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Defining a Model-Based Systems Engineering Approach for Systems Engineering Technical Reviews

Warren Vaneman—has more than 32 years of leadership and systems engineering experience from various positions within the intelligence community, including as Chief Architect of the Enterprise Ground Architecture at the National Reconnaissance Office. He is also a retired Navy Reserve Captain. He has a BS from the State University of New York Maritime College, an MS in systems engineering and a PhD in industrial and systems engineering from Virginia Tech, and a Joint Professional Military Education Phase 1 Certificate from the Naval War College. The International Council on System Engineering (INCOSE) certifies him as a Certified Systems Engineering Professional (CSEP). [wvaneman@nps.edu]

Ron Carlson—served 26 years in naval aviation as a pilot, seven years of which were at NAVAIR where he led NAVAIR Systems Engineers through several years of systems engineering revitalization. He joined the NPS SE department 10 years ago. He has a Master of Philosophy in Systems Engineering from Stevens Institute of Technology, master's degrees in strategic studies and national policy from the Naval War College and business administration–aviation from Embry Riddle Aeronautical University, and his Bachelor of Science in nuclear engineering from the University of Michigan. [rrcarlso@nps.edu]

Abstract

The DoD Digital Engineering Strategy calls for formalized planning, development, integration, management, and use of models to support systems engineering activities and decision-making across the lifecycle. As DoD organizations migrate to a Model-Based Systems Engineering (MBSE) environment, efficiencies will be gained by making the model the focus of engineering development activities throughout the engineering and acquisition lifecycle. Technical reviews will be key benefactors of this environment because model-based reviews allow for complexity to be managed more efficiently, and data, in lieu of "systems engineering products," will be the commodity used to evaluate the technical review criteria. Current technical reviews are based around lengthy reviews of static, contractually obligated documents that are used to demonstrate successful completion of the review criteria. MBSE technical reviews will provide greater insight with faster comprehension for the details across a program's lifecycle. This will not only provide efficiencies for the review, but will also improve the program's cost and schedule efficiency. This paper presents preliminary findings from our ongoing research by discussing the systems engineering activities that are performed during the system acquisition lifecycle and technical reviews from an MBSE perspective. These activities will then be evaluated to see how MBSE will complement technical reviews.

Introduction

> "Advancements in computing, modeling, data management, and analytical capabilities offer great opportunities for the engineering practice. Applying these tools and methods, we are shifting toward a dynamic digital engineering ecosystem. This digital engineering transformation is necessary to meet new threats, maintain overmatch, and leverage technology advancements."
>
> —Kristin Baldwin, Acting Deputy Assistant Secretary of Defense for Systems Engineering (DASD[SE], 2018)

Model-based processes are one of the most widely-discussed issues within the Department of Defense (DoD) today. The DoD Digital Engineering Strategy (2018) provides a vision on how the DoD will modernize, develop, deliver, operate, and sustain systems.

This strategy is important because advances in technology have led to larger and more complex systems. This implies a need for a clear, concise way to express the system design (clear, logically consistent semantics), and a need to represent systems differently to account for emergent behavior within the system due to the increased complexity.

The Digital Engineering Strategy provides five goals (DASD[SE], 2018).[1] This paper is the first step in defining a Model-Based Systems Engineering[2] (MBSE) approach for Naval Systems Engineering Technical Reviews. While our research will likely address each of the five goals, the most significant goal for this paper is as follows (DASD[SE], 2018):

Goal 1: Formalize the Development, Integration, and Use of Models to Inform Enterprise and Program Decision-making.

- 1.1 Formalize the planning for models to support engineering activities and decision-making across the lifecycle.
- 1.2 Formally develop, integrate, and curate models.
- 1.3 Use models to support engineering activities and decision-making across the lifecycle.

There is a strong need to ensure that the systems engineers and stakeholders understand the different model types and what information can be gleaned from them. When developed properly, models can provide a precise virtual representation of the functional, physical, parametric, and program entities of the systems. Increased emphasis is on the model itself, specifically the objects and relationships it contains, rather than the diagram to encourage better model development, usage, and decision-making. To enable this, new policies must be established to defined model-based processes, and governance of the authoritative source of truth—often known as the single source of technical truth.

Our ongoing research is defining how DoD organizations can conduct milestone reviews in a MBSE-environment. This effort requires an examination of current technical review processes; a derivation of new MBSE processes that will provide the requisite system and programmatic information to satisfy the review criteria; and a demonstrated model-based technical review environment. This paper takes the first step. The next section discusses the essence of MBSE. Then we provide a framework that establishes the relationships between key elements that are used for system definition and development, and establishes the framework from which technical reviews in a MBSE environment can be addressed. The next section provides a background of technical reviews. The last section provides our initial conclusion, and the direction for our research.

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[1] GOAL 1: Formalize the development, integration, and use of models to inform enterprise and program decision-making.
GOAL 2: Provide an enduring, authoritative source of truth.
GOAL 3: Incorporate technological innovation to improve the engineering practice.
GOAL 4: Establish a supporting infrastructure and environments to perform activities, collaborate, and communicate across stakeholders.
GOAL 5: Transform the culture and workforce to adopt and support digital engineering across the lifecycle.

[2] For the purpose of this paper, the terms “Model-Based Systems Engineering” and “Digital Engineering” will be considered synonymous. Model-Based Systems Engineering is defined in the second section.

The Essence of Model-Based Systems Engineering

The objective of systems engineering is to facilitate a process that consistently leads to the development of successful systems (Long & Scott, 2011). Model-Based Systems Engineering (MBSE) was envisioned to transform the reliance of traditional document-based work products to an engineering environment based on models. Model-Based Systems Engineering is the formalized application of modeling (static and dynamic) to support system design and analysis, throughout all phases of the system lifecycle, through the collection of modeling languages,[3] structures,[4] model-based processes,[5] and presentation frameworks[6] used to support the discipline of systems engineering in a model-based or model-driven context (Vaneman, 2016).

One can argue that systems engineering has always used models (i.e., diagrams, documents, matrices, tables, etc.) to the represent systems. In these traditional document-based models, the system's entities were represented multiple times, making it difficult, if not impossible, to view the system holistically. The transformation to MBSE means more than using model-based tools and processes to create document-based models, but shifts the focus to a virtual system model of the system, where there exists a singular definition for any system element.

To illustrate the concept of a virtual model of system, consider the dimensions of a systems engineering project (Figure 1; Larson et al., 2013; Vaneman & Vaneman 2018), where the cube represents a system. The system has height, width, and depth. System height provides a decomposition from the highest system level down to components and parts. System width defines the lifecycle of the system, and provides insight across the entire system lifecycle from concept definition to disposal. System depth provides the complex relationships between systems, functions, requirements, and so forth. The system

- satisfies capabilities;
- performs functions and has behavior;
- is defined by requirements;
- is testable;
- has risks; and

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[3] Modeling Languages—Serve as the basis of tools and enable the development of system models. Modeling languages are based on a logical construct (visual representation) and/or an ontology. An ontology is a collection of standardized, defined terms and concepts and the relationships among the terms and concepts.

[4] Structure—Defines the relationships between the system's entities. It is these structures that allow for the emergence of system behaviors and performance characterizations within the model.

[5] Model-Based Processes—Provides the analytical framework to conduct the analysis of the system virtually defined in the model. The model-based processes may be traditional systems engineering processes such as requirements management, risk management, or analytical methods such as discrete event simulation, systems dynamics modeling, and dynamic programming.

[6] Presentation Frameworks—Provides the framework for the logical constructs of the system data in visualization models that are appropriate for the given stakeholders. These visualization models take the form of traditional systems engineering models. These individual models are often grouped into frameworks that provide the standard views and descriptions of the models, and the standard data structure of architecture models. The Department of Defense Architecture Framework (DoDAF) is an example.

- incurs costs.

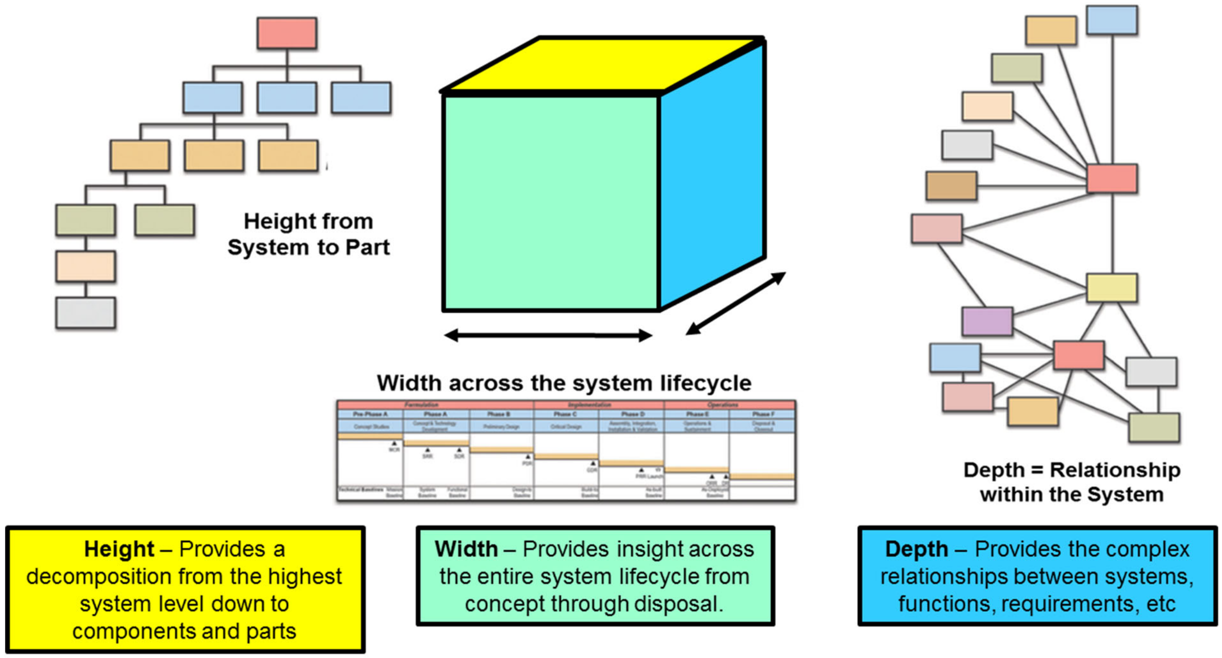

Figure 1. Dimensions of a Systems Engineering Project
(Larson et al., 2013; Vaneman & Vaneman, 2018)

In this virtual system model, each entity is represented as data, ideally only once, with all necessary attributes and relationships of that entity being portrayed. The key to defining this virtual system is model structure. Model structure defines the relationships between the system's entities, establishes concordance[7] within the model, and allows for the emergence of system behaviors and performance characterizations within the model (Vaneman, 2016).

To use the system entities to make programmatic decisions, the area of system focus must be isolated and portrayed in a manner so that decision-makers can arrive at an answer and make decisions. In MBSE, this is accomplished through the presentation framework, which provides the logical constructs of the system data in visualization models that are appropriate for the given stakeholders. These visualization models take the form of traditional systems engineering models, and are often grouped into standard viewpoints[8] and views[9]. The standard framework within the DoD is the Department of Defense Architecture Framework (DoDAF; Dam, 2014).

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[7] Concordance (or referential integrity) is the ability to represent entity data so that it is consistent across views and abstraction levels (Vaneman, 2016).
[8] A viewpoint describes data drawn from one or more perspectives and organized in a particular way useful to decision-making.
[9] A view is a related set of information using models for the representation of data in any understandable format.

DoDAF defines eight viewpoints (Figure 2; Dam, 2014) and 52 views. The framework provides the flexibility for other "fit for purpose" views to be defined as needed to address a problem, provided that the spirit of the viewpoint is maintained.

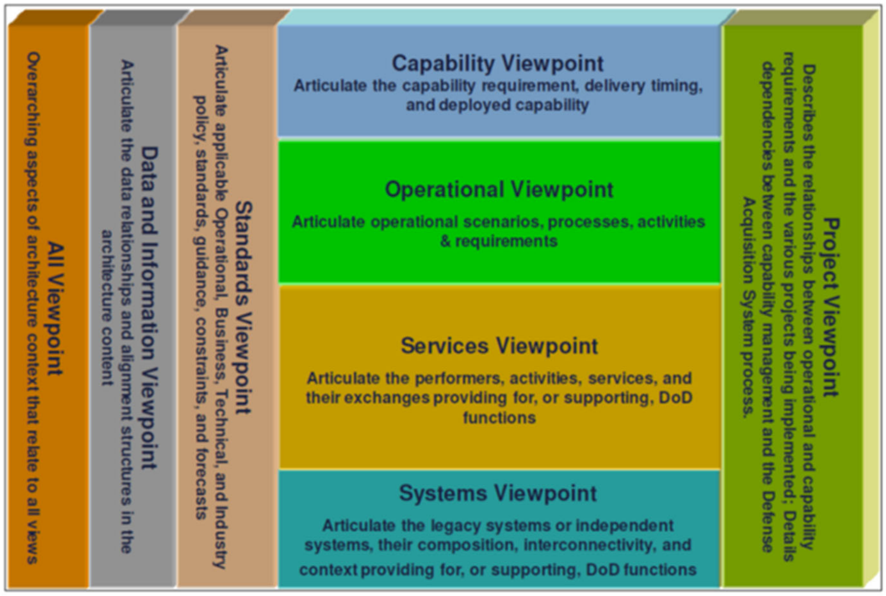

Figure 2. DoD Architecture Framework
(Dam, 2014)

This is an important feature of DoDAF since the framework only covers the architectural perspectives of the system, and does not include other system perspectives encountered throughout the lifecycle such as behavior, requirements, risks, verification and validation, and costs.

The 52 different DoDAF views can be represented in a document-based systems engineering environment. In such an environment, the diagram, not the system entities, becomes the "atomic" level and do not contain structure, and therefore lack concordance. In a MBSE environment, the system entities are at the "atomic" level, are related by structure, have concordance, and are represented in the 52 views.

These MBSE concepts represent a fundamental change in the systems engineering discipline, practices, and processes because they allow for the precise representation of the system's entities and attribute, and through model structure, provide concordance. Complexity in the model-based environment is significantly reduced by separating and characterizing systems issues into various entity-based viewpoints and views. As such, MBSE requires a mindset change, a change in systems engineering processes, and a change in expectations of the artifacts required during the systems engineering process.

MBSE Development Throughout the System Acquisition Lifecycle

The DoD Digital Engineering Strategy Goal 1 calls for formalized planning, development, integration, management, and use of models to support engineering activities and decision-making across the lifecycle (DASD[SE], 2018). The realization of these goals will satisfy the transformation from the traditional document-based, to a model-based, systems engineering environment. This requires a fundamental shift in the development and use of engineering data to support system and programmatic decisions. In this environment, the model becomes central to the engineering of systems, and ultimately the way that decisions are made.

The System Acquisition Lifecycle Model identifies five primary phases, which take the system from concept develop and materiel solution analysis through operations and support. These phases, with their associated technical reviews, are briefly described in Table 1 (derived from Manning, 2019). The first three phases of the system acquisition lifecycle, through Engineering and Manufacturing Development culminating with Acquisition Milestone C, is where the most significant systems engineering activities occur. Implementing MBSE during later phases of the system acquisition lifecycle is possible, but programs should consider model adoption carefully. Beaufait (2018) demonstrated that MBSE can benefit programs post-Milestone C; however, introducing MBSE that far into the lifecycle of the program will face challenges related to cost, schedule, and a lack of understanding of MBSE. At this stage of the program, the implementation of MBSE has an additional cost that is likely not planned in the budget, and skeptical program managers are reluctant to make that investment in exchange for the promised benefits of MBSE (Beaufait, 2018).

The following discussion addresses model-development across the system acquisition lifecycle through Engineering and Manufacturing Development. Figure 3[10] is a relationship diagram that will be used to depict and explain model development and use throughout the lifecycle. While various DoDAF views and other systems engineering artifacts are shown in the diagram, the instantiation of these views only represents how the system data will be displayed within the presentation framework. Again, in an MBSE environment, the system is represented virtually; therefore, the data and relationships, not the views, are the "atomic" level of detail.

The System Lifecycle Model During the Materiel Solution Analysis Phase

The Materiel Solution Analysis (MSA) Phase assesses potential solutions for a needed capabilities identified by the stakeholder and formally documents in the Initial Capabilities Document (ICD). During this phase, various alternatives are analyzed to select the materiel solution and develop the strategy to fill any technology gaps. This phase describes the desired performance to meet mission requirements, defines metrics, identifies the operational requirements needed to satisfy the capabilities, and provides an initial analysis of risks (Manning, 2019).

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[10] Figure 3 is meant to be viewed digitally so that it can be expanded.

Table 1. Summary of the DoD System Acquisition Lifecycle Phases

Lifecycle Phase	Description of the Lifecycle	Technical Reviews within Lifecycle
Materiel Solution Analysis (MSA)	MSA assesses potential solutions for a needed capability in an Initial Capabilities Document (ICD) The MSA phase is critical to program success and achieving materiel readiness because it's the first opportunity to influence systems supportability and affordability by balancing technology opportunities with operational and sustainment requirements.	• Initial Technical Review (ITR) • Analysis of Alternatives (AoA) • Alternative System Review (ASR) ♦ **Milestone A**
Technology Maturation and Risk Reduction (TMRR)	The purpose of TMRR is to reduce technology risk, engineering integration, lifecycle cost risk and to determine the appropriate set of technologies to be integrated into a full system. The TMRR phase conducts competitive prototyping of system elements, refines requirements, and develops the functional and allocated baselines of the end-item system configuration.	• System Requirement Review (SRR) • System Functional Review (SFR) • Preliminary Design Review (PDR) ♦ **Milestone B**
Engineering and Manufacturing Development (EMD)	EMD is where a system is developed and designed before going into production. The phase starts after a successful Milestone B - the formal start of any program. The goal of this phase is to complete the development of a system or increment of capability, complete full system integration, develop affordable and executable manufacturing processes, complete system fabrication, and test and evaluate the system before proceeding into the Production and Deployment (PD) Phase.	• Critical Design Review (CDR) • Test Readiness Review (TRR) ♦ **Milestone C**
Production and Development (PD)	PD is where a system that satisfies an operational capability is produced and deployed to an end user. The phase has two major efforts; (1) Low-Rate Initial Production (LRIP) and (2) Full-Rate Production and Deployment (FRP&D). The phase begins after a successful Milestone C review.	• Full Rate Production (FRP) • Initial Operational Capability (IOC) ♦ **Full Operational Capability (FOC)**
Operation and Support (OS)	OS is where a system that satisfies an operational capability is produced and deployed to an end user. The phase has two major efforts: (1) Low-Rate Initial Production (LRIP) and (2) Full-Rate Production and Deployment (FRP&D). The phase begins after a successful Milestone C review	• Sustainment ♦ **Disposal**

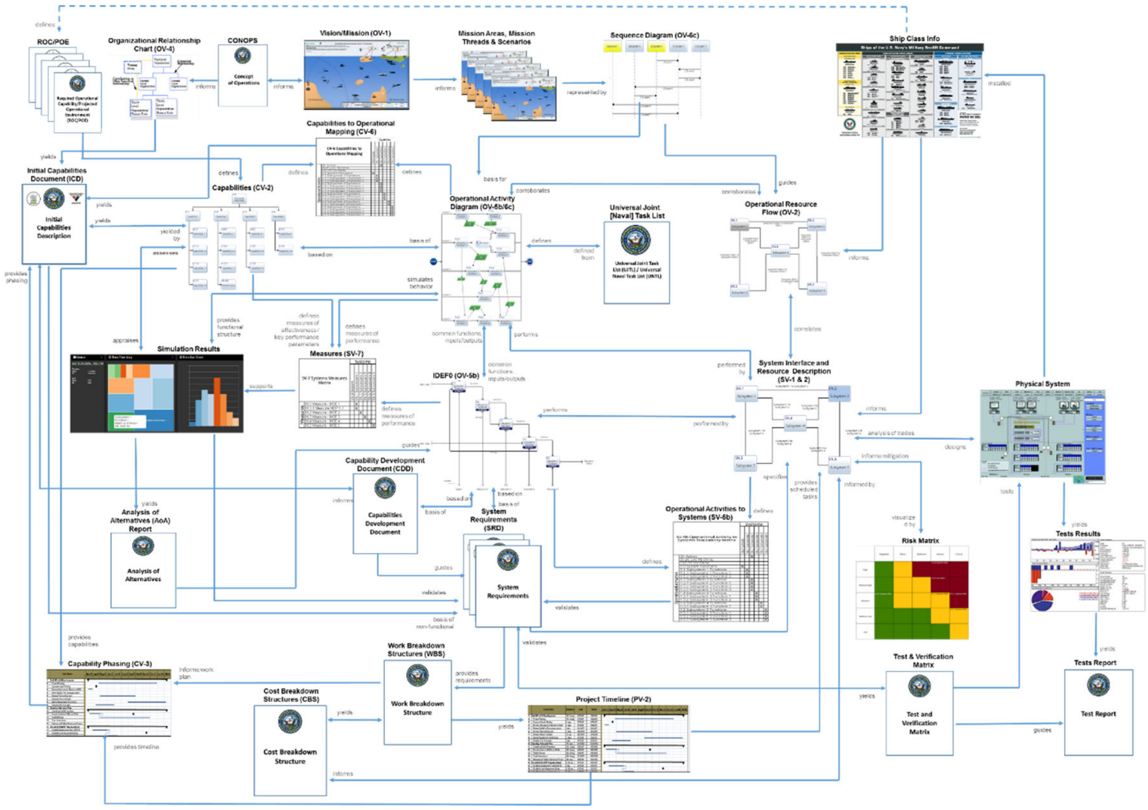

Figure 3. MBSE Development Process

The MSA process (see Figure 3) begins with the identification of stakeholder-needed capabilities, often contained in the Required Operational Capability/Projected Operational Environment (ROC/POE) documents. Often a system will be governed by multiple ROC/POE documents due the breadth of the future system deployment. The ROC/POE serves as the basis for the Capability Taxonomy (CV-2), the beginning of the modeling effort. Many ROC/POEs capture the majority of the capabilities to be satisfied, however, usually does not contain all of them.

The Concept of Operations (CONOPS), often provided by the stakeholders, provides additional insights into the capabilities required. The CONOPS often includes an overarching High-Level Operational Concept Graphic (OV-1), which shows an overview of the operational concept, as well as the vision and mission of the system. The CONOPS usually identifies mission areas that contain mission threads and scenarios. The mission threads can be represented in scenario-focused OV-1. These OV-1s offer sufficient detail to visualize the steps of the operations. These mission threads can be further represented by sequence diagrams (OV-6c). The OV-6c serves as the basis for the Operational Activity Model (OV-5b-6c).

The OV-5b/6c is a fit for purpose view that represents the sequence of functions as well as the inputs and outputs for each function. The functions in the OV-5b/6c are the same functions contained in the OV-6c, viewed from a different perspective. The functions can be grouped by the subsystem that they are assigned to. The OV-5b/6c can be further developed by information from the Universal Joint Task List (UJTL).

The operational entities depicted in the OV-5b/6c are based on the capability entities depicted in the CV-2. Thus, function *x* is based on capability *y.* These relationships are shown in the Capabilities to Operational Mapping (CV-6). Using the Organizational

Relationship Chart (OV-4), the initial Capability Phasing (CV-3), the CV-2, and the CV-6, the ICD can be defined. In a MBSE environment, the ICD is an integral part of the model and thus has concordance with the views used to portray it.

The functions contained in the OV-5b/6c can be viewed differently by using the IDEF0 (OV-5b). The functional entities in the OV-5b are the same functional entities in the OV-5b/6c. These entities are only represented once on the model, but can be viewed in several different ways, thus the model exhibits concordance. The OV-5b also contains the inputs and outputs included in the OV-5b/6c. The OV-5b goes further in capturing system data by identifying the policies, guidelines, rules, and regulations that govern the functions. This view also initially identifies the system elements and relates them to the functions that they satisfy.

With the data captured thus far, two additional complimentary views—the Operational Resource Flow (OV-2) and the System Interface Description (SV-1)—can be developed. Both of these views have a common structure that depicts the system elements that were first identified in the OV-5b. The connections in the OV-2, influenced by the functions in the OV-5b/6c, represent the data, and data characteristics (i.e., direction of flow, type, size, frequency, and duration), that flow between two system elements. The connections in the SV-1 represent the physical means (e.g., pipes, data links) by which data is transferred. The OV-2 defines the “what” that needs to be transferred, and is correlated to SV-1, which shows “how” the data is transferred.

With the data developed to this point, system measures can be defined in the Systems Measures Matrix (SV-7). The Measures of Effectiveness (MOE) and the Key Performance Parameters (KPP) are defined by the capabilities depicted in the CV-2. The Measures of Performance (MOP) are derived by the operational entities depicted in the OV-5b and OV-5b/6c.

At this point, the data captured can be used to perform the analysis of alternatives (AoA). An AoA typically consist of the initial assessment of three areas—cost, risk, and performance. The system entities are related to operational entities via the OV-5b, and risk, and initial costs, in the SV-1. System performance is represented mathematically within the operational entities. Many MBSE tools allow for these entities to be defined by several statistical distributions, thereby allowing for discrete event and Monte Carlo Simulation.

The last activity engineered in the MSA is development of the draft Capabilities Development Document (CDD). The CDD specifies the operational requirements for the system that will deliver the capabilities, that meet the operational performance requirements, specified in the ICD, and depicted by the entities developed thus far (Manning, 2019). The primary views used to develop the CDD are the CV-2 and OV-5b.

Milestone A marks the end of the MSA Phase. The purpose of Milestone A is to make recommendations and seek permission to enter the Technology Maturation and Risk Reduction (TMRR) Phase (Manning, 2019).

The System Lifecycle Model During Technology Maturation and Risk Reduction

The purpose of the Technology Maturation & Risk Reduction Phase is to reduce risks associated with technology, integration, and lifecycle cost, determine the appropriate set of technologies to be integrated into a full system, validate designs and costs, and evaluate manufacturing processes for the system build. TMRR refines requirements, conducts competitive prototyping of system elements, and develops the functional and allocated baselines of the final system configuration (Manning, 2019).

The modeling process (see Figure 3) continues with the further development of the CDD. The CDD guides the development of the system requirements document (SRD). The SRD defines system level functional and performance requirements for a system (Manning, 2019). While the SRD is guided by the CDD in a document-based engineering environment, in a MBSE environment it is primarily derived from the OV-5b, SV-1, and the Operational Activities to Systems Matrix (SV-5b). As the system engineering effort progresses, these views are iteratively refined, with more detailed data being developed with each iteration, thereby allowing for a natural progression of the requirements hierarchy from ICD to the CDD, to the SRD, and ultimately to sub-system requirements documents.

In a MBSE environment, requirements are derived from the system-entity data, and corresponding relationships, in the model. The primary view to visualize the relationships used to derive functional requirements is the OV-5b. This view contains all of the data required (system elements, functions, inputs, outputs, controls) to generate requirements. The initial system structure also influences the system requirements.

The interfaces are defined via the SV-1. As previously stated, the flow interfaces between system elements in the OV-2 need to be correlated with the physical interfaces in the SV-1 to identify the proper interface requirements. The SV-5b is used to validate the system requirements by ensuring that each operation is satisfied by a system element, and each system element is assigned to to an operation. The draft CV-3, which was developed in MSA, is matured here.

A correllary to the SRD is the Test and Verification Matrix, which shows how the system will be tested. Developing a Test and Verification Matrix in conjunction with the SRD is a good practice that validates that the requirements can be tested as written.

Once a detailed set of requirments is defined, the Work Breakdown Structure (WBS) can be developed. A WBS is a tool used to define a project in discrete work elements. It relates the elements of work to be accomplished to each other and to the end product. It's used for planning, development of the Cost Breakdown Sructure (CBS), and the execution and control of the system development (Manning, 2019). The CBS allocates costs to the various levels of the WBS.

The WBS informs the development of the final Capability Phasing (CV-3). A Project Timeline (PV-2) is derived from the WBS. This view depicts the detailed schedule for system development.

During TMRR, the system in interatively developed, and a comprehensive risk assessment is conducted. The purpose of the risk assessment is to identify the root cause of cost, schedule, and performance issues within the systems. In a MBSE environment, the risks are related to system elements portrayted in the SV-1 and SV-2.

Towards the end of TMRR, system devlopment has sufficiently matured where three-dimensional models and prototypes are developed. TMRR ends with Milestone B, where the program office seeks approval to enter the Engineering and Manufacturing Development (EMD) Phase. Milestone B is considered the official start of the program (Manning 2019).

The System Lifeycle Model During Engineering and Manufacturing Development

Systems design and development continue with the Engineering and Manufacturing Development (EMD) Phase, where the system is developed and designed before going into production. The goal of EMD is to complete the development of a system or increment of capability, complete full system integration, develop affordable and executable manufacturing processes, complete system fabrication, and test and evaluate the system before proceeding into the Production and Deployment (PD) Phase (Manning, 2019).

EMD consists of two major efforts: integrated system design and system capability; and manufacturing process demonstration. These two major efforts integrate the end item components and subsystems into a fully operational and supportable system. They also complete the detailed design to meet performance requirements with a producible and sustainable design and reduce system level risk. EMD typically includes the demonstration of a production prototype (Manning, 2019).

During EMD, MBSE is used for further iterative developed. As the system models are refined and further developed, other models within the framework must be changed to represent the new system baseline. Different system components lead to different operations. As the system and operations are changed, the capabilities must be re-evaluated to ensure that they are still being satisfied. Changes in the system baseline also impact risks—maybe new risks emerge, or current risks are mitigated. The change in the system baseline will likely have an impact on both cost and schedule. Given that the MBSE environment exhibits concordance, when a change is made in a system element it is captured in the model and then the changed element is portrayed throughout the model and all of the different viewpoints.

The MBSE environment can also be used to support the testing and verification of the system. During the development of the SRD, a Test and Verification Matrix was developed. This Test and Verification Matrix can be used to develop a test plan, which can be executed throughout the test and verification process.

Milestone C marks the end of the EMD Phase. The purpose of Milestone C is to make a recommendation or seek approval to enter the Production and Deployment (PD) Phase (Manning, 2019).

The system model discussed in this section provides the data required to make programmatic decisions. The system model will be used in Section IV to address the criteria during the system milestones reviews.

Technical Reviews in an MBSE Environment

The DoD Digital Engineering Stategy Goal 1 specifically states that the model of the system should be used for decision-making. A series of decision-making events within the system acquisition lifecycle that could benefit from the MBSE approach are the system acquisition technical reviews.

System acquisition technical reviews are discrete points in time, within a system's lifecycle, where the system is evaluated against a set of program-specific accomplishments (criteria). These criteria are used to track the technical progress, schedule, and program risks. The technical reviews serve as gates, that when successfully evaluated, demonstrate that the program is on track to achieve its final program goals, and should be allowed to proceed to the next acquisition phase. Figure 4 shows the technical reviews superimposed on the Systems Acquisition Lifecycle Model (derived from Defense Acquisition University, 2018).

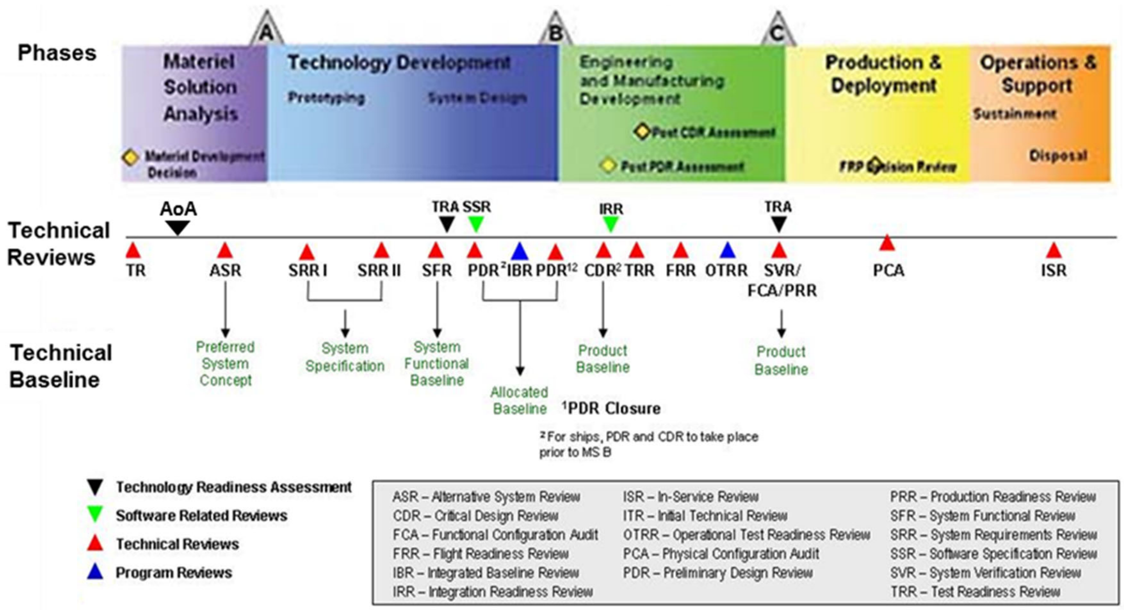

Figure 4. System Acquisition Lifecycle Model
(Adapted from Defense Acquisition University, 2018)

Currently, milestone reviews are based around lengthy reviews of static, contractually obligated documents that are used to demonstrate successful completion of the exit criteria. System documents and artifacts are baselined to represent the system and traditionally serve as evidence of programmatic progress. Typically, these documents are not synchronized, thus lack concordance. As discussed in the MBSE approach above, the "virtual" model of the system is created where each entity is ideally modeled once but represented several times. For technical reviews, the model-based data is depicted by views within a presentation framework, similar to a document-based review.

The difference in concordance is maintained, allowing decision-makers access to insights that have been heretofore unavailable. This includes emerging system behavior, and the assurance that a common system baseline is used to report on various aspects of the systems. Using the model as the source for decision-making throughout the system acquisition lifecycle is a significant departure since programs often generate unique artifacts for the sole purpose of the reviews.

Table 2 shows the applicability of model-based systems engineering views to the system acquisition lifecycle. The relationships in the matrix were made by correlating the generic criteria for each review, or content of the major documents, to the data in each system engineering view. The existing review criteria is designed to be addressed by document-based processes. These criteria need to be revised to account for the new insights that can be gleaned through a model-based approach.

As an example, consider the Alternative Systems Review (ASR). The ASR assesses the preliminary materiel solutions that have been developed during the Materiel Solution Analysis (MSA) Phase. The technical review ensures that one or more proposed materiel solution(s) have the best potential to be cost-effective, affordable, and operationally effective and suitable, and can be developed to provide a timely solution to at an acceptable level of risk to satisfy the capabilities listed in an Initial Capabilities Document (ICD; Manning, 2019).

Table 2. Applicability of Systems Engineering Views With the Systems Acquisition Lifecycle

	Materiel Solution Analysis			Technology Develoment				Engineering and Manufacturing Development			Documents			
Systems Engineering Views	Analysis of Alternatives (AoA)	Alternative Systems Review (ASR)	Milestone A	System Requirements Review (SRR)	System Functional Baseline (SFB)	Preliminary Design Review (PDR)	Milestone B	Critical Design Review (CDR)	Test Readiness Review	Milestone C	Initial Capabilities Document	Capability Development Document (CDD)	System Requirements Specifications	Test Report
CV-2	x	x		x							x	x		
CV-3	x	x		x							x	x		
CV-6		x		x							x	x		
OV-1	x	x		x							x	x		
OV-2	x	x		x								x	x	
OV-4		x		x							x	x		
OV-5b	x	x		x	x	x						x	x	
OV-5b/6c	x	x		x	x	x					x	x	x	
OV-6c	x	x		x	x	x					x	x	x	
PV-2					x	x		x						
SV-1	x	x		x	x	x		x	x			x	x	x
SV-2					x	x		x	x				x	x
SV-5b				x	x	x		x	x			x	x	x
SV-7	x	x		x	x	x		x	x			x		x
Cost Esttimate	x			x				x						
Risk Matrix	x	x			x	x		x						
Similation Results	x			x		x		x	x				x	x
Test and Verification Matrix						x		x	x					x
Test Results								x	x					x
Work Breakdown Structure					x	x		x						

The system engineering process typcially has progressed to the point where the following information is available for the ASR (TTCP, 2014):

- Description of how the users will conduct operations, and how they expect to use the new system in this context of major mission areas and scenarios;
- Statement of need, and capabilities, in terms oriented to the system users, the stakeholders, and independent of specific technology solutions;
- The required system characteristics and context of use of services and operational concepts are specified;
- Major stakeholder capabilities are identified and documented, but detailed system requirements analysis has yet to be completed;
- The constraints on a system solution are defined;
- Results of an analysis of alternatives with a recommended preferred solution;
- Initial plans for systems engineering (e.g., Overview and Summary information [AV-1], Systems Engineering Plan [SEP], Systems Engineering Management Plan [SEMP]) providing the notion of “how” this system can be realized, including the level of process and process maturity needed to generate a system of the required complexity;
- Initial definition of the environment and the characteristics of the threat;

- Initial test & evaluation strategy including test cases derived from user operational vignettes, concept of operations, and capability description;
- An understanding of where the greatest risks and challenges may reside.

An analysis of the ASR generic criteria (DAU, 2018) is shown in Table 3. First the criteria is reviewed in the context of traditional reviews. Many of the criteria were assessed to be partially satisfied. These results do not suggest that ASRs have not been performed properly in the past. Rather, given the absence of concordance in document-based reviews, the criteria requiring different types of data, using different artifacts is extrmely difficult to achieve efficiently and effectively. All of the criteria were assessed to be satisfied in MBSE environment because of the concordance. The model-based systems engineering views needed to address the criteria are also shown in the table.

Conclusions and Future Work

As DoD organizations migrate to the MBSE environment, efficiencies will be gained by transitioning from the document-based reviews to model-based reviews. Model-based reviews allow for complexity to be managed more efficiently because data, in lieu of "systems engineering products," is the commodity that will be used to evaluate the exit criteria. The MBSE milestone reviews will provide greater insight with faster comprehension of the details across a program's lifecycle. This will not only provide efficiencies for the review, but will also improve the program's cost and schedule efficiency.

This paper provided some additional concepts developed during the initial phase of our research. These concepts are in the spirit of the DoD Digital Engineering Strategy Goal 1: "Formalize the development, integration, and use of models to inform enterprise and program decision-making" (DASD[SE], 2018).

While Goal 1 became the natural focus, other goals need to be considered when developing processes to implement a true MBSE environment. The most signifiant goal is one that is often overlooked, Goal 5: Transform the culture and workforce to adopt and support digital engineering across the lifecycle.

The systems engineering culture must change to focus on the virtual model of the system, and away from technical documentation. This is critical when considering conducting technical review in an MBSE environment.

Table 3. ASR Criteria and Related Views

Criteria	Satisfied by Traditional Review?	Satisfied by MBSE?	Views
Is the initial CONOPS updated to reflect current user position about capability gap(s), supported missions, interfacing/enabling systems in the operational architecture?	Partial	Yes	CV-2, CV-6, OV-1, OV-6c, OV-5b/6c
Are the required related solutions and supporting references (ICD and CDDs) identified?	Partial	Yes	CV-2, CV-3, CV-6, OV-4, OV-5b, OV-5b/6c
Are the thresholds and objectives initially stated as broad measures of effectiveness and suitability (e.g., KPPs)?	Yes	Yes	CV-2, OV-5b, OV-5b/6c, SV-7
Is there a clear understanding of the system requirements consistent with the ICD?	Yes	Yes	CV-2, CV-3, CV-6, OV-4
Are high-level descriptions of the preferred materiel solution(s) available and sufficiently detailed and understood to enable further technical analysis in preparation for Milestone A?	Partial	Yes	OV-2, OV-5b, SV-1
Are interfaces and external dependencies adequately defined for this stage in lifecycle?	Partial	Yes	OV-2, SV-1
Are system requirements sufficiently understood to enable functional definition?	Partial	Yes	OV-5b, OV-5b/6c
Is a comprehensive rationale available for the preferred materiel solution(s), based on the AoA?	Partial	Yes	CV-2, CV-3, CV-6, OV-2, OV-4, OV-5b, OV-5b/6c.
Can the proposed material solution(s) satisfy the user needs?	Partial	Yes	CV-2, CV-3, CV-6, OV-2, OV-5b, OV-5b/6c.
Have cost estimates been developed, and were the cost comparisons across alternatives balanced and validated?	Partial	Yes	OV-2, OV-5b, SV-1
Have key assumptions and constraints associated with preferred materiel solution(s) been identified?	Partial	Yes	OV-2, OV-5b, SV-1

This paper considers systems engineering throughout the acquisition lifecycle using a model-based approach. While MBSE was discussed, and the underlying principles of capturing system elements only once and using model structure to establish concordance were briefly discussed, this research focused heavily on the information portrayed in the various views within the presentation framework. In a true MBSE environment, systems engineering will be conducted at the entity level, thus making the model the focus and the views secondary.

The systems engineering community has not widely considered the effects on making the model the focus. One area that is being explored by our ongoing research is how will the technical review criteria need to be changed to gain the full benefit of model-based insights.

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