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Evaluating Current Systems Engineering Models for Applicability to Model-Based Systems Engineering Technical Reviews

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Abstract

Program technical reviews are discrete points in time, within a system's life cycle, where the system is evaluated against a set of specific accomplishments, known as "entrance criteria." These entrance 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. Current technical reviews are based around lengthy evaluations of static, contractually obligated documents that are used to demonstrate successful completion of the entrance criteria. These documents represent "snapshots" of the systems as seen through the prism of the entrance criteria and do not represent a view of the system in its totality. As a result, the program, and system, is often viewed by the entrance criteria individually, which fails to account for the system from a holistic perspective. Department of Defense (DoD) organizations are migrating to Model-Based Systems Engineering (MBSE) environments, with a vision of modernizing, and better developing, delivering, operating, and sustaining systems. Model-based reviews allow for complexity to be managed more efficiently because data, not "systems engineering products," is the commodity that will be used to evaluate the entrance criteria. The data-driven MBSE technical reviews will provide greater insights with faster comprehension for the details across a program's life cycle. This paper highlights the results of our FY19 Acquisition Research Project. It discusses applicability of current technical review criteria to MBSE technical reviews.

Keywords: Technical Review, Model-Based Systems Engineering

Introduction

Model-based processes are one of the most widely-discussed issues within Department of Defense (DoD) today. For example, Model-Based Systems Engineering (MBSE) is a quarterly discussion at the Navy's Systems Engineering Stakeholders Group (SESG), and has been a tenant of the National Defense Industrial Association Systems Engineering and Mission Conference for the past several years. The DoD Digital Engineering Strategy (Deputy Secretary of Defense for Systems Engineering [SASD(SE)], 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.

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.

Our FY19 Acquisition Research Program (ARP) project developed the process for using MBSE to conduct a technical review. It demonstrated the benefits of MBSE with respect to establishing relationships between seemingly disparate portions of the system (e.g., operations and systems). These relationships yield behaviors that are not realized through document-based systems engineering. This portion of the research was presented by Vaneman and Carlson (2019) during the 16th Annual Acquisition Research Symposium and is further defined in Vaneman, Carlson, and Wolfgeher (2020).

The second part of the FY19 ARP project evaluated the suitability of current systems engineering models for MBSE technical reviews. This evaluation is the focus of this paper. The second section of this paper provides an overview of Systems Engineering Technical Reviews and serves as a point of departure of our evaluation. The third section discusses Systems Engineering Technical Reviews (SETR) in an MBSE environment. The fourth section discusses applicability of current technical review criteria to MBSE technical reviews.

Systems Engineering Technical Reviews

The System Acquisition Life-Cycle Model identifies five primary phases which take the system from concept development and material solution analysis through operations and support (Manning, 2019). Systems Engineering Technical Reviews (SETR) are discrete points in time, within a system's life cycle, during which the program is assessed against a set of program specific accomplishments (entrance criteria). The SETRs serve as gates, that when evaluated successfully, 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 1 shows the technical reviews superimposed on the Systems Acquisition Life Cycle Model (derived from Defense Acquisition University [DAU], 2018). The acquisition phases, with their associated technical reviews, are described in Table 1 (derived from Manning, 2019).

The technical reviews that were considered most likely to benefit from MBSE are conducted during the Materiel Solution Analysis (MSA), Technology Maturation and Risk Reduction (TMRR), and the Engineering and Manufacturing Development (EMD) Phases—the phases that lead to Milestone C. Beaufait (2018) studied the applicability of MBSE to programs post-Milestone C and concluded that MBSE can benefit programs post-Milestone C; however, introducing MBSE that far into the life cycle 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).

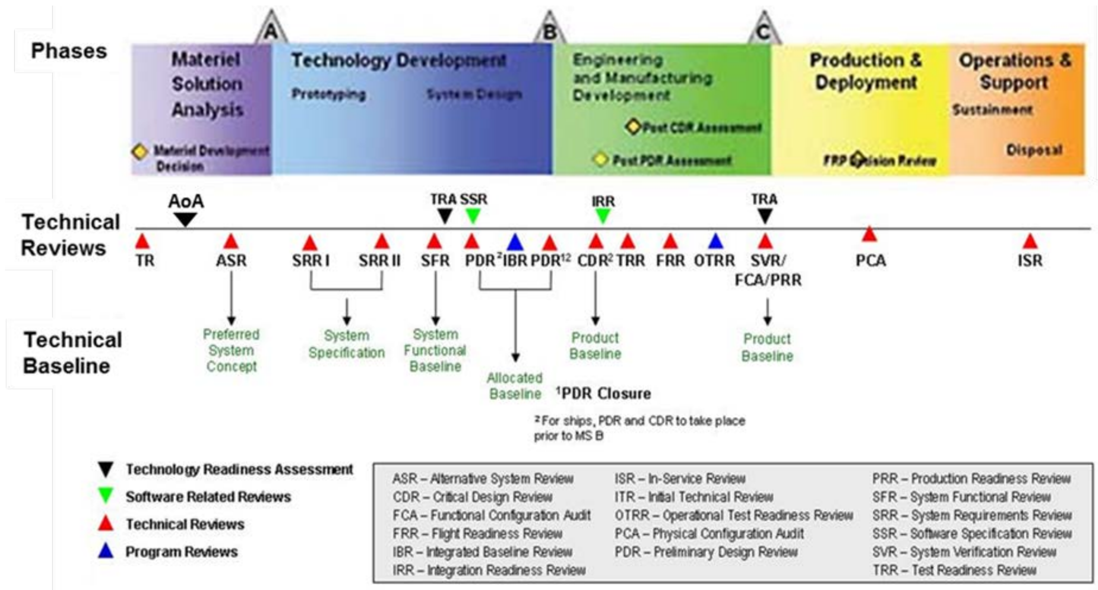

Figure 1. System Acquisition Life Cycle Model. (DAU, 2018)

The technical reviews that this research considered for applicability to an MBSE environment are (Manning, 2019):

- Initial Technical Review (ITR): A multi-disciplined review to support a program's initial Program Objective Memorandum (POM) within the Materiel Solutions Analysis phase (MSA).
- Alternative System Review (ASR): A review that assesses the preliminary materiel solutions that have been developed during MSA.
- System Requirements Review (SRR): A review to ensure that system requirements have been completely and properly identified and that a mutual understanding between the government and contractor exists, during the Technology Maturation and Risk Reduction (TMRR) phase.
- System Functional Review (SFR): A review to ensure that the system's functional baseline is established and can satisfy the requirements of the Initial Capabilities Document (ICD) or draft Capability Development Document (CDD) within the currently allocated budget and schedule, during TMRR.
- Preliminary Design Review (PDR): A review that establishes the allocated baseline of a system to ensure a system is operationally effective. A PDR is conducted before the start of detailed design work and is the first opportunity for the government to closely observe the contractor's hardware and software design. This review is conducted during TMRR.

Current SETRs are based around lengthy reviews of static, contractually obligated "artifacts" that are used to demonstrate successful completion of the entrance criteria.

Participants typically “freeze” these “artifacts” many days prior to the SETR in order to provide baselines from which to synchronize various products used during the review. This baselining and eventual loss of concordance[1] between “artifacts” are the primary drawbacks when conducting reviews using “artifact-based” methods.

[1] Concordance is the ability to represent a single entity, such that data in one view, or level of abstraction, matches the data in another view, or level of abstraction, when talking about the exact same thing. This allows for complexity to be managed more efficiently because each entity is ideally represented in the model only once, essentially creating a virtual representation of the system in the model. Systems engineering views are generated from the data (Vaneman, 2018).

Table 1. Summary of the DoD System Acquisition Life-Cycle Phases. (Vaneman & Carlson, 2019)

Life-Cycle Phase	Description of the Life Cycle	Technical Reviews within Life Cycle
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, life-cycle 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)	A system is developed and designed during EMD 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)	A system that satisfies an operational capability is produced and deployed to an end user during PD. 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)	During OS, 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**

SETRs in an MBSE Environment

Current SETR reviews require various Department of Defense Architecture Framework (DoDAF) views, and other systems engineering artifacts, to serve as evidence for various aspects of the system's progress and status. These views are often "document-based" and thus are developed statically without an underlying model structure. In an MBSE environment, the system is represented virtually; therefore the data and relationships, not the views, are the “atomic” level of detail.

In an MBSE environment, the model is a virtual representation of the system and becomes the focus of a SETR. Using the model as the source for decision-making throughout the system acquisition life cycle is a significant departure since programs often generate unique artifacts for the sole purpose of the reviews. Each system element should be represented only once in the model just as it is in the real-world system. The data that comprises the model is iteratively developed and maintained throughout the system life cycle.

A significant difference between traditional document-based technical reviews and model-based technical reviews is model structure. Structure defines the relationships between the system entities, establishes concordance within the model, and allows for the emergence of system behaviors and performance characterizations. Structure provides decision-makers with 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. A discussion of model development is beyond the scope of this paper, but a lengthy description can be found in Vaneman, Carlson, and Wolfgeher (2020).

While an MBSE environment contains a virtual representation of the system, current SETR criteria relies on model-based data, which is depicted by views within a presentation framework, similar to a document-based review. While a virtual representation of the systems will exist, the acquisition community currently lacks the experience of viewing the data in this format. Thus, the SETR criteria still requires the information to be viewed in the standard document-based systems engineering format. This is acceptable, because the virtual system can represent data in any desired presentation framework (e.g., DoDAF), but there is additional information available to the reviewer in the model itself as described below.

Table 2 (Vaneman & Carlson, 2019) shows the applicability of MBSE views to the system acquisition life cycle. 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. Given that the MBSE environment creates a virtual system, the SETR criteria need to be revised to account not only for the current, but also the additional insights that can be gleaned through a model-based approach.

Table 2. Applicability of Systems Engineering Views with the Systems Acquisition Life Cycle. (Vaneman & Carlson, 2019)

	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						

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

The system engineering process typically has to progress to the point where the following information is available for the ASR (The Technical Cooperation Program [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 and 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 entrance criteria[2] (DAU, 2019), against traditional and MBSE reviews is shown in Table 3 (Vaneman & Carlson, 2019). First the criteria are 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 extremely difficult to achieve efficiently and effectively. All of the criteria were assessed to be satisfied in an MBSE environment because of the concordance. The model-based systems engineering views needed to address the criteria are also shown in the table.

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[2] Entrance criteria are used to track the technical progress, schedule, and program risks.

Table 3. ASR Criteria and Related Views. (Vaneman & Carlson, 2019)

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 description 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 are adequately defined for this stage in the life cycle?	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

Applicability of Current Technical Review Criteria to MBSE Technical Reviews

An initial assumption for this research was that the approximately 85 systems engineering model visualizations that currently exist, can be used to address all SETR questions for review through the TMRR phase. However, this research does recognize that some questions may have to be adjusted from binary (yes or no) questions (e.g., "Does the project have a Risk Management Guide?") to questions that provide more concrete details to allow for better program and system analysis.

Our research found that MBSE, as it currently exists, can be used to satisfy the criteria found throughout the MSA phase, and during most of the TMRR phase. However, we found that current MBSE environments do not adequately address the criteria for a PDR. Review criteria for PDRs were evaluated from the Defense Acquisition University (DAU), the Navy's Strategic Systems Program (SSP), and the Naval Air Systems Command (NAVAIR). The criteria from NAVAIR was eventually selected to be reviewed because it was found to be the most comprehensive.

During this research, 846 PDR questions were evaluated for applicability to be addressed by current MBSE. Of these 846 questions, only 80 questions could be addressed directly by current MBSE models. To make the problem manageable, the 864 questions were categorized into 56 PDR criteria categories. Of these 56 categories, only 11 categories were adequately satisfied by MBSE, 13 categories were partially satisfied by MBSE, and 32 categories were not adequately satisfied by MBSE. Tables 4 and 5 show the 56 PDR criteria categories and the assessed MBSE ability to satisfy those criteria.

These disappointing results do not mean that employing MBSE methods to PDRs should be abandoned. To achieve better PDR results, it is clear that new visualization techniques must be developed to fully realize the benefits of an MBSE environment. Developing new visualizations also makes sense because many of the approximately 85 current visualizations have been used by the systems engineering community for decades. While many of these models have been the cornerstone of technical reviews, a true MBSE environment where the model is a virtual representation of the system, will glean additional insights that have heretofore been unrealized.

In addition to the PDR evaluation categories not being represented in MBSE visualizations, there is another issue. Over time, the scope of the PDR questions increased to the point where many senior leaders agree that questions were added without an appropriate audit of suitability. For PDRs to be more effective in their current form, and in an MBSE environment, a detailed evaluation of the review criteria needs to be explored, and questions need to be modified, to truly use MBSE to assess the program and system at PDR.

Table 4. **PDR Criteria Categories and the MBSE Ability to Satisfy Them**

PDR Criteria Category	MBSE Ability to Satisfy Criteria
Schedule Planning	↑
Program Critical Path	→
Cost/Schedule/Performance/Key Performance Parameters (KPP)	↑
Latest Cost Estimate	→
Production Costs Estimates	↓
Operating and Support (O&S) Costs Estimate	→
Earned Value Management (EVM)	→
Work Breakdown Structure (WBS) review	↑
Software Metrics	→
Program Management	↑
Configuration Management (CM)	↑
Systems Engineering Processes	↑
Acquisition Logistics Support Management and Staffing	↓
Automated Information Technology (AIT)	↓
Risk Management (RM) Processes	↑
Logistics Budgeting and Funding	↓
Test Processes (TEMP, T&E Strategy, etc.)	→
Production Processes (ISO 9000, etc.)	↓
Software	→
Producibility	↓
Human System Safety	↓
Aeromechanics	↓
Structures	↑
Materials	↓
Mass Properties	↓
Human Systems Integration Engineering	↓
Environmental Regulations	↓
Safety and Health	↓
System Safety	↓
Hazardous Material Management	↓
Pollution Prevention Program	↓
Maintenance Planning	→

Table 5. PDR Criteria Categories and the MBSE Ability to Satisfy Them

PDR Criteria Category	MBSE Ability to Satisfy Criteria
Testability and Diagnostics	→
Manpower, Personnel, and Training (MP&T)	↓
Training Outline and Curricula Design	↓
Training Material	↓
Training Devices/Simulators	↓
Supply Support	↓
Organic Support	↓
Supply Chain Management/PBL Management	↓
Warranty Management	↓
Support Equipment	↓
Technical Data	↑
Product/Technical Data Package and Publications	↓
Computer Resources	↓
Facilities	↓
Packaging, Handling, Storage and Transportation	↓
Design Interface	↑
Manufacturing Planning	↓
Parts and Materials Selection	↓
Commodity Management	↓
Root Cause Corrective Action	→
Obsolescence	↓
Platform Diagnostics Integration	→
Life-Cycle Logistics	→
Performance Requirements	↑
Key	
Adequately satisfies criteria in category	↑
Partially satisfies criteria in category	→
Does not satisfy criteria in category	↓

Conclusions

Formalized planning for modeling and decision-making across the life cycle must include a new approach for SETRs. This not only includes the content of the reviews, but how the models will be assessed against the criteria (Dam, 2018). We found that current processes for assessing documents are not adequate in an MBSE environment. For example, many questions are binary in nature and do not provide any insight into the "health" of a program. For example, a question of the form, "Does the program have a risk management plan?" The answer is "yes" or "no" and does not provide any insights into the quality of the plan content or the program "health."

The DoD Digital Engineering Strategy (SASD[SE], 2018) states that there is a strong need to ensure that decision-makers understand the different model types and what information can be gleaned from them. The results of our analysis of how MBSE will satisfy a PDR were unexpected because we believed that current MBSE visualizations would address a wider range of the PDR content. While our research found only 11% of PDR questions to be adequately addressed by current MBSE methods, we do not recommend abandoning the use of MBSE for PDR assessments. Instead, it is clear from this research that new visualizations must be developed to adequately address the needs, and provide greater insight with faster comprehension for the details across the life cycle.

As DoD organizations migrate to an MBSE environment, efficiencies will be gained by transitioning from the traditional paper-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 entrance criteria. The MBSE milestone reviews will provide greater insight with faster comprehension for the details across a program's life cycle. This will not only provide efficiencies for the review but will improve the program's cost and schedule efficiency.

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