


Establishing the Technical **FOUNDATION:** Material Solution Analysis Is More Than Selecting an Alternative

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Several government and independent studies indicate effective systems engineering and program planning in the early stages of acquisition are essential to controlling costs and improving program results. To lay the foundation for successful and executable programs, This article describes the challenge of conducting good systems engineering and technical planning during the Materiel Solution Analysis (MSA) phase after completion of the Analysis of Alternatives and prior to Milestone A. It also presents the work of the Department of Defense Development Planning Working Group to mitigate this challenge by describing the technical activities in the MSA phase necessary to develop the level of knowledge and system concept maturity necessary to proceed into the next phase of acquisition. These technical activities are represented in a notional MSA Phase Activity Model.

Keywords: *systems engineering (SE), technical planning, Materiel Solution Analysis (MSA) phase, early SE, engineering analysis*



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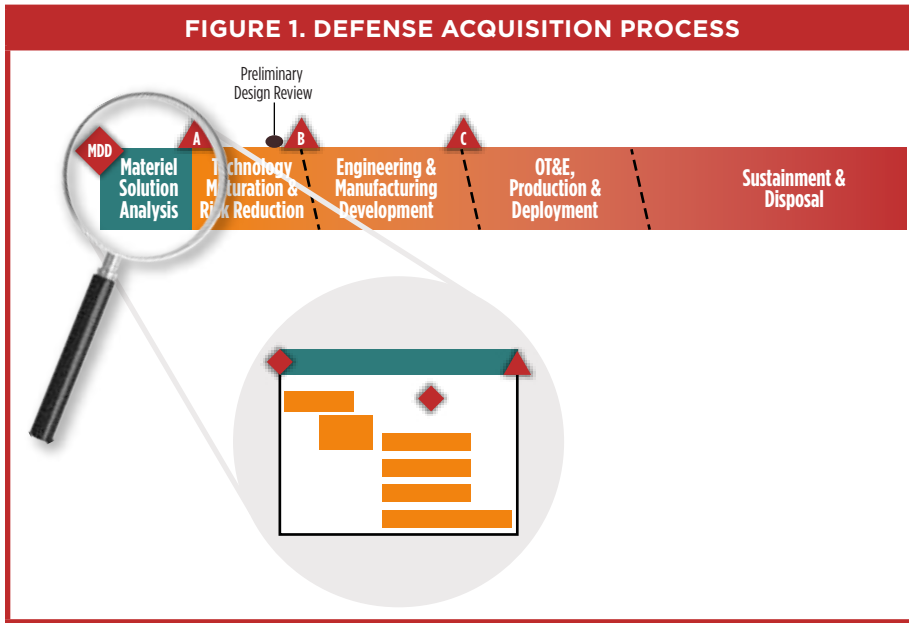
Department of Defense (DoD) weapon systems programs develop some of the most technically advanced and capable systems in the world. Unfortunately, some programs have experienced significant cost and schedule growth, poor technical planning, and inadequate risk management. Several government and independent studies point to early systems engineering and technical planning as key to establishing executable programs and controlling costs later in the acquisition life cycle (U.S. Government Accountability Office [GAO], 2009; National Research Council [NRC], 2008). These studies show that scoping and requirements decisions made prior to Milestone A can have a tremendous impact on downstream development success and production costs. Yet, despite broad recognition that early technical planning is a smart investment, DoD Components reported challenges to obtaining sufficient resources to accomplish these early systems engineering activities. Instead, the focus during the Materiel Solution Analysis (MSA) phase tends to be on the formal Analysis of Alternatives (AoA) and selection of a preferred materiel solution. As such, resources allocated to perform post-AoA systems engineering and technical planning are often inadequate to prepare for the next program milestone and subsequent phase of acquisition.

DoD Components consistently experience difficulty in defending the need for resources to complete systems engineering and technical planning, outside of the AoA, in preparation for Milestone A. This resourcing challenge can partially be attributed to a common misperception that the AoA comprises nearly all of the effort during the MSA phase, and that AoA results are all a program needs to proceed to a Milestone A decision. To address this misperception and to help justify the need for resources for post-AoA systems engineering, the Development Planning Working Group (DPWG), a government-only working group with representation from across the DoD, began an effort to describe the technical activities that should be completed in the MSA phase. This effort focused on developing the level of knowledge and system concept maturity required by policy to proceed into the next phase of acquisition. This article presents the methodology and results of that effort.

Background

As shown in Figure 1, MSA is the first phase in the acquisition process. According to Department of Defense Instruction (DoDI) 5000.02, the purpose of the MSA phase is to conduct the analysis to select a preferred materiel solution, begin translating validated capability gaps into

system-specific requirements, and conduct planning to satisfy the phase-specific criteria for the next program milestone designated by the Milestone Decision Authority (MDA) (DoD, 2015). Commonly, the MDA will decide to invest in technology maturation and preliminary design in the Technology Maturation and Risk Reduction (TMRR) phase.



Note. MDD = Materiel Development Decision; OT&E = Operational Test & Evaluation.

The purpose of the TMRR phase is to reduce technology, engineering, integration, and life-cycle cost risk to the point that a decision to contract for Engineering and Manufacturing Development (EMD) can be made with confidence in successful program execution for development, production, and sustainment (DoD, 2015). Using the TMRR phase for true risk reduction was an initiative of Better Buying Power version 2.0 (Kendall, 2013) and was incorporated into DoDI 5000.02 (DoD, 2015). The TMRR phase also includes the Preliminary Design Review (PDR), which locks down the system's basic architecture and establishes the allocated baseline. Early systems engineering in the MSA phase provides the foundation for TMRR-phase contract award(s) and preliminary design activities. Technical activities in the MSA phase help identify critical technologies, support development of a competitive prototyping strategy, and identify the set of risks that will drive TMRR phase risk-reduction efforts. This early systems engineering work is vital to setting the program up for long-term success.

The DPWG initiated its effort based on three foundational assumptions. These assumptions are supported by studies (GAO, 2009; NRC, 2008) using empirical data of past program performance, as well as observations by acquisition leaders and subject matter experts. These assumptions, along with key supporting evidence, are summarized below.

Assumption 1: DoD programs experience cost, schedule, and performance issues. For years, DoD weapon systems programs have been prone to “significant cost, schedule, and performance problems” (GAO, 2009, p. 25), poor technical planning, and inadequate risk management. In 2008 alone, 96 DoD Major Defense Acquisition Programs (MDAP) experienced a combined cost growth of \$296 billion and an average schedule delay of 22 months (GAO, 2009, p. 1). These overruns have made it difficult for the DoD to equip its warfighters efficiently and effectively to defend against new and emerging threats. In today’s fiscal environment, the challenge has become even more critical.

Assumption 2: Early systems engineering and technical planning can help mitigate these cost, schedule, and performance issues throughout a program’s life cycle. At the request of the Air Force, the NRC conducted a retrospective study in 2008 to assess the contribution of pre-Milestone A and early-phase systems engineering to positive or negative development outcomes. The study’s findings and recommendations are based on case studies of eight Air Force MDAPs and on the subject matter expertise of the committee members. The study found that early systems engineering processes and functions are essential to ensuring programs deliver products on time and on budget, but that current implementation of early systems engineering in the Air Force was unstructured and inconsistent. In particular, the study identified the following tasks that should be completed before Milestone A: consideration of alternative concepts (solutions); setting of clear, comprehensive Key Performance Parameters (KPP) and system requirements; and early attention to interfaces and interface complexity to the Concept of Operations (CONOPS) and to the system verification approach (NRC, 2008). The relevant set of conclusions and recommendations from this study can be found in Appendix A.

Assumption 3: Programs are not adequately resourced to complete sufficient early systems engineering and technical planning. DPWG representatives from each of the DoD Components shared similar experiences regarding difficulty in justifying and obtaining funds for post-AoA systems engineering work to support Milestone A requirements. In some cases, programs attempted to fund this work by including it in the

scope of the AoA, resulting in lengthy and expensive AoAs as noted by the Cost Assessment and Program Evaluation (CAPE) representative. This assumption is also supported by a 2014 follow-up study by the NRC on the effectiveness of Air Force development planning. That study found that the amount of program element funding for Air Force development planning is insufficient and recommended that the Air Force align adequate resources to achieve the desired planning analysis and recommendations (NRC, 2014). The complete set of conclusions and recommendations from the 2014 NRC study can be found in Appendix B.



Approach and Methodology

Despite clear evidence from the NRC study that systems engineering and technical planning in the early phases of acquisition are critical to long-term program success, many programs lacked the necessary resources to adequately complete the post-AoA systems engineering and robustly plan the technical effort for system development. The DPWG decided to address the problem by creating an activity model describing the set of technical activities a defense acquisition program should complete before Milestone A. Using the activity model, program managers could more fully develop the appropriate level of knowledge and system concept maturity necessary to proceed into the next phase of acquisition. The activity model is based on current milestone and phase information requirements in DoDI 5000.02 and can be used to justify and defend the need for resources to complete the

technical activities. The model does not propose any new requirements on programs; it synthesizes existing requirements from several sources and describes the activities necessary to meet those requirements. It was coordinated with representatives from each of the DoD Components.

The DPWG was led by the Office of the Deputy Assistant Secretary of Defense for Systems Engineering and included representatives from each of the DoD Components, the Joint Staff, CAPE, and other offices organizationally aligned under the Office of the Secretary of Defense for Acquisition, Technology, and Logistics. Over the course of 8 months, the DPWG held six workshops to collaboratively examine current requirements regarding Milestone A and the MSA phase, and to explore DoD Component processes for completing the AoA and post-AoA technical planning efforts.

The DPWG used a two-pass approach to identify and organize all potential technical activities into a comprehensive set supported by policy and best practice. The two-pass approach helped ensure that a broad set of technical activities was analyzed and that the set of activities was closely tied to milestone and phase information requirements to support resource justifications. The two-pass approach also ensured that all milestone and phase information requirements were supported by one or more activities in the model.

The first “forward pass” consisted of brainstorming typical technical activities performed in the MSA phase based on the Services’ current policies and processes. As part of this first pass, a standard set of AoA activities was compiled based on an analysis of several recent AoA study plans and AoA reports. This set of AoA activities, confirmed by CAPE, helped to bound the AoA scope and set the stage for identifying the additional technical activities required to prepare for Milestone A and the TMRR phase. The second “backward pass” looked at the technical content of products required at Milestone A and identified activities that are needed to produce that technical information. Any activities identified during the backward pass that were missing were added to the model. Activities that were redundant or not tied to a product or information required at Milestone A were removed from the model.

The intent of the activity model is to help program personnel understand and justify the need for resources to complete adequate systems engineering and technical planning prior to Milestone A. The activity model can also be used to guide programs in planning and executing the MSA phase, ensuring all necessary activities are considered, planned, and resourced. However,

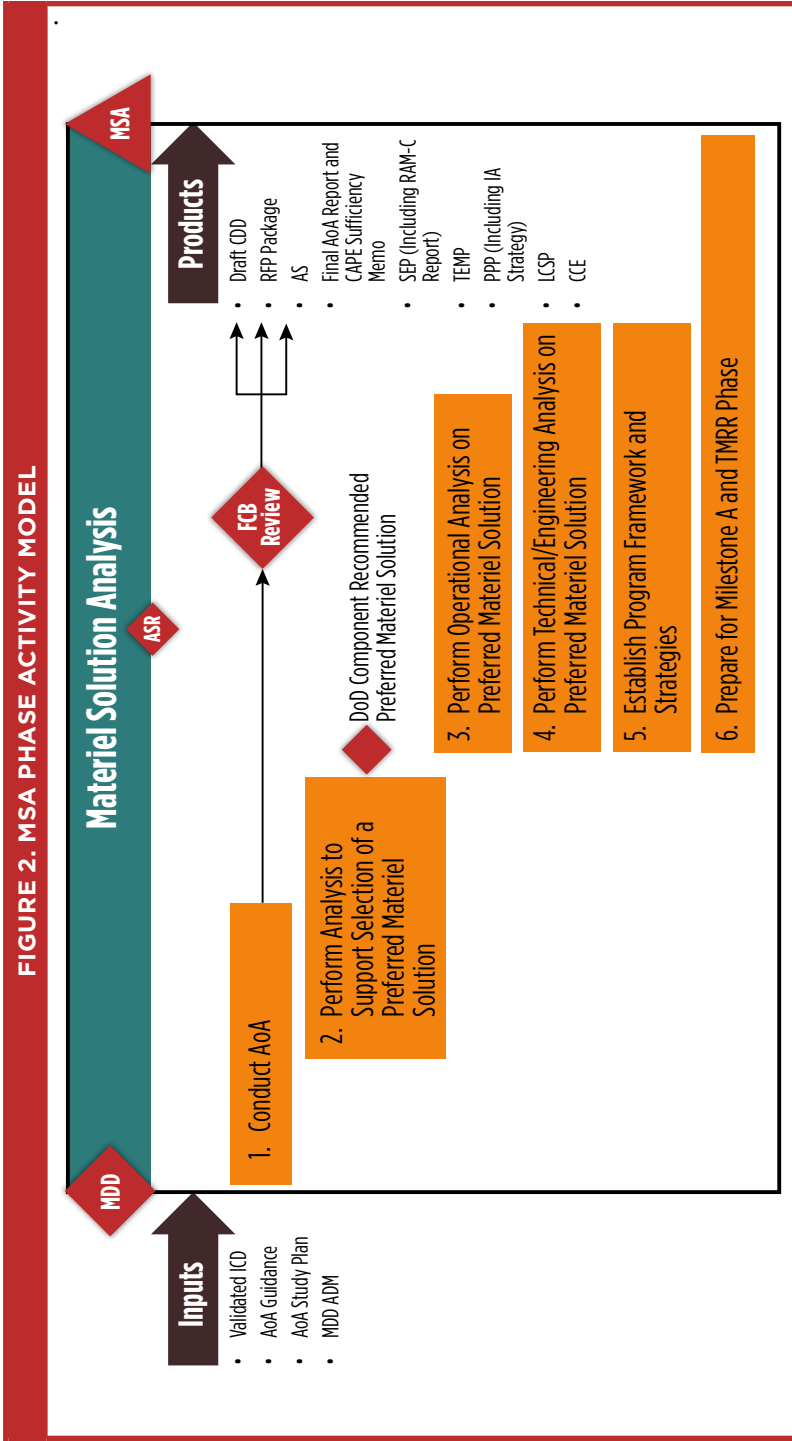
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Findings

The MSA Phase Activity Model developed by the DPWG can be applied across the DoD and includes nominal inputs, technical products, reviews, and technical activities. The model comprises six major activities, each composed of lower-level tasks and subtasks. The six major activities are (a) conduct of the AoA, (b) selection of a preferred materiel solution, (c) operational analysis on the preferred materiel solution, (d) engineering and technical analysis on the preferred materiel solution, (e) development of program plans and strategies, and (f) preparation/run-up for the milestone decision. In many cases, program systems engineers provide essential technical support for several activities or tasks, but do not lead or have decision authority for those activities or tasks. Other functional disciplines also work closely with the systems engineering team during this phase. When completed in concert with other programmatic and acquisition activities, these systems engineering technical activities help develop the appropriate level of knowledge and system concept maturity necessary to proceed into the next phase of acquisition.

Figure 2 depicts the six major activities in the MSA activity model, as well as the key inputs, products, and reviews. The relative start/finish time of each activity is depicted in the figure; however, the durations of activities are nominal and vary based on the program. Many tasks and subtasks are performed concurrently and iteratively within a major activity to help the program refine the attributes and performance parameters, and develop the necessary knowledge and products for Milestone A. The following discussion describes the inputs, products, and reviews in more detail and presents an overview of the activities.



Note. ADM = Acquisition Decision Memorandum; AS = Acquisition Strategy; ASR = Alternative Systems Review; CCE = Component Cost Estimate; FCB = Functional Capabilities Board; IA = Information Assurance; LCSP = Life-Cycle Sustainment Plan; PPP = Program Protection Plan; RAM-C = Reliability, Availability, Maintainability, and Cost; SEP = Systems Engineering Plan; TEMP = Test and Evaluation Master Plan.

MSA Phase Inputs

The MSA phase begins after a favorable Materiel Development Decision (MDD), when the MDA authorizes entry into the Defense Acquisition System. Based on MDD review criteria found in DoDI 5000.02, *Operation of the Defense Acquisition System*, the following are included as inputs for the MSA Phase Activity Model (DoD, 2015):

- Initial Capabilities Document (ICD) validated by the Joint Requirements Oversight Council
- AoA Study Guidance written and approved by the director, CAPE
- AoA Study Plan written by the DoD Component and approved by the director, CAPE

An Acquisition Decision Memorandum (ADM), signed by the MDA, authorizes entrance into the MSA phase and is also considered an input to the MSA Phase Activity Model.

According to Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01I, *Joint Capabilities Integration Development System*, the ICD formally documents the results of the Capabilities-Based Assessment (CBA) (Chairman of the Joint Chiefs of Staff [CJCS], 2015a). The CBA and other relevant studies, including their associated information and data such as that generated by models and simulations, may be useful for understanding the operational need and context. These studies should be made available to the AoA study team and the program manager during the MSA phase.

An important component of the MDA's decision to proceed into the MSA phase is based on effective development planning leading up to MDD. Before MDD, the DoD Component is expected to conduct early systems engineering analyses to provide an assessment of whether the proposed candidate materiel solution approaches are technically feasible and have the potential to effectively address capability gaps, desired operational attributes, and associated external dependencies. The DoD Component is also expected to develop the plan to staff and fund the activities preceding the next decision point, such as analytic, engineering, and programmatic activities, and show that this plan is complete and fully resourced (DoD, 2015).

MSA Phase Technical Products

For the MSA Phase Activity Model, Milestone A is assumed to be followed by the TMRR phase. DoDI 5000.02 contains a complete list of statutory and regulatory requirements for Milestone A. Some regulatory

requirements may be tailored by the MDD ADM. The Milestone A decision approves program entry into the TMRR phase as well as release of the final Requests for Proposal (RFP) for TMRR contracts (DoD, 2015).

CJCSI 3170.01I (CJCS, 2015a) contains a requirement for a draft Capability Development Document (CDD) to be written during the MSA phase to inform the Acquisition Strategy (AS) and system performance specification, and to guide TMRR phase efforts. The draft CDD specifies capability requirements in terms of developmental KPPs, Key System Attributes (KSA), and Additional Performance Parameters (APA), and is based on the capability requirements and capability gaps specified in the ICD. The Joint Staff policy (CJCS, 2015b) states:

The post-AoA review shall be completed in sufficient time to permit Sponsor preparation of a draft CDD or similar documentation prior to Milestone A, not submitted to the Gatekeeper for staffing and validation at that time, to inform the development of the request for proposals in support of the TMRR Phase. (p. A-15)



Based on the policies described previously, the following set of Milestone A products incorporates technical content and is supported by MSA activities included in the MSA Phase Activity Model:

- Draft CDD
- RFP package for TMRR phase contracts
- AS
- Final AoA Report, including AoA sufficiency memo signed by the director, CAPE
- Systems Engineering Plan (SEP), including the initial Reliability, Availability, Maintainability-Cost (RAM-C) Rationale Report as an attachment
- Test and Evaluation Master Plan (TEMP)
- Program Protection Plan (PPP), including the Cybersecurity Strategy
- Life-Cycle Sustainment Plan (LCSP)
- Component Cost Estimate (CCE)

Reviews Conducted During the MSA Phase

During the MSA phase, the program may conduct an Alternative Systems Review (ASR) to support a dialogue between the end user and the acquisition community, which leads to a draft system performance specification for the preferred materiel solution (Defense Acquisition University [DAU], 2013). The draft system performance specification defines the performance requirements in terms of the required results and the criteria for verifying compliance, the operational environment, and the interface and interoperability requirements (Defense Standardization Program, 2009). Through the ASR, the program should evaluate whether the proposed set of requirements satisfies the customers' needs and expectations, and whether there is sufficient understanding of the technical maturity, feasibility, and risk of the preferred materiel solution to proceed into the next phase (DAU, 2013).

CJCSI 3170.01I (CJCS, 2015a) requires a post-AoA review of AoA results and other engineering analysis before Milestone A. The post-AoA review should establish mutual understanding of the operational capability needs in the ICD; the proposed KPPs in the draft CDD; and the maturity, feasibility, and risks of the preferred materiel solution. As stated in policy (CJCS, 2015b):

Following Sponsor completion of the AoA, the post-AoA review provides the validation authority and other stakeholders the opportunity to assess how the different alternatives address the validated capability requirements and associated capability gaps, and at what life cycle costs. (p. A-15)

... The post-AoA review is not a validation of the AoA results, but rather informs the validation authority's advice to the Milestone Decision Authority (MDA) on the AoA results, recommended alternative(s), and proposed KPPs, KSAs, and APAs. The validation authority may recommend alternative(s) different from those recommended by the Sponsor when such a recommendation would better serve the management and prioritization of the capability requirement portfolio. (p. A-16)

Completion of the ASR and post-AoA review helps to ensure the expected performance attributes and system capabilities are consistent with customer needs, and guide the additional engineering and technical analysis needed to prepare the draft CDD and the system performance specification.

MSA Phase Activities

The systems engineering effort in the MSA Phase Activity Model is broken into three levels of increasing detail. Activities are defined as major efforts aimed at achieving a common outcome or contributing to a set of related products. Six activities constitute the MSA Phase Activity Model, including conduct of the AoA. Tasks and subtasks are more detailed and are performed in support of an activity. Tasks and subtasks often focus on a single product or outcome, such as the system performance specification or PPP. A description of the tasks and subtasks associated with each major activity follows.

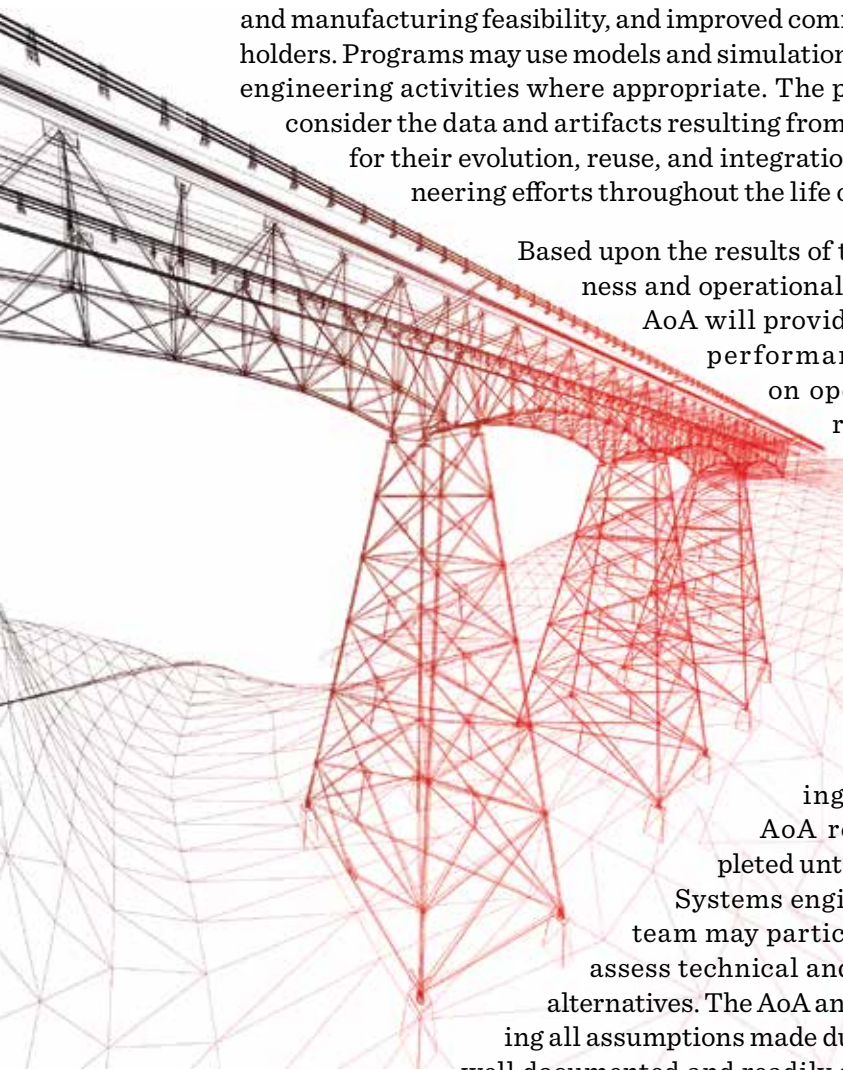
Activity 1: Conduct AoA. The AoA encompasses all efforts and analyses conducted by the AoA study team under the direction of the Senior Advisory Group/Executive Steering Committee (SAG/ESC) and CAPE (DoD, 2015). The objective of the AoA is to characterize and analyze each candidate materiel solution relative to the others. Candidate materiel solutions are characterized by identifying key attributes and performance measures (discriminators), unique logistics or information support needs, operational dependencies, and concepts of employment. This characterization of alternatives may be completed using market research, relevant trade studies, or information obtained from industry (e.g., through Requests for Information

or funded concept definition studies). The AoA study team then examines the operational effectiveness and operational suitability of each candidate materiel solution against appropriate measures of effectiveness and measures of performance, based on selected missions, threats, and scenarios. The AoA also includes an initial risk analysis for each candidate materiel solution. The risk analyses examine technical risks encompassing technology, engineering, integration, and manufacturing, as well as cost, schedule, and operational risks. Finally, initial life-cycle cost estimates are provided for each candidate materiel solution.

It is important to note for several reasons that completion of the AoA does not mean the system concept is ready to proceed to Milestone A. First, the AoA supports a decision on the preferred materiel solution, but does not directly recommend a preferred solution. Analysis should be performed to assess affordability and other constraints to determine which solution the DoD Component should pursue. Second, the AoA may not take into account certain factors if they are deemed not to be discriminators. For example, a system attribute such as reliability may not be a discriminator during the AoA because all of the alternatives under consideration have comparable reliability characteristics. Reliability would not be included in the analysis because it does not help differentiate between alternatives, but further engineering analysis on system reliability would need to be completed on the preferred materiel solution to satisfy Milestone A review criteria and develop appropriate performance specifications. Finally, significant effort is needed to develop detailed program planning and cost estimates to support the next program milestone and subsequent phases.

It is important to note for several reasons that completion of the AoA does not mean the system concept is ready to proceed to Milestone A.

Several tools and methodologies may be used to support the AoA and other MSA phase tasks. For example, models and subsequent simulations are tools that can help facilitate a better understanding of the mission context, a more complete evaluation of the trade space, earlier assessment of technical



and manufacturing feasibility, and improved communication among stakeholders. Programs may use models and simulations to support analysis and engineering activities where appropriate. The program manager should consider the data and artifacts resulting from these activities and plan for their evolution, reuse, and integration into program and engineering efforts throughout the life of the program.

Based upon the results of the operational effectiveness and operational suitability analyses, the AoA will provide thresholds for certain performance parameters based on operational requirements related to the mission.

These thresholds will inform the development of KPPs, KSAs, and APAs in the draft CDD (CJCS, 2015b).

In the MSA Phase Activity Model, the AoA concludes with the final SAG/ESC meeting, even though the final

AoA report may not be completed until later in the MSA phase.

Systems engineers from the program team may participate in the AoA to help assess technical and engineering risk of the alternatives. The AoA analysis and results, including all assumptions made during the study, should be well documented and readily available to the program team so they can fully understand the results and be able to build on these initial efforts.

Activity 2: Perform analysis to support selection of a preferred materiel solution. Using the AoA results, the DoD Component should conduct additional analyses to support the selection of a preferred materiel solution from the remaining candidate materiel solutions trade space. The additional analyses may address affordability, operational effectiveness

and suitability, and/or technical/engineering challenges and trends aimed at balancing cost, performance, schedule, and risk to determine the DoD Component-selected preferred materiel solution.

Affordability analysis is a DoD Component leadership responsibility that involves looking across the portfolio to make responsible investment decisions based on current and future capability needs (DoD, 2015). The program may support the DoD Component affordability analysis by examining the impact of a new materiel solution on current and planned systems, as well as the impact of those systems on a new program. A broader look at portfolio capabilities, system of systems (SoS) dependencies, and funding obligations may reveal technical, cost, and schedule risks that drive the selection of the preferred materiel solution. The affordability analysis also will inform the affordability cost goal set at Milestone A (DoD, 2015).

This activity ends after the DoD Component has selected which materiel solution it will pursue. All work after this point is concentrated on maturing the preferred materiel solution and preparing for the Milestone A decision.

Activity 3: Perform operational analysis on preferred materiel solution. This activity begins after the DoD Component has selected a preferred materiel solution, and it is often completed concurrently and iteratively with technical/engineering analysis, development of program frameworks and strategies, and preparation for Milestone A. After the DoD Component has selected a preferred materiel solution, the program team refines the operational context for the system concept and may provide technical justification to refine the operational requirements. These refinements should build upon AoA results and the subsequent analysis, and will support the post-AoA review to ensure user buy-in on the proposed solution and operational concepts (CJCS, 2015a). The program should maintain a working relationship with end users to achieve a balance between user requirements (documented in the draft CDD), cost, and technical feasibility.

During the AoA, accurate and complete CONOPS and mission threads provide a strong operational foundation for evaluating alternatives and assessing operational effectiveness and suitability. After the AoA is complete, the DoD Component combat developer creates an Operational Mode Summary/Mission Profile (OMS/MP) that includes the operational tasks, events, durations, frequency, operating conditions, and environment for the preferred materiel solution. The program team uses the OMS/MP to better understand the context in which the potential system concept will be employed and how this context affects the system acquisition, including

programmatic, and technical interfaces and interdependencies (DoD, 2015). The program team also uses the OMS/MP to develop system performance and sustainment requirements, and analyze SoS impacts.

Program systems engineers and capability requirements managers look at the preferred materiel solution as an element of a broader SoS architecture to better understand the end-to-end system performance and its implications for the CDD, including external interfaces and interoperability constraints. This SoS-focused analysis may identify changes in other systems needed to fully address the capability gap. The DoD Architecture Framework provides one approach for capturing and presenting architectural data, including operational context and system dependencies. This standardized approach can facilitate improved communication and sharing of technical information among various stakeholders.

Program systems engineers and capability requirements managers look at the preferred materiel solution as an element of a broader SoS architecture to better understand the end-to-end system performance and its implications for the CDD.

Operational analysis also includes identification of changes to Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities, and Policy (DOTmLPF-P) that must be planned, tracked, and implemented for the materiel solution to be effective when it becomes available. DOTmLPF-P Change Recommendations (DCR) may be identified by the systems engineering team, but it is the DoD Component's responsibility to implement the DCR.

The program team also assesses the system-level performance parameter thresholds generated during the AoA to develop the candidate KPPs, KSAs, and APAs that will be documented in the draft CDD. Operational sustainment requirements such as materiel availability, operational availability, and reliability are also refined or developed. These key requirements are briefed to the validation authority along with the results of the AoA and other analyses to ensure the proposed solution will meet the needs of the warfighter (CJCS, 2015a, 2015b).

Activity 4: Perform technical/engineering analysis on preferred materiel solution. After the DoD Component selects a preferred materiel solution, the program team begins its technical and engineering analysis, which builds upon the results of the AoA and pre-MDD technical effort. Technical analysis and engineering tasks and subtasks are often conducted iteratively to refine the parameters and attributes of the preferred materiel solution. Primary engineering tasks include conducting trade studies and sensitivity analyses, assessing technical feasibility and risk, and performing functional analysis around mission tasks in the OMS/MP. Engineering and technical analysis results in the preliminary system functional baseline, including system performance requirements, interface requirements, certain environmental or design constraints, notional system architecture design, and initial manufacturing planning. Early technical work is critical to provide the program manager with the initial system requirements, technology, and development considerations and risks. This early analysis also provides essential information on test and evaluation issues, support and maintenance objectives, work scope, and cost and schedule drivers. All of these factors affect the acquisition approach developed by the program manager and addressed in the AS.

The engineering analysis includes identifying potential hardware and software options required for implementation. The program team, as part of its system solutions analysis, conducts a technology maturity assessment of the hardware and software options with a focus on identifying critical technologies. Critical technologies become one basis for risk reduction and prototype efforts identified in program plans and executed during the TMRR phase. These prototype efforts should also be used to evaluate manufacturing processes.

The program team should conduct reliability and maintainability (R&M) engineering to develop maintenance and support concepts, articulate R&M and sustainment requirements, and establish goals for R&M performance throughout the acquisition process. R&M performance includes not only the estimated R&M requirements relating to design, but also other critical life-cycle support parameters. R&M engineering subtasks help program personnel to identify and reduce R&M risks, and mitigate operational and maintenance impacts of these risks. The RAM-C Rationale Report, attached to the SEP at Milestone A, documents the rationale for sustainment KPPs (Office of the Secretary of Defense, 2009).

It is important for the program to conduct initial program protection analysis and planning during the MSA phase to design the system concept with system security in mind and to manage risks associated with critical program information and mission-critical functions. The PPP outline identifies tasks a program should conduct at this point in the acquisition process. Systems engineers should (a) conduct an initial criticality analysis to identify mission-critical functions; (b) identify candidate-critical program information; (c) identify potential threats, vulnerabilities, and countermeasures; (d) develop the Cybersecurity Strategy; and (e) document the findings within the PPP (Kendall, 2011b).

Early technical work is critical to provide the program manager with the initial system requirements, technology, and development considerations and risks.

Activity 5: Establish program framework and strategies. Concurrent with operational and engineering analysis, the program team determines the overall acquisition strategy and program framework driving the technical effort in later phases. This strategy may include plans for technology development, competitive prototyping, test and evaluation, and management of systems engineering processes, among others.

Comprehensive program and technical planning includes several basic program planning elements, which all programs should address and document in the appropriate Milestone A documents: AS, SEP, TEMP, PPP, and LCSP. These planning elements are based on the expected content for each planning document, according to approved outlines (Kendall, 2011a, 2011b, 2011c).

The MSA Phase Activity Model contains 11 tasks required to establish the program's acquisition strategy and management framework, which map directly to the planning elements discussed in this section. These tasks span multiple disciplines and include, among others, defining the program management approach (i.e., managing schedule and resources); developing

the systems engineering approach for technology maturation, design, and development; defining plans to manage key interfaces (both technical and programmatic); and defining plans and processes to manage risks.

Activity 6: Prepare for Milestone A and TMRR phase. Finally, the program pulls together the technical and programmatic analysis and coherent set of plans and technical data developed throughout the MSA phase to satisfy the review criteria for Milestone A. This activity includes supporting the development of program documents required at Milestone A (e.g., SEP, AS, PPP, etc.), providing technical content for the RFP package for the TMRR phase, and supporting other contracting activities with technical considerations. In preparation for the Milestone A Defense Acquisition Board, the program should anticipate several key questions, including what has the program learned during the MSA phase, how will the program apply this knowledge going forward, and why is the program ready to proceed into the recommended next phase?

The primary RFP technical content is contained in the system performance specification, Statement of Work, technical evaluation criteria, and the Contract Data Requirements List. The program office and DoD Component may conduct a government-only requirements review to agree on the performance specification requirements to be included in the RFP and their traceability back to the draft CDD.

Other operational analysis is conducted during the MSA phase with a focus on the preferred materiel solution, and its operational context and constraints. This activity, along with any necessary update to the results and recommendations of the AoA study, is captured in a draft CDD. The draft CDD should contain at least the following sections (CJCS, 2015b):

- Operational Context, with focus on the operational context and the CONOPS.
- Capability Discussion, with focus on previously validated capability requirements being addressed in the draft CDD.
- Program Summary, with focus on the synchronization of SoS efforts across other CDDs, Capability Production Documents, and Joint DCR.
- Development KPPs, KSAs, and APAs, with a focus on the initial/draft performance attributes resulting from the AoA or other studies/analyses.

- Other System Attributes, with a focus on attributes that require significant TMRR phase efforts.
- Technology readiness assessment, with a focus on identifying critical technologies that need to be matured during the TMRR phase.

This activity ends with a successful Milestone A decision, which authorizes the program to enter the TMRR phase and grants funding to complete TMRR activities.

Conclusions

The DoD recently revised and reissued the information required to support the MDA's deliberations at Milestone A to approve a program's transition to the next phase (DoD, 2015). These milestones and phase information requirements provide confidence to the decision authority that thoughtful and comprehensive plans are in place. For this to occur, resources must be provided to perform the activities to analyze and determine strategies and plans from multiple perspectives (i.e., requirements, costs, trade-offs, risks, etc.) The DPWG developed a coherent and complete set of technical activities that provides context beyond systems engineering, but also details the systems engineering activities that bridge the gap between the AoA and the milestone and phase information requirements for the selected solution to be presented at Milestone A. This activity model can be used to estimate and justify the resources needed to successfully transition from the selection of a preferred solution through a favorable Milestone A decision.

As informed as this MSA activity model is, more research could be performed to move toward evidence-based policy in the DoD. For example, the plans, specifications, and other information requirements needed for Milestone A are a necessary, but not sufficient, element of a program's success. Given the complexity of today's MDAPs, acquisition timelines are measured in years, not months. It may be reasonable to focus some research on evaluating the correlation between perceived program success coming out of a system-level PDR and the program's plans previously established at Milestone A.

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Appendix A

2008 NRC Study Findings and Recommendations

At the request of the Air Force, the National Research Council conducted a retrospective study in 2008 examining the role that systems engineering can play during the defense acquisition life cycle in addressing the root causes of program failure, especially during the pre-Milestone A and early phases of a program. Paul G. Kaminski and Lester L. Lyles led a committee that produced findings (i.e., conclusions) and recommendations based on case studies of eight Air Force MDAPs and on the subject matter expertise of the committee members. The study found early systems engineering processes and functions were essential to ensuring programs deliver products on time and on budget, but that current implementation of early systems engineering in the Air Force was unstructured and inconsistent. Their report made seven recommendations, of which two are relevant to systems engineering processes and activities. These two are highlighted in the complete list of recommendations below.

RECOMMENDATIONS

Ch 3 SYSTEMS ENGINEERING WORKFORCE

The Air Force should assess its needs for officers and civilians in the systems engineering field and evaluate whether either its internal training programs, ..., or external organizations are able to produce the required quality and quantity of systems engineers and systems engineering skills.

The Air Force should support an internal systems engineering career track that rewards the mentoring of junior systems engineering personnel, provides engineers with broad systems engineering experience, provides appropriate financial compensation to senior systems engineers, and enables an engineering career path into program management and operations.

Decisions made prior to Milestone A should be supported by a rigorous systems analysis and systems engineering process involving teams of users, acquirers, and industry representatives.

Ch 4 SYSTEMS ENGINEERING FUNCTIONS AND GUIDELINES

The Air Force leadership should require that Milestones A and B be treated as critical milestones in every acquisition program and that a checklist such as the "Pre-Milestone A/B Checklist" suggested by the committee be used to judge successful completion.

The committee believes that the Air Force should strive to structure major development programs so that initial deployment is achieved within, say, 3 to 7 years.

RECOMMENDATIONS, CONTINUED

Ch 4 SYSTEMS ENGINEERING FUNCTIONS AND GUIDELINES

The committee recommends that the Air Force place great emphasis on putting seasoned, domain-knowledgeable personnel in key positions—particularly the program manager, the chief system engineer, and the person in charge of “requirements”—and then empower them to tailor standardized processes and procedures as they feel is necessary.

A development planning function should be established in the military departments to coordinate the concept development and refinement phase (now Materiel Solution Analysis and Technology Maturation and Risk Reduction phases) of all acquisition programs to ensure that the capabilities required by the country as a whole are considered and that unifying strategies such as network-centric operations and interoperability are addressed.

Of their 24 findings, 15 are associated with the two highlighted recommendations above and are directly relevant to systems engineering processes and activities.

Chapter	Findings
Chapter 2 Relationship Between Systems Engineering and Program Outcome	<p>There is a need to establish and nurture a collaborative user/acquirer/industry team pre-Milestone A to perform system trade-offs and manage overall system complexity.</p> <p>One must clearly establish a complete and stable set of system-level requirements and products at Milestone A.</p> <p>It is necessary to manage the maturity of technologies prior to Milestone B and to avoid reliance on immature technologies.</p>
Chapter 3 Systems Engineering Workforce	<p>The government, Federally Funded Research and Development Centers, and industry all have important roles to play throughout the acquisition life cycle of modern weapon systems.</p> <p>The source selection for system development and demonstration (now Engineering, Manufacturing and Development [EMD]) should not be made until after the work associated with Milestones A and B is complete.</p> <p>Working together, government and industry can develop and explore solutions using systems engineering methodology to arrive at an optimal systems solution.</p>

Chapter	Findings
Chapter 4 Systems Engineering Functions and Guidelines	<p>There must be tight collaboration between user and developer in all pre-Milestone A activities, especially in all systems engineering activities.</p>
	<p>Attention to a few critical systems engineering processes and functions, particularly during preparation for Milestones A and B, is essential to ensuring that Air Force acquisition programs deliver products on time and on budget.</p>
	<p>The development time issue is addressable by applying systems engineering to key risk drivers, technology maturity, and external interfaces before Milestones A and B.</p>
	<p>The definition of clear Key Performance Parameters (KPP) by Milestone A and clear requirements by Milestone B that can remain stable through Initial Operational Capability (IOC) can be essential to an efficient development phase.</p>
	<p>It is also important that critical technologies be sufficiently mature prior to starting System Development and Demonstration (now EMD).</p>
	<p>The committee observed that although today's systems are not necessarily more complex internally than those of 30 years ago, their external complexity often is greater, because today's systems are more likely to try to meet many diverse and sometimes contradictory requirements from multiple users. This kind of complexity can often lead to requirements being changed between Milestone B and IOC, and it can lead to relying on immature technology.</p>
	<p>The committee believes that the accumulation of processes and controls over the years—well meant, of course—has stifled domain-based judgment that is necessary for timely success. Formal systems engineering processes should be tailored to the application. But, they cannot replace domain expertise.</p>
	<p>Identification of alternatives, of risk drivers, and of external interfaces should be completed before the Analysis of Alternatives (AoA).</p>
	<p>Many aspects of KPPs, Concept of Operations, cost and schedule, performance assessments, risk, and implementation strategy may be addressed after the AoA.</p>

Appendix B

2014 National Research Council Study Findings and Recommendations

In 2013, the Air Force Studies Board of the National Research Council sponsored the committee on Improving the Effectiveness and Efficiency of U.S. Air Force Pre-Acquisition Development Planning, led by Claude Bolton and Paul Kaminski. The committee was asked to provide recommendations on the following topics:

1. How can development planning be improved to help improve near-term acquisition decisions?
2. How can development planning be improved to help concepts not quite ready for acquisition become more mature, perhaps by identifying the need for more engineering analysis, hardware prototyping, etc.?
3. How can development planning be improved to enable the development of corporate strategic plans, such as science and technology investment roadmaps, Major Command capability roadmaps, workforce development plans, etc.?
4. How can development planning be used to develop and train acquisition personnel?

The committee's report, issued in 2014, provided the following recommendations. Those recommendations that are relevant to pre-Milestone A systems engineering processes and activities, or to adequate funding of these activities, are highlighted.

Recommendation 1. The Air Force should redefine development planning as “a key process to support the Secretary of the Air Force and the Chief of Staff of the Air Force in strategic decisions that guide the Air Force toward mission success today and in the future, within available funds and with acceptable risk.”

Recommendation 2. The Chief of Staff of the Air Force and the Secretary of the Air Force should claim ownership of development planning in the Air Force and provide top-level guidance and leadership to all Air Force organizations

responsible for carrying out development planning. This leadership should encourage and facilitate interaction among these organizations.

Recommendation 3. The Air Force should enhance its strategic planning and programming process with a Chief of Staff of the Air Force planning team function that reports to the Chief of Staff of the Air Force with the primary responsibility for integrating development planning across Air Force core functions and coordinating it with Core Function Leads.

Recommendation 4. The Air Force should develop and standardize the use of capability collaboration teams across all Service core functions as a means to facilitate development planning.

Recommendation 5. The Air Force should align adequate resources to ensure the success of the Chief of Staff of the Air Force planning team and its interactions with the capability/collaboration teams to enhance Air Force development planning. The key element of the development planning process provided by the Deputy Chief of Staff for Operations, Plans and Requirements, is the targeted Core Function Support Plan, which starts with the 12 Core Function Leads identifying and prioritizing capability gaps. The resources needed should provide focused support from the Core Function Leads; the necessary analytical and technical capabilities of the personnel comprising and supporting the Chief of Staff of the Air Force planning teams and the capability collaboration teams; and the financial means to achieve the desired planning analysis and recommendations.

Recommendation 6. The Secretary of the Air Force and the Chief of Staff of the Air Force should emphasize development planning as a key workforce development tool for Air Force science and technology, acquisition, and operational personnel. In emphasizing this development, lessons learned from initiatives such as the U.S. Special Operations Command GHOST (Geurts Hands-On Support Team) initiative and its related “Revolutionary Acquisition

Techniques Procedure and Collaboration” forum should be captured and examined for application to the broader development planning tool set. In this sustained emphasis on development planning, analytical skills, technical innovation, concept development, systems engineering rigor, and excellence become part of the broader Air Force culture.

Recommendation 7. The Air Force should periodically assess how well development planning is meeting its overall objective of providing the necessary support for the strategic decisions that guide the Air Force toward mission success, within available funds and with acceptable risk. A systematic approach would include identifying weaknesses, shortcomings, and failures; the causes of these; and ways to address them in the next stages.

Their recommendations are drawn from a set of conclusions based on the subject matter expertise of committee members and interviews with Service leaders, representatives from three Air Force major commands, and two Air Force product centers where development planning takes place. The conclusions are summarized below.

CONCLUSIONS

Lack of focused responsibility, capability, and funding for cross-core function analysis and trade-offs has limited the effectiveness of Air Force Development Planning (AF DP).

The amount of program element funding for development planning is insufficient to perform effective DP.

AF DP is not effective at leveraging promising low-Technology Readiness Level laboratory-developed technology.

Air Force Science and Technology (AF S&T) planning process is insufficiently mature to demonstrate how S&T investments should best be linked to prioritized Air Force needs.

AF DP is not effective at leveraging industry Independent Research and Development investments.

AF DP recognizes the increasing importance of the cyber domain, but lacks the priority, policies, flexibility, and procedures in the development planning and end-to-end acquisition processes to address the cyber security topic effectively.

AF DP does not always help improve near-term acquisition decisions.

CONCLUSIONS, CONTINUED

AF DP does not always help mature pre-acquisition concepts by identifying specific needs for more engineering analyses, prototyping, and technology development, among other factors.

AF DP is not adequately influencing S&T, acquisition, and operational workforce development.

The key element of the development planning process provided by the Deputy Chief of Staff for Operations, Plans and Requirements, is the targeted Core Function Support Plan, which starts with the 13 core function lead integrators identifying and prioritizing capability gaps.

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