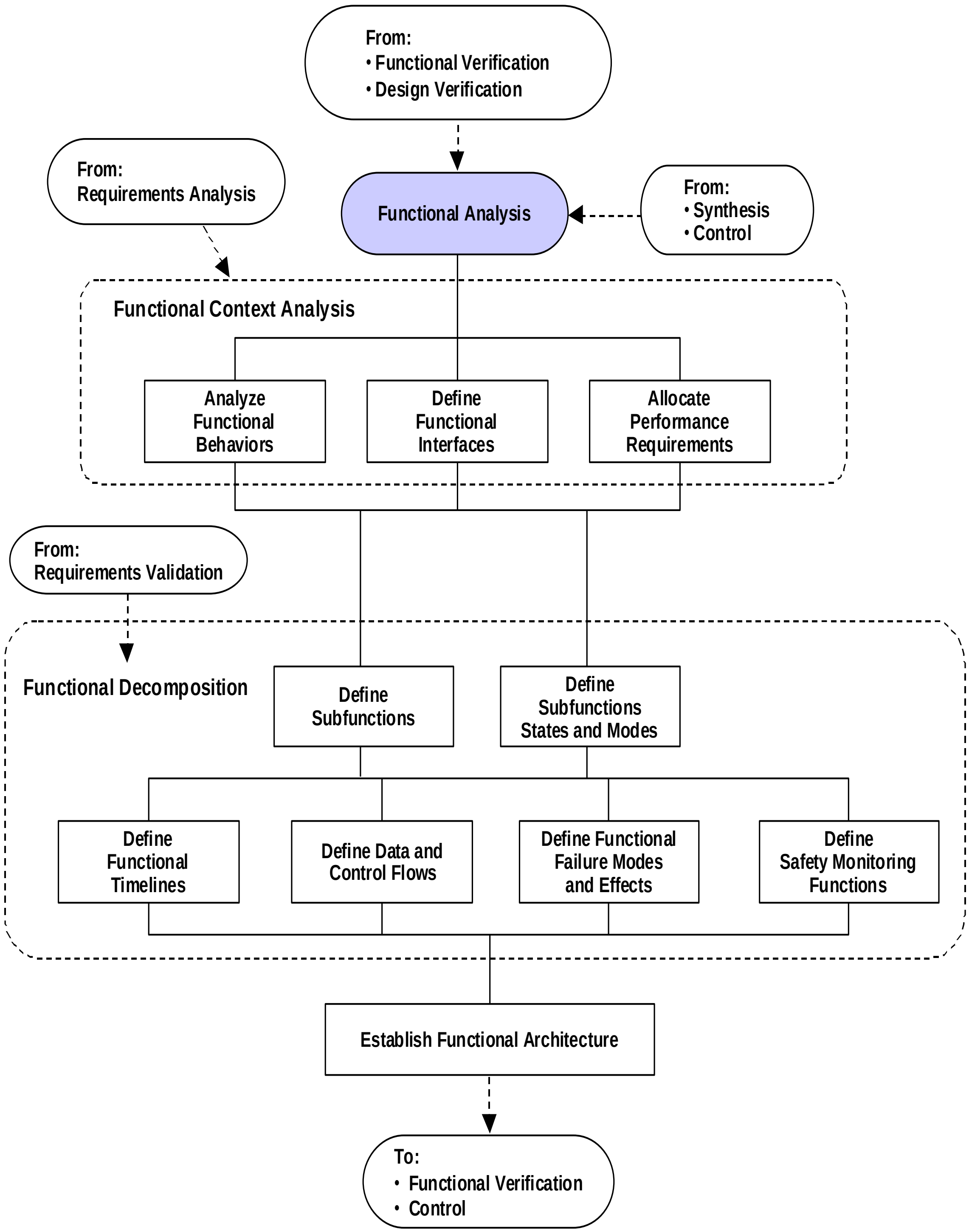


Figure 2-3 Functional Analysis Process [9]

The next step in the systems engineering process is Functional Verification. The two objectives of this task are "to assess the completeness of the functional architecture in satisfying the validated requirements baseline and to produce a verified functional architecture for input to synthesis [9]." The functional verification sub-process receives the functional architecture from the functional analysis sub-process. Figure 2-4 defines the process and the subtask that composed the process. The four tasks are depicted serially – Define Verification Procedures, Conduct Verification Evaluation, Identify Variances and Conflicts, and Verified Functional Architecture. The Conduct Verification Evaluation task is depicted as feeding serially into three subtasks depicted in parallel, and receives feed-forward input from the requirements baseline. Its three subtasks are depicted as feeding serially into the Identify Variances and Conflicts task, which features feedback to the prior sub-processes Functional Analysis and Requirements Analysis. The primary product of the Functional Verification sub-process is a verified functional architecture that connects to the Synthesis sub-process and to the Control sub-process.

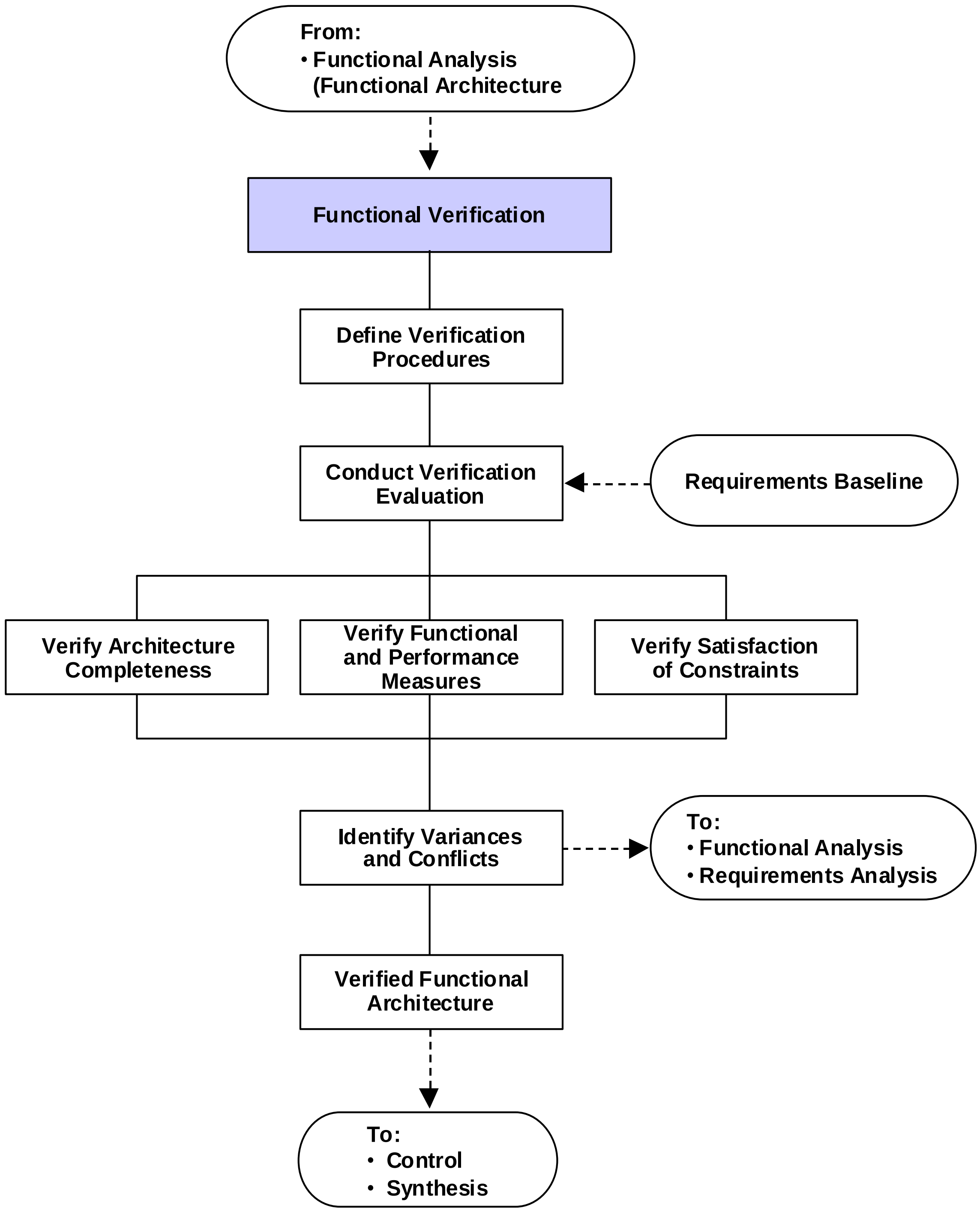


Figure 2-4 Functional Verification Process [9]

Each requirement is traced to a function that is allocated to system elements. Analysis of alternatives is performed to "determine which design solution best satisfies allocated functional and performance requirements, interface requirements, and design constraints and adds to the overall effectiveness of the system or higher-level system [9]." By tracing each requirement to a function and selecting the appropriate functional design, the functional architecture is recorded and verified.

The task of Synthesis includes "defining design solutions and identifying subsystems to satisfy the requirements of the verified functional architecture [9]." The synthesis sub-process receives the functional architecture as its primary input. Its primary product is "a design architecture that provides an arrangement of system elements, their decomposition, interfaces (internal and external), and design constraints [9]."

Figure 2-5 illustrates the Synthesis sub-process. A key focus of the synthesis sub-process is widely known as analysis of alternatives, with the goal of selecting a preferred solution or arrangement, including cognizance of cost, schedule, performance and risk. The purpose of the Synthesis sub-process is to "translate the functional architecture into a design architecture that provides an arrangement of system elements, their decomposition, interfaces (internal and external), and design constraints" [9]. The analysis of alternatives utilizes the systems analysis sub-process as necessary "to evaluate alternatives; to identify, assess, and quantify risks, and select proper risk-mitigation approaches; and to understand cost, schedule, and performance impacts [9]." The primary entry point into the synthesis sub-process is from the functional analysis sub-process, but secondary entries occur from the functional verification sub-process, the design verification sub-process (apparently via feedback), and the control sub-process. As depicted, the tasks are staged in serial steps, with groups of tasks conducted in parallel

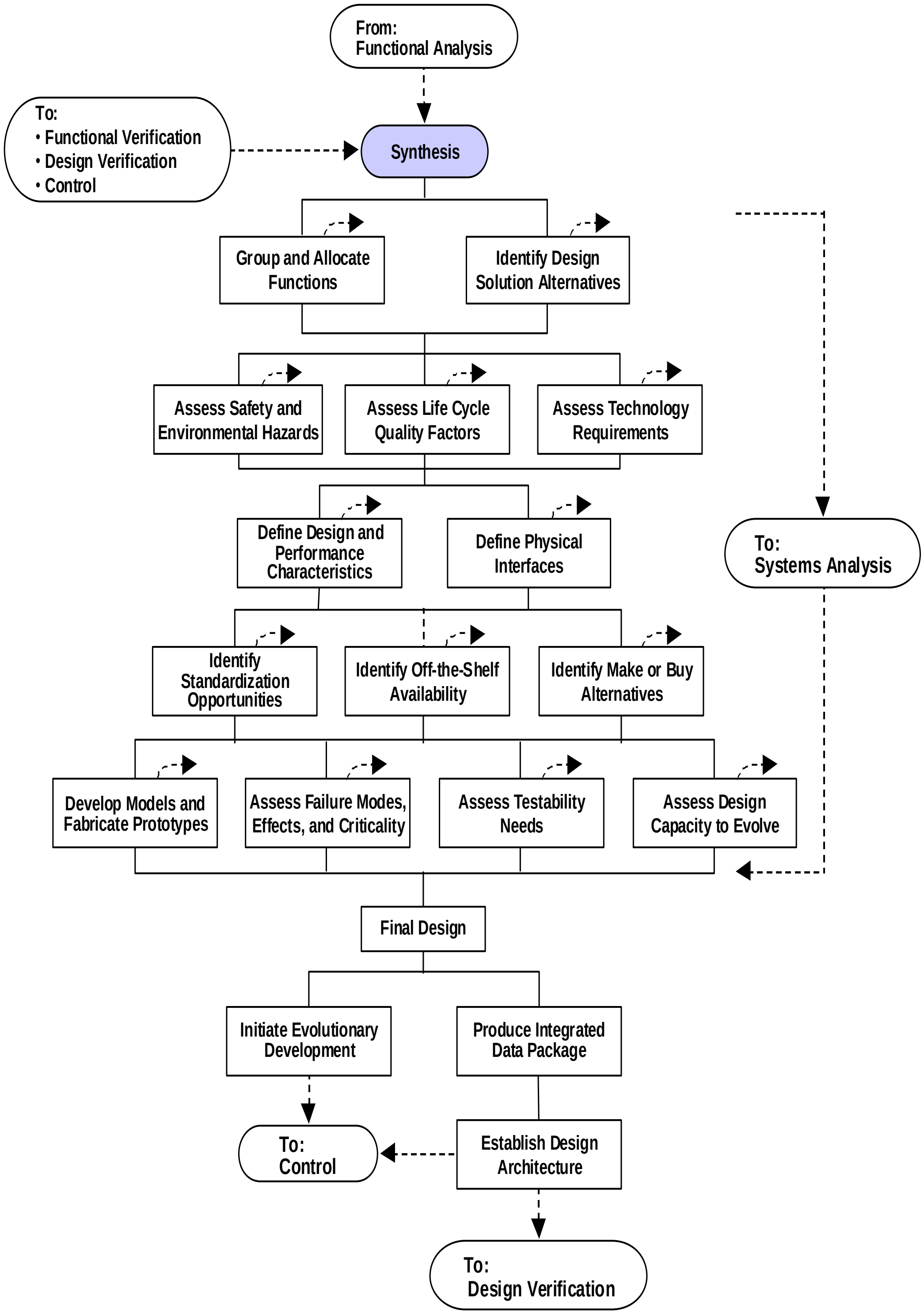


Figure 2-5 Synthesis Process [9]

at the various stages. The first five stages interact laterally with the systems analysis sub-process, which in turn feeds forward to the sixth stage. The final stage produces the design architecture that is fed forward into the design verification sub-process.

The next step in the systems engineering process is the Design Verification task. The purpose of this step is to assure that the requirements of the lowest level of the design architecture, including derived requirements, are traceable to the verified functional architecture and that the design architecture satisfies the validated requirements baseline. To accomplish this task, there are fifteen sub-processes as shown in the Figure 2-6. The design verification sub-process receives the design architecture [not depicted] from the synthesis sub-process. The tasks are staged serially and parallel as shown. The tasks receive the requirements baseline and the functional architecture from the upstream sub-processes. As with the earlier steps, there is a provision for iterative recycling to the requirements analysis sub-process and to the synthesis sub-process. The fourth task produces the verified design architecture, which is provided to the control sub-process. The remaining subtasks produce additional internal (systems engineering process) products which are the verified system architecture, the specifications and configuration baselines, and the product breakdown structure(s).

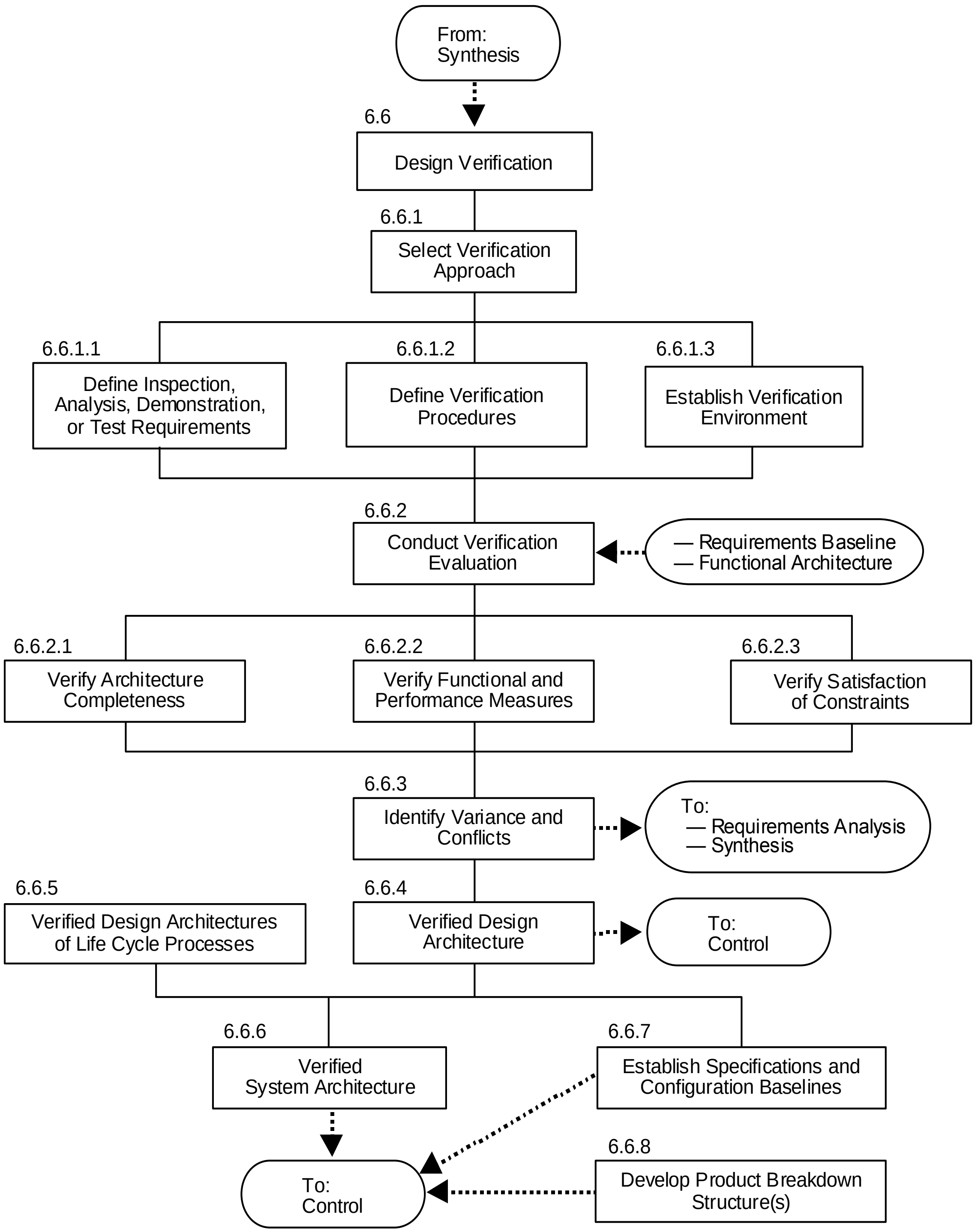


Figure 2-6 Design Verification Process [9]

The next step in the systems engineering process is the Systems Analysis sub-process. The systems analysis sub-process interacts with the requirements analysis sub-process, with the functional analysis sub-process, and with the synthesis sub-process, while also supporting system effectiveness assessment and risk management throughout the systems engineering process. The systems analysis sub-process supports the following objectives:

- Resolving conflicts identified during requirements analysis
- Decomposing functional requirements during functional analysis
- Allocating performance requirements during functional analysis
- Evaluating the effectiveness of alternative design solutions during synthesis
- Selecting the best design solution during synthesis
- Assessing system effectiveness throughout the systems engineering effort
- Managing risk factors throughout the systems engineering effort

The systems analysis sub-process receives inputs from the requirements analysis sub-process, from the functional analysis sub-process, and from the synthesis sub-process. It provides outputs to these same three sub-processes, and also interacts with the control sub-process. The system analysis sub-process includes tasks of assessing requirements conflicts, functional alternatives, and design alternatives in addition to identifying risk factors and defining trade-off analysis scope and conducting the trade-off analysis. Other tasks in this sub-process are selecting risk-handling options, alternative recommendations, trade-offs and impacts and making a design effectiveness assessment. The key objective of trade-off analyses is to select among competing alternatives, with consideration of "stakeholder needs, system effectiveness, design to cost, or life cycle cost objectives within acceptable levels of risk [9]."

The task of control, which is shown in almost all the figures and is an essential part of the systems engineering process, is for the purpose of managing and documenting the activities. The control sub-process includes project control of "outputs and test results, the planning for the conduct of the systems engineering process activities (engineering plan, master schedule, and detail schedule), and technical plans generated by engineering specialties" [9]. The control sub-process provides the following:

a) A complete and up-to-date picture of SEP activities and results, which are used in accomplishing other activities.
b) Planning for and inputs to future applications of the SEP.
c) Information for production, tests, and support.
d) Information for decision makers at technical and project reviews.

The control process also contains several tasks and subtasks in management, progress tracking, and updating baselines and technical plans as shown in Figure 2-7.

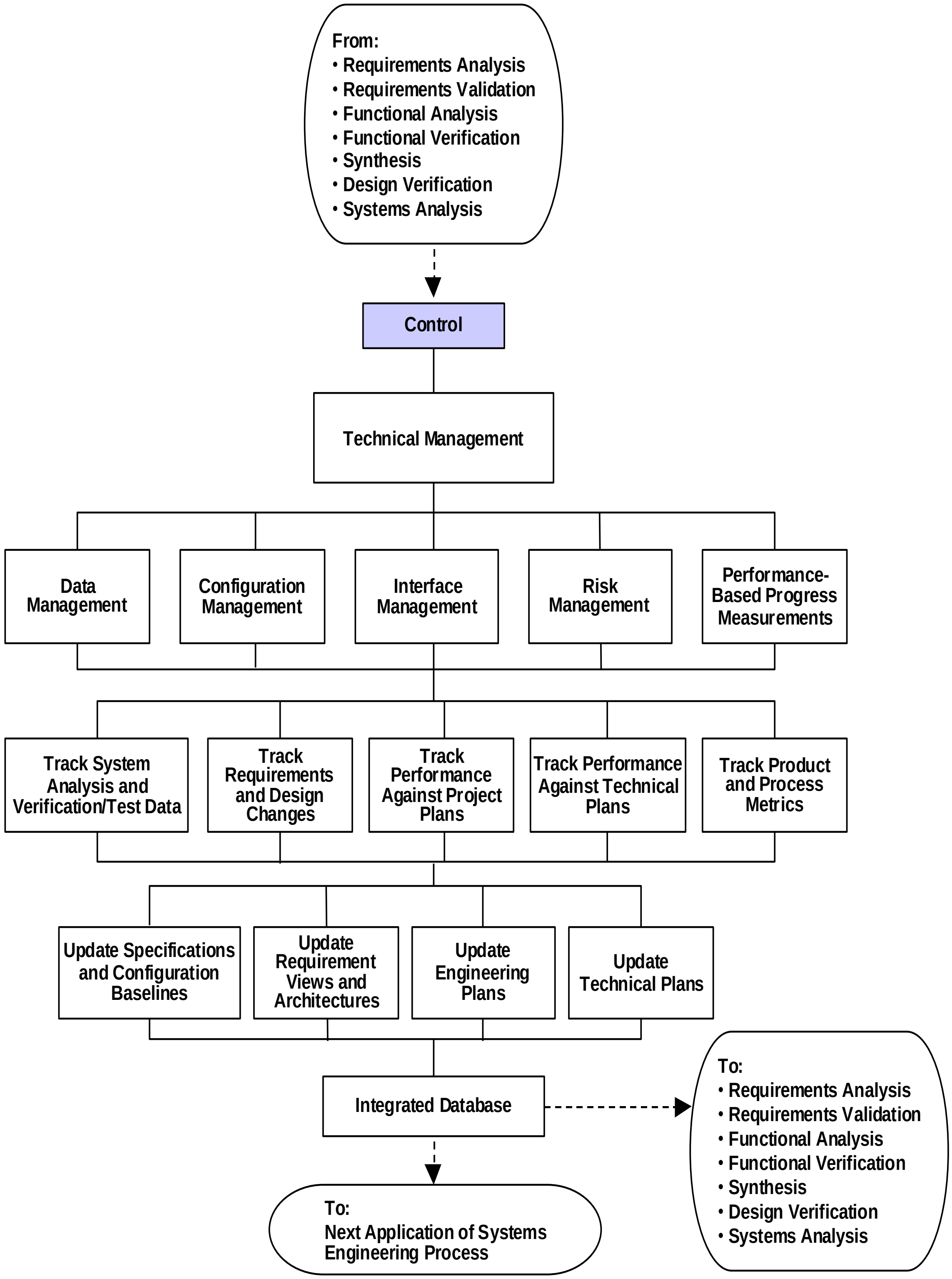


Figure 2-7 Control Process [9]

As shown from this modest summary of the 101 pages of IEEE Std 1220-205, the systems engineering process is defined in detail and is fairly specific on implementation which answers one of the previous questions for this research: are there conflicts between the processes? This standard is considered by the engineering community as the primary source for systems engineering instruction. Although the standard does define the process and the process flows, the standard is vague in one particular aspect. The control sub-process is the link throughout the systems engineering life cycle process. However, the control task begins after the requirements are generated and initiated into the systems engineering process. Discipline needs to be implemented earlier in the gap between the requirements being established and passed to the developing agent. Chapter 1 detailed several issues that emanated from incomplete requirements definition, requirements creep, and lack of understanding by developer of what is really needed. As detailed as this standard is, it fails to address the means by which the end-user's needs are tracked into the system design process. The IEEE Std 1220-2005 discipline begins at a point somewhere after the customer has handed over their requirements/needs and prior to the actual development execution. At this point, requirements are manipulated for the purpose of better understanding and implementation. However, this manipulation most often limits the ability to track the actual customer's intent and can sometimes cause engineers and program managers to go forward without understanding to what the real objective is. Implementing a control type function at the initial stages of requirements definition and then maintaining traceability to that function throughout the entire life cycle of the program development will address this shortfall in the SE process as commonly applied.

2.2 Recommendations to US Congress for Changes to Systems Engineering

The National Defense Industrial Association (NDIA) Report on top systems engineering issues, September 2010, provides recommendations for each issue identified. Issues one, three, four, and five are specifically related to this research [11].

1. Increasingly urgent demands of the warfighter require effective capabilities be fielded more rapidly than the conventional acquisition processes and development methodologies allow.

3. Systems engineering practices known to be effective are not consistently applied or properly resourced to enable early system definition.

4. Decision makers do not have the right information at the right time to support informed and proactive decision making that ensures effective and efficient program planning, management and execution.

5. Lack of technical authority can impact the integrity of developed systems and result in cost/schedule/system performance impacts as the technical solution is iterated and reworked in later stages of the development.

The recommended action for resolving the first issue is for NDIA to perform a study with joint government and industry participation. This study will "develop risk-driven guidance on tailoring SE processes and activities and DoD acquisition requirements from the Defense Acquisition System to achieve rapid acquisition and deployment [11] [12]." The rationale for this recommendation is to leverage industry experience in accelerating the acquisition process. The study team is to consist of cross-functional experts in all areas of systems engineering and program acquisition in order to identify trade off opportunities, critical factors for success and measures of effectiveness. The study rationale states, "Successful material solutions are a function of well documented architectural and design baselines of existing systems and components allowing effective reuse, integration, and verification in the extension of system functionality [11] [13]."

Issue three recommendation is to establish a working group which will help identify key systems engineering information for decision makers. This group will review proven engineering tools and techniques and determine why the acquisition community is not consistently applying these tools and techniques. NDIA recommends developing a "template for presenting key SE information, including activities, value/expected results, risk of not performing the activities, and future consequences [11]." They also recommend, "Make the SE discipline a required process in the transition from Science and Technology phase to early Concept Development phase [11]."

The fourth issue recommendation relies on the implementation of the previous issues study and working group recommendation. The NDIA proposes developing a roadmap "to facilitate the definition and implementation of a technical measurement process to support engineering management decisions. The roadmap would provide suggestions for packaging and communicating measurement results into information products that decision makers can use [11]." The NDIA report does not differentiate between its suggested technical management process and those already in existence in the IEEE Std 1220-2005 or if its suggested roadmap is a reinvention of part of the IEEE Standard. There is clearly a need for a more detailed and quantifiable technical management effort in the pre and early architectural development stage and carried throughout the systems engineering process. However, the NDIA report does not go into details about the content of the suggested process, the timing of its implementation with the development process nor the mechanisms through which it is implemented.

The recommendation for issue number five is to establish an independent technical oversight that reports at a higher level than the program manager. This oversight allows significant issues to be raised and balance out the politics of program authority. There is no mention of how this works in conjunction with the Weapon System Acquisition Reform Act of 2009 and the established DoD's Director of Engineering Office, which was created to provide this linkage, nor does it identify where the separate path ends.

The NDIA paper also recommends increased rigor for technical reviews. However, the paper does not define what type of milestone entrance criteria or technical detail criteria above that defined in the existing IEEE Standard. The idea of creating more vigorous technical reviews is valid for many programs that have streamlined their acquisition processes to reduce the amount of engineering design deliverables, thus deleting much of the material that is required at technical or decision reviews. Programs have saved money by allowing the prime contractor to take responsibility for the detailed engineering material and eliminating government oversight based on the argument that the additional oversight had not led to better program decisions. On the other hand, this approach has not resulted in better development programs either, as the Government has lacked adequate data and insight into that data for good program manager decisions as described in the previous chapter's GAO reports. Defining key criteria in the architectural development stages of requirements generation and carrying these criteria throughout the program's life-cycle is the key to cost effectively increasing rigor in the technical review process and providing the appropriate decision criteria throughout the development process. The problem has not been the lack or overabundance of data for industry or government program management to evaluate, but rather the lack of an explicit measure against which to evaluate the data, traceable clearly back to the original end-user needs. The end results of saving money on eliminating structured engineering practices and government oversight have proven to increase overall program cost due to issues with technical failures and rework. Therefore the short-term savings costs several times more in the long term.

2.3 Literature Review of Systems Engineering Process Issues and Solutions

There are not many publicly released publications on detailed solutions to resolve the surmounting issues in defense acquisition systems engineering. The ones that exist provide many diverse opinions on alternative approaches or applications of the systems engineering process. One such approach is applying an Axiomatic Design concept created by Nam Suh. Suh acknowledged that poor design practices result in high cost and delays in product delivery. Some military products, such as tanks, are rumored to take seventeen years to develop. When a person considers that World War II only lasted four years for some participants, lengthy development times cannot meet customer needs. In addition, "weapons may be superseded by better devices or may be irrelevant by changes in political or military strategy [15]." Suh believes most of the problems stem from technical factors dealing with the application of functional requirements that are either incorrect or excessive. Design decisions are being made with wrong information and decision makers are unable to recognize faulty decisions early. Suh stated,

> "System design has lacked a formal theoretical framework and thus, has been done heuristically or empirically. After systems are designed, they are sometimes modeled and simulated. In many cases they have to be constructed and tested. Such approach to system design entails both technical and business risks because of the uncertainties associated with the performance and the quality of a system created by means of empirical decisions [16]."

Suh hypothesized that customer needs are turned into solution neutral hierarchical structured functional requirements. These functional requirements must be independent from each other and at a minimum level. The functional requirements are mapped to the physical domain, which leads to the identification of design parameters, which can be physical, or software. The design world consists of four domains: customer, functional, physical, and process. The domains are mapped into a product design matrix and a process design matrix. This mapping will detail the relationships between the design parameters and the process variables. Process variables are selected based on what is deemed necessary to implement the design parameters into a solution. Suh believes that design should be governed by axioms. "Axioms are truths than cannot be derived but for which there are no counterexamples or exceptions [17][18]." Suh created two axioms for mapping the functional requirements and assuring independence from one another:

Axiom 1 The Independence Axiom

Maintain the independence of functional requirements.

Axiom 2 The Information Axiom

Minimize the information content. [15][18][19].

Suh theorizes that complex systems with many functional requirements and software intensive lines of code have a decreasing probability of satisfying the highest functional requirement as the number of functional requirements and design parameters increase. He states, "One of the goals of axiomatic approach to design is to reduce the complexity [16]." By applying the two axioms to the developed set of functional requirements and a synthesized set of design parameters, the proposed designs can be evaluated.

Although Suh's belief of the system design process lacking a formal theoretical framework, the IEEE 1220 Standard attempts to meet that need by specifically detailing the formal process for design. Although there is a specific design procedure, many developers utilized their internal design practices that may deviate from the IEEE standard. Dr. Suh appears to emphasize that his axiomatic approach to design will solve common issues found with other processes. There are diverse thoughts in the SE community on the need to develop prototypes. Suh's approach is to move straight from design to product development. The complexities of large scale, software intensive, state of the art technology defense systems and the risks of failures of such systems in their use environments is considered by most acquisition managers too high of a risk not to test a prototype. Apple Corporation spent $100 Million in test labs to extensively analyze product prototypes before going into production [49].

Dr. Suh's approach has been applied to manufacturing systems and organizations and is detailed in his referenced books and papers. His use of functional requirements is in a similar context as the IEEE standard for taking customer requirements and breaking them down to a design solution. There is no relationship to axiomatic design and mission analysis input into the systems engineering process. Suh's focus is on the design process, whereas this paper is focused on a more overall objective of establishing mission centric analysis products for consistency in decision making.

An article in the Journal of Engineering Design introduces the Transdisciplinary

Product Development Lifecycle (TPDL) model that builds on the Axiomatic Design method. This model extends axiomatic design to systematically encompass the test domain in addition to new domain characteristics that define and manage input constraints and system components. The objective of the TPDL model is to improve the "quality of the design, requirements management, change management, project management, and communication between stakeholders [22]."

System Constraint hierarchy is included with functional requirements and design parameters in the system architecture. The addition of the test domain and the four other characteristics increases the ability to capture and maintain product development lifecycle knowledge in addition to communicating that knowledge between customer needs and product stakeholders. Increasing the use of the axiomatic design method for the entire product development lifecycle has merit in that the disciplined approach to tracking system functional requirements is key to tracking and managing system development. It is unclear how axiomatic design can be implemented in the test discipline, as neither axiom is relevant for determining test requirements.

Another approach to system design is the "FAR approach – Functional Analysis/Allocation and Requirements flow-down using use case realizations [23]." This approach drives functional analysis/allocation and requirements flow-down utilizing use case modeling. Use case modeling is a "functional decomposition technique that provides a semi-formal framework for structuring the system functionality into user goals. These user goals are further specified by a number of scenarios describing the interaction between a system and its actors (users and environment) [23]." Utilizing the FAR approach, system level requirements are derived. Eriksson, Borg, and Börstler believe that the traditional systems engineering process does not provide enough support for achieving a design with high levels of reuse. [23] These authors consider modeling techniques to be specifically developed in closed environments that are not easily shared with the other engineering disciplines. The FAR approach closes the traditional systems engineering requirements loop by "producing a use case model as the output of the functional analysis and allocation task [23]." As a result, the use case model will have an overview of the total system functionality, which is needed for the design synthesis task. The FAR uses the control task, from the IEEE 1220 Standard for System Engineering Process, to trigger results defined as "Functional Architecture Description (FAD) and a Requirements Allocation Sheet (RAS) [23]." The FAD contains all the use case realizations. The use case realizations are actual use case scenarios, that is the design model of a systems physical architecture detailing all the subsystem interfaces. Utilizing the FAD and the RAS as inputs to the requirements flow down task, the output will be subsystem unique requirements specifications. In order to identify each use case scenario, the following three types must be distinguished:

- "Main Success Scenario" – describes the normal way of achieving the goal state in the use case name.
- "Alternative Scenarios" - describes alternatives ways of achieving the goal stated in the use case name.
- "Exceptional Scenarios" – describes how different failures are detected and handled by the system [24].

These types of scenarios should cover all potential use cases and provide the input required for the FAD and RAS.

The FAR approach is another method of aiding in the system design process. The concept of implementing use case modeling is widely accepted today in the software engineering community and is gaining momentum in the systems engineering community. The FAR approach relieves the systems engineer of the responsibility of specifying subsystem requirements, as those become the responsibility of the domain engineers. The International Council on Systems Engineering declares, “experience has shown that passing specifications between for example systems – and software engineering does not yield satisfactory results [25].” Domain engineers are forced to “analyze the origin of the subsystem requirement, which will give them a better system understanding [23].” Systems engineering must stay included in the process to ensure the requirements generated at the subsystem levels do not deviate and represent the original system level intended requirements.

In large complex systems such as Department of Defense systems, the technique of use case modeling is a common practice for requirements analysis. This technique helps identify the tremendous number of requirements necessary for systems with diverse operations and flexibility. The FAR approach is focused on extending use case modeling beyond a requirements analysis tool and utilizing it to form the basis for the initial steps in the systems engineering process of functional allocation and requirements flow down. While it clearly elaborates functional allocations between subsystems, it cannot alone replace the functional, timing, and performance allocation resulting from more classical requirements analysis techniques. Rather, when used in conjunction with those techniques, it can improve the balance of capabilities across the system.

The Boeing Company utilized value stream mapping to improve their systems engineering process on the C-17 program. Value stream mapping is a lean manufacturing technique used to analyze the sequence of activities, materials and information required to produce a product or service to a consumer. One of the purposes of the technique is to eliminate waste. The technique originated at Toyota where it was referred to as "material and information flow mapping [26]." Boeing's mission for this project was "to define and ensure common application of systems engineering processes using a controlled tailored approach, that will facilitate C-17 program and mission success [27]." The value stream mapping effort was performed on product development life-cycle processes, starting with customer needs through system verification. Primary areas of focus were systems engineering workforce, customer involvement, systems engineering process disciplines, and internal customer satisfaction and supplier to include quality. The effort began with a self-assessment and progressed through systems engineering surveys, internal and external to the C-17 program, then through the value stream mapping exercise into an executable improvement plan. The improvement plan included several projects in the areas of "interface management, project reviews, requirements process enablers, needs definition, systems integration, trade study improvement, verification improvement, project team memberships, and statement of requirements development improvement [27]." The implementation of lean techniques has a role in systems engineering as identified by the Boeing C-17 effort. Large-scale programs with multiple program support organizations are constantly challenged to maintain focus on mission and not get waylaid by the myriad activities or issues that can arise.

Program issues seem to be common in interfaces between system components. These issues are typically not discovered until later in the product development cycle in the verification and testing phase. As a result, these interface issues and the delays in discovery result in more extended program delays and cost overruns. Much larger problems exists when these issues are not discovered until the assets are actually fielded and in operation. At this point, more than program issues are at risk. For weapon systems, lives are at risk. Systems engineering is considered the process to remove these issues and to ensure that interfaces are defined and complete. There is wide concern with this process being adequate for the larger, more complex systems. The systems engineering process is considered successful for complicated programs but not so much for complex programs. The difference between complicated and complex is defined by Lockheed Martin vice president Jeff Wilcox as, "complicated is decomposable, which is what systems engineering is based on. Complex systems are not strictly decomposable, and systems engineering has to adapt [28]." Adoption of use case analysis and simulation tools can assist with understanding and insight into complex SE domains, particularly for loosely coupled, non-deterministic systems.

There is a significant relationship between system functionality and software especially as system functionality is increasingly implemented in software hosted on generic processing systems. Systems engineering must be more holistic to include the increase in software as well as extend to include more aspects like supplier base. The former National Aeronautical and Systems Agency (NASA) Director, Michael Griffin, "believes program failures could be avoided by engineering elegant system designs [28]." However, he did not have a definition of elegant design but believes it is apparent when it is achieved. And, since it is not easily definable, it is not teachable. He does however state that a system that works as intended, is efficient, and has a robust design is an elegant design. He stated, "The space shuttle, when operated as intended, will produce the most amazing results, but get outside the envelope and bad things happen. That's not a robust design [28]."

The United States Defense Advance Research Projects Agency (DARPA) has developed a new systems engineering approach that eliminates the traditional development structure of design, build, test and redesign. The system is the Meta program. A library is developed with metadata files consisting of tens of thousands of digital files that characterize components and also characterize component interactions. Basically, engineers will shop the library for the components they want to use to build the system. The breadth of the tool set allows for flexibility and adaptability of the chosen files, therefore making the system more adaptable and flexible. Common metalanguage links everything together and aids in keeping designs less complex. By developing a system utilizing models and simulations, it can be probabilistically verifiable without executing expensive real world testing. This concept appears very similar to use case modeling defined above. It is also the intent of implementing use case modeling and extinguishing development of prototypes for testing and evaluation. Many years of experience and research have all shown that there are unknowns in all designs. Models are only as good as the data that are used to develop them. However, there is a need for these libraries to be developed in order to be a repository for information as well as design products as intended. Connecting multidisciplinary models across engineering domains and adding either comprehensive stochastic variation and/or an external optimization loop can lead to rapid discovery of unknowns. At the same time, the Meta approach presupposes a solution concept for which the designer picks components from the Meta library. This has the drawbacks of 1) requiring significant experience on the part of the designer picking components, 2) driving solutions to evolutionary changes to known solutions and discouraging revolutionary solutions, and 3) decreasing the likelihood that a robust exploration of the solution space is undertaken before the design is solidified.

The traditional approach to alleviating complexity (complicatedness, in the parlance of Jeff Wilcox) is to break the system down into modular parts also known as components or elements. Each of these elements acts as an independent system and contains its own unique functionality. In many cases each of the elements is managed and developed separately. The independent development of each unit increases the likelihood of disconnects within the interfaces and unintended behavior as the components interact. Interfaces between the elements are critical to function as a total system. An alternative approach to solving the problem of designing complex systems without losing system interface functionality is to build the system incrementally [29]. Incremental engineering utilizes existing systems or prototypes as the foundation to initiate new start up programs or incremental changes. The knowledge base learned from these existing assets allows engineers to achieve a step ahead to a more complex system approach [30][31]. The development cycle is decreased; therefore the system does not have to be divided into modular parts to effectively manage it.

Incremental engineering has been expanded to include evolutionary acquisition. Evolutionary acquisition is the preferred acquisition strategy for rapid development by the Department of Defense. Each system is delivered with a full operational capability with known upgrades planned for the future. Each of the upgrades is managed as a separate increment [32]. The benefit of incremental engineering is the ability to change small parts of an operational system rather than replace the entire system. Y. Bar-Yam from the New England Complex Systems Institute asserts, "The development environment should be constructed so that exploration of possibilities can be accomplished in a rapid (efficient) manner [33]." Wider adoption of the evolutionary changed part is executed if it is determined that performance was increased to the level warranting the effort of the change. Therefore, engineering analysis and operational feedback is a necessary part of the evolutionary acquisition strategy.

Evolutionary acquisition is widely utilized for complex defense systems development. Many of the large defense systems are comprised of existing elements that are upgraded to operate in new or additional mission environments. Utilizing evolutionary engineering allows for more rapid improvements to operational systems while maintaining safety. Management's oversight involves establishing tasks that provide context and design for the innovation process and to establish full communication feedback loops for performance validation and new innovations. Evolutionary acquisition continues to use established systems engineering standards as described previously in this paper, as well as specific techniques that are unique to the developing agent. However, the systems engineering issues that are prevalent in DoD acquisition programs continue to exist.

Chapter 3

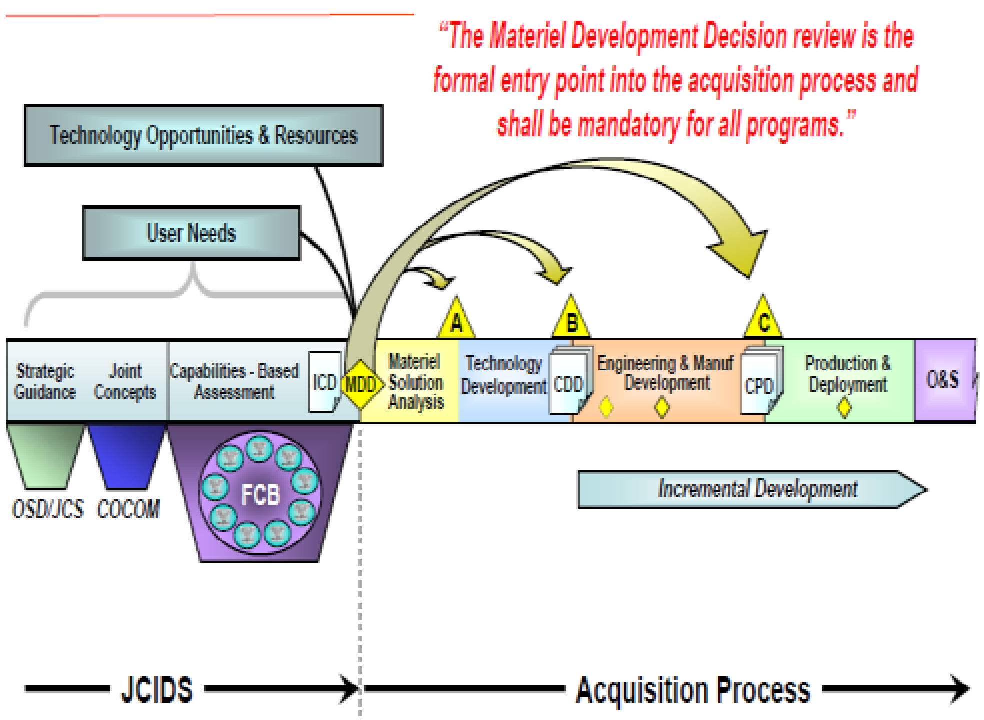
Research Question

Instilling good systems engineering processes into any project is significant because it increases the efficiency, controls cost and schedule, and helps standardize best practices within the engineering community. As described earlier in this dissertation, the quantity, quality, and volume of scholarly work on this topic documents the importance of systems engineering globally. The Department of Defense (DoD) recognizes this and relies heavily on systems engineering. The DoD 5000 series guidebook contains required systems engineering standards and prescribes their application. Even with these guidelines and standards, however, many DoD programs suffer significant cost and schedule overruns. This dissertation asserts that improved practices inserted in the early stages of the systems engineering process would address this problem. Other scholars describe numerous efforts undertaken to improve the acquisition process through better product design techniques, but those efforts do not suggest improvement by inserting a new step in the process. Research captured here identifies the value of inserting a Mission Architecture Step (MAS) that will produce a Mission Analysis Plan (MAP) in the early stages of an acquisition program. These will then influence the development of a system as it moves through the acquisition process. The addition of these new features will increase efficiency and better control cost and schedule while providing decision makers with the data they need when they need it. An exploration of the current acquisition methodology, what is missing from it, and how these proposed improvements will impact it demonstrates the point.

3.1 Current Methodology

When the Department of Defense identifies a warfighter deficiency, it documents that shortfall in an Initial Capabilities Document (ICD). This document was previously called the Mission Need Statement (MNS) and is still referred to by this name in non-defense departments. The ICD captures a high-level capability gap(s) and provides justification for the initiation of a new material or non-material acquisition program. In many cases, the deficiencies fall into areas across multiple services (Air Force, Navy, Army and Marines) and therefore the ICD captures common requirements for a program that supports multiple users. The ICD does not identify or direct a specific solution. Rather, it directs preliminary engineering analysis to determine the scope of the mission need or gap. This analysis validates key performance parameters, operational risk, and the need to continue with a material or non-material solution. Before approval of an ICD, it is vetted through a rigorous and extensive planning and budgeting process at the highest levels in the Department of Defense. It is important to note that the vetting process is a very detailed, legal, and sometimes highly political process. It is not a trivial effort and definitely not something that is done quickly. After vetting, the warfighter deficiency is ranked against other services and agency needs and then prioritized.

Once selected, meaning its priority is deemed to be above the rest, DoD can resource a project and allocate it to a service or agency for development. It has thus begun the DoD acquisition process portrayed below in Figure 3.1. The defense acquisition system is governed by DoD Directive 5000.01 for policies and principles and by DoD Instruction 5000.02 for operation of the defense acquisition system. An essential part of the acquisition process is a milestone framework. Milestones are defined as decision points for entering each phase of development. The milestones are depicted in Figure 3.1 as the alphanumeric letters A, B, and C. Milestones serve as guides at each step, or gate, in the development phase.



OSD – Office of Secretary of Defense
FCB – Functional Capabilities Board
JCS – Joint Chiefs of Staff
MDD – Material Development Decision

COCOM – Combatant Command
O & S – Operations and Sustainability
CDD – Capabilities Development Document
CDP – Capabilities Production Document

Fig 3.1 DoDI 5000.2 Initiation of New Programs [45]

Following approval of the ICD before milestone A, the material developer must conduct a Material Solution Analysis that is initiated by an analytical comparison of alternative solutions. This analytical comparison is referred to as an Analysis of Alternatives (AoA) and law governs the content of this analysis [63]. The purpose of the AoA is to assess a broad range of options that can be possible solutions to meeting the mission need. "The results of the AoA contribute to the selection of a preferred material solution that satisfies the capability need documented in the ICD" [45].

A designated study team conducts the AoA with guidance from DoD Cost Assessment and Program Evaluation. The team develops a study plan in accordance with the DoD acquisition instructions defined in the Defense Acquisition Guidebook. The guidance requires, at a minimum, full consideration of possible trade-offs among cost, schedule, and performance objectives for each alternative considered. In addition, the guidance requires an "assessment of whether or not the joint military requirement can be met in a manner that is consistent with the cost and schedule objectives recommended by the Joint Requirements Oversight Council" [45]. It is recommended that a broad range of solutions be considered so that the preferred solution has been fully vetted and objectively determined to be the lowest risk technical solution.

Historically, AoAs have not yielded the results envisioned by Congress and the DoD. According to a 2009 GAO report, "Many of the AOAs that GAO reviewed did not effectively consider a broad range of alternatives for addressing a warfighting need or assess technical and other risks associated with each alternative" [64]. The report continued also determined that, "While AOAs are supposed to provide a reliable and objective assessment of viable weapon solutions, we found that service sponsors sometimes identify a preferred solution or a narrow range of solutions early on, before an AOA is conducted… Furthermore, while DOD has an opportunity to influence the scope and quality of AOAs, it has not always provided guidance for conducting individual AOAs" [64].

These findings strongly suggest that the DoD AoA process lacks the strong SE infrastructure required to ensure a robust analysis of potential solutions. The GAO findings point to a lack of consistent, robust Technical Performance Measures (TPMs) and evaluation criteria and procedures that ensure adequate time is allotted for a full assessment. The GAO also found a lack of traceability from AoA evaluation criteria to subsequent program TPMs.

On the other hand, the GAO found "…that the programs that considered a broad range of alternatives tended to have better cost and schedule outcomes than the programs that looked at a narrow scope of alternatives" [64]. Critical to the success of these AoAs has been the existence of clearly defined, solution-independent evaluation criteria.

3.2 What is Missing?

Before to entering a development phase, entrance and exit criteria based on quantifiable engineering achievements, technology maturity, resources, schedule objectives and reaffirmation of the DoD's need are defined for that phase. Each milestone progresses in development maturity from engineering analysis of product selection to proving the technology, developing a prototype and testing it, then fielding an early operational capability, and finally to production and full operational fielding. All fielded products require maintenance and support for their entire life of operation, therefore this requirement must be considered as well during the design of the system.

Resources are limited, so acquisition professionals must achieve effectiveness and efficiency in all corporate processes as well as engineering development efforts. If problems arise in these processes and can be clearly captured in their full context, it becomes much easier to generate an appropriate solution. For example, if a cornfield needs to be irrigated and a pond sits half a mile away, what is the best solution for getting the pond water to the cornfield? A quick, simple solution would be to blast the space between the pond and the cornfield to create a ditch for the water to flow. However, this solution may cause too much water to flow too quickly, which will drown the corn versus simply irrigating it. In addition, the explosion could damage surrounding property. So, the appropriate solution is to irrigate the corn without destroying it, and blasting would not meet that objective. The farmer's need to irrigate the corn without damaging it or any surrounding farmland becomes the true mission. Therefore, an irrigation pipe may be the more appropriate solution. This irrigation illustration captures the need for a clearly defined systems engineering process. An effective process places emphasis on assessing mission needs, identifying collateral issues, and using data to formulate criteria that drive appropriate design solutions.

3.3 What the Mission Architecture Step does and Why it is Needed

The shortfall of timely and consistent data available to decision makers, in addition to the lack of consistent application of systems engineering practices, creates expense, complication and delay. Adding a Mission Architecture Step when the mission need is designated as an acquisition program would mitigate shortfalls in the existing systems engineering approach [11]. The MAS should be inserted at the beginning of the

AoA and drive the systems engineering process. When appropriately used, it would serve as a touchstone throughout the systems engineering process and would maintain a functional requirements baseline. The MAS will provide the roadmap for the AoA to consider and assess all possible solutions. Establishing a quantitative baseline, as the MAS does, at the initiation of a program's systems engineering process is both logical and valuable. Figure 3.2, which illustrates the systems engineering process in a V-model, depicts the establishment of a quantitative baseline at the Mission Architecture Step at the top of the V. As depicted, the Mission Architecture Step initiates at the onset of the systems engineering process and continues throughout the program's lifecycle. The MAS is depicted as central to improving the systems engineering process because of its ongoing focalization effect. The impact of this in the acquisition process is fundamental and should not be overlooked.

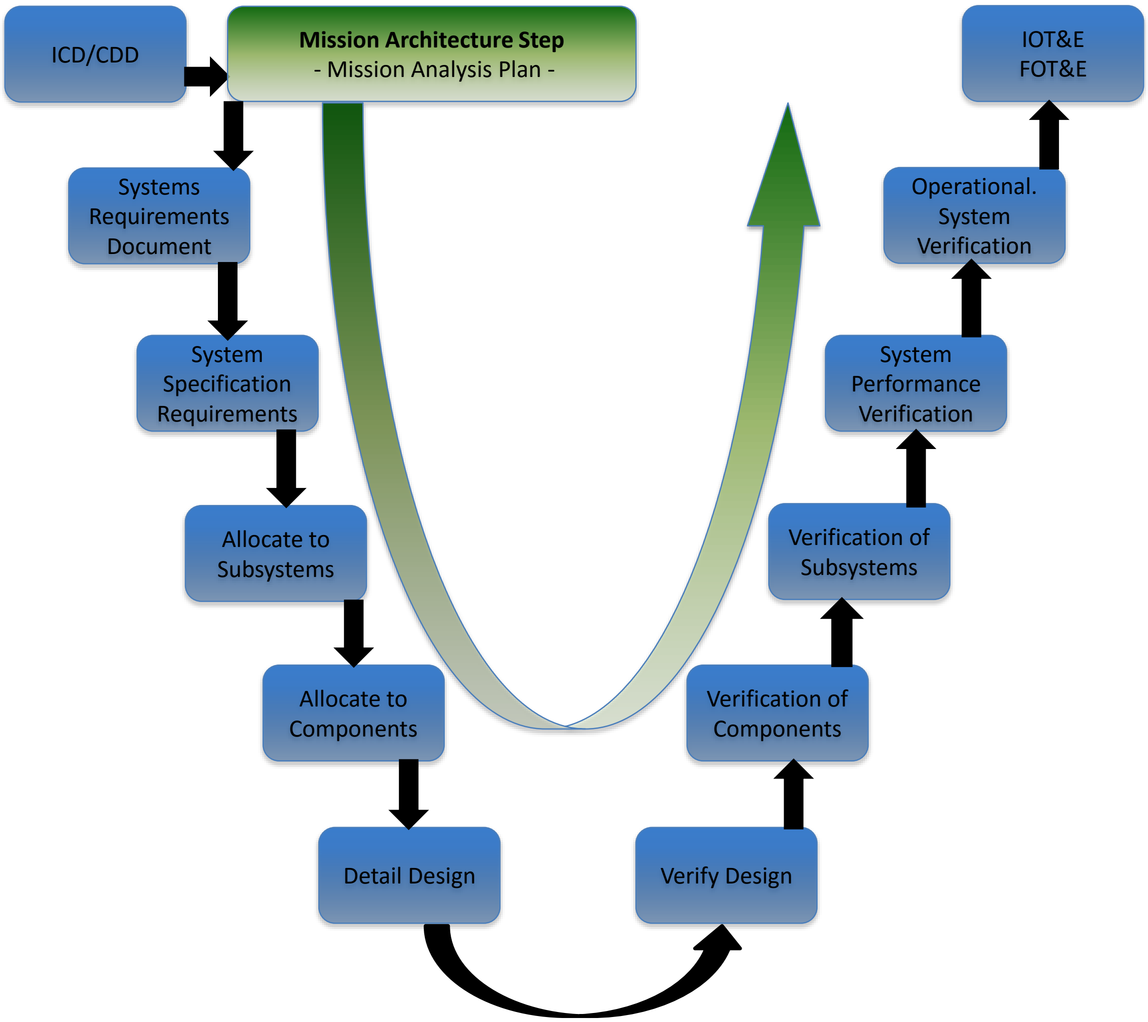


Fig 3.2 Mission Architecture Step Drives Systems Engineering Process

Similarly, Figure 3.3 depicts the current acquisition process without the Mission Architecture Step. This approach lacks a timely quantitative baseline traceable to the underlying warfighter deficiency. Figure 3.4 illustrates the improved process with the Mission Architecture Step, and the Mission Analysis Plan it produces, included. Adding the MAS and MAP at the front of a program creates a quantified baseline criterion for the development of all tools and data needs. This criterion is valid at any stage of development and applies to all elements and interfaces in the system.

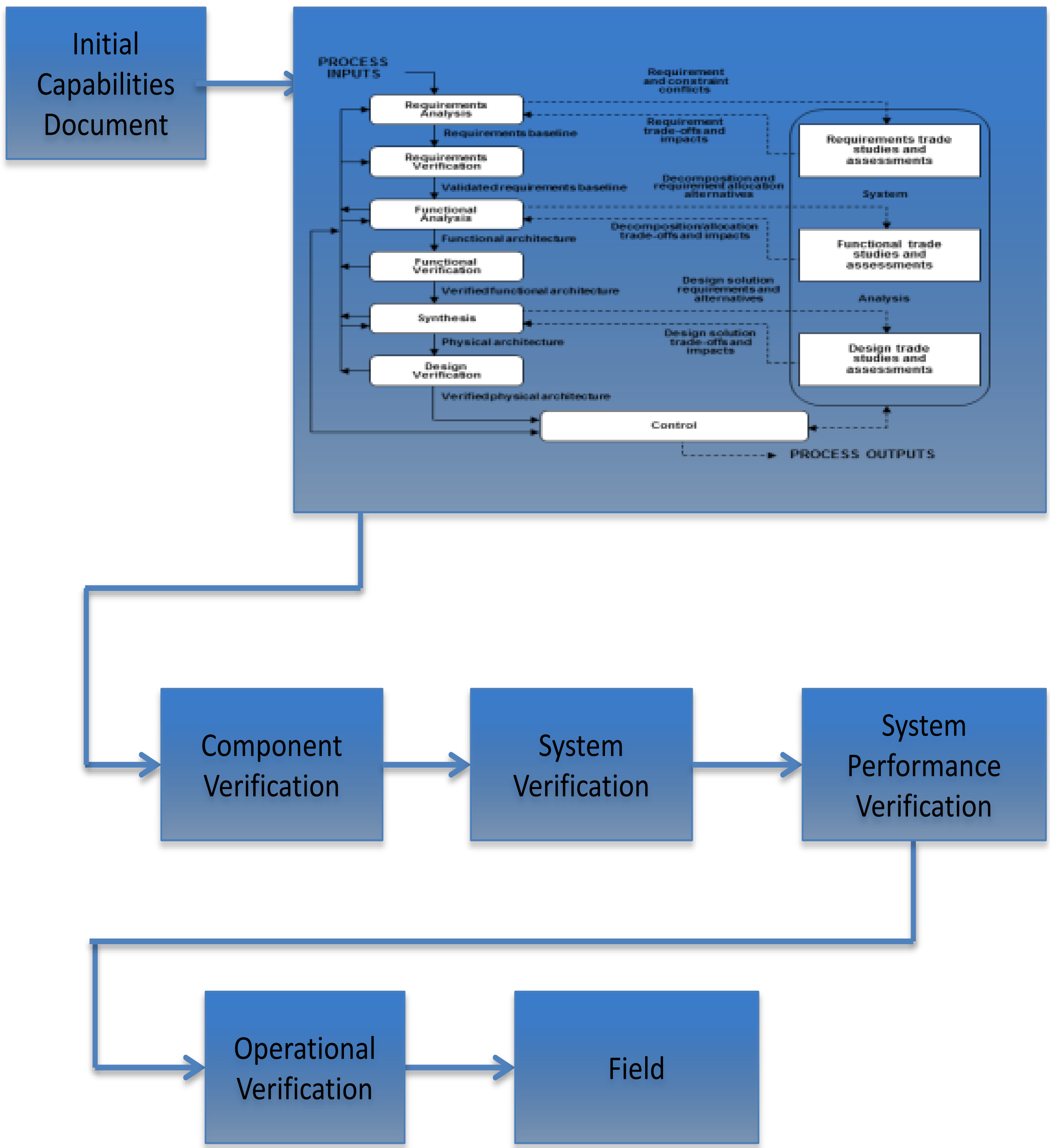


Fig. 3.3 Current DoD Engineering Acquisition Process

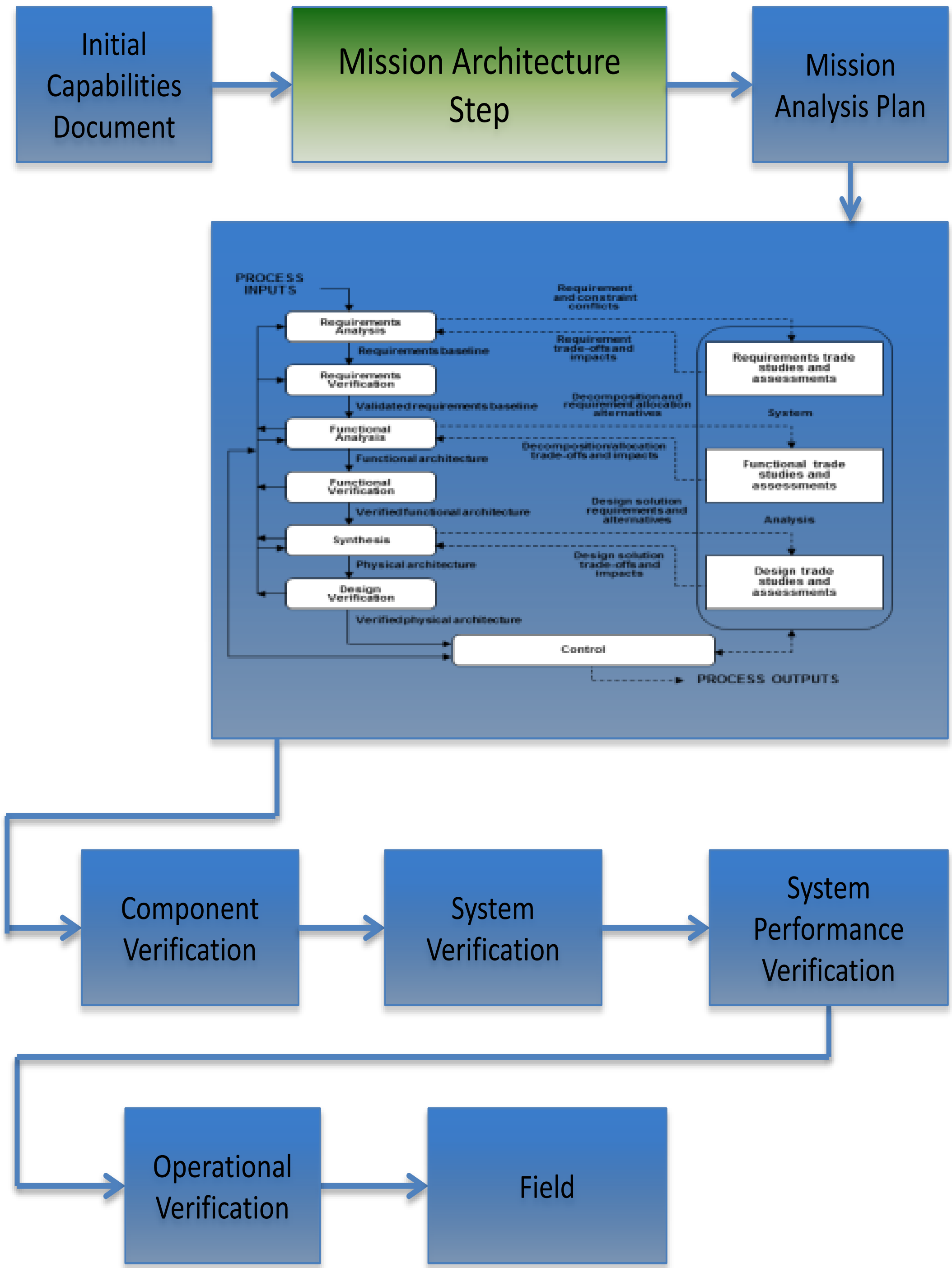


Fig. 3.4 DoD Engineering Acquisition Process Improved with Mission Architecture Step

The Mission Architecture Step allows the development of an evaluation plan by each analyst organization. Within this step are two components: the Mission Analysis (MA) and the resulting Mission Analysis Plan (MAP). The first of these is a functional decomposition of the mission. The mission is set forth by the ultimate customer and describes the "what" not the "how". The MA's functional decomposition breaks down the mission into finer functional elements that can be more precisely defined and can have some parameter or metric assigned to them. This functional decomposition does not assume a solution. It also does not explicitly define the requirements. Rather, its purpose is to clearly state the elements of the mission in finite components. The functional decomposition continues until each element of the mission is broken down as far as possible.

The ultimate output of the MA is a Mission Analysis Plan (MAP). This is a hierarchical collection of the lowest level components of the mission, or its basic functional elements (BFEs). The MAP's purpose is manifold. It serves as a mission function dictionary (collection of the elemental components of the mission complete with definition and parameters). Its hierarchical structure provides the framework for the overarching mission and ultimately defines the framework for the requirements definition. The collection of parameters (which are loosely related to metrics) defines how one knows the requirements will be measured to ensure satisfaction of the mission. It lays the groundwork for defining the tools that will be used to measure the requirements and the satisfaction of the mission.

Ultimately, the MAP produces the foundation for requirements definition for each assessment event and each milestone in the acquisition process. The plan contains the quantified metrics to ensure measures of effectiveness and performance are assessed accurately. By doing this, the Mission Analysis Plan improves the process and prevents disconnects. Specifically, the MAP:

1. Defines the specific details of each function. This includes all inputs and outputs for each function/sub-function at each milestone.
2. Provides a mechanism for communication between customer requirements and the system developer. It clarifies the requirements and their intent prior to initiating design work.
3. Directs the systems engineering process execution.
4. Defines interfaces through input and output that feed other functions.

In short, the Mission Analysis Plan provides the foundation for continuity of measuring data consistently by all analysts. Because of its presence early in the acquisition process, subsequent test and assessment plans will have traceability to the product requirements. As a result, the MAP focuses the systems engineering process on accurate and complete requirements definition at the outset of the systems engineering process. The requirements definition identifies the functional attributes of the solution (end product) and sets forth the parameters against which the solution will be measured to ensure completeness and sufficiency. At the conclusion of the requirements definition, there should be no BFEs without a corresponding requirement. Conversely, there should be no requirements without a BFE. Additionally, the identification of the key data points drives test parameters and requirements. High fidelity models and simulations need live test data points for anchoring (verification and validation), which also drives test data needs. The MAP captures these needs early in the program acquisition phase and implements this work up front, allowing for a solid program planning structure and systems engineering plan.

The Mission Architecture Step and Mission Analysis Plan it produces are system life products. They provide a functional roadmap that is applicable for single systems or in complex systems that are composed of systems of systems, new start programs, existing acquisition programs, and programs that are comprised of assets with different levels of maturity. The Mission Architecture Step is continuous in the sense that the MAP it produces is a living document that serves as a touchstone throughout the systems engineering process. Systems engineers should continuously refer back to the MAP to ensure all BFEs have been translated to requirements and that no new requirements, not driven by a BFE are included. The Mission Architecture Step is life-cycle based. It is not iterative. It should be locked down (baselined) and only changed through a board action.

One can think of the MAP as a strategic guide that sets the overall direction for the alternative of options, requirements definition and design process. It ensures fidelity of the solution with the mission. It should not be altered often, if at all. When a new requirement develops, however, it can accommodate and help manage requirement changes or adjustments. In addition, the MAP provides the full system impacts of adding a new requirement. In many cases, the impacts are not easily identified as they occur at interfaces or in other affected sub-functions. For example, the Missile Defense system is a complex, continuously evolving system of systems. Assets are added and dropped to meet current needs and increased performance for current threats. New weapon systems will be added or have new capabilities that alter performance parameters. With the

Mission Analysis Plan in place, analysis of a potential new asset can be compared directly to the product requirements, thus avoiding the inclusion of unneeded requirements definition, extraneous features in the solution, unnecessary or mis-specified analysis tools, analyses, and tests. This prevents unnecessary costs and schedule delays.

In summary, the Mission Architecture Step, the Mission Analysis it includes, and the resultant Mission Analysis Plan provide a structured, fundamental baseline for the development of a system. They provide **a** detailed definition of what data is required and why. Test and assessment plans are tied directly to the Mission Analysis Plan. Modeling and simulation plans are also tied directly to the Mission Analysis Plan. With the MAP in place, these plans are completely integrated and reflect the system under test. Validation and verification of tools and data have a clear, direct data structure for reference. As a result, decision makers have confidence in the results of these assessments, cost overruns and delays are prevented, and new assets can be deployed more quickly, efficiently and with greater accuracy.

Chapter 4

Demonstration of Functional Decomposition within the Mission Architecture Step

Chapter 1 identified problems associated with the significant cost growth in acquisition, research and development programs. As documented there, these problems are attributed to an average of 21-months in delays in deliveries to the warfighter and cost growth of $295 billion in program executions [3]. The National Defense Industrial Association for System Engineering reports identified the following specific causes across the board for the majority of weapon system acquisitions issues [3].

1. Sufficient knowledge about system requirements, technology, and design maturity is lacking at program initiation.

2. Programs are managed with lower level of product knowledge at critical junctures than expected under best practice standards.

3. Managers rely heavily on assumptions about system requirements, technology, and design maturity, which are consistently too optimistic

4. There is consistent lack of disciplined analysis that would provide an understanding of what it would take to field a weapon system before system development.

5. Knowledge gaps are largely the result of a lack of disciplined systems engineering analysis prior to beginning system development.

6. Early systems engineering provides knowledge that enables a developer to identify and resolve gaps before product development begins.

7. Disciplined systems engineering prior to beginning system development is not typically conducted in DOD, therefore requirements are added well into the acquisition cycle.

8. Significant contract cost increases occur due to the scope of requirements changes or become better understood by the contractor.

9. Ambitious product development with more technical unknowns and less knowledge about performance and production risk.

10. Knowledge to develop realistic cost estimates is lacking.

The report went on to identify some areas that will help improve the process [3].

I. Assure requirements for specific weapon systems are clearly defined and achievable give available resources.

II. Requirements should not change without assessing their potential disruption to the program and assuring how they can be accommodated within schedule and funding constraints.

III. Milestone decisions should be based on quantifiable data and demonstrated knowledge.

IV. Each milestone should be incremental, knowledge-based for product development programs that improve capability as new technologies are matured.

4.1 The Mission Function Decomposition

As the previous chapter asserted, the Mission Architecture Step, the Mission Analysis and Mission Analysis Plan, effectively addresses these problems. A key component of this step is performing a thorough decomposition of the mission functions. This comprehensive mission function decomposition constitutes the Mission Analysis and feeds the Mission Analysis Plan. As such, understanding mission function decomposition is essential to demonstrating the overall value of the Mission Architecture Step and its potential for creating cost and time savings.

The mission function decomposition is accomplished by identifying the main (Tier 1) functions required to accomplish the mission objective as identified in the

Mission Need Statement. These Tier 1 functions are developed using engineering expertise, physics, and archived data. The set of Tier 1 functions is comprehensive, and the functions within the set are mutually exclusive and divisible. In the Mission Analysis phase, these functions are continually broken down into progressively lower tier functional sub-elements, also referred to as parent-child relationships. The transition between each functional sub-element has quantifiable, measurable points. These quantified metrics are not definitive data values but instead units of measurement. A parent quantified measure feeds into a child function in order to constitute action by that functional sub-element. This decomposition process continues until the point at which a set of basic functional elements emerges. The set of basic functional elements is also comprehensive and the functional elements within it are mutually exclusive, but they are not further divisible. As a result, the basic functional element is the lowest level of a function that can be described with a parameter but without assuming a solution. At that point the mission function decomposition concludes. The resulting product is a quantified mission architecture captured in a Mission Analysis Plan.

4.2 Mission Analysis and Missile Defense Case Study

There are many varieties of software tools available to help perform this work. One powerful open source tool is Rhapsody. Simple decompositions can also be built with basic features in Microsoft Office. It is essential that the tool selected provide the ability to identify relationships, interfaces, and stipulations for each of the functions. Figure 4.1 shows a relationship diagram example in Rhapsody. Figure 4.2 is a sample Rhapsody input screen. This paper does not endorse the Rhapsody tool but only identifies it as an available product to help accomplish the functional decomposition work and to show the type of input required to generate a comprehensive Mission Analysis Plan.

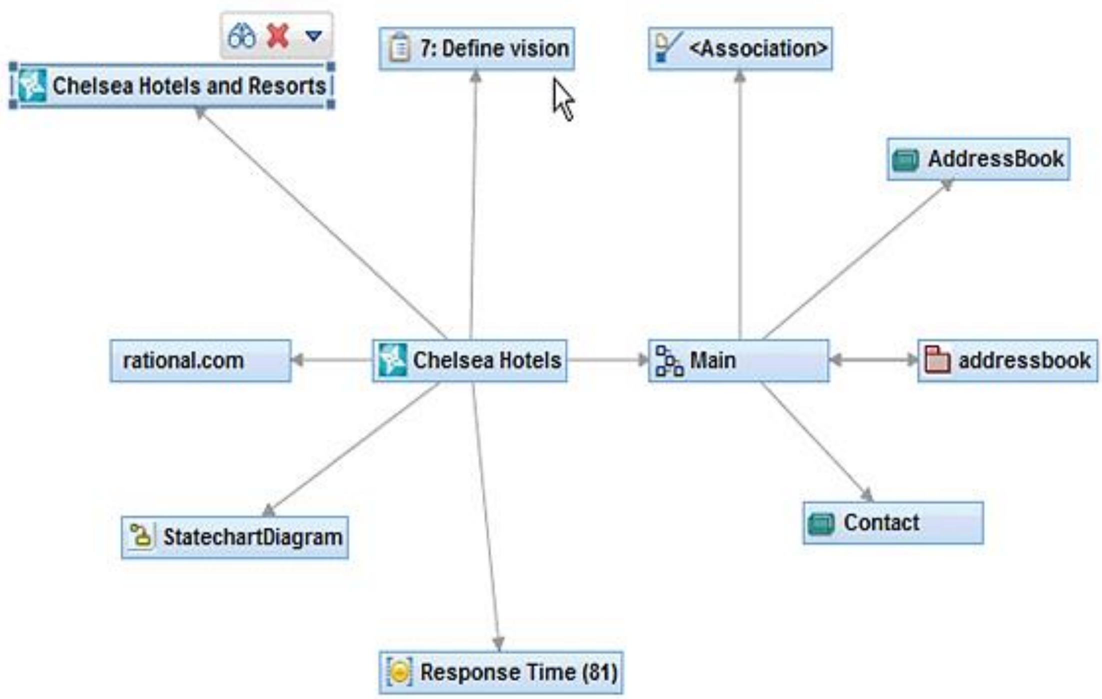


Fig. 4.1 Rhapsody Model Relationship Diagram [43]

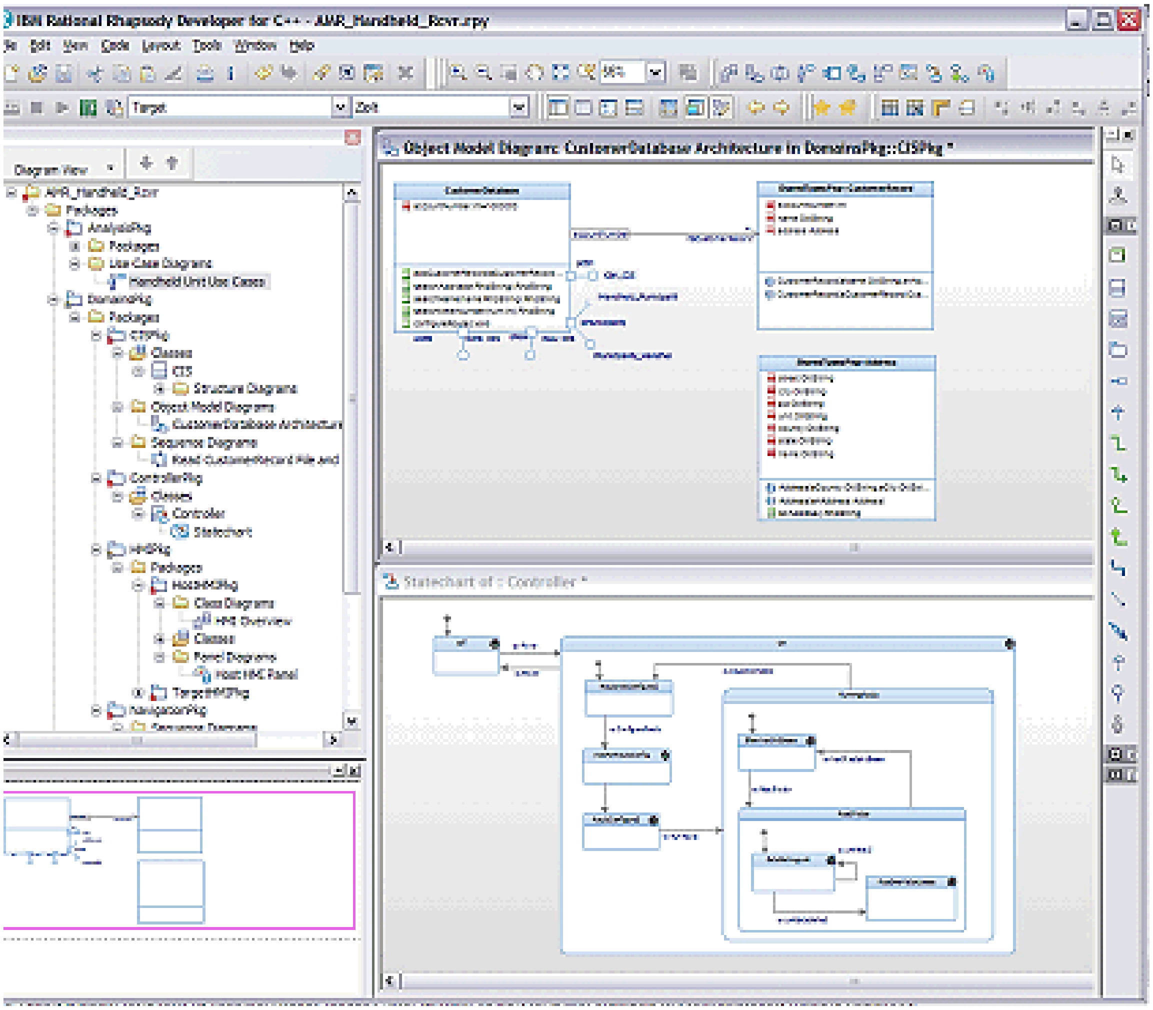


Fig. 4.2 Rhapsody Input Screen Example [43]

In the functional decomposition that follows, Microsoft Office tools are used to break down the components of the mission need for a missile defense mission. Figure 4.3 illustrates a Tier 1 function construct for the missile defense mission. The basic functions to execute a missile defense mission are to command and control the mission, to see the threat missile and to defeat the threat missile. Each are allocated a function control number and title as below:

1.0 Control the Battle

2.0 Perform Sensor Operations

3.0 Engage the Missile

Each of these Tier 1 functions is decomposed and allocated a sample metric quantification measurement unit to each function sub-element. These metrics are both outputs from the parent function element and inputs to the next level child sub-element. As shown in the relationship diagram, the metric will be related to another function, which will be apparent by the name of the metric and measurement unit. In the end, a comprehensive functional decomposition with defined sub-function element relationships and their associated metrics become the Mission Analysis Plan.

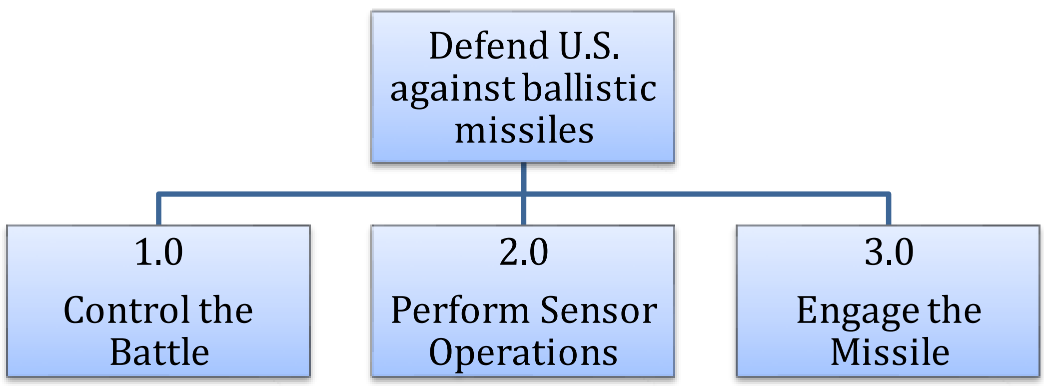


Table 4.3 Functional Breakdown of a Mission Need for Missile Defense

The 1.0 Control the Battle Function is a command and control function. The purpose of this function is to plan, visualize, direct, command, and control battle actions.

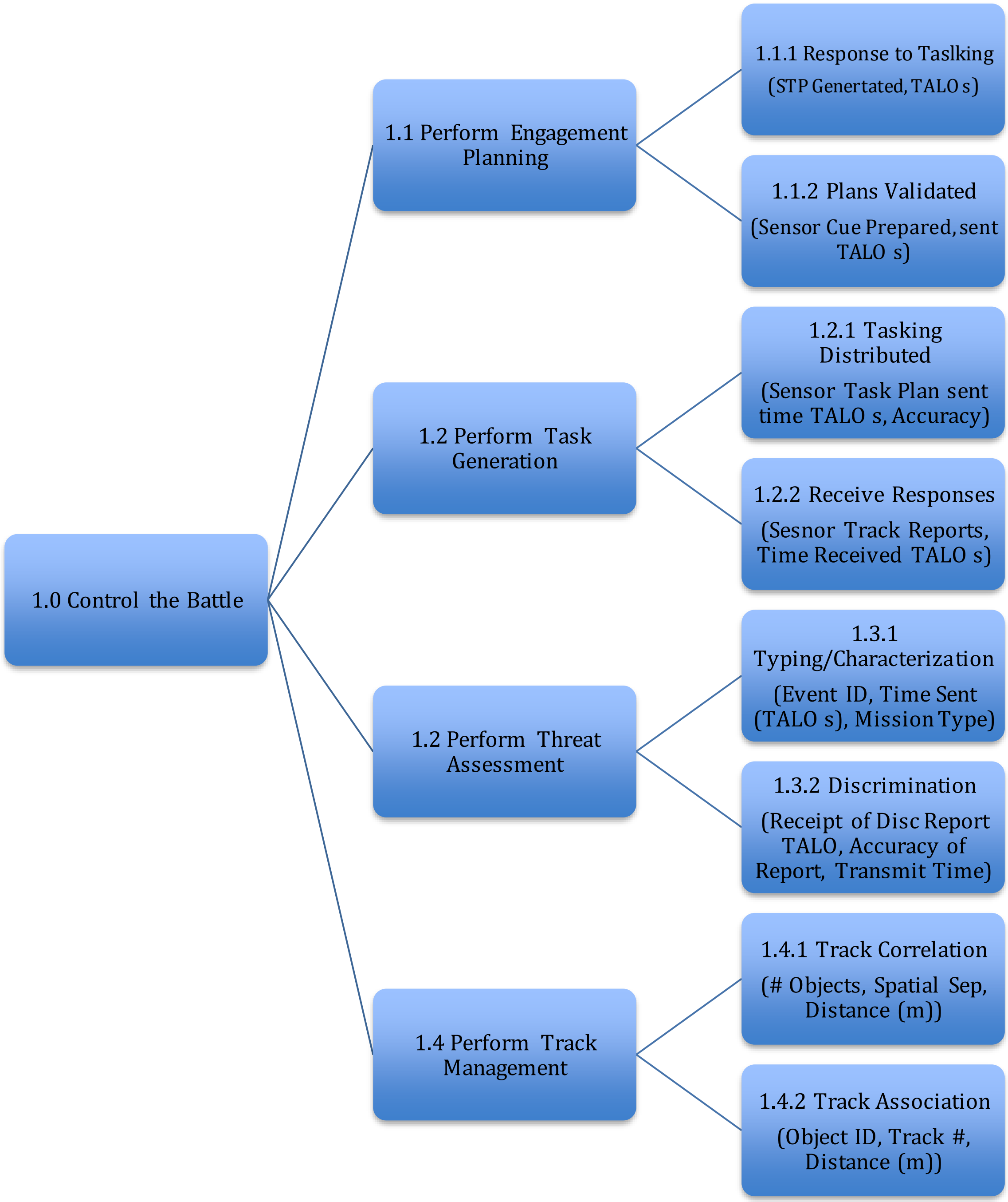


Fig. 4.4 Function 1.0 Control the Battle Functional Decomposition

This includes personnel staffing, facilities and equipment. An example of a detailed functional decomposition for the Control the Battle Function is illustrated in Fig 4.4. The third tier function sub-elements identify quantifiable measurement units in the parentheses below the function title.

The next two functional decompositions demonstrated below are for 2.0 Perform Sensor Operations and 3.0 Engage the Missile and are illustrated in Figures 4.5 and 4.6 respectively. The purpose for performing the sensor operations function is the management and operations of the sensor activities associated with identifying and tracking a missile threat and associated objects. This function will perform the necessary actions to determine which object is the lethal threat. The Sensor Operations Functions include initialization and calibration for system readiness, receipt and action of sensor task plans from the battle manager, and action on those task plans. The Sensor Operations Function provides key information for generation of target information and in-flight target updates to the weapon designated for threat negation. The purpose of the engage the threat function is to manage and control the weapon system activities before, during, and after the battle. The weapon function involves all weapon activities to include readiness and activation, battle manager weapon task plan receipt action, weapon system launch operations, in-flight maneuvers and threat engagement.

As stated earlier, the Mission Analysis effort decomposes each of the mission functions to its lowest level. Each of the function sub-elements is allocated a measurable parameter that drives the input to the next tier function sub-element. The lowest level for a function sub-element is determined when it can no longer be devolved without

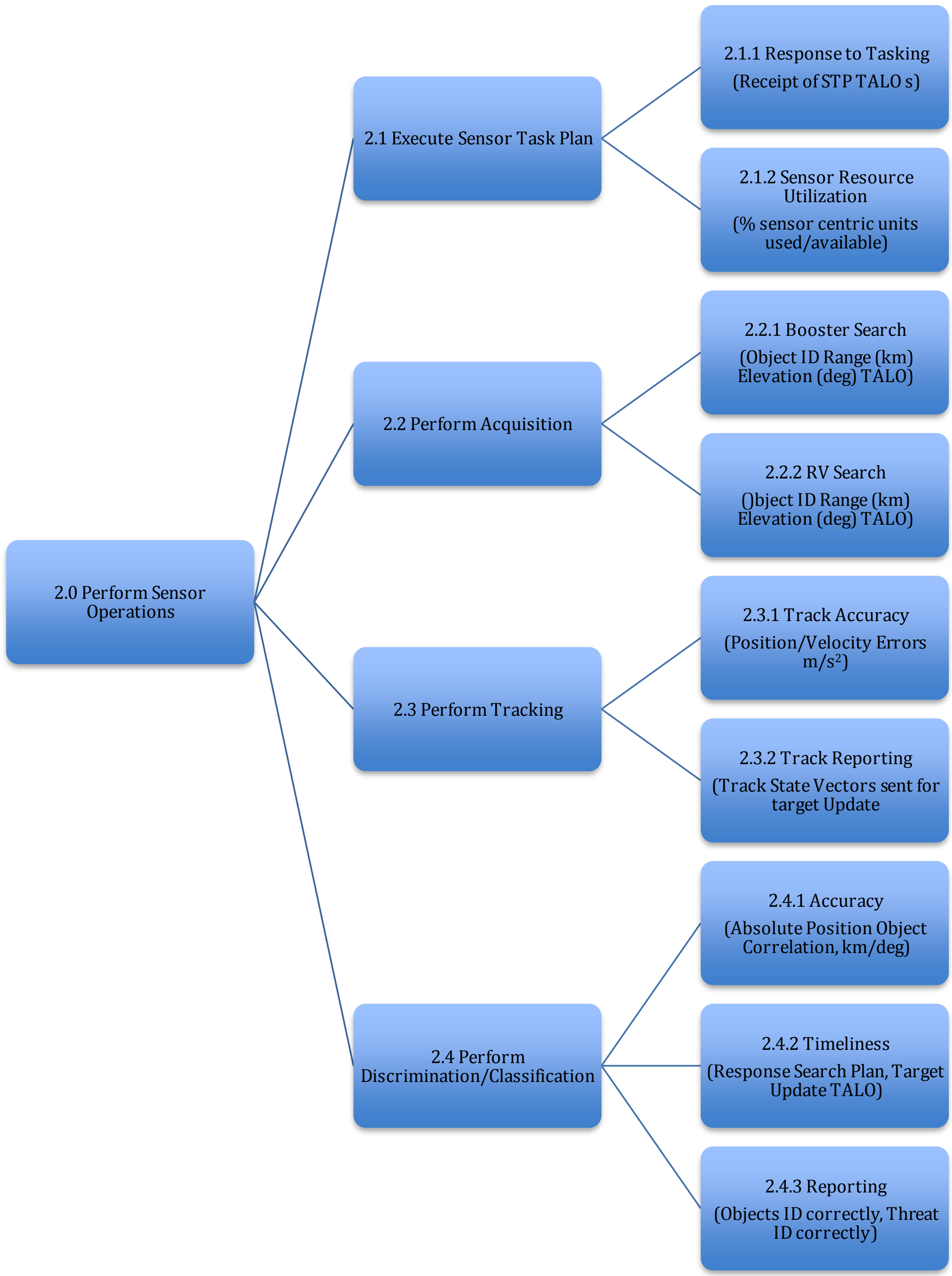


Fig 4.5 Function 2.0 Perform Sensor Operations Decomposition

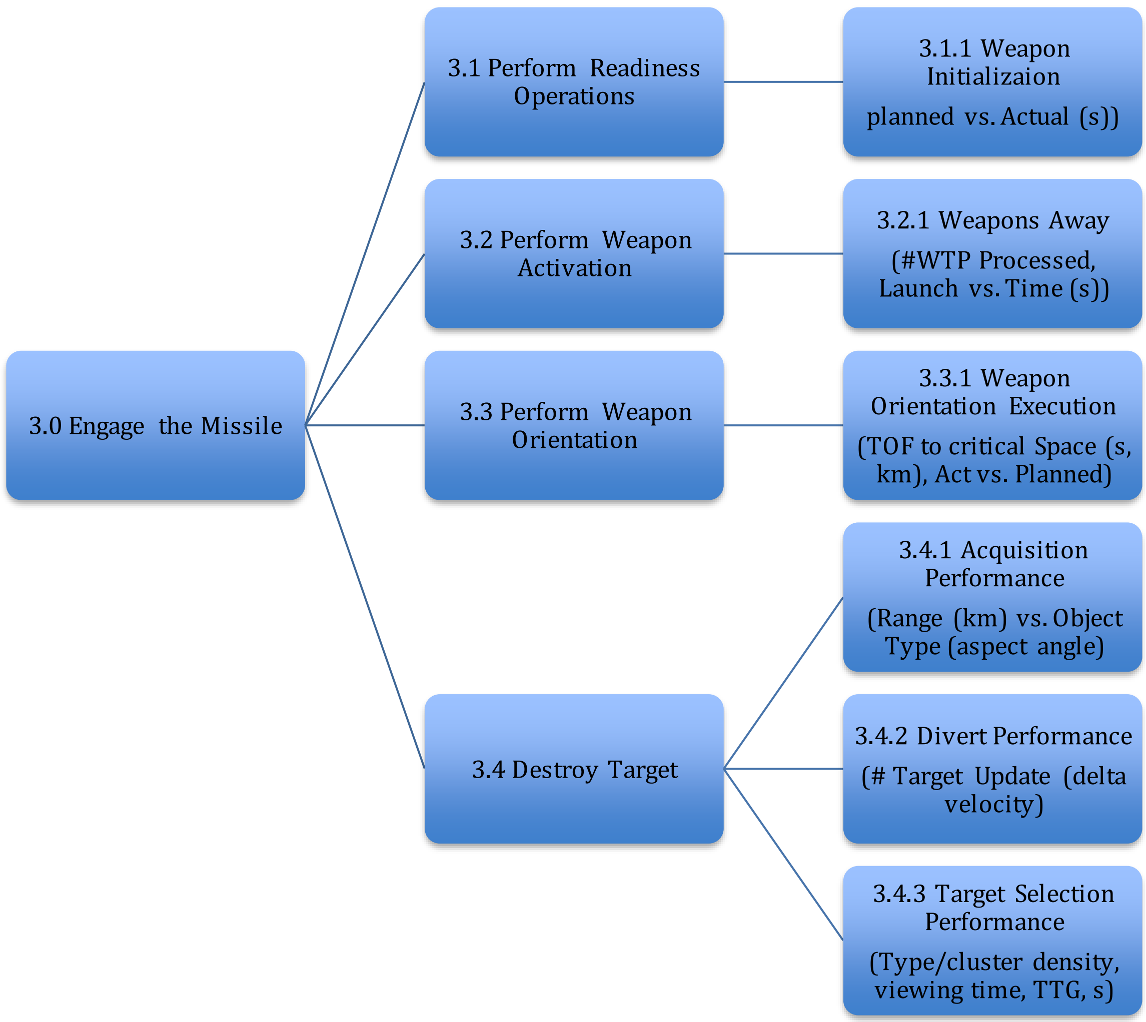


Fig. 4.6 Function 3.0 Engage the Threat Decomposition

presuming a solution. For example, the threat engagement function 3.2.1 Weapons Away, shown on Figure 4.6, is devolved to a third level sub-element. This function defines the weapon response to the receipt of a task plan and the action taken to physically move in response to this tasking. In an attempt to decompose this function further, a solution would have to be assumed to determine what type of weapon movement is required. The movement action is different for a directed energy weapon versus a missile interceptor versus a satellite projectile versus an unknown new technology weapon type. Therefore, this functional element decomposition is complete.

As illustrated in this case study, the mission function decomposition of the functions 3.0 Control the Battle, 5.0 Perform Sensor Operations and 6.0 Engage the Missile results in a set of basic functional elements. These basic functional elements fully define the actions required to meet the objectives set forth in the Mission Need Statement. From this, a full set of elemental requirements can be derived that address the basic functions of the Mission Need Statement. This set of requirement elements, when aggregated, will create and define the system requirements and is the basis for the system design. This set of requirements plugs into the systems engineering process and influences it throughout the development and fielding of the system. It is a touchstone that redirects the systems engineering process back to the basic requirements and thus avoids misdirection while providing decision makers with better data as they develop the weapon system. By providing this better set of requirements to the systems engineering process, the Mission Architecture Step with the Mission Analysis and Mission Analysis Plan will help avoid cost and schedule overruns. As such, it creates a much improved implementation of the systems engineering process which results in an improved acquisition process.

Chapter 5

Verification of the Mission Architecture Step by Modeling and Peer Review

This chapter describes a model developed to illustrate the potential effects of the Mission Architecture Step (MAS) on the expected duration of the systems engineering (SE) process cycle time. Also included are the results of a peer review conducted by the author. The peer review was designed to collect feedback and opinion about what level of contribution the Mission Architecture Step might have in the systems engineering and acquisition processes. The results of this model and peer review as presented here document the overall usefulness and added value the Mission Architecture Step could provide. Earlier chapters of this dissertation describe cost and schedule overruns in the majority of weapons systems acquisitions and asserts that adding a Mission Architecture Step early in the systems engineering process could remedy many of these typical problems. The research presented here through a model and peer review support this assertion.

5.1 Mission Architecture Step Model

The author developed process flow models of the systems engineering process as it is applied to the acquisition process. The model is based on the major steps taken through the system life-cycle engineering V process for both the unimproved process and with the implementation of the Mission Architecture Step. The model is depicted in Figure 5.1

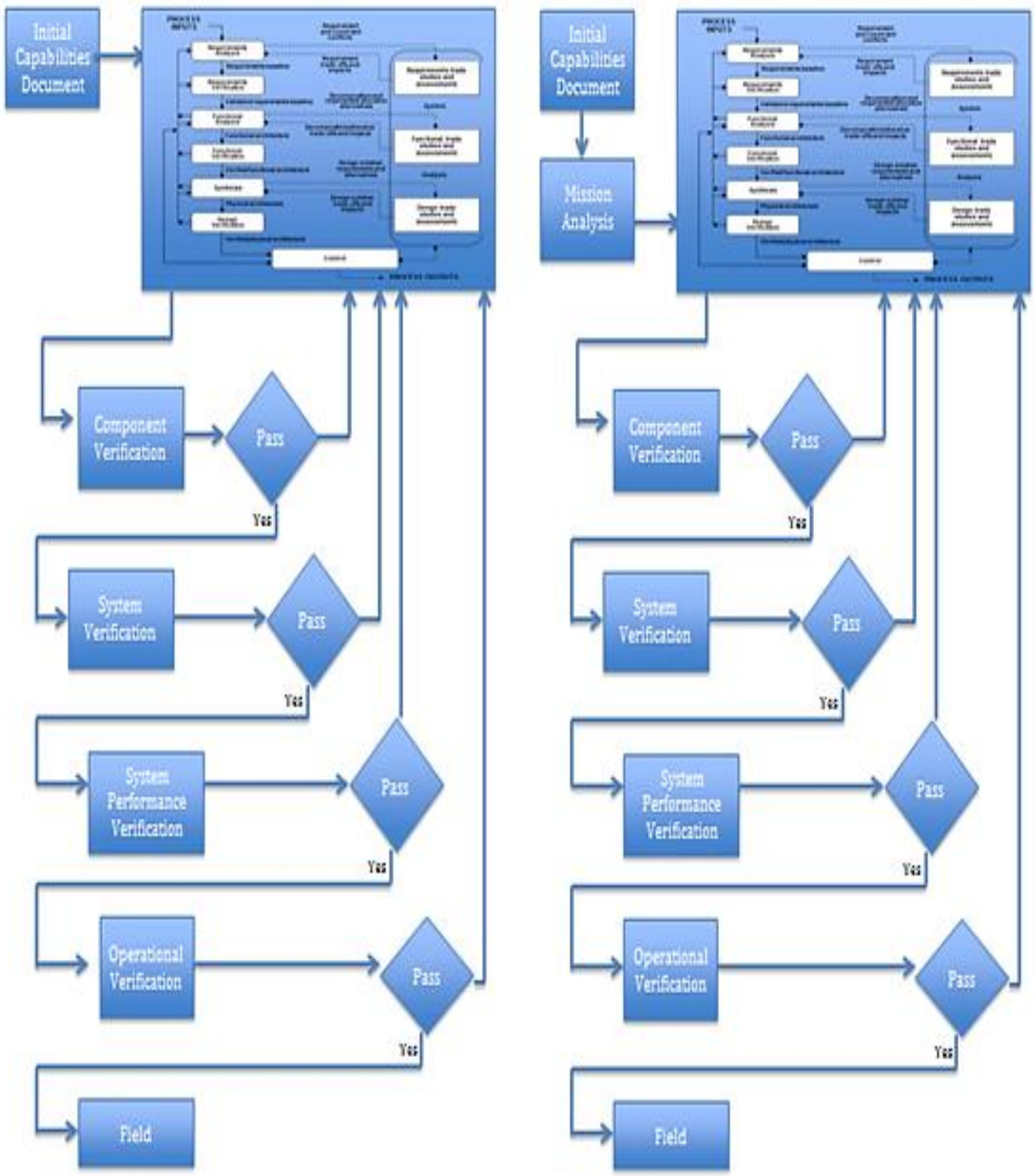


Fig 5.1 Process Flow Model for Engineering Acquisition Process with and without Mission Architecture Step

5.1.1 Model Construct

As described in Chapters 3 and 4, the MAS results in a complete set of basic functional elements defined by the mission. These functional elements in turn are the foundation for basic requirements elements that comprise a complete set of mission-based requirements that are used as an input to the systems engineering process. The robust requirements set will positively affect steps in the systems engineering process that define, verify, document, review, and test requirements. These positive effects derive from shorter process step durations and less time consumed in failure reviews and rework. For those steps that are affected by MAS implementation, the author defines a revised expected duration with probability distribution, and the probability of successfully passing the step. This enables a comparison between baseline scenarios and scenarios in which the MAS is implemented. For those steps not directly affected by a more robust requirements input (e.g. product testing cycle time, production startup time, manufacturing quality, product qualification time), the model assumes no changes in duration and distribution. In constructing this model, the author relied on data reflecting typical industry standards, broadly accepted assumptions regarding systems engineering cycle times, and personal experience as a leader in several major weapon systems acquisition efforts. Using this data, the model determines how each step in the systems engineering process should be affected by the MAS implementation.

The model utilized time as the main dependent variable and defined each process step with an expected duration (measured in months) and a probability distribution of the expected duration. A decision point followed each of the verification milestones shown in Fig 5.1. The model assumes that should a verification milestone fail, the failed process step repeats, but with an expected duration equal to the 90 percent of its previous expected value. The net 10 percent reduction accounts for additional time to conduct a failure review and much shorter cycle time to conduct verification on the same requirement or component because of learning and familiarity. Should the process fail a second time, the expected duration is reduced another 10 percent. Each rework decision feeds back to the systems engineering process, due to fact that product failures result in extensive failure review effort and design correction. In addition to accounting for lessons learned, the model accounts for whether an activity passed or failed before recycling back to the systems engineering process. Those activities that passed do not receive a full scrub, whereas the activity that triggered recycling will receive a full scrub. This is accounted for in the task duration. Table 5.1 summarizes modeling parameters assigned to each step for both the baseline and MAS-implementation scenarios.

No MAS Implementation				**MAS Implementation**			
Step	E(Duration)	Probability Distribution	Pass Rate	Step	E(Duration)	Probability Distribution	Pass Rate
N/A				MAS Implementation	6 mos	Uniform	1.0
SE Process	24 mos	Uniform	.50	SE Process	18 mos	Uniform	.80
Component Verification	12 mos	Uniform	.50	Component Verification	7 mos	Uniform	.90
Subsystem Verification	12 mos	Uniform	.70	Subsystem Verification	7 mos	Uniform	.90
System Verification	12 mos	Uniform	.70	System Verification	8 mos	Uniform	.90

Table 5.1 Model Parameters

5.1.2 Data Analysis

The author employed Monte Carlo simulation techniques to compare systems engineering process cycle time in both the baseline and MAS-implemented scenarios. The model was set up to include the Mission Analysis Plan implemented at the beginning of the systems engineering process for the improved Mission Architecture Step scenario. The results are tested for expected cycle time improvement and statistical significance of the outputs. Each of the process models completed 99,999 Monte Carlo runs. Minitab ® was used to perform statistical analysis of the data.

The data displayed in Figures 5.2 and 5.3 show the probability density function for the engineering acquisition process baseline and with the inclusion of the MAS. Both sets of data displayed similarly shaped distribution frequency. The histograms show the data are not normal, exhibiting positive skew. With positive skew, the mean is greater than the median and indicates a tendency toward more undesirable outcomes (longer cycle time) due to a heavier weighting of undesirable outcomes. The mean and median durations are distinctly less for the MAS-implemented scenario. The MAS-implemented plot exhibits less positive skew than the baseline (non-MAS) plot. The non-MAS plot exhibits a flatter curve (platykurtic) and longer, fatter tails. This indicates a higher probability of extreme outcomes that could cause program cancellations. The MAS curve is more peaked (leptokurtic) and has shorter, thinner tails.

A lower probability of extremely undesirable outcomes could be as important to a program's survival as a shorter expected cycle time. History has shown that customers sometimes accept a longer, costlier development cycle if the expected cost is relatively stable, but have very little tolerance for programs that suddenly exhibit huge overruns and delays. The benefits of MAS are therefore two-fold: lower cost/cycle time and more predictable outcomes.

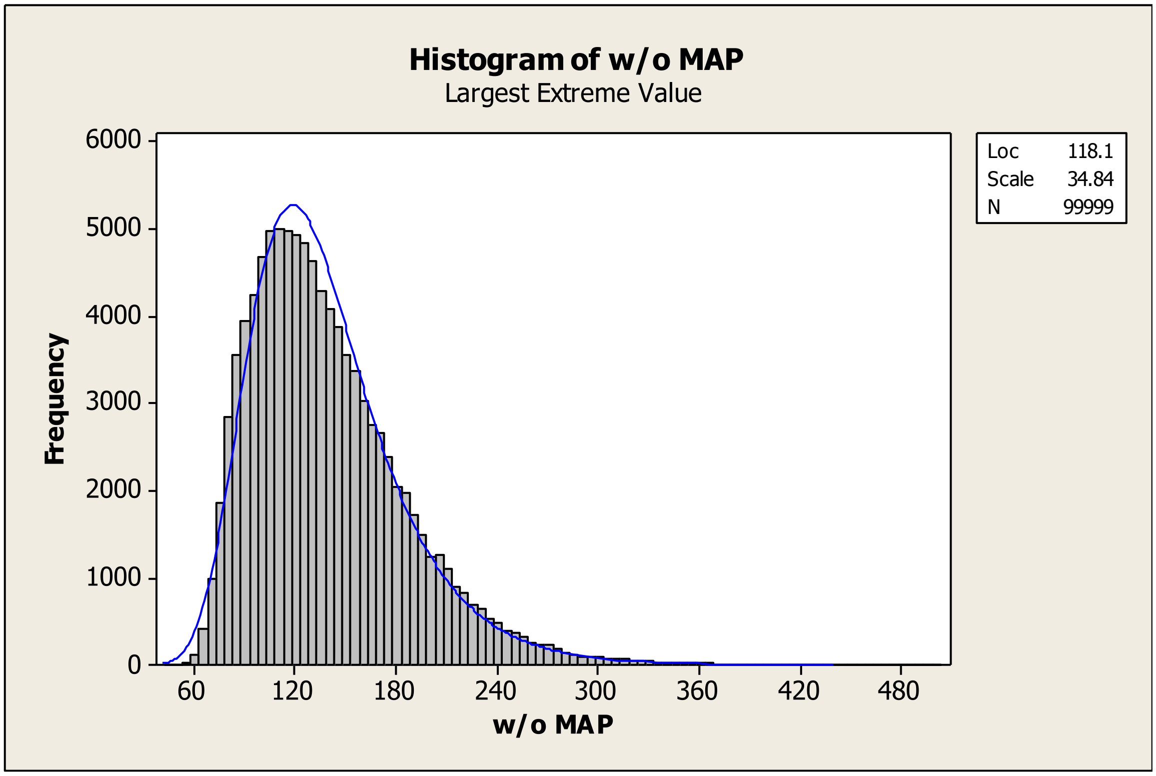
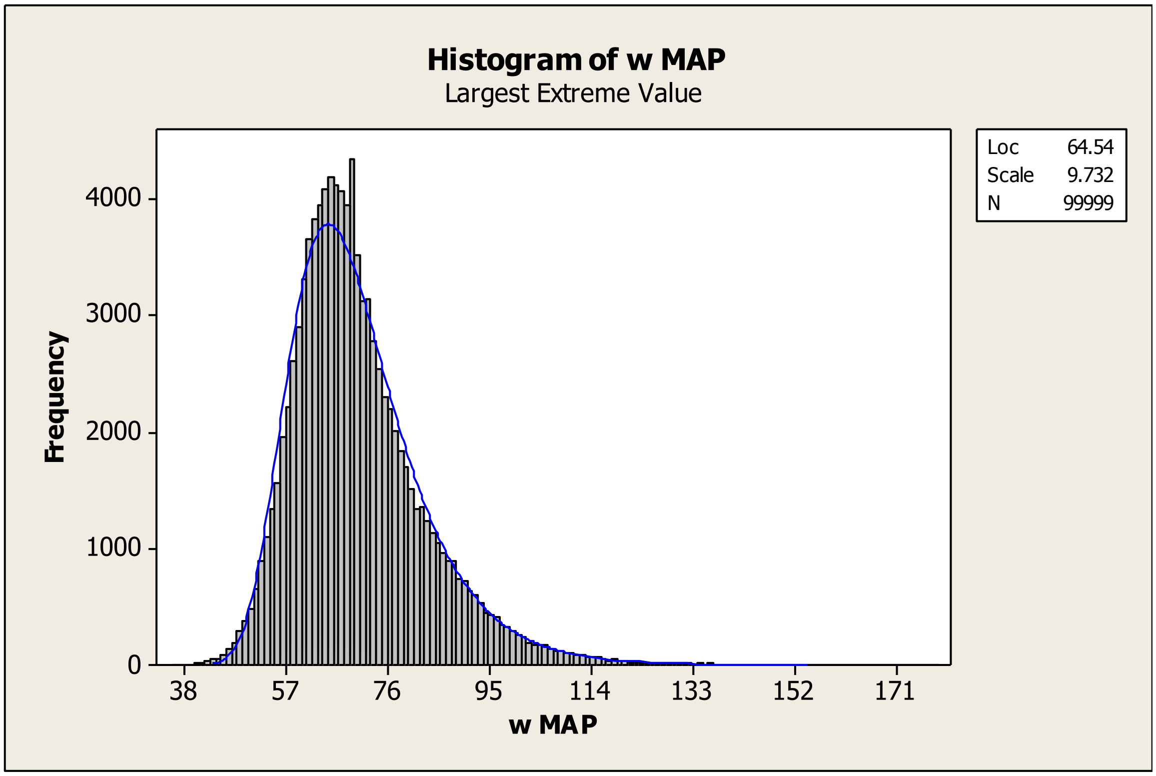


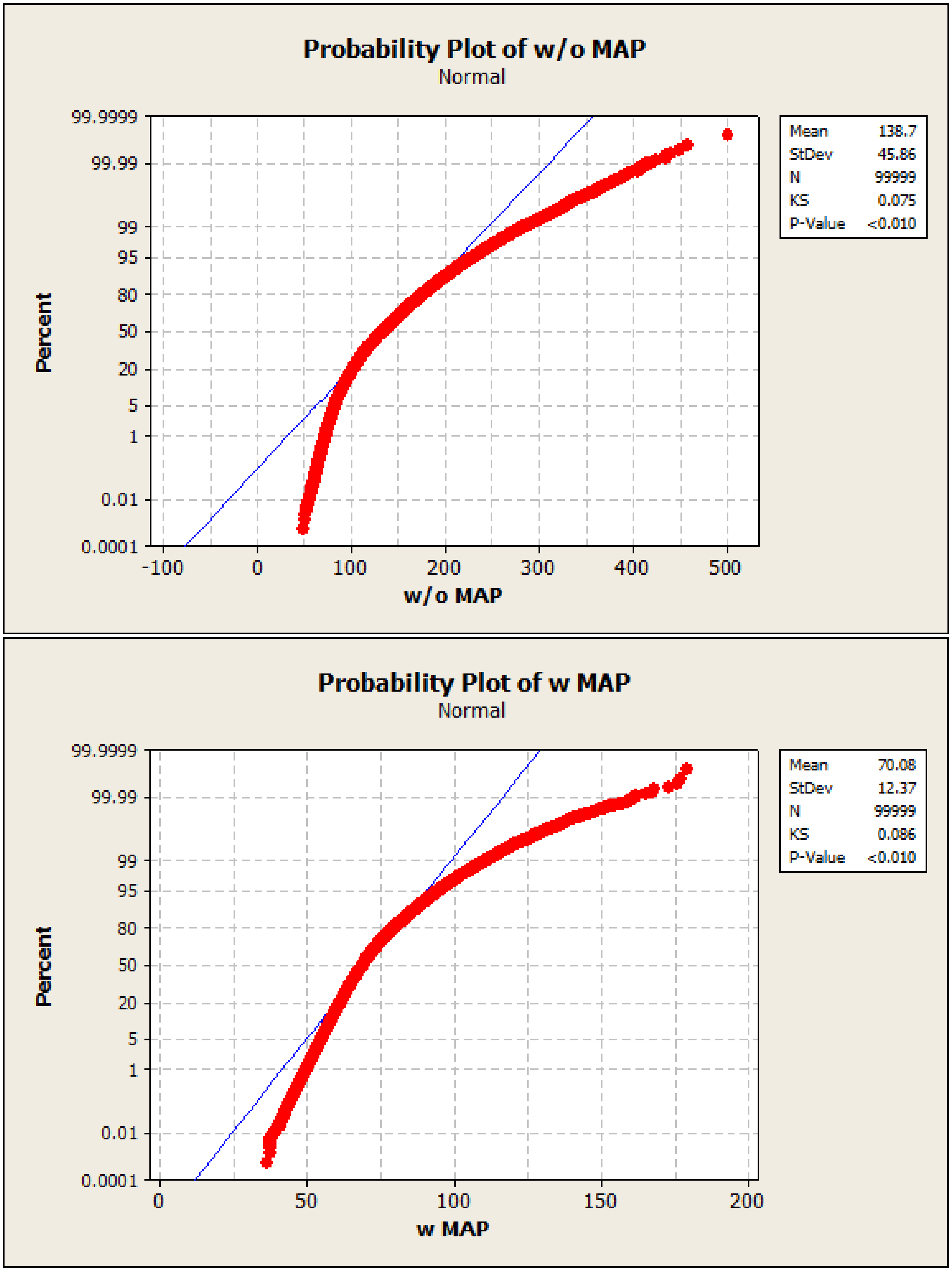
Figure 5.2. Probability Density Function for Engineering Acquisition Model

The author used Minitab® to determine the best distribution fit and did not identify one with a significant p-value. However, as shown in Figures 5.2 and 5.3, the Largest Extreme Value Distribution provides good visual correlation to both distributions, as well as better hypothesis test metrics than the other distributions. Also, the Largest Extreme Value Distribution includes location and scale parameters that exhibit some relationship to the distributions themselves.



Figures 5.3 Probability Density Function for Engineering Acquisition Model with the Mission Architecture Step

Figure 5.4 displays the empirical probability distributions plotted against a normal curve. Each of the model data displayed similar distributions. We can observe at least two significant details from Figures 5.4. First, the distributions are not strongly normal or Gaussian. This visual evidence complements the obvious asymmetry in the distributions, as depicted in the histograms of Figures 5.2 and 5.3. Second, for any given task duration, the new process with the Mission Architecture Step is substantially more likely to have been successfully executed within the specified duration. For example, consider 150 months, which is one of the grid lines in each plot. The new process appears to have greater than 99.9% likelihood of successful completion, whereas the legacy process appears to have about 66.5% likelihood of successful completion.



Figures 5.4 Distribution Fit against Normal Curve

In light of the non-Gaussian distribution of the datasets, Figure 5.5 depicts the empirical data in concert with a best-fit Largest Extreme Value cumulative distribution for each dataset. As is clearly seen, the Largest Extreme Value distribution provides significantly better correlation to the data than does a Normal distribution. This visual assessment is consistent with quantitative hypothesis test metrics such as Anderson-Darling, and Cramer-von Mises. When using Minitab® to quantify these metrics for the empirical data, they averaged between 15-25 times better for the Largest Extreme Value distribution than for the Normal distribution.

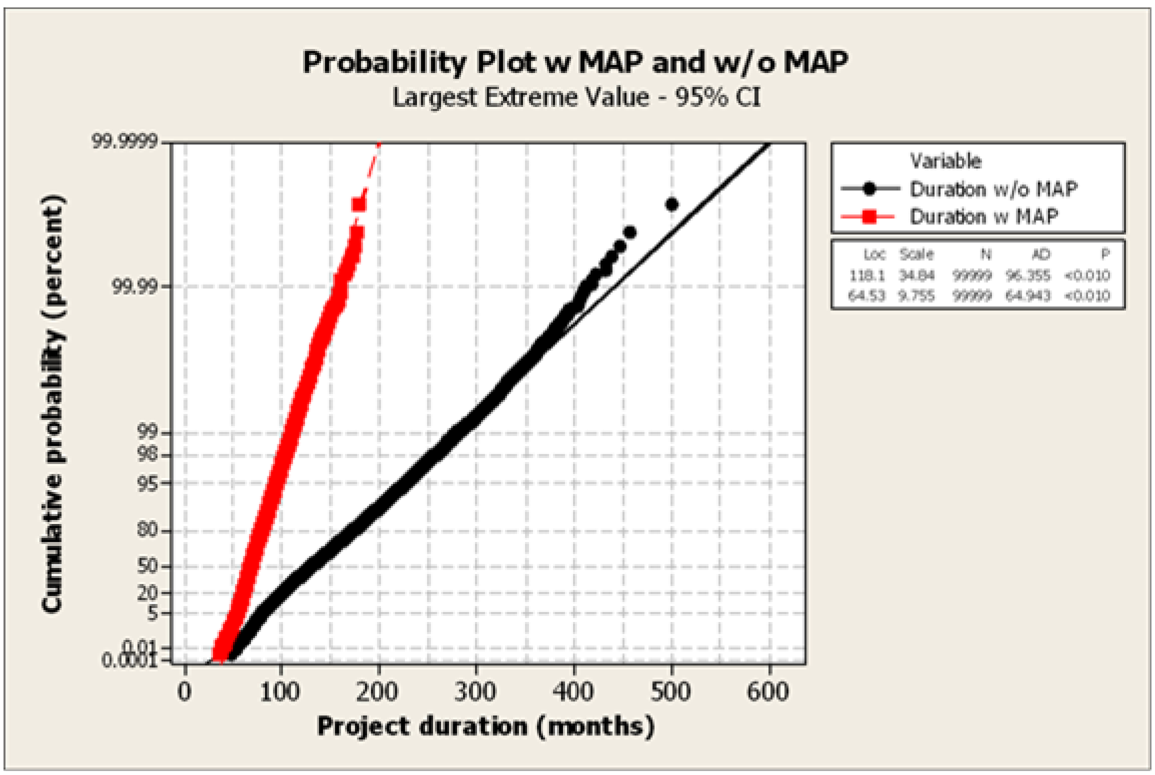


Figure 5.5 Probability Plot, including each Empirical Dataset (with Map and without MAP), and its corresponding Best-fit Largest Extreme Value Distribution

Since the datasets do not conclusively follow a commonly used distribution in which to perform common test such as t-test and ANOVA, non-parametric methods were used to perform a Mann-Whitney test against the median of the two data sets. The Mann-Whitney Test was conducted at a 95 percent confidence interval. The following results in Tables 5.2 and 5.3 prove to be significant showing the medians of the two processes are not equal:

	N	Median
With MAP	99999	67.97
w/o MAP	99999	130.25
Point estimate for ETA1-ETA2 is -60.94 **95.0 Percent CI for ETA1-ETA2 is (-61.23,-60.66)** **W = 5296997743.5** **Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0000**		

Table 5.2 Mann-Whitney Test and Confidence Interval with and without Mission Architecture Step

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
w/o MAP	99999	0	138.67	0.145	45.86	47.41	104.89	130.25	163.68
w MAP	99999	0	70.077	0.0391	12.367	35.610	61.782	67.966	76.037

Table 5.3 Descriptive Statistics with and without Mission Architecture Step

Due to the distribution of the datasets, a hypothesis test on the mean and variance cannot be readily performed, although looking at the values on simply an order of magnitude (and with a large sample size n=99,999), it can be inferred that the mean and variance with MAP is lower. The median of the existing engineering acquisition process is 130.25 months and the median of the improved engineering acquisition process with addition of the Mission Analysis effort is significantly improved by adjusting to 67.966 months. In addition, the 25th and 75th percentile of the boxplot does not show any overlap in Fig 5.6.

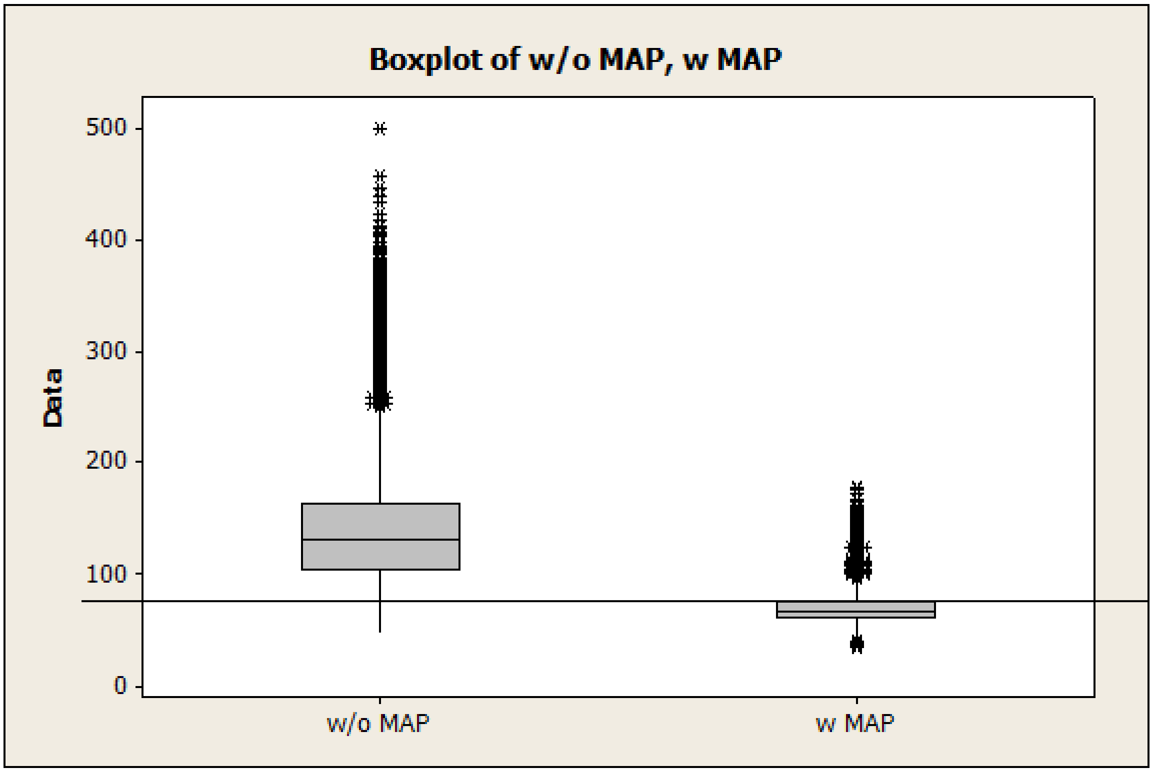


Fig 4.23 Boxplot of Data Population for Engineering Acquisition Process with and without Mission Architecture Step

Finally, relationship of the variability in project duration versus the number of Monte Carlo runs was calculated and is shown in Figure 5.7. The data show the variance flattens out at approximately the 1000 run mark. By running the MAS process improvement model for 99,999 Monte Carlo runs, the variance test ensures enough repeated random sampling was performed to obtain viable numerical results.

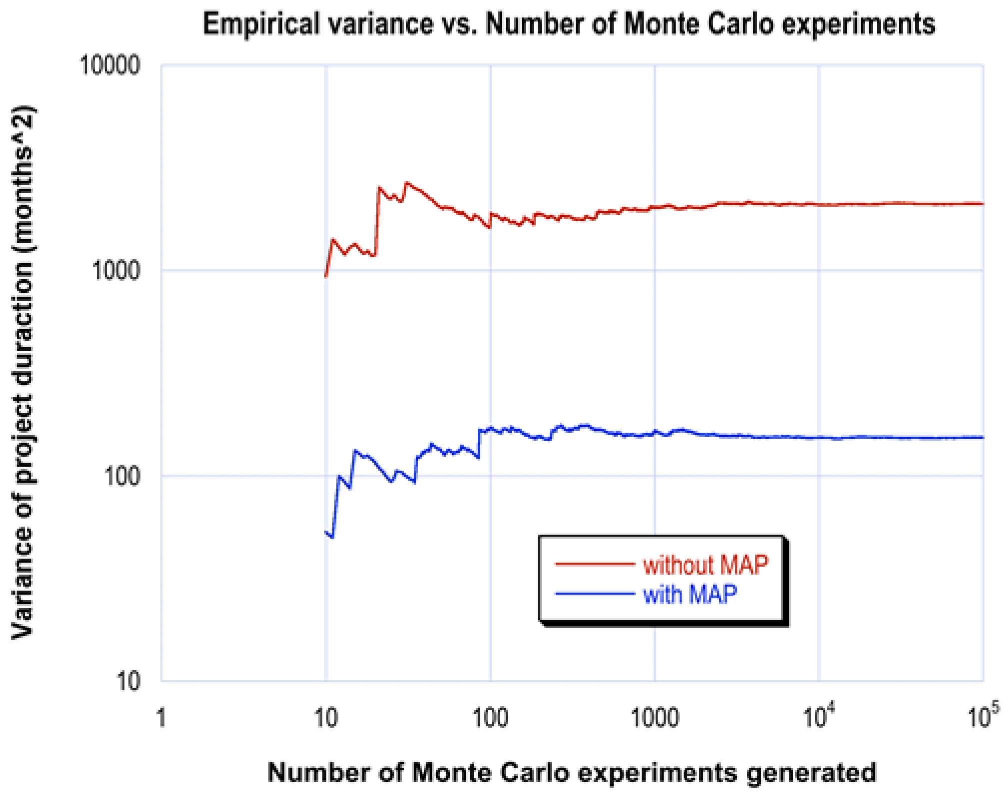


Figure 5.7 Relationship of the Variability in Project Duration versus the Number of Monte Carlo Runs

5.1.3 Return on Investment

It is well understood in the Engineering community that implementing good Systems Engineering will reduce risk early and improve program success by eliminating problems in integration and test. What is not understood is a quantification of the optimal systems engineering program. Each systems engineer practitioner is guided by heuristics learned during their career. And these heuristics will differ for system engineer practitioner. "Heuristic wisdom is that an increase in the quantity and quality of systems engineering can reduce project schedule while increasing product quality" [65].

Several studies have been accomplished in an effort to quantify the return on investment of systems engineering in a project. The data used in these studies were scarce due to the wide variance in the practitioner's perception and application of systems engineering. Dr. Eric Honour has devoted his career to quantifying the optimal amount of systems engineering. He researched six prior statistical studies in addition to his own work and analyzed the theoretical relationships among project cost and schedule, technical value, technical size, technical complexity, and technical quality. Honour concluded that the systems engineering effort is correlated to the size and complexity of the project. The return on investment for optimal systems engineering effort is approximately 15-20 percent of the total project effort [66]. He further concluded that most of the projects, which spent less than this optimal amount, experienced schedule delays and cost overruns in excess of 40 percent [66].

Utilizing Honours work on quantifying the optimal amount of systems engineering effort can be applied to determining what is required for the Mission Analysis Plan effort. The amount of effort required for the best return on investment will be directly correlated to the size and complexity of the project. Since the MAP is a newly proposed effort, project data does not exist to analyze the optimal investment for implementing the MAP in the acquisition process for a project. However, there is a finite end to the MAP implementation and that end occurs when each sub-function element cannot be decomposed further. As a result, the MAP effort will always be contained within the mission scope of the capability requirement being addressed.

5.1.3 Model Results Summary

The addition of a Mission Architecture Step at the beginning of the systems engineering process is shown to add much needed structure to the engineering acquisition process. The mission functional decomposition increases clarification of user requirements and understanding, in addition to promoting the generation of more detailed information to increase efficiency in the execution of the systems engineering process. Modeling the engineering processes provided evidence that the improved process provided a significant decrease in the median time for a program acquisition.

5.2 Peer Review

The verification method chosen for this research was a peer review in the form of a survey about a Missile Defense case study. The survey collected data to validate the theories and solutions asserted in this dissertation. The survey utilized the case study on Missile Defense described in Chapter 4. The author defined the Mission Analysis Plan, and showed how it forms the foundation for assessment and evaluation tool suite linkage, as well as the requirements process traceability. Using the case study and survey research together provided qualitative information and complimented it with quantitative data [68]. Table 5.4 describes the relative strengths of the case study alone and the survey alone. The combination of the two shows the compliment for weaknesses and strengths.

	Case Study	Survey
Controllability	Low	Medium
Deductability	Low	Medium
Repeatability	Low	Medium
Generalisability	Low	High
Discoverability (explorability)	High	Medium
Representability (potential model complexity)	High	Medium

Table 5.4 Relative Strengths of Case Study and Survey Methods [68]

The survey design was longitudinal as the information was collected over a period of six months. The survey population was not enumerated, therefore the sample had to be determined based on specific criteria which eliminated the ability to conduct a random sampling. In order to get accurate data for this theoretical study, the sampling had to be judgmental. The criteria for the sample population was selected based solely on twenty plus years of professional experience in the areas of systems engineering, program management or system analysis.

In all cases, the author contacted the subjects directly and conducted all interviews face-to-face, which is considered the most "reliable method for data collection [69]." There were some subjects who were conveniently available due to a professional conference forum. This allowed for expansion of the sample population to include persons not previously known by the author. Each subject contacted agreed to participate in the survey. The population experience proportion is displayed in Figure 5.8. A population bias exists in that there were a smaller sample of analyst than systems engineers and program managers. The bias is not easily calculated or considered an undercoverage issue because many of the systems engineers were also system analysts but chose to be portrayed in the systems engineer category. In addition, a few of the program managers are also engineers, however only one of them was a systems engineer.

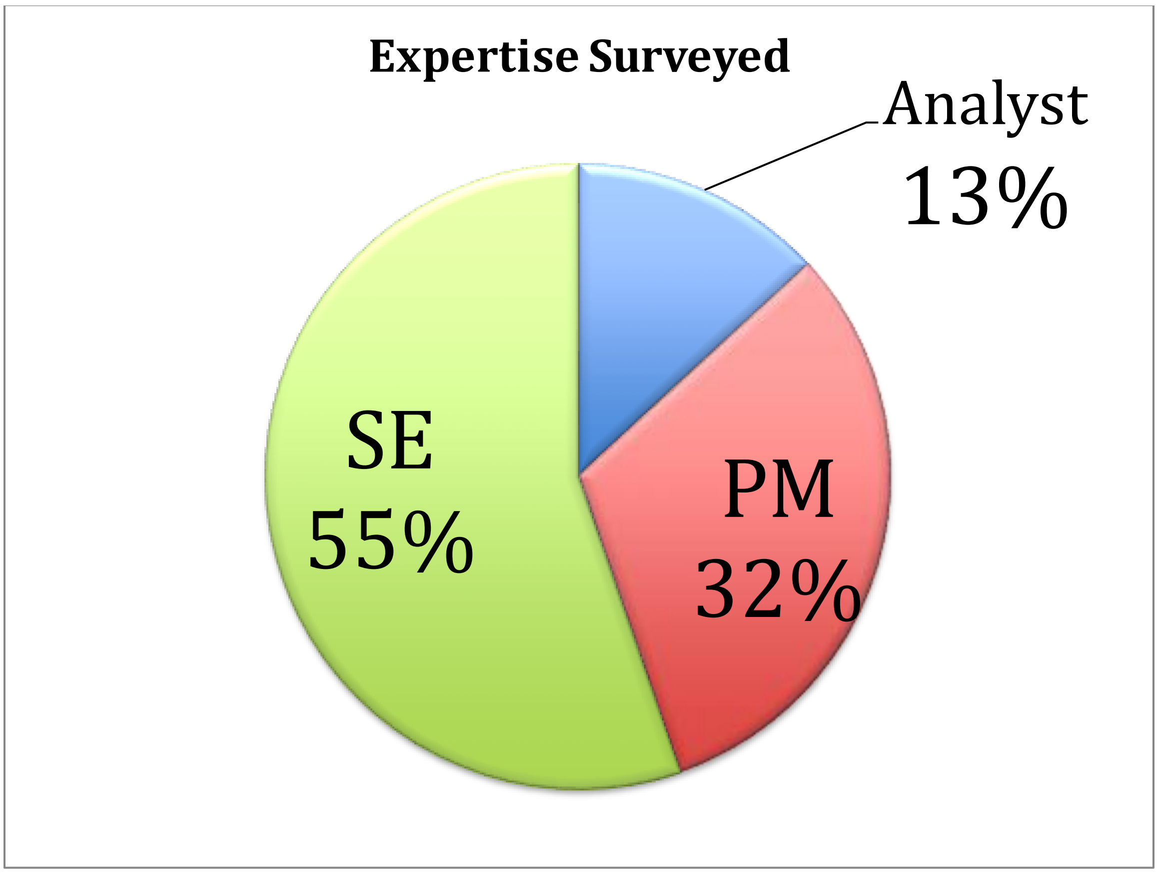


Fig. 5.8 Survey Expertise

Figure 5.9 displays the survey participants' length of experience in the Department of Defense, Defense Industry, NASA and other commercial industry. The number of experts surveyed was thirty-eight with their average experience at 28.63 years.

Survey participants consisted of active duty and retired military (Army, Navy, Air Force), active and retired civil service employees, Chief Executive Officers, Presidents and Vice Presidents of companies, directors and other key organizational leaders. Each participant, because of their experience, is in a position of authority in his or her current position of employment. Participants included:

- Four General Officers/Admirals (2 Army, 1 Navy, and 1 Air Force)
- Six PhD's (4 Engineering, 2 Physicists)
- Nine Company Officers (5 Presidents, 2 CEOs, 2 Vice Presidents)
- Five Senior Executives in the Defense Department
- Fourteen Directors or Division/Team Leads

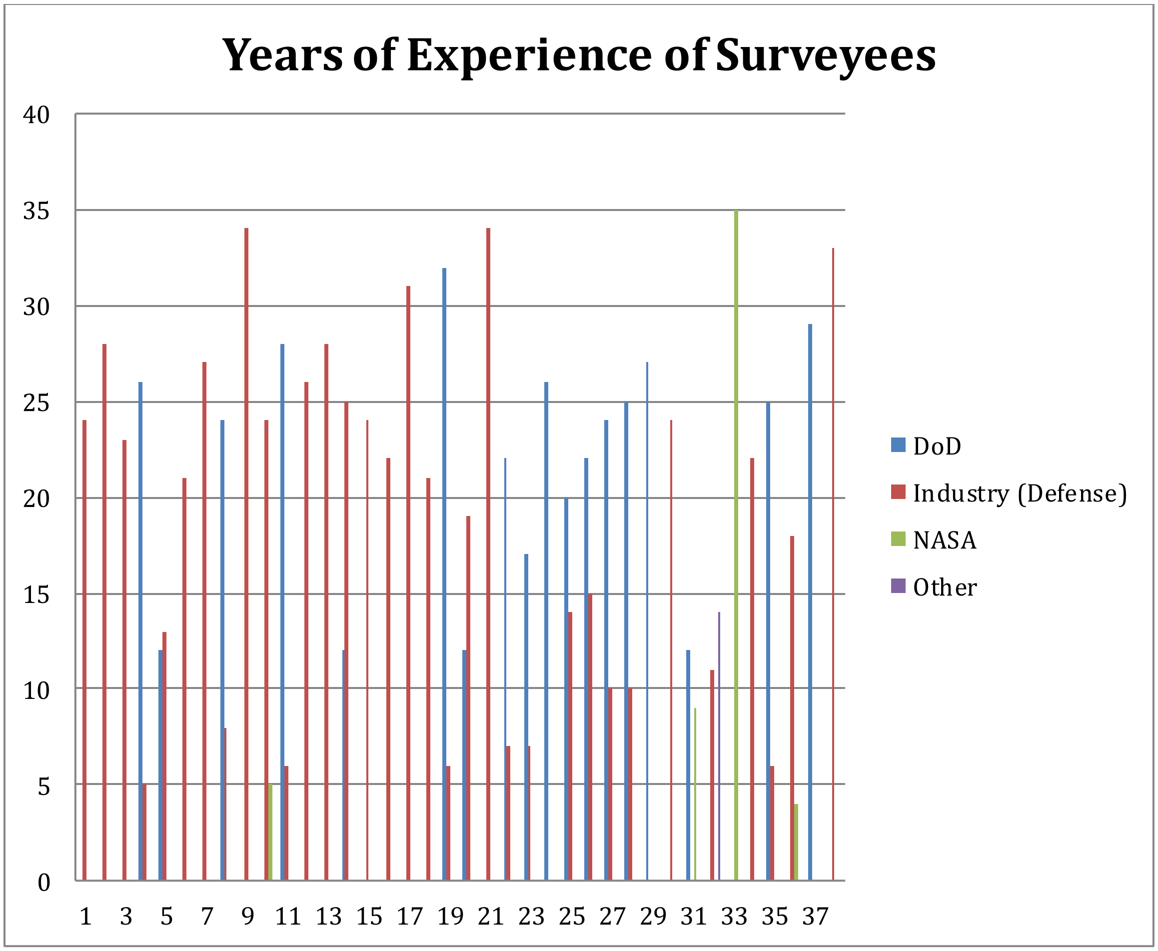


Fig 5.9 Survey Experience Base

The research focus is in the Department of Defense so the sample needed to be drawn primarily from that population. The purpose of expanding the population sample to include NASA and non-DoD personnel was to develop the potential opportunity of opening the research to other commercial applications for future work.

The majority of the survey participants reside in Huntsville, Alabama. Huntsville hosts a large contingent of the Department of Defense Missile and Space sector in addition to the Army Material Command. Huntsville is also home to the NASA Marshall Space Flight Center. More than ninety percent of the subjects have spent their careers in multiple locations inside and outside of the United States of America. Figure 5.10 displays the survey participants' current employment locations. The size of the star indicates the population sample size from each employment location.

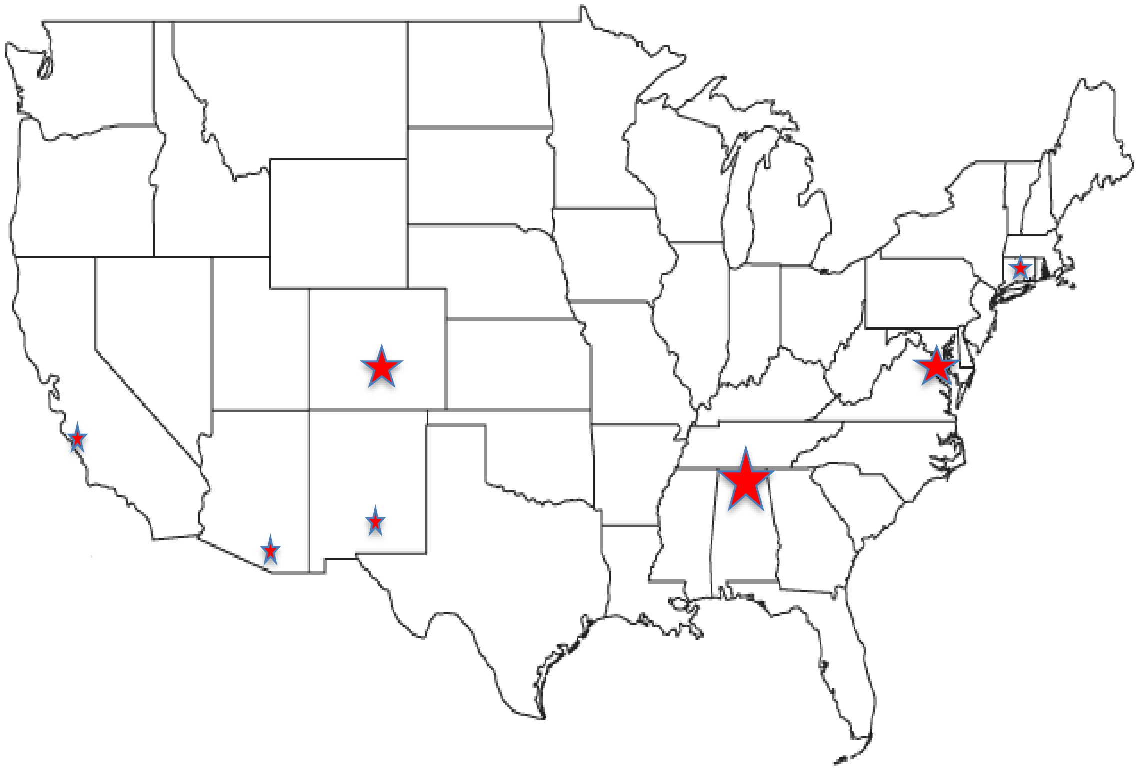


Fig. 5.10 Survey Participant Locations

>15 participants   5-10 participants   1-2 participants

The Missile Defense case study was presented to each survey participant and is provided in Appendi

- Strongly Agree
- Agree
- Undecided
- Disagree
- Strongly Disagree

These questions were carefully selected to avoid any bias associated with wording or flow. There was no concern of respondent bias or measurement error due to the experience criteria for the sample selection. The subjects answered based on their professional experience and opinion. The author avoided presenting a desirable image causing the survey participants to respond with false answers [73]. The following are the survey questions asked:

1. Do you see this new Mission Architecture Step and its associated products drive development cost down?
2. Do you see this new Mission Architecture Step and its associated products help maintain development schedule?
3. Will this new Mission Architecture Step and its associated products help provide confidence in decisions?

Responses to each of the questions were overwhelmingly positive. The next three figures (Fig 5.11, 5.12, 5.13) show the survey results.

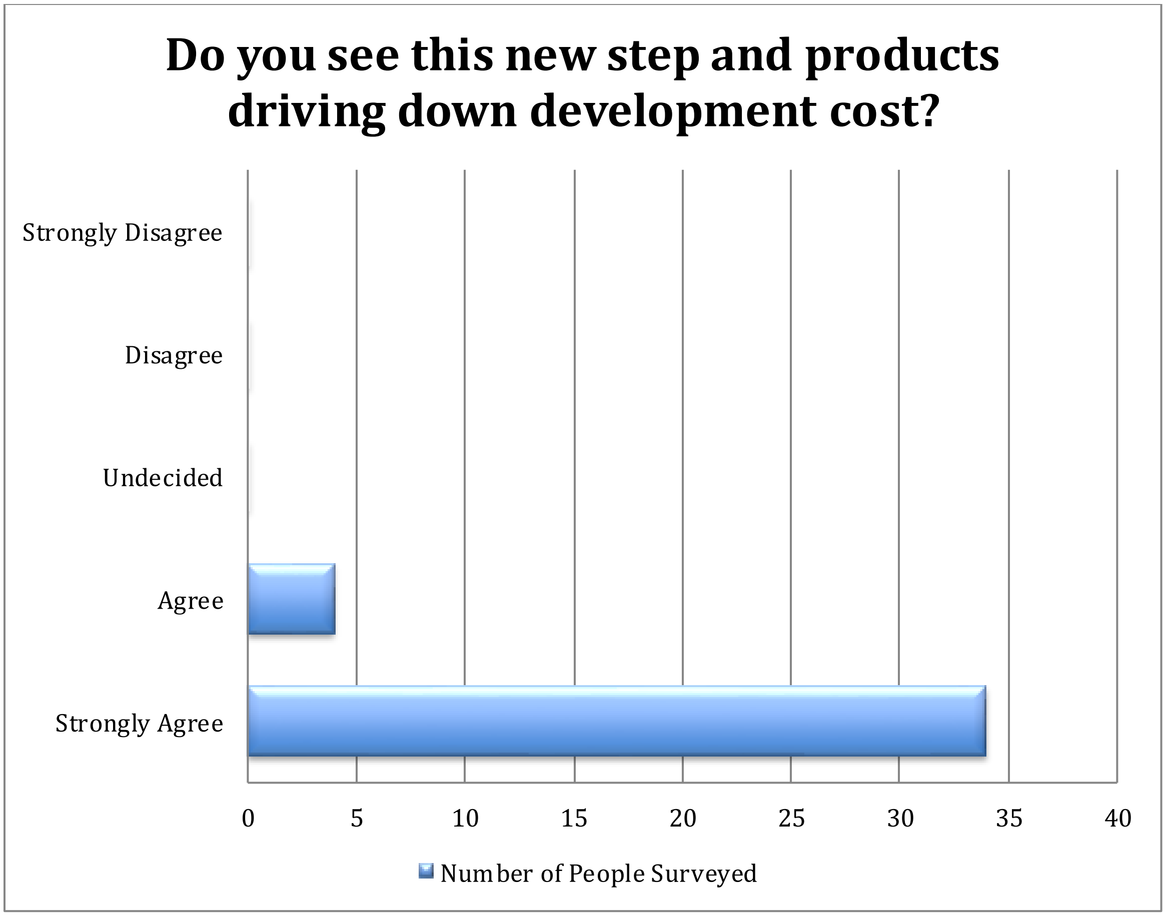


Fig 5.11 Survey Question 1 Results

Most survey participants provided comments in addition to the basic Likert scale response. The following are the author's summarized version of comments that were made in response to question number one:

- When the metrics are understood, component level requirements and interfaces are more easily understood.
- This engineering method provides early information that can help determine the biggest bang for the buck.
- This step provides visibility, which helps make right decisions that do not waste money.

- This organizes efforts to eliminate wasting time, which is wasting money.

- This structured baseline decreases program risk, which helps eliminate future rework. Rework is added cost and added schedule.

- This approach identifies problems sooner which allows for less expensive fixes. It can fix problems without backtracking. Earlier identification of problems means less changes overall. This saves in both the cost and schedule area.

- The upfront work provides the information necessary to define the level of fidelity of assessment tools, capability test venues and test designs early, which can save a whole lot of money on creating a test infrastructure by designing to known need versus overdesigning.

- Not only will it drive development cost down but also potentially help save development cost. Will help identify architecture subsystems limitations, interactions, integration issues sooner in the life-cycle.

    - Will be able to do conceptual design 10 times faster
    - Can converge to system design 40 percent cheaper
    - System can be more economical to maintain

- Unknowns tend to be cross-functionality and across disciplines. This process and product helps avoid errors.

- Rework is the most expensive work there is. Deviations cost money.

- This process and products will help understand how something is supposed to work – its intent. It also provides incredible insight so areas that may not work right can be found early.

- This will really help in models and simulation accreditation. We need this process in place now.

Both question one and question two responses had some survey participants answer agree with the question versus strongly agree. One of the primary reasons for this divergence is that several of the participants identified outside influences impacting both cost and schedule of a program. One such influence is an unexpected budget cut due to department budget issues. Budget cuts are real and can be very disruptive for a program.

Understanding the impacts of a cut and being able to clearly identify and articulate the impacts can help manage the path forward.

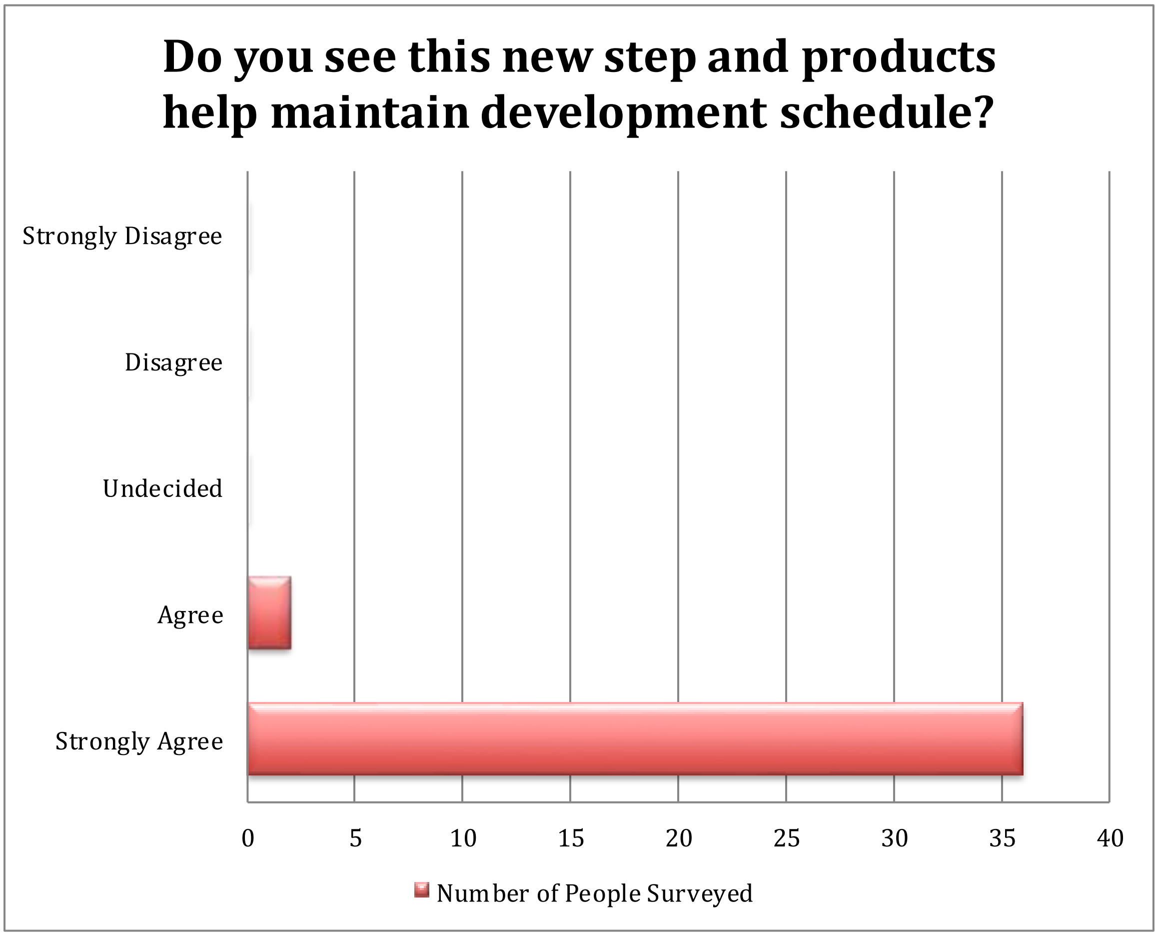


Fig. 5.12 Survey Question 2 Results

Many of the additional comments provided and summarized for the question number one also applied to question number two. Below are additional comments for question number two:

- This provides visibility, which makes it clearer where to put development dollars.
- The key to this process is it allows visibility where there are impacts.

- When hit with a budget reduction, this allows for identification of where the impact is taken. That is particularly important with scarce resources.
- This step provides the ability to see failure impacts.
- This will help managers keep constant pulse on things.
- This new process will help in assessing progress and monitoring progress along schedules.
- The additional visibility this structured process provides helps set milestones.
- This helps leadership with decisions.
- This definitely allows insight, less guessing. Adds fidelity to schedule and assesses progress.
- This step will provide greater awareness to decision makers and lower tier personnel.

All the survey participants were in strong agreement that this new Mission Architecture Step will help build confidence in the data used by decision makers. The following are summarized comments for this question:

- The key to having confidence is this baseline and tools built from it.
    - New system – management focus is on ground up for confidence in data results
    - Existing system – must build confidence based on output. Leadership needs to see tangible results early and often.
- With this data, it is believable due to structured foundation.
- This would help eliminate requirements creep.
- This helps acquisition and operational decision makers make smart trade decision. Poor information yields poor decisions.
- It provides a common set of metrics that provides a well thought out way of communicating up and down the organization.

Fig. 5.13 Survey Question 3 Results

- Common baseline for tools and metrics builds confidence in data and this confidence gains as the schedule continues along. Success breeds success.

- This definitely provides more confidence in decisions. The metrics goes down into a level of fidelity – like a clock – dependable. It is a more precise measuring device, so have confidence in data.

- It provides a more comprehensive knowledge sooner in program's life-cycle.

- This is a critical step. It provides the foundation for validation. This step will provide basis for accomplishing an effective system analysis with validated baseline. Therefore, management can believe the data when tools are validated.

- A person can have a lot of data, maybe 90 percent of the data, but is afraid to make decisions. Having this system and product, all data will be linked to the mission and therefore more easily understandable. Decision makers will have more confidence in it so they will be prepared to make decisions more quickly.

The survey results conclude the addition of this systematic Mission Architecture Step, Mission Analysis and Mission Analysis Plan provides increased confidence in data for decision makers. Each of the peer review participants unanimously agreed that this new step at the beginning of the system engineering process would aid in maintaining or reducing program development cost. They also fully agreed that the input allows a program development schedule to be more easily maintained and allows insight into potential deficiencies.

Chapter 6

Summary, Suggested Future Work and Conclusion

6.1 Summary

The majority of acquisition programs in U.S. Defense Department are delivering products to the warfighter much later than planned and with significant cost overruns. Many of these programs are unable to deliver the capability planned. And, many programs are terminated after spending too much money, taking too long, and then not being able to demonstrate a recovery plan that provides a reasonable return on investment. These problems frequently develop because decision makers very rarely have adequate data to make effective and timely decisions. Cost and time overruns have become high profile interest items for Congress, government, and watchdog groups [76]. Numerous Government Accountability Office reports and other department reviews found significant problems with systems engineering application in the department and in the program management offices.

The objective of this research was to investigate ways to address these perennial problems. As part of that, the author had to resolve the following:

1. Are there multiple system engineering processes? If so, are there conflicts between the processes?
2. Is the system engineering process broken or incomplete?
3. What can be done to improve the process?

The research found that the industrial standard for the systems engineering process is very thorough and definitive It is captured in detail and is specific regarding its implementation. Therefore, the problems currently being experienced are attributable to a gap between the program offices and the warfighter requirements in that the requirements are not being documented adequately, not understood, and not implemented consistently in the systems engineering process. Stated differently, the problems currently evident in defense acquisition are not necessarily due to deficiencies in systems engineering, but rather to the lack of implementation of a structured systems engineering process where requirements are being improperly and inadequately captured and translated at a critical point in the acquisition process.

In the current systems engineering standards the systems engineering control sub-process is the link throughout the systems engineering life cycle process. However, the control task begins after system requirements are generated and initiated. Discipline needs to be implemented earlier and inserted into the gap between the requirements being established and the hand-off of those requirements to the developing agent. As detailed as the current standard is, it is missing discipline at the architecture level that must be tracked throughout the process and traced back to the initial customer's objectives. Several issues emanate from this insufficient or incomplete requirements definition. Currently, the discipline begins at a point somewhere after the customer has handed over their requirements/needs and before the actual development execution. At this point, requirements are manipulated for the purpose of better understanding and implementation. However, this manipulation most often limits the ability to track the actual customer's intent and can sometimes cause engineers and program managers to lose sight of their real objectives. Implementing a control type function at the initial stages of requirements definition and then maintaining traceability to that function throughout the entire life cycle of the program development will alleviate this omission.

The author utilized twelve years of study in this area, which culminated in this academic exercise, to explore this problem. The resulting research identified a specific need for displaying data requirements through a Mission Architecture Step in the gap stage between the Initial Capabilities Document development and the initiation of the systems engineering process. The process improvement provided by the Mission Architecture Step (MAS) facilitates a systematic, structured engineering process and product at the warfighter mission level. In short, the MAS precedes and drives the systems engineering process, alleviating the many disconnects identified in the current approach.

Decomposing the mission functions to the lowest possible level and allocating a metric unit to each sub-function creates a structured approach to initiate the systems engineering process and develops the program tools needed for assessment. This mission functional decomposition is the Mission Analysis (MA) component of the Mission Architecture Step and is a system life-cycle product. The MA and its mission decomposition generates a Mission Analysis Plan (MAP), which serves as a data dictionary and a baseline for the necessary data products for assessment and evaluation purposes. The Mission Analysis Plan is continuously updated and traced to the system design and then the developed products. New and emerging requirements are better assessed and implemented though the Mission Analysis Plan. The data needed are defined by the mission. Assessments are consistent across all aspects of the acquisition system. The result is a better-informed systems engineering process as well as a clearer path through the acquisition process.

The Mission Architecture Step and it role in initiating the systems engineering process is applicable for single systems or in complex systems that are composed of system of systems. It is applicable for new start programs, existing acquisition programs, and programs that are comprised of assets with different levels of maturity. It has the potential to be applicable both within defense acquisition and in other, non-defense, arenas as well. As such, it represents a significant contribution to engineering and program acquisition.

The case study used in this research to illustrate and explain the application of the Mission Architecture Step is a missile defense system, which is a complex and continuously evolving system. The mission it involves is determined based on a known threat and may change or be expanded to defeat emerging threats. New weapon systems will be added or have new capabilities that change performance parameters. Using the Mission Architecture Step, a potential new asset can be compared directly to the criteria defined by the quantification allocated in the functional decomposition. This allows for greater visibility and optimum availability of information to decision makers.

The Mission Analysis Plan, a key product of the Mission Architecture Step, provides a structured, fundamental baseline for the engineering development of a system. It provides the detailed definition of what data are required and why. Test and assessment plans are tied directly to the Mission Analysis Plan. Modeling and simulation plans are also tied directly to the Mission Analysis Plan. By following the mission functional decomposition, these plans are completely integrated and reflect the system under test. Validation and verification of tools and data have a clear direct data structure for reference. Decision makers and program managers have greater confidence in the results of these assessments.

Validation of this research was executed by a peer review involving experts in the field of program management, systems engineering and data analysis. After considering the Mission Architecture Step, this group of leaders was surveyed regarding the potential value and effectiveness of this proposed new approach. The results showed overwhelmingly that the Mission Architecture Step and the Mission Analysis Plan would provide the much-needed structure on which to base the development of program assessment and evaluation tools. The subject matter experts who participated in the survey indicated that the process improvement the MAS provides would give insight and the mechanism for getting the entire program engineering community to work together and therefore eliminate opportunities for disconnects. Generating validated data and concise products allows decision makers to be much more confident in the data required and used to make program decisions.

6.2 Future Work

After completion of this work, the author plans to submit a paper detailing her findings to the "Journal of Systems Engineering." The paper will describe the Mission Architecture Step and how it increases efficiency in system definition and strengthens the ability to identify user requirements and technological specifications. Additionally, it will detail how the functional decomposition component of the Mission Analysis and Mission Analysis Plan that it produces facilitate better decision making, verification and validation [80]. In addition, there are several opportunities for future work in this area. The following details potential work areas and rationale:

1. Data and tools verification, validation and accreditation process and application using the Mission Architecture Step: The mission functional decomposition provides a very structured engineering process and product for all program development tools to be based. Future work should take an accepted verification, validation and accreditation process used by the Department of Defense and apply the Mission Architecture Step [77]. This should determine what level of detail needs to be defined in the model development and the data assessment due to the Mission Architecture Step's underlying foundation at the system engineering process initiation.

   Decision makers need to know what the data means and if they can trust the data to tell them what is needed. Validation, verification and accreditation practice provides confidence in the data. Research should be directed at discovering how much more confidence is gained with the engineering work and assessment tools linked to the Mission Analysis Plan. How much reduction in work or a change in the way validation is performed when the Mission Analysis Plan is in place should also be investigated. Finally, how much the verification, validation and accreditation process improved with a systematic quantified driver should also be studied. This would document the overall contribution of the Mission Architecture Step and its related products.

2. Human Dynamics and Social Engineering: Most engineering organizations and managers are completely immersed in their environment, are comfortable with the way things have always been done, and have difficulty embracing new ideas or processes. Established organizations tend to have a strong institutional bias to incremental improvements [79]. Accepting a new process and taking the time to learn how to implement it accurately is critical to the success of the process. Personnel must be able to focus on the product, but at the same time understand how the process leads to the product. To truly accept and the MAS, engineers must fully understand and embrace its value.

   Work should determine the best socially economic method for implementation of the Mission Architecture Step into existing engineering organizations. Training will be required, including developing a training module for inclusion into Defense Acquisition University. Training plans should address cost, schedule, and possible certifications. It should also focus on illustrating the value of the Mission Architecture Step and highlight how using this approach will improve the data available to engineers and facilitate better decision making.

   Early adopters need to lead the way by getting the initial training and the leeway to experiment with, internalize, and prove the innovation. Management must adopt the process in order to lead the engineering workforce. Early adopters must identify a mechanism or mechanisms that will help insert this breakthrough innovation into established organization and/or established management bias. They must make sure the focus is on product and effectiveness and not process. Cost and time savings should be clearly documented so that engineers see the value of the Mission Architecture Step and are encouraged to adopt it in order to capture the improvements it affords in these areas.

3. Design of Experiment using Mission Function Decomposition Mission Analysis Plan: Using techniques of defining mission discrete units, researchers should define how to implement the Missions Architecture Step in a cost constraint environment. Applying the process to an old, existing program where cost and schedule data are available can provide a foundation to accomplish this.

   Researchers could conduct a blind study between two teams for a product. The product should have some complexity, such as a small rocket with maneuvering capability. One team should follow the current systems engineering process and the second team should implement a Mission Architecture Step in the process. The teams should be given cost and schedule constraints as well as milestone decision criteria. Testing and evaluation tools should be required. A new requirement should be provided at two different times in the acquisition process, once during the detailed design phase and the second during prototype fabrication. This study is ideal for an extensive Program Management course, an advanced systems engineering course, or a senior design project that is conducted over two semesters and must include budgeting allocation and expenditure activities.

   Results will address the cost and schedule of implementing the Mission Architecture Step. Comparisons should be made by collecting failure results data, rework actions at every level, and schedule and cost data applied to earned value management [80]. Detailed system requirements, specification, and design would be required. Component analysis, testing, and system analysis and test are required to meet exit criteria or completion criteria.

6.3 Conclusion

Improving the clarity and understanding of the system requirements before the initiation of the systems engineering process will address many of the common problems currently troubling weapon systems acquisitions. The Mission Architecture Step described in this dissertation will provide that additional clarity. The functional decomposition that occurs within the Mission Architecture Step provides a data dictionary that is captured in a Mission Analysis Plan (MAP). That plan informs and guides the systems engineering process throughout a weapon system acquisition.

The MAP gives decision makers relevant and critical data at appropriate times so that they can make informed decisions. In doing so, it will reduce cost and shorten schedules. As a result, the Mission Architecture Step, the Mission Analysis it contains, and the Mission Analysis Plan it produces provide a fundamental improvement in the process for designing and acquiring large, complex systems and will successfully address the perennial problems of cost and schedule overruns that so often characterize such efforts. The Mission Architecture Step has the flexibility to be applied in the acquisition of virtually any complex system, but is specific enough to document standards, requirements, and data in a way that facilitates better decision making and greater certainty. As a result, this new approach to the acquisition process and the way it relates to current systems engineering efforts provides a unique contribution to the field of engineering and offers a higher standard of practice in all relevant efforts.

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Appendix A

Case Study Survey

Appendix A contains the case study survey given in the research peer review. At the time of the survey, the research was focused on Mission Analysis and later evolved into the broader context of Mission Architecture that includes Mission Analysis and the resulting analysis product, Mission Analysis Plan. The intent behind the term Mission Analysis Step in the survey is consistent with final Mission Architecture Step as described in the preceding manuscript.

Adding Mission Input Step to Systems Engineering Process to Develop an Adaptive Architecture Template Yielding a Mission Analysis Plan

Patricia A. Gore

Aug 2012

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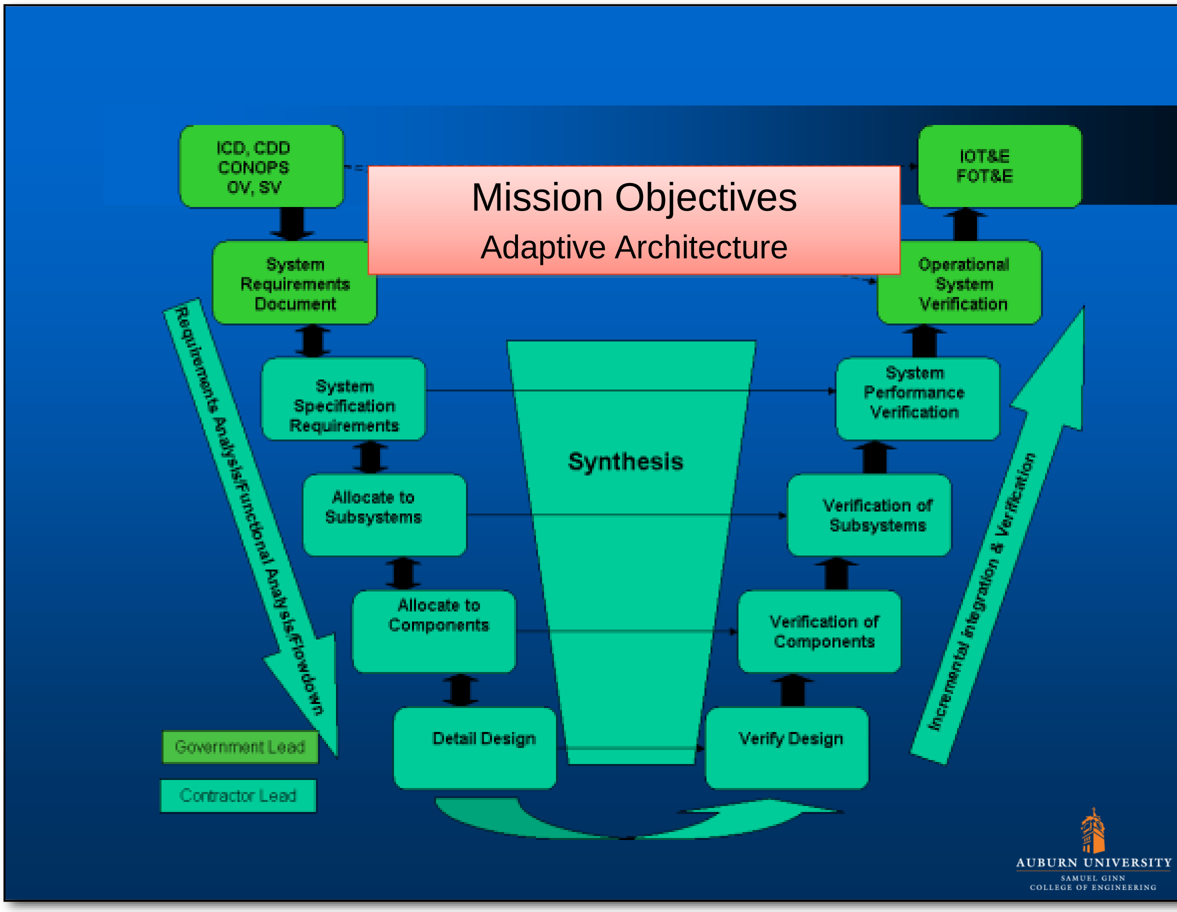
ICD, CDD
CONOPS
OV, SV
IOT&E
FOT&E
Mission Objectives
Adaptive Architecture
System
Requirements
Document
Operational
System
Verification
Requirements Analysis/Functional Analysis/Flowdown
System
Specification
Requirements
Synthesis
System
Performance
Verification
Allocate to
Subsystems
Verification of
Subsystems
Allocate to
Components
Verification of
Components
Incremental Integration & Verification
Detail Design
Verify Design
Government Lead
Contractor Lead
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Mission Objectives and Analysis

- Define Mission from Operational Requirements/Warfighter Needs
- Decompose Mission Objectives into Mission Functions
- Decompose Mission Functions to lowest level possible
- Quantify Functions
  - Functions are quantified to a metric/measureable unit
  - Can be in terms of ranges
- Mission Functions are not the same as System Functions
  - May have similar functional decomposition but have a different purpose
- Mission Functional Decomposition are tracked through life-cycle

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What It Does

- Defines Quantifiable parameters for decision makers
    - Identifiable at any point in system development and maturity
    - Clear and concise – no issues with misunderstanding of analysis data meaning
- Provides the exact measures required for development of Analysis, Evaluation, and Assessment Tools (Mission Analysis Plan)
    - Models and Simulations
    - Test – Ground, Live, and Hardware-in-the-loop
- Assessment data is more easily validated, verified and accredited
    - Tools are tied together by fundamental baseline
    - Clearer picture of what tools are needed for development
    - Clearer definition of applicability of legacy tools and updates required
    - Clearer decision on requirement for fidelity of tools
- Allows for easy assessment of new architecture assets/elements

Solid Engineering Disciplined Approach

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What It Does Not Do

- NOT a Performance Tool
  - Mission functional decomposition is for overall mission and not for the system
- Does NOT Replace the SE Process System Functional Decomposition
  - These are two separate functional decompositions
  - Mission is for overall mission and not solution specific
  - System decomposition is solution specific and may include multiple decompositions due to number of operational scenarios and system architectures per scenario
- System Decomposition will Mimic the Mission Decomposition by using the same breakdown and metrics as foundation baseline and trace back to Mission

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Mission Functional Decomposition Example

Mission – Defend the US against Incoming Ballistic Missiles

Functions:

1. Perform System Status
2. Perform Control of Defense
3. Perform Engagement Planning
4. Perform Early Warning Surveillance
5. Perform Sensor Operations
6. Perform Engagement

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Function Breakdown Example

5. Perform Sensor Operations

   5.1 Execute Sensor Task Plan

   5.2 Perform Acquisition

   5.3 Perform Tracking

      5.3.1 Perform Track Accuracy (metric) (e.g meters/sec^2)

      5.3.2 Perform Track Reporting (measurable unit metric)

   5.4 Perform Discrimination and Classification

These functional task will devolve to much lower levels, each with a metric defining how the function is defined and measured

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Survey

Survey will utilize the Likert Scale to Score Answers as well as verbal responses

For the Following Questions, Please Identify One of the Responses Below:

1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

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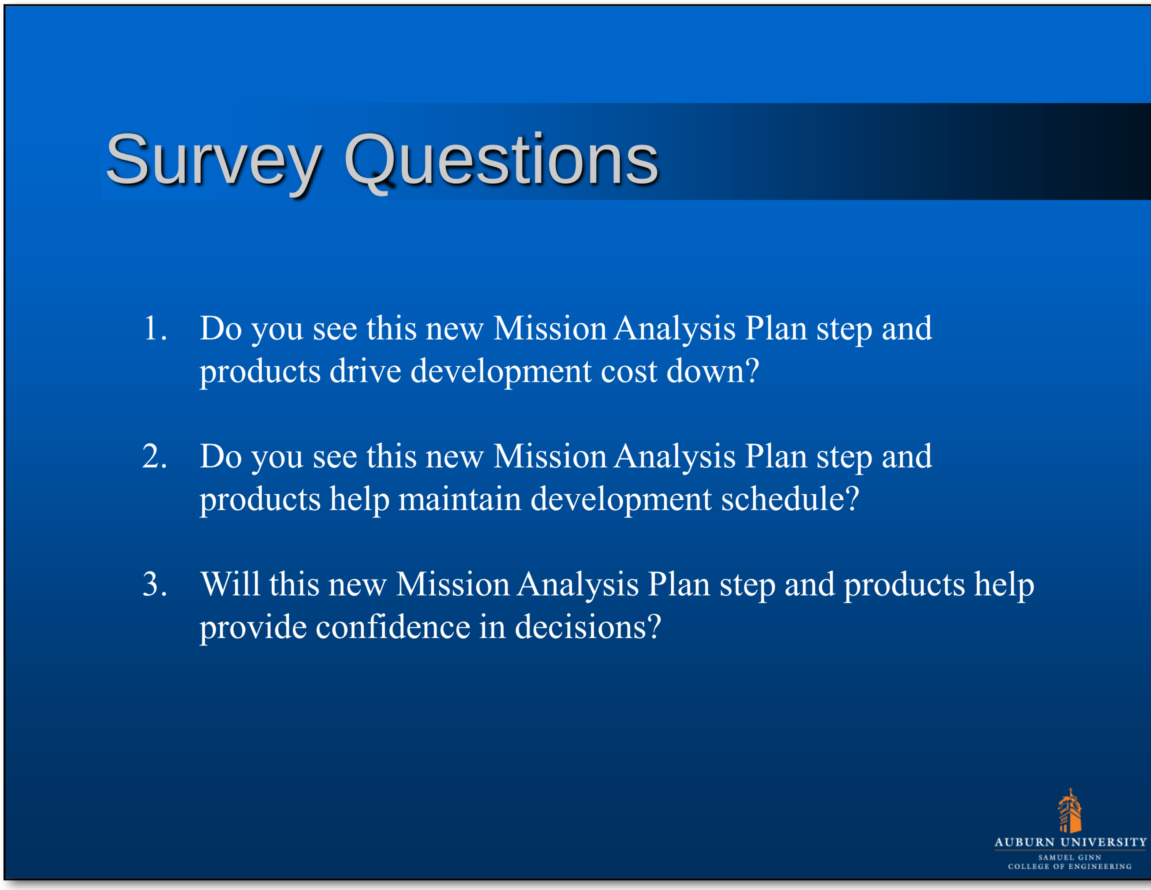
Survey Questions
1. Do you see this new Mission Analysis Plan step and products drive development cost down?
2. Do you see this new Mission Analysis Plan step and products help maintain development schedule?
3. Will this new Mission Analysis Plan step and products help provide confidence in decisions?
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Demographic Questions

1. How many years experience do you have working?
   - Military
   - Govt Civillian
   - Defense Contractor
   - Other Govt (NASA, DOE, etc)
   - Non Govt
2. What part of the country/world do you reside? Did you live in any particular place for the majority of your experience?
3. What area is your primary expertise (PM, SE, Analysts)?

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Appendix B

Survey Raw Data

Survey Participant # 1

Current Job Title: Vice President, Advanced Programs

Years Experience:
DoD:
Defense Industry: 24
NASA:
Other:

Expertise: System Analysts, Modeling and Simulation Focus

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely Yes, Strongly Agree
    b. Early detail definition of data requirements eliminates the problems with inadequate model and simulation tool development.
    c. As system design matures, the more mature simulation tool suites will help earlier in finding interface issues and defining performance parameter issues and strengths.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Definitely, Strongly Agree
    b. The previous answer applies in addition to the ability to better define problems associated with budget cuts.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. This process and product will go a long way to help build confidence in the data.
    c. The verification and validation of the models and simulations will have a detailed basis for anchoring.

Survey Participant # 2

Current Job Title: Executive Vice President and General Manager

Years Experience:
DoD:
Defense Industry: 28
NASA:
Other:

Expertise: Program Management

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely yes, Strongly Agree
    b. The early detail and structure will help determine where emphasis on design tools and evaluation tool need to be placed.
    c. Will help mitigate and avoid restarts.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Yes, Strongly Agree
    b. By eliminating disconnects and re-start issues, not only cost is contained but also schedule.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. The structure provides significant validation for any decision needed.

Survey Participant # 3

Current Job Title: Vice President, Engineering and IT Solutions

Years Experience:
DoD:
Defense Industry: 23
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. It can't help but drive the cost down. Critical details are developed up front and eliminates going in the wrong direction.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same answer as above. When there is less backtracking and rework/redesign, then effort is applied to the right products.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Absolutely yes, Strongly Agree
    b. The detailed data forms a strong baseline for everything that is being done in the design and acquisition.

Survey Participant # 4

Current Job Title: Division Director, Defense – U.S. Central Region

Years Experience:
- DoD: 26
- Defense Industry: 5
- NASA:
- Other:

Expertise: Program Manager

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
   a. Yes, Strongly Agree
   b. Can understand the metrics and component level requirements and interfaces
   c. Helps determine the biggest bang for the buck
   d. Component level requirements are where the biggest bucks are spent. Need to get them right early and this helps.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
   a. Yes, Strongly Agree
   b. Helps define where to put the development effort and dollars.
   c. Key to this process is that is provides the information to understand impacts
      i. Where the impacts are in performance
      ii. Where the impacts are with disconnects
   d. This will be a huge help with all the scarce resources.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
   a. Strongly Agree
   b. Key is having confidence in the baseline and tools
      i. Most initially compare with something to generate confidence
      ii. New system – ground up for confidence
      iii. Existing system – must build confidence based on output, see tangible results.

Survey Participant # 5

Current Job Title: Vice President, Division Manager, Analysis, Concepts Exploration and Systems Engineering Division

Years Experience:

DoD: 12
Defense Industry: 13
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely, Strongly Agree
    b. Decisions on which direction to take is easy with this kind of detail and structure.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Interfaces can be fleshed out earlier which helps avoid mistakes and going in the wrong direction.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Decision tools will have structure behind them.
    c. The data generated for design decisions and evaluation events will have the detail to validate.

Survey Participant # 6

Current Job Title: Senior Program Manager

Years Experience:
DoD:
Defense Industry: 21
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. As an engineer, we cannot get enough information. Being able to reconcile missing requirements early, helps determine how best to budget and spend money.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same reason as above. When we are able to put our efforts working the right areas and problems, then we are less likely to encounter problems and can stay on schedule.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Same rationale as the above two answers.
    c. The disciplined engineering structure provides the right data at the right time to make decisions.

Survey Participant # 7

Current Job Title: President

Years Experience:
DoD:
Defense Industry: 27
NASA:
Other:

Expertise: System Analysts

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. By structuring on the up front mission
        i. Better determine the level of fidelity for tools
        ii. Can determine the capability test venues needed
        iii. Develop test designs earlier
    c. Saves a whole lot of money to create a test infrastructure
        i. Can design what is needed versus overdesigning, such as targets
        ii. Data collection assets identification versus just using anything available. Such as a building a sensor to ride on the bus.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Helps in assessing progress and monitoring progress along schedules.
    c. Helps set the milestones.
    d. Helps leadership with decisions.
    e. Definitely allows decisions, less guessing.
    f. Adds fidelity to schedule to assess progress.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree with more confidence in decisions
    b. Goes down into the level of fidelity needed
        i. Like a clock – dependable
        ii. More precise measuring devices, so have confidence.

Survey Participant # 8

Current Job Title: Program Manager, Homeland Security

Years Experience:
DoD: 24
Defense Industry: 8
NASA:
Other:

Expertise: Program Manager

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely Yes, Strongly Agree
    b. Sooner identify problem, less expensive to fix it. Don't have to backtrack.
    c. Less changes necessary

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely Yes, Strongly Agree
    b. Similar answer as above.
    c. Earlier identification – less changes – eliminate wasting time.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Provides a common baseline for tools and metrics
    c. Confidence builds as move through schedule. "Success breeds success".

Survey Participant # 9

Current Job Title: Department of Defense Client Executive

Years Experience:
DoD:
Defense Industry: 34
NASA:
Other:

Expertise: System Engineering

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Agree
    b. Must ensure the requirements process must touch enough of the mission constituents.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Yes, Agree
    b. Change and flexibility must be taken into account and with limits bounded by reality. Otherwise, answer is strongly agree.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. This provides the metrics, flexibility and a well thought out way of communicating up and down the organization.

Survey Participant # 10

Current Job Title: Principle Engineer

Years Experience:

DoD:

Defense Industry: 24

NASA: 5

Other:

Expertise: System Engineer, System Analysts

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. Biggest potential is driving development cost
    c. Helps in architecture subsystems limitation and interactions.
    d. Finds integration issues sooner in life-cycle.
    e. System more economical to maintain.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Provides greater awareness to decision makers and lower tier personnel

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. More comprehensive knowledge sooner in life-cycle

Survey Participant # 11

Current Job Title: President and Chief Operating Officer

Years Experience:
DoD: 28
Defense Industry: 6
NASA:
Other:

Expertise: Program Manager and Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Agree
    b. Comprehension of operational architecture is key
        i. Material solution will derive from the reflection of ConOps
    c. Warfighter feedback is earlier
    d. System and operational trade space visible up front which allows for smarter choices

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same answer as above.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Puzzles need picture or a puzzle box. This provides the picture in more detail.
    c. Since picture keeps changing, knowledgeable trade space helps provide information and surety for program manager.

Survey Participant # 12

Current Job Title: Vice President

Years Experience:
DoD:
Defense Industry: 26
NASA:
Other:

Expertise:

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely yes, Strongly Agree
    b. Helps execute the Systems Engineering process.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely yes, Strongly Agree
    b. Constant pulse point on things

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Yes, Strongly Agree
    b. Will help to eliminate requirements creep

Survey Participant # 13

Current Job Title: Chief Engineer

Years Experience:
DoD:
Defense Industry: 28
NASA:
Other:

Expertise: System Engineering and System Analysts

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
   a. Yes, Strongly Agree
   b. Will organize effort to keep from wasting time and money

2. Do you see this new Mission Analysis step and products help maintain development schedule?
   a. Yes, Strongly Agree
   b. Helps to knows impact of failures.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
   a. Absolutely yes, Strongly Agree
   b. If you can believe in the data, can believe in what the data is telling you.

Survey Participant # 14

Current Job Title: Owner, President

Years Experience:
DoD: 12
Defense Industry: 25
NASA:
Other:

Expertise:

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. Unknowns tend to be cross-functionality and across disciplines. This will identify them earlier.
    c. Helps avoid errors.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. The design tool will have more foundation behind them which will help design or requirements creep.
    c. The deterministic – cause and effect values is key

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. This process/product adds greater levels of fidelity
        i. The earlier identification of parameters does this
        ii. This detail is what is needed to generate believable data.

Survey Participant # 15

Current Job Title: President

Years Experience:
DoD:
Defense Industry: 24
NASA:
Other:

Expertise: System Analyst

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely yes, Strongly Agree
    b. Helps industrial accountability to deliver system performance.
    c. More definitive direction, less opportunity to deviate or go down the wrong path.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Gets entire engineering community to work together. Communication and understanding.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Everything that is needed to make decisions is now available.
    c. Removes hesitancy and doubt.

Survey Participant # 16

Current Job Title: Vice President

Years Experience:
DoD:
Defense Industry: 22
NASA:
Other:

Expertise: System Analyst

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Strongly Agree
    b. Sets structure for evaluation and assessment tools.
    c. Technology changes are easily incorporated.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same rationale as first answer.
    c. Rate of changes of computers, software and technology that makes a model development specific to a product is no longer valid with this process.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Validity behind data is there for the purpose needed.
    c. Eliminates manipulation of data.

Survey Participant # 17

Current Job Title: President and Chief Executive Officer

Years Experience:
DoD:
Defense Industry: 31
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely yes, Strongly Agree
    b. Will better understand the cost driver.
    c. Can put effort where it needs and eliminate things that are not needed.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely yes, Strongly Agree
    b. Will understand how something is supposed to work – intent
    c. Areas may not work right together and this will find that early.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Incredible insight gained

Survey Participant # 18

Current Job Title: Director

Years Experience:
DoD:
Defense Industry: 21
NASA:
Other:

Expertise: Program Manager

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Agree
    b. Better information early helps make the right decisions early.
    c. Focusing on mission eliminates requirements creep issues with solution changes.
    d. Congressional funding and direction causes delays which in turn increases cost. No engineering process can eliminate this fact of life.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Focusing purely on schedule and work required, this process and product will eliminate waste.
    c. Can be more streamlined

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Absolutely yes, Strongly Agree
    b. Wish this was in place now, can really use it.

Survey Participant # 19

Current Job Title: Deputy for Strategic and Missile Defense

Years Experience:
DoD: 32
Defense Industry: 6
NASA:
Other:

Expertise: Program Manager

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Agree
    b. Must always remain in tune with political forces.
    c. Underlying structure provides the confidence for decision makers to work with political forces. Eliminates many of the budget cuts that cause program delays and increase in overall cost.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Quantification is based on perfection, performance is not.
    c. Underlying structure provides recipe for developing system assessment tools.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Solid foundation

Survey Participant # 20

Current Job Title: Senior Engineer

Years Experience:
- DoD: 15
- Defense Industry: 20
- NASA:
- Other:

Expertise: System Engineer and System Analyst

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. Will really help in models and simulations – can accreditate system
    c. Need this right now.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Agree
    b. This will definitely help in maintaining schedule
    c. Lots of other things impact schedule
        i. Outside influence (external funding, political issues, etc.)
        ii. Internal issues (failures, environment)

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. We have 90% of data but people are afraid to make decisions – this will lock data to the mission information.

Survey Participant # 21

Current Job Title: Technical Director

Years Experience:
DoD:
Defense Industry: 34
NASA:
Other:

Expertise: System Analyst

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely yes, Strongly Agree
    b. This is brilliant. Existing tools can be used to do this work and then import to system engineering tools.
    c. Cost cannot help but be improved with the knowledge gained early and throughout the product life.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely yes, Strongly Agree
    b. Same answer as above.
    c. Everyone will work to the same data.
    d. This should alleviate fear of making decisions.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Absolutely, Strongly Agree
    b. Managers are making decisions now with too much information that is not directly relevant.
    c. Eliminates issues with not understanding the data and what the data means. This significantly raises confidence.

Survey Participant # 22

Current Job Title: Senior Manager

Years Experience:
DoD: 22
Defense Industry: 6
NASA:
Other:

Expertise: Program Manager

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Strongly Agree
    b. Defines interfaces early.
    c. Early identification ensures early management.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same rationale as above.
    c. Eliminate cost waste and schedule is saved as a result.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Absolutely yes, Strongly Agree
    b. Ensures credible reporting.

Survey Participant # 23

Current Job Title: Vice President, Missile Sector

Years Experience:
- DoD: 17
- Defense Industry: 7
- NASA:
- Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Strongly Agree
    b. Provides much needed structure for prime contractor, which also identifies areas for incentive.
    c. Easier to track contractor performance

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely yes, Strongly Agree
    b. Schematic for work is detailed with this product.
    c. Less opportunity for misdirection.
    d. Can find issues earlier.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. The engineering structure behind the assessment tools and data generate significant confidence.

Survey Participant # 24

Current Job Title: Deputy Program Manager

Years Experience:
DoD: 26
Defense Industry:
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Has to do so, Absolutely Yes
    b. This structure for engineering
        i. Goes into the detail that is missing
        ii. Designs in confidence
        iii. Does this without breaking the bank.
    c. Decisions are smarter

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same reason as above.
    c. Focusing on mission provides the flexibility to make changes and add value without major disruption.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Decisions will be much easier with this detailed engineering work behind the data.
    c. Decisions will be much more accurate also.

Survey Participant # 25

Current Job Title: Program Management Director, System Engineering and Integration

Years Experience:
DoD: 20
Defense Industry: 14
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
   a. Strongly Agree
   b. System Engineering is done at bare bones today – only go through one set of requirements
      i. Anything new is deviation, therefore more cost and schedule
      ii. State of the art needs to be able to be used, not tied to old technology of when component/product development is initiated.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
   a. Strongly Agree
   b. The deep functional decomposition captures parameters that are not found until later in the systems engineering effort and most of the time not until the design part.
   c. Schedule is automatically saved when more information is available early.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
   a. Strongly Agree
   b. More information is known for every decision that needs to be made at all levels of decision – drawing board to program management and congress
   c. Data has easily understood substance behind it.

Survey Participant # 26

Current Job Title: Chief Technical Officer

Years Experience:
DoD: 22
Defense Industry: 15
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
   a. Absolutely, Strongly Agree
   b. This builds the gold standard for business practices
   c. Provides a starting structure, does not provide performance – this is really good.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
   a. Strongly Agree
   b. Construct captures all the key criteria.
   c. Recipe for program management and engineering to follow, can tell early when going in the wrong direction.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
   a. Strongly Agree
   b. Decisions makers have solid basis behind all data.
   c. Everything linked to mission objective, so easier to make decisions and communicate decision rationale

Survey Participant # 27

Current Job Title: President

Years Experience:
DoD: 24
Defense Industry: 10
NASA:
Other:

Expertise: Program Manager

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes definitely, Strongly Agree
    b. Out of cycle changes are less disruptive, structure allows for much more flexibility.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Structure provides detailed insight.
    c. No wasted effort of determining which tools to develop.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Basis of depth is there.
    c. Can understand the pro's and con's for each choice.

Survey Participant # 28

Current Job Title: Vice President, Quality and Mission Assurance

Years Experience:
DoD: 22
Defense Industry: 10
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Strongly Agree
    b. System Engineering is being left out of most defense programs, this will force it back.
    c. Currently, just doing things that look good, this will put the details into what needs to be done and give credence to what looks good and possibly make it better.
    d. Will be able to select what to focus.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Focus will be on what trying to accomplish.
    c. Currently not doing end-to-end error budgets. This will force better systems engineering and margin analysis.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Decisions can be made with strict engineering detail.
    c. Decision makers will still have to cope with political or outside influence, having a good engineering foundation helps convince the outside influence of what is really needed.

Survey Participant # 29

Current Job Title: Director, Strategy and Development

Years Experience:
DoD: 27
Defense Industry:
NASA:
Other:

Expertise: Program Management

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely, Strongly Agree
    b. Provides clarity to complex systems.
    c. Will help identify critical areas and issues early.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same as above.
    c. Money and time can be budgeted with better precision

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. As a Program Manager, I am faced with many decisions that need more substantial work behind the data. However, schedule and urgency causes me to rush to make a decision with the best information I have. This structure behind the engineering process will provide that much needed depth.
    c. Need this now.

Survey Participant # 30

Current Job Title: Director, Regional Missile Defense Systems

Years Experience:
DoD:
Defense Industry: 24
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. Defense systems are influenced by criticality of mission
    c. Difference is all about the consequences, metrics developed carefully and early changes the score.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely, Strongly Agree
    b. Same answer as above, schedule is saved when cost is saved and vice versa.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. Forces a different way of looking at acquisition
    c. Focus on mission accomplishment
    d. Structure provides much needed confidence.

Survey Participant # 31

Current Job Title: Branch Chief

Years Experience:
DoD: 12
Defense Industry:
NASA: 9
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely yes, Strongly Agree
    b. More information up front helps better definition for the design work and helps avoid errors.
    c. Rework is large cost driver

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely yes, Strongly Agree
    b. Same reason as above plus the benefit of building tools from a fundamental baseline versus a constant changing baseline.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. This process and product can be used for any acquisition program, not just Defense.
    c. NASA would greatly benefit from this.

Survey Participant # 32

Current Job Title: Assistant Director

Years Experience:
DoD:
Defense Industry: 11
NASA:
Other: 14

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. The detail data definitions allow for fewer misunderstandings, increases communications.
    c. Interface issues are found early and therefore less integration issues are system verification.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely yes, Strongly Agree
    b. The more detailed information known up front allows for requirements to be better vetted and understood.
    c. Design work and design solutions have greater flexibility.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. The right information will be available for decisions at any level or work.

Survey Participant # 33

Current Job Title: Senior System Analyst

Years Experience:
DoD:
Defense Industry:
NASA: 35
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. Complex systems require the ability to adapt to change, must be flexible
    c. This helps because the focus is on the mission.
    d. Brilliant

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Schedule is easily lost due to miscalculations in design, misunderstanding in requirements, and improper development and testing tools.
    c. This helps minimize those issues.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. This approach solidifies the structure needed in System Engineering.
    c. Products can be easily validated.

Survey Participant # 34

Current Job Title: Assistant Director

Years Experience:
- DoD:
- Defense Industry: 22
- NASA:
- Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely, Strongly Agree
    b. This also helps eliminate sustainment issues by eliminating interface issues.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Much better insight for engineers and program managers. Can prioritize better.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. There will be depth in the data and any alternative approaches that are considered.
    c. This provides a more comprehensive detail to better understand cause and effect.

Survey Participant # 35

Current Job Title: Director, International Operations

Years Experience:
- DoD: 25
- Defense Industry: 6
- NASA:
- Other:

Expertise: Program Manager

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Strongly Agree
    b. Breaking down the mission this way allows maximum utility of complex systems.
    c. Not only does it provide much needed structure early, it allows for more insight to requirements changes.
        i. Models and simulations uses and fidelity can be established earlier because requirements are understood.
        ii. Significant cost overruns are due to rework and tool redesign.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Same reason as above.
    c. This will help find issues early.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree
    b. There are many aspects that influence decisions, political, real world issues, and program health.
        i. This structure provides real value in knowing the technical data is based on the mission.
        ii. Helps Balance decisions with all the influence variables.

Survey Participant # 36

Current Job Title: Senior Analyst

Years Experience:
DoD:
Defense Industry: 18
NASA: 4
Other:

Expertise: System Analyst

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Absolutely yes, Strongly Agree
    b. Warfighter involvement is much earlier since they are needed to flush out mission devolution.
    c. System requirements are more precise early, minimizing rework.
    d. Analysis and Assessment tools will be defined earlier and will have more valid requirements.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Absolutely yes, Strongly Agree
    b. Same rationale as above.
    c. Defining the data needs by mission functions is exactly the answer for complex systems.
    d. Eliminates disconnects in analysis community on data definitions and ensure tools are developed to fidelity needed.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Strongly Agree, yes.
    b. Assessment tools and data products will have the structured traceability to be validated.
    c. We will know what is behind the information to make any decision.
    d. Huge boost in confidence and assurance.

Survey Participant # 37

Current Job Title: Senior System Engineer

Years Experience:
DoD: 29
Defense Industry:
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
    a. Yes, Strongly Agree
    b. Mission vice performance allows greater flexibility, much needed for complex systems.
    c. Will drive out interface issues early, rework is very expensive and time consuming.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
    a. Strongly Agree
    b. Mission foundation provides greater integration capability.
    c. Will save schedule from having less much rework.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
    a. Absolutely, Strongly Agree
    b. The metrics foundation gives greater insight into any problem.
    c. More information is not always better; the right information is what is needed. This generates the right information.

Survey Participant # 38

Current Job Title: Chief Scientist, Integrated Missile Defense

Years Experience:
DoD:
Defense Industry: 39
NASA:
Other:

Expertise: System Engineer

Responses to Survey Question:

1. Do you see this new Mission Analysis step and products drive development cost down?
   a. Yes, Strongly Agree
   b. System Engineering work, trade studies and architecture development will have more comprehensive requirements to help solidify products.
   c. This effort is more work up front but will definitely pay for itself and greater in the design effort and in the development tool effort.

2. Do you see this new Mission Analysis step and products help maintain development schedule?
   a. Strongly Agree
   b. Interface issues are found and eliminated early in design vice testing.
   c. Also true for integration issues.

3. Will this new Mission Analysis step and products help provide confidence in decisions?
   a. Strongly Agree
   b. Really like the mission approach. Simplifies the whole requirements generation effort.
   c. Clearer understanding of what is involved in each decision.
   d. Want to get this implemented.

Appendix C

Dissertation Support and Peer Review Participants

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