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PROCESS TO ASSESS AND CURATE SYSTEMS ENGINEERING TECHNICAL REVIEW CRITERIA FOR EMPLOYMENT WITH MODEL-BASED SYSTEMS ENGINEERING

by

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December 2020

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13. ABSTRACT (maximum 200 words)

The Department of Defense has mandated the integration of digital engineering into acquisition engineering throughout the entire life cycle. One critical element to achieve this directive is the incorporation of Model-Based Systems Engineering (MBSE) into System Engineering Technical Reviews (SETR). However, little research exists that provides an evaluation of the current MBSE environment's ability to satisfy SETR criteria. Furthermore, no research exists that assesses the state of SETR criteria with respect to its readiness for MBSE integration. This thesis performs this missing research by creating a process to assess SETR criteria. The process was then employed to assess Preliminary Design Review (PDR) criteria with respect to their suitability, quality, and readiness for integration into the current MBSE environment. The process is agnostic to the SETR event and the criterion's background. A verification of previous findings related to the current MBSE environment's ability to satisfy SETR criteria was performed. The research found that the PDR criteria is unable to integrate with the current MBSE environment, requiring changes to enable integration, including new MBSE views. This finding verifies the previous findings. The final finding notes that regardless of MBSE integration, the PDR criteria require significant curation in order to provide the necessary robustness and effectiveness to provide insight into the health and status of a SoI under review.

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PROCESS TO ASSESS AND CURATE SYSTEMS ENGINEERING TECHNICAL REVIEW CRITERIA FOR EMPLOYMENT WITH MODEL-BASED SYSTEMS ENGINEERING

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ABSTRACT

The Department of Defense has mandated the integration of digital engineering into acquisition engineering throughout the entire life cycle. One critical element to achieve this directive is the incorporation of Model-Based Systems Engineering (MBSE) into System Engineering Technical Reviews (SETR). However, little research exists that provides an evaluation of the current MBSE environment's ability to satisfy SETR criteria. Furthermore, no research exists that assesses the state of SETR criteria with respect to its readiness for MBSE integration. This thesis performs this missing research by creating a process to assess SETR criteria. The process was then employed to assess Preliminary Design Review (PDR) criteria with respect to their suitability, quality, and readiness for integration into the current MBSE environment. The process is agnostic to the SETR event and the criterion's background. A verification of previous findings related to the current MBSE environment's ability to satisfy SETR criteria was performed. The research found that the PDR criteria is unable to integrate with the current MBSE environment, requiring changes to enable integration, including new MBSE views. This finding verifies the previous findings. The final finding notes that regardless of MBSE integration, the PDR criteria require significant curation in order to provide the necessary robustness and effectiveness to provide insight into the health and status of a SoI under review.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASR	Alternative Systems Review
CDD	Capability Development Document
CDR	Critical Design Review
DAG	Defense Acquisition Guidebook
DAU	Defense Acquisition University
DE	Digital Engineering
DOD	Department of Defense
DoDAF	Department of Defense Architecture Framework
FCA	Functional Configuration Audit
FDDR	Full Deployment Decision Review
FRP DR	Full-Rate Production Decision Review
GAO	Government Accountability Office
LML	Lifecycle Management Language
MBSE	Model-Based Systems Engineering
MSA	Material Solution Analysis
NAVAIR	Naval Air System Command
OT&E	Operational Test & Evaluation
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PRR	Production Readiness Review
SETR	Systems Engineering Technical Review
SFR	System Functional Review
SoI	System of Interest
SRR	Systems Requirements Review
SVR	System Verification Review
SysML	Systems Modeling Language
UML	Unified Modeling Language

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EXECUTIVE SUMMARY

The Department of Defense's (DOD) digital engineering Strategy defines five goals and the vision of integrating digital engineering (DE) into DOD systems throughout their full life cycles. Goal 1 specifies establishing formal methods to support the development, integration, and the universal employment of digital models as a fundamental element of engineering activities to provide a comprehensive digital representation of the system of interest (SoI) throughout its entire life cycle. Goal 1 is further broken down into three separate, but interrelated, sub-goals: formalize the planning for models to support engineering activities and decision making across the life cycle; formally develop, integrate, and curate models; and use models to support engineering activities and decision making across the life cycle (Office of the Deputy Assistant Secretary of Defense for Systems Engineering 2018).

Model-based systems engineering (MBSE) provides a method for performing systems engineering in a model-based environment. Although, MBSE does not encompass all the various disciplines, or their models, it does capture a significant portion of a system's information necessary to model an SoI as directed within the DOD digital engineering Strategy. In support of executing Goal 1 of the DOD digital engineering Strategy, a significant need exists to generate a process to curate and thereby improve the existing System Engineering Technical Review (SETR) criteria for use within MBSE.

According to the findings by Vaneman, Carlson, and Wolfgeher (2020), numerous Preliminary Design Review (PDR) criteria are not suitable to be addressed within a MBSE environment. The findings also stated that a significant portion of the PDR criteria shortcomings related to their binary nature. This binary nature instills within the criteria a lack of robustness, thereby limiting their usefulness in evaluating the SoI in general, regardless of the employment of MBSE.

This thesis will address the binary nature of the criteria along with other faults that prevent the criteria from providing insight into the SoI and limit the benefits of MBSE. Performing an assessment of those PDR criteria shall take place through the employment

of the process that will assess, document, and alter (as appropriate) criteria that lack the required robustness and usefulness.

The scope of the thesis is to define the establishment of a process that details how to curate existing SETR criteria, and alter them as necessary, to more accurately capture the "health and status" of a SoI under review in preparation for integration of model-based views and data. The process created shall guide users through gated questions that shall assist in the curation of the existing SETR criteria by categorizing, documenting, and if necessary altering or removing them. The thesis shall employ this process to perform a review of previously gathered and assessed PRD criteria to verify the need for the creation of the described process and to verify the previous findings. This review shall justify the creation of such a process by verifying the findings of the PRD criteria previously evaluated.

One core deliverable of the thesis is a process, employable within a formalized plan, which enables the evaluation of SETR criteria. The evaluation consists of three separate assessments of each SETR criterion for three specific characteristics that each should possess. The first characteristic assessed is the consistency with, or appropriateness to, the required level of development addressed by the SETR criterion in comparison to the current SETR event. The second characteristic is the SETR criterion's quality to assess or its ability to provide insight into the health and status of the program or SoI under review. The final characteristic is each SETR criterion's ability for representation by an existing MBSE view. These assessments will determine a set of SETR criteria ability to evaluate an SoI, to what extent criteria can map to existing MBSE views and the scope of criteria that require additional alteration either to the criteria or to MBSE views to permit the mapping of the criteria.

The employment of this process as the companying research for this thesis occurred on data that solely consisted of the NAVAIR PDR criteria. The supplemental Microsoft Excel document captures the NAVAIR PDR criteria analyzed and the results of the research.

When performing the criteria assessments, the research did not distinguish between the criteria area of focus (e.g., programmatic or technical). The research only assessed each criterion based on the three previously mentioned characteristics.

The results of the research performed indicate not only are most of the reviewed PDR criteria not ready for MBSE integration, but they require curation for employment in the current intended usage.

The data shows that over 43% of the criteria deemed partially or fully inconsistent with the level of development at preliminary design and nearly all criteria evaluated as binary in nature. To provide perspective on the prevalence of binary criteria, over 95% of the criteria that had their Characteristic 2 assessed contained a binary nature. Taking a deeper look at the data after the first two assessments of the remaining criteria, as the removal of some criteria occurred; an observation is possible along with possible implications. An observation from this deeper look is that without rewording only 2.54% of all PDR criteria assessed are consistent with the required or expected level of development and have the ability to provide insight into the health and status of the SoI. The possible implication is all SETR criteria likely require some level of curation unless the reviewed PDR criteria are severe outliers.

In summarizing the results, the execution of an assessment of the SETR's criteria critical characteristics provided insight into the health and status of the criteria. This insight supplied the knowledge of whether the SETR criteria would have the ability to accomplish their intended purpose. The results of the assessment presented a bleak reality of the SETR criteria reviewed. Over 43% of the criteria did not fully address the appropriate level of development as aligned with the SETR event. The criteria that proceeded to the next assessment had nearly all criteria, approximately 97%, partially or fully failing to meet the evaluation requirement of having the ability to provide insight into the health and status of the SoI. The final assessment of the remaining criteria found that only approximately 13% of the criteria assessed had the ability to map partially of fully to an existing MBSE view.

A conclusion one can draw from the data is the effectiveness of any PDR performed with this set of criteria lacks the intended robustness and usefulness when attempting to provide insight into the health and status of the SoI under review.

Four recommendations for future work or consideration originate from the thesis findings. The first recommendation is that additional SETR criteria undergo assessment and curation in preparation for MBSE integration. Having healthy and robust set of SETR criteria that can accurately capture the "health and status" of an SoI under review is necessary prior to the integration and implementation of MBSE into SETR events.

The second recommendation is for the acquisition community to assign necessary attributes to SETR criteria during their development and curation. The performance of this effort would mirror what Systems Engineering teaches its practitioners regarding the assignment of necessary attributes for requirements during their development.

The third recommendation is to investigate the creation of additional MBSE views that will support the evaluation of SoIs. A need exists to perform an evaluation regarding the needed MBSE views to support a curated set of SETR criteria.

The final recommendation is to consider the automation of the applicable portions of SETR criteria assessments. The employment of Formal Methods in conjunction with the development of a software program could directly handle some evaluations while other assessments could have their burden reduced through the assistance the software provides by decreasing the initial workload prior to human interaction of assessing SETR criteria.

References

Office of the Deputy Assistant Secretary of Defense for Systems Engineering. 2018. *Department of Defense Digital Engineering Strategy.* Washington, DC: Department of Defense.

Vaneman, Warren K, and Ronald Carlson. 2020. "Evaluating Current Systems Engineering Models for Applicability to Model-Based Systems Engineering Technical Reviews." *Naval Engineers Journal* 1–8.

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense's (DOD) digital engineering Strategy defines five goals and the vision of integrating digital engineering (DE) into DOD systems throughout their full life cycles. Goal 1 specifies establishing formal methods to support the development, integration, and the universal employment of digital models as a fundamental element of engineering activities to provide a comprehensive digital representation of the system of interest (SoI) throughout its entire life cycle. The formal methods will afford the ability to maintain consistent performance of analysis and decision making for programs throughout the DOD enterprise. Goal 1 is further broken down into three separate, but interrelated, sub-goals: formalize the planning for models to support engineering activities and decision making across the life cycle; formally develop, integrate, and curate models; and use models to support engineering activities and decision making across the life cycle (Office of the Deputy Assistant Secretary of Defense for Systems Engineering 2018).

Model-based systems engineering (MBSE) provides a method for performing systems engineering in a model-based environment. MBSE does not encompass all of the various disciplines, or their models, but it does capture a significant portion of a system's information necessary to model an SoI as directed within the DOD digital engineering Strategy. However, presently a disconnect exists between a major element in DOD acquisition, System Engineering Technical Reviews (SETR), and MBSE. In support of executing Goal 1 of the DOD digital engineering Strategy, a significant need exists to generate a process to curate and thereby improve the existing System Engineering Technical Review (SETR) criteria for use within MBSE. This process would afford the ability to fully integrate and permit the utilization of the content required to fulfill the SETR's criteria throughout the acquisition life cycle.

B. OBJECTIVES

According to the findings by Vaneman, Carlson, and Wolfgeher (2020), numerous Naval Air System Command (NAVAIR) Preliminary Design Review (PDR) criteria are

not suitable to be addressed within the current MBSE environment. The findings also stated that a significant portion of the PDR criteria shortcomings related to their binary nature. This binary nature instills within the criteria a lack of robustness, thereby limiting their usefulness in evaluating the SoI in general, regardless of the employment of MBSE. The creation of a process to curate the SETR criteria and alter them as necessary will allow a robust inquiry and thereby greater insight into the SoI under review. This additional insight will permit a more accurate understanding of the "health and status" of the SoI.

C. THE RESEARCH QUESTIONS

1. How does one determine if a process to curate existing SETR criteria and alter them as necessary to more accurately capture the "health and status" of an SoI under review through model-based views and data is required?
2. How does one create a process to curate existing SETR criteria and alter them as necessary to more accurately capture the "health and status" of an SoI under review through model-based views and data?
3. If required, how does one verify that a process generated to address the problem fulfills its intended purpose?

D. RESEARCH METHOD

The thesis will address one of the major faults of the NAVAIR PDR criteria as Vaneman, Carlson, and Wolfgeher's paper (2020) asserts**.** Specifically, that a lack of robustness prevents the criteria from providing insight into the SoI and limits the benefits of integrating MBSE. To address this topic the creation of a process shall occur. The process will assess, document, and alter (as appropriate) SETR criteria that prevent or limit a thoughtful examination of an SoI. Following the creation of the process, an assessment of the previously stated PDR criteria shall take place through the employment of the process. The design and verification of this process acts as the core of the research method employed that is the basis of this thesis.

E. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The scope of this thesis is to establish a process that details how to curate existing SETR criteria, and alter them as necessary, to more accurately capture the "health and status" of an SoI under review through model-based views and data. The process shall guide users through gated questions that assist in the curation of the existing SETR criteria by categorizing, documenting, and if necessary altering or removing them.

This thesis includes a review of NAVAIR PRD criteria. This review will act as a verification of the process and provide an example demonstration of the process on set of existing PDR criteria. Additionally, the review will employ the process to evaluate the ability of the criteria to map to existing MBSE view.

Finally, a validation of the necessity of the process will occur with the verification of the existence of disproportionate number of PDR criteria containing traits that prevent or limit a thoughtful examination of an SoI.

Three specific limitations bound the scope of the thesis. The first limitation is the set of SETR criteria that the thesis will evaluate. Academic review and notational observance are the driving elements to limit the thesis' scope to these criteria. Through observations of programs, projects, working groups, and communities of interest the current leading edge of MBSE employment within DOD acquisition is at SETRs just before or at the level PDR. The thesis shall cover the NAVAIR PDR criteria reviewed and addressed within Vaneman, Carlson, and Wolfgeher (2020) paper where they argue the current state MBSE is unable to fully-address all of the required criteria to comprehensively evaluate a given system during a PDR. Based on these elements the current largest need for improvement is at the PDR level, thereby establishing the bounding focus on PDR criteria exclusive of other SETR criteria.

The second limitation is the extent of the process presented. The thesis shall define the establishment of a process that details how to curate existing SETR criteria, and alter them as necessary, to more accurately capture the "health and status" of an SoI under review in preparation for implementation of model-based views and data. However, the thesis will not address the creation of new MBSE views to permit the capture of any

criteria, and its data, not currently able to map to an existing MBSE view the criteria. This limitation bounds the scope to the existing PDR criteria and MBSE views.

The final limitation on the scope of the thesis relates to the MBSE language employed. The thesis employs the Life cycle Management Language (LML) as part of the research and in the creation of the process. While the LML has the ability to map its functions to other MBSE languages, various documents have presented LML's enhanced ability to model the full life cycle of an SoI in ways other MBSE languages currently lack (Vaneman, Sellers, and Dam 2018).

The thesis makes the following two assumptions. First, the NAVAIR PDR criteria covers a sufficient breath of SETR criteria to make the thesis and the presented process agonistic regarding the various DOD branches. The second assumption is while not all readers may know or employ LML, the readers are able to translate the process into their language and tool of choice through the employment of language mapping that exist external to this thesis.

F. ORGANIZATION OF STUDY

This introductory chapter has provided a general outline of the thesis with special focus given to the background, objectives, scope, limitations, and assumptions. The subsequent chapters shall expand on select portions of this chapter. Chapter II shall detail the literature review performed. Chapter III shall present the purpose of the process created and define the approach of the process. Chapter IV shall describe the issue addressed along with the data analyzed, the results of the research, and finally provide an interpretation of the results. Chapter V shall offer a summary of the work performed, recommendations based on the research performed and its successive results, and detail potential future work.

II. LITERATURE REVIEW

A. BACKGROUND

To date the majority of the literature regarding MBSE has focused on the benefits MBSE can bring to the field of systems engineering (Estefan 2008; Jackson, Wilkerson and Castet 2016; Holladay et al. 2019; Noguchi 2019) or benefits to a system throughout its entire life cycle (Vaneman, Sellers and Dam 2018; Goldwasser and Ryder 2019). In addition, some documents (Dam 2014) have addressed how MBSE can meet the requirements of the DOD Architecture Framework (Department of Defense 2009) in support of systems engineering and acquisition. Only recently has literature been published that begins to investigate the implementation of integrating MBSE into the initial phases of the DOD acquisition (Vaneman and Carlson 2019). To date, one of most complete literature based reviews of implementing the integration of MBSE primarily focused on SETRs up to and including PDR determined that a large majority of PDR criteria were unable to be sufficiently addressed by existing MBSE views. As part of the findings it was documented that a majority of the PDR criteria were binary in nature and thereby provided little to no insight into the "health and status" of the SoI. These PDR criteria, which are binary in nature, do not afford information or data that is suitable to robust employment within a MBSE environment (Vaneman, Carlson, and Wolfgeher 2020).

B. REVIEW OF EVOLVING MODEL-BASED SYSTEMS ENGINEERING ONTOLOGIES AND STRUCTURES

MBSE provides a method for performing systems engineering in a model-based environment that limits or removes the need for the generation of document-based artifacts. However, there exists numerous varying thoughts on different processes and methods of how to define MBSE. This fractured view of MBSE prevents a single cohesive implementation. Vaneman states:

> However, more than a decade after it was defined, MBSE remains a mysterious concept that means many things to many different people and organizations. Some will contend that MBSE is the Unified Modeling Language (UML) or Systems Modeling Language (SysML), while others

> believe that MBSE is the Department of Defense Architecture Framework (DoDAF) or the Zachman Framework. As a result, MBSE is frequently implemented as a series of "architectural products," instead of a singular virtual representation of the system that can be used for a wide array of systems engineering analysis. This due, in part, to lack of an adopted ontology that defines entities, and provides the structure, used to represent systems. (W. K. Vaneman 2018, 1)

Vaneman argues that with an agreed upon singular formalized ontology, the field of systems engineering could begin the full implementation of MBSE permitting improved engineering support and management of system complexity. Vaneman presents the following definition of MBSE, "as the formalized application of modeling (static and dynamic) to support system design and analysis, throughout all phases of the system life cycle, through the collection of modeling languages, structures, model-based processes, and presentation frameworks used to support the discipline of systems engineering in a model-based or model-driven context" (Vaneman 2018, 2). Four components establish this definition of MBSE according to Vaneman, who denotes them as follows:

1. Modeling Languages – Serves 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.
2. Structure – Uses the ontology, and defined relationships between the systems entities, to establish concordance, thus allowing for the emergence of system behaviors and performance characterizations within the model.
3. 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.
4. 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. (2018, 2)

At the intersection of these four components lays the possibility for MBSE's greatest potential efficacy. It is critical for the DOD and systems engineering to have a

single cohesive implementation of MBSE that provides its greatest potential efficacy. The scope and complexity of acquisition programs is ever increasing beyond the human capacity to comprehend it in its entirety at once. Even with the proper employment of systems engineering utilizing document-based work products, acquisition projects are out pacing engineers' ability to agree to changes; document them; and implement them while providing insight into the SoI's changes and all of the possible impacts in a timely manner to management and leadership. Through the implementation of MBSE, the possibility exists to provide a single continuous current understanding of the SoI where no lag time is present. When presenting information and data on the SoI the viewer can observe the current-status and not a status of when the collection of the information and data occurred. Additionally, there is only one source of data. This removes possible confusions of which version is current; providing a "single source of truth" for the SoI regarding its information and data. These features offer the potential to provide managers and leadership vital and unambiguous insights into an SoI in a timely manner better enabling the ability to deliver an SoI within budget and on time.

The definition and components of MBSE as presented by Vaneman creates the basis for the understanding and implementation of MBSE within this thesis. In establishing this baseline for the definition and understanding of MBSE, the thesis has the ability to proceed with addressing the stated research questions.

C. REVIEW OF DEPARTMENT OF DEFENSE DIGITAL ENGINEERING STRATEGY

The DOD DE Strategy defines the purpose of integrating DE into DOD systems throughout their full life cycles, along with its vision of integration and five interconnected goals. Goal 1 specifies establishing formal methods to support the development, integration, and the universal employment of digital models as a fundamental element of engineering activities to provide a comprehensive digital representation of an SoI throughout its entire life cycle. The formal method will afford the ability to maintain consistent performance of analysis and decision making for programs throughout the DOD enterprise. Goal 1 is further decomposed into three separate, but interrelated, sub-goals: formalize the planning for models to support engineering activities and decision making

across the life cycle; formally develop, integrate, and curate models; and use models to support engineering activities and decision making across the life cycle (Office of the Deputy Assistant Secretary of Defense for Systems Engineering 2018).

While MBSE does not account for all of aspects of DE, it is capable of capturing a significant portion of a system's information and data. Through its application, MBSE enables the execution of a substantial portion of the DOD DE Strategy. One aspect of that application will require the employment of MBSE when performing SETR events. However, while the term MBSE and certain concepts date to 1993 and have continued to mature as computational power and technology have improved, MBSE still requires additional progress to develop a precise and consistent approach to modeling an SoI throughout their life cycles (International Council on Systems Engineering 2019).

D. REVIEW OF DEFENSE ACQUISITION GUIDEBOOK: CHAPTER 3

All DOD acquisition is fundamentally governed by two documents, DOD Directive 5000.01 and DOD Instruction 5000.02. These documents provide guidance with the intent of ensuring the DOD procures quality products which are compliant to the stakeholders' requirements providing measureable improvements to the specified capabilities necessary to perform the stated missions at a fair and reasonable price. While the documents were created in the 1970s, the DOD has updated them and added supplemental documents throughout the years.

To compliment DOD Directive 5000.01 and DOD Instruction 5000.02 the DOD has published the Defense Acquisition Guidebook (DAG) as a resource for the acquisition workforce to provide best business practices which are tailorable for each program based on its needs and at the discretion of those performing the work. Each chapter of the DAG addresses a separate focus area that a program will perform at some point, or throughout, of the life cycle of its system. The DAG's Chapter 3's purpose is to provide guidance related to the general discipline of systems engineering by detailing a definition of systems engineering and its broad application, to include processes and efforts, within DOD acquisition programs.

Chapter 3 of the DAG describes one of the most significant set of activities that occur during the development life cycle of an SoI within DOD acquisition programs. The System Engineering Technical Reviews (SETR) are a set of strategic assessments. These assessments permit a review board to interrogate the data and information of a program or SoI throughout its life cycle against a set of criteria tailored to each specific SETR. The review board investigates of a broad set of characteristics, based on the tailored criteria, regarding a program or SoI such as concept of operations, requirements, risks, schedule, program progress, technical maturity, manufacturability, and a host of other characteristics. Certain characteristics undergo review during particular phases of the DOD acquisition process within the systems' development life cycle for a specific SETR, while other characteristics see review at every SETR. These activities result in vital periodic evaluations of the program or SoI that provide insight to its current health and status. The program's or SoI's level of technical maturity determines when the execution of any specific SETR occurs within its development life cycle. This policy ensures the occurrence of SETR's are event-based and not schedule-based. Chapter 3 of the DAG states, "Technical Maturity Points identifies the objectives of each SE assessment and the technical maturity point marked by each review (Defense Acquistion University 2017)."

Chapter 3 of the DAG provides the Technical Maturity Points within a table. Presented below is a modified version of that table which only denotes the SETR events.

Table 1. DOD Acquisition Technical Maturity Points. Adapted from Defense Acquistion University (2017, 43–47).

Technical Maturity Points			
Technical Review	**Objective**	**Technical Maturity Point**	**Additional Information**
Alternative Systems Review (ASR)	Recommendation that the preferred materiel solution can affordably meet user needs with acceptable risk.	System parameters defined; balanced with cost, schedule and risk.	Initial system performance established and plan for further analyses (e.g., assessing technical maturity and associated risks) supports Milestone A criteria.

Technical Maturity Points			
Technical Review	**Objective**	**Technical Maturity Point**	**Additional Information**
System Requirements Review (SRR)	Recommendation to proceed into development with acceptable risk.	Level of understanding of top-level system/ performance requirements is adequate to support further requirements analysis and design activities.	Government and contractor mutually understand system /performance requirements including: (1) the preferred materiel solution (including its support concept) from the Materiel Solution Analysis (MSA) phase; (2) plan for technology maturation; and (3) maturity of interdependent systems.
System Functional Review (SFR)	Recommendation that functional baseline satisfies performance requirements and to begin preliminary design with acceptable risk.	Functional baseline established and under formal configuration control. System functions in the system performance specification decomposed and defined in specifications for lower level elements, that is, system segments and major subsystems.	Functional requirements and verification methods support achievement of performance requirements. Acceptable technical risk of achieving allocated baseline.
Capability Development Document (CDD) Validation	Requirements validation authority action. Provides a basis for preliminary design activities and the PDR.	Major cost and performance trades have been completed and enough risk reduction has been completed to support a decision to commit to the set of requirements (i.e., CDD or equivalent)	Support preparation for CDD validation by performing systems engineering trade-off analysis addressing relationships of cost, requirements, design, and schedule. Once validated, a Configuration Steering Board assumes responsibility to review all requirements changes and any significant technical configuration

Technical Maturity Points			
Technical Review	**Objective**	**Technical Maturity Point**	**Additional Information**
			changes for ACAT I and IA programs in development, production, and sustainment that have the potential to result in cost and schedule impacts to the program.
Preliminary Design Review (PDR)	Recommendation that allocated baseline satisfies user requirements and developer ready to begin detailed design with acceptable risk.	Allocated baseline established such that design provides sufficient confidence to proceed with detailed design. Baseline also supports 10 USC 2366b certification, if applicable.	Preliminary design and basic system architecture support capability need and affordability goals and/or caps achievement.
Critical Design Review (CDR)	Recommendation to start fabricating, integrating, and testing test articles with acceptable risk.	Product design is stable. Initial product baseline established.	Initial product baseline established by the system detailed design documentation; affordability/should-cost goals confirmed. Government assumes control of initial product baseline as appropriate.
System Verification Review (SVR)/Functional Configuration Audit (FCA)	Recommendation that the system as tested has been verified (i.e., product baseline is compliant with the functional baseline) and is ready for validation (operational assessment) with acceptable risk.	System design verified to conform to functional baseline.	Actual system (which represents the production configuration) has been verified through required analysis, demonstration, examination, and/or testing. Synonymous with system-level Functional Configuration Audit (FCA).
Production Readiness Review (PRR)	Recommendation that production processes are	Design and manufacturing are	Production engineering problems resolved and

Technical Maturity Points			
Technical Review	**Objective**	**Technical Maturity Point**	**Additional Information**
	mature enough to begin limited production with acceptable risk.	ready to begin production.	ready to enter production phase.
Physical Configuration Audit (PCA)	Recommendation to start full-rate production and/or full deployment with acceptable risk.	Product baseline established. Verifies the design and manufacturing documentation, following update of the product baseline to account for resolved OT&E issues, matches the physical configuration.	Confirmation that the system to be deployed matches the product baseline. Product configuration finalized and system meets user's needs. Conducted after OT&E issues are resolved.
Full-Rate Production Decision Review (FRP DR) or Full Deployment Decision Review (FDDR)	Decision to begin full-rate production and/or decision to begin full deployment.	Manufacturing processes are mature and support full-rate production and/or capability demonstrated in operational environment supporting full deployment (i.e., system validated through OT&E).	Delivers fully funded quantity of systems and supporting materiel and services for the program or increment to the users.

Chapter 3 of the DAG denotes the importance and value provided to both the government and developers by performing these reviews as follows:

> Department experience (e.g., Government Accountability Office (GAO) Report 12–400SP) has found that successful programs use knowledge-based product development practices that include steps to gather knowledge to confirm the program's technologies are mature, their designs are stable and their production processes are in control. Successful materiel developers ensure a high level of knowledge is achieved at key junctures in development. (Defense Acquistion University 2017, 43)

SETR's provide an opportunity to have insight into the health and status of a program. This insight can offer the possibility to detect and fix potential issues prior to allowing the continuation of development for an SoI where the cost of changes rises substantially the as the program progresses.

E. REVIEW OF A ROADMAP FOR ADVANCING THE STATE OF THE PRACTICE OF MBSE FOR GOVERNMENT ACQUISITION

The rate of MBSE adoption by prime contractors of government acquisition has increased in recent years. An increase in MBSE adoption has also begun within the government acquisition community. Noguchi states that the driving factor for prime contractors to increase MBSE adoption is the desire to improve "knowledge management, technical communication, data interchange, and increased efficiency" (Noguchi 2019). While for the government acquisition community, Noguchi asserts improved efficiency provides a driving force, but he also suggests a "need for a better approach for managing the complexity of those Government mission enterprises" (Noguchi 2019). Similar to the currently discontinuous MBSE definitions, the efforts to adopt MBSE, by both prime contractors and the government acquisition community, have been fragmented and often unconnected. The intent of Noguchi's paper, as stated in its title: *A Roadmap for Advancing the State of the Practice of MBSE for Government Acquisition*, is to provide:

> …an initial attempt at establishing a shared vision to drive discussions among the Government acquisition community—and the associated community of prime contractors, systems engineering and integration (SE&I) contractors, and Federally Funded Research and Development Centers (FFRDC)—to drive investment and collaboration to improve the state of the practice of MBSE within this community. (Noguchi 2019, 1)

Noguchi presents the broad workings of MBSE along with a collection of benefits that MBSE is able to provide to a program regardless of the organization, governmental or not, that has chosen to employ MBSE. Additionally, he provides the structure of digital models within DE and their interactions across a generalized organizational hierarchy. This provided information establishes a base understanding of MBSE and its place within DE and a generalized organization to permit discussion of what Noguchi has stated as the four primary areas of MBSE that require focus for government application. The four primary areas of MBSE that require focus for government application are:

1. Enabling Enterprise Systems Engineering
2. Improving System Acquisition and Execution Outcomes
3. Institutionalizing Evolved Systems Engineering
4. Advancing the State of MBSE Tools (Noguchi 2019, 5)

Although, Noguchi's four focus areas contain similarities to the DOD DE Strategy's five goals (presented below), significant differences exist between the two lists. Additionally, the DOD document addresses DE while Noguchi's paper addresses MBSE.

1. Formalize the development, integration and use of models to inform enterprise and program decision making
2. Provide an enduring, authoritative source of truth
3. Incorporate technological innovation to improve the engineering practice
4. Establish a supporting infrastructure and environments to perform activities, collaborate, and communicate across stakeholders
5. Transform the culture and workforce to adopt and support digital engineering across the life cycle (Office of the Deputy Assistant Secretary of Defense for Systems Engineering 2018, 4)

The DOD DE Strategy's goals and focus areas are not exclusively sequential to their numbering; however, some of the tasking must naturally follow a sequential structure. As part of Goal 1 the DOD DE Strategy looks to first codify the development, integration and use of models to inform enterprise and program decision making into a unified practice regardless of the organization performing the work prior to full employment through the entire community of practice of government acquisition. After this formalization, the focus moves to multiple efforts to establish Goals 3 and 4 thereby, enabling the realization of Goals 2 and 5.

In contrast, Noguchi presents all of his focus areas as having concurrent efforts. Each of these focus areas have assigned efforts for the near term, longer term, and for their end state. In addition, each focus area has included generalized efforts performed as work to date. Another difference between the documents is that while Noguchi acknowledges MBSE requires improvement, the foundation of focus area 4, he advocates for a broad application of MBSE now rather than first formalizing development and integration of models.

Despite the differences between the documents, many points of alignment exist. One such alignment is the agreement of the need to continue the establishment and refinement of MBSE application within SETRs in the near term. This required refinement was the impetus behind Vaneman, Carlson, and Wolfgeher paper (2020) and by extension this thesis.

F. REVIEW OF DEFINING A MODEL-BASED SYSTEMS ENGINEERING APPROACH FOR MILESTONE TECHNICAL REVIEWS

In support of achieving Goal 1 of the DOD DE Strategy, Vaneman; Carlson; and Wolfgeher performed research that culminated in the creation of a paper addressing a topic that literature has just begun to cover, MBSE's integration into a critical aspect of DOD acquisition. Vaneman, Carlson, and Wolfgeher (2020) researched the three following questions:

1. Define a systematic process for developing the virtual model of the system, as the program progresses through the acquisition life cycle.
2. Identify representative SETR entrance criteria and related questions and determine how those questions could change to better represent the data required for system and program decisions in a MBSE environment.
3. Define how the model of the system can be used in lieu of "artifacts" to provide decision-makers with a more complete representation of the system during SETRs. (3)

In addition to supporting the DOD DE Strategy, the research also denotes a deficiency of the current SETR process well-known to DOD acquisition professionals, that the employment of a MBSE environment has the potential to solve. Vaneman, Carlson, and Wolfgeher (2020) state SETRs' deficiency as:

> 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 between "artifacts" are the primary drawbacks when conducting reviews using "artifact-based" methods. (34)

Vaneman, Carlson, and Wolfgeher detail how the generation of a systematic process to develop a virtual model of a system throughout its life cycle requires an iterative effort. As a system progresses thorough the five primary phases of the system acquisition life cycle the model expands to include additional information and requires updating of existing modeled data and relationships. However, since each element present within the system has a single representation within the virtual model of the system each element requires only a single update per iteration.

Regarding the second research question, from which this thesis stems, Vaneman, Carlson, and Wolfgeher investigated if the current MBSE environment has the ability to evaluate comprehensively SETRs' criteria, thereby enabling the execution of model-based SETRs.

The integration of the MBSE environment into DOD acquisition has the possibility to allow model-based SETRs where the data reviewed against the criteria is the current system information. As previously discussed, system information within the MBSE environment, which focuses on the model, provides all observers and users of the system information a single continuous current understanding of the SoI. The model purpose is to capture not only the data inherent to the element modeled, but also its relationships to other elements. In the usage here, an element can denote anything from a system of systems to the least complex aspect of a system modeled.

Based on their investigation of the second question Vaneman, Carlson, and Wolfgeher (2020) conclude that:

> MBSE supported early technical reviews, where traditional MBSE visualizations were very applicable. However, SETRs at PDR and later, showed less promise for being fully accomplished using current MBSE visualizations as evaluated today. (54)

While their investigation concluded at PDR, the presented conclusions provide guidance on where to focus future efforts. At least two primary areas that require focus are readily identifiable. First is the establishment of new MBSE visualizations based on those current SETR criteria that are currently fully un-addressable. The second, which this thesis will focus on, is an assessment of current PDR criteria to enable the generation of a process to curate SETR criteria and alter them as necessary. The process will allow a robust inquiry and thereby greater insight into the SoI under review. This will directly address the related findings of Vaneman, Carlson, and Wolfgeher that numerous PDR criteria are not suitable to be addressed within a MBSE environment. The criteria's lack of robustness, often due to their binary nature, results in severely limited usefulness as part of reviewing the SoI. (Vaneman, Carlson, and Wolfgeher 2020)

G. SUMMARY OF LITERATURE REVIEW

Chapter II discussed various sources of literature regarding a spectrum of interconnected topics relating to MBSE. The chapter starts with a definition of MBSE and the related challenges in defining MBSE. The discussion progressed into a broad description of the DOD DE Strategy, which then quickly focused on its Goal 1 and a note that the application of MBSE will enable the execution of a significant portion of this strategy. In addition, the discussion mentioned one portion of the employment of MBSE would concentrate on MBSE's role performing SETR events. To provide a common understanding the chapter provided a general account of DOD acquisition followed by an overview of SETR events to permit further investigation of the previous assertion. The examination of the assertion that a major portion of the DOD's DE Strategy would involve MBSE's employment in performing SETR events began with reviewing a proposed roadmap for the advancement of practicing MBSE within the federal government's acquisition programs. The review compared and contrasted the roadmap to the DOD's DE Strategy. A point of similarity between them lead to the chapter discussing research that reviewed and interrogated MBSE's integration and ability to ingrate into SETR events. This research culminated in finding a number of deficiencies and shortcomings within both MBSE's integration and the current SETR process.

Based on the presented significance and proven benefits of performing SETR it is the author's assertion that being able to execute SETRs within a MBSE architectural framework is critical to successfully implementing the DOD DE Strategy.

III. PROCESS

A. PURPOSE

As captured by one of the sub-goals within Goal 1 of the DOD DE Strategy, the creation of a formalized plan to enable the employment of models to support engineering activities and decision making across the life cycle is required. The process created as part of this thesis shall afford a tool employable within a formalized plan. The employment of the process on a set of SETR criteria allows for an assessment of three specific characteristics that each SETR criterion possess. The first characteristic assessed is the consistency with, or appropriateness to, the required level of development addressed by the SETR criterion in comparison to the current SETR event. The second characteristic is the SETR criterion's quality to assess or its ability to provide insight into the health and status of the program or SoI under review. The final characteristic is each SETR criterion's ability for representation by an existing MBSE view. These assessments will determine a set of SETR criteria ability to evaluate an SoI, to what extent criteria can map to existing MBSE views and the scope of criteria that require additional alteration either to the criteria or to MBSE views to permit the mapping of the criteria.

The research performed as the basis of this thesis endeavored to employ the developed process to the PDR criteria previously collected and assessed by Vaneman, Carlson, and Wolfgeher (2020). The application of the process permits a verification of Vaneman, Carlson, and Wolfgeher's findings and allows a better understanding of the state of the PDR criteria with regards the three characteristics. An additional outcome of performing the process is the quantification of the binary criteria.

B. APPROACH

The process detailed below provides an approach that permits a consistent and repeatable assessment of the three defined characteristics for each SETR criterion. Employment of this process within a formalized plan would support Goal 1 of the DOD DE Strategy.

1. Review, Document, and Alter SETR Criteria

Review, Document, and Alter SETR Criteria is the title of Function 0.0. The title of the top-level function captures the intent of the process as a whole. Function 1.0 through Function 3.0 sequentially assesses one of three characteristics for each SETR criterion as specified within the function's name. The results of the assessments, within each function, determines the next step for each criterion assessed. As necessary, the criterion will undergo alteration to enhance the criterion's ability to enable a robust evaluation of the program or SoI thereby providing insight into the current health and status, while maintaining (if appropriate) the original intent. Each function that performs assessments also documents the results of the related assessments. In addition, the documentations includes any alteration or rewording performed on the criteria. Finally, Function 4.0 acts as a measure against separate lists of documented results and rewording of criteria. It accomplishes this by producing one single document that captures a consolidation of all the documented assessments of the SETR criteria. As seen within Figure 1, the LML action diagram Review, Document, and Alter SETR Criteria decomposes into four lower level functions.

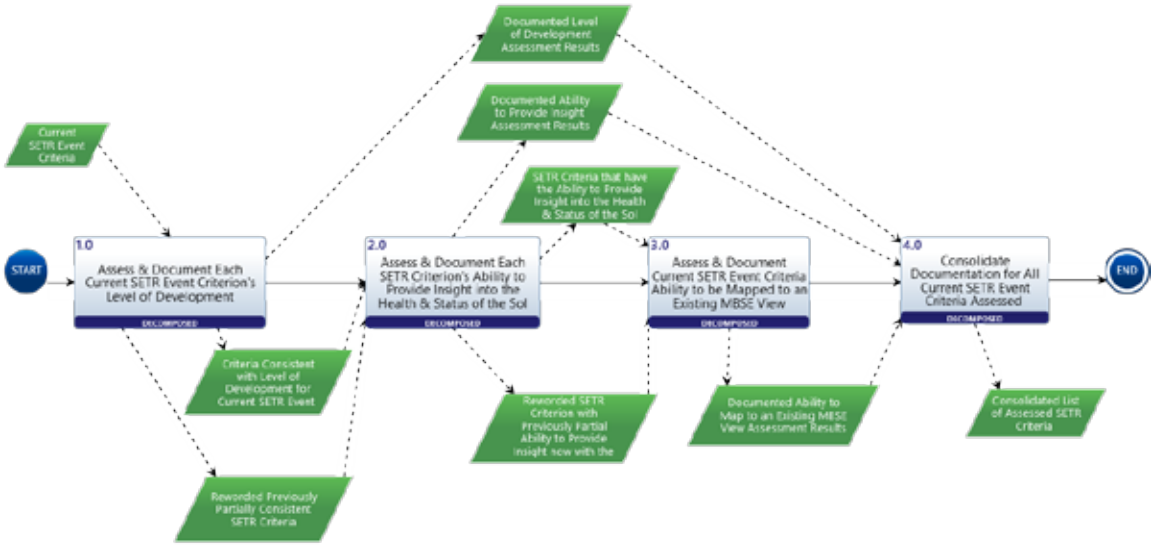

Figure 1. Review, Document, and Alter SETR Criteria LML Action Diagram

2. Assess and Document Each Current SETR Event Criterion's Level of Development

Function 1.0 decomposes into five lower level functions as shown in Figure 2.

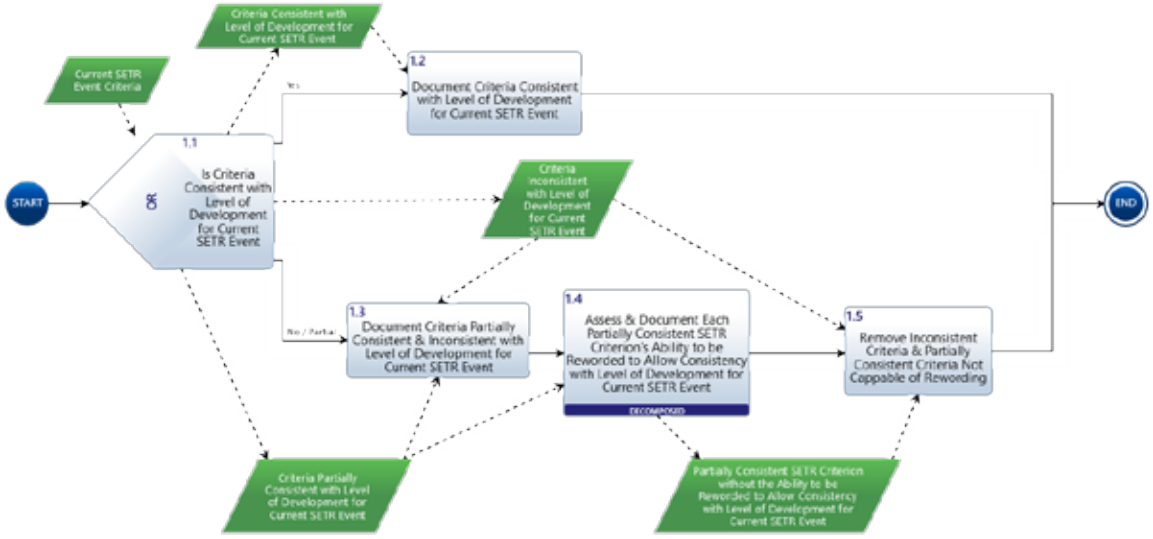

Figure 2. Assess and Document Each Current SETR Event Criterion's Level of Development LML Action Diagram

The first lower level function, Function 1.1, is the first assessment performed on every SETR criterion reviewed. The assessment evaluates whether the criterion matches the documented required or expected level of development for an SoI at the appropriate level of development for the current SETR event. The possible responses are 'YES', 'PARTIAL', and 'NO'.

The employment of the DAG permitted the determination of each criterion's appropriateness in relation to the required or expected level of development for a current SETR event. The DAG consists of multiple chapters that denote what is generally required for each SETR event. However, it is not possible for the DAG to predict every potential program or SoI that may undergo review. To accommodate this the DAG states to tailor each SETR based on the program or SoI under review (Defense Acquistion University 2017). This is where the systems engineer must exercise exceptional teamwork and

communication to enable all relevant stakeholders and domain specialist the ability to provide meaningful input in tailoring the SETR criteria.

A response of ‘YES’ indicates no further assessment of this characteristic for this criterion is required and the criterion progresses onto Function 1.2. Function 1.2 documents all criteria assessed as containing a level of development consistent with the appropriate level of development for the current SETR event as well as the justification for the assessment. No further actions occur within Function 1.0 regarding these criteria documented within Function 1.2.

A response of ‘PARTIAL’ indicates additional assessment is required for this criterion. Function 1.3 documents all criteria assessed as containing a level of development either partially consistent or inconsistent with the appropriate level of development for the current SETR event. Rather than only documenting these criteria, it is critical to document the justification of the assessment. In documenting the justification, the reasoning and any objective quality evidence is available for questioning and as an example for future assessments.

A criterion assessed as containing a level of development partially consistent with relation to the current SETR event will progress to Function 1.4. Each criterion that advances to Function 1.4 will undergo a further assessment. Figure 3 shows the LML action diagram of Assess and Document Each Partially Consistent SETR Criterion Ability to be Reworded to Allow Consistency with Level of Development for Current SETR Event, which consists of five lower level functions.

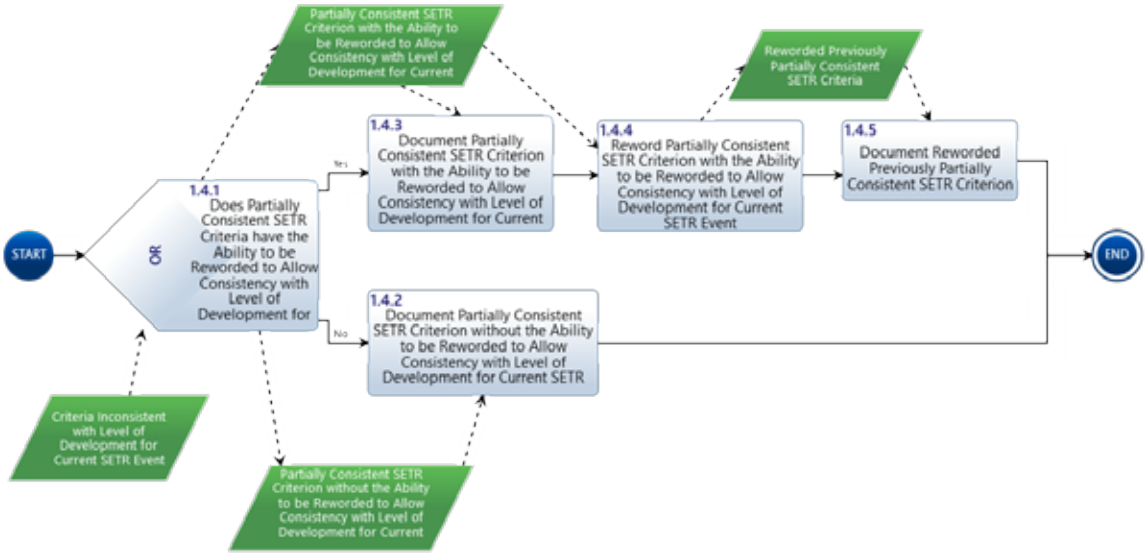

Figure 3. Assess and Document Each Partially Consistent SETR Criterion Ability to be Reworded to Allow Consistency with Level of Development for Current SETR Event LML Action Diagram

The first lower level function, Function 1.4.1, will assess whether rewording the criterion would afford the ability to alter its question such that it addresses a subject that is consistent with the appropriate level of development for the current SETR event, while maintaining the criterion's original intent. The possible responses are 'YES' or 'NO'.

To determine whether rewording these partially consistent criteria would afford the ability to change their questions a thorough examination of each criterion's question and the likely response(s) is required. The utilization of the DAG, other acquisition resources, along with communication between all relevant stakeholders and domain specialist to provide meaningful input in tailoring the SETR criteria are vital to making an accurate assessment.

A response of 'NO' indicates no further assessment of this criterion will occur beyond documentation of the criterion's result as well as the justification for the assessment. In documenting the justification, the reasoning and any objective quality evidence is available for questioning and as an example for future assessments.

A response of 'YES' indicates if reworded the criterion has the ability to design a question that is consistent with the appropriate level of development for the current SETR

event while maintaining the criterion's original intent. Each criterion assessed as such progresses to documentation of the assessment, rewording of the criterion, and finally a documentation of the reworded criterion. Function 1.4.3 performs the documentation of all criteria assessed with the necessary ability for rewording. In addition to documenting the result of the assessment, there is benefit in documenting the justification for the assessment. After documentation, Function 1.4.4 performs a rewording of the criterion thereby designing a question that addresses a subject consistent with the appropriate level of development for the current SETR event, while mindful of the original intent.

When rewording the criterion one should consider whether the rewording makes the criterion: binary in nature, have no or partial ability to provide insight into the health and status of the SoI, or prevents its mapping to an existing MBSE view. While these are not desirable characteristics, the intent of the Function 1.4.4 does not expressly address altering the criterion regarding those characteristics. However, even though these characteristics will undergo an assessment later there are benefits to addressing these characteristics during this rewording as it will reduce the amount of effort required when performing additional assessments later in the process. Ultimately, the person performing this function must ensure the reworded criterion will enable the ability to design a question that addresses a subject that is consistent with the appropriate level of development for the current SETR event.

Function 1.4.5 is the final lower function of Function 1.4. The function documents all criteria reworded in Function 1.4.4. Capturing what each reworded criterion now states is vital to ensuring its continued assessment throughout the remainder of the process.

Function 1.5 is the final lower level function within Function 1.0. This function takes note of the criteria deemed as inconsistent during the assessment performed within Function 1.1 and the partially consistent criteria deemed as unfit for rewording as part of the assessment performed within Function 1.4.1. Function 1.5 then removes these criteria from the pool of SETR criteria that will undergo further assessment within Function 2.0. However, they will undergo collection and consolidation with any other removed criteria within Function 4.0.

3. Assess and Document Each SETR Criterion's Ability to Provide Insight into the Health and Status of the SoI

A criterion assessed to have a level of development consistent with the appropriate level of development for the current SETR event, whether initially or after rewording, will progress to Function 2.0. Each criterion that advances to Function 2.0 will undergo assessment and documentation regarding the criterion's quality to assess an SoI or its ability to provide insight into the health and status of the SoI under review. Figure 4 shows the LML action diagram of Assess and Document Each SETR Criterion's Ability to Provide Insight into the Health & Status of the SoI, which consists of five lower level functions.

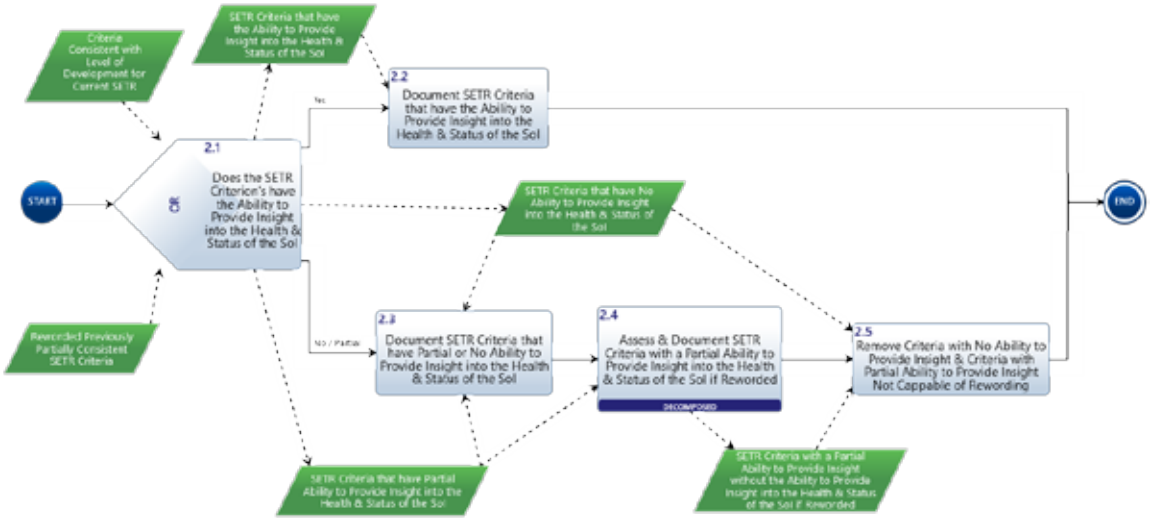

Figure 4. Assess and Document Each SETR Criterion's Ability to Provide Insight into the Health & Status of the SoI LML Action Diagram

The first lower level function is Function 2.1 that performs an assessment of each criterion regarding whether it can provide insight into the health and status of the SoI under review. The possible responses are 'YES', 'PARTIAL', and 'NO'. To determine whether each criterion can provide insight into the health and status of the SoI under review, examination of both the nature of the question and the likely response is required. One particular check performed for every criterion relates to whether the question is binary in nature. If the criterion is binary in nature the best one can hope for is to achieve limited

insight, based on a likely response of yes or no, without further questioning that may not occur. A criterion assessed as binary in nature would result in a 'PARTIAL' response, unless additional aspects of the criterion prevented the ability to provide insight. In the situation stated above where the criterion has a binary nature and another aspect prevents the ability to provide insight, assessment would result in a response of 'NO'.

A response of 'YES' indicates no further assessment of this criterion for this characteristic is required. The following is one example of a reviewed PDR criterion deemed to have a 'YES' response for this assessment. "What are the inter-service maintenance requirements, organic and contractor mix, projected workloads, installation requirements and time phasing for accomplishing depot maintenance requirements?" This criterion is non-binary in nature and inquires about required critical aspects of a system under development. A criterion assessed to have a response of 'YES' progresses to Function 2.2. It is within this function that the documentation of all similarly assessed criteria occurs. Along with documenting, the criteria deemed to have the ability to provide insight into the health and status of the SoI under review; benefits exist in additionally documenting the justification for the assessment. No further actions within Function 2.0 occur regarding the criteria documented within Function 2.2.

A response of 'PARTIAL' indicates additional assessment is required for this characteristic of this criterion. Function 2.3 will document all criteria assessed as containing a partial ability to provide insight into the health and status of the SoI under review as well as the justification of each assessment. In documenting the justification, the reasoning and any objective quality evidence is available for questioning and as an example for future assessments.

After the documentation within Function 2.3, the criteria assessed to have a partial ability to provide insight into the health and status of the SoI will progress to Function 2.4. Here each criterion will undergo assessment and documentation regarding its ability to provide insight into the health and status of the SoI under review if reworded. Figure 5 shows the LML action diagram of Assess and Document SETR Criteria with Partial Ability to Provide Insight into the Health and Status of the SoI if Reworded, which consists of five lower level functions.

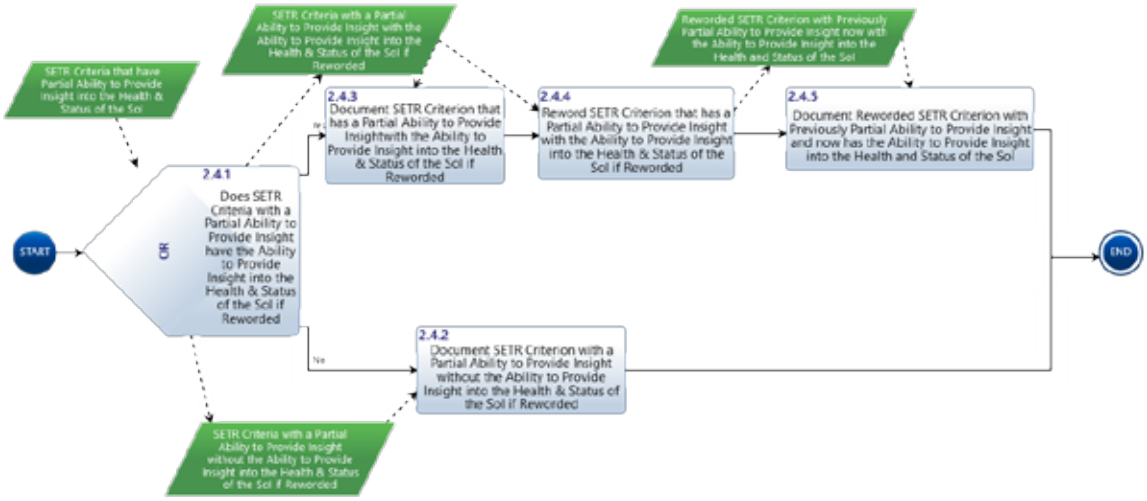

Figure 5. Assess and Document SETR Criteria with Partial Ability to Provide Insight into the Health and Status of the SoI if Reworded LML Function Diagram

Function 2.4.1 performs an assessment of each criterion regarding whether if reworded could it provide insight into the health and status of the SoI under review. If the previous assessment was partial, the question within the criterion may have a binary nature or another aspect preventing the criterion's ability to provide insight. These criteria previously assessed as partial will likely present a minimal effort in rewording to provide the required ability. In regards to binary criterion, simple changes to how one poses a question permits the removal of the binary nature of the criterion while maintaining the intent of the question. Some examples of this could change asking 'if a particular task has completed' to 'how the particular task was completed', 'when it was completed', 'by what date will it be completed'. Each of these potential changes removes the binary nature of the criterion and provides the ability to increase the level of insight into the health and status of the SoI under review. However, any criteria assessed as having a partial ability to provide insight that are not binary in nature may present more of a challenge when rewording. To determine whether these criteria have the ability to provide insight into the health and status of the SoI under review after rewording, examination of the criterion's question and the likely response is required. Ultimately, the possible responses for this assessment regarding rewording of the criteria are 'YES' or 'NO'.

A response of ‘NO’ indicates this criterion undergoes documentation within Function 2.4.2. This function documents these criteria as well as the justification for the assessment. In documenting the justification, the reasoning and any objective quality evidence is available for questioning and as an example for future assessments.

Criterion assessed as having a response ‘YES’ progresses to documentation of the assessment, rewording of the criterion, and finally documentation of reworded criterion. Function 2.4.3 performs the first of these actions with the documentation of all criteria assessed as having the ability to provide insight into the health and status of the SoI under review if reworded. Along with documenting the criteria as deemed to have the ability to provide insight into the health and status of the SoI under review if reworded, there is benefit in documenting the justification for the assessment. After this documentation, Function 2.4.4 performs a rewording of these criteria. While mindful of the original intent and maintaining it as appropriate, this function rewords the criterion thereby bestowing it the ability to provide insight into the health and status of the SoI under review.

While not required at this point, as assessment of the other reviewed characteristics of criteria that have progressed through this function will occur later, when rewording the criterion one should consider whether the rewording prevents the criterion for mapping to an existing MBSE view. If possible, addressing this characteristic during this rewording will reduce the amount of effort required for these criteria later in the process. Ultimately, the person performing this function must ensure the reworded criterion will enable the ability to provide insight into the health and status of the SoI under review.

Function 2.4.5 is the final lower level function within Function 2.4. The function documents all criteria reworded in the Function 2.4.4. Certain criterion documented herein could exist with the following characteristic, a partial or no capability of mapping to an existing MBSE view. Although, this is not a desirable characteristic the intent of Function 2.4.4 did not expressly address altering the criterion regarding that characteristic. Capturing what each reworded criterion now states is vital to ensuring its continued assessment throughout the remainder of the process.

Function 2.5 is the final lower level function within Function 2.0. This function compiles the criteria deemed as having no ability to provide insight during the assessment performed within Function 2.1 and the criteria with a partial ability to provide insight deemed not capable of rewording as part of the assessment performed within Function 2.4.1. Function 2.5 takes this compiled list of criteria and removes them from the pool of SETR criteria that will undergo further assessment within Function 3.0. They will undergo collection and consolidation with any other removed criteria within Function 4.0.

4. Assess and Document SETR Criteria Ability to be Mapped to an Existing MBSE View

A criterion assessed to have the ability to provide insight into the health and status of the SoI under review, either initially or after rewording, will progress to this function. Each criterion that advances to Function 3.0 will undergo assessment for its ability to map to an existing MBSE view. Figure 6 shows the LML action diagram of Assess and Document SETR Criteria Ability to be Mapped to an Existing MBSE View, which consists of three lower level functions.

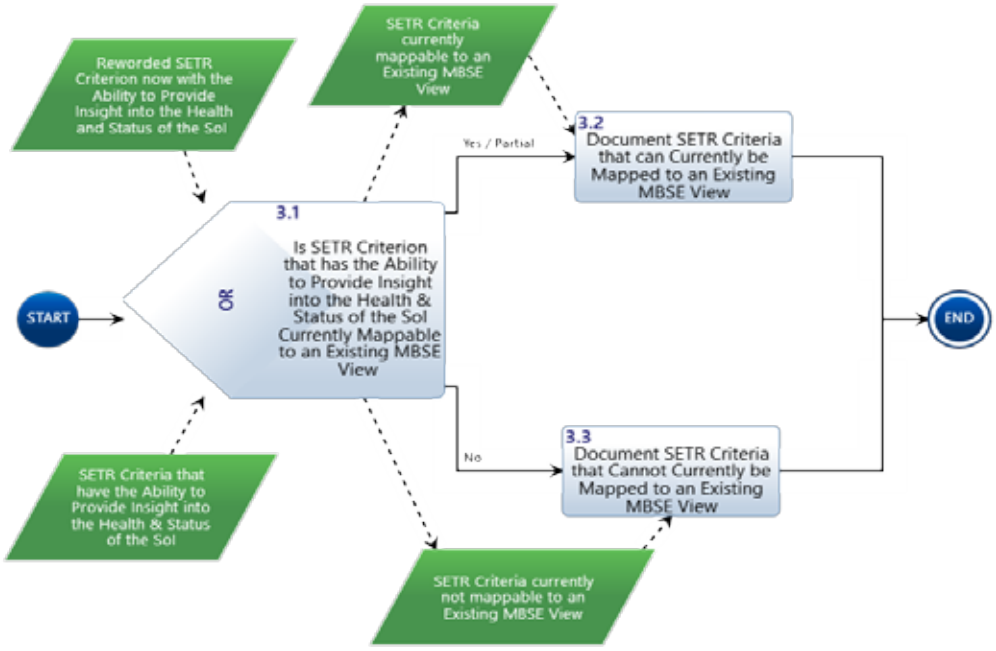

Figure 6. Assess and Document SETR Criteria Ability to be Mapped to an Existing MBSE View LML Action Diagram

The first lower level function within Function 3.0 is Function 3.1. This function performs of an assessment of each criterion regarding whether the criterion is capable of mapping to an existing MBSE view. The possible responses are ‘YES’, ‘PARTIAL’, and ‘NO’. To determine whether each criterion is capable of mapping to an existing MBSE view, the person performing the assessment must have a robust understanding of the application of systems engineering diagram, models, and data employed. This knowledge will enable the identification of potential MBSE views relevant to the criterion evaluated thereby allowing the mapping of the information or data required to address the criterion onto a MBSE view.

A response of ‘YES’ or ‘PARTIAL’ indicates the data or information required to address the criterion is partially or fully able to map to an existing MBSE view. The following criterion is an example with a response of ‘YES’. “Has an allocated baseline, or equivalent, been established, and is it complete and under configuration control?” The existing MBSE view Operational Activity to System Traceability Matrix or SV-7 has the ability to capture and represent the information required to address this criterion. Each criterion assessed as either response progresses to Function 3.2. This function documents all criteria assessed as having a partial or full capability to map to an existing MBSE view. Certain criterion documented herein could exist with only a partial capability of mapping to an existing MBSE view. These criteria require capture, as they are able to provide some insight into the system of interest. These captured criteria that provide partial insight provide value through an awareness of what MBSE views require potential creation or alteration in the near future. Along with documenting the criteria as capable of mapping to an existing MBSE view, there is benefit in additionally documenting the justification for the assessment. No further actions occur to the criteria documented within Function 3.2 within Function 3.0.

A response of ‘NO’ indicates the data or information required to address the criterion is unable to map to an existing MBSE view. The reason for this assessment varied extensively. Two of the primary reasons included either information that MBSE does not address or a MBSE view that could address does not currently exist. The following is one example of information that MBSE does not address. “Was a systems engineering

knowledgeable chairperson assigned?" These criteria will progress to Function 3.3. This function documents all criteria assessed as not capable of mapping to an existing MBSE view. Rather than only documenting the criteria as deemed not currently capable of mapping to an existing MBSE view, the function shall also document the justification of each assessment. In documenting the justification, the reasoning and any objective quality evidence is available for questioning and as an example for future assessments. No further actions occur to the criteria documented within Function 3.3 within Function 3.0.

5. Consolidate Documentation of All Assessed SETR Criteria

Throughout the process, documentation of the results from the assessments of each criterion's characteristics has occurred. As a measure against this disparate set of documentation leading to a loss of data, a consolidation of all the documentation capturing the assessments and rewording of the SETR criteria will occur to produce one single document.

Function 4.0 consists of three lower level functions. Figure 8 shows the LML action diagram of Consolidate Documentation of All Assessed SETR Criteria.

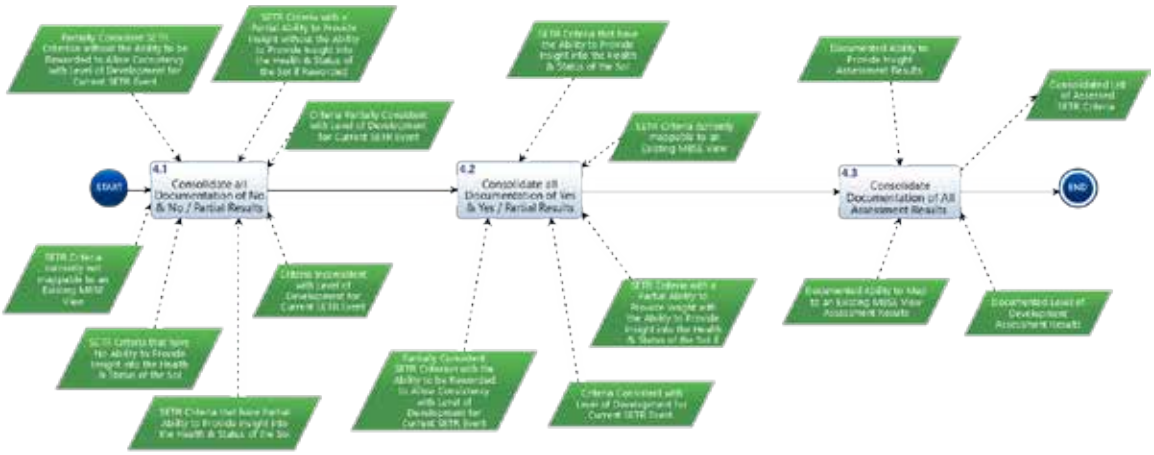

Figure 7. Consolidate Documentation of All Assessed SETR Criteria LML Action Diagram

Function 4.1 is the first lower level function within Function 4.0. This function assembles and documents the consolidation of all criteria assessed to have a resulting ‘NO’ or ‘NO / PARTIAL’ response as part of any evaluation performed by any function within the process. This assembled list has the possibility to provide various insights to the criteria and the SoI such as areas of weakness, areas with insufficient consideration, or areas for growth.

The second lower function, Function 4.2, collects and documents the consolidation of all criteria assessed to have a resulting ‘YES’ or ‘YES / PARTIAL’ response as part of any evaluation performed by any function within the process response. This collected list has the potential to provide various insights to the criteria and the SoI such as areas of strength, areas over considered/managed/resourced, or areas for opportunity.

Function 4.3 is the final lower level function within Function 4.0. This function merges and documents this consolidation of all criteria consolidated within Function 4.1 and Function 4.2. In addition, all reworded criterion will undergo collection and consolidation for the purpose of documentation within this Function.

The document created herein this Function will act as the single source of documentation regarding the review, documentation, and alteration of the SETR criteria. This list will empower leadership in decision making regarding the employment or exclusion of criteria well before SETR events, to enable improved evaluations of SoIs. Additionally, it will provide insight into what level of MBSE integration is achievable with the existing MBSE views and the SETR criteria.

IV. DATA ANALYSIS

A. ISSUE RESEARCHED AND DATA ANALYZED

Previous research investigated the implementation of integrating MBSE into SETR events. This research concluded that at PDR, and subsequent SETR events, the vast majority of criteria were unable to map onto existing MBSE views thereby preventing representation of the criteria and its related information and data with the current set of MBSE views. As part of the findings it was documented that a preponderance of the PDR criteria were binary in nature and thereby provided little to no insight into the "health and status" of the SoI. These PDR criteria, which are binary in nature, do not afford information or data that is suitable to robust employment within a MBSE environment (Vaneman, Carlson, and Wolfgeher 2020).

The research performed in support of this thesis analyzed the PDR criteria by evaluating three primary characteristics of each criterion. The first characteristic governs the criterion's consistency with, or appropriateness to, the required or expected level of development for an SoI under review during PDR. The second characteristic relates to the criterion's quality to assess an SoI or its ability to provide insight into the health and status of the SoI under review. The final characteristic addresses whether each criterion has the capability to map to an existing MBSE view.

When performing the criteria assessments, the research did not distinguish between the criteria area of focus (e.g., programmatic or technical). The research only assessed each criterion based on the three previously mentioned characteristics. Six criteria of the 753 criteria did not undergo assessment based on lack of information or understanding of the content within the criteria. The supplemental Microsoft Excel document captures the NAVAIR PDR criteria analyzed and the results of the research.

B. RESEARCH RESULTS

1. Results of Function 1.0: Assessment of Characteristic 1

The results of performing Function 1.1 to assess each criterion's first characteristic revealed 420 of the 747 criteria, or nearly 56.4% of all assessed criteria, were determined consistent with the required or expected level of development for an SoI under review during the preliminary design phase. The following is an example of a criterion deemed appropriate or consistent to evaluate an SoI at the preliminary design level of development. "Has a System Functional Review (SFR) been successfully completed?"

The evaluation of the criteria comprised the employment of various chapters from the DAG along with additional acquisition instructions, policies, guidance, and documentation. While it is not possible for the DAG to predict every potential program or SoI that may undergo review it does provide a broad scope of expected criteria based on the SETR event and general structure of the SoI (e.g., hardware intensive, defense unique software intensive, incrementally fielded software intensive, accelerated acquisition, hardware dominant hybrid, software dominant hybrid). The remaining 327 criteria consisted of criteria determined either partially consistent (195 or nearly 26% of all assessed criteria) or inconsistent (132 or nearly 17.7% of all assessed criteria). Figure 8 details the distribution of the assessed criteria.

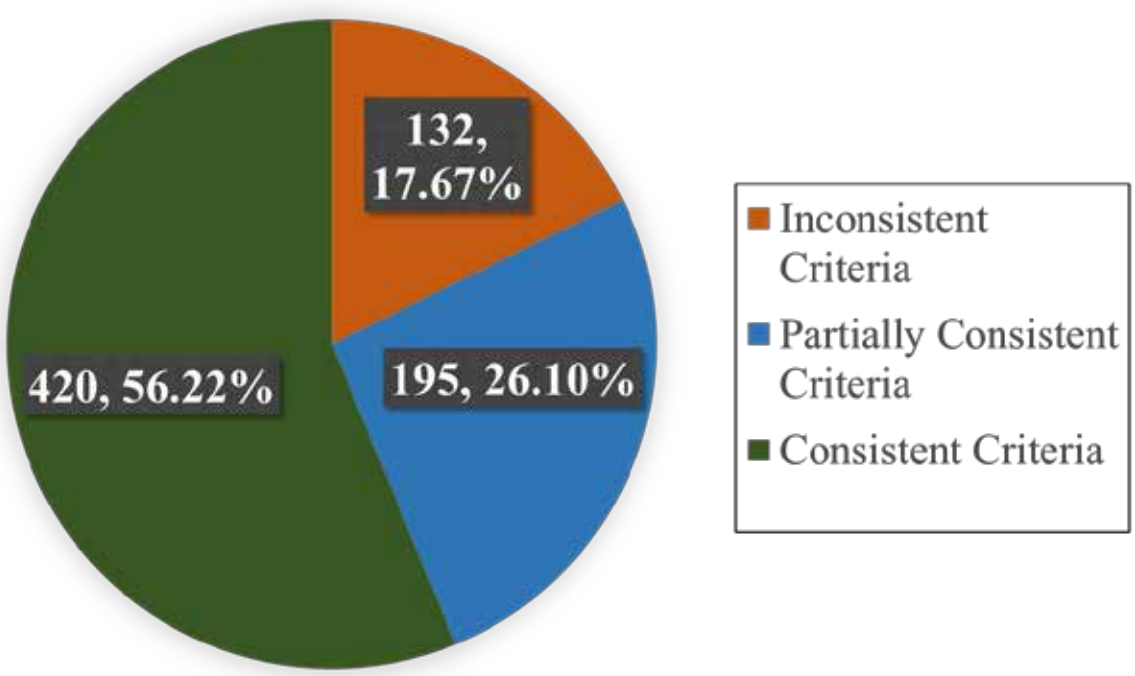

Figure 8. Distribution of Assessed Criteria Regarding Their Consistency to an Expected Level of Development for an SoI during the Preliminary Design Phase

Criteria assessed as partially consistent primarily contained one of two reoccurring traits. The first trait related to criteria addressing multiple deliverables or artifacts of which some were not appropriate for a preliminary design level of development. An example is numerous criteria made inquiries regarding the system's Capability Development Document (CDD) and its Capability Production Document (CPD). A validated CDD is required as an entry criterion for PDR making this portion of those criteria appropriate. However, the creation of a CPD will not occur until after the Critical Design Review (CDR) and likely near the end of the Engineering and Manufacturing Development (EMD) Phase thereby making this portion inconsistent. The results of this example lead to the assessment of those criteria as partially consistent. The other reoccurring trait involved criteria that inquired about outcomes regarding deliverables that would exist only in a draft status at the time of PDR. As partial information or data would exist at the time of PDR the assessment of partially consistent occurred for the criteria with this trait. The EMD Request for Proposal (RFP) and the Life Cycle Sustainment Plan are examples of artifacts that at

the time of PDR would exist in a draft status. In the case of the EMD RFP it may have released, but still under source selection, preventing any data regarding a contractor's response or information.

Criteria assessed as inconsistent predominantly contained one trait. The trait consisted of inquiring about either a specific deliverable or group of deliverables not yet required or available at the time of PDR. Each of these criteria with this trait appeared improperly placed within PDR and belonged within an alternative SETR event that more closely aligned to the level of development addressed within each of these criteria. One example is numerous criteria made inquiries regarding elements of the system regarding the system's CPD. The creation of a CPD does not occur until after the CDR and likely near the end of the EMD Phase thereby making these criteria inconsistent. Another example of this trait, numerous criteria addressed elements of the system in regards to and traits of Performance Based Logistics (PBL). However, per DAG Chapter 4 (Defense Acquistion University 2019) and the *PBL Guidebook* (Assistant Secretary of Defense Logistics & Material Readiness 2016) state that the transition to PBL shall occur no sooner than post Milestone C.

The performance of Function 1.4 included the further assessment of the criteria deemed partially consistent. This further assessment interrogated whether rewording of the criterion would permit the criterion consistency with the required or expected level of development for an SoI under review during PDR. The further assessment of the partially consistent criteria resulted in 194 of the 195 criteria deemed as possessing the ability for rewording that allowed consistency. Rewording the criteria to remove the deliverable(s) inconsistent with a PDR level of development allowed those specific criteria to become consistent. Table 2 shows examples of criteria deemed partially consistent as currently written within NAVAIR's PDR criteria and a possible way to reword them to attain consistency. While the assessment performed at this point of the process only addresses the criterion's first characteristic, as suggested within Chapter 3 the rewording also looks to remove other undesirable traits such as a binary nature. The supplemental Microsoft Excel document captures the justification for the assessment of Characteristic 1 for each

criterion. The justification details the reason for the assessment, often with a source sited, that provides direction regarding how to reword the criterion.

Table 2. Examples of Criteria as Written Contrasted with Suggested Rewording

Assessment of Characteristic 1	Criterion as Currently Written	Criterion Suggested Rewording
Partially Consistent	Does the AS address a plan to satisfy Human Systems Integration (HSI) requirements for each domain addressed in the Capability Development Document (CDD) / Capability Production Document (CPD), including minimum standards for those domains not specifically addressed in the CDD / CPD?	How does the AS plan to address satisfying Human Systems Integration (HSI) requirements for each domain addressed in the Capability Development Document (CDD), including minimum standards for those domains not specifically addressed in the CDD?
Partially Consistent	Have facilities / test resources (contractor and Government) been defined and included in the planning?	What are the required Government facilities and test resources defined and included in the planning? What required contractor facilities and test resources does the EMD RPF capture? What facilities and test resource planning for T&E in later acquisition phases has taken place?

As part of performing Function 1.4.3, the 133 criteria (one from partially consistent criteria set and the 132 inconsistent criteria set) deemed inconsistent or unfit for rewording underwent documentation and then removal from the set of criteria for all future assessments. The following is the partially consistent criterion deemed unfit for rewording. “Transient support requirements when the system requires some level of support for continental U.S. and outside continental U.S. activities that are not regular homeports or support sites.” Deciphering the intent of the criterion could not occur, as this criterion does not pose a question or is it even a complete sentence. It is unclear if whether this derives

from a transcription error of the original criterion or if the verbiage presented captures the actual criterion.

The partially consistent criteria deemed suitable for rewording to address a level of development appropriate to a preliminary design numbered 194.

The combination of the criteria deemed consistent initially (420 criteria or nearly 56.4% of all assessed criteria) with the partially consistent criteria deemed consistent after rewording (194 criteria, approximately 26% of all assessed criteria) created a revised list of 614 criteria for assessment of the second characteristic.

2. Results of Function 2.0: Assessment of Characteristic 2

The performance of Function 2.1 consisted an assessment of the second characteristic to determine whether each criterion can provide insight into the health and status of the SoI. This assessment reviewed the revised list of 614 combined criteria. The results revealed that only 19 criteria, or approximately 3% of the 614 criteria reviewed, can provide insight into the health and status of the SoI. The following criterion is one example deemed to have the ability to provide insight. “What is the status versus the critical path?” The results also assessed 558 criteria, or approximately 91%, to have a partial ability to provide insight into the health and status of the SoI. The remaining 36 criteria, or approximately 6%, had no ability to provide insight into the health and status of the SoI. Figure 9 displays the distribution of the assessed 614 criteria.

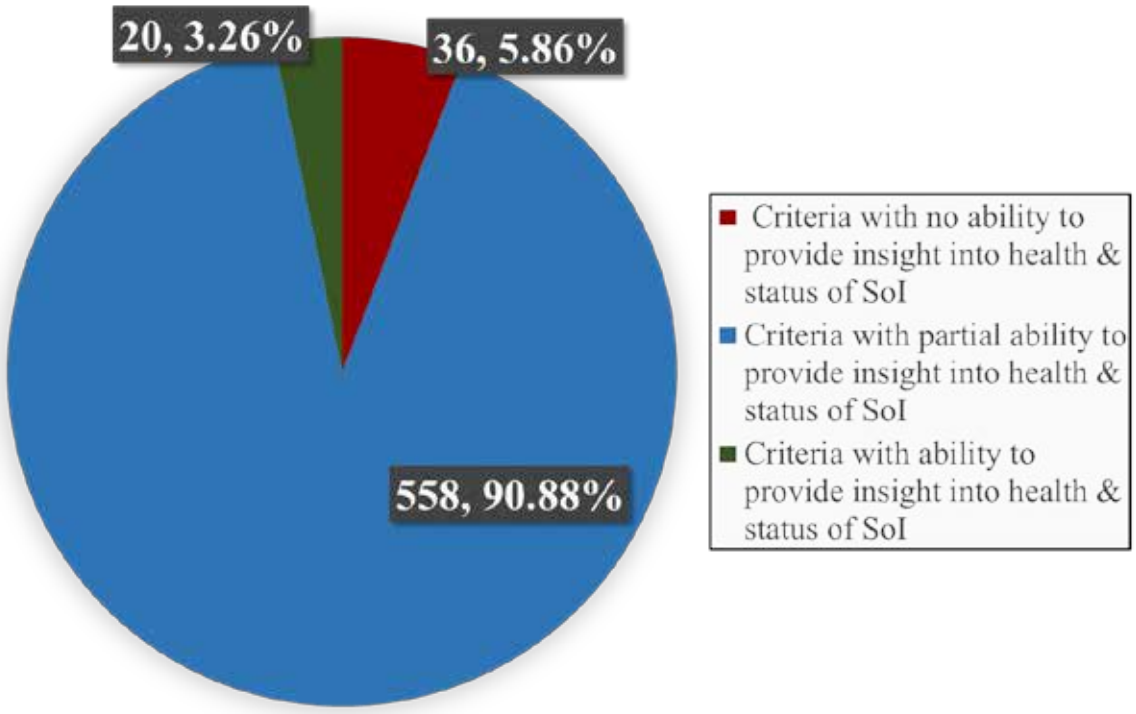

Figure 9. Distribution of Assessed Criteria Regarding Their Ability to Provide Insight into the Health and Status of the SoI

The assessment of the second characteristic involved the examination of both the nature of the question and the likely response. The review identified two traits of the criteria that attributed to the high percentage of criteria deemed as having partial or no ability to provide insight into the health and status of the SoI. The first trait, which was the predominate trait, governed whether the criterion under review had a binary nature and thereby limited their potential to provide insight into the health and status of the SoI. When a criterion is binary in nature the best one can hope for is to achieve limited insight, based on a likely response of yes or no, without further questioning that may not occur. An example of a binary in nature criterion with partial ability to provide insight is "Has the software schedule been updated based upon the preliminary software design?"

The second trait related to whether the criterion under review duplicated another criterion within the list of criteria. The duplication covered both word for word duplications and those criteria that duplicated the intent of another criterion. While this trait occurred much less frequently than the first trait, their inclusion is detrimental to the SETR event.

The following criterion is an example of a binary in nature criterion that is also duplicative and as such, one of the two entries of the criterion has no ability to provide insight. “Have developmental test plans been formulated in accordance with the TEMP?” Two instances of this criterion exist word for word within the set of NAVAIR PDR criteria; with the only variation between the two criteria based in the defining of TEMP within one criterion.

The performance of an additional assessment occurred, as part of the performance of Function 2.4, on those criteria determined to have partial ability to provide insight into the health and status of the SoI. The further assessment of the 558 criteria, deemed to have partial ability to provide insight, resulted in the determination that 553 of the criteria possess the capability for rewording. The criteria deemed not to have the ability for rewording consisted of criteria assessed as duplicative. Figure 10 displays the distribution of the results from the further assessment of the 558 criteria deemed to have a partial ability to provide insight into the health and status of the SoI.

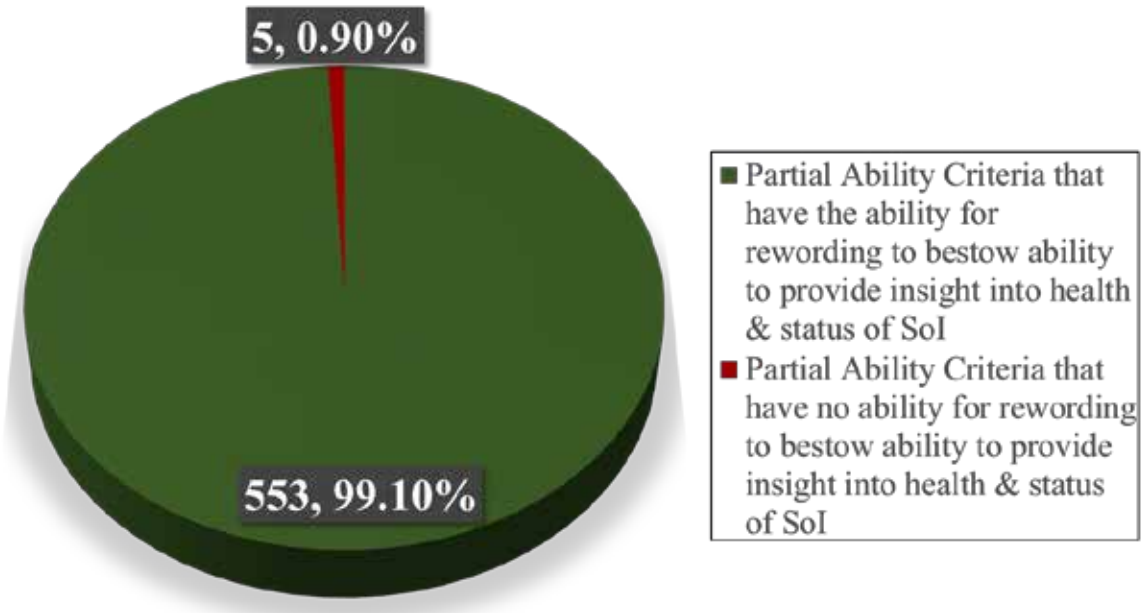

Figure 10. Distribution of Assessment Results of Criteria with Partial Ability to Provide Insight Regarding Their Ability for Rewording to Bestow the Ability to Provide Insight

Table 3 shows examples of criteria assessed with partial ability to provide insight as currently written within NAVAIR's PDR criteria and a possible way of how to reword them to provide insight.

Table 3. Examples of Criteria as Written Contrasted with Possible Rewording

Assessment of Characteristic 2	Criterion as Currently Written	Criterion Possible Rewording
Partial Ability to Provide Insight	Have long lead items been identified, and are the production processes sufficiently mature for this phase of the program?	What long lead items been identified? How are they being addressed? How mature are the production processes? What are the indications they are sufficiently mature for this phase of the program?
Partial Ability to Provide Insight	Are software requirements allocated to COTS, GOTS and reused software appropriate?	What software requirements have been allocated to COTS, GOTS and reused software? How was it determined the allocated requirements are appropriate?

Documenting the results of the assessment is the first half of performing Function 2.4.2. Removing the 41 criteria (five from the set of criteria with partial ability and the 36 criteria with no ability to provide insight) with either no ability to provide insight or unsuitable for rewording, from the set of criteria for all future assessments, is the second half of Function 2.4.2.

After the assessment of the second characteristic, a second merger of the criteria occurred to create a further revised list of criteria for the assessment of the third characteristic. The revised list comprised 573 criteria from the initially assessed to have (20 criteria) the ability to provide insight or able to attain the ability to provide insight through rewording (553 criteria).

3. Results of Function 3.0: Assessment of Characteristic 3

Finally, the 573 criteria from the revised list of PDR criteria underwent an assessment, performed as part of Function 3.0, to evaluate each criterion's third characteristic. The third criteria characteristic regards each criterion's ability to map to an existing MBSE view. The results from this review closely aligned with the findings of Vaneman, Carlson, and Wolfgeher (2020). The assessment found only 75 criteria, or approximately 13% assessed of having some ability to map to an existing MBSE. Two groups of criteria existed within the 75 criteria. The first consisted of 60 criteria that had the ability to map to an existing MBSE view. The second group contained of 15 criteria that had a partial ability to map to an existing MBSE view. Figure 11 displays the distribution of the 573 assessed criteria regarding their ability to map to an existing MBSE view.

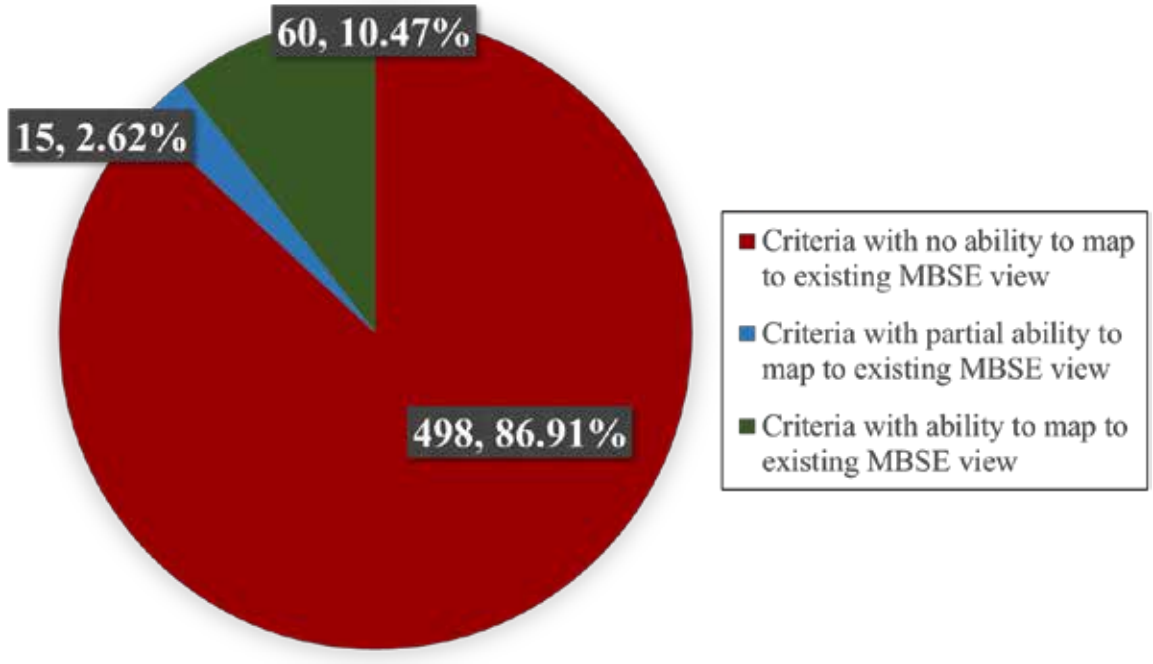

Figure 11. Distribution of Assessed Criteria Regarding Their Ability to map to an Existing MBSE View

The 75 criteria with some ability to map to existing MBSE views originated from 27 thematic areas. Thirteen of these 27 thematic areas assessed to have the most promise

of MBSE satisfying their criteria based on the criteria ability to map to existing MBSE views. Table 4 documents the number of criteria that were deemed partially or fully able to map to existing MBSE views, along with the total number of criteria within each of the Thematic Areas.

Table 4. Distribution of Criteria within Most Promising Thematic Areas

Thematic Area	Number of Criteria Mappable to an Existing MBSE View	Number of Criteria Partially Mappable to an Existing MBSE View	Total Number of Criteria	MBSE Views
Completion / Exit Criteria	8	-	16	CV-2, CV-3, OV-4, OV-5a, OV-5b, PV-3
Cost / Schedule / Performance / Key Performance Parameters (KPP)	-	1	2	SV-7
Human Systems Integration Engineering	5	-	19	SV-1, SV-5a, SV-5b,
Net-Centric Operations and Warfare Consolidated Compliance Checklist	2	-	6	SV-5a, SV-5b
Net-Centric Operations and Warfare Policy Requirements	5	-	5	SV-5a, SV-5b, StdV-1
Performance Requirements	4	-	9	CV-6, SV-5a, SV-5b, SV-7
Production Costs Estimates	-	1	2	Work Breakdown Structure, Cost Breakdown Structure

Thematic Area	Number of Criteria Mappable to an Existing MBSE View	Number of Criteria Partially Mappable to an Existing MBSE View	Total Number of Criteria	MBSE Views
Program Risk Assessment	5	-	9	Risk Matrix
Requirements Management	8	-	18	SV-1, SV-3, SV-5a, SV-5b,
Safety and Health	3	-	4	StdV-1
System Constraints (Budgets)	7	2	9	SV-1, SV-7
System Preliminary Design	5	-	5	SV-3, SV-4
System Requirement Assessment for Individual CI's	3	-	6	SV-5a, SV-5b, SV-7

C. INTERPRETATIONS OF RESULTS

The results of this research show that after rewording the set of PDR criteria would decrease in size, from 753 to 573 criteria; however, the remaining criteria would address a level of development consistent with the expected or required level of development for PDR. Furthermore, the criteria would have the ability to provide insight into the health and status of the SoI through asking robust, pointed, and meaningful questions. Additionally, the results display that the bulk of the PDR criteria are unable to support MBSE integration when employing existing MBSE views.

A conclusion one can draw from the data is the effectiveness of any PDR performed with this set of criteria lacks the intended robustness and usefulness when attempting to provide insight into the health and status of the SoI under review.

The data from the research shows that over 40% of the criteria assessed are partially or fully inconsistent with evaluating an SoI at a preliminary design level of development. In addition, the data finds that 589 of 614 criteria deemed consistent, whether initially or after rewording, as having a binary nature. In other words, nearly 96% of the consistent

criteria contain a binary nature, thereby limiting their potential to provide insight into the health and status of the SoI. The implication is all SETR criteria likely require some level of curation unless the reviewed PDR criteria are severe outliers.

Taking a deeper look at the data of the remaining 573 criteria after the first two assessments, additional observations are possible along with associated potential implications. One can see the distribution of the criteria; regarding whether the criteria require rewording and which characteristics the criteria did not possess thereby necessitating rewording. Figure 12 details this distribution of the 573 criteria that remain after the first two assessments.

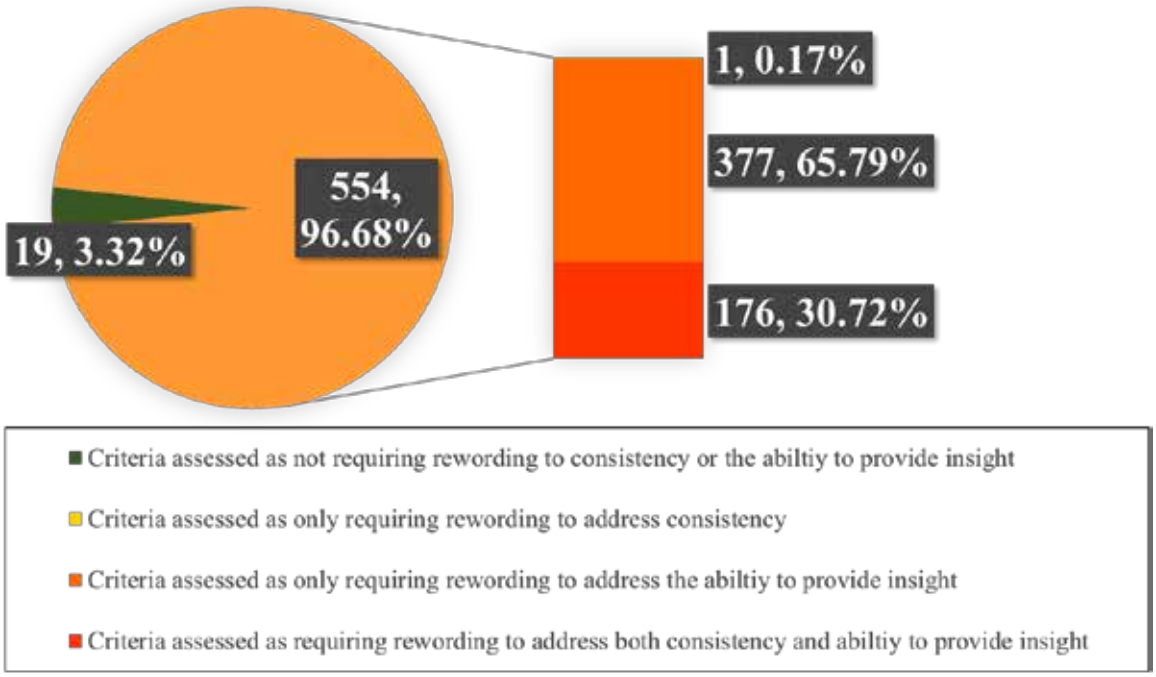

Figure 12. Distribution of Remaining Criteria After the First Two Assessments Detailing the Characteristics Requiring Rewording

An observation from this deeper look is that without rewording only 19 criteria or 2.54% of all PDR criteria assessed are consistent with the required or expected level of development and have the ability to provide insight into the health and status of the SoI. As seen within Figure 6, this increases to 3.32% after removing criteria either inconsistent,

no ability to provide insight, or capable of rewording to enable either of these characteristics. However, after rewording the revised list of assessed PDR criteria 573 (or approximately 76.7%), are consistent with the required or expected level of development and have the ability to provide insight into the health and status of the SoI. This observation shows curation of the PDR criteria is a mandatory step to ensure proper evaluation of programs and SoIs. The curation should include, at least, an assessment of the level of development each criterion addresses; whether each criterion is binary in nature; and if any duplication of the criteria exists prior to attempting MBSE integration into SETR events.

The observation made during the review of the previously collected PDR criteria relates to the terminology employed. Numerous criteria and PDR criteria categories or thematic areas all employed terminology no longer in use within the acquisition life cycle or DOD acquisition in general. The System Development and Demonstration (SDD) phase is one example that occurred frequently; however, it is not part of the acquisition life cycle. Having outdated terminology introduces confusion and uncertainty for both reviewers and personnel attempting to provide information thereby reducing the overall efficacious of the SETR event.

V. CONCLUSIONS

A. SUMMARY

In support of executing Goal 1 of the DOD digital engineering Strategy, the research performed as part of this thesis created a process to assess and permit curation of the SETR criteria. The assessments within the process looked to curate the SETR criteria, but also provide a more complete understanding of the SETR criteria health and status with respect to appropriateness to the SETR event, quality of assessing the SoI, and ability to map to an existing MBSE view. In determining the health and status of the SETR criteria one has the ability to comprehend the likely quality of any SETR event performed with those specific criteria. Additionally, the third portion of the assessment affords the insight into the readiness of the SETR criteria for integration with MBSE through use of existing MBSE views. The curation, coupled with the knowledge provided, allows the ability to improve or enhance the existing SETR criteria for use within MBSE and for SETR events in general.

The previously discussed questions and their responses, captured below, shaped the original intent of the process and the realization of the final process.

1. How does one determine if a process to curate existing SETR criteria and alter them as necessary to more accurately capture the “health and status” of an SoI under review through model-based views and data is required?

The execution of an assessment of the SETR’s criteria critical characteristics provided insight into the health and status of the criteria. This insight supplied the knowledge of whether the SETR criteria would have the ability to accomplish their intended purpose. The results of the assessment presented a bleak reality of the SETR criteria reviewed. Over 43% of the criteria did not fully address the appropriate level of development as aligned with the SETR event. The criteria that proceeded to the next assessment had nearly all criteria, approximately 97%, partially or fully failing to meet the evaluation requirement of having the ability to provide insight into the health and status of the SoI. The final assessment of the remaining criteria found only 75 criteria, or

approximately 13% assessed, had the ability to map partially or fully to an existing MBSE view.

2. How does one create a process to curate existing SETR criteria and alter them as necessary to more accurately capture the "health and status" of an SoI under review through model-based views and data?

Based on the status of the SETR criteria, the process created, and presented within Chapter 3, ultimately focused on assessing and curating the existing SETR criteria. The assessment entailed the review of SETR criteria characteristics and alteration as necessary to more accurately capture the "health and status" of an SoI under review. The process also addressed assessing the SETR criteria's ability to map to an existing MBSE view.

This process supports one of the three sub-goals of Goal 1 of the DOD digital engineering Strategy. The sub-goal is to formalize the planning for models to support engineering activities and decision making across the life cycle. The process formalizes a way to curate SETR criteria in preparation of MBSE integration. Additionally, the process denotes which criteria can map to existing MBSE views thereby providing a gauge of the current readiness of specific SETR criteria to have MBSE integrated.

3. How does one verify that a solution generated to address the problem fulfills its intended purpose?

The research performed on the previously gathered NAVAIR PDR criteria and the resulting outcome provide verification that the process can detect inadequacies within an existing set of SETR criteria. The use of these newly curated criteria in the performance of a PDR could provide validation.

B. RECOMMENDATIONS FOR FUTURE WORK AND CONSIDERATION

The following four recommendations capture potential future work, which would continue supporting the execution the DOD digital engineering Strategy's Goal 1.

The first recommendation based on the state of the reviewed SETR criteria is that additional SETR criteria undergo assessment and curation in preparation for MBSE

integration. Having a healthy and robust set of SETR criteria that can accurately capture the “health and status” of an SoI under review is necessary prior to the integration and implementation of MBSE into SETR events.

The second recommendation is for the acquisition community to assign necessary attributes to SETR criteria during their development and curation. The performance of this effort would mirror what systems engineering teaches its practitioners regarding the assignment of necessary attributes for requirements during their development. While the requirements’ attributes may not all directly translate to necessary or desirable attributes for SETR criteria, they are a good starting point. Working from one of the existing set of requirements’ attributes, or a combination of sets, a group of SETR criteria attributes could undergo identification with the goal of a codified set of attributes. Even with the understanding that SETR criteria perform a separate role than requirements, ensuring the application of systems engineering rigor to the generation and curation of criteria will lead to improved evaluation, and thereby understanding, of the SoI.

The third recommendation is to investigate the creation of additional MBSE views that will support the evaluation of SoIs. While the created methodology assessed each criterion’s ability to map to an existing MBSE view, the requirement for additional MBSE views will exist for the full integration of MBSE into SETR events. A need exists to perform an evaluation regarding the needed MBSE views to support a curated set of SETR criteria.

The final recommendation is to consider the automation of the applicable portions of SETR criteria assessments. The curation of SETR criteria has inherent assessments that only a human can perform. However, the performance of some assessments could leverage Formal Methods and software programing. The employment of Formal Methods in conjunction with the development of a software program could directly handle some evaluations while other assessments could have their burden reduced through the assistance the software provides by decreasing the initial workload prior to human interaction of assessing SETR criteria.

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SUPPLEMENTAL: NAVAIR PDR CRITERIA AND RESULTS OF ASSESSMENT

This supplemental Microsoft Excel document captures a large portion of the research performed in support of this thesis. It may be obtained through the Dudley Knox Library of the Naval Postgraduate School.

This portion of the research comprised of an evaluation consisting of three separate assessments of each PDR criterion for three specific characteristics that each should possess. The first characteristic assessed is the consistency with, or appropriateness to, the required level of development addressed by the SETR criterion in comparison to the current SETR event. The second characteristic is the SETR criterion's quality to assess or its ability to provide insight into the health and status of the program or SoI under review. The final characteristic is each SETR criterion's ability for representation by an existing MBSE view. The assessments determine a set of SETR criteria ability to evaluate an SoI, to what extent criteria can map to existing MBSE views, and the scope of criteria that require additional alteration either to the criteria or to MBSE views to permit the mapping of the criteria. The document contains all of the NAVAIR PDR criteria analyzed along with the results and the associated explanations for each assessment.

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LIST OF REFERENCES

Estefan, Jeff A. 2008. *Survey of Model-Based Systems Engineering (MBSE) Methodologies.* INCOSE MBSE Initiative, INCOSE.

Department of Defense. 2009. *DOD Architecture Framework Version 2.0. DoDAF V2.0*. Washington, DC: Department of Defense, May 28.

Dam, Steven H. 2014. DOD Architecture Framework 2.02 - A Guide to Applying System Engineering to Develop Itegrated, Executable Architectures. Manassas: SPEC Innovations.

Assistant Secretary of Defense Logistics & Material Readiness. 2016. *PBL Guidebook.* Guidebook, Department of Defense.

Jackson, Maddelena, Marcus Wilkerson, and Jean-Francois Castet. 2016. Exposing hidden parts of the SE process: MBSE patterns and tools for tracking and traceability. 2016 IEEE Aerospace Conference. Big Sky: IEEE. 1–12.

Vaneman, Warren K. 2018. Evolving Model-Based System Engineering Ontologies and Structures. 28th Annual INCOSE International Symposium. INCOSE. 1–10.

Defense Acquistion University. 2017. "Defense Acquisition Guidebook Page Viewer: Chapter 3 Systems Engineering." Defense Acquisition University. September 25. Accessed March 09, 2019. https://www.dau.edu/tools/dag/Pages/DAG-Page-Viewer.aspx?source=https://www.dau.edu/guidebooks/Shared%20Documents%20HTML/Chapter%203%20Systems%20Engineering.aspx.

——— 2019. *Chapter 4 Life Cycle Sustainment.pdf.* February 27. Accessed 2020. https://www.dau.edu/guidebooks/_layouts/15/WopiFrame.aspx?sourcedoc=/guidebooks/Shared%20Documents/Chapter%204%20Life%20Cycle%20Sustainment.pdf&action=default.

Office of the Deputy Assistant Secretary of Defense for Systems Engineering. 2018. *Department of Defense Digital Engineering Strategy.* Washington, DC: Department of Defense.

Goldwasser, Debora Arena, and Christopher Ryder. 2019. *Model-Based Systems Engineering as the Catalyst for a Rapid Acquisition Process (RAP).* 2019 IEEE International Systems Conference (SysCon). Orlando: IEEE. 1–7.

Holladay, Jon B., Jessica Knizhnik, Karen J. Weiland, Amanda Stein, Terry Sanders, and Paul Schwindt. 2019. *MBSE Infusion and Modernization Initiative (MIAMI): "Hot" Benefits for Real NASA Applications.* 2019 IEEE Aerospace Conference. Big Sky: IEEE. 1–14.

International Council on Systems Engineering. 2019. *Transitioning Systems Engineering to a Model-based Discipline -SEBoK.* October 31. Accessed May 11, 2020. https://www.sebokwiki.org/wiki/Transitioning_Systems_Engineering_to_a_Model-based_Discipline.

Noguchi, Ryan A. 2019. A Roadmap for Advancing the State fo the Practice of Model Based Systems Engineering for Government Acquistion. INCOSE International Symposium. Orlando: INCOSE. 678–690.

Vaneman, Warren K., Jerry J. Sellers, and Steven H. Dam. 2018. Essential LML – Life cycle Modeling Language (LML): a Thinking Tool for Capturing, Connecting and Communicating Complex Systems. Manassas,VA: SPEC Innovations.

Vaneman, Warren K, and Ronald Carlson. 2019. Model-Based Systems Engineering Implementation Considerations. *Proceedings of the 13th Annual IEEE Systems Conference*. Orlando: Institute of Electrical and Electronics Engineers.

———. 2020. "Evaluating Current Systems Engineering Models for Applicability to Model-Based Systems Engineering Technical Reviews." *Naval Engineers Journal* 1–8.

Vaneman, Warren K., Ronald R. Carlson, and Christopher Wolfgeher. 2020. *Defining a Model-Based Systems Engineering Approach for Milestone Technical Reviews.* Acquistion Research Program Sponsored Report Series, Monterey, CA: Naval Postgraduate School.

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