



Life Cycle Benefits of Collaborative MBSE Use for Early Requirements Development





Dear Customer & Industry Practitioners,

Founded in 1919 with roots going back to the Wright Brothers, the Aerospace Industries Association (AIA) is the nation's pre-eminent association of manufacturers and suppliers of civil, military and business aircraft, helicopters, unmanned aircraft systems, space systems, aircraft engines, missiles, and related components, equipment, services and information technology.

Thank you for the opportunity to provide the AIA's perspective on the advantages of utilizing Model-based Systems Engineering (MBSE) across the entire life cycle when developing aerospace and defense-related systems. We believe the government and industry can realize significant benefits by increasing and improving collaborative government and industry use of MBSE, especially during the early requirements definition phase. This white paper discusses the current state and benefits of MBSE across the entire life cycle and provides proposals for addressing such issues as MBSE Collaborative Framework, Government Data Rights, Intellectual Property, and Life Cycle Effectiveness with MBSE.

In its Systems Engineering (SE) Vision 2025, the International Council on Systems Engineering (INCOSE) defines MBSE as "the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases" (INCOSE 2007). Model Based Engineering (MBE) has another closely related definition that includes MBSE. The National Defense Industrial Association (NDIA) defines MBE as "an approach to engineering that uses models as an integral part of the technical baseline that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle" (NDIA 2011). The motivation to shift away from document-based systems engineering paradigm to a model-based one lies in the measurable benefits that models provide across the entire life cycle of a product including: cost savings, risk reduction, easier technical exchange, consistent data-backed and physics-based decision making, and richer trade analyses.

An area where MBSE immediately adds value is during the early requirements development phase, particularly where government and industry are able to collaborate to generate future program requirements. Approximately 75 percent of Life Cycle Cost (LCC) is fixed by Milestone A (DAU 1993). Moreover, all too frequently technology capabilities and program resources are found to not match the requirements at Milestone B. The downstream challenges created by these requirements include system designs that are not stable, that underperform during Engineering and Manufacturing Development (EMD), do not meet cost, schedule, and quality targets during production, and are found to be operationally non-suitable (Zimmerman 2014). MBSE has clearly demonstrated the potential to help address many, if not all, of these common challenges that confront complex development efforts due to the substantial difficulty to produce stable requirements for a complex system using a document-centric approach (IBM 2011).

The Department of Defense (DOD)-funded Transforming Systems Engineering through MBSE final technical report shows the difference in today's dynamic nature of Systems Engineering (SE). (Blackburn 2015) Because practitioners can do iterative development, industry and customers have an



opportunity to compress the development life cycle of a system. For example, leading industry groups are using the MBSE discipline to generate requirements from cross cutting models, which is resulting in significant cost and time savings from the traditional SE approach.

There are several examples where the DOD intends to advance the maturity and capability of MBSE within its programs. One example is in the policy changes outlined in the Government Accountability Office's June 2015 report on service chief's concerns for better requirements definition before program starts (GAO 2015). Another was presented at a recent MBSE INCOSE workshop (International Symposium Corporate Advisory Board meeting) highlighting the current issues for model-based systems engineering within the DOD. The issues included gaps in development and maintenance of a single, integrated system model of program technical data as well as the difficulties in sharing the models between acquisition activities. The MBSE vision from the Office of the Deputy Assistant Secretary, Department of Defense (ODASD) emphasizes the need for consistency in developing and utilizing models which evolve, provide cohesion, and unify a program across its life cycle from development to sustainment. The DOD has also identified requirements-related barriers industry faces during competition and execution of new programs that need to be addressed. For example, regarding early requirements development, the current Better Buying Power 3.0 effort brings attention to specific desired outcomes including providing draft technical requirements to industry early and engaging industry in funded concept definition work, removing unproductive requirements imposed on industry, and improving requirements definition for services.

Both of these efforts provide supporting rationale for implementing an MBSE approach to collaborative early requirements development. This will support improved generation of stable, clear, affordable and non-conflicting requirements for new and major upgrade programs, without the shortfalls experienced to date. It is AIA's view that in order to move towards the desired future state, four key topics areas must be addressed: the need for a DoD/Industry MBSE Collaborative Framework; Government Data Rights; Intellectual Property Protection; and Life Cycle Effectiveness with MBSE.

This paper summarizes AIA's assessment of the current state of MBSE within industry and government. Specific details on best practices, usage of tools, standards and languages, roadblocks, and areas of need are also included.

MBSE Collaborative Framework

Government-industry collaboration on pre-milestone B requirements definition should reside within a secure model-based engineering framework supporting diverse toolsets and controlled data exchange to develop program requirements. We see some progress on this recommendation already. And by highlighting the existing achievements and future plans for standardization, we hope there will be a clearer vision of what such a framework would look like to all of government and all of industry. The purpose of a collaboration framework is to enable people from different positions and functions in the value stream to communicate effectively so as to achieve a common goal – it is an equalizer.

Government Data Rights

Striking the right balance in affording appropriate government data rights to enable the aforementioned collaboration will require an examination of recent regulatory changes to determine barriers in which government and industry currently operate. AIA's "Rebalancing Acquisition" report from July 2014 provided defense procurement recommendations addressing the government's goal to obtain extended data rights; similar logic needs to be applied to MBSE-related data rights. For example, costs savings can be realized around data acquisition activities with a better approach to acquisition planning and determining what sources of data are most critical to the DOD. Given the data-rich nature of MBSE artifacts and models, careful examination is needed to ensure acquired data will support the system for its full program life cycle.

Intellectual Property Protection

A similar balance will need to be achieved concerning intellectual property protection of company investments. While long term competition opportunities are fundamental to the current acquisition process, the potential for MBSE collaboration between government and industry is diminished by the prospects of lost IP rights, and from the contractor's perspective, government avoidance of the need to procure follow-on data and software licensing.

Life Cycle Effectiveness with MBSE

To ensure industry and government can efficiently work across the life cycle with MBSE, we recommend standards-driven data accessibility, semantically precise data translation, a tool-agnostic methodology for data exchanges, and an agreed-upon deliverable data set to exercise the thread between tools and testing interoperability. Existing efforts are already making headway in each of these fronts; we highlight a few of them of notable interest.

The need for effective application of MBSE is also substantiated by the exponential increase in complexity due to the nature of systems-of-systems. No longer is a single platform the only system-of-interest when considering a specific mission or operational reality. System-to-system capabilities, plug-and-play approaches, and modular open systems architectures all present unique challenges MBSE must address. For example, the Naval Air Systems Command (NAVAIR) is placing more emphasis on



in-house mission analyses to factor in campaign and mission analyses cutting across mission scenarios and platforms. They are leveraging MBSE enable technologies and evolving platforms of capabilities to rank by priority emerging situations and increase the analysis and frequency of design changes earlier in the life cycle. There is also some collaboration by industry to integrate simulated platform capabilities into mission analyses which provides much greater fidelity for mission-level analyses. Interoperability and integration, however, are still somewhat challenging.

As stated in the Integration & Interoperability edition of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) Leading Edge magazine, the Navy is tackling the systems-of-systems complexity issue through several MBSE-related thrusts including development of an integrated capability framework, providing guidance on system-of-systems engineering, and a focus on mission engineering (NSWCDD 2015).

These recommendations are a sample of possible solution steps and we are confident future discussions around these points will help us progress the current state and utility of MBSE to a fully government-industry collaborative environment.

Executive Summary

The shift away from document-based systems engineering to model-based engineering and the application of Model-Based Systems Engineering (MBSE) in government and industry is growing but has not yet been institutionalized. Improved standardization of methods, model/data exchanges and intellectual property rights are key enablers to broad MBSE adoption throughout the industry.

As a better way to do Systems Engineering (SE), the benefits of MBSE are maximized when applied at the start of concept phase and its application continues through development, deployment and sustainment.

MBSE is defined as an approach to system development using models as an integral part of the technical baseline.

MBSE enables industry partners to maintain multiple options through preliminary design review (PDR) or critical design review (CDR), enabling agility in the face of changing requirements and technologies without the legacy cost of maintaining multiple baselines.

In contrast to the automotive and microelectronics industries which exhibit stable or decreasing trends in the time-to-market of new products with increasing software and hardware complexity, the aerospace industry is experiencing an opposite trend of escalating lead times to develop, integrate, test, and deploy assets and platforms into operation.

There is an impetus to reverse this trend in order for the DOD to stay in front of the rapidly evolving threat space in a cost-effective manner.

For example, it's conservatively estimated that a large majority of the functionality of a 5th generation air vehicle system will be rooted in software. The models feeding the structure of the software need to be accurate as possible.

A promising solution to the problem lies in increased value-added utilization of and collaboration in MBSE to augment SE activities. To better understand MBSE, we:

- Identify the current maturity of MBSE activities across the industry
- Identify the applicable MBSE standards
- Define the role of MBSE throughout the course of an acquisition, beginning with Development Planning/Early Systems Engineering and progressing through development, delivery and sustainment.
- Address challenges from early requirements definition, such as contradicting cross-domain requirements, by proposing a collaborative industry and government MBSE environment
- Discuss appropriate MBSE-related data rights to the government and protections of industrial intellectual property

AIA's overall recommendations are as follows:

Define a government-industry collaborative, secure model based engineering framework that will support, establish, and monitor the application of diverse toolsets and controlled data exchange to develop program requirements

Various standards bodies, industry associations, and collaborative efforts are publishing standards and developing frameworks to achieve a broad architecture to allow for the easy exchange of models and data. Some examples include:

- PDES, Inc – An international organization focusing on standards for model integration and product life cycle management (PLM)
- System Architecture Virtual Integration (SAVI) – An industry initiative by a number of aerospace companies and government organizations to improve model-based software-reliant aircraft systems
- INCOSE – The international authority on Systems Engineering currently focusing on its “SE Vision for 2025” and grand challenge to make MBSE a standard practice and is integrated with other modelling and simulation as well as digital enterprise function. It also has an active MBSE community addressing the challenge of ensuring that modeling is done with the purpose of ensuring all the elements and sub-systems work together to achieve the objectives of the whole system.
- SISO – An international group focusing on modeling and simulation interoperability

- OMG – An international consortium focused on modeling standards, visual design, and execution and maintenance of software and other processes. The originator of UML, on which SysML is based.
- LOTAR International – Develops, tests, publishes, and maintains standards for long-term archiving (LTA) of digital data, such as 3D CAD and PDM data. Smarter, semantic linking of data will propel the utility of this effort even further in the future.

Additionally, government agencies, institutes and services are also instantiating MBSE initiatives, such as:

- NIST – Currently devoting resources towards model interoperability and exchange, and computer-readable requirements structure definition and standardization
- NASA – Moving the agency towards integrated model-based architecture paradigm, for example JPL's Open MBEE Project (Delp 2014).
- Army – Employing standards for interoperable and data-rich 3D PDF data viewing and model exchange, as well as the Engineered Resilient Systems (ERS) initiative (Holland 2015).
- US Air Force – Digital Twin initiative to maintain digital models of developed platforms through the entire life cycle (Kraft 2013).

- National Network for Manufacturing Innovation – DMDII, Defined Digital Design and Manufacturing (or simply “digital manufacturing”) as the aggregation, analysis, and application of data across the life cycle of a manufactured product. This data consists of both product and process data from across the value chain.
- Unified Architecture Framework (UAF) – An effort curated by the Object Management Group (OMG) to consolidate several different architecture frameworks, such as DoDAF, MoDAF and NAF to reduce difficulties during model translation from one architecture framework to another.
- CREATE - A DOD effort and component of the Engineered Resilient Systems initiative developing and leveraging physics-based modeling tools for various military platforms for more accurate decision-making during design changes and AOA activities. Helps achieve the goal of keeping descriptive and analytic modeling needs in alignment.

Additionally, we provide commentary on the security aspects of the MBSE collaborative framework through alignment with the guidelines provided in the DOD PM Guidebook for Integrating the Cybersecurity Risk Management Framework into the DOD Acquisition Life Cycle and in NIST 800-53A Guide for Assessing the Security Controls in Federal Information Systems and Organizations.

Identify the regulatory changes required to provide the government an appropriate amount of data rights

The 2014 AIA Rebalancing Acquisition Strategy report provided similar recommendations regarding specific pieces of data rights regulations industry has concerns with, which we expand upon within an MBSE perspective. The goal is to find the right balance affording the government with mission-critical data while minimizing the burden of providing data never to be used.

Identify the regulatory changes required to protect industry intellectual property while enabling pre-milestone B collaboration between potential future industry competitors

In order for the requirements-specific efforts outlined in Better Buying Power 3.0 to become reality, industry will need an appropriate amount of IP protection to encourage collaboration while still allowing for fair, future competition. We expand on previously specified regulatory recommendations for the context of MBSE, such as encouraging a critical look at Section 815 of 2012 NDAA “Rights in Technical Data and Validation of Proprietary Data Restrictions” and 10 USC 2320(a)(2)(F) “Rights in Technical Data”.

MBSE can help address the problem in two ways. First, by making sure the top-level capability is defined in terms of capability need and not simply as “jumping to a solution”. As mentioned before, the nature of systems-of-systems complexity requires capability definitions be clearly tied to a need. Second, the use of abstraction in MBSE can allow description of potential capability in models without full release of the industrial IP of the natural details of the solution.

Assuming abstraction in MBSE is achievable, there needs to be a consistent approach defined to abstraction and the statements regarding the accuracy of abstracted models to ensure a level playing field.

Ensure MBSE is effective across the entire life cycle of a program with standards-based data accessibility, robust data translation, common tooling, and defined deliverable data for tools to be able to ingest data in the proper format.

While MBSE provides valuable capabilities for early milestone activities, we realize the decisions made at the beginning of the life cycle have tangible implications felt throughout the entire process. The strategic use of MBSE is equally as important as the discipline, and without a common government-industry strategy, we will realize additional difficulties as we move towards a model-based paradigm.

For example, standards such as DO-331 “Model-based Development and Verification”, an annex to DO-178C, provides guidance on airworthiness of software for airborne systems and equipment certification. The standard states verification by model is sufficient for most software testing activities, but now necessitates the model and verification process are compliant to DO-178C. Fortunately there are code verification tools out on the market specifically addressing the standard.

Though still in the works, ARP-4761A “Model-based Safety Analysis” also recognizes the advances of MBSE and integrates systems engineering with safety engineering. While not yet a mandate, it will be necessary to anticipate any compliance-related details within ARP-4761A in the event that it becomes one.

Finally, the ability to extract meaningful and clear decision-supporting information from models is another important benefit of MBSE. NIST has been active in implementing and testing standards related to model translation from one modelling tool to another. Additionally, ISO/IEC/IEEE 42010 describes what is a model architecture, how to represent an architecture in views, and rules for architecture well-formedness, completeness, and analyzability.

As a backdrop to our recommendations, we also provide as an appendix a strategic follow-on plan to develop a Concept of Operations (CONOPs) describing how to implement past findings in similar reports, specifically those found in NDIA’s Systems Engineering Division 2011 final report on model-based engineering (NDIA 2011).

The objectives of the CONOPs is to expose concrete points in time along the life cycle that would benefit from government-industry collaboration within MBSE, define the candidate data and model types, and applicable standards for each identified life cycle event, and describe roles and responsibilities at each event. The desired outcome is a unified vision of what a MBSE government-industry collaborative interaction would look like.



Introduction

What is Model-based Systems Engineering?

Model-based Systems Engineering according to INCOSE, is an approach to engineering using models as an integral part of the technical baseline including the requirements, analysis, design, implementation, and verification of a capability, system or product throughout the acquisition life cycle.

Model-based Systems Engineering represents a paradigm shift away from traditional document-based systems engineering; a discipline historically characterized by heavy reliance on paper drawings requiring manual configuration and change management. Even though models of components and subsystems existed, they were usually thought of as secondary means of technical communication when compared to paper drawings. With the dramatic increase in system complexity, the aerospace and defense industry has recently transitioned in the way it develops and communicates complex systems, thus requiring a heavier reliance on data-rich models serving as the primary means of technical communication. While the industry is still a ways off from completely weaning itself from documents, models will continue to gain a

foothold as a fundamental component of our business. When the models are precise enough, there are instances of utilizing them to generate documents. NASA/JPL is leveraging a single source of “truth”, which is a large constraint network representing requirements that can be used in requirements autogeneration activities as well as linking into the models of a system.

Models, as defined by INCOSE, are used to manage the system throughout its entire life cycle and include physical analogs, analytic equations, state machines, block diagrams, functional flow diagrams, object-oriented models, computer simulations, and mental models. Expertise in model development and usage provides key decision-making benefits when engineers make specific design changes, verify and validate requirements, conduct various analyses, and communicate technical risks to stakeholders. Additionally, when models are created properly, they provide a certain degree of autonomy, a higher level of precision and accuracy, and an ability to incorporate real-world physics-based analysis.

Models are generated using tool sets provided by numerous vendors. Each tool set provides capabilities allowing engineers to design,

analyze, and document systems. Coupled with models are different modeling languages and architecture frameworks describing relationships and dependencies between and within related models. The languages and frameworks enable a force-multiplier effect in the ability to concretely specify information using a common, standard syntax. Additionally, standards play a large role in defining taxonomies, guidance, and data exchange parameters regarding the development and sharing of models.

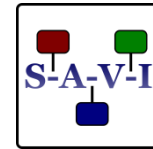
The MBSE ecosystem is a diverse and vibrant environment easily becoming as complex as the systems and systems-of-systems that are modeled within the discipline. Despite this reality, the benefits realized with MBSE are numerous. MBSE saves time and money during system development, provides a platform of clear technical communication, and enables concrete information exchange among users and stakeholders.

Domestic MBSE Efforts

The extensive number of MBSE practitioners across numerous entities, agencies, and corporations provides a wide breadth of common and unique MBSE practices across the A&D industry.

Some of the domestic entities within the MBSE discipline include:

- The Aerospace Vehicle Systems Institute (AVSI) is an aerospace industry research cooperative made up of academia, government, and industry members who are jointly advancing the state of the art technologies enabling virtual integration of complex systems through its System Architecture Virtual Integration (SAVI) program.



- The National Institute of Standards and Technology (NIST) within the Department of Commerce is actively involved in the MBSE community through standards development and tracking, and annual MBSE summits with government, industry, and academia. (NIST 2015)



- The Johns Hopkins University Applied Physics Lab (JHUAPL) has been focusing its MBSE research towards the net-centric operations and warfare domains, which have been challenging environments given their data-rich and complex scopes.



- Systems Engineering Research Center (SERC) is the university-led systems engineering research arm of the DOD, providing whitepapers and guidance on the application of MBSE in the DOD acquisition life cycle.



International MBSE Efforts

A small sample of international players within the MBSE discipline and their scope of work include:

- The International Council on Systems Engineering (INCOSE) and the Object Management Group Systems Engineering Domain Special Interest Group (OMG SE DSIG) are jointly leading the “MBSE Initiative” to develop and evolve standards for modeling languages, integration of systems and software engineering, and promoting rigor in data transformation between disciplines and tools



- SISO, an IEEE Sponsor, is the Simulation Interoperability Standards Organization which is dedicated to the promotion of modeling and simulation interoperability and reuse. The group maintains several categories of IEEE standards within the modeling and simulation discipline.



- International Organization for Standardization is an international conglomerate of representatives from national standards organizations and provides progress towards publication of standards pertaining to common logic and domain-specific modeling. One example includes ISO 10303-233 Application Protocol: Systems Engineering (AP233), which is one of the series of STEP (Standard for the

Exchange of Product Model Data) engineering data exchange standards.



- The Institute of Electrical and Electronics Engineers (IEEE) has a Technical Committee on MBSE focusing on identifying synergies between various practices within the discipline and participation in ISO Architecture Modeling standards development.



Motivation and Current Challenges

Observed Benefits of MBSE

INCOSE describes several specific benefits and advantages of MBSE. MBSE provides improved communications between the customer, project management, systems engineers, hardware and software developers, testers, and specialty engineering disciplines.

MBSE increases the ability to manage system complexity. A unified system model can be viewed from multiple perspectives without modifying the underlying data. It can be used to analyze impacts of design changes, and exploit opportunities within the trade space. MBSE improves project quality through provision of system models that are precise and syntactically unambiguous and can be used to evaluate consistency, correctness, and completeness of a system.

MBSE improves the means to teach and learn about the system which is coming together. Cycle times and maintenance costs can be decreased when modifying the design.

We observe significant "rallying" around the evolving MBSE approach. Across the A&D enterprise, prime contractors are embracing and realizing the promise of better, cheaper, faster; often achieving two, if not all three, of the goals. Manufacturing partners are realizing the efficiencies associated with increased access to higher quality, more timely design data. Stephen Welby, Deputy Assistant Secretary of Defense for Systems Engineering acknowledges the potential of MBSE to realize Better Buying Power mandates and is publishing the DOD MBSE Vision (Digital Thread/System Model Concept) in response to NDIA's 2011 Vision. IEEE, INCOSE, the OMG, AIA and prominent professional organizations are aligning and advancing the standards and practice of MBSE. The "art" of MBSE is also being refined by the pronounced and energetic engagement of other technical disciplines including: Civil Engineering, the Medical industry, Communications, Automotive and other Industries.

One specific program witnessed a 68 percent reduction in specification defects after the introduction of MBSE practices (Saunders 2011). Using MBSE reduced early requirements risk having the potential to cost anywhere between 25 – 90 times more to fix depending upon when problems arose (NDIA 2011). The 2015 INCOSE MBSE Survey shows an increase in the number of companies practicing MBSE and developing internal methods, tools, and training. The survey also concludes MBSE has a high perceived value.(INCOSE IW 2015).

Current Challenges

DOD Challenges

The 21st century presents a confluence of unexpected, unpredictable threats, exponential growth in system complexity, and decreasing workforce experience. The capacity to synthesize, evaluate, and execute sophisticated system procurements and operational strategies must improve in the face of constant disruption – technical, strategic, financial, and political.

Systematic and rigorous modeling of threats and operational space improve the ability to objectively define and evaluate acceptable solutions and respond to probable change. The process of modeling a problem requires the highest level of cognitive understanding and exposes knowledge bias, gaps, and consequence sensitivities.

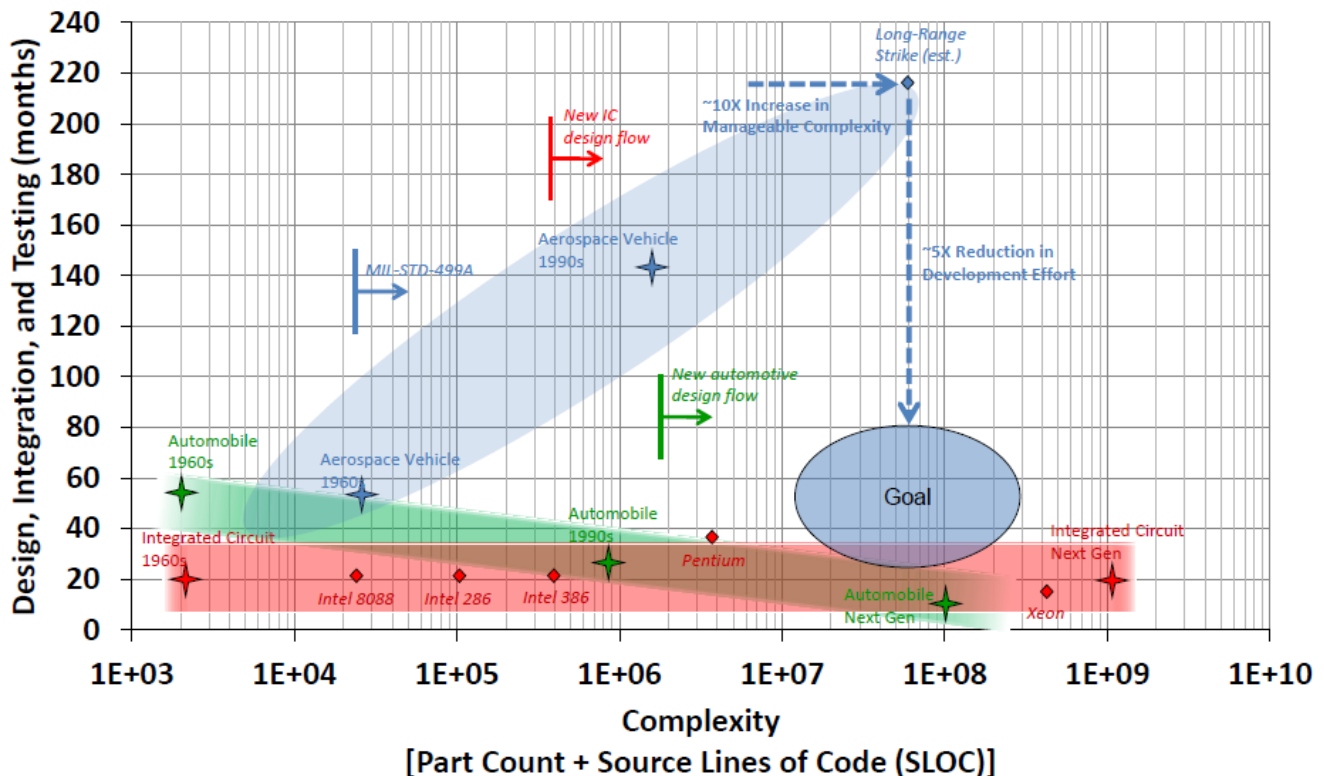


Figure 1. Complexity growth in A&D vehicles compared to automotive and integrated circuits (Image credit: Darpa)

Since 1960, as seen in **Figure 1**, the complexity of automobiles, integrated circuits, and aerospace vehicles has dramatically increased, but the total time of design, integration, and test for aerospace vehicles is experiencing opposite trends than the other industries (DARPA 2010).

The DOD budget volatility, as shown in a report by the Stockholm International Peace Research Institute (SIPRI) and the U.S. Bureau of Economic Analysis provides direct challenges to the advancement of MBSE for DOD and the aerospace and defense industry (Walker 2014). Both the DOD and the A&D industry stumble in allocating an appropriate amount of funding

towards common, enterprise MBSE initiatives and solutions. What typically results is a series of MBSE initiative stovepipes easily falling victim to budget woes with little cross-organization support and adoption.

In regards to workforce challenges, similar concerns were raised during the last round of significant defense budget cuts, specifically on the availability of talent and skilled professionals able to carry out new aircraft design (RAND 1992). Fast forward to now, and the defense industrial base is feeling the same pressures from reduction of funded manpower. Without a consistent focus on maintaining and advancing the adoption and advocacy of MBSE, our ability to deliver new capabilities to combat emerging threats will be greatly challenged.

Similar feelings were expressed in the 2014 Quadrennial Defense Review by General Martin Dempsey (Chairman JCS), “My greatest concern is that we will not innovate quickly enough or deeply enough to be prepared for the future, for the world we will face two decades from now.” This is a significant and immediate problem given that the average design cycle of a complex A&D vehicle is around 20 years (QDR 2014).

To address the issue of threat environment complexity, as game theorist and Nobel Laureate Thomas C. Schelling of the University of Maryland School of Public Policy said “There is a tendency in our planning to confuse the unfamiliar with the improbable. The contingency we have not considered seriously looks strange; what looks strange is thought improbable; what is improbable need not be considered seriously” (Wohlstetter 1962). This quote speaks to the need for systematic, rather than intuitive- threat assessment, a key benefit of MBSE.

Another key struggle is the need to avoid false, or misinterpreted constraints or needs. It is important to define and understand the requirements space and ensure it is consistent with the design intent the system is planning to address. Requirements identification should be a cross-functional activity between the acquisition, user, and financial entities of the end customer, where all parties have an equal say as to what parameters are most important to achieve design intent.

There is also a need for characterization of “true” requirements and performance sensitivities maximizing design options and enabling contractor innovation, while minimizing costly late-in-development engineering changes or failed systems.

Additionally, we need to reduce the degrees of separation in information exchange between problem definition and solution development, enable value-added oversight by facilitating timely exchange of insight and operationally relevant knowledge with the contractor. In the words of aerospace industry leader Norm Augustine, “The more time you spend talking about what you have been doing, the less time you have to spend doing what you have been talking about. Eventually, you spend more and more time talking about less and less until finally you spend all your time talking about nothing.”

Finally, we need to avoid the reification fallacy – we must understand that reports, analyses, teleconferences, and chart reviews are the process, not the product. As the workforce experiences fewer and fewer systems becoming operational, there is risk the work process and bureaucracy is perceived to be the objective, rather than the successful deployment of the system.

DOD and Industry are challenged in terms of their ability to jointly reconcile a capability need statement and proposed architecture addressing those needs and subsequently enable the authoring of stable, clear, affordable and non-conflicting requirements.

Additionally, DOD and Industry are similarly challenged in sharing architectures which provide useful benefits across the entire development life cycle, including defining requirements, trading design aspects, design engineering, cost budgeting, staging, manufacturing, fielding, training, sustaining and disposing.

Problem Scope Areas

What is currently working well and what needs to change in regards to MBSE within industry and government?

Integration between MBSE and Product Life Cycle Management (PLM)/Application Life Cycle Management (ALM) will unleash new capabilities in product development that has not been realized to date.

PLM has origins in mechanical computer-aided design (CAD). Tools within PLM manage mechanical part data, workflows, objects and relationships. There is some electrical CAD data integration at the drawing level merging the mechanical and electrical disciplines.

ALM was created by software developers as a PLM equivalent for software. ALM manages software source code and executable development, as well as workflows. The tools are typically built on top of software configuration management environments.

MBSE provides management of system architecture models and relationships. Typically there is no workflow management, except on the entire model as a workflow object.

In capturing the power of MBSE integration with PLM/ALM, we can see substantial benefits of mechanical, electrical, and software objects represented in system architectures exhibiting the same representative qualities of those objects in PLM and ALM tools.

In order to achieve such a level of integration, some steps include:

- Use system architectures in MBSE to connect to objects in PLM/ALM space.
- Synchronize the relationships in MBSE, PLM and ALM
- Add PLM workflow management to individual objects in system architecture
- The architecture expressed by MBSE becomes the basis for model management of lower level models that may reside in PLM/ALM
- Leverage the system architecture in MBSE to manage information objects such as requirements, design descriptions, and textual content.
- Reuse PLM/ALM object libraries across projects within the context of the MBSE system architecture.
- Ensure data consistency, persistence and correctness through version control and accurate PLM/ALM workflow checks and approvals

Current State	Necessary Changes
Some instances of weaker tool support in regards to bridging requirements and modeling. The bridge between requirements and MBSE models is much stronger than the requirements and document-based design paradigm	The need for the DoD and prime contractors to utilize MBSE in order to generate stable, clear, affordable and non-conflicting requirements for all programs as opposed to RFPs falling victim to unnecessary requirements expansion
Auto-generating models from requirements and vice-versa is not a robust, sustainable solution.	The need for the DoD and prime contractors to utilize MBSE to generate concept architectures whose value and usefulness extend across the entire life of the program and are utilized to evaluate feasibility, mature model integrity, identify requirements space and subsequently converge to the desired design intent
Unrealistic document auto-generation expectations, specifically the accuracy and utility of the auto-generated product	A seamless transition strategy from document-centric to model-centric activity, with built-in oversight and approval functions
Team, model, and skill fragmentation on programs with little holistic modeling	An increased focus on requirements management tools, SysML and UML value proposition, and the importance of user skill level and tool familiarity leading to better version control and consistent model maturation over the product life cycle
One team works requirements, one team works models.	A consistent MBSE workflow to enhance cross discipline collaboration as well as automatic model consistency and multidisciplinary maturation consistent with requirements for product definition and design
Too much emphasis on the diagrams, not enough on models. DoDAF products often generated only for the sake of customers, rather than to help the program itself. DoDAF products do not take advantage of computational capabilities enabling dynamics to improve operational understanding.	Better understanding of what is useful to the program and auto-generation based upon what's in the model.
Model interchange and sharing is still clunky. Standard interfaces, like promotion of OSLC, will help, but there still is a challenge of data semantics. Hopefully PLM will help, as well.	Use richer approaches for doing cross-domain integration. New upcoming research to address the current state.
Inability to communicate effectively or in a timely manner so as to establish a solid foundation for a program, specifically in a solid requirements baseline, technical baseline, set of analyses, parameters and data.	Need for a more effective way to communicate solid requirements, preferably ones generated from physics-based modeling and mission analysis.

Table 1. Profile of current state and necessary changes for MBSE.

A seamless transition strategy from document-based to model-based for programs

Practitioners need a seamless transition strategy from document-based to model-based programs with the realization documents are not the records of authority, but should now take a secondary role in regards to technical communication and decision making.

Assuming the value in shifting to a model-based paradigm is quantified and realized, companies need a capability to help with all facets of the transition.

Programs typically face a challenge in the translation and reuse of legacy product data. Significant investments were made in developing legacy product data, such as requirements documents, design documents, interface control documents, and part and assembly drawings. Without the right tools or processes, the translation to copy document data into models can be equally as taxing and cost prohibitive. Additionally, just having the right tools is not enough; proper usage maximizes the utility of the tool. Modernization programs are a common example of the data translation challenge for both customers and contractors.

As the shift towards a model-based paradigm becomes a reality, MBSE practitioners with the right tools should be able to import legacy product data and adjust the data and model in a reasonable amount of time.

Understanding the difficulties of the process, legacy content does not need full compliance with “model expectations” – but should be broken down into manageable content that can be gradually evolved into model formats.

An easy step to mitigate the challenge is to increase the presentation of underlying engineering content itself rather than a diagram when customers and colleagues request a document.

MBSE also provides value in supporting integration and test activities in the SE process, including verification. A significant challenge, though, is on-going model maintenance that should endure for the life of the program

Too much emphasis on the diagrams, not enough on models. Presentation of the actual engineering content should be the first response when a document is requested.

There needs to be an increased focus on the model, specifically the objects and relationships it contains, rather than the diagram to encourage better model development and usage.

Diagrams are not models, but provide insight into a model through the perspective and view offered by the diagram.

The goal of MBSE is to define and utilize models accurately reflecting the actual design.

The challenge is not finding the “appropriate” diagram to use, but rather determining what are the appropriate relationships to use to connect the different objects. SysML and DoDAF tend to focus on the diagrams, and fail to address the underlying set of objects and appropriate relationships to use between objects.

For example, consider what relationship binds an activity/function to a functional requirement or what relationship is used to show allocation between an activity/ function and a software component. Software to processor?

Processor to box? What are the object types necessary to effectively define software-intensive electro-mechanical systems and what relationships should be used between them?

When a model team focuses on the diagram, they may inadvertently neglect the underlying model. Many teams still create diagrams in a model just like they would with non-MBSE tools. They capture the picture, but fail to connect the dots within a holistic model.

DoDAF captures different views, but what about the relationships between the objects captured in different views? How does an object in one diagram relate to an object in a separate diagram? Where is the relationship defined?

SysML, when not used to its fullest extent, also tends to focus on diagrams and the appropriate diagram types, but then fails to address possible relationships beyond those assigned to the diagram.

Ultimately, there exists a need to help the MBSE community understand all different model elements types (objects) and the appropriate relationships to use between each pair of objects to express different ideas. Many engineers struggle with “which relationship” to use, and then the tools either discourage (not allow), or encourage (you can do anything) creating relationships. The diagram is then a “window” into the model, providing one perspective or view on different types of model elements and relationships – typically constrained to only certain objects and relationships.

We rely upon prose and a document-based Systems Engineering process. Customer expectations for deliverables in the form of documents can be a limitation.

Traditional aerospace systems engineering relies on a document-based process; a carryover of legacy business. Transition from this approach is made difficult due to the inertia of a risk-averse industry, traditional expectations of customers, partners, and vendors, and the cost of change.

Most legacy product data is captured in document-based approaches such as requirements documents, design documents, interface control documents, and part and assembly drawings.

Regarding requirements, MBSE goes beyond legacy static requirements analysis by providing a digital way to manage the interrelationships of the requirements and dynamically test system behaviors, thus supporting the test and verification stages of the systems life cycle.

Traditional systems engineering is still taught as a document-based process, but this is starting to change with the instruction of modeling/simulation and MBSE.

The culture of traditional systems engineering is hard to change, especially in the aerospace and defense industry which relies on “tried and true” methods to limit risk. Customers still expect deliverables in the form of documents, even if they like the idea of modeling and the benefits it’s supposed to provide.

Typical projects “reuse” existing work with massive copying from legacy product data. The reality is there was and still is a huge investment in these documents. Thus it’s easy to avoid migrating document content to a model structure when customers only expect the former.

There are certain benefits to prose documents which are hard to mirror in model-based content, or at least very difficult to explain to a traditionalist how they can be mirrored.

Detailed prose explanations of form or function are most easily digested in document format. Looking at a diagram or clicking through a model is often not an easy way to understand a complex concept.

The reality is the document interface is more natural, particularly for text-based documents. Many come out of school knowing how to read a report, regardless of their discipline. There is a learning curve for any modeling environment.

These reasons for resistance may get weaker over time as fresh engineers come in with greater exposure to new technologies and tools. However, export of document-based content must always be a capability of modeling tools.

Lack of consistent push by customer base for MBSE to be applied to programs.

MBSE is highly touted within some customer organizations, but for various reasons there is a perception of not enough emphasis from civil, commercial, or DOD customers for industry partners to implement MBSE on development programs, leading to an inherent delay in the realization of MBSE's benefits on real programs.

Industry does not see enough push from customers to implement MBSE during program execution. A possible exception is in some restricted programs where modeling is occurring at the customer level and the expectation is industry feed the model with

information reflecting the scope of the contractor's work.

Typically the extent of MBSE expectations from customers is the contractor delivering DoDAF diagrams. These can often be accomplished in drawing programs without really doing any modeling.

Much is claimed about how MBSE is used within some customer organizations, but we have not seen implementation get pushed externally.

For example, NASA JPL claims "approximately 20 development tasks are applying MBSE at JPL across the full life cycle" as of January 2014 (Nichols 2014).

The lack of consistent experience base between customers and industry makes it difficult to set reasonable expectations. Additionally, there is the perception of higher upfront costs, especially in cost-constrained acquisitions.

There may also be a perception MBSE need only be applied at a conceptual level and there is a difficulty in exchanging models between customer and contractor making the process cumbersome.

So what is the consequence of this lack of push towards MBSE? Unless dictated in initial RFP, industry will not typically propose use of MBSE. Reasons may include perceived early costs which could make proposals have a higher cost, lack of demonstrated benefits at the contractor level, and in some cases perception the customer may lack understanding of MBSE.

The perceptions result in a chicken-and-egg scenario. Without direction by customer,

contractors will not typically adopt MBSE on their own, resulting in reduced MBSE benefits on real programs

MBSE is confusing to management, and benefits are not often clear to them. Resource investment can be high, especially for teams who have less experience in MBSE. These issues combine to make investment from management hard to get unless mandated by customer.

Implementation of MBSE at the contractor level is made difficult due to two opposing scenarios. Overly ambitious expectations of MBSE without proper understanding of the concept can lead to premature failure of implementation. Alternatively, lack of understanding of MBSE benefits can inhibit adoption on cost-constrained programs.

While some companies, particularly larger ones, have experimented in MBSE for many years, others are just beginning to investigate its application and benefits. To maintain competitiveness in today's market, management and/or rank and file see the opportunity to apply MBSE with the hopes of improving efficiency, avoiding escapes, or responding to customer expectations.

Incorrect assumptions about how MBSE can be applied must be dispelled, and that requires presence of at least some critical mass of MBSE-knowledgeable staff, which can vary based on contractor. Without tempering of expectations, and clarification of benefits and costs for implementing MBSE, new initiatives may be set up for failure. Premature failure can reduce the likelihood of giving MBSE a chance on subsequent projects.

A lack of understanding of MBSE benefits can inhibit adoption on cost-constrained programs. MBSE may be championed by staff at a company, but making the case to management can be difficult. As described above, the definition, execution, and benefits of MBSE can be difficult to convey even for staff experienced in traditional systems engineering.

Consequently, traditional aerospace companies may be reluctant to take on a new approach such as MBSE when traditional systems engineering methods are familiar and comfortable despite evidence of significant schedule slips and cost overruns.

It takes great fortitude by management, or mandate by a customer, to expend the resources to stand up an MBSE capability on a major program when the benefits may not be realized until much later in the execution phase, benefits may never be discretely quantifiable (due to the cost-avoidance nature of MBSE), and specific historical examples of savings can be hard to come by. To be successful, MBSE often requires changes in organizational attitudes.

An obvious way of demonstrating MBSE's usefulness is to implement it in parallel with traditional document-based SE process, and compare results. However, this is even more costly and therefore rarely performed.

Solution Space and Recommendations

General Recommendations

Transition to MBSE, which relies on a model of the proposed solution – the proverbial single source of authoritative data existing throughout the program life cycle.

Currently, SysML and modeling tools enable the coherent and unambiguous communication of a proposed solution in terms of system architecture and component interactions with the ability to link any/all system parameters and performance simulations as appropriate. Requirements statements are included as data.

Use of a collaborative and secure government-industry Model Based System Engineering (MBSE) environment in the early phase of requirements development will result in reduced risk and improved quality of technical requirements while improving communications and increasing the productivity of the effort.

1) Reduced risk

- Reduced errors – multiple points-of-view and experience
- Better integration of operational needs to technical requirements
- Early modeling and simulation to generate data for decisions
- Consistent workflow for model maturation, requirements convergence, data consistency, and multi-organizational go/no go decisions

2) Improved quality

- Reduced misinterpretation – requirements defined in modeling language ensures consistent

interpretation of model-related physics and capability assumptions

- Earlier issue identification
- More rigorous traceability of requirements enables evaluation and data persistence as requirement spaces evolve and converge
- Improved and consistent documentation

3) Improved communications

- Continuous access to all stakeholders
- Awareness of requirements evolution and data persistence, correctness, and accuracy
- Integrated view available for participants through policy and acquisition customer and A&D Industry.
- Formalized “modeling language” representations reduces impact of syntax vs. semantics

4) Increased productivity

- Streamlined government-industry team interactions (asynchronous/synchronous) across time-zones
- Enables evaluation and reuse of existing applicable requirements products from government database
- Single source for any documentation generated
- Shared common definitions easier to revise across model
- Quicker proposed change impact evaluation
- Ensures consistent physics interpretation of requirements based on model maturation and meeting of product design intent

Overall Recommendation One

Establish a government-industry collaborative, secure MBSE framework to support diverse toolsets and controlled data exchange to develop stable, clear, affordable, non-conflicting program requirements and facilitate the total life cycle benefits of MBSE.

We recommend an industry standard data exchange framework with government. Specifically, a consolidated standard for data syntax, encryption, and a consolidated data mapping standard for translating one data type to another will be necessary to bolster the data exchange framework.

The standards supporting the framework will allow for easier sharing and translation of model data from one format to another, and from one tool to another. The vision is to decrease the knowledge barriers related to tools and data syntax between stakeholders with a framework doing all the heavy lifting autonomously.

The end result is a better process to develop better requirements at the start of the program, and ensure MBSE benefits through the entire life cycle of the program. As stated before, though, this will require significant organizational changes, not simply applying MBSE on a single program in order to maximize the return on investment.

Overall Recommendation Two

Revise regulations required to provide the government appropriate data rights

The AIA's 2014 Acquisition Rebalancing report provides recommendations for smart, efficient, and effective defense procurement. One recommendation is centered around regulations for provision of data rights to the government.

Within the formal DOD Instructions are requirements for the identification and development of data rights strategies in the early phases of a program. Data rights are typically tied to independent investments made by companies in order to create new products eventually becoming part of a program's baseline. Concerning MBSE, the fear is the stipulations of the instructions would also apply to data embedded in any models developed in the early phases of a program that could have potential reuse value in future competitions.

Another point to the data rights recommendation concerns the use of evaluation criteria solely based on data rights. Within 10 U.S. Code 2320, it states "such regulations may not impair any right of the United States or of any contractor or subcontractor with respect to patents or copyrights or any other right in technical data otherwise established by law." In the event technical data embedded in a model under patent or copyright, the protections provided by 10 USC 2320 apply. Thus, any evaluation criteria requiring full disclosure and transfer of ownership of data rights within a model is not in alignment.

A third point related to data rights and MBSE is the unnecessary amount of overhead needed to provide all data rights to DOD, when it would be much more efficient to identify the data rights that are absolutely necessary to provide (AIA 2014).

Software derived from MBSE tools is also affected by technical data rights regulations, and within the commercial space, the barriers to provide the desired data rights is causing a lack of commercial participation in doing business with the DOD due to the highly protective

nature of trade secrets by commercial companies. The recommendation is similar to the one in the Acquisition Rebalancing report; strengthen protection of MBSE-related data such that competition evaluation criteria cannot be based on compliance to data rights desires from the DOD.

Overall Recommendation Three **Revise regulations to protect industry intellectual property, while enabling collaboration pre-milestone B between potential downstream industry competitors**

We recommend cooperative mission planning and CONOPS development during pre MS-A without exclusion from later competitions in TMRR and EMD.

Revising regulations to protect industry intellectual property while enabling collaboration within MBSE during pre-milestone B activities between potential downstream industry competitors will help increase the quality and achievability of generated requirements due to increased contractor buy-in early in the process and using models to better capture and convey design capability intent.

Without being excluded from later competitions in TMRR and EMD phases, industry is ready to come together with the customer to help refine the requirements generating process through a collaborative MBSE framework. A significant amount of trust can be developed in the conceptual stages of a program where the government and industry can discuss needs, clarify design intent and plan preliminary stages. The intention is to allow a clearer exchange of concepts and early capabilities without divulging all the IP of a system. Industry partners who elect to help define mission requirements should not be excluded

from future competitions, especially if satisfaction of the requirements is possible and meets needs with significant risk reduction.

We recommend maintaining multiple baselines/variants up through PDR/CDR with a review of the present state of each model. MBSE enables contractors to do this efficiently and cost-effectively (in ways that weren't possible in a document-based workflow). This will dramatically reduce risk on development programs by not locking down a single architecture option too early. It would also drive contractors to develop and maintain models that support trade space analyses (be they analytic, descriptive, etc.), so when requirements change, there already is an infrastructure in place to quickly react to those changes. This notion is evident in the purpose of the Engineered Resilient System effort.

Ability to provide models as compartmentalized 'black-boxes' with only the interfaces defined in detail

The value in allowing industry partners to be able to provide models as compartmentalized 'black boxes' with only the interfaces defined in detail establishes a level of protection that enables the contractor to compete in future competitions and/or reuse the models for other systems.

Revising IP regulations to allow for the described 'black box' paradigm as a satisfactory means of sharing abstracted information and data enables a more welcoming environment to collaborate in with the customer. The custom algorithms and processes that are embedded in the model can remain anonymous while the effects, inputs, and outputs of the model can still be made visible. At this abstraction level,

key requirements decision can still be made with greater accuracy than with no collaboration at all.

Ability to phase the visibility of certain models so that at early stages visibility is limited, but increases at each subsequent milestone.

With proper IP regulations in place, the aperture to which the 'black box' is exposed can increase in time as the system models exhibit higher fidelity and competitors can show tangible decreases in technical risks by their respective offerings.

Early interaction between competitors while they are still able to protect the proprietary data within the models will provide a significant leap in the ability for the customer to iron out potential conflicts in requirements, key performance measures, and technical performance measures prior to final RFP. As the competitors continue through concept refinement, more exposure to how the models operate can be increased in order to fine tune the details of the desired system. Once final RFP is ready, all competitors will have a much clearer picture of what the customer desires and how to translate the models into a deliverable system.

The barrier to achieve this is where the models are only representative of "desirement". It is evident an iterative response approach from contractors as new design constraints/desirements are realized by the customer is a step forward.

Compounding the barrier is the complexity of the requirements at the mission or CDD-level may sometimes be misunderstood, and when the contractors try to decompose to the system-

level and below, there is extra effort which causes cost growth.

Also, some requirements may have minimal contextual value. The iterative approach between contractor and customer can help sift out the non-value-added requirements because requirements written in an operation-centric manner provide the most value.

From a contracting perspective, because contracting lawyers may not understand digital artifacts and do not know how to procure them, a new type of contracting model is needed to allow MBSE to thrive as a means to deliver systems. The recommendation is to raise an executive-level interest to increase actionable response.

Overall Recommendation Four

Data accessibility: informed or driven by industry standards, or open access forms of data exchange. Roadblocks: diversity of tools, decades-long programs, and the manner to make data accessible.

For MBSE to work across the life cycle, data must be accessible, transportable, and reusable in the digital realm. Historically, adopting an approach based on open standards mitigates the risk of tool or vendor lock-in at the cost of losing features or information only available in the native format. As the industry adopts tools supporting model-based methods, the community will need to refine and mature the standards to transform this paradigm to a consistent, correct, persistent data set across model formats. Through the use of linked data, the process of sharing data between tools and across the life cycle will create information and support features not previously available. Tailored and encrypted data representations of the unified technical baseline are rendered as

views of a family of federated models. Reuse and release restrictions, including export control and security classification, are stored as metadata and applied systematically during access and storage. Customer interchange occurs through views which simultaneously enable collaboration while protecting contractor intellectual property.

Implementing such an environment requires a commitment towards tooling and infrastructure as the primary knowledge management repository throughout the life of an acquisition program. Standards must be adopted and specified through the acquisition process; tools must be rigorously tested for conformance to the standards; infrastructure must be regularly maintained and made resilient against physical and cyber threats. Above all, the models which contain all this information must be purposefully architected and thoughtfully maintained for as long as that data is made available. Over the life of an acquisition program, tools will come and go as a means to create, modify, and visualize data, but the data persists throughout.

Through efforts like the Digital System Model (DSM), the government must migrate to a content-based infrastructure “that integrates the authoritative data, information, algorithms, and systems engineering processes which define, derive, and manage all knowledge aspects of the system for the specific activities throughout the system life cycle.” The adoption of a standard systems engineering ontology will ease the burden of maintaining data over the life cycle by encoding the semantics along with the content. As tool vendors adapt to this new paradigm, their offerings will evolve to take advantage of this semantic content, accelerating adoption and multiplying the benefits of this approach.

LOTAR (Long Term Archival and Retrieval) is another related effort to develop, test, publish and maintain standards for long-term archiving (LTA) of digital data, such as 3D CAD and PDM data. Smarter, semantic linking of data and meta-models will propel the utility of this effort even further.

Other challenges include tagging of the data, security (export controls), and releasability (i.e. what is proprietary?). Doing this across multiple teams adds another level of difficulty, especially encrypted electronic data exchanges between government, suppliers, and primes.

Generally contractors use different tools. Government agencies and groups use different tools as well. How we exchange data is very important. If the government can develop their own tools, and mandate contractors use them, it's potentially one way we can mitigate the tool mismatch and data exchange barriers.

A standardized deliverable data set is needed to exercise the thread between tools and test interoperability to. This data set should be used as a standard for folks who are making decisions on procuring tools or sharing tools. Interoperable, tools are able to support this.



Conclusion

MBSE is the formalized application of modeling to support systems engineering activities across the entire life cycle of a system. The systems engineering discipline is shifting from document-centric to model-centric, where models are given greater emphasis as single sources of truth and primary means of technical communication. The benefits MBSE provides span across the entire value stream and include more accurate and stable requirements generation, physics-based modeling of platforms in operational environments, and earlier verification and validation of technical performance measures.

Though the benefits are extensive and proven, there still remains areas of improvements and hurdles to overcome before MBSE can reach its full potential. This report provides four specific recommendations to advance the current state of MBSE. The first recommendation is to establish a government-industry collaborative, secure MBSE framework to support diverse toolsets and controlled data exchange to develop stable, clear, affordable, non-conflicting program requirements and facilitate the total life cycle benefits of MBSE. The government and industry are both making strides towards establishing a collaborative, such as Engineered Resilient Systems, Digital Twin, and LOTAR. The focus will need to be on the data interoperability of the framework, as well as rich semantic encoding of the underlying data.

The second recommendation is to revise regulations required to provide the government appropriate data rights. Striking the right balance of affording data rights while protecting investments within MBSE will enable industry and government to collaborate during the early phases of a system's life cycle. The third recommendation is with respect to ensuring intellectual property rights where early phases of mission planning and CONOPs development between industry and government still allow for protection of competing solutions. Leveraging a "black box" and phased visibility approach of the competing system will improve mission understanding and competitiveness. Maintaining multiple design options up through Preliminary Design Review (PDR)/Critical Design Review (CDR) will also provide a larger design space to consider. Additionally, a new contracting approach may be necessary to better understand the nuances of acquisition by MBSE.



Finally, data accessibility is a key enabler of MBSE; data must be accessible, transportable, and reusable across the digital realm. Realization of this goal will come through supporting industry standards, frameworks and infrastructure built upon those standards, and practitioners who employ the appropriate processes along the way. Examples directly addressing this recommendation include Open Services for Life Cycle Collaboration (OLSC) and Digital System Model.

With these recommendations, an appropriate call for action is for industry and government to come together and think strategically about the best course forward for collaboration on MBSE. As stated before, several industry associations with MBSE-related initiatives will be developing a CONOPs for collaborative industry-government MBSE in 2016. Additional details can be found in the Appendix of this paper.

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Appendices

Industry/Government Collaboration CONOPs

In 2016, as a follow-on effort to this white paper, the AIA will be coordinating a joint industry association CONOPs development exercise to operationalize the submitted recommendations as well as relevant recommendations from referenced papers. The goal is to pinpoint several aspects of a collaborative industry/government MBSE framework including:

- Applicable standards
- Data types and models definitions
- Roles and responsibilities mapped to specific milestones and program events
- The specification for an enterprise “data bus” between industry and government
- Further details on a “black box”, scaled visibility approach to collaborative system development

Anticipated participation includes representatives from INCOSE, NIST, OMG, NDIA and SERC. Additional calls-for-partners will be made as the task’s scope becomes more granular over time along with evaluations of when to engage with government counterparts for input and participation.

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