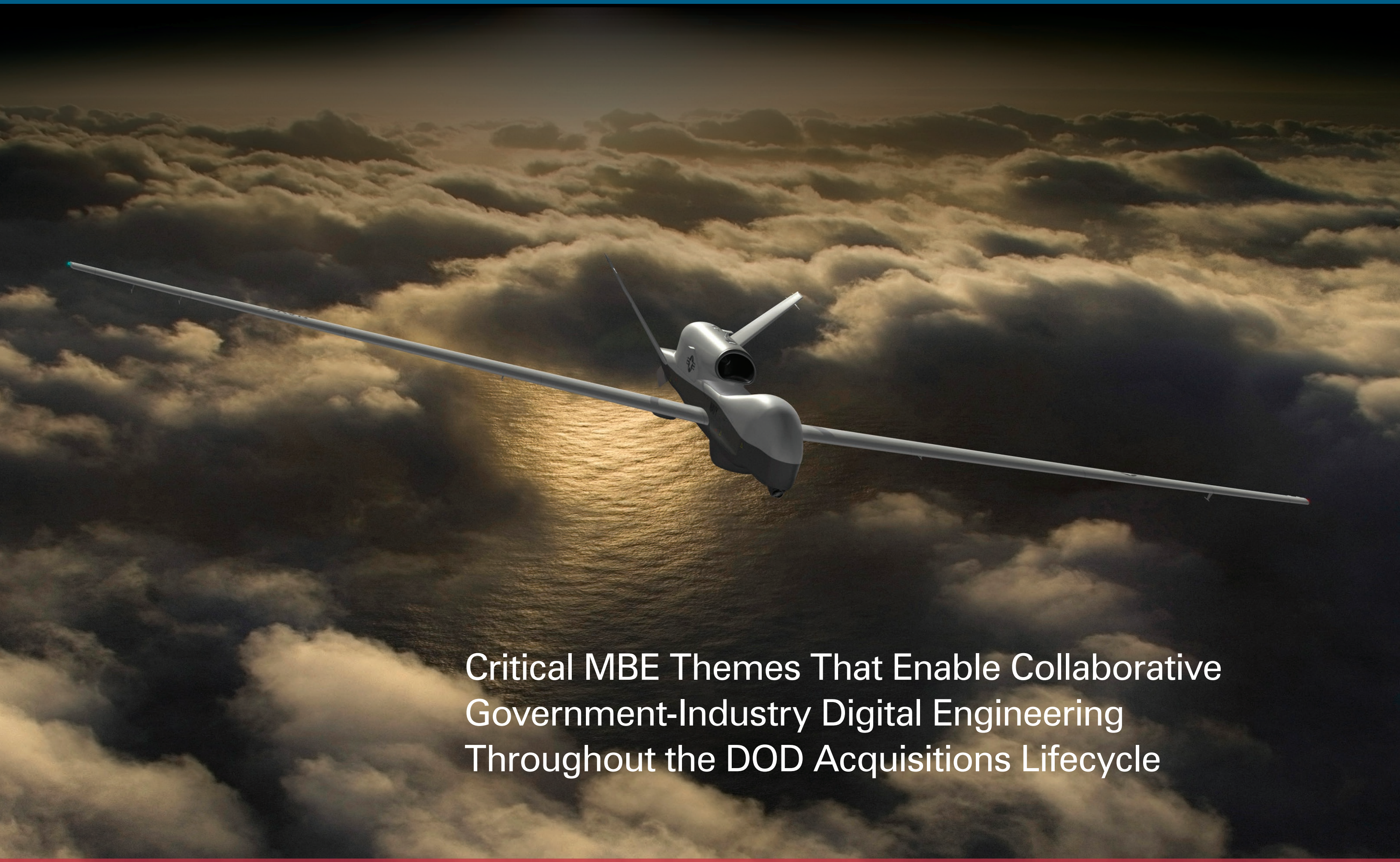
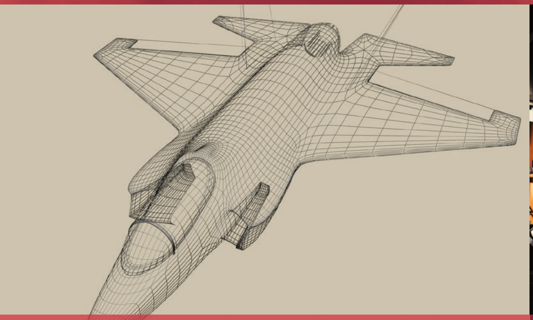
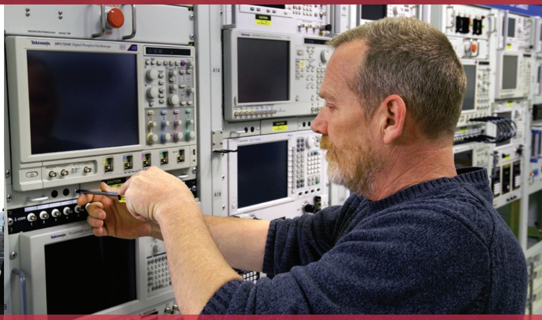
AEROSPACE INDUSTRIES ASSOCIATION

Evolving Defense Acquisition Through Digital Transformation



Critical MBE Themes That Enable Collaborative Government-Industry Digital Engineering Throughout the DOD Acquisitions Lifecycle





AUGUST 2018

Executive Summary

The future threat landscape is becoming more agile and dangerous as our adversaries field new capabilities at an increased pace and complexity. New and emerging technologies such as Artificial Intelligence (AI) swarm logic, multifunction digital electronics, cyber, and advanced anti-access area denial systems are all contributing to an increasingly lethal battle space. If changes aren't made in the near term, the Department of Defense's (DOD) traditional document-centric acquisition processes may be unable to efficiently field solutions that can keep pace with these ever-changing future threats.

We in industry see a critical need to transform the process by which the U.S. government acquires, develops, fields and sustains future weapon systems so that they can keep up with the ever changing and increasingly complex threat landscape of our adversaries. Model Based Systems Engineering (MBSE) offers a solution for such a transformation within the DOD Acquisitions and Development lifecycle process.

MBSE, used in this context, would transition away from the traditional document-centric process of maturing a weapon system from initial conception through sustainment into a much more dynamic, efficient and flexible digital engineering process. Model-based artifacts will enable increased traceability and allow errors, inconsistencies and broken links in the system to be detected earlier in the development lifecycle. This in turn will drive down the cost needed for "re-work," which exponentially increases the later problems are discovered in the lifecycle.

The ultimate vision is to realize a single digital representation of the defense system, where each subsystem component is accurately represented via analytical and descriptive models that can easily be traced to the initial set of mission and requirement definitions.

In 2017, the Aerospace Industries Association (AIA) MBSE working group collaborated with key government stakeholders from the Office of the Deputy Assistant Secretary of Defense to discuss strategic focus areas that would need to be addressed in order to transition from a document-centric to a model-centric paradigm. This paper highlights some of the key issues and themes that the AIA MBSE team has identified to help both industry and government take the next steps in realizing this vision.

We will cover the following themes in this paper:

- Definition of the MBSE CONOPS Objectives and Desired End State
- Information Access Management and Data Rights
- Collaborative Development Practices with MBSE
- MBSE CONOPs Enablers for Deriving Best-Value from Digital Artifacts

Section 1.0 Introduction

The U.S. Department of Defense (DOD) is transforming the way the government acquires, develops, fields and sustains future weapon systems. The DOD System Engineering Transformation (SET) initiative will replace the current process of using documents and spreadsheets to serve as the technical baseline, in favor of linked models and digital artifacts. Having the technical baseline in the form of connected and trusted models is commonly referred to as the "Digital Twin". Implementing the Digital Twin within Model Based Engineering (MBE) inclusive of Model Based Systems Engineering (MBSE), Model Based Manufacturing (MBM) and Model Based Sustainment (MBS) enables authoritative technical data, software, information and knowledge so decision makers have the right information when they need it.

This document focuses on the Concept of Operations (CONOPS) that pertain specifically to MBSE and is not meant to address Digital Engineering in full. The end goal is to enable the government to become a "smart buyer" and field future weapons on budget and on time to keep pace with the ever complex and agile threat landscape.

Government-industry partnership in model-based development and lifecycle management enables a model-based acquisition package including digital artifacts that link mission operations and capabilities to the enterprise level architectures. This Digital Engineering Ecosystem improves a user's ability to visualize, work, develop, share and use additional model features through improved digital artifact portability. A fundamental MBSE tenet is that design truth is captured using digital artifacts within one or more descriptive and/or analytical models. In the future state, the descriptive and/or analytical models are digitally federated and linked. The holistic approach to information access management in this digital engineering ecosystem includes use descriptions, exchange mechanisms and data protection (both cyber and proprietary). Information protection provides a structured process to determine data protection requirements by program phase and product type.

The Digital Engineering Ecosystem allows critical and consistent design decisions to be made early in a product's development while design freedom is at a maximum. Using models improves the rate that engineers can transfer design knowledge while reducing design ambiguity at the same time. Progression of time warrants decision support of the large amount of information due to knowledge increasing with interdependent attributes being integrated. Therefore, adoption of MBSE with use of digital artifacts will support trade-offs among multiple conflicting goals and contraints for the design where risk and uncertainty are high.

The end goal is a "collaborative" CONOPs environment for executing MBSE throughout the system lifecycle.
This goal is enabled by the four main themes covered in this whitepaper:

> Definition of the MBSE CONOPS Objectives and Desired End State
> Information Access Management, IP and Data Rights
> Collaborative Development Practices with MBSE
> MBSE CONOPs Enablers for Deriving Best-Value from Digital Artifacts

The desired outcome is a unified vision, "The Right Information at the Right Time in the Right Format" enabled by a MBSE government-industry collaborative CONOPS.

Section 2.0 Overarching MBSE CONOPs Objectives and Desired End State

2.1 A Long-Term Objective for Model Based Acquisition

Our long-term shared objective is to evolve our current system acquisition process from event- and document-based to model-based. Our objective is consistent with government Office of the Deputy Assistant Secretary of Defense for Systems Engineering (ODASD (SE)) Digital Engineering Ecosystem goals and the U.S. Naval Air Systems Command (NAVAIR) vision for system development. This section addresses the long-term objective to achieve the end goal. Sections 3, 4 and 5 will address the current state as well as short and long-term strategies to achieve the end goal.

2.2 Government ODASD (SE) Digital Engineering Ecosystem

MBSE moves the engineering discipline from its current state of stove-piped models and data sources toward a future Digital Engineering Ecosystem, which links data sources and models across a product's lifecycle and provides the authoritative source of design truth.

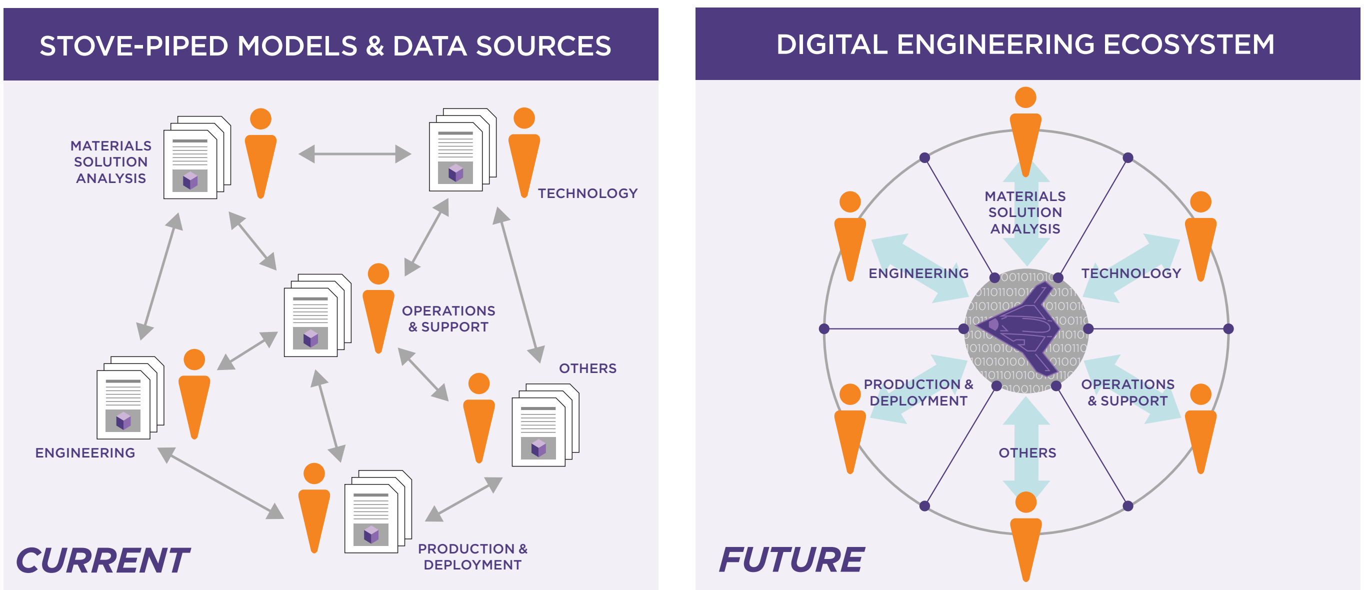


Figure 2.2-1. A Vision of model-based acquisition and development

2.3 Collaborative Government Industry Framework

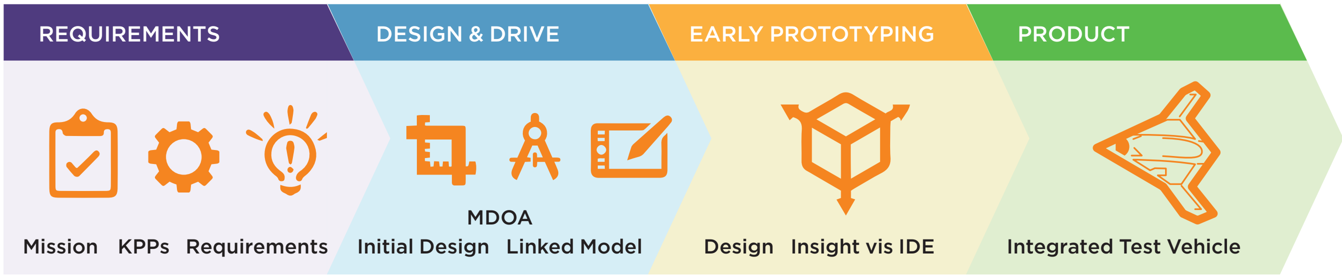


Figure 2.2-2. Activity diagram representing an implementation of the CONOPS in Figure 1

Figure 2.2-1 illustrates a NAVAIR vision of the framework for system development, showing the major activities of government and industry. This represents an example of the vision that DOD is moving towards. The activity diagram of Figure 2.2-2 is a workflow implementation based on the framework. We share this vision. The acquisition contract separates the government creation of Key System Attributes (KSAs) and system specifications from developers (industry). A feedback loop provides information from industry back to the government for recommended modification to KSAs. In itself, this is not so very different from conventional acquisition. The addition of model-based activity is revolutionary, however, in reducing the cost and schedule and improving the delivered system. The improvement resides chiefly in two areas: 1) mission, enterprise architecture, and requirements modeling by the government; and 2) full system development by industry in a digital model.

1. Government use of digital models for mission engineering and analysis, architecture development, and requirements specification enables validation of the contract requirements. With the model in place, the government can quickly provide updated KSAs in response to industry feedback.

2. Industry use of digital models for system definition, design, performance, integration and verification provides validation of the KSAs. Importantly, the validation is available before any commitment to full-scale hardware procurement and software development.

Government-industry partnership in a model-based development process includes models developed and initially maintained by the government, at the level needed to express the enterprise architecture, mission operations and performance, and KSAs. A model-based acquisition package includes integrated models that link mission operations and capabilities to the enterprise level architectures. These models will provide a complete starting point for industry proposal and development. The government acquisition team reaps the same benefits (i.e., model-based advantages over document-based baselines) as model-based development provides to industry.

While the ultimate goal is the Digital Engineering Ecosystem, we will not achieve it in one bold step, but incrementally, as tools and protocols evolve to adopt and comply with common standards for interfaces, exchange media and data models. Each step on the path to the ecosystem provides new benefits. For example, each time tool vendors reach a new level of compliance it improves users' ability to share additional model features through improved portability. Gradually, we will improve the ability of government and industry to collaborate in a model. While long term objectives include interoperability of different modeling environments without having to overspecify particular tools or formats, our interim objective is portability – being able to transfer information in models from one environment to another.

When we develop and manage both the government and industry models on an interconnected digital engineering platform that is collaboratively accessed by all stakeholders, we will reduce the time and cost from conception to delivery and improve quality of delivered systems. We will then be able to use the models throughout system life to provide upgrades and future product variants for lower cost.

2.4 Right Information, Right Time, Right Format

In order to achieve the desired vision shown in Figures 2.2-1 and 2.2-2, it is necessary to ensure that each stakeholder has access to the appropriate data whenever needed, and that stakeholders can communicate and collaborate on the needed information within the context of a configuration controlled baseline.

Government Stakeholders. Government stakeholders include System owners (user organizations), acquisition program managers, funding agencies, Systems Engineering and Technical Assistance and Federally Funded Research and Development Center technical support staff, and government laboratories.

Right information. Government stakeholders need access to industry developed models for review and comment. The government can then incorporate feedback from industry into the government-validated models, then close the loop with updated KSAs and other model data. Complete government visibility into industry model details enables collaboration but may cause development delays through excessively detailed communication. The appropriate level of detail exchanged in the model is driven by the program phase and product type.

Right time. Government needs access to industry model data from contract inception through completion and delivery, to disposal.

Right format. The long-term goal is for government stakeholders to have direct access to relevant industry developed models through a dashboard with appropriate views aligned with the data protection requirements for a given program phase and product type.

Industry Stakeholders. Industry stakeholders include contracts and program managers, systems engineers, design and development disciplines engineers, specialty engineers, Logistics and supply chain.

Right information. Industry stakeholders need access to selected elements of the government models that provide KSAs, operations concepts, architecture models and mission performance data. They also need full visibility into all aspects of the development models that relate to their discipline.

Right time. Timeliness of access depends on the program phase that the stakeholder work begins. For example, some participants will be involved throughout, and others will access the models as needed.

Right format. Ultimately, industry standards, tools and processes will mature to the point that every stakeholder will access the digital engineering model directly through a dashboard or similar medium. For the immediate future, however, there is a need to provide data to some stakeholders in custom forms or views, including documents and file transfers for special tool interfaces.

The ultimate goal is for complete and seamlessly integrated digital on a connected infrastructure, with all stakeholders having access to the necessary data and tools in the format or view that is appropriate to their discipline, and all stakeholders able to collaborate across the entire team.

Section 3.0 Information Access Management

This section discusses Digital Engineering Ecosystem information access management for protection of intellectual property (IP), and data rights, as well as data loss prevention through cyber means. Current state challenges and strategies to enable efficient, data-protected collaboration in a model-based ecosystem are presented.

3.1 Current State Challenges

The end goal for the Digital Engineering Ecosystem is the ability to realize a more agile, rapid and flexible development and fielding of future complex weapon systems. As detailed in Section 2.0, having an accurate digital representation of the system through connected models is the primary means to achieve this goal using the MBSE Con-Ops.

For the models and digital artifacts to be useful for decision makers, they have to be accurate, and of high quality:

1. The models themselves need to have accurate and high quality "data" to represent the system or subsystems they are describing.

2. The MBSE Con-Ops needs to have a set of governing rules and principles to ensure that the "right" amount of data can be exchanged and transferred across models, across contractors and ultimately, with the government customer.

The "right" amount of data used in this context refers to the need to balance the amount, type and format of data exchanged in the model centric acquisition lifecycle. Within the Digital Engineering Ecosystem, defense contractors should not be put into a position where they are required to disclose all their data that provides them with competitive advantage. This exposure may potentially violate their IP rights and put key competition sensitive discriminators at risk for those contractors. At the same time, the right amount of data must be shared between connected models to maintain the accuracy of the technical baseline to represent the single source of truth. This will enable decision makers to make better decisions faster and more efficiently. Achieving the right "information balance" will be key to fully realize the benefits of MBSE within the Digital Engineering Ecosystem.

3.2 Proprietary Data Protection

Currently there exists a gap in policies and standards to determine how the "right" amount of information exchange will be achieved within the new Digital Engineering Ecosystem. This is the problem area that IP and Data Rights Con-Ops in the new data-rich environment should seek to address. While it is beyond the scope of this whitepaper to propose a solution, we will outline in this section some key topics that should be considered by industry and government in the areas of IP and data rights.

In providing a solution to the IP and data rights problem, we will borrow a basic model that people are familiar with: The Five Ws and How approach to problem solving. Tailored to IP and Data Rights in the Digital Engineering Ecosystem, these questions are summarized below as:

> **Who** can see and modify the digital artifacts?
> **What** specifically do those digital artifacts contain?
> **Where** will the information be accessed and stored?
> **When** and how frequently will the information exchange(s) happen during the system lifecycle?
> **Why** is the data being exchanged necessary for various stakeholders with access?
> **How** will the information be used by key decision makers at various stages of acquisitions?

One important thing to note is that each of these questions should result in answers that contain facts, with references to back them up. These questions cannot be answered with a simple "yes" or "no" as the answers will depend on the type of system under development as well as what stage of the acquisition process is being considered.

Within the new Digital Engineering Ecosystem, there are three possible scenarios for information access between customer and contractor. The scenarios are:

1. Provide access to controlled baselines in contractor environment. This is considered a low IP and data rights loss risk option

2. Provide access to controlled baselines in contractor environment and provide selected models and data in accordance with contract data requirements. This is considered a medium IP and data rights loss risk option

3. Provide all required baseline models and data in accordance with contract data requirements. This is considered a medium-high IP and data rights loss risk option.

Baseline assumptions for these scenarios are that the customer provides a baseline set of models and data that provides the framework for the contractor solutions. Determining which scenario to utilize for the exchange of protected information requires consideration of the following:

- Trust relationships
- Risk remaining after mitigation
- Capability of current IT technology
- Business need
- Digital product standards
- Cybersecurity standards

Customer access to in-process baselines in contractor infrastructure is recommended to limit risk of information spillage and potential loss of IP and data rights. The approach to information management, in the digital enterprise builds a scaffolding of understanding based on the following:

Understanding the information flows between customer, prime contractor, interfacing systems prime contractors and suppliers is critical to determining the levels and types of access required. Figure 3.2-5 shows a high-level information exchange flows between customer, prime, subcontractors, interfacing system primes, and international customers (for reference only). International customer considerations were not included in this study.

3.3 Summary

To summarize, existing IP and Data rights policies and standards need to be modified and new ones developed to meet the needs of the new Digital Engineering Acquisition Con-Ops. Information management requirements identified in this study are:

- Recommend customer access to in-process baselines in contractor infrastructure during competitive phases to limit risk of information spillage
- Provide information access based solely on acquisition decision making needs
- Revise existing data item descriptions using government-industry collaboration forums to support transition to Digital Enterprise
- Use an agreed to structured process to determine key information types and protection requirements by program phase and product type
- Create a common information access management ontology useable by current and future information technology, data loss prevention and network access control applications to manage access

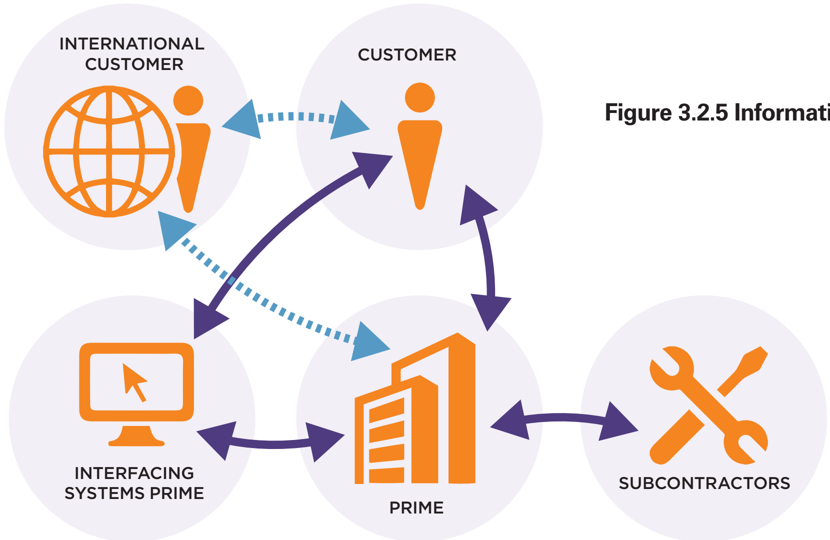


Figure 3.2.5 Information Exchange Flows

Section 4.0 Collaborative Development Practices with MBSE

In acquiring and designing complex system of systems, the best value with MBSE can only be achieved by successfully realizing two primary objectives: All the individual models for the system can be linked together to form one authoritative source of truth, and all stakeholders from both government and industry have access to work, develop and review those models, at the appropriate depth and breadth of content for their roles, in a collaborative environment. In this context, the "models" in the MBSE collaborative environment contain not only the descriptive models for the system, but the engineering, analytical and mission level models as well. In this section, we present perspectives on collaborative MBSE CONOPs development best practices and pitfalls, as well as highlight key stakeholder concerns about such an environment.

4.1 – Stakeholder Concerns about Collaborative Development

The primary concerns of an MBSE collaborative development environment can be summarize by the 3 C's: Cost, Consistency and Collaboration. These are summarized below:

Cost – Use of a Collaborative Development environment as part of system acquisition, design and sustainment introduces the additional cost of providing collaboration tools and tool training to team members that traditionally use paper or digital paper artifacts. The cost of Collaborative Development becomes an even greater burden for second and third-tier vendors as the purchase of the tools needed for collaboration or providing system models may become cost prohibitive. However, proper use of these system models should reduce the overall implementation costs by reducing integration issues and demonstrating the system meets its design intent and requirements.

Consistency – MBSE's purpose forces the engineering rigor and traceability to reduce the risk of the system not working, or not being useful for all of its intended purposes. Modern Collaborative Development environments use digital artifacts to define a system, and these digital artifacts have a history of becoming unusable over relatively short periods of time (5-20 years). As digital tools and artifacts evolve, maintaining the consistency of the digital model becomes a major concern. Inaccurate or inconsistent artifacts introduced over time may cause critical linkages and connections in the model to be broken. In the end this will eventually lead to a physical implementation that does not work and prevents the realization of a single, traceable and connected digital representation of the system.

Collaboration – A MBSE collaborative environment using digital artifacts should make it easier to update approved system models producing an optimized solution. Taken to an extreme, however, the collaborative environment could make it too easy to make changes and delay implementation through constant changing of the system model. Care needs to be taken to ensure that processes are in place to maintain a consistent single representation of the system model as the authoritative source of truth. Use of a system model before it is ready for its planned use can further delay system development. A well-defined collaborative CONOPs should address the processes and use cases of how the various players within this MBSE environment should use, update and maintain the digital artifacts to optimize the solution.

4.2 – Best Practices for Collaborative MBSE CONOPs

Build Metrics into MBSE CONOPs – It is expected that an MBSE collaborative CONOPs environment will need to be continuously modified and refined over time based on evolving needs and requirements. Having metrics to characterize the performance as it's implemented is critical to optimize continuous improvements and evaluate the changes in the CONOPs. Without collecting the relevant metrics, it's hard to assess if the collaborative CONOPs environment is achieving the results desired, or even is strategically headed the right direction. Therefore, the AIA team recommends that we build into the MBSE CONOPs the capability to automate or formalize the collection these metrics in the framework. Below is a list of some key metrics that could potentially be collected:

1. Complexity of the models via number of modeling artifacts, objects added, as well as their interconnections.

2. The clarity and ease of understanding of the models to key stakeholders, subject matter experts and/or decision makers

3. Number of system defects/inconsistencies that were caught and mitigated via the interconnected models and the traceability of the digital thread

4. Customer satisfaction with the model centric environment and agile based evaluations

5. Time to generate and complete trade studies and new operational scenarios in the MBSE environment

Transition Away from Document-Centric to Model-Centric – As systems become more and more complex, the tools and processes used to acquire, design and field them must also increase in sophistication and flexibility in order to realize optimal solutions on schedule and at cost.

Therefore, we recommend that one of the key focus areas in the MBSE collaborative CONOPs should be to reduce, and at times to eliminate reliance on documents and spreadsheets to convey requirements, design and end user needs. The main limitation with documents is the lack of a straightforward path to enable traceability and verification between all the detailed technical system design specs and the pages and pages of "words" contained in the review artifacts. Mistakes and errors are more likely in these situations because the reviewers assume that the solution exists and is sound because of "political engineering" rather than on a thorough quantitative design analysis compared against properly defined requirements.

We propose that a "document-centric to model-centric" artifact transition plan be defined and implemented at the beginning of the MBSE collaborative CONOPs transformation. Specifically, one where documents that once defined operational scenarios, requirements and system design gradually are phased out and replaced with a single authoritative source of truth in the form of interconnected models. The end goal of such a transition would be to relieve the burden of human consumption and review of large amounts of data, and institute a more streamlined and machine-driven process through the continuous validation of traceable digital artifacts.

Agile Baseline Reviews versus Milestone Reviews – Fig. 4.2-1 shows the Agile MBSE process. By building in agility into the MBSE CONOPs, defects and schedule slips will still occur, but the time lost is greatly reduced because issues are visible much sooner. Specifically, the "Agile design" process will implement the following four-step feedback loop:

1. Build and Develop
2. Test
3. Review
4. Modify

These four steps are described in detail below:

1. In step one, the digital models are built out and developed within the same unified MBSE environment/framework. The MBSE environment enables all results, parameters and designs to be checked into a system level model that represents the authoritative technical truth of the system.

2. Working from a single authoritative source of truth, the framework is able to perform automated updates and tests to trace parameters, KSAs, key performance parameters and other modeling results back up through the system requirements. This way, any inconsistencies and errors introduced are discoverable as the models and digital artifacts are built and connected in the environment.

3. Key stakeholders and end users will have continued access to the digital design and data artifacts and are able to provide their inputs and suggestions into the system. Depending on the scope of the system design, time between reviews can be a short as bi-weekly to monthly during certain phases of development.

4. Engineers and modeling subject matter experts are then able to take the inputs and feedback and modify system designs and the digital models accordingly, using the established change management process. The process then returns back to step one for the next design iteration.

Figure 4.2-1 Graphical Representation of Agile MBSE CONOPs

4.3 – Key Issues to Address in Realizing the MBSE Development Environment

Currently, a large collection of diverse modeling tools and languages are used at various stages and levels in the system acquisition and development lifecycle. The main measure of success for realizing a single "authoritative source of truth", lies in the MBSE framework/CONOP's ability effectively to tie together all these disparate modeling resources and form one integrated "system model." To achieve this, the AIA team has identified two primary gaps that need to be "bridged" at the strategic level: bridging the models and tools utilized at different phases of the system lifecycle and bridging the descriptive models with the analytical models.

Gap 1. Digital artifacts and models for a given system are currently unable to be effectively managed, transitioned and passed between various design phases and milestones in the acquisition and development lifecycle. This gap is largely because the models and simulation tools that used at each of these phases are different and not readily compatible. An example is the disconnect between early mission engineering and requirements development models, with the more specialized mathematical and computer aided engineering models at the later phases of system development. Many mammoth-sized spreadsheets and documents are often used as "the bridge" that connects the digital engineering results between phases and milestones. This process is very inefficient and puts a tremendous burden on the "humans in the loop" to maintain, update and ensure the integrity of the technical baseline. To realize the vision for having an authoritative source of technical truth throughout the lifecycle of a given system, this gap must be addressed in the future MBSE collaborative environment.

Gap 2. The second gap lies in a fundamental disconnect between two primary classes of modeling tools: analytical models versus descriptive models. The exact definitions for both analytical and descriptive models used here can be found in the Systems Engineering Body of Knowledge from the International Council on Systems Engineering, the Institute of Electrical and Electronics Engineers Computer Society, and the Systems Engineering Research Center. In general, analytical modeling tools focus on the mathematical relationships and equations that support quantifiable analysis about key system parameters; whereas the descriptive modeling tools focus on capturing the logical relationships, interconnections between system parts, the functions that its components perform, or the test cases that are used to verify system requirements. When singled out by themselves, the analytical and descriptive models represent specific aspects of a system but do not provide a holistic digital representation of the system.

Section 5.0 MBSE CONOPs Enablers for Deriving Best-Value from Digital Artifacts

Several opportunities exist to derive and optimize the value obtained from the digital artifacts produced under MBSE. Each opportunity incurs a cost of implementation, requires one or more enabler, and returns one or more benefit on cost, schedule, technical, risk, quality or other factors.

MBSE benefits include:

- Reducing cycle time to meet demand for agility in addressing rapidly emerging and evolving mission needs driven by changing threats and technology
- Improving efficiency of the engineering process to reduce cost, shorten schedule and improve the quality of the deliverable products
- Making better decisions through integration and fusion of previously separate and disparate information
- Improved product quality achieved through process rigor

Each program tailors their MBSE processes to select the opportunities that provide the best value, while considering the programs-unique objectives and challenges, and the state of the required enablers. Value is defined as the benefits realized by exploiting the fact that MBSE captures information in digital artifacts versus document-based artifacts. The best value is achieved when the MBSE processes are optimized to leverage the most significant opportunities possible within the available budget.

These opportunities have been incorporated with the current state of the industry, to define the MBSE CONOPs future state as described in Section 5.1. Each opportunity is identified below, and each opportunity, and the enablers required to achieve the specified future state are described under Section 5.2:

- Capture the Truth in Models as Digital Artifacts
- Automated Generation of Reports from Models through Extraction
- Automated Generation of Digital Artifacts from Models through Analysis, Execution and Synthesis
- Model Based Management
- Digital Artifacts as Deliverables

5.1 MBSE CONOPs Future State

In the future, the descriptive and analytical models are the primary and exclusive method of information exchange for the customer acquisition and contractors engineering processes, and documents are used minimally, if at all. Contractors primarily receive models, which conform to a customer – contractor's will deliver models as outputs to the customer, and contractors' team members and engineering disciplines collaborate through the digital exchange of models and or modeling products. People are freer to perform value added acquisition and engineering tasks better suited to people, such as capturing knowledge and evaluating the quality of the proposed solution.

Performance characteristics in the descriptive models are digitally integrated with the performance predicted by the analytical models. Descriptive models allow the relationships between different analytical models to be described and used to understand relationships between different modeled characteristics. Descriptive and analytical models, and supporting processes and tools, are used to estimate, measure and track the maturity and quality of the digital artifacts so that the risk of meeting technical, cost, schedule and performance are predicted and managed. Because this information is associated with individual digital artifacts, we can measure and assess maturity in a continuous and atomic manner, as opposed to periodically at major milestone events such as system requirements review, system functional review, preliminary design review and critical design review, where the entire system is measured and assessed at a singular point in time.

Contractors primarily receive models, which conform to a customer – contractor agreed standard architecture framework such as the Unified Architecture Framework. The models are reused directly with some automation built around an agreed to, standard framework. Contractors deliver an extended model which conforms to the standard architecture framework and data model with custom extensions. Contractors build static and dynamic views to give meaning to these extensions. The views are delivered in the context of the model.

Contractors' efforts shift to machines to automate generation and formatting of standard and tailored views; human effort shifts to higher-level reasoning, strategy and knowledge capture. Contractors work in a shared (likely distributed) set of federated models which each conform to a standard architecture framework with a defined ontology; contractors may also receive viewpoints which the customer has chosen to share in advance. Contractors provide and augment these models, potentially extending the base ontology to cover contractors-specific constructs. Contractors may provide viewpoints to cover the ontology extensions. Contractors' efforts shift to machine reasoning of models (based on defined ontology); human effort focuses on strategy, innovation and knowledge capture.

Customer effort shifts to machines to check model conformance, completeness and quality. People still review standard and tailored views but tedious labor-intensive work is covered by machine automation. Customer effort shifts to machine reasoning of models (based on defined/extended ontology); human effort focuses on strategy, innovation, knowledge capture and performance analysis. The customer will be able to practically consume the delivered models and derive value from that consumption without significant effort.

5.2 MBSE CONOPs Future State Opportunities & Enablers

The future state can be achieved through a phased evolution from the current state, as improved by mid-term (2 – 5 years) and long term (5 – 10 years) activities. The long-term vision should be updated to leverage knowledge gained and lessons learned through implementation of the mid-term activities.

The overall trend supports owning the technical baseline and other related efforts and capitalizes on the dramatic improvements in computing, cloud infrastructure and machine learning. The following subparagraphs describe the most significant opportunities required to evolve to the desired future state of the MBSE CONOPs.

5.2.1 Capture the Truth in Models as Digital Artifacts

A fundamental tenet of MBSE is that the truth – cost, schedule, technical, performance, risk and/or other baselines – is captured using machine-readable digital artifacts within one or more descriptive and or analytical models. In the future state, the descriptive and or analytical models are digitally integrated, such that one model may be designated as the authoritative source of truth for each digital artifact used within any combination of descriptive and or analytical models which use or reference information from the designated authoritative source of truth model.

5.2.2 Automated Generation of Reports from Models through Extraction

The capability provided by many modeling tools, third party add-ons and contractor-developed tools to automatically generate reports from information contained in descriptive and analytical models has been used widely over the past 5 years. The available tools have been used to produce all or part of several of the traditional Contract Data Requirements List (CDRL) documents such as requirement specifications, architecture description, design description and interface design description documents, as well as custom reports. The content and format of the reports has primarily been driven by CDRL data item descriptions authored for heritage document-based acquisition and development programs, and in support of the entrance and exit criteria of milestone reviews. Overall, the report generation tools have evolved to have capabilities that produce an acceptable to good end-product quality but do require a significant amount of human effort to configure the tools to produce the desired outputs and quality.

5.2.3 Automated Generation of Digital Artifacts from Models through Analysis, Execution and Synthesis

A fundamental benefit of using descriptive and analytical models to capture information and knowledge as digital artifacts, is that the information is stored in digital, machine-readable forms, which enable interpretation, analysis and/or transformation by computer programs and other supporting tools. The primary techniques to exploit these benefits include static analysis, dynamic analysis, model execution and synthesis, as described below.

Static Analysis applies user-defined rules and algorithms, to calculate user-defined properties from digital artifacts. The outputs calculated by static analyses are derived from time-invariant input properties contained within the descriptive and/or analytical models. Static analyses are typically implemented via analytical models and or supporting tools. Examples of static analyses include mass properties, fault tolerance, reliability, cost, schedule and readiness level. Importantly, while the values of the input properties may vary over the program lifecycle, they are considered as static at each point in time when the static analysis is performed.

Dynamic Analysis applies user-defined rules and algorithms, to calculate user-defined properties from digital artifacts. The outputs calculated by dynamic analyses are derived from time-variant input properties contained within the descriptive and/or analytical models. The dynamic analysis outputs typically represent performance characteristics which are expressed as a function of time, such as a time history of values, the time to converge, the time to diverge or others. Dynamic analyses are typically implemented via analytical models and or performance simulations. Dynamic analyses typically report the values of performance characteristics and are frequently expressed as "the time to" perform some behavior or achieve a specified state or condition.

Model Execution leverages the fact that behavior models can be executed within the modeling tools in which they have been created and or transformed into source code which may be compiled, linked and executed as simulations. Model execution may be applied to perform virtual validation from behavior models that depict the concept of operations and or virtual verification from behavior models that depict the design and/or implementation of the associated requirements. When combined with and/or integrated into the programs' test automation framework, model execution supports model-based test activities.

Synthesis automatically creates new digital artifacts from the descriptive and or analytical models, which reduces the human effort required to create and maintain the products and improves their accuracy and consistency. Synthesis typically uses combinations of the techniques applied by static analysis, dynamic analysis and model execution, to create and/or update digital artifacts from other digital artifacts. Examples of synthesis include generation of requirement, interface or collaboration model elements from analysis or execution of behavior models. Some advantages of synthesis include:

- Recognizing the relationships between key artifacts allows definition of transformations and combinations that allow creation of other products from the key artifacts.
- Models can better represent what has traditionally been encoded in text-based requirements and other deliverables.
- The ability to visualize, execute and test models instills better confidence that the required behavior, functionality, performance and interfaces are communicated accurately, thus reducing the number of text-based requirements.

Contractors have started to exploit the benefits of static analysis, dynamic analysis, model execution and synthesis over the past 5 years. Initial efforts have demonstrated significant benefits while revealing the importance of achieving improved digital integration between the descriptive and analytical models.

5.2.4 Model Based Management

MBSE provides the ability to estimate, measure and track the maturity and quality of a design so that the risks to meeting technical, cost, schedule and performance targets are predictable and managed. Because this information is associated with individual digital artifacts, we can measure and assess maturity in a continuous and atomic manner – as opposed to delaying until a milestone event, such as preliminary design review, where the entire system is measured and assessed.

5.2.5 Digital Artifacts as Deliverables

As the customer and contractors are transitioning from document-based engineering to digital engineering, the personnel supporting the acquisition and engineering activities are becoming increasingly familiar with the use of digital artifacts as the authoritative source of truth for cost, schedule, technical, performance, risk and/or other baselines. This cultural transformation will eventually eliminate or reduce the need for, and/or use of, milestone reports and documents, in favor of frequent and/or continuous exchange of digital artifacts as contract deliverables, as described in Section 3. In the future, document-based deliverables will be rare exceptions, and will be used only for information for which there is minimal or no value for inclusion in descriptive or analytical models.

6.0 Conclusion

In this paper, we have outlined many of the benefits – as well as some of the challenges – to transforming the process in which the U.S. government acquires, develops, fields and sustains future weapon systems in an ever changing and increasingly complex threat landscape. A collaborative, model-centric environment where the right information is shared at the right time in the right format will make the entire DOD Acquisitions and Development lifecycle process more efficient and responsive.

Model Based Systems Engineering offers a promising way to achieve such a transformation. Implementation will be an iterative process, requiring planning and specific activities in the short, medium and long-term. This paper is one of many steps along that road.

The threat environment will only grow more complex and challenging with time – it is imperative that we evolve to deliver the American warfighter the best capabilities more quickly and efficiently. If we do not, we risk losing the battlefield edge that is decisive in conflicts around the world.

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