Leading the Transformation of Model-Based Engineering: The Model-Based Capability Matrix

Al Hoheb
The Aerospace Corporation
albert.c.hoheb@aero.org

Joe Hale
NASA/MSFC (retired)
givem@comcast.net

MBSE Leaders Solve Problems
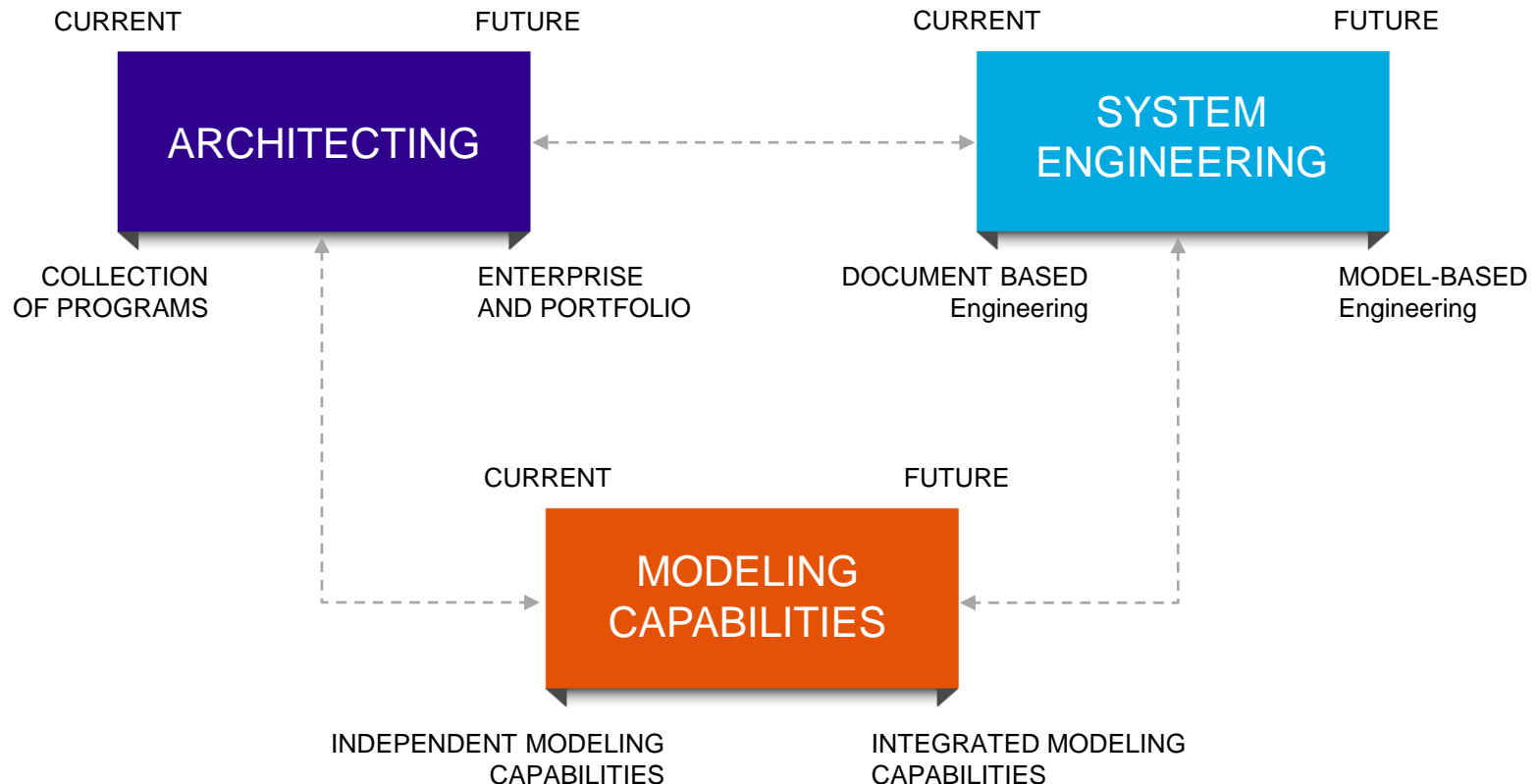
- What are my modeling objectives?

- How can we characterize the capabilities needed and their evolution?
- How do I know I've characterized all the capabilities?
- What capabilities do my enterprise stakeholder organizations need?
- What capabilities should my effort Manager, System Engineer, Specialists, Information Technologist, Modelers, Human Resource, and Contracts staff need?
- What are the "norms" from other organizations?

- Initiate an effort that is proven?
- What kind of plan do I need to transform the organizations?
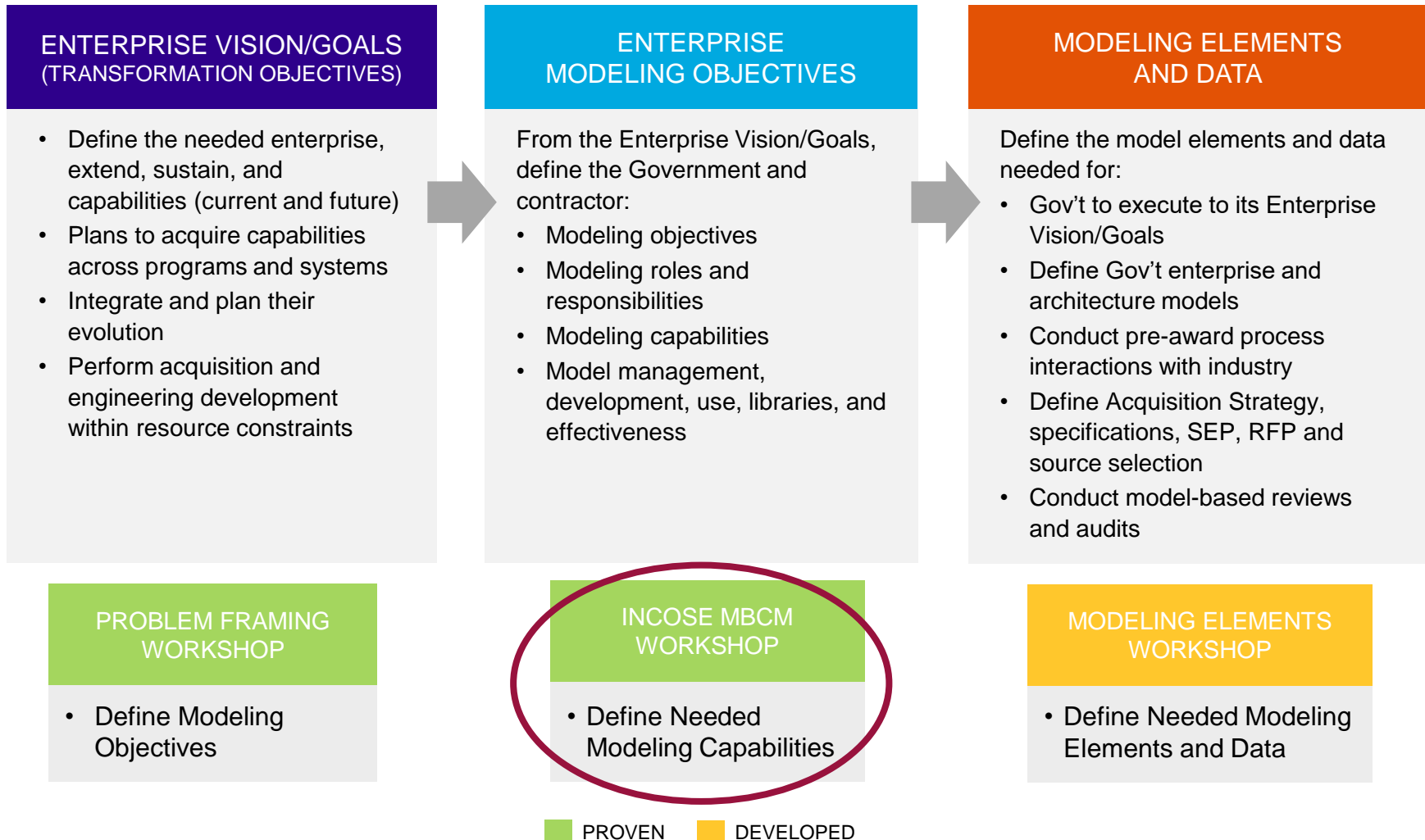
Leaders are faced with jargon/ideas, to be made sense of, before decisions are made

Organization Transformation Needs Drive the Modeling Effort

CURRENT   FUTURE   CURRENT   FUTURE

ARCHITECTING   **SYSTEM ENGINEERING**

COLLECTION OF PROGRAMS   ENTERPRISE AND PORTFOLIO   DOCUMENT BASED Engineering   MODEL-BASED Engineering

CURRENT   FUTURE

MODELING CAPABILITIES

INDEPENDENT MODELING CAPABILITIES   INTEGRATED MODELING CAPABILITIES

Integrated modeling capabilities are necessary for both architecting and System Engineering

Model-Based Implementation Approach

ENTERPRISE VISION/GOALS (TRANSFORMATION OBJECTIVES)	ENTERPRISE MODELING OBJECTIVES	MODELING ELEMENTS AND DATA
• Define the needed enterprise, extend, sustain, and capabilities (current and future) • Plans to acquire capabilities across programs and systems • Integrate and plan their evolution • Perform acquisition and engineering development within resource constraints	From the Enterprise Vision/Goals, define the Government and contractor: • Modeling objectives • Modeling roles and responsibilities • Modeling capabilities • Model management, development, use, libraries, and effectiveness	Define the model elements and data needed for: • Gov't to execute to its Enterprise Vision/Goals • Define Gov't enterprise and architecture models • Conduct pre-award process interactions with industry • Define Acquisition Strategy, specifications, SEP, RFP and source selection • Conduct model-based reviews and audits

PROBLEM FRAMING WORKSHOP	INCOSE MBCM WORKSHOP	MODELING ELEMENTS WORKSHOP
• Define Modeling Objectives	• Define Needed Modeling Capabilities	• Define Needed Modeling Elements and Data

🟩 PROVEN   🟧 DEVELOPED

Workshops provide proven and repeatable methods to ensure comprehensive solutions

Model-Based Capabilities Matrix CONOPS

Per the User's Guide

Identify the Enterprise, Program, or System Transformation Objectives

Pre-work to apply the matrix

Use the Matrix to identify the organization current and needed MBSE capabilities to meet the Transformation Objectives

"Half-day workshop"

Use Matrix results to plan the MBSE capabilities needed to meet the Transformation Objectives

- Organization's transformation Plan
- Plan new capabilities
- Enhance processes
- Assess during a review
- Org DE compliance Plan
- SEP/SEMP
- Multi-year roadmap
- Pre-source selection Acquisition strategy
- Qualifying sources
- MBSE roles and responsibility definition

A workshop provides a proven approach to apply the matrix

What is the INCOSE Model-Based Capabilities Matrix?

- It is an assessment tool used to characterize an organization's current and desired model-based capabilities
  - In its simplest form, a **capability statement** is a **statement** about your organization and its **capabilities** and skills that defines what its able to do by employing model-based effort
- A capability:
  - Produces an outcome
  - Activated by resources
  - Has both and input and output
  - Changes over the life cycle
- The Matrix has identified 42 unique and necessary capabilities
  - Provided as an Excel spreadsheet
  - Can be tailored to suite needs
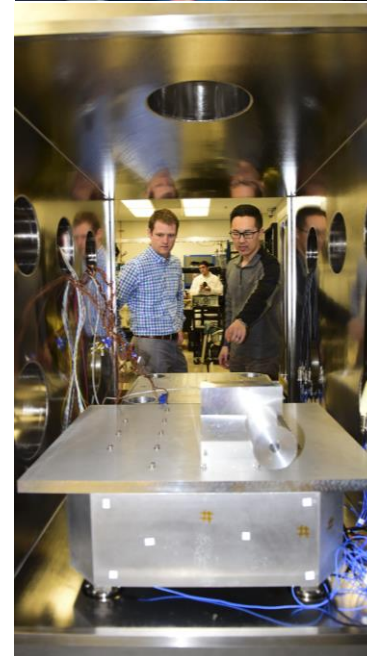
Model-Based Capabilities Matrix Structure

- Rows: Organization modeling capabilities for an organization (42 Capabilities)
  - Area/Role-Based view or Digital Engineering (DE) goal view – same capabilities
  - Each view has the capabilities sorted by the role-based or DE goal key field

- Columns: Increasing Stages of Capability generally defined as:
  - **Stage 0:** No MBSE capability or MBSE applied ad hoc to gain experience
  - **Stage 1:** Modeling efforts are used to address specific objectives and questions
  - **Stage 2:** Modeling standards are applied; ontology, languages, tools,
  - **Stage 3:** Program/project wide capabilities; model integrated with other functional disciplines, digital threads defined and digital twin
  - **Stage 4:** Enterprise wide capabilities: contributing to the enterprise, programs/projects use enterprise defined ontologies libraries, standards

CAPABILITY STATEMENTS	STAGE 0	STAGE 1	STAGE 2	STAGE 3	STAGE 4
CAP 1					
CAP 2					
CAP 3					
CAP 4					

INCOSE Model-Based Capabilities Matrix

DoD DE Strategy	Model-Based Capability	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4
Goal 1. Use of Models	MBSE Use Strategy	No documented MBSE use strategy, or the strategy is described for ad hoc efforts. Each MBSE effort is stand-alone to address specific concerns.	Organization MBSE use strategy is documented as part of its overall organizational strategy at the system level. The strategy is related to the overall risk strategy.	Organization MBSE use strategy is documented as part of the organization's overall strategy at the enterprise level. The strategy is related to the overall risk strategy. Modeling results used to inform systems engineers across system engineering phases and for all disciplines.	Organization MBSE use strategy is documented as part of the organization's overall strategy at the enterprise level. The strategy is related to the overall risk strategy. Modeling is integrated with business information tools and results used to inform systems engineers, program management, and all staff across the enterprise.	Organization MBSE use strategy is documented as part of the organization's overall strategy at the enterprise level. The strategy is related to the overall risk strategy. Modeling is integrated with business information tools and results are used to inform systems engineers, program management, and all staff across the enterprise. It manages a full range
Goal 1. Use of Models	Common DE and MBSE Terminology	Appropriate terminology defined for the project or program.	Common Glossary/Data Dictionary.	Top Tier terminology is defined for the enterprise.	Discipline and engineering specialty terminology is added to cover lower level models.	Common, tiered taxonomies are defined and consistent across enterprises and consistent with accepted community standards.
Goal 1. Use of Models	SE Agreement Process	Modeling is not incorporated as part of the agreement processes.	Given a clear business case, modeling is applied in an ad hoc manner across projects or programs.	Given a clear business case, modeling is applied in a consistent manner across projects or programs.	Consistent model business case descriptions are being practiced across an enterprise.	Consistent model business case driven planning guidance is in place and is being practiced across an
Goal 1. Use of Models	SE Organizational Project-Enabling Processes	Modeling is not incorporated as part of the Organizational Project Enabling processes.	Given a clear business case, modeling is applied in an ad hoc manner across projects or programs.	Given a clear business case, modeling is applied in a consistent manner across projects or programs.	Consistent model business case descriptions are being practiced across an enterprise.	Consistent model business case driven planning guidance is in place and is being practiced across an enterprise.
Goal 1. Use of Models	SE Technical Management Processes	Modeling is not incorporated as part of the Technical Management processes.	Modeling is part of the processes to improve quality and models contribute to the authoritative source of truth.	Modeling is the basis for the processes. Digital artifacts are used to make SE Technical Management decisions.	Modeling is the basis for the processes and is used to optimize results across the project or program.	Modeling is the basis for the processes and is used to optimize results across the enterprise.
Goal 1. Use of Models	Model Configuration Management	Model Configuration management is ad hoc.	Model configuration management is an assigned role.	Model configuration management adheres to a standard.	Model configuration management is applied to all models for a system.	Model configuration management is applied to all models for an enterprise.
Goal 1. Use of Models	Model Data Management	Model Data Management is ad hoc.	Model data management is an assigned role.	Model data management adheres to a standard.	Model data management is applied to all models for a system.	Model data management is applied to all models for an enterprise.
Goal 1. Use of Models	SE Technical Processes	Modeling is not incorporated as part of the Technical processes.	Modeling is part of the processes to improve quality and models contribute to the authoritative source of truth.	Modeling is the basis for the processes with digital threads covering some of the processes. Digital artifacts are used to make SE decisions.	Modeling is the basis for the processes with digital threads covering all selected processes. Digital artifacts and digital twins are used to make SE	Modeling is the basis for the processes with digital threads covering all processes. Digital artifacts, and digital twins are used to make SE decisions.
Goal 1. Use of Models	Modeling Stakeholder Requirements	Stakeholder requirements are not modeled.	Stakeholder requirements are in a requirements management tool.	Stakeholder requirements in a management tool are linked to enterprise and system models and are bi directional traceable. The requirements are linked model data that provide digital artifacts spanning the life cycle and depth of design information.	Enterprise and system stakeholder requirements are bi directional traceable.	Stakeholder requirements are traceable across enterprises.
Goal 1. Use of Models	Model-Based Verification and Validation	No plan for verifying or validating requirements in the models.	Plan for verifying and validating requirements in the models.	Verification and validation plan relies on model contents and analysis via requirements "analysis."	Modeling development processes have been established, modeling patterns, styles, and standards have been defined, and standard V&V procedures and programs have been formulated	Modeling development processes have been established, modeling patterns, styles, and standards have been defined, and standard V&V procedures and programs have been formulated
Goal 1. Use of Models	SE-driven Model Plan	No documented MBSE plan.	Models are developed for parts of the system engineering or enterprise engineering processes or for only parts of the life cycle. Appropriate tools, environments, methods, and resources are provided.	Full System/Enterprise Models are developed and applied variously across the product life cycle and across Systems Engineering organizations. Appropriate tools, environments, methods, and resources are provided.	Multiple System Models are integrated for the enterprise. Consistent tool coverage and use within separate Systems Engineering Organizations. Appropriate tools, environments, methods, and resources are provided.	Consistent tool coverage within separate Systems Engineering Organizations across the enterprise. Multiple enterprise models are interfaced within or across mission areas. Appropriate tools, environments, methods, and resources are
Goal 1. Use of Models	Model Based Reviews; Management Program Reviews /MPR(s), Milestone reviews, program reviews, technical reviews, audits	Reviews are not model based. Review and audit is set by calendar date against a contract event such as contract award. Digital artifacts aren't planned for use to satisfy entry/exit criteria.	Identification of model-based digital artifacts to satisfy entry/exit criteria. Model results called out explicitly as products with defined product quality. Use of digital artifacts allow for some criteria items to be addressed prior to the event.	Review process is still a scheduled event with known entrance and exit criteria as well as frozen baselines. Use of digital artifacts allow for some criteria items to be addressed prior to the event. Model-based digital artifacts to satisfy criteria along with linked narrative. Model content is identified that satisfies criteria are linked to external list of criteria	Review and audit is set by model data and information availability. Review process allows for more flexible reviews so that some criteria are acknowledged and accomplished before the scheduled review. Predominantly model-based digital artifacts with as-needed documents to satisfy criteria with linked narrative.	Enterprise organizations coordinate on common review criteria application, tailoring, and the use of specific digital artifacts to meet specific criteria. Models record the acceptance of criteria items. Rolling, frequent reviews of model contents of identified "Knowledge Points" allow stakeholders to accept that the review is complete for that
Goal 1. Use of Models	Model Metrics	Metrics are not used to manage the model development, quality, or effectiveness.	Available metrics are reported from the various modeling tools used.	Metrics, beyond those available from the tool configuration, are reported to address model development, quality, and effectiveness needs.	Metrics are used to manage the model development, quality, or effectiveness for a system or enterprise.	Consistent metrics are used across the enterprise to manage the model development, quality, or effectiveness with trend information kept and
Goal 1. Use of Models	Modeling Integration	Elements within a model are not integrated.	Elements within a model follow a structured approach (such as OOSEM).	Model elements not needed and that don't fit within the structured approach are removed. Model constraints are identified and model blocks	Integration across systems models for a project/program use the same structured approach. A Library of reusable SysML blocks is created and	Integration across systems models for an enterprise use the same structured approach. A Library of reusable SysML blocks is created and
Goal 1. Use of Models	Verification and Validation of Models	The organization has not stated model objectives -- no basis for verification and validation of the models.	The organization has stated model objectives but not model requirements. Partial V&V evaluation of the resultant model is possible.	Model objectives and some general model requirements have been stated. Plans for V&V evaluation of the model traceable to the model requirements have been made.	Model objectives and some detailed model requirements for specific models have been stated. V&V evaluation of the models traceable to the model requirements is planned and includes V&V of modeling patterns, styles and standards, as well as having defined procedures.	Modeling development processes have been established, modeling patterns, styles, and standards have been defined, and standard V&V procedures and programs have been formulated (including associated automated scripts and tools). V&V of the models is performed and updates to the
Goal 1. Use of Models	Modeling Assurance	Model Assurance is not considered.	Model assurance is defined with known scales and methods.	Model assurance targets are identified in association with the effort schedule and cost.	Model assurance measurement and corrective actions are conducted for projects/programs.	Model assurance measurement and corrective actions are conducted for the enterprise.
Goal 1. Use of Models	Model Management	Model management is ad hoc.	Model management is an assigned role.	Model management adheres to a standard or to a defined approach.	Model management is applied to all models for a system.	Model management is applied to all models for an enterprise.
Goal 1. Use of Models	Distributed Database/Tool interoperability	No interoperability between model based tools.	Model Based Tool-to-Tool has ad hoc interoperability.	Partial Federated Database Management System (FDBMS).	Main tools interoperable. Supporting tools interact through file transfer.	Fully Federated with standard "plug-and-play" interfaces. Data is interchanged among tools.
Goal 1. Use of Models	Model Based Data/Tool	Data/Tool independences are not considered and	Data/Tool independences are considered and	Data/Tool implementations independences are	Data/Tool implementations independences are	Data is independent of tools and allows for

Tabs: Role-Based MBCM | MBCM-RB Capabilities | **DE-Based MBCM** | MBCM-DE Capabilities | OSD DE Strategy Goals | +

42 capabilities, each with 0-4 stages to characterize them, prints on 2 sheets of 11x17 inch paper

Matrix Detail for One Capability Row

DOD DE STRATEGY GOAL	MODEL-BASED CAPABILITY NAME	STAGE 0	STAGE 1	STAGE 2	STAGE 3	STAGE 4
Goal 1. Use of Models	Model Management	Model management is ad hoc	Model management is an assigned role	Model management adheres to a standard or to a defined approach	Model management is applied to all models for a system.	Model management is applied to all models for an enterprise.

CAPABILITY DESCRIPTION

Model management establishes policy to manage model development, model configuration management, model collection activities, model valuation, acquisition and strategic model loans, and for ensuring the proper application

Matrix Excel File Capability Definitions

- When using the matrix it's helpful to have the Capability Descriptions

- The Matrix Excel File has tabs to view/print the descriptions
  - *Area/Role view of the Matrix*
  - *Digital Engineering Strategy view of the Matrix*

- Print them to add context when applying the Matrix
  - *ISO/IEC/IEEE 15288 documents*

Current Use

GOVERNMENT ORGANIZATIONS THAT ARE APPLYING THE MATRIX

- MDA

- GBSD

- AF/SMC

- AF ASE

- NAVAIR

- USA

- NNSA

- others

ALL HAVE TAILORED THE MATRIX TO SUIT THEIR NEEDS

GETTING FEEDBACK ON RESULTS IS DESIRED

POSITIVE OUTCOMES

- Provides an excellent tool to communicate across roles; PM, SE, IT, Modelers, Contracts

- Comprehensive to catch items

- Captures gaps and characterizes opportunities

- Tailorable

- Workshop helps to ensure that the modeling capabilities are linked to the enterprise/ program goals and modeling objectives

- Assists in identifying how much modeling capability is "enough"

- Satisfies many use cases

Use Case Examples

STRATEGIC VISION

Define a future state description of one or more domains/attributes of a mature Model-Based Enterprise

PROGRAM REVIEW "BINGO"

As the review is conducted, use the Matrix to identify the capabilities identified and their stage

ROADMAP

Define a Roadmap of increasing capability of one or more domains/attributes towards a mature Model-Based Enterprise

QUALIFYING BIDDERS

Define how the Model Based Capabilities Matrix may be used to qualify bidders to be allowed to provide proposals

YARDSTICK

Define a method of characterizing the current capability of one or more domains/attributes for a Model-Based Enterprise

SOURCE SELECTION

Define how the Model Based Capabilities Matrix may be used to support source selection

TACTICAL PLANNING

Given the current capability of one or more domains/attributes of a Model-Based Enterprise, determine on which domain(s)/attribute(s) to apply effort/resources to advance in the near-term

Model-Based Capabilities Matrix Workshop Findings

- Customers adopt modeling lexicon to use for effective communication
  - Provides definitions and references for the modeling terms
- Customers realize the breadth and influence of modeling to effect the organizational transformation needed
  - Spans Enterprise and Systems Engineering, Program and Project management as well as modeling and IT (to characterize needed modeling environments)
  - Characterizes the needed modeling capabilities that were previously unidentified
- Quickly characterizes the current state of a modeling capability and a desired state for any team of stakeholders
  - Zeros in on the items that are more important and require more thought
  - Drives the interface and contract requirements
- Enables a logical response to the request to define needed modeling capabilities mapped to organizational goals
- Drives many enterprise and program documents
  - Program plan, system engineering plan, pre-award communication and data interchange, contract definition, post award execution
- Can be a game-changer on how stakeholder teams interact and exchange information

User feedback

INCOSE MBCM Products and Status
Available on INCOSE Connect

- Model-Based Capabilities Matrix (MBCM) – final
  - Excel
  - Two views; Area/Role-based view, and OSD Digital
    Engineering Strategy goal view
  - Same capabilities allocated differently for the 2 views
  - Prints on 2 pages of 11"X17" paper
- User's Guide version – final
  - Word doc
  - Frequently Asked Questions (FAQs). Useful for newcomers
    or to explain the effort to potential sponsors
- Workshop charts, so you can run a workshop

INCOSE Model-Based Capabilities Matrix and User's Guide

Version 5.3, November 2019

Joe Hale,
NASA/MSFC,
joe.hale@nasa.gov

Al Hoheb,
The Aerospace Corporation,
albert.c.hoheb@aero.org
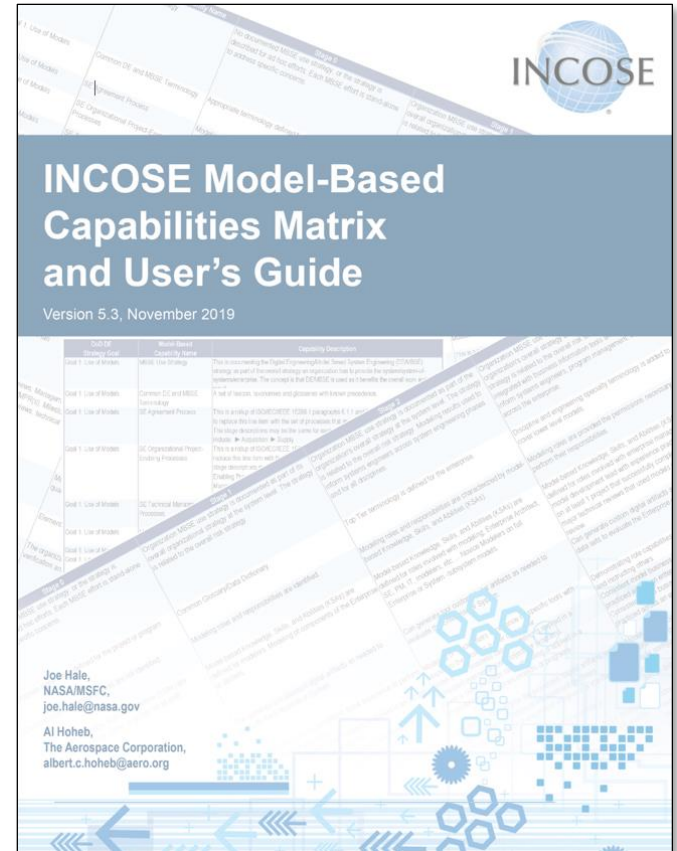
Challenge Team site location

To access the products:
1. Need to be an INCOSE member
2. INCOSE Login and add "Challenge Team" on your profile page
3. Clear Browser cache to ensure new web pages are loaded
4. Log out, then back in
5. Go to Connect, Working Groups, Challenge Team

Model-Based Capability Matrix (MBCM) Development

Challenge Team Effort – Started in January 2018

CO-LEADS

- **Al Hoheb**
  The Aerospace Corporation/SED
  albert.c.hoheb@aero.org
- **Joe Hale**
  NASA/MSFC
  joe.hale@nasa.gov

CHALLENGE TEAM

- Federation of those willing to assist in the development and deployment of the products; **162**
- As a challenge team member you are on the mailing list to receive product updates, notices for meetings and workshops
- Request feedback on products and after you apply it

PRODUCTS

- Model-Based Capabilities Matrix (MBCM) excel-based Matrix
- Model-Based Capabilities Matrix User's Guide
- Model-Based Capabilities Matrix Workshop charts
- INCOSE Challenge Team Technical Project Plan (TPP) version 2.2

RESOURCES

- http://wiki.omg.org/MBSE/ references provide an on-line overview of the products and the Challenge team efforts
- INCOSE Connect – member download area
- Soon to be available from the INCOSE Store

Matrix Effort Pedigree and Plan

- ✓ Nov 2016 Aerospace MBSE Community Roadmap
- ✓ Oct 2017 NASA MFSC MBSE Maturity Matrix
- ✓ Nov 2017 OSD Digital Engineering Working Group – presentation and co-lead kickoff
- ✓ Jan 2018 INCOSE IW Breakout **Workshop** – presentation and workshop; – 2 half day session with over 50 participants, resulted in draft INCOSE matrix version 1.0, inputs: IEEE/ISO/IEC 15288.1, 15288.2, 15289, and the DoD Digital Engineering Strategy
- ✓ Mar 2018 INCOSE Challenge Team Inputs -- comments
- ✓ May 2018 Aerospace System Engineering Forum -- presentation and **workshop**; draft INCOSE matrix version 1.1
- ✓ May 2018 USAF DE Working Group presentation – presentation, draft version 1.2
- ✓ June 2018 INCOSE Challenge Team Inputs -- draft version 1.3 in, draft users guide
- ✓ July 2018 INCOSE IS **workshop** -- draft version 1.3 in, draft users guide
- ✓ Aug 2018 version 1.4, wiki site initially populated
- ✓ Sept 2018 1.5, updated users guide
- ✓ Oct 2018 OSD Cross-check against the OSD DE Strategy – all strategy elements covered
- ✓ Oct 2018 NDIA SE Conference **workshop –** first fully populated matrix. Ver 1.5
- ✓ Nov 2018 Presentation to MIT/LL
- ✓ Dec 2018 INCOSE Challenge Team Inputs – matrix ver1.6a, TPP 2.1 (signed), User's Guide 4
- ✓ Jan 2019 INCOSE IW Outbrief and Breakout **workshop** -- matrix ver 1.7
- ✓ Feb 2019 Aerospace System Engineering Forum **workshop** – workshop program acquisition scenario
- ✓ Mar 2019 Aerospace internal and customer **workshop** -- matrix ver 2.0, organized to the OSD DE Strategy
- ✓ Jun 2019 Challenge Team meeting – matrix ver. 2.0b, additional capabilities, UG 5.2, **INCOSE Connect document download**
- ✓ July 2019 INCOSE IS **workshop** – FAQs
- ✓ **Aug 2019 INCOSE document publication approval submittal**
- ✓ Sept 2019 INCOSE Western Region - presentation
- ✓ Oct 2019 NDIA SE ME Conference presentation and **workshop**
- ✓ Oct 2019 Begin design for an on-line assessment tool, launch in Jan 2020, benchmark results in May 2020
- ✓ Jan 2020 INCOSE IW presentation and **workshop (approved community documents for INCOSE Store download)**
- • **Jan 2020 Aerospace web portal to the on-line Matrix Assessment**
- • **May 2020 Aerospace Systems Engineering Forum – Northern VA, outbrief benchmarking**

The products have been continuously peer developed and reviewed, resulting in publication

How do I learn more about this, get it?

- Participate in the Tuesday 1/28 workshop, 10 a.m. – 12 p.m., Pier 3 conference room

- Download materials from INCOSE Connect

- Download materials from the INCOSE Store

- Access the Aerospace Web page that also has a free assessment tool that provides a free user report

  – *Model-Based Capabilities Assessment*

  – *https://aerospace.org/mbca*

- Participate in the 5-7 May 2020 Aerospace Systems Engineering Forum where benchmarks will be provided

  – *https://aerospace.org/events/system-engineering-forum*

2020 Annual INCOSE international workshop
Torrance, CA, USA
January 25 - 28, 2020

Gain Experience on Assessing an Organization for Model-Based Capabilities

Tuesday, 28 January 2020

10:00-12:00, room: Pier 3

INCOSE Model-Based Capabilities Matrix - for Organizational Assessments:
- Benefit from the overview of the INCOSE products: Matrix assessment instrument and User's Guide to understand the products available and how they can assist you
- Apply the matrix to either of two scenarios with peers; a government satellite acquisition or a commercial product line extension defining driving business needs and necessary model-based objectives
- Profit from team out-briefs on what worked/what was challenging
- Gain experience to run a similar workshop for your organization
- Learn about the on-line assessment tool and how it can be used

Background:
The INCOSE Matrix (mapped to the DoD Digital Engineering Strategy) and User's Guide products have rapidly progressed from January 2018 to current publication. They are already being successfully applied to organizations to characterize their current and desired Model-Based Capabilities -- up to the enterprise level. This provides specific targets to evolve organization's model-based capabilities to meet their business needs and not over reach.

INCOSE Challenge Team Co Leads:
- Joe Hale, NASA/MSFC, givem@comcast.net
- Al Hoheb, The Aerospace Corporation, albert.c.hoheb@aero.org

Workshop materials:
- Provided to workshop attendees
- May be downloaded from INCOSE.org (member login only), Collaboration Portal "Connect," Working Groups, Challenge Team, INCOSE Model-Based Capabilities Matrix.
- The INCOSE Matrix and User's Guide may be downloaded from the INCOSE Store

Assessment of Model-Based Capabilities

- https://aerospace.org/mbca provides an on-line assessment is corporate service to anyone for free, we have access to the data for benchmarking

- Al Hoheb, Aerospace, Joe Hale, NASA/MSFC (retired), developed and published the Model-Based Capabilities Matrix assessment tool and User's Guide through INCOSE

Users
- MDA
- GBSD
- NWC
- AF/SMC
- AF ASE
- NAVAIR
- USA
- NNSA

We run assessments and workshops for our customers