Final Report of the

Model Based Engineering (MBE) Subcommittee

NDIA Systems Engineering Division

M&S Committee

10 February 2011

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Executive Summary

Purpose

Numerous recent studies and reports [3, 7, 8, 9, 10] have documented the increasing complexity of defense systems. The growth in complexity has increased risk and development time to the point where the time to field new systems and evolve existing systems is not acceptable. In addition, defense systems are operating in a rapidly changing environment, and the ability of systems to respond to those changes requires higher degrees of system adaptability. Traditional systems engineering methods, processes, and tools need significant improvement to meet the challenges posed by the increasing system complexity trend [10] , as do traditional software engineering methods [3]. Additionally, increasing complexity arising from the interdependence of large numbers of component suppliers is posing integration problems that challenge the limits of tradtional approaches [1].

Model Based Engineering (MBE) is an emerging approach to engineering that holds great promise for addressing the increasing complexity of systems, and systems of systems, while reducing the time, cost, and risk to develop, deliver, and evolve these systems. The purpose of this study was to assess the current state of MBE, identify the potential benefits, costs, and risks of MBE within the context of the DOD acquisition life cycle, and provide recommendations that would enable the widespread adoption of MBE practices across the DOD acquisition life cycle.

Findings and General Recommendations

MBE, as defined by the subcommittee, is an approach to engineering in which models:

- Are an integral part of the technical baseline,
- Evolve throughout the acquisition life cycle,
- Are integrated across all program disciplines (e.g., systems engineering, operations analysis, software engineering, hardware enginnering, manufacturing, logistics, etc.), and
- Can be shared and/or reused across acquisition programs, including between Government and Industry stakeholders.

As described within the report, this would enable significant benefits across all phases of the acquisition life cycle resulting in accelerated development and delivery of capabilities to the Warfighter that are more timely, reliable, interoperable, and affordable.

The subcommittee found that the current state of practice, methods, processes, and tools has significant gaps that must be closed to enable the widespread adoption of MBE. We found that modeling is currently used extensively across multiple domains to support engineering a product, system, or capability, but that there is a wide variation in the maturity of practice across engineering disciplines. While there is wide use of models across many domains, they are used in a stove-piped fashion and are not well integrated from one acquisition phase to another. The lack of integration also occurs across programs, as there is limited formal model reuse from one program to another, and a lack of infrastructure to support efficient reuse. The subcommitte also noted that there is growing interest in MBE as evident in many activities across industry, academia and standards bodies to help move the state of practice forward. These activities must be leveraged to enable widespread adoption of MBE.

Transitioning from the current state of practice to an MBE approach will be complex and must be addressed on multiple fronts. The transition can only be successful if approached in a collaborative manner with the involvement of the Government, Industry, tool vendors, standards organizations, and academia. The subcommittee developed a broad set of recommendations that are organized into three focus areas. First, we recommend that the Government work collaboratively with Industry and other stakeholders to develop the MBE Business Model. While many agree with the compelling vision of MBE, there is a lack of quantitative data to support a compelling the Business Model and move it beyond academics. This recommendation includes:

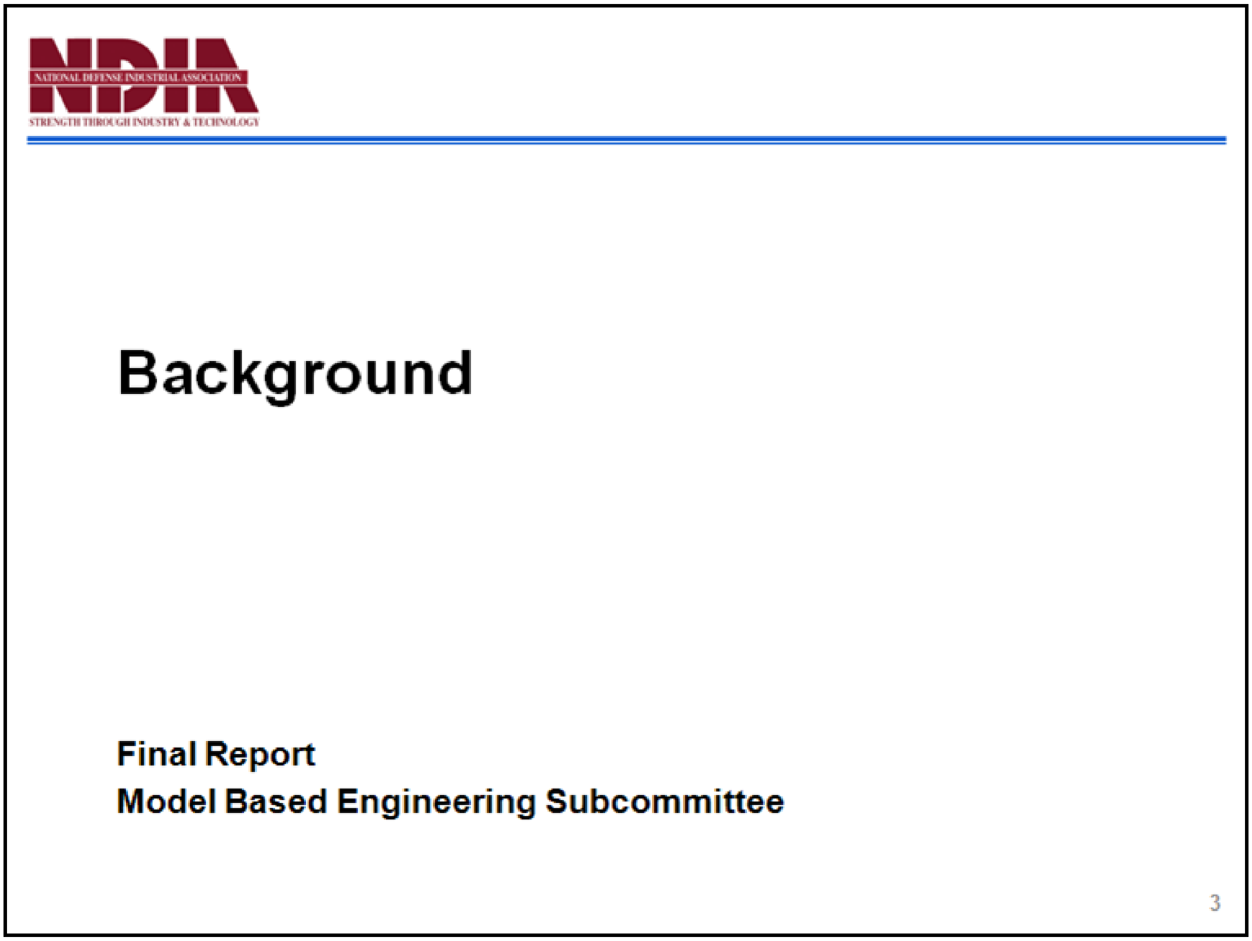
- Defining the data required to generate the business case / value proposition required by each stakeholder;
- Launching a small number of model based contracting pilot projects;
- Conducting a “Grand Challenge” like project to accelerate the cross-discipline end-to-end MBE implementation;
- Implementing a model registry concept;
- Using operational models to facilitate capability integration across programs; and
- Developing sensitive information protection guidelines.

Second, the subcommittee recommends that the Government work with Industry, tool vendors, and standards organizations to collaboratively develop MBE standards. The cross-discipline, cross-acquisition life cycle phase, and cross-program collaboration and reuse that are at the heart of MBE can only be achieved with a robust set of standards for meta data, model interconnection and interchange, domain specific modeling languages, and other technologies common to MBE stakeholders. This recommendation includes:

- Developing an MBE Common Reference Model;
- Developing an MBE standards roadmap;
- Initiating a research program to close high-priority technical gaps;
- Developing the standards identified in the standards roadmap;
- Providing seed funding for the development of reference implementations of select MBE standards; and
- Developing MBE program planning guidance.

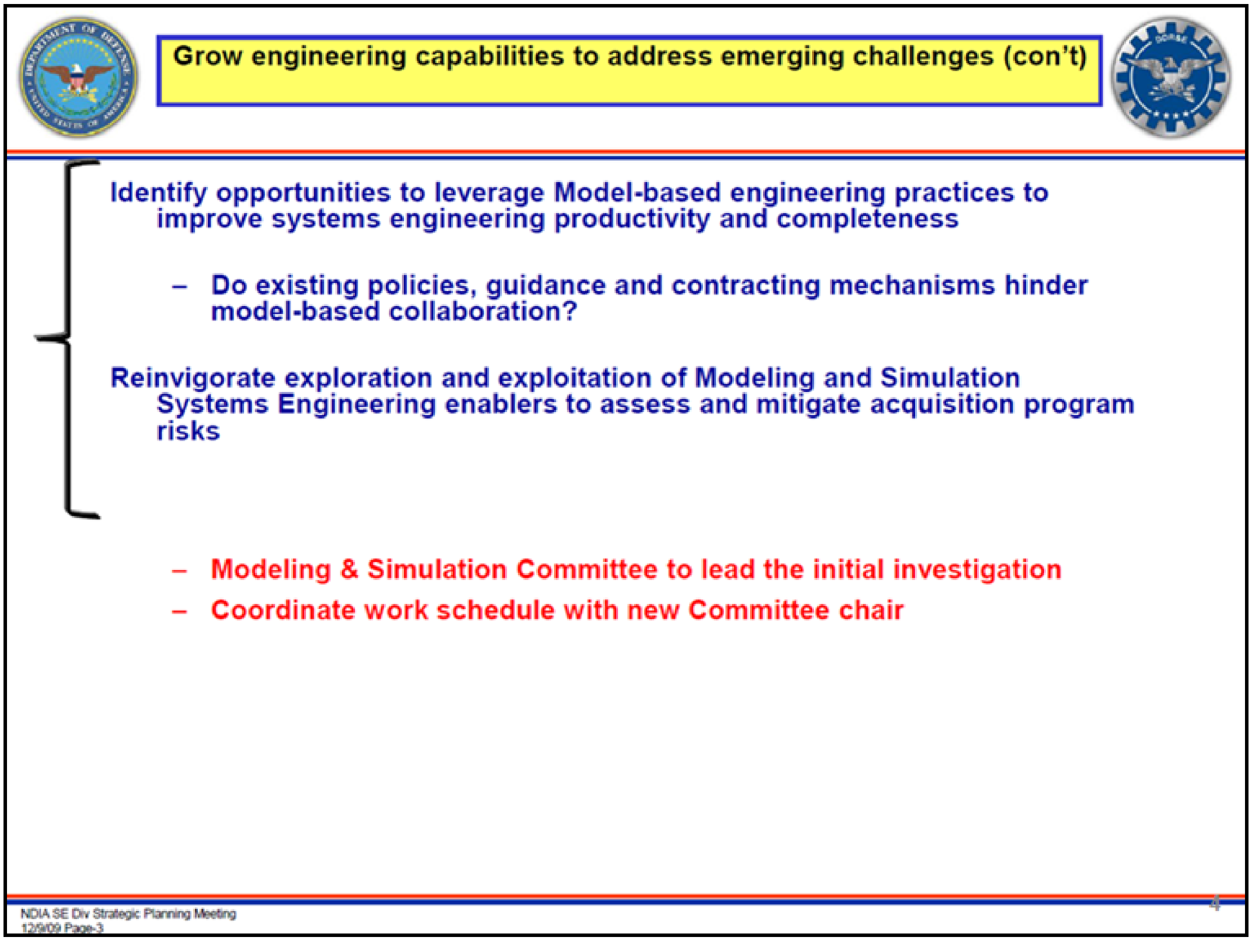
Finally, the subcommittee recommends that the Govement, Industry, and tool vendors develop the workforce. The MBE approach represents a shift away from individual disciplines working in isolation, and towards collaboration across the disciplines. This will require training and education that informs the workforce as to the roles played by all disciplines in each phase of the acquisition life cycle, and how their discipline interacts with the other disciplines. As MBE is an emerging approach, there is a dearth of "greybeards" and best practices which less expereinced staff can draw from. Overcoming this shortfall will require the formalization of MBE-specific mentoring programs and the means to capture and share knowledge across the MBE community.

The subcommittee believes that the implementation of the recommendations contained within this report will enable MBE to become common practice across the life cyle for the acquisition and evolution of systems and solutions. While the implementation of the recommendations will be neither quick, nor without investment, we believe that the broad acceptance and use of MBE will enable the DOD, Industry, and the Warfighter to realize the benefits of accelerated delivery of capabilities that are more reliable, interoperable, and affordable.



Background

The following subsections provide background for this report. The genesis of the MBE Subcommittee is discussed, followed by the subcommittee's charter and membership. Our definition of MBE is presented along with characteristics of models used in MBE.



Genesis of the MBE Subcommittee

During the NDIA Systems Engineering Division's Strategic Planning Meeting in December 2009, The OSD Director, Systems Engineering (now DASD/SE) identified numerous challenges. Among these were:

- Identifying opportunities to leverage Model-based engineering practices to improve systems engineering productivity and completeness. Included in this challenge was developing an understanding of whether existing DoD and Service policies, guidance, and contracting mechanisms were supportive, or hindered, model-based engineering and model-based collaboration.
- Reinvigorating exploration and exploitation of M&S Systems Engineering enablers to identify, assess, and mitigate acquisition program risks.

The NDIA Systems Engineering Division determined that these two challenges are important to the practice of Systems Engineering and that they should be investigated. The investigation was assigned to the System Engineering Division's Modeling & Simulation (M&S) Committee. During the M&S Committee's April 2010 meeting, a Model Based Engineering Subcommittee was formed to conduct the investigation and report findings and recommendations.

MBE Subcommittee Charter

- Assess and promote Model Based Engineering (MBE) practices in support of the DOD capability acquisition life cycle*
  - Define Model Based Engineering (MBE)
  - Define how MBE is related to M&S
  - Identify the potential costs, risks, and benefits of MBE
  - Identify the potential limitations of MBE
  - Identify how MBE practices can be used in capability acquisition with a primary focus on Systems Engineering to include concept engineering, concurrent design, development, and manufacturing
  - Identify MBE approaches to assess and mitigate risks throughout the capability acquisition life cycle
  - Identify the issues and challenges with using MBE practices across the capability acquisition life cycle
  - Identify where/how existing policy, guidance and contracting mechanisms support/hinder Model Based collaboration across program/capability boundaries
  - Provide recommendations:
    - For changes in policy, guidance, and contracting mechanisms that could further support Model Based collaboration
    - For near-term opportunities to leverage MBE in capability acquisition
    - For areas of MBE research & development that may have high potential pay-off

* - Acquisition Life Cycle: All phases of the capabilities life cycle including research, development, Test & Evaluation, production, deployment, operations and support, as well as evolution of deployed systems in response to changes in their environment over time.

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MBE Subcommittee Charter

The first activity for the MBE Subcommittee was to develop a charter to specify the scope of the investigation and the information and recommendations that would be developed by the subcommittee. After completion of an initial version of the charter, a telecon was conducted with the leadership of the Systems Analysis organization within the Director, Systems Engineering (now DASD/SE) Systems Engineering Directorate to review the charter. Minor changes were made to the initial charter as a result of the telecon, and the final version of the MBE Subcommittee charter is shown above.

MBE Subcommittee Membership

- Jeff Bergenthal (Lockheed Martin (LM); MBE subcommittee lead)
- Eileen Bjorkman (SAF/A6W; former AMSWG chair)
- Jim Coolahan (Johns Hopkins University/Applied Physics Laboratory (JHU/APL); SISO)
- Bill Espinosa (USN)
- Sandy Friedenthal (LM; INCOSE MBSE)
- Tony Pandiscio (Raytheon)
- Lou Pape (Boeing)
- Greg Pollari (Rockwell Collins; AVSI SAVI)
- Hans Polzer (LM; NCOIC)
- Jennifer Rainey (JHU/APL)
- David Redman (AVSI; AVSI SAVI)
- Mark Rupersburg (General Dynamics Land Systems)
- Frank Salvatore (High Performance Technology Inc)
- Don Schneider (Foxhole Technology)
- Dennis Shea (Center for Naval Analysis)
- Roddey Smith (Northrop Grumman)
- Charlie Stirk (CostVision; PDES, Inc.)
- Steve Swenson (Aegis Technologies; SISO)
- Bill Tucker (Boeing)
- Mike Truelove (Army CAA)

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MBE Subcommittee Membership

The subcommittee members are identified above. The organization each member is affiliated with is shown in parenthesis. Highlighted in blue, are organizations that individual members belong to that are engaged in model-based initiatives.

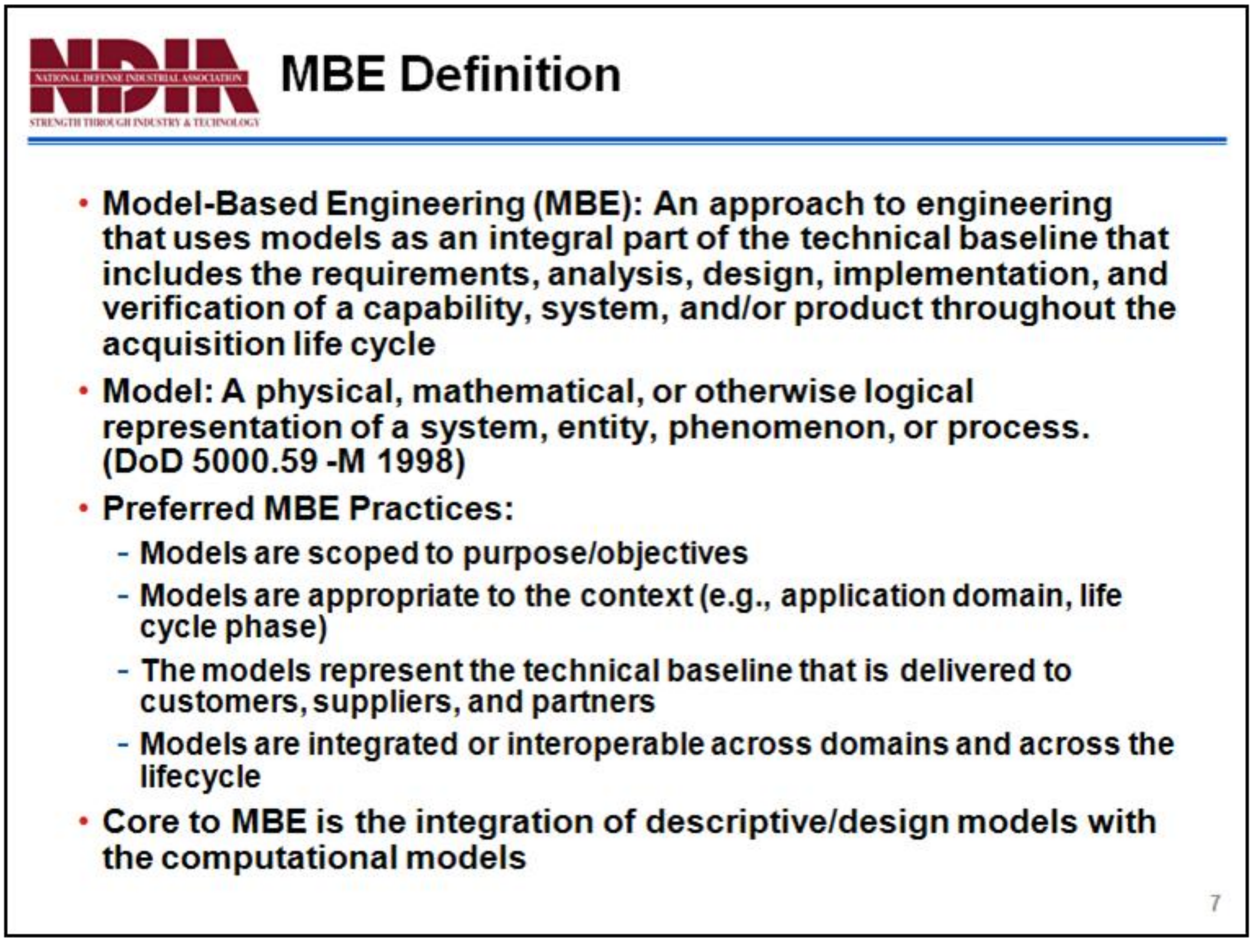
The Simulation Interoperability Standards Organization (SISO) is an international organization dedicated to the promotion of modeling and simulation interoperability and reuse for the benefit of a broad range of M&S communities. MBE related activities at SISO include the Core Manufacturing Simulation Data (CMSD) product that defines a data interface specification for efficient exchange of manufacturing life cycle data in a simulation environment, and the System Life Cycle (SLC) forum that focuses on M&S and related enablers of integrated, collaborative enterprises for system/vehicle or weapon system product development, particularly from a life-cycle wide, mission capability/system-of-systems perspective.

The International Council on Systems Engineering (INCOSE) is a not-for-profit membership organization founded to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems. INCOSE's mission is to share, promote and advance the best of systems engineering from across the globe for the benefit of humanity and the planet. INCOSE established a Model-Based Systems Engineering (MBSE) Initiative in 2007, and began conducting MBSE Workshops in 2008. MBSE is part of INCOSE's overall SE Vision 2020.

The Aerospace Vehicle Systems Institute (AVSI) is a cooperative of aerospace companies, the Department of Defense, Federal Aviation Administration and NASA working together to improve the integration of complex subsystems in aircraft. AVSI addresses issues that impact the aerospace community through international cooperative research and collaboration conducted by industry, government and academia. One AVSI project, the System Architecture Virtual Integration (SAVI), is addressing virtual system integration.

The Network Centric Operations Industry Consortium (NCOIC) is an international organization for accelerating the global implementation of network centric principles and systems to improve information sharing among various communities of interest for the betterment of their productivity, interactivity, safety, and security. NCOIC has an M&S Functional Team that is developing net-centric patterns for improving the interoperability of models across company and national boundaries. It recently approved a capability pattern for an integrated middleware environment for live, virtual, and constructive models and simulations. Other patterns are in development, for example, one on using M&S to improve C3I capabilities, and using M&S to support T&E of complex net-centric systems of systems.

PDES, Inc. is an international industry/government consortium committed to accelerating the development and implementation of standards that enable enterprise integration and PLM interoperability for its member companies. Its members represent leading manufacturers, national governmental agencies, software vendors and research organizations. PDES, Inc. supports the Digital Enterprise through the development and implementation of information standards to support Model-based Engineering, Model-based Manufacturing, and Model-based sustainment. Testing of implementations and data exchange using the ISO 10303 standard is an integral part of PDES, Inc.



MBE Definition

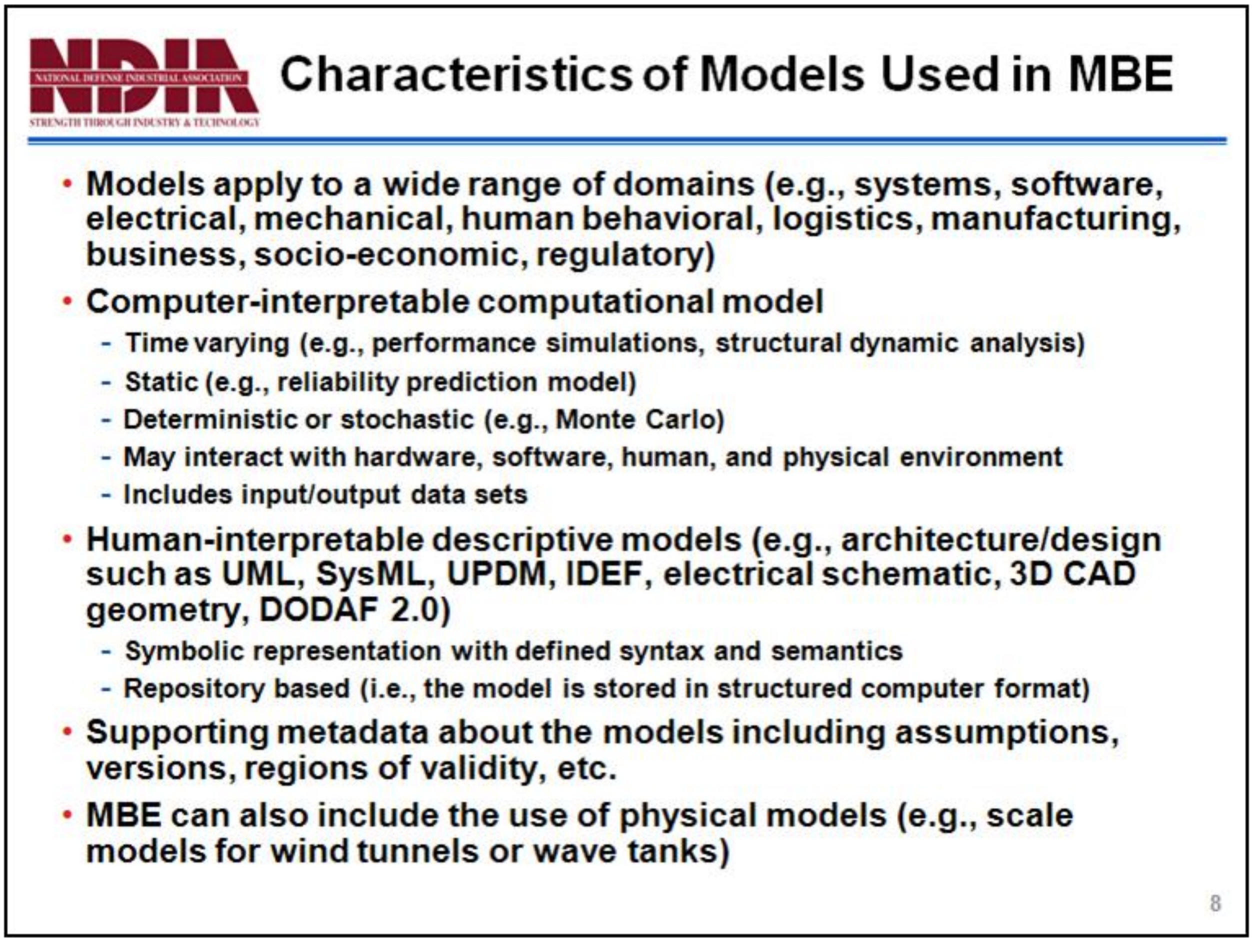
The subcommittee defines Model-Based Engineering (MBE) as an approach to engineering that uses models as an integral part of the technical baseline that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle.

The subcommittee recognizes and acknowledges that MBE has been defined differently by DASD(R&E) in its Systems 2020 initiative ("Application of modeling and simulation throughout the development process to foster more effective concept engineering and concurrent design, development, manufacturing, deployment and evolution." [9]) and by BAH in their Systems-2020 Study ("Model-based engineering (MBE) is defined as leveraging modeling and simulation techniques to deal with the increasing complexity of systems. This approach facilitates the interaction of the different domains encountered in the concept creation-design-manufacturing cycle. Models can assist with all aspects of the complex system life cycle, from the interaction of stakeholders in an easy to use environment, to enabling the automatic interaction of submodules at different physical scales, to facilitating the manufacturing process as a network of services.” [8]).

We identified several preferred MBE practices, and note that there is tension among the preferred MBE practices:

- Models that are scoped and/or appropriate to a specific context may not need to be interoperable across domains and/or the full product life cycle. Example: a developmental version of a component may only need to operate in a particular IT environment for a limited time. One of the challenges to MBE will be to determine the extent to which models have to be maintained and updated over time and across platforms. This preferred practice cannot apply to everything that satisfied the broad definition for “model” quoted above.

- The statement “Models represent the technical baseline to customers…” has several very different connotations, depending on who (Government or Industry) developed the model in question. If the DoD developed the model, then “baseline” would refer to a description of DoD requirements and would become the basis for soliciting bids, evaluating deliverables, etc. If a contractor developed the model, then the “baseline” would be either a description of an item to be delivered or the deliverable itself.



Characteristics of Models Used in MBE

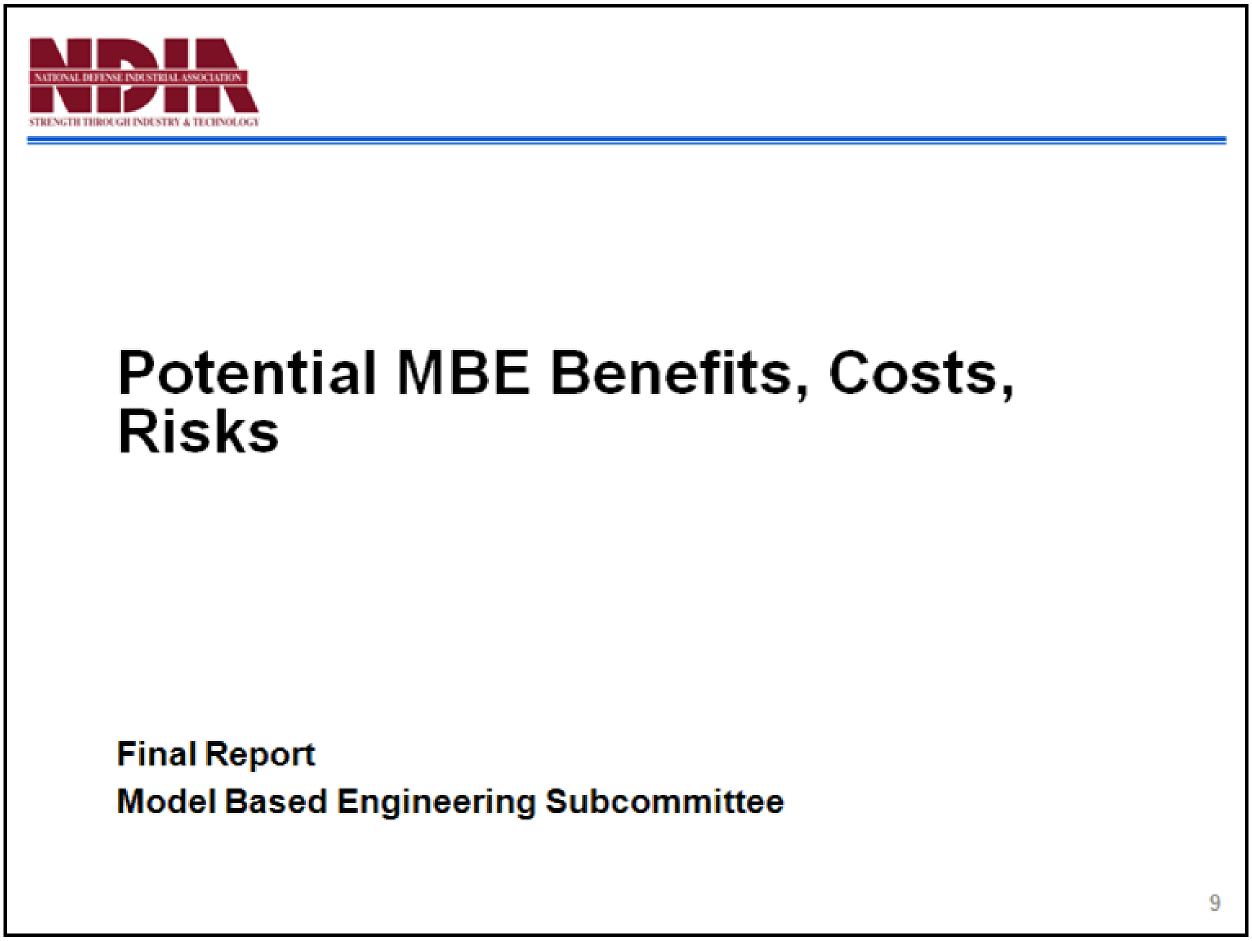
MBE requires the use of many types of models to address different aspects of a product or capability. The characteristics of these models are heavily dependent on the modeling domain. The modeling domain may address the systems, mechanical, electrical or software aspects of the product, and/or the specification, design, analysis, test, manufacturing, or maintenance of a product. The characteristics may also depend on the application domain, such as telecommunications, aerospace vehicle design, and automotive design. Domain specific modeling languages are often used to address the concerns of specific modeling domains.

The model characteristics also depend on whether the model is predominantly computational or descriptive. A computer-interpretable computational model is a model that is used to perform quantitative analysis on some aspect of the system. This includes time varying analysis models such as a performance simulation or thermal analysis of heat flow, and includes static computation models such as a reliability prediction analysis model. The models may be deterministic or they may represent parameter uncertainty such as with a monte-carlo performance simulation. The models may also be integrated with hardware, software, and humans in the loop.

The computational model contrasts with a human-interpretable descriptive model that is used to describe the system and design characteristics. A graphical modeling language with a formal syntax and semantics is typically used to represent the model. The model information is generally captured in a model repository provided by the modeling tool. Typical design models include a 3 dimensional geometric model of mechanical designs, schematic capture tools for electrical design, software design models represented in UML or AADL, and system architecture design models represented in SysML, UPDM, and others.

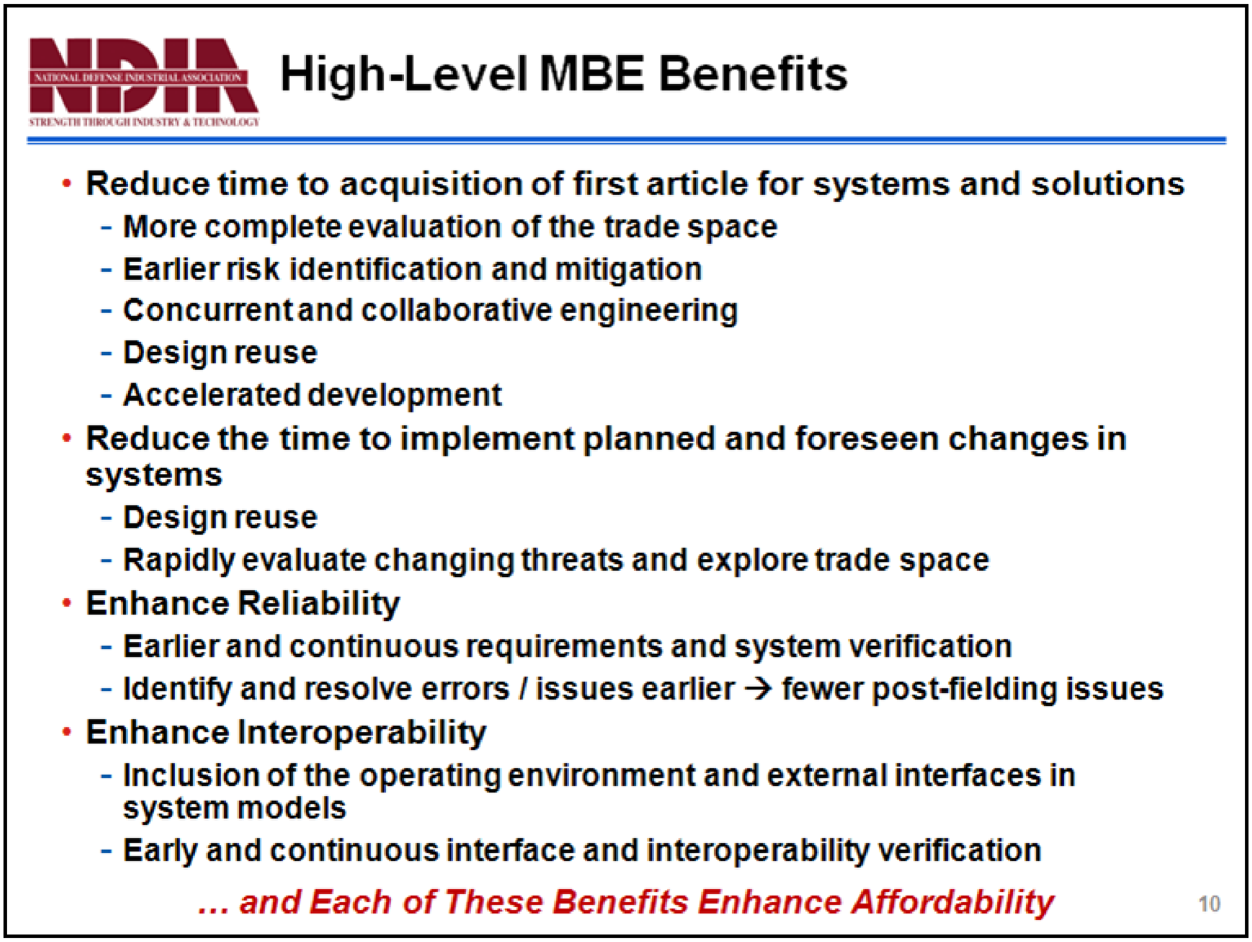
In addition to the model itself, a model is characterized by additional information sometimes referred to as metadata. This may include information on its version, intended purpose, scope of the model in terms of its depth, breadth, and fidelity, range of applicability, and modeling assumptions, as well as many other types of information. This information is essential for not only understanding the results from the model, but also for understanding the appropriateness of the model relative to addressing the specific concerns at hand.

The use of physical models such as wind tunnel models or other physical mockups and prototypes are extremely important and fundamental to engineering a product or capability. These models are considered part of MBE, and must be integrated with other computational and descriptive models. However, the focus of the recommendations is on enhancing the computational and descriptive modeling capability.



Potential MBE Benefits, Costs, Risks

The following subsections provide descriptions of the potential MBE benefits, costs, and risks. First, the high-level benefits of MBE are described in the context of the DASD/SE Systems 2020 initiative. Next, the various benefits that MBE will provide are shown across the phases of the acquisition life cycle. MBE's ability to aid in risk identification and mitigation is then shown through virtual integration and through early and continuous verification. Finally, the potential costs and risks of MBE are discussed.



High Level MBE Benefits

In the Systems 2020 initiative, the DASD/SE has identified a set of objectives and a set of constraints that must be maintained, or enhanced, as the objectives are achieved [9]. The institutionalization of MBE will directly support the achievement of two of the three Systems 2020 objectives:

- Reduce the time to acquisition of first article for systems and solutions
- Reduce the time to implement planned and foreseen changes in systems

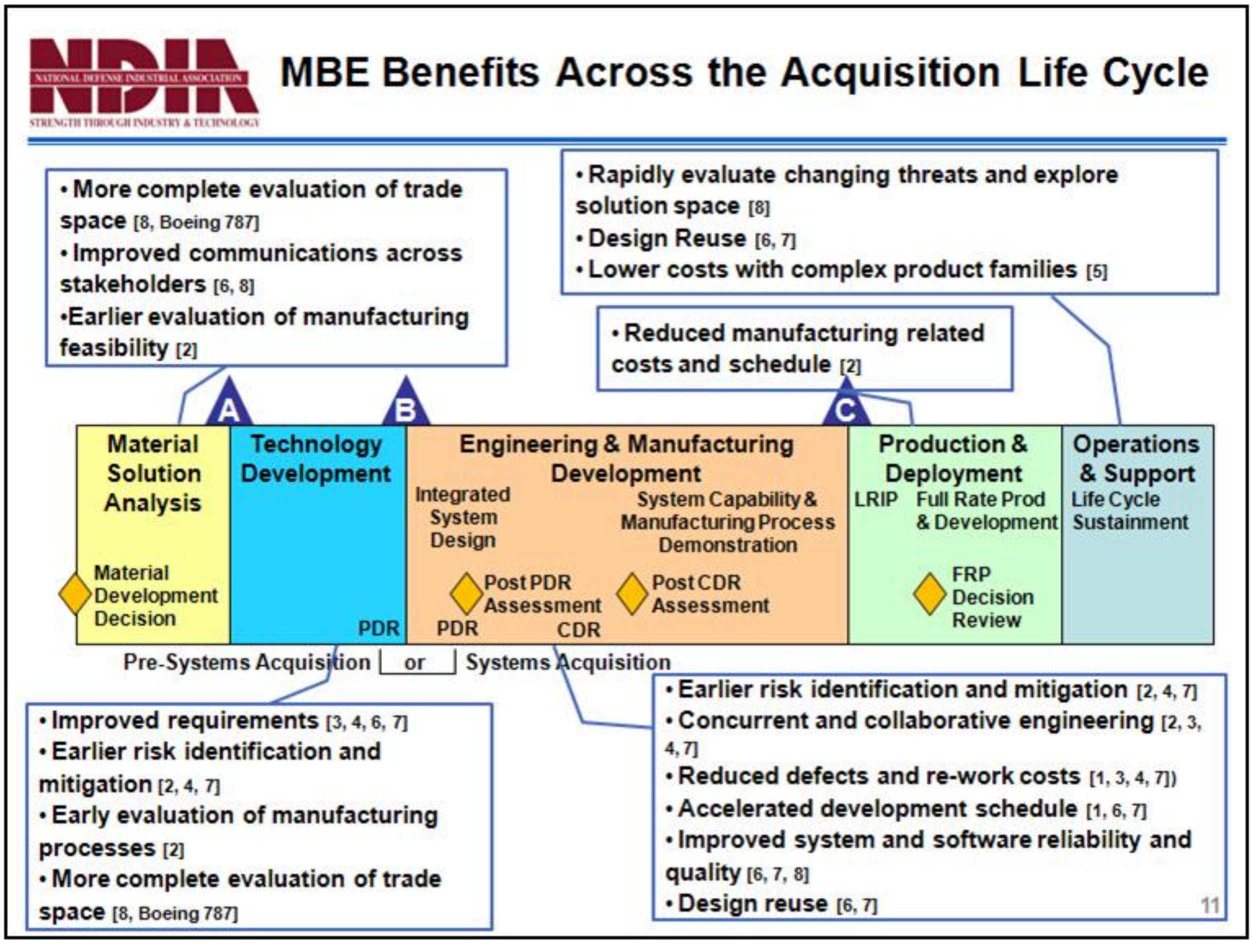
The institutionalization of MBE will also result in enhancing two of the three Systems 2020 constraints:

- Reliability
- Interoperability

For each of these objectives and constraints, the major ways in which MBE will support the achievement of the objective or enhancement of the constraint are identified. MBE benefits that are common to more than one objective and/or constraint include:

- Performing more complete evaluation of the solution and design trade space to support not only more rapid acquisition of the first article, but also to support more rapid system evolution to respond to a changing threat
- Reusing designs as the system or solution evolves, and across programs, to reduce design and development time
- Identifying, mitigating, and resolving risks, issues, and errors earlier to reduce development time and cost, and enhance reliability
- Verifying requirements and interfaces earlier and continuously throughout the life cycle to enhance reliability and interoperability.

Each of the high level MBE benefits also directly enhance affordability by reducing the time and cost to design, develop, deliver, and support capabilities.

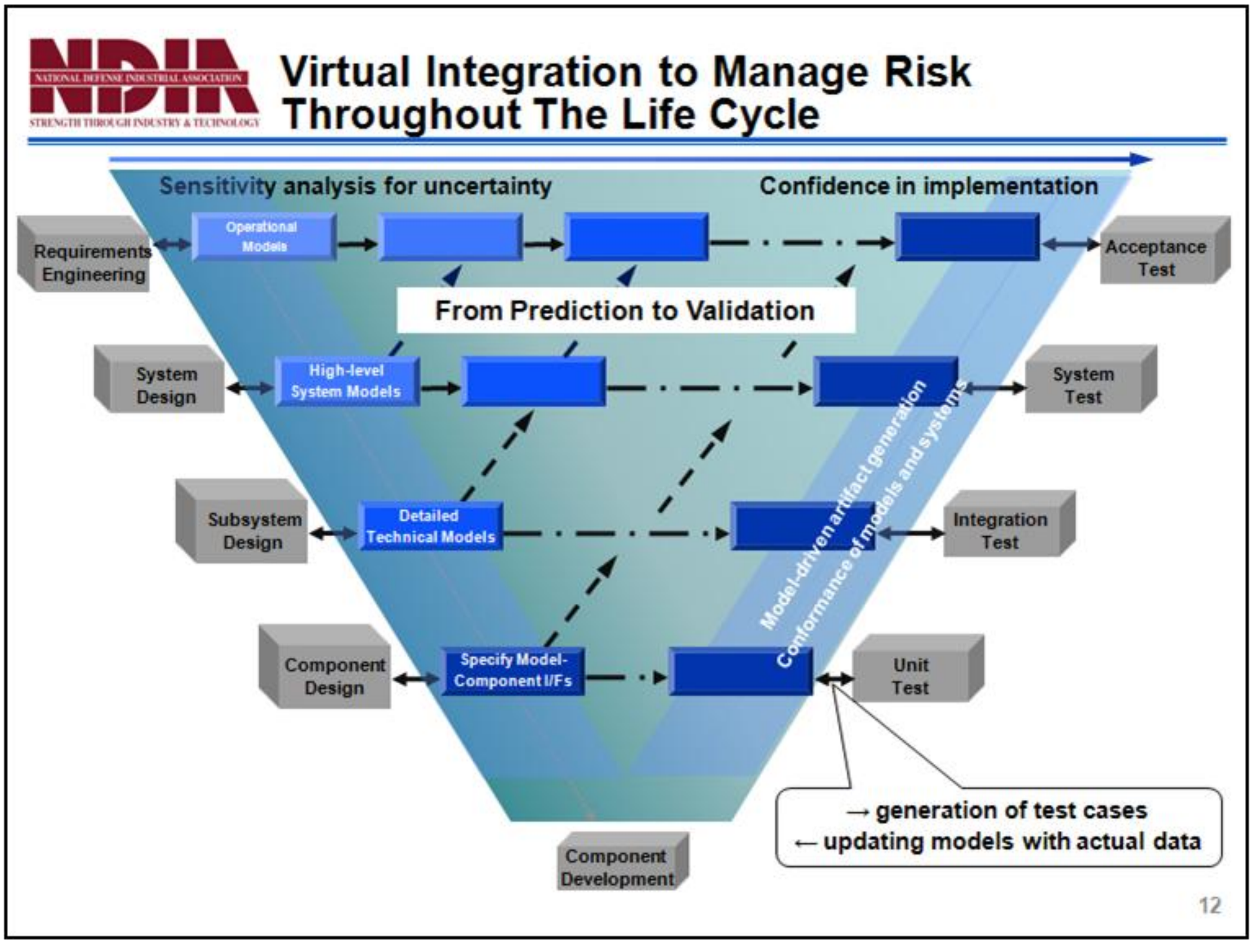


MBE Benefits Across the Acquisition Life Cycle

The subcommittee reviewed a number of papers, studies, and reports to develop an understanding of how MBE could provide benefits in each of the phases of the DOD system acquisition life cycle. Above, we list the various benefits which MBE will provide in each phase of the acquisition life cycle. Following the benefit, we have included the reference to the paper, study, and/or report that described the benefit. (The studies, papers, and reports reviewed by the subcommittee appear at the end of this report). In one case (annotated as Boeing 787), the benefit was provided by a subcommittee member, however, we were not able to obtain a publicly releasable report.

Many of the benefits identified in the early acquisition life cycle phases result in measurable benefits during later phases. For example, the development and use of manufacturing models would allow for manufacturing feasibility to be evaluated during the Material Solution Analysis phase, and would allow for manufacturing processes to be evaluated during the Technology Development phase. Gaps and issues uncovered in these earlier evaluations could then be rectified during the Engineering and Manufacturing Development phase, leading to reduced manufacturing related costs and schedule in the Production & Deployment phase. [2]

Because MBE is an emerging approach, there are few studies or reports where the benefits have been calculated in quantified terms. Those benefits that have been quantified range from calculations of the time and cost savings during integration for a complex air vehicle [1], to labor savings during the Operations & Support phase by using model-based approaches for a complex product family [5], to quantification of design and interface errors uncovered earlier and software auto-generated from models [7], and finally a very significant increase in the size of the trade space evaluated, with no increase in time [Boeing 787].



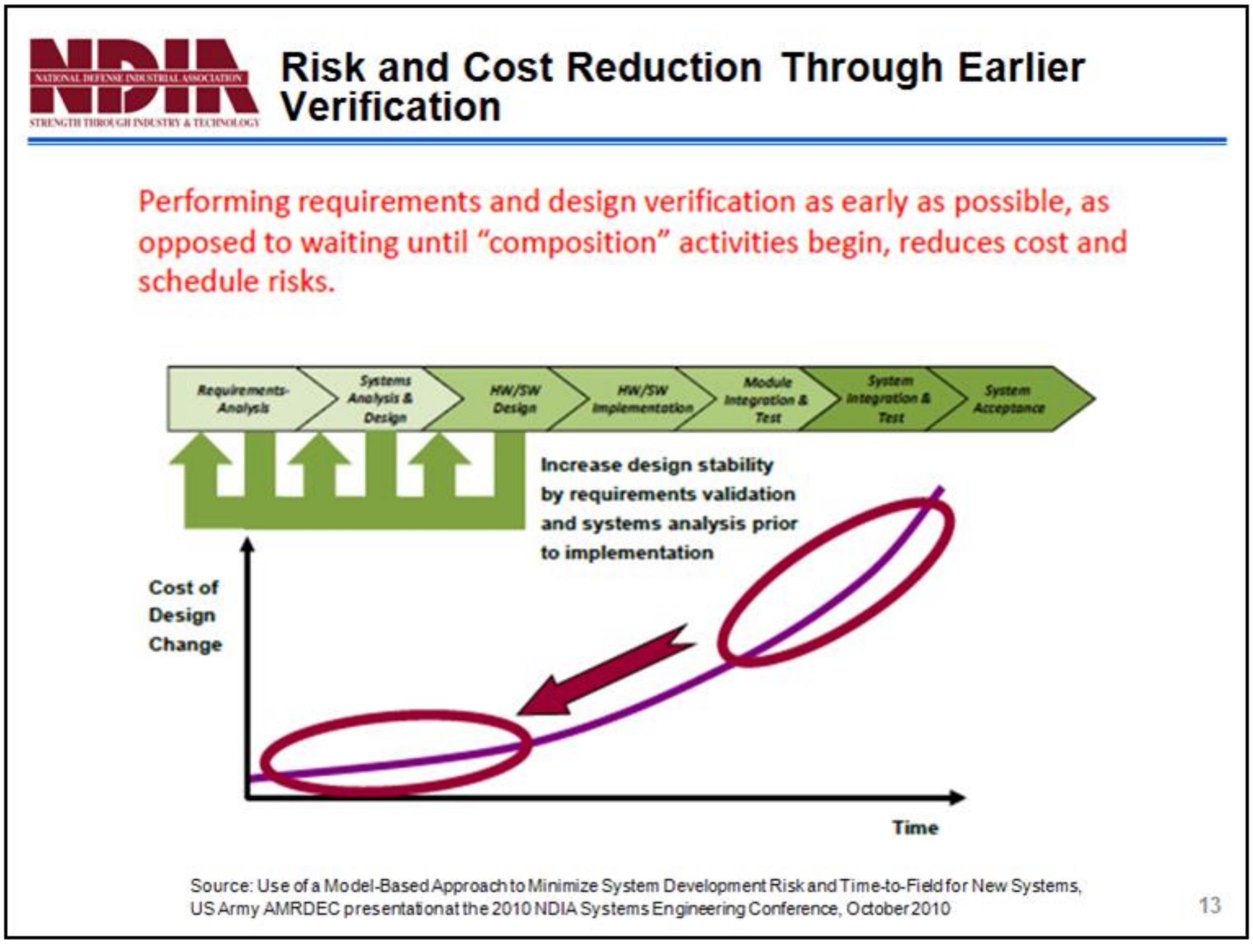
Virtual Integration to Manage Risk Throughout the Life Cycle

At least two classes of risk need to be addressed to support DoD goals for improving system acquisition. Technical risk involves the unknowns associated with the introduction of new technologies in new systems designs. Program risk involves the effects on development cost and schedule arising from technical risk and other programmatic unknowns such as requirements stability, funding and availability of shared resources. Application of emerging MBE tools and techniques can help contain these risks by collapsing the traditional development "Vee."

An analysis of program delays and cost overruns in commercial aerospace development programs indicates that a major cause of these issues is requirements errors that are only discovered during the system integration phase of development. The trend toward increasing delays and cost overruns correlates well with the increase in system complexity over generations of commercial aircraft as measured by total onboard source lines of code. The issues arise largely due to the fact that existing "waterfall" systems engineering practices were created to effect the development of systems that were much less complex than modern systems.

Model-based engineering tools and practices enable an adaption of the classic development “V.” Rather than simply decompose the system into its component down the left side of the V and then integrating and testing these components up the right, MBE enables incremental testing of the components during development, well before designs have been committed to hardware. This introduces the ability to manage risk incrementally. At each step in refinement of the detailed design, systems, subsystem, and component requirements can be virtually tested against the current understanding of the design requirements and assumptions. Tested and validated subsystem elements increase the confidence that the system will operate as intended, while tested and validated components elements increase the confidence that the subsystem will operate as intended. Thus testing and validation can be more tightly coupled to the design activities allowing more rapid design convergence and validation of derived requirements in the same phase of the development lifecycle.

To improve the process further, there is a need to perform system integration tasks virtually as early in the development lifecycle as possible. This addresses the need to not only have components behave according to their specifications, but also that all the various component will integrate and lead to a system that behaves as intended. Issues that are discovered during system integration often arise from unknown unknowns, that is requirements for components may be considered adequate, but the interactions between are often insufficiently or improperly specified. This can lead to emergent behaviors that were not foreseen. Virtual integration of a potentially disparate set of models and design artifacts from the various traditional design disciplines (avionics hardware, software, hydraulics, electrical systems, aerodynamics, fuel systems, landing gear, engines, …) may help contain risk by improving the confidence in the system design at earlier stages of development than is afforded by the traditional waterfall process. The technologies necessary to do this in a modern development environment comprised of OEM’s and suppliers stretched across the globe, does not currently exist. Though there is current research addressing this problem, the scope is sufficient that a significant, coordinated effort is needed.



Risk and Cost Reduction Through Earlier Verification

The cost to correct requirements errors increases exponentially with development phase. A requirement error introduced during the requirements development phase that is detected and corrected during system test is 25 to 90 times more costly to correct than if it was corrected during the phase in which was introduced. Much of this cost escalation is derived from the expanded impact of change. The trends toward more tightly integrated and increasingly complex systems, coupled with more decentralized development environments, make understanding the full scope of change impact difficult to determine using current development practices. Thus "early and often" integration using increasingly capable system models is necessary to not only help contain risk, but to enable much more agility to the changing design requirements typical of most modern systems developments. Accurate, virtual representations of systems components enable early integration testing without the need to commit preliminary designs to hardware. This mitigates the effects of requirements instability by reducing the cost of change and by producing higher levels of design confidence at earlier stages in the design lifecycle.

Potential MBE Costs and Risks

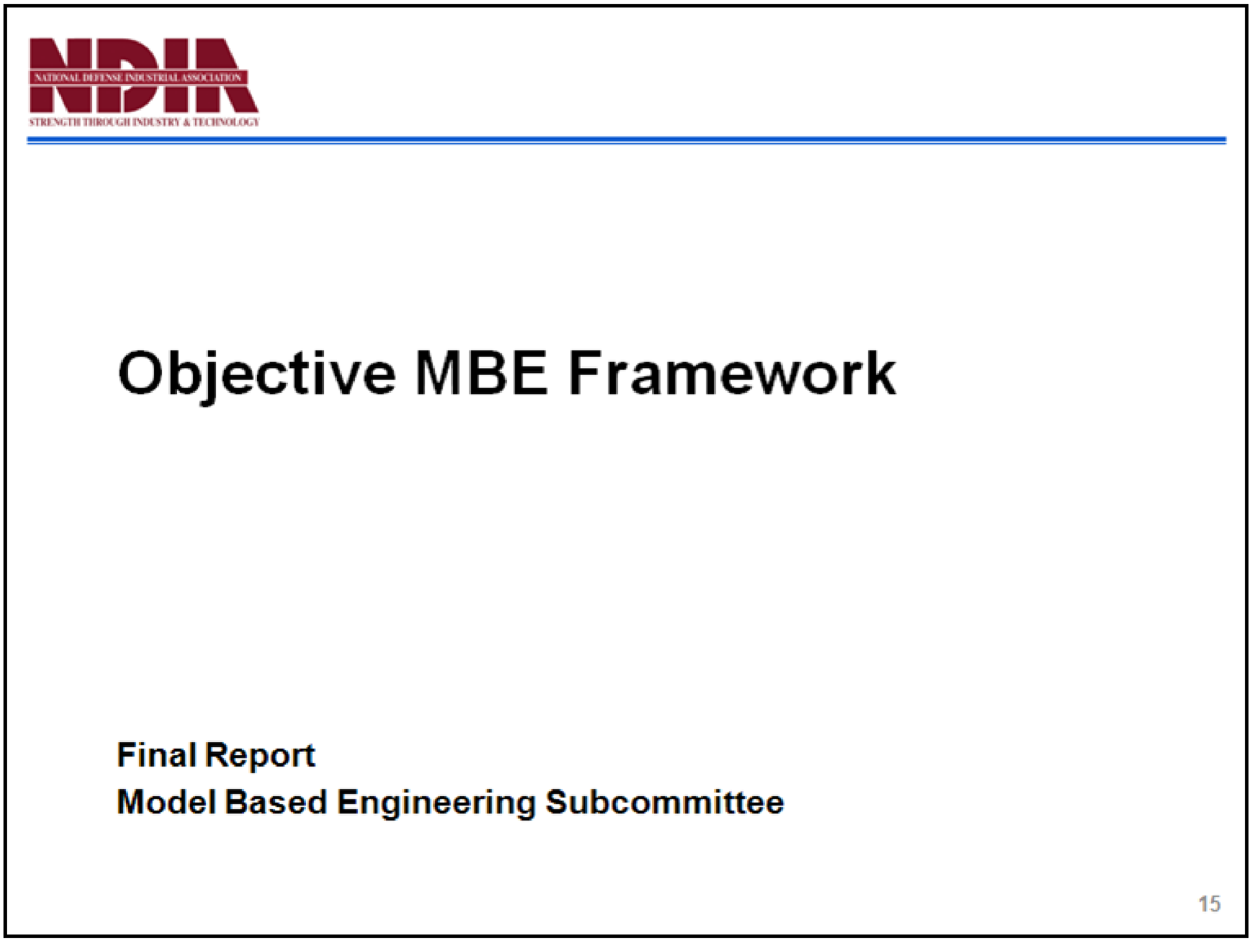
Realizing the full benefit of model-based engineering, including model based systems engineering will require investment in tools, training, and infrastructure. MBE tools have already been incorporated to a degree in existing system design processes. Their adoption has largely been driven by the acute need for better tools to handle increasing system complexity by human engineers. Models represent another level of abstraction, much the way that high level programming languages enabled the design of increasingly complex software systems by abstracting the details of the assembly language instructions. However as this need was immediate, the application of MBE is system design has been largely siloed in different engineering disciplines.

To address the increasing complexity of systems, the application of MBE must be institutionalized throughout the development environment. This implies that communication of design intent via models must traverse both internal, departmental boundaries, but also the boundaries between OEM and supplier. Such a deployment must necessarily be planned and coordinated to be cost effective. Furthermore, the initial investment may be prohibitive if the entire cost is borne by the first project on which such a coordinate process is implemented. The prospect of each OEM individually developing such a coordinate MBE approach would surely be reflected on their common customer, just as the development by a supplier of unique processes for each OEM customer would be reflected back on all OEM customers. Furthermore, the capability to produce, analyze, verify, validate, exchange, integrate, and apply models must extend from the end customer down through the supply chain to the Tier II and III suppliers. The infrastructure to facilitate this must be developed to enable accurate and precise communication of design intent across organizational boundaries while supporting a mutually beneficial business model and protection of proprietary and other sensitive information.

A potential risk lies in placing excessive expectation on MBE tools to deliver the cost and schedule savings and design agility desired by the DoD. As tools simply represent automation of design processes, they will not replace strong, rigorous, and disciplined enterprise processes. A rational design process that is supported by and compliant with government acquisition policies must first be developed by the defense industry stakeholders. This may make use of some existing guidance and comply with some existing regulations, but the change in the design an acquisition paradigm afforded by MBE is significant enough that some change will be necessary to achieve the full potential benefit of MBE technologies. Adequate tools must be developed to support and integrate with these emerging processes such that a mature set of tools and processes can be deployed on real development programs with minimum risk.

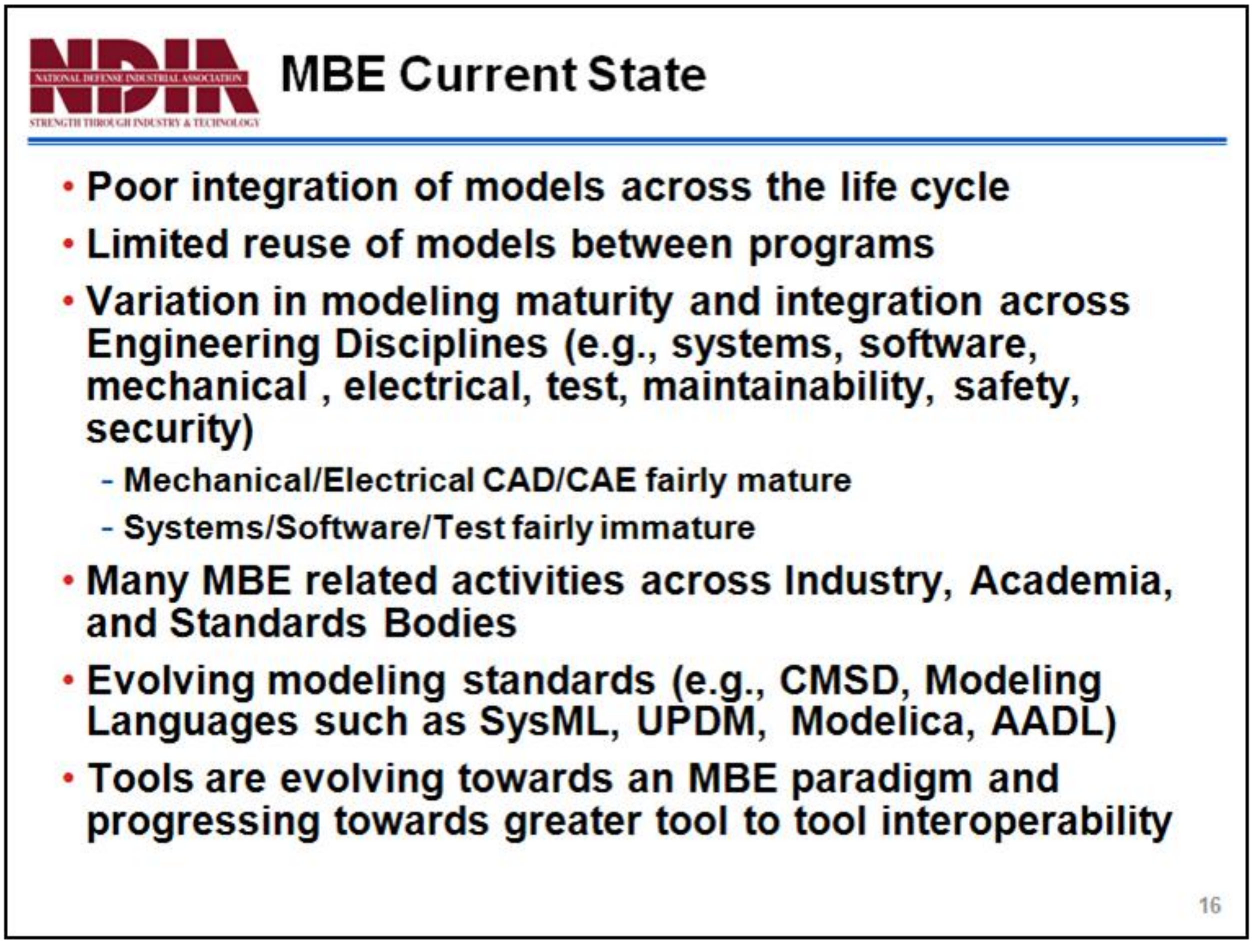
The significance of the change to the development paradigm implies that a workforce must be developed that is versant in the emerging tools and processes. Training for proficiency in new tools is necessary, but not sufficient. MBE provides abstraction of system complexity to a level that enables humans to better understand the “big picture” and to thus design their component informed of its relationship to other components. Specific training activities need to be implemented as part of a change of the design *culture* that moves people away from the archaic “waterfall” thinking and towards more continuous design/integrate/test processes. The culture must also accommodate changes that have become prevalent such as the movement away from the expectation of a complete set of requirements prior to program launch.

Finally, the full benefits promised by MBE can be achieved only if we are successful in incorporating the full design processes. Precise and accurate communication of design intent must transcend stove-piped responsibilities. Model artifacts must be able to flow across organizational and discipline boundaries. Interacting electronic, software, and mechanical subsystems must be virtually integrated to allow analysis of system properties. This will ultimately require a strong interdisciplinary team to support the development of concurrent engineering processes and practices.



Objective MBE Framework

The following subsections provide MBE Subcommittee's vision of the objective MBE framework. We provide a summary of the MBE current state, a graphical depiction of the MBE future (to be) state, and a discussion of the primary gaps that must be closed to transition from the current state to the "To Be" state.



MBE Current State

In order to establish a desired future state of MBE, it is important to understand the current state of practice of MBE. The difference between the current state and future state is used to identify gaps, which serve as the basis for defining improvement plans.

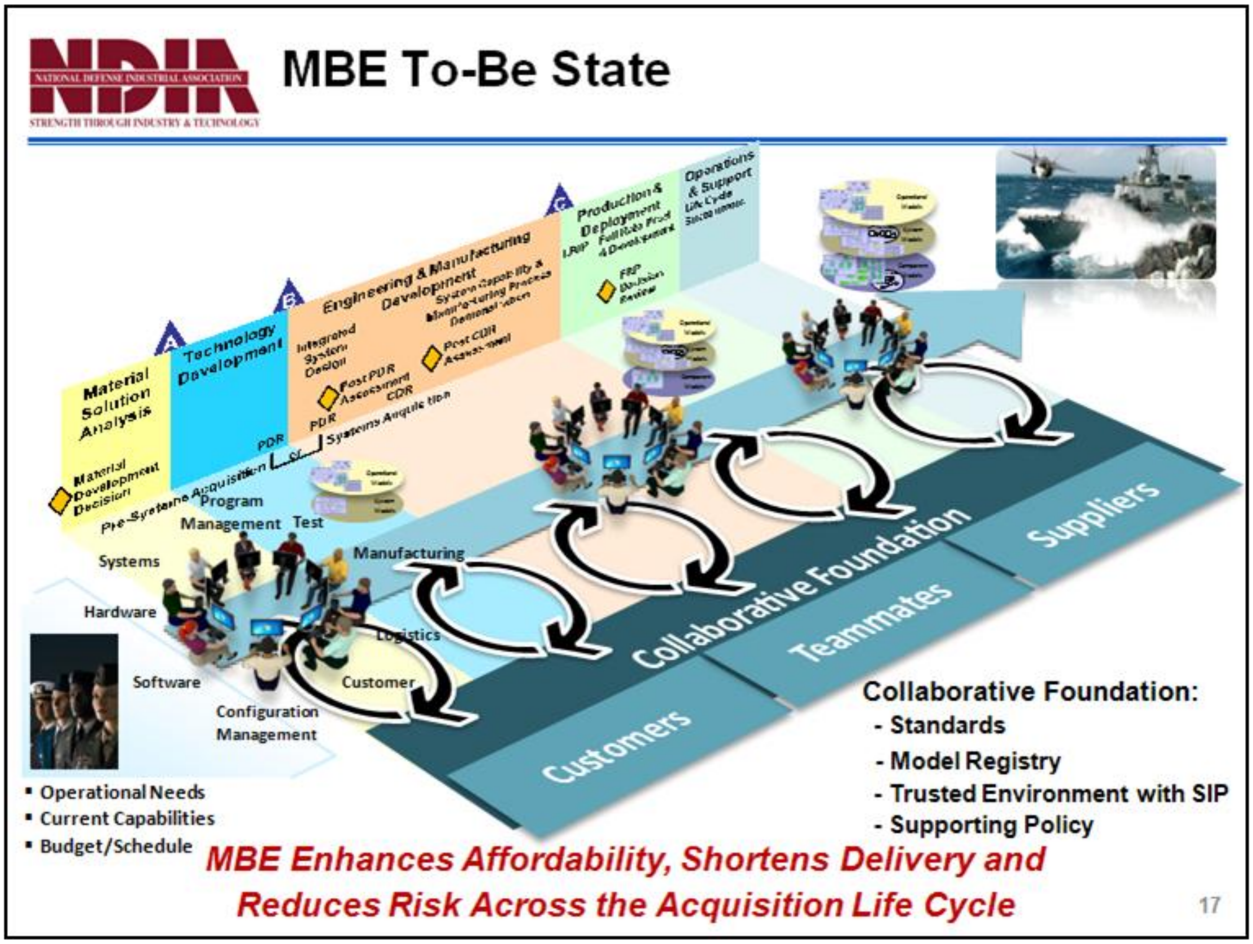
Modeling is currently used extensively across multiple domains to support engineering a product, system, or capability. The current state is characterized by a wide variation in maturity of practice across engineering disciplines. For example, three dimensional geometric modeling and electrical design modeling have become common practice with well defined modeling methods, tools, and techniques throughout the aerospace and defense industry, as well as many other industries. Their model serves as the basis for defining the bill of materials for the overall system. Simulation modeling is also a common practice, although the specific practices for developing simulation models vary widely. Systems of systems, system, and software architecture and design modeling are emerging practices that are used only in pockets. Some aspects of system and software modeling, such as the use of Simulink models for design of control systems and control algorithms, and auto generation of the implementing code, are reaching high levels of maturity within some organizations. In other areas, the modeling languages, methods, tools, and the skill of the workforce are in an early stage of maturity, but are advancing rapidly.

Although in the current state of MBE there is wide use of models across many domains, they are used in a stove-piped fashion and not well integrated from one model to another. The system, software and hardware design models are generally developed independently with little established integration among the models, tools, and methods. The multitude of engineering analysis models and other simulation models are also generally developed and implemented independently of one another. There are significant opportunities for inconsistent input data and assumptions about the system that are used for different models. Effectively managing the consistency between the diverse range of descriptive and analytical models is one of the challenges associated with the current state of MBE.

The lack of integration also occurs across programs. There is limited formal model reuse from one program to another unless a particular model is required by a customer, or the same engineer is modeling across different programs. There are many contractual and technical reasons that contribute to this, resulting in each model being developed from scratch, with the resultant cost, schedule, and model validation challenges.

There is growing interest that MBE provides potential to address some of the challenges faced by DoD acquisition to reduce risk, make our systems more affordable, and reduce the timeline to field a system or system upgrade, as described in the benefits section of this presentation. This growing interest is evident in many activities across industry, academia and standards bodies. Many of these activities recognize of some of the challenges with the current state and the promise of MBE, and are working to help move the state of practice forward. These include organizations such as INCOSE that has a Model-based Systems Engineering (MBSE) Initiative, and the Consortium of Aerospace companies that are working on the AVSI project to demonstrate the benefits of virtual integrations. Standards bodies such as PDES, OMG, NIST, and SISO are all addressing different standards in support of MBE. At the same time, there is increasing focus on tool interoperability among modeling tools. One example of this is the OMG Model Interchange Working Group that is working with multiple vendors to increase the model interchange capability among UML, SysML and UPDM tools.

Aerospace and Defense companies from across industry are also increasing their internal efforts internally to improve and deploy their modeling practices. Modeling also continues to be an essential part of the engineering curriculum within academia, and there is increased emphasis on teaching these practices to industry.



MBE To Be State

The MBE to-be state leverages MBE across the acquisition life cycle to enhance affordability, shorten delivery time, and reduce risk. In the to-be state, the models become an integral part of the technical baseline, and evolve throughout the programs life cycle. The current state is characterized by gaps between domain silos and lifecycle development phase hand-offs that are often the source of errors until later in the development process when they are more expensive to fix. The future state of MBE seeks to reduce these errors though seamless integration of model data across domains and across the lifecycle by aligning shared model properties and assumptions. Different engineering disciplines concurrently operate on different facets of the system and/or product design, such that the impact of a change in one model can be readily assessed in another model. Engineering and programmatic knowledge is shared through a common technical baseline. The models developed by each discipline evolve in maturity throughout the life cycle, and are not thrown away and redeveloped as the program transitions from one phase of development to another. This includes the up-front mission analysis models, the system requirements and architecture models, the detailed hardware and software design models, and the detailed simulation models used to assess and verify all aspects of the system as it evolves. Early validation of requirements including those for manufacturing and support, and efficient development of a fully integrated technical baseline result in significant improvement to the development process.

The collaborative foundation provides a means to share the information from the model registry across the extended enterprise of customers, teammates and suppliers. The foundation includes the modeling standards that enable information exchange, the model registry that enables ready access to the different models, and a trusted environment which enforces protection of intellectual property and secure access to sensitive and classified data. The collaborative environment also enables reuse from one program to another to enable sharing across a family of products and system of systems.

The MBE to-be state includes a workforce that is skilled in the use of the matured modeling methods and tools, an infrastructure that supports this capability, and policies that enable it.

NDIA NATIONAL DEFENSE INDUSTRIAL ASSOCIATION STRENGTH THROUGH INDUSTRY & TECHNOLOGY

Primary Gaps That Must Be Closed

- Policy
  - Policy / contracting mechanisms
  - Business model(s) that incentivize MBE adoption
- Processes/Methods
  - Currently, models (other than CAD) are not part of the Technical Baseline
  - Model / data/ tools management (GOTS and COTS)
  - Information management
  - Model-based methods
- Tools/Technologies/Standards
  - Domain specific language and data standards
  - Formal semantics
  - Data rights protection in an open architecture environment
  - Model interconnect and interchange
- People
  - Workforce gaps across stakeholder communities
  - Acceptance of the use of models as a business practice
  - Model validation and confidence (reputation management; evidence based credibility)
- Infrastructure/Environment
  - Easy access to models / content developed by others
  - Lack of common, shared Operational Scenarios
- The Business Case for MBE

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Primary Gaps That Must Be Closed

MBE envisions the extensive use, sharing, and reuse of models and digital products in a collaborative environment — both within Industry (including between Industry partners), between Government and Industry, and across acquisition programs. Moreover, the models and digital products will represent authoritative elements of the technical baseline and be authorized to serve as contractually binding mechanisms similar to how text-based documents, and perhaps physical mockups, do today. The use of digital products in this way will likely require a few new policies and changes to some existing DoD policies and the DFAR. For example, changes will be necessary to facilitate authorized access to, and the sharing of, models and other digital products (e.g., DoD-approved scenarios) while controlling access and safeguarding Government and Industry sensitive information including the intellectual property contained in models; legitimizing the use of models within the acquisition process; ensuring open and adequate competition in an MBE marketplace; and protecting the Government from potential legal challenges brought about by the increased use of information technology in acquisition contracts.

There are gaps between the current state and the desired To Be state relative to the availability of mature MBE processes and methods. With the exception of CAD/CAE models, other models such as simulation, analysis and architecture models are not fully integrated into the technical baseline. If fully integrated, these models would be used in a consistent and comprehensive part of the development process to specify, design, analyze, verify, and validate the system. In addition, the models would be used by the Engineering Review Board (ERB) in to assess the impact of proposed specification and design changes. The current MBE processes and methods do not adequately support management of highly complex cross-domain models, including configuration, version, and variant management and reuse of models and the modeling environment, or the ability to propagate changes from one model to changes in other models.

The cross-discipline, cross-acquisition life cycle phase, and cross-program collaboration and reuse of the MBE To Be state can only be realized by closing specific technology gaps and developing robust tools and standards. Specific gaps to be closed include domain specific languages and data standards, and formal semantics to encourage and enable model interoperability and reuse. Standards must be developed to support model interconnect and interchange, and any standards initiative should leverage the ongoing efforts by INCOSE, AVSI, SISO, STEP PDES, OMG, and NIST. Finally, the MBE To Be state resembles an open architecture environment, which will require tools, policy, and approaches for data rights protection.

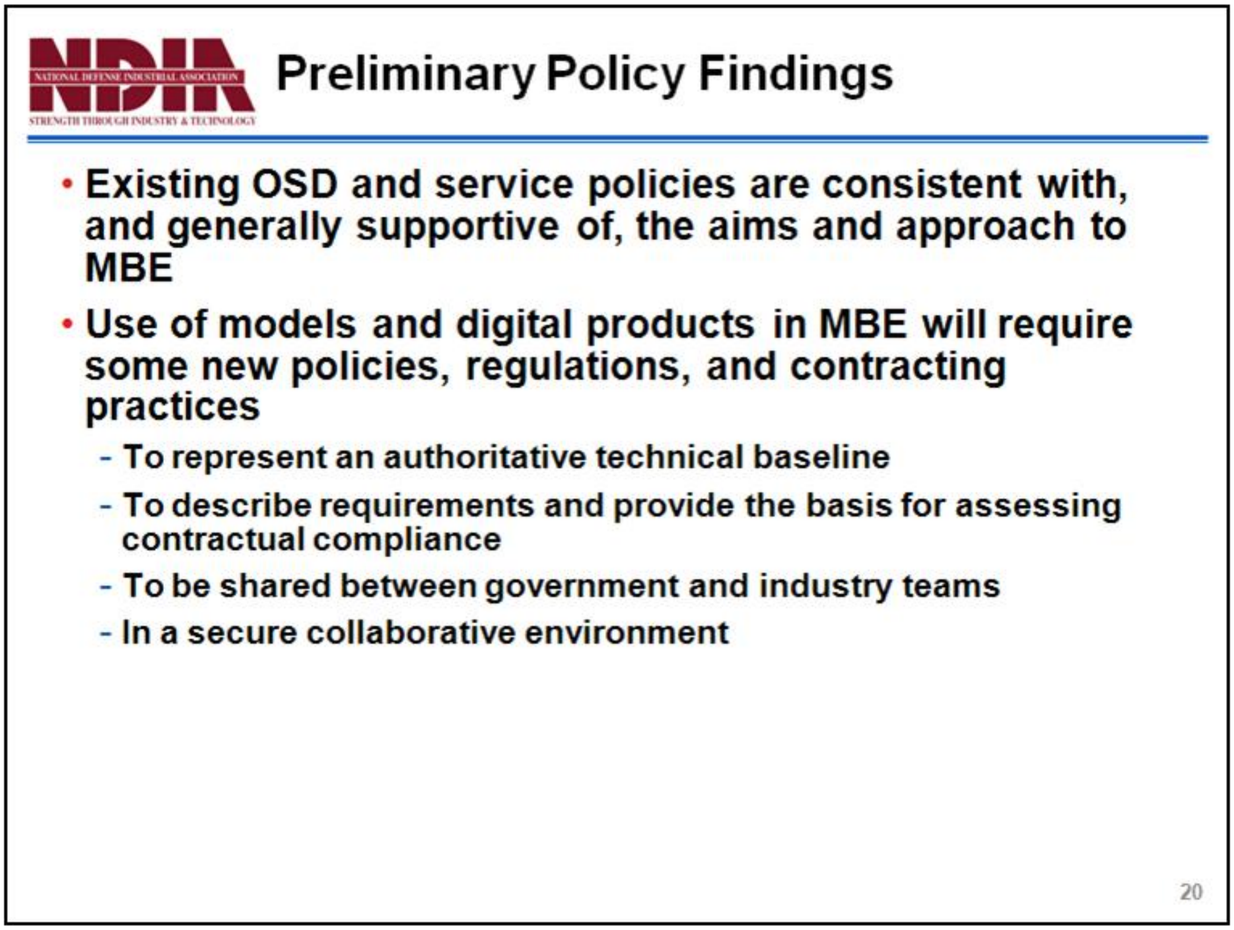
In the end, it is people that perform systems engineering and acquisition, spread across many stakeholder organizations, both on the customer (Government) side and the supplier (Industry) side. MBE is an emerging approach to engineering, resulting in a shortage of qualified model-based practitioners across stakeholder communities, particularly in leadership positions. There is also a lack of general acceptance of the routine use of models and simulations as part of typical business practices. Additionally, there is reasonable concern about the degree to which models are valid across the potential range of their use, and about the level of confidence (both qualitatively and statistically) that can be placed in model-based results.

Models and simulations must be sharable across traditional program boundaries, but shareable in a way that both protects intellectual property and incentivizes innovation. This has significant business model implications. For example, there is currently no equivalent to the "app store" paradigm we see in the commercial sector for government and industry models. The subcommittee believes that the solution to this gap can build on and extend the current DoD Meta Data Standard and M&S Catalogue. It is also important to ensure that models of operational capabilities, and associated use cases and scenarios, are shareable across program boundaries to ensure system consistency with operational needs and interoperability with other systems in related operational domains. Today these operational scenarios are often stovepiped, inconsistent with one another, and generally not shared outside specific programs or narrow customer domains because there is no infrastructure and environment for doing so.

Lastly, a business case must be developed to document and quantify the value propositions for all stakeholders. MBE is an emerging practice, and little evidence exists that quantifies the benefits. The few quantified examples are compelling [1, 5, 7], but are not broad enough to encompass all stakeholders.

Policy, Guidance and Contracting Mechanism Impediments and Issues

The following subsections provide the preliminary findings of the MBE Subcommittee's review of existing policy, guidance, and contracting mechanisms, and provide recommendations on policy and regulations that we believe are required to enable MBE.

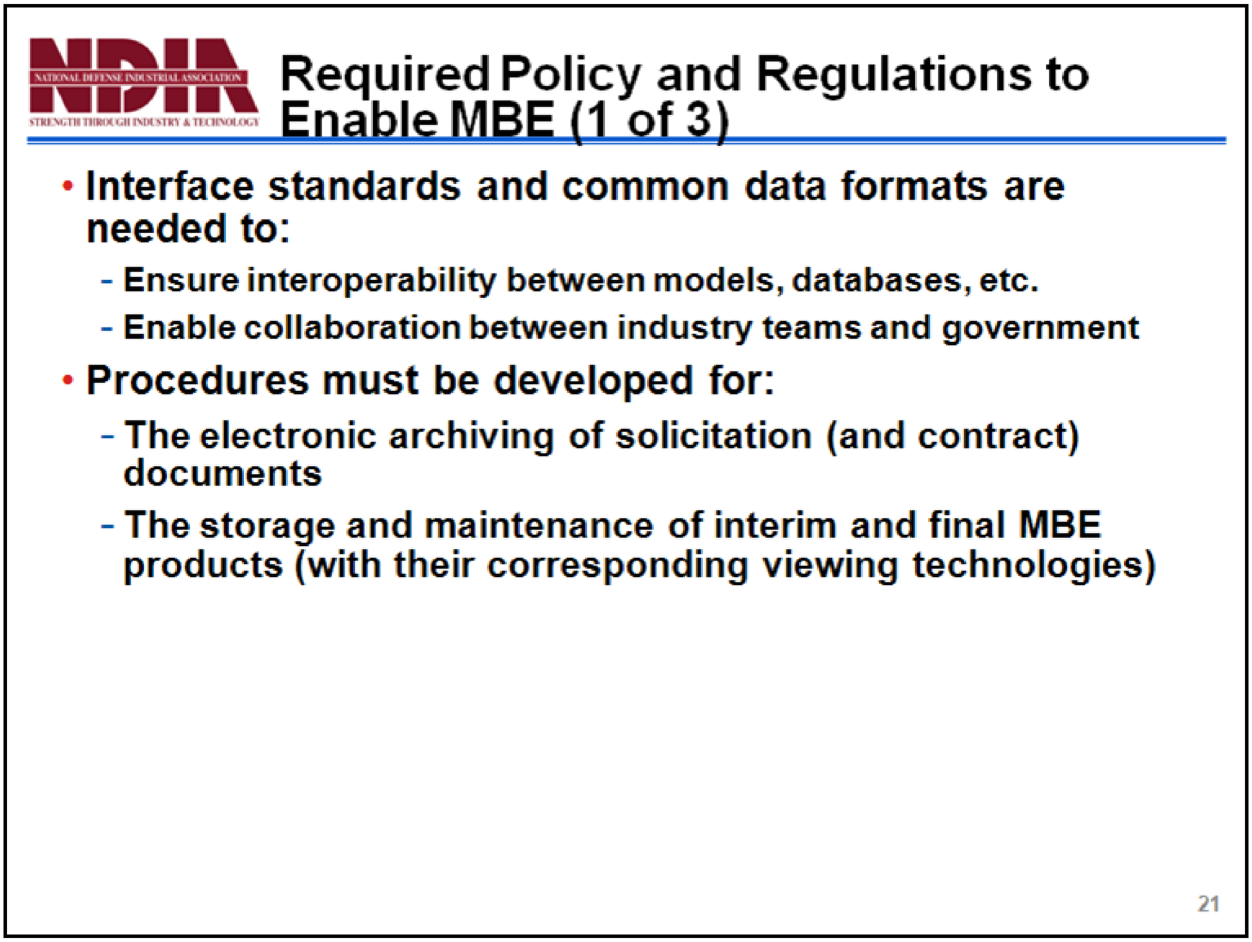


Preliminary Policy Findings

The subcommittee reviewed the applicable set of current OSD and service-specific policies and guidance related to weapon system acquisition (listed in the appendix). Although existing regulations are generally consistent with, and in many cases actually supportive of, the aims and approach to MBE, these policies may not go far enough in:

- Ensuring open and adequate competition, and
- Protecting the Government from potential legal challenges brought about by the increased use of information technology (models and other digital products) to create authoritative and authorized elements of the technical baseline.

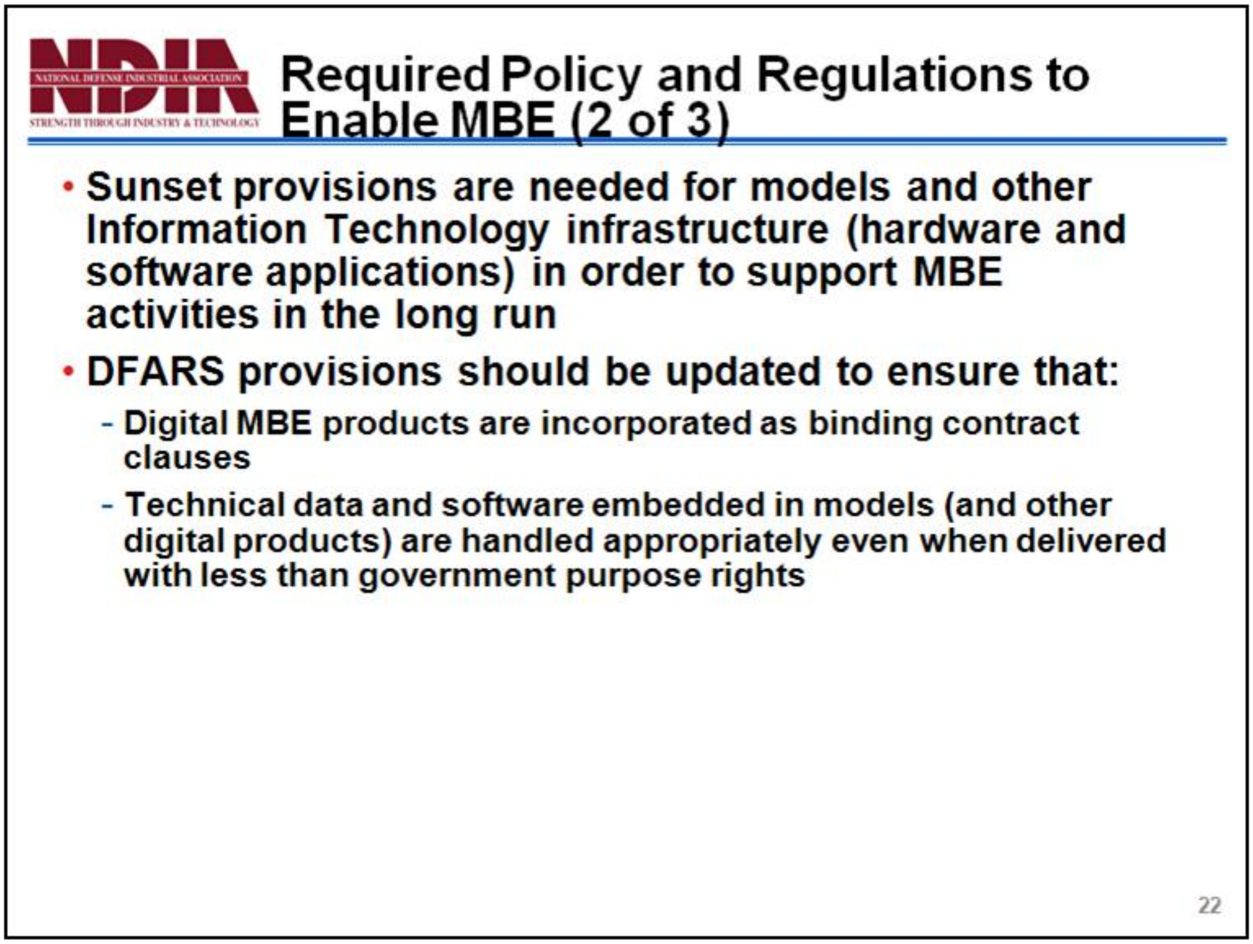
The aspects of MBE that will lead to changes in current policy and guidance include access control to models and databases, electronic record keeping and retention, digital vice text-based products, software interface standards, and data rights. In some cases we were unable to find any existing policy addressing the issue (e.g., access control to MBE products). In other cases, the existing policy was simply inadequate or needed to be updated to reflect a different application (e.g., electronic/digital signatures and certifications). In the remaining areas, the existing policy appears adequate and users simply need to be made aware of, and trained in, the current policy.



Required Policy and Regulations to Enable MBE

Fostering the MBE collaborative environment presents a few challenges that can be addressed through new or updated policy and guidance. For example, MBE is built on a foundation of collaboration and openness, including the sharing and exchange of ideas, concepts, models, data, test results, etc. between all of the stakeholders (government and industry teams) involved in development of weapon systems, and extended in many cases to include stakeholders of other systems with which this weapon system is expected to interoperate. To facilitate the extensive use of heterogeneous models developed by different organizations and different disciplines, and the ready exchange of information between models and between organizations will require establishing and then enforcing **model and data interoperability standards**. The focus should be on interface standards and externally visible and accessible, behavioral and protocol standards. Standards should be chosen to allow a broad range of industry participants.

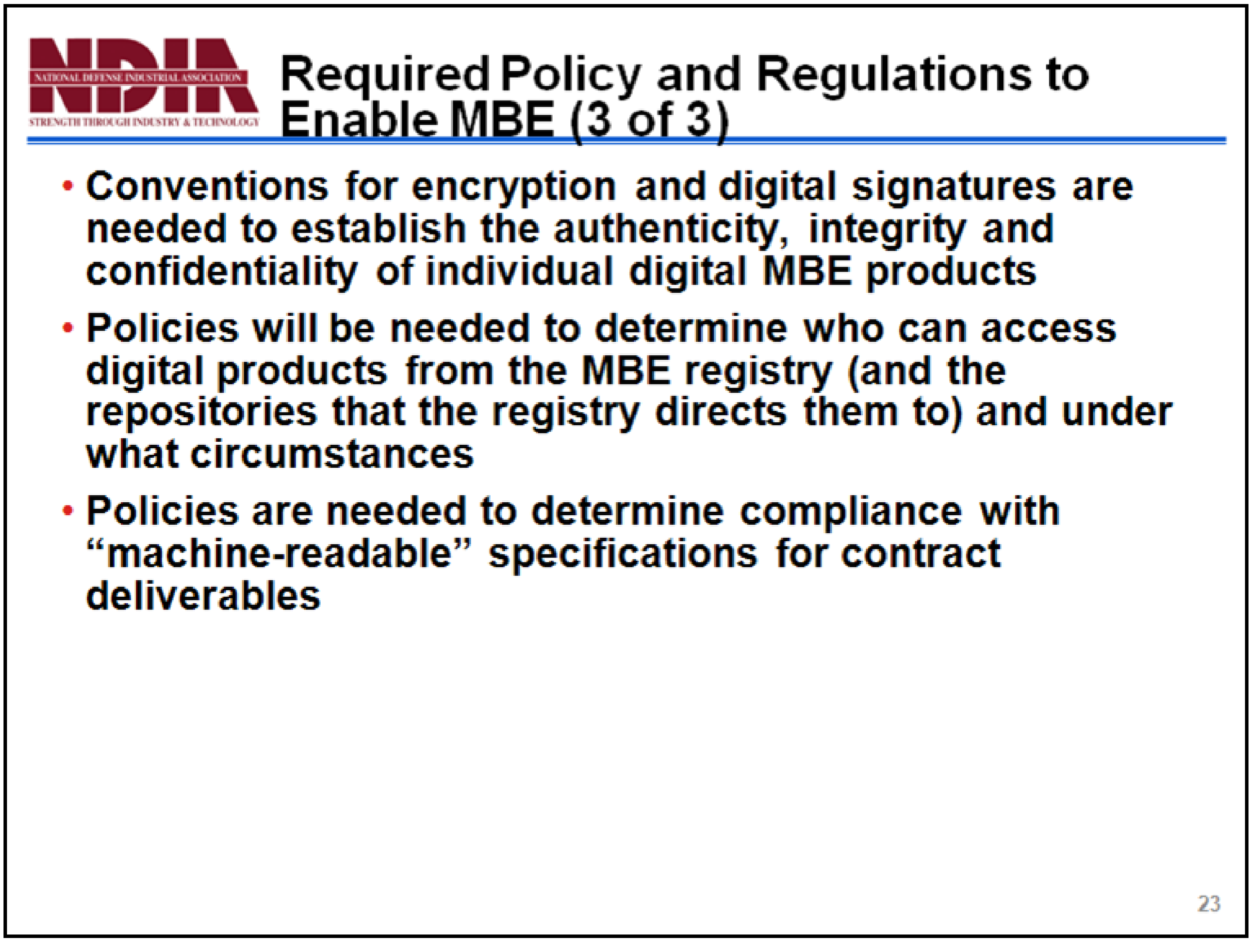
Requirements for the **retention of electronic records** are outlined in DoD 7000.14-R (DoD Financial Management Regulation) Volume 5, Chapter 21 and Volume 10, Chapter 8. The federal statute governing record retention is 44 USC 3302. The Navy's records retention policy can be found at this Link: http://www.fas.org/irp/doddir/navy/secnavinst/m5210_1.pdf. In addition to the government requirement, there is a parallel requirement for government contractors. That requirement is contained in the FAR...and is to retain for three years after the contract is closed out. In addition to retention requirements, more specific procedures are needed governing the form of electronic retention to support any possible litigation downstream. For example, in January 2011 the Supreme Court agreed to review a two-decade old civil dispute between the Navy and two defense contractors over the A-12 aircraft. MBE policy on electronic archiving would have to address both the time-period for retention and the electronic form of retention. The electronic records have to be retrievable and (machine) readable. These requirements may levy additional requirements on retention of software applications and hardware to ensure that the models are accessible and useable during the time period needed.



To support the need to revisit and review the decisions and activities associated with an acquisition program, including in response to formal protests and other litigation associated with a program, the models and other digital products need to remain accessible (and operational) through the necessary computer hardware and software. Whereas text and graphics associated with acquisition programs today can be maintained for millennia if recorded in a fixed medium, computer models (because of the hardware and software required to run the models) have a half-life measured in years. New acquisition policy and regulations are needed to define **sunset provisions** to ensure the necessary configurations of hardware and software to access and operate the models and digital products remain available during this period. This includes provisions to ensure “backwards compatibility” of files saved across software versions or policy stating the extent to which a model needs to be fully functional across platforms (defined by relevant combinations of hardware and software).

Current acquisition guidance and policy (including JCIDS) requires written (text-based) submission of documents to support the acquisition process. These include the Capability Development Document (CDD), the Capability Production Document (CPD) and other written documents to support the Materiel Development Decision (MDD), the Systems Engineering Plan (SEP), the Test and Evaluation Master Plan (TEMP) and others. Changes are needed in policy and guidance (including the **DFAR**) to **authorize the use of models and other digital products as opposed to text and graphics only and stating where and how these digital products can be incorporated by reference into required text-based documents.** Also, the Weapon System Acquisition Reform Act (2009) requires competitive prototypes of systems and critical subsystems in the Technology Development phase. There is no policy on whether "virtual" prototypes, developed through MBE, could substitute for physical prototypes and satisfy the WSARA requirement.

The models, databases, and other digital products developed within the MBE collaborative environment and made accessible to acquisition stakeholders will include proprietary and business sensitive information in the form of intellectual property (e.g., algorithms, databases, technical approaches, etc). MBE emphasizes the collaboration among government and industry teams throughout the acquisition process and the sharing of models, data, and interim products between phases of program development and among stakeholders. The stakeholders are likely to include a number of industry developers, vendors, and suppliers, several which could represent competitors. Access to digital products means they are prone to reverse engineering and stealing trade secrets. Additional policy is needed to **protect the intellectual property that is embedded in MBE tools and products.**



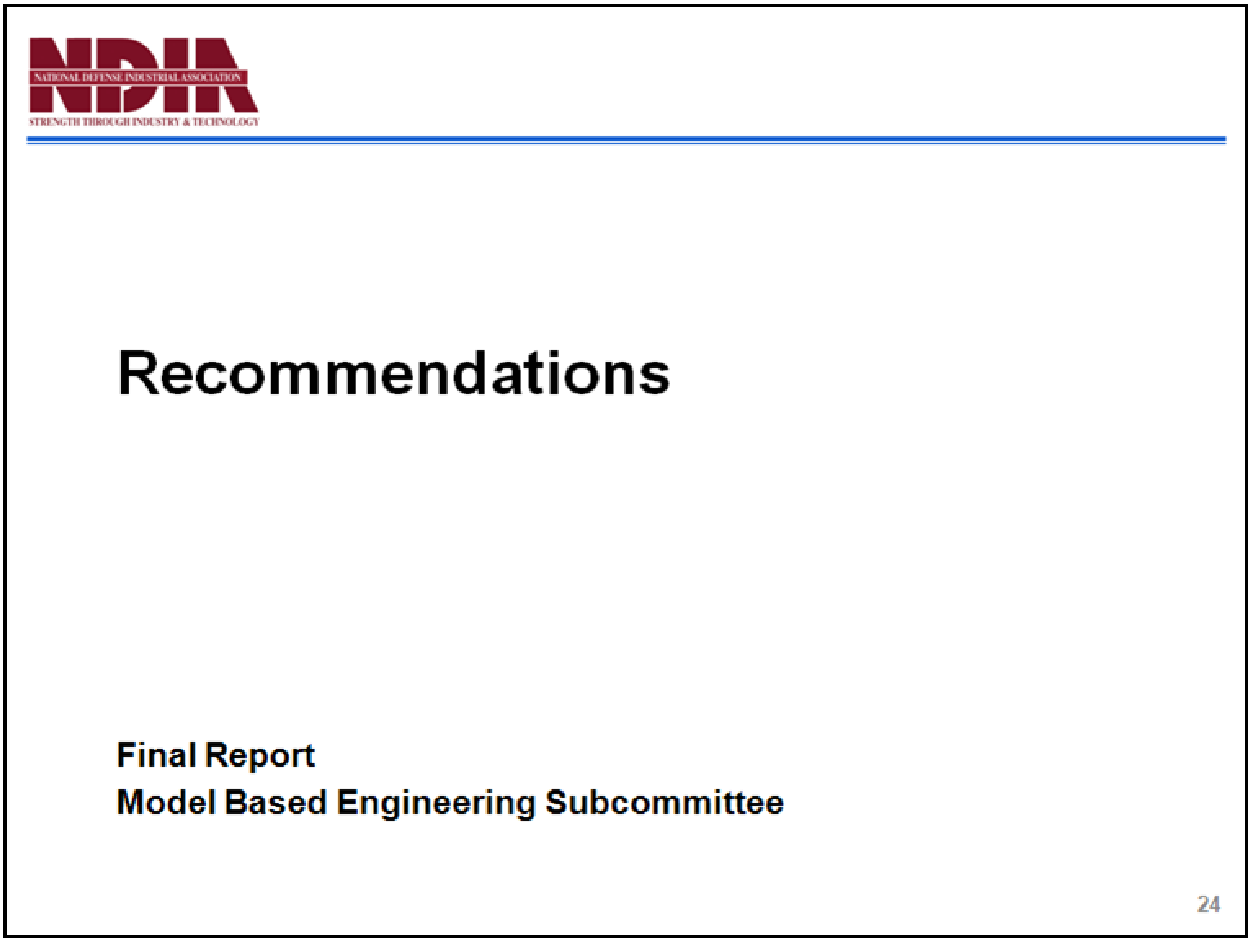
To ensure the authenticity, integrity, and confidentiality of MBE products these need to be **encrypted and digitally signed**. Electronic/Digital Signatures and Certifications are addressed in DoD 7000.14-R (DoD Financial Management Regulation) Volume 10, Chapter 17). All MBE users will need to be trained in the Assistant Secretary of Defense for Networks and Information Integration ASD (NII) guidelines for digital signature and the DoD-wide interoperability requirements (for Public Key Infrastructure) prescribed in DoD Instruction 8520.2.

The implementation of MBE must ensure a level playing field among potential industry participants. This starts with ready **access to electronic files** on contract announcements, and proceeds through solicitation documents and, once the contract is awarded, onto the models and databases used in the design and development of the system. The information technology (software applications and hardware) required for a firm to participate in an MBE program must not give an unfair advantage to large firms capable of making the needed investment in technology, nor hinder competition among potential bidders. For example, today some military web sites require a CAC card for access. Other sites are not compatible with a particular version of a web browser. DoD would have to develop a policy on the information technology required to participate in MBE acquisitions.

Sharing and collaboration should also include government-initiated actions to share government-controlled models and databases, including formally “approved” scenarios and CONOPs. Industry access is important especially if these resources will be used in evaluating proposals or to support other government activities, such as test and evaluation. Classified models and databases should be made available to industry participants that meet the appropriate security criteria.

Support for the collaboration and sharing of models and other digital products that is at the center of the MBE concept will require some form of registry (that points to numerous repositories) to register the modeling tools and digital products and other components of the MBE infrastructure such as scenarios, CONOPs, environmental data and other databases. To make these tools useful to others will require metadata be provided by the original developer on all models and digital products. Once the models and databases have been registered, policy and procedures will be needed governing access to these products by others working MBE.

The MBE approach to acquisition may replace some traditional text-based acquisition products (including contracting paperwork) with computer models or may incorporate digital products (such as models) into new forms of acquisition products. In such cases, there may be challenges with **interpreting, evaluating, and then enforcing “soft standards” (non-text based) digital products**. While there are current legal conventions on construing written documents, including written contracts, the task of determining compliance with something that is only machine-readable and cannot be printed out and shown to a judge adds a new dimension for disagreement. Established conventions developed for interpreting text and engineering drawings will have to be updated to account for the digital products associated with MBE.



Recommendations

The following subsections provide the recommendations that were developed by the MBE Subcommittee. Our recommendations fall into three major areas:

- Collaboratively work with stakeholders to develop the MBE Business Model,
- Work with Industry, Vendors, and Standards Organizations to develop MBE standards, and
- Develop the workforce.

Collaboratively Work with Stakeholders to Develop the MBE Business Model (1 of 2)

Recommendation	Government Role	Industry Role	Vendor Role
1. Define the data required to construct the business cases / value propositions, and how that data will be captured	Establish a Government charted collaborative to define required data and metrics ; lead efforts for Government stakeholders	Participate through Industry, Academic & Professional groups (e.g., NDIA, AVSI, INCOSE); lead efforts for Industry stakeholders	Incorporate metrics in tools to support continuing improvement
2. Launch a small number of model based contracting pilot projects; Encourage Programs Of Record (PORs) to participate	Develop MBE pilot programs; with defined goals supported by award fees, Government Labs; Incorporate in new program starts & existing PORs	Program deliverables, metric data processes aligned to MBE goals; Share MBE best practices with govt. & industry	Develop tools and technologies; evolve products; Standardize tool interfaces for interoperability
3. Conduct a "Grand Challenge" like project to accelerate the cross-discipline end-to-end MBE implementation	Government organization to establish budget/scope for challenge; work with industry to identify gaps; use competition/prizes to bridge gaps	Participate in identification of key gaps; develop teams with industry/ vendors/ academia/ professional groups	Help industry understand & leverage state-of-art capabilities; evolve tools & technologies

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Collaboratively Work With Stakeholders to Develop the MBE Business Model

While many agree with the compelling vision of MBE, there is a lack of significant data to support a compelling the Business Model and move it beyond academics. Without the supporting data, DOD would be more reluctant to mandate MBE, Industry would be more cautious of infrastructure investment, and Vendor development would be slower.

In order to develop the data required to support the Business Model, the Subcommittee makes a series of recommendations for collaborative actions between the Government, Industry, and Vendor Stakeholders. The steps establish the criteria for success; generate data through projects and challenges; mature the process to increase benefits; and, as appropriate, institutionalize MBE through incentives.

1. The first step is to understand what success looks like and the supporting data required. The broad-based Collaborative Team (Government, Industry, Vendor) would agree on metrics and methods to capture them.

2. Next, the Government would develop MBE pilot programs – perhaps similar to Model-Based Acquisition programs such as USMC LVSR and MPC - encouraged by award fee. Program deliverables could be model-based with CDRLs being package, performance, and descriptive models. Increased Industry investment would encourage Vendor development in the areas of interoperability and standards.

3. If the data produced from pilots is encouraging but gaps remain, we recommend a "Grand Challenge" to sponsor revolutionary, high-payoff research to bridge the gaps, perhaps, similar to the 2005 and 2007 DARPA prize competitions for driverless cars.

NDIA NATIONAL DEFENSE INDUSTRIAL ASSOCIATION STRENGTH THROUGH INDUSTRY & TECHNOLOGY

Collaboratively work with Stakeholders to develop the MBE Business Model (2 of 2)

Recommendation	Government Role	Industry Role	Vendor Role
4. Explore a model registry concept; assess and shape applicability of M&S Catalog and Defense Meta Data Standard	Appoint Government organization to lead applicability assessment of Catalog; explore Catalog extensions, alternative concepts, managed M&S environments	Participate in evaluation of Catalog/registry concepts; and managed M&S environments	Develop tools and technologies; evolve managed M&S environments & products
5. Use operational models to facilitate capability integration across programs	Leverage DOD Portfolio Management Initiative to establish cross-program links	Use model registry and interoperability standards in designs	Enable cross-project links in tool databases
6. Develop Sensitive Information Protection (SIP) guidelines (IP, ITAR, etc.)	Appoint a lead Government organization; work with like efforts (e.g., TSCP) to develop proper MBE cognizant guidelines	Participate in development of Guidelines through Industry/ Acad/ Prof groups; lead development of IP guidelines to accommodate MBE	Develop tools and technologies to accommodate SIP guidelines

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4. In addition to interoperability and standards, there must be a reliable source of authoritative models. Trusted models must be developed and thoroughly verified through physical test. For each program, models, meta data, and test data must be traceable to known configurations. A model registry, or catalog, would provide pointers to authoritative models and their developers as well as operational environments and the intended uses. Two ongoing DOD initiatives, the M&S Catalog and the Defense Meta Data Standard, should be assessed for applicability.

5. The next step in maturing MBE and generating even greater value is would be to extend the span from a single program to multiple programs.

6. While interoperability and registries will promote greater sharing, sensitive data will at the same time require protection. The Collaborative Team will need to establish guidelines, new technologies, and integrate them into the tools.

TSCP – Transglobal Supply Chain Program who is working on how to express IP, ITAR, and security classification in terms of information rights in standard ways, and how to incorporate that into existing modeling standards using security technologies like encryption, digital signatures, and digital rights management.

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Work with Industry, Vendors and Standards Organizations to Develop MBE Standards (1 of 2)

Recommendation	Government Role	Industry Role	Vendor Role
1. Conduct Consensus Conference and Develop MBE Common Reference Model (CRM)	Convene Consensus Conference with Industry, Academic, Prof Groups, International community, and Government; use RFI to identify participants. Appoint a lead Government organization; set objectives and timeline	Participate in development of MBE Common Reference Model	Incorporate Common Reference Model into tool development and evolution
2. Develop MBE Standards Roadmap	Appoint a lead Government organization; set objectives and timeline. Involve Industry, Associations, and International community	Participate in Standards Roadmap development	Participate in Standards Roadmap development
3. Initiate a research program to close high priority gaps in the MBE CRM	Establish budgets, R&D acquisition approaches (BAA, SBIR, STTR), and technology transition plan	Develop tools and technologies; support transition efforts	Develop tools and technologies; support transition into tools as appropriate

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Work with Industry, Vendors and Standards Organizations to Develop MBE Standards

Realization of the MBE To Be State can only occur with a broad base of technical and programmatic standards that fully support collaboration and reuse across disciplines, across life cycle phases, and across programs. The subcommittee makes a series of recommendations for collaborative actions between Government, Industry, and Vendor Stakeholders to develop the standards. The recommendations call for the development of the overarching technical guidance, development of the technical standards and reference implementations, and development of program planning guidance to support the successful contracting and execution of MBE-based programs.

1. The initial step is to develop an MBE Common Reference Model that will provide an abstract framework for understanding the relationships among MBE stakeholders, and for the development of consistent standards and specifications that support MBE. We suggest that a Consensus Conference be conducted to initiate the development of the Common Reference Model. It is important that the Consensus Conference attracts a

wide number of participants that are currently engaged in model-based activities and research.

2. Next, the Government should lead the development of an MBE Standards Roadmap, involving Industry, Associations, and the international community so that ongoing model-based standards initiatives can be leveraged to the greatest extent possible.

3. Should the Common Reference Model and Standards Roadmap identify any high priority technical gaps that must be closed, the Government should initiate a research program to close the gaps and transition the technology.

Work with Industry, Vendors and Standards Organizations to Develop MBE Standards (2 of 2)

Recommendation	Government Role	Industry Role	Vendor Role
4. Develop individual standards identified in the MBE Standards Roadmap and the MBE CRM	Prioritize which standards in the roadmap have the biggest impact on operational benefit	Provide industry perspective to develop MBE standards	Participate in standards development and implement MBE standards in tools
5. Provide seed funding for reference implementations of selected MBE standards identified in Roadmap	Establish budgets, acquisition approaches, and technology transition plan; actively work with appropriate standards organizations	Perform reference implementations and feed back results into MBE CRM & Standards Roadmap	Incorporate into tool development and evolution as appropriate
6. Develop MBE program planning guidance (how is a model delivered, documentation, CDRLs, processes, artifacts)	Establish chartered collaborative with ASD R&E as the lead. Glean lessons learned and best practices from Pilot Projects and early adopters. Solicit input from Industry/ Academic/ Prof groups; develop and evolve Program Planning Guidance	Provide input to support Program Planning Guidance development and evolution	Provide input on tool qualification; adhere to tool qualification guidance

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4. Development of MBE standards should follow, in accordance with the Roadmap and the Common Reference Model. Industry and Vendor participation is vital to ensure widespread buy-in, and early implementation of the standards in vendor tools. One, or more, standards organizations should be engaged to formalize the standards.

5. Widespread adoption of new standards can be achieved more easily if reference implementations are developed and made available. An example of this type of effort is the seed funding provided by DOD for the reference implementations of the High Level Architecture's (HLA) Runtime Infrastructure (RTI) and Realtime Platform Reference Federation Object Model (RPR FOM). The availability of the RTI and RPR FOM made it easier for the Services and Industry to implement the initial HLA compliant simulations.

6. Finally, MBE Program Planning Guidance must be developed. Key information, lessons learned, and best practices will be gleaned from the Pilot Projects (Business Model recommendation #2) and early adopters. Industry, Vendors, and Academia will provide input as well to help develop and evolve the Program Planning Guidance.

Develop the Workforce (1 of 2)

Recommendation	Government Role	Industry Role	Vendor Role
1. Use the MBE CRM to educate the holders of each role about the needs and contributions of the other roles. Encourage job rotation or cross training	Provide general MBE training to acquisition workforce; offer job rotation	Provide general MBE training to system development workforce; offer job rotation	Develop and offer MBE tool training that is compliant with the MBE CRM
2. Insure role based continuing education and training is available to the workforce	Provide role specific MBE training, offer job rotation	Provide role specific MBE training, offer job rotation	Provide role specific MBE training, emphasizing multirole tasks
3. Apply understanding of needed skills during workforce selection – recognize relevant education and experience. A strong understanding of M&S V&V is especially important	Consider MBE training and experience when assigning people to affected roles	Consider MBE training and experience when assigning people to affected roles	N/A

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Develop the Workforce

The subcommittee agreed that all professionals engaged in a Model Based Engineering program need to be made aware of the strengths and weaknesses of the MBE approach, and that the needed awareness is a function of their role in the program. As described in other sections of this report the committee is aware that the principles of model based engineering can be misapplied, or even misused to misrepresent product capabilities. As an example, all participants in the process must be aware that a model or simulation proven to be valid in one application may not be valid or even relevant in another. Relatively fewer participants need to understand the details of the M&S verification process.

1. The subcommittee suggests that, rather than establishing MBE as a specialty in the acquisition workforce, the workforce development process should ensure that the members of that workforce have the level of understanding of MBE appropriate to their role. The MBE Common Reference Model will be used to help educate the holders of each role about the needs and contributions of the other roles. M&S has a significant and growing role in system development and acquisition, making it critically important

that government and industry members have a common, shared, and articulated understanding.

2. M&S, including MBE has matured to become a normal aspect of the acquisition landscape and our acquisition professionals should include M&S as part of their normal, role based professional development. We in the community must work together to ensure that the needed training is available, is relevant, and is of high quality.

3. While no different than current practice, an understanding of needed skills must be applied during workforce selection. This should include MBE training and experience.

Develop the Workforce (2 of 2)

Recommendation	Government Role	Industry Role	Vendor Role
4. Provide mentoring to help people and organizations adapt to a new way of doing business	Provide tools and capability that allow collaboration in the development and implementation of MBE	Provide tools and capability that allow collaboration in the development and implementation of MBE	Offer mentoring services to Government and Industry customers
5. Provide a mechanism to capture knowledge and incorporate it into best practices and training programs	Develop and evolve a knowledge base that is used by the MBE community	Develop and evolve a knowledge base that is used by the MBE community	Utilize customer feedback and lessons learned to evolve tools and update training

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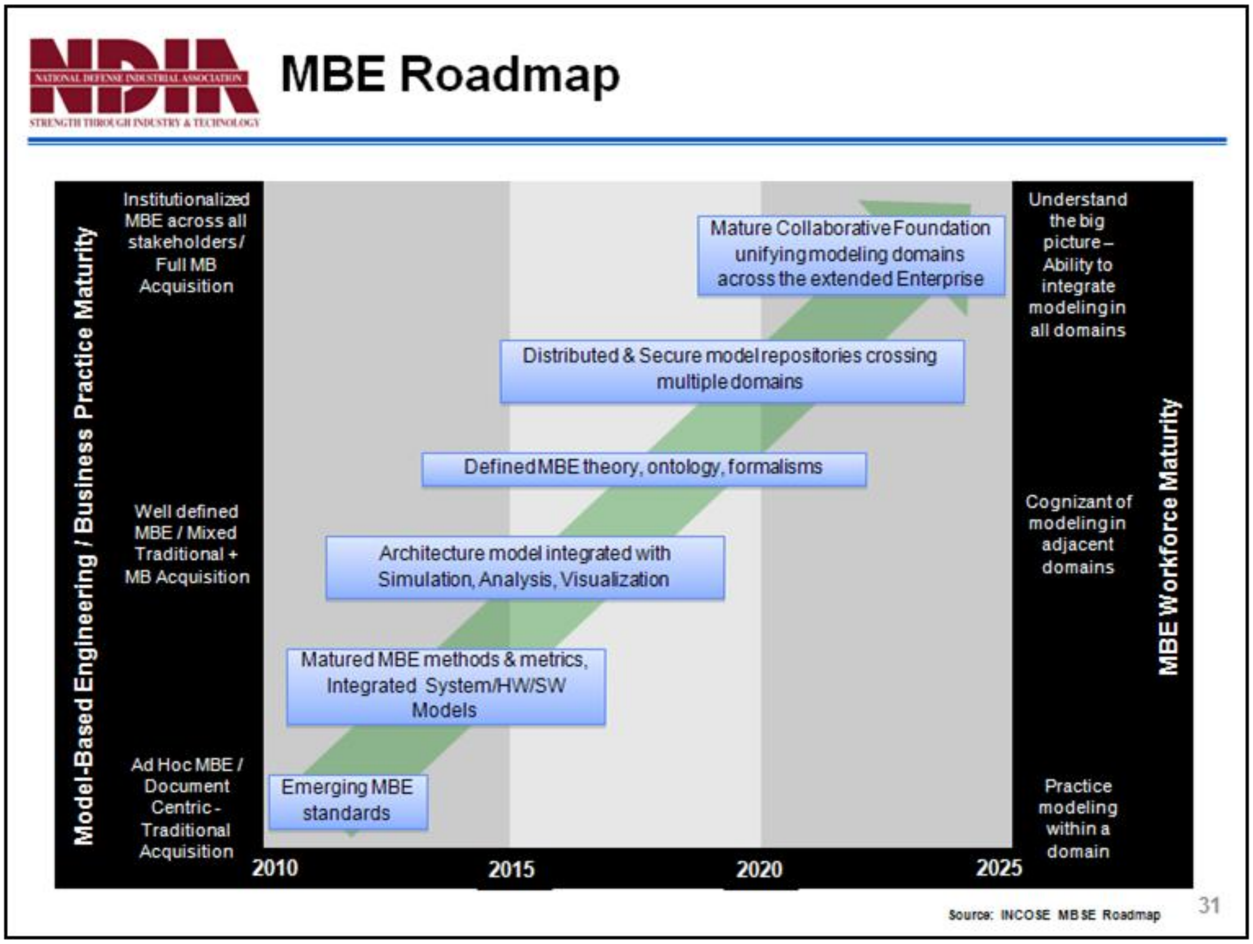
4. Training, alone, is not sufficient. The concepts of MBE can be quite complex, and individual staff members, and organizations, new to MBE will require mentoring. Tools and capabilities should be developed that support MBE collaboration. We believe Vendors can play an important role in providing mentoring services to the Government and Industry.

5. Knowledge must be captured on MBE successes and pitfalls. This captured knowledge can be incorporated into training programs, best practices, and MBE tool improvements that can be available to the MBE community.



MBE Roadmap

The MBE Roadmap represents the proposed maturity of MBE practice over time. The maturity of the practice reflects both how well the practice is defined, and the extent to which the practice has been adopted by industry. The roadmap is intended to help guide investment and resources from government, industry and academia to advance the practice of MBE and apply it to system acquisition. The suggested roadmap shown above is adapted from the MBSE roadmap developed by the International Council on Systems Engineering (INCOSE). The left vertical axis represents increase capability/maturity of MBE tools and processes. The right vertical axis represents increasing capability/maturity of a workforce versant in the MBE tools and processes. Note that there is significant overlap in the timing of the development activities shown as blue boxes in the diagram. It is intended that the steps along the maturation path happen largely concurrently rather than sequentially.

The path starts with emerging MBE standards. The extent to which a coherent MBE process is deployed to all stakeholders in the defense/aerospace industry largely depends on the development and adoption of adequate standards. Unambiguous communication of design intent across organizational boundaries via models must be based on a common understanding of key attributes. These will form the basis of a robust MBE system acquisition/development paradigm.

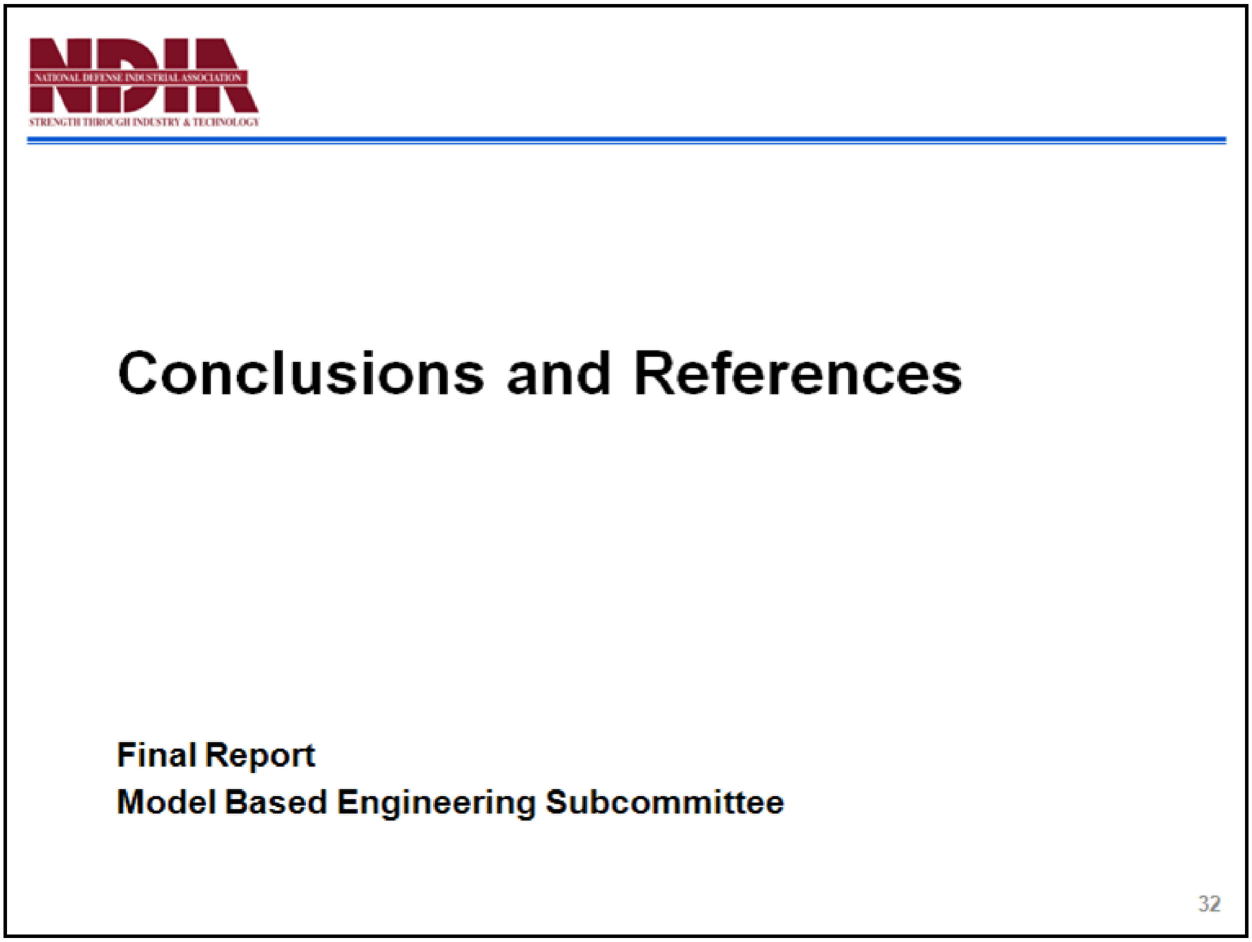
The next step involves maturing MBE tools and methods to incorporate more of the systems design lifecycle. As previously discussed, modeling techniques is relatively mature within distinct development disciplines. Significant development of the technologies necessary to integrate these domains into a consistent, analyzable system model is still required. This activity is a first step toward a fully integrated model. Model tools and processes in the avionics HW and SW are relatively mature and are being extended to incorporate more systems design elements. This is evident by development of technologies such as AADL and SysML, which build off formalisms such as VHDL (electronic hardware design) and UML (software design).

The next step builds on the integration of component models by placing them in the context of a coherent architectural model. Moving to an architecture-centric design process affords several benefits. Platform-Based Engineering (PBE) or Product Line Engineering can leverage existing, proven architectures in developing solutions for new missions. A central architecture which is used to generate specific views of the systems design (logical, physical, thermal, etc.) maintains a “single truth” for the system design, thus avoiding errors arising from mismatched assumptions between stove-piped design organizations. A coherent architecture further provides a means to maintain an integrated system throughout the design and test development phases. The key is to start a system design integrated and maintain the integration throughout development. This continuity implies that simulation and analysis of the system benefits from the current level of maturity of all components.

The activity defining MBE theory, ontology, and formalisms will lead to improved techniques to virtually integrate systems. This may potentially enable optimization of architecture-based designs for metrics such as complexity, cost, adaptability, or performance. It may lead to further capability to abstract complexity and produce correct-by-construction system designs reducing the need for current VV&A and/or T&E practices.

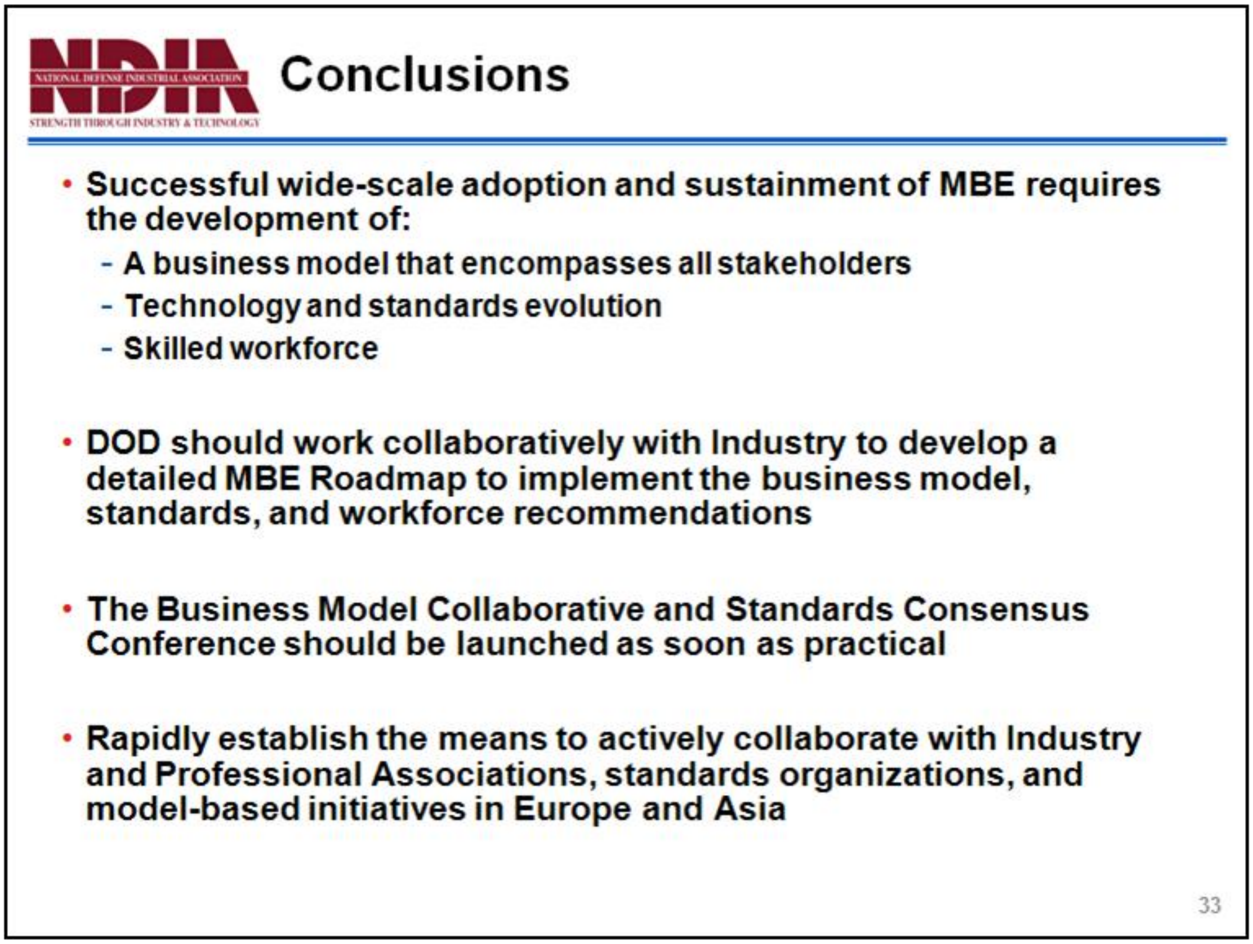
The next development is another step toward full integration, integrating formerly stove-piped design departments within a given organization. The standards, tools, and techniques necessary to unite the myriad of modeling efforts that already exist within an organization will allow system-level analyses and potentially uncover emergent system properties.

The final step represents a fully mature MBE process that is widely deployed and adopted by the relevant stakeholders. In this case, the boundaries of the integrated system model extend beyond the organizational boundaries. This facilitates accurate and precise communication of design intent from the end customer to the system integrator to lower level suppliers. It further allows analysis of system properties in a physically distributed, but logically integrated system model that is unified by a “single truth” system architectural model. This capability must exist in an infrastructure that simultaneously ensures controlled access and protection of intellectual property and secure data. Finally, this environment is support by legal and business policies and practices that motivate development of the capabilities.



Conclusions and References

The following subsections provide the conclusions reached by the MBE Subcommittee and a list of the documents, studies, reports, and regulations that were reviewed by the subcommittee.



Conclusions

MBE has the potential to provide significant benefits to the DOD and to Industry. These benefits will only be achieved if MBE becomes common practice across the life cycle for the acquisition and evolution of systems and solutions. The MBE Subcommittee strongly believes that successful wide-scale adoption and sustainment of MBE can only occur with:

- A business model that is supportive of all stakeholders
- The development and evolution of the technology and standards required by the MBE To Be state
- A workforce that is skilled in using MBE across the acquisition life cycle, to include acquisition/contracting skills, technical skills, and program management skills

The MBE Subcommittee believes that there are three near-term actions that can be taken to provide a solid foundation for future MBE activities. The first near-term action is for DOD, in collaboration with Industry, to develop a detailed MBE Roadmap that provides the plan of action and milestones for the implementation of the business model, standards, and workforce recommendations that are detailed in the Recommendations section of this report. The high-level roadmap provided in the Recommendations section of this report can be used as an initial guide for the development of the detailed MBE Roadmap.

The second near-term action is to launch, as soon as is practical, the Business Model Collaborative (see MBE Business Model recommendation 1) and the Standards Consensus Conference (see MBE Standards recommendation 1). The wide-scale use of MBE across the acquisition life cycle will necessitate adaptations within current business models and adaptations in current acquisition and engineering processes. It is critical to initiate the collaborative work to adapt and evolve the current models and processes at the beginning of the MBE initiative.

The third near-term action is for the DOD to rapidly establish the means to actively collaborate with companies, associations, and organizations that are actively engaged in model-based initiatives throughout the world. As noted in the description of the MBE Current State, several industries and associations in the US, Europe and Asia are actively involved in model-based activities and initiatives. Active collaboration with these companies and associations will allow the DOD to more easily leverage and adapt tools, technologies, methodologies, best practices, and lessons learned.

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