

# **Final Report**

## **Model Based Engineering (MBE) Subcommittee**

**Jeff Bergenthal (Subcommittee Lead)**

**NDIA Systems Engineering Division  
M&S Committee**

**February 2011**

- **Background**
- **Potential MBE Benefits, Costs, Risks**
- **Objective MBE Framework**
- **Policy, Guidance and Contracting Mechanism  
Impediments and Issues**
- **Recommendations**
- **Conclusions and References**

# Background

**Final Report**  
**Model Based Engineering Subcommittee**



## Grow engineering capabilities to address emerging challenges (con't)



Identify opportunities to leverage Model-based engineering practices to improve systems engineering productivity and completeness

- Do existing policies, guidance and contracting mechanisms hinder model-based collaboration?

Reinvigorate exploration and exploitation of Modeling and Simulation Systems Engineering enablers to assess and mitigate acquisition program risks

- Modeling & Simulation Committee to lead the initial investigation
- Coordinate work schedule with new Committee chair

- **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.

# 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)

- **Model-Based Engineering (MBE):** 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
- **Model:** A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. (DoD 5000.59 -M 1998)
- **Preferred MBE Practices:**
  - Models are scoped to purpose/objectives
  - Models are appropriate to the context (e.g., application domain, life cycle phase)
  - The models represent the technical baseline that is delivered to customers, suppliers, and partners
  - Models are integrated or interoperable across domains and across the lifecycle
- **Core to MBE is the integration of descriptive/design models with the computational models**

# Characteristics of Models Used in MBE

- **Models apply to a wide range of domains (e.g., systems, software, electrical, mechanical, human behavioral, logistics, manufacturing, business, socio-economic, regulatory)**
- **Computer-interpretable computational model**
  - Time varying (e.g., performance simulations, structural dynamic analysis)
  - Static (e.g., reliability prediction model)
  - Deterministic or stochastic (e.g., Monte Carlo)
  - May interact with hardware, software, human, and physical environment
  - Includes input/output data sets
- **Human-interpretable descriptive models (e.g., architecture/design such as UML, SysML, UPDM, IDEF, electrical schematic, 3D CAD geometry, DODAF 2.0)**
  - Symbolic representation with defined syntax and semantics
  - Repository based (i.e., the model is stored in structured computer format)
- **Supporting metadata about the models including assumptions, versions, regions of validity, etc.**
- **MBE can also include the use of physical models (e.g., scale models for wind tunnels or wave tanks)**

# Potential MBE Benefits, Costs, Risks

**Final Report**  
**Model Based Engineering Subcommittee**

# High-Level MBE Benefits

- **Reduce time to acquisition of first article for systems and solutions**
  - More complete evaluation of the trade space
  - Earlier risk identification and mitigation
  - Concurrent and collaborative engineering
  - Design reuse
  - Accelerated development
- **Reduce the time to implement planned and foreseen changes in systems**
  - Design reuse
  - Rapidly evaluate changing threats and explore trade space
- **Enhance Reliability**
  - Earlier and continuous requirements and system verification
  - Identify and resolve errors / issues earlier → fewer post-fielding issues
- **Enhance Interoperability**
  - Inclusion of the operating environment and external interfaces in system models
  - Early and continuous interface and interoperability verification

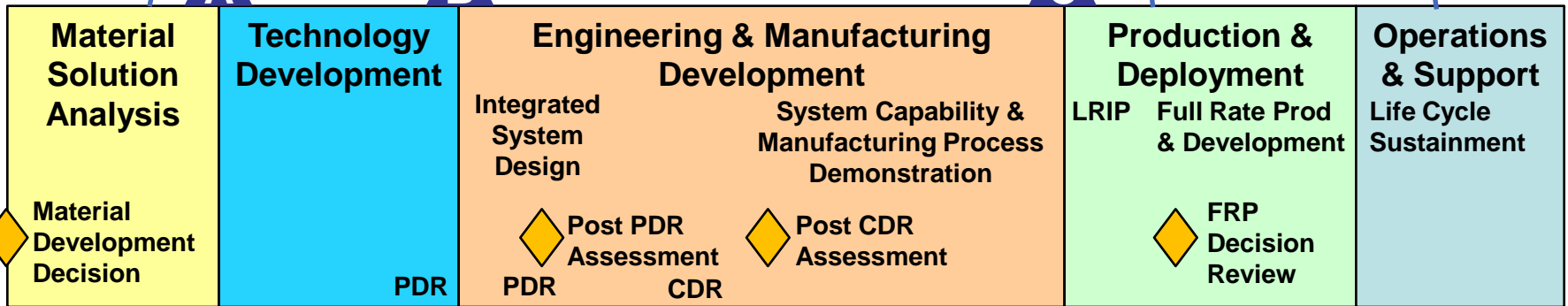
***... and Each of These Benefits Enhance Affordability***

# MBE Benefits Across the Acquisition Life Cycle

- More complete evaluation of trade space [8, Boeing 787]
- Improved communications across stakeholders [6, 8]
- Earlier evaluation of manufacturing feasibility [2]

- Rapidly evaluate changing threats and explore solution space [8]
- Design Reuse [6, 7]
- Lower costs with complex product families [5]

- Reduced manufacturing related costs and schedule [2]

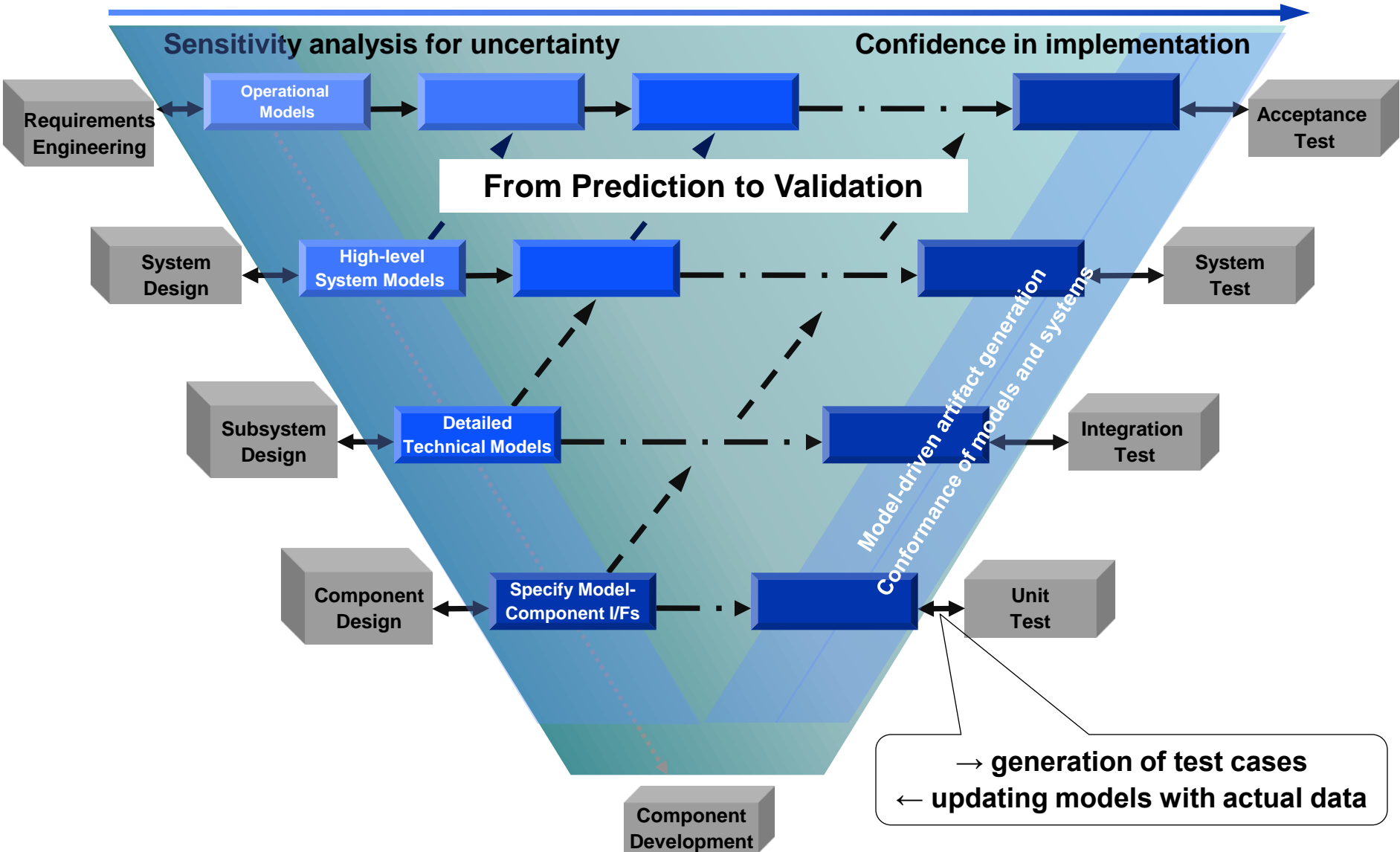


Pre-Systems Acquisition | or | Systems Acquisition

- Improved requirements [3, 4, 6, 7]
- Earlier risk identification and mitigation [2, 4, 7]
- Early evaluation of manufacturing processes [2]
- More complete evaluation of trade space [8, Boeing 787]

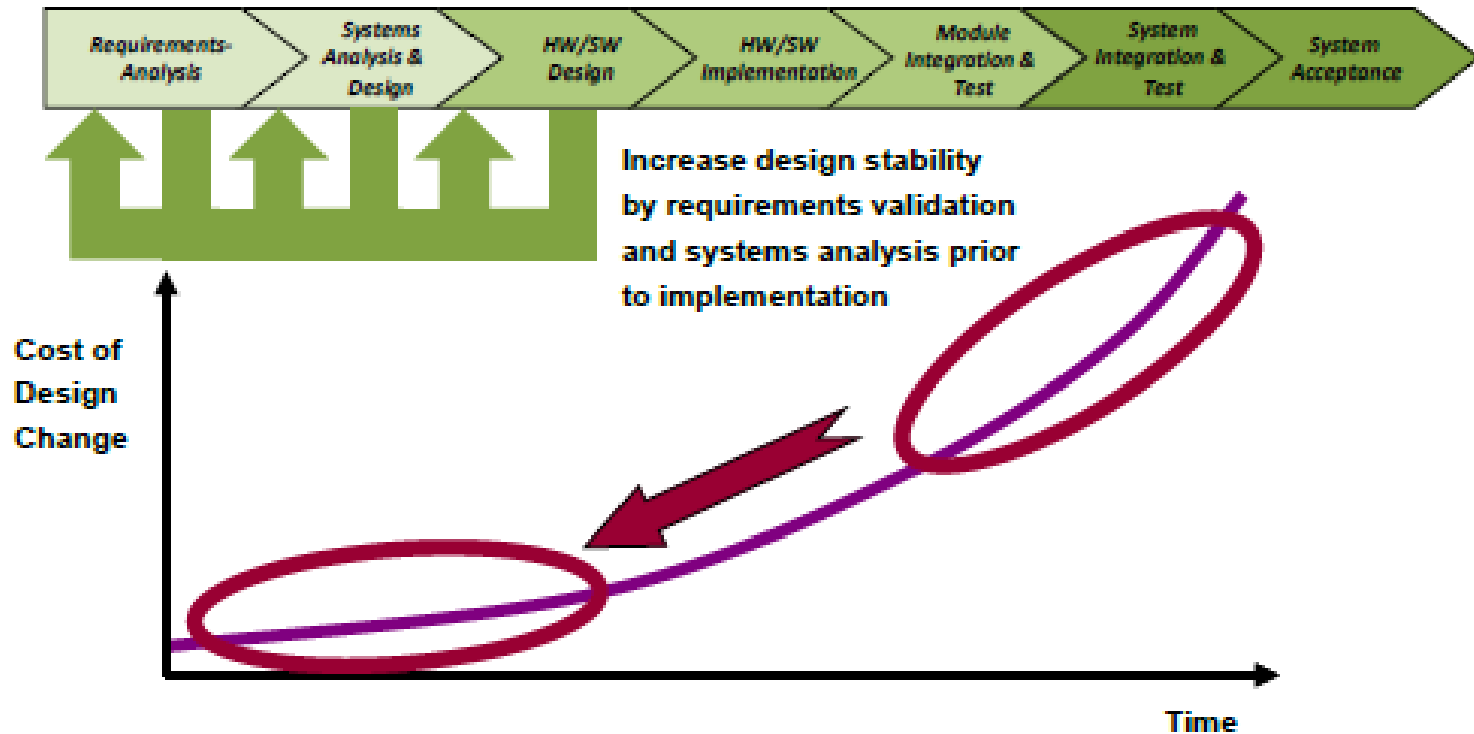
- Earlier risk identification and mitigation [2, 4, 7]
- Concurrent and collaborative engineering [2, 3, 4, 7]
- Reduced defects and re-work costs [1, 3, 4, 7]
- Accelerated development schedule [1, 6, 7]
- Improved system and software reliability and quality [6, 7, 8]
- Design reuse [6, 7]

# Virtual Integration to Manage Risk Throughout The Life Cycle



# Risk and Cost Reduction Through Earlier Verification

Performing requirements and design verification as early as possible, as opposed to waiting until “composition” activities begin, reduces cost and schedule risks.



# Potential MBE Costs and Risks

---

- **Initiating an MBE approach will require investment in tools, training, and infrastructure**
  - MBE must be institutionalized to be cost effective
  - The initial investment may be prohibitive if only used on one project
- **MBE approaches and tools will not replace strong, rigorous, and disciplined enterprise processes**
  - They must be integrated with the processes
- **Training is necessary, but not sufficient**
- **Must address stove-piped responsibilities**
  - Model artifacts will cross organizational / discipline boundaries
  - Requires a strong interdisciplinary team to support concurrent engineering processes and practices

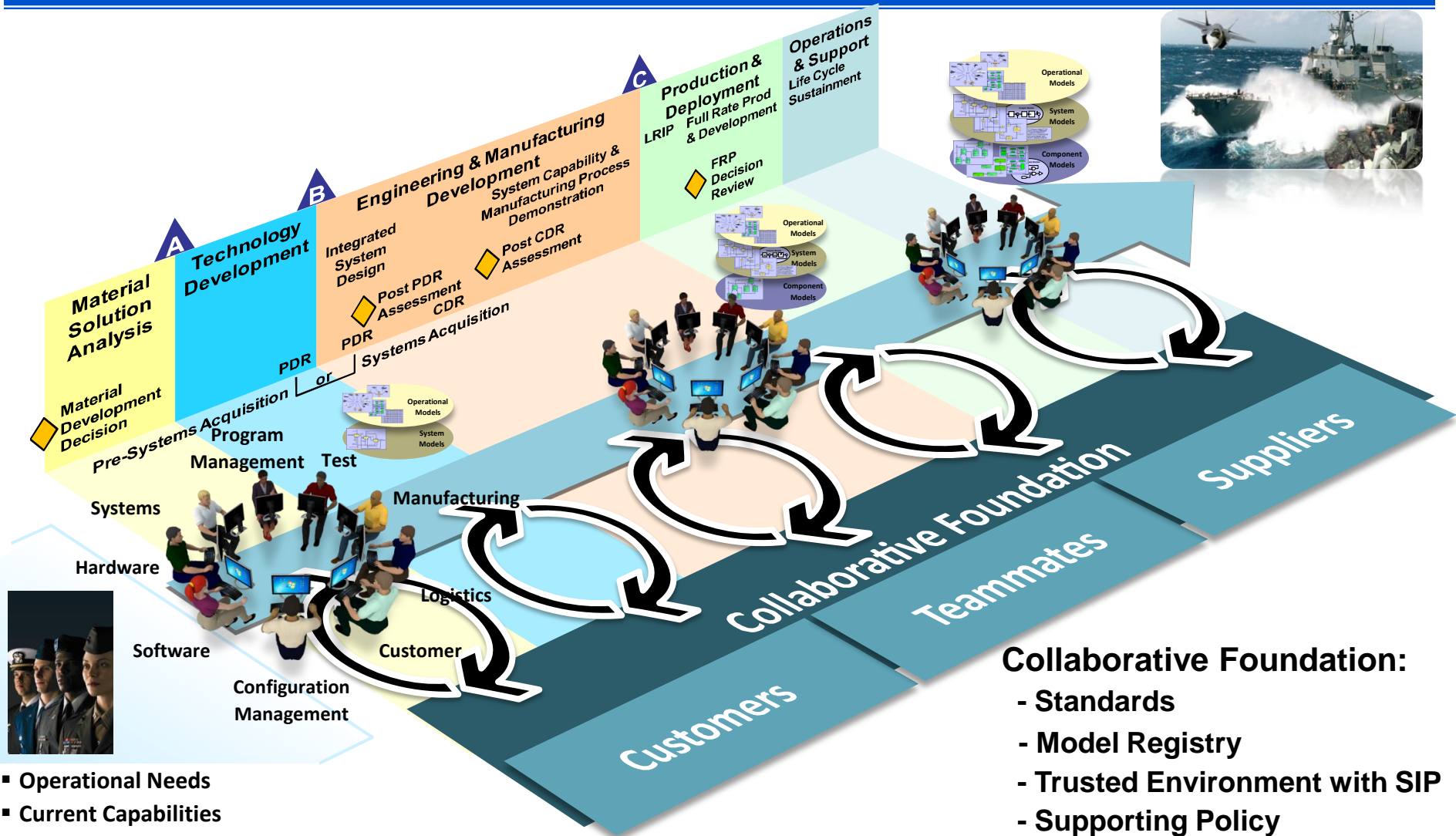
# Objective MBE Framework

**Final Report**

**Model Based Engineering Subcommittee**

- **Poor integration of models across the life cycle**
- **Limited reuse of models between programs**
- **Variation in modeling maturity and integration across Engineering Disciplines (e.g., systems, software, mechanical, electrical, test, maintainability, safety, security)**
  - **Mechanical/Electrical CAD/CAE fairly mature**
  - **Systems/Software/Test fairly immature**
- **Many MBE related activities across Industry, Academia, and Standards Bodies**
- **Evolving modeling standards (e.g., CMSD, Modeling Languages such as SysML, UPDM, Modelica, AADL)**
- **Tools are evolving towards an MBE paradigm and progressing towards greater tool to tool interoperability**

# MBE To-Be State



- Operational Needs
- Current Capabilities
- Budget/Schedule

***MBE Enhances Affordability, Shortens Delivery and Reduces Risk Across the Acquisition Life Cycle***

# 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**

# **Policy, Guidance and Contracting Mechanism Impediments and Issues**

**Final Report**

**Model Based Engineering Subcommittee**

# Preliminary Policy Findings

---

- **Existing OSD and service policies are consistent with, and generally supportive of, the aims and approach to MBE**
- **Use of models and digital products in MBE will require some new policies, regulations, and contracting practices**
  - **To represent an authoritative technical baseline**
  - **To describe requirements and provide the basis for assessing contractual compliance**
  - **To be shared between government and industry teams**
  - **In a secure collaborative environment**

# Required Policy and Regulations to Enable MBE (1 of 3)

---

- **Interface standards and common data formats are needed to:**
  - **Ensure interoperability between models, databases, etc.**
  - **Enable collaboration between industry teams and government**
- **Procedures must be developed for:**
  - **The electronic archiving of solicitation (and contract) documents**
  - **The storage and maintenance of interim and final MBE products (with their corresponding viewing technologies)**

## Required Policy and Regulations to Enable MBE (2 of 3)

---

- **Sunset provisions are needed for models and other Information Technology infrastructure (hardware and software applications) in order to support MBE activities in the long run**
- **DFARS provisions should be updated to ensure that:**
  - **Digital MBE products are incorporated as binding contract clauses**
  - **Technical data and software embedded in models (and other digital products) are handled appropriately even when delivered with less than government purpose rights**

## Required Policy and Regulations to Enable MBE (3 of 3)

---

- **Conventions for encryption and digital signatures are needed to establish the authenticity, integrity and confidentiality of individual digital MBE products**
- **Policies will be needed to determine who can access digital products from the MBE registry (and the repositories that the registry directs them to) and under what circumstances**
- **Policies are needed to determine compliance with “machine-readable” specifications for contract deliverables**

# Recommendations

**Final Report**  
**Model Based Engineering Subcommittee**

# 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 chartered 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

# 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

# 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

# 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 DDR&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

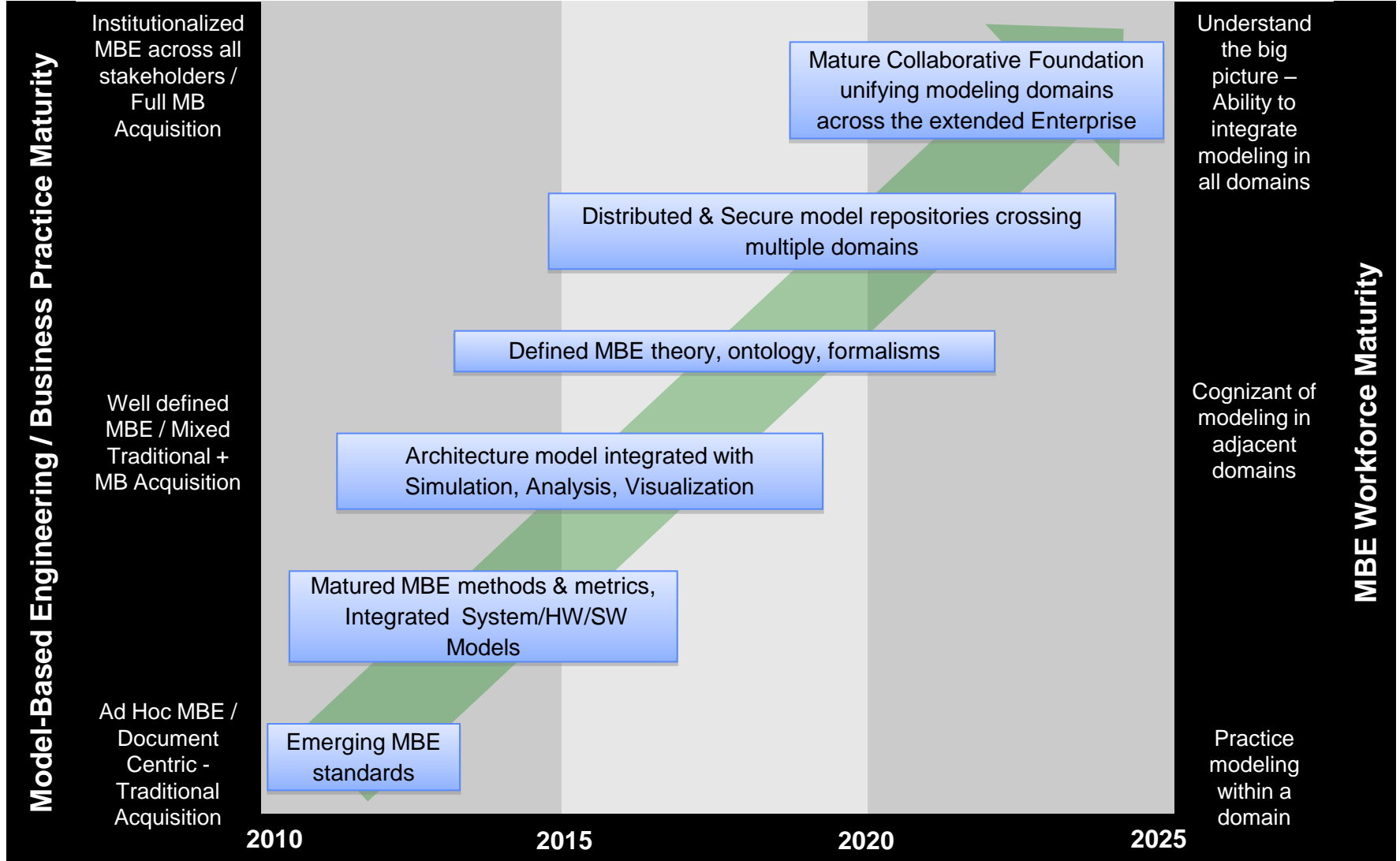
# Develop the Workforce (1 of 2)

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

# 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

# MBE Roadmap



# Conclusions and References

**Final Report**  
**Model Based Engineering Subcommittee**

# Conclusions

---

- **Successful wide-scale adoption and sustainment of MBE requires the development of:**
  - **A business model that encompasses all stakeholders**
  - **Technology and standards evolution**
  - **Skilled workforce**
- **DOD should work collaboratively with Industry to develop a detailed MBE Roadmap to implement the business model, standards, and workforce recommendations**
- **The Business Model Collaborative and Standards Consensus Conference should be launched as soon as practical**
- **Rapidly establish the means to actively collaborate with Industry and Professional Associations, standards organizations, and model-based initiatives in Europe and Asia**

# References and Literature Surveyed

---

1. **Proof-of-Concept Project AFE #58 Summary Final Report *produced under the System Architecture Virtual Integration (SAVI) Program* 8 October 2009**
2. **Modeling & Simulation Investment Needs for Producible Designs and Affordable Manufacturing, Systems Engineering Implications; NDIA JCSEM M&S Sub-Committee Final Report, February 2010**
3. **Software Intensive Systems, Naval Research Advisory Committee Report, July 2006**
4. **Preliminary Observations on DoD Software Research Needs and Priorities: A Letter Report, Committee on Advancing Software-Intensive Systems Producibility, National Research Council, 2008**
5. **Complex Product Family Modeling for Common Submarine Combat System MBSE, Lockheed Martin July 2010**
6. **Deployment of MBSE Processes Using SysML, US Army ARDEC and HPTI, presentation at the 2010 NDIA Systems Engineering Conference, October 2010**
7. **Use of a Model Based Approach to Minimize System Development Risk and Time-to-Field for New Systems, US Army AMRDEC SED, presentation at the 2010 NDIA Systems Engineering Conference, October 2010**
8. **Systems-2020 Study, Final Report, Booz Allen Hamilton, 16 August 2010**
9. **Systems 2020 Strategic Initiative Overview Briefing, Office of the Director, Defense Research and Engineering, presentation at the NDIA SE Division M&S Committee Meeting, June 2010**

10. **Development of 3-Year Roadmap to Transform the Discipline of Systems Engineering, Systems Engineering Research Center, SERC-2009-TR-006, 31 March 2010**
11. **Technology Tools for Rapid Capability Fielding: Final Outbrief, Office of the Director, Defense Research and Engineering, presentation at the NDIA SE Division M&S Committee Meeting, April 2010**
12. **The Economic Impacts of Inadequate Infrastructure for Software Testing, National Institute of Standards and Testing, Planning Report 02-3, May 2002**
13. **21<sup>st</sup> Century Strategic Technology Vectors, Volume IV – Accelerating the Transition of Technologies into US Capabilities, Defense Science Board 2006 Summer Study, April 2007**
14. **Toward Model-Based Embedded System Validation Through Virtual Integration, DOD Software Tech News, Volume 12, Number 4, January 2010**
15. **Model Based Engineering for Medical Device Software, Ray, et. al., 2008**
16. **Model Based Engineering Design Pilots at JPL , Kordon, et. al., Proceedings of the 2007 IEEE Aerospace Conference**
17. **Simulation Based Engineering Science, Revolutionizing Engineering Science through Simulation, Report of the National Science Foundation Blue Ribbon Panel on Simulation Based Engineering Science, May 2006**
18. **INCOSE MBSE Initiative Summary, S. Friedenthal, presentation at the NDIA SE Division M&S Committee Meeting, June 2010**
19. **Core Manufacturing Simulation Data Product Development Group, S. Leong, presentation at the NDIA SE Division M&S Committee Meeting, June 2010**

20. Department of Defense Directive 5000.01, The Defense Acquisition System, certified current as of 20 November 2007
21. Department of Defense Instruction 5000.02, Operation of the Defense Acquisition System, 8 December 2008
22. Chairman of the Joint Chiefs of Staff Instruction 3170.01G, Joint Capabilities Integration and Development System, 12 October 2010
23. Defense Acquisition Guidebook, 12 October 2010
24. Modeling and Simulation Guidance for the Acquisition Workforce, Office of the Deputy Under Secretary of Defense for Acquisition and Technology, October 2008
25. Army Regulation 70-1, Army Acquisition Policy, 31 December 2003
26. Department of the Army Pamphlet 70-3, Army Acquisition Procedures, 1 April 2009
27. Air Force Policy Directive (AFPD) 63-1/20-1, Acquisition and Sustainment Life Cycle Management, 3 April 2009
28. Air Force Instruction (AFI) 16-1002, Modeling and Simulation (M&S) Support to Acquisition, 1 June 2000
29. AFI 63-1201, Life Cycle Systems Engineering, 23 July 2007
30. AFI 63-101, Acquisition and Sustainment Life Cycle Management, 17 April 2009 (Incorporating Through Change 2, 16 June 2010)
31. Air Force Pamphlet 63-128, Guide to Acquisition and Sustainment Life Cycle Management, 3 October 2009

32. **SECNAV M-5000.2, Department of the Navy Acquisition and Capabilities Guidebook, December 2008**
33. **SECNAVINST 4105.B, Independent Logistics Assessment and Certification Requirements, 18 December 2008**
34. **SECNAVINST 5000.2D, Implementation and Operation of the Defense Acquisition System and the Joint Capabilities Integration and Development System, 16 October 2008**
35. **SECNAVINST 5400.15C, Department of the Navy Research and Development, Acquisition, Associated Life-Cycle Management and Logistics Responsibilities and Accountabilities, 13 September 2007**
36. **SECNAVINST 5430.7Q, Assignment of Responsibilities and Authorities in the Office of the Secretary of the Navy, 17 August 2009**
37. **Department of the Navy Acquisition Plan Guide, March 2007**
38. **Navy Marine Corps Acquisition Regulation Supplement (NMCARS), 13 July 2010**
39. **OPNAVINST 3811.1D, Threat Support to Weapon and Information Technology Systems Planning and Acquisition, 5 June 2008**
40. **SECNAVINST 5200.38A, Department of the Navy Modeling and Simulation Management, 28 February 2002**
41. **SECNAVINST 5000.36A, Department of the Navy Information Technology Applications and Data Management, 19 December 2005**
42. **DON Policy on Digital Product/Technical Data, 23 October 2004**