Model-Based Systems Engineering Cost Study

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Introduction

Articulating the Problem and End State

We need more analogies and partnerships to help us with the next steps to answer:

- What is the initial cost for setting up MBSE themed support for a project/program?
- What are the long-term costs for MBSE for configuration management and curation of the models?
- What key MBSE factors and quantifiers should one consider when reviewing a proposal?
- What are possible +/-/ugly features of MBSE versus traditional systems engineering methods?
- What is the LCCE for implementing MBSE?
- We have some intermediate results that seem fruitful (next slides)

Desired Results:

- Considerations for MBSE Life Cycle Costing
- Requirements that are needed for effective estimates for Life Cycle Costs
- Stronger analogies to enable accurate cost impacts and scaling factors

LCCE = Life Cycle Cost Estimation
MBSE = Model-Based Systems Engineering

Approach

Scoping the problem first and in detail, with a fresh perspective

Intent was to capture holistically the problem for MBSE LCCE

- How is MBSE being introduced to new programs – its origins – after thorough or well-planned activities?
- What are the assumptions and constraints to consider?
- What Use Cases are available or can be developed?

We employed different methods of analysis and research to map out the influence of factors on MBSE LCCE

- Article and Book Research
- Root Cause Analysis → Get the questions to feed the next few bullets
- Interviews with MBSE practitioners and architects
- Survey for current practices done today
- Derive requirements that are needed for effective estimates
- Analysis of the problem which will help define the correct questions (checklist) to cover different considerations of the MBSE LCCE problem

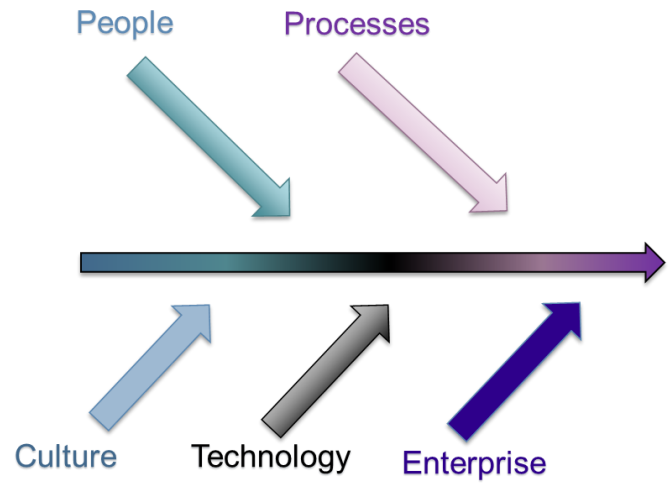
LCCE = Life Cycle Cost Estimation
MBSE = Model-Based Systems Engineering

Scoping out the problem helps to form future budgets and make them defensible for enterprise MBSE Practices

Questions Derived from Root Cause Analysis for Surveys/Panels

Summarized version to help us with panel interactions

- What is the expected level of experience for an SE utilizing MBSE on a new program?
- What is the learning curve for the average SE to learn to use MBSE?
- How often have you seen a switch in the type of MBSE tool used?
- What is the learning pattern for new contracts? Any observations or experiences?
- How fast can MBSE incorporate new assumptions to a program once established for a program?
- What does a program look like if MBSE is done day to day from start to finish versus adding it on later?
- How much does it cost to train people before a contract starts? Was the training effective?
- Is there some place to look at all the costs to implement MBSE support? Does this exist?
- How much configuration management is involved with MBSE?
- What areas in MBSE are you seeing grow or mature?
- How hard is it to implement MBSE infrastructure in each area?
- Where do you see MBSE ten years from now?
- How long does it take to create an MBSE model from scratch?
- How often are MBSE related repositories and/or archives updated?



The RCA helped us set up the survey/panel questions for meaningful answers to scope the domain

MBSE Interview Themes and Main Concepts

Summary of Interviews with Subject Matter Experts

Current Impediments

Immature state of present MBSE programs

Slow transition from legacy to full maturation of MBSE

Budgetary constraints

Misuses of MBSE

More than 25 MBSE and SE SMEs contacted

10+ In-depth interviews done

More interviews to be done in the future for further research

More than 5 MBSE programs observed (see references)

Improving MBSE

Training

Main and supporting tools, licensing, and user access, upgrades, IT

MBSE leadership, team experience and expertise levels

Solid foundation and development planning in defining the scope, requirements, parameters, boundaries, interfaces, architecture

Capability maturity model index

Successful MBSE

User and model documentation

Model maintenance

Configuration management

Standard and common infrastructure

Interoperability

Model interoperability and integration

CONOPs, metrics, verification and validation

Reuse

Other Factors to Consider

Classified setup

"The additional cost to SE efforts to set up MBSE from 1.00 (its base cost) to at least 1.01 and as much as 1.25"

Note that the Program Management effort would be additional costs as well

"MBSE provides 3% improvement in on-time delivery and … improvement in overall development costs"

See Sandia Report SAND2016-2607

Carroll ER, Malins RJ. *Systematic Literature Review: How is Model-Based Systems Engineering Justified?* Sandia National Labs. Published March 2016. Accessed June 17, 2022. Doi: 10.2172/1561164 https://www.osti.gov/servlets/purl/1561164/

Key MBSE Cost Highlights and Takeaways from Interviews

Post Interview Research in Traditional SE Cost Estimation Modeling Methods

- MBSE cost data is rare with no current enterprise-wide implementation
- Reflect on the parametric approach with COSYSMO and observe delta costs from document-based systems engineering to model-based SE, which will provide guidance and range
- Exploring similar methodologies

COSYSMO – costing data for MBSE exists but needs tailoring

- Ricardo Valerdi created the COSYMO model "to more accurately estimate the time and effort associated with performing the system engineering tasks in complex systems"
- Note: model is for traditional systems engineering, so parameters must be altered for MBSE
- Size drivers and effort multipliers of application and team factors were identified
- Rating scales were then created for the effort multipliers
- For the COSYSMO effort equation, a variable is from historical data, which is difficult to attain for MBSE

SEER for Systems Engineering – single state of models

- Same/similar size and cost drivers as traditional systems engineering and COSYSMO
- For example, consider the tool support cost driver where tool usage is significant and essential to the success of implementing MBSE
- Galorath's SEER for SE provides estimates with the user changing input parameters
- Estimations are based on Galorath's historical SE data
- More information can be found in the SEER for Systems Engineering User Guide and *Get Systems Engineering Costs Under Control*

Accurately Estimate Systems Engineering Costs with Little Data. Galorath Incorporated. https://galorath.com/products/seer-systems-engineering/
SEER for Systems Engineering User Guide. Galorath Incorporated. https://seer-university.galorath.com/wp-content/uploads/2017/02/SEER-for-Systems-Engineering-User-Guide.pdf
Galorath. Get Systems Engineering Costs Under Control. https://www.youtube.com/watch?v=wp7tcCtQ21k

Difficulty in finding historical MBSE specific data

Considerations for MBSE Life Cycle Costing

1 of 2

How is MBSE started?

- Team formation
- Staff expertise and organization
- Staff cost equations
- Note: Prepare for a major increase in preliminary design cost compared to document-based SE

What are some MBSE cost basics?

- Tool trade study
- Tool licensing (floating) access, environments, procurement
- Model methods and language choice
- IT equipment/processes
- Note: Changing tools and methods in the future may be costly

What is needed after choosing the MBSE modeling basics?

- Initial training
- “Hands-on” experience and skills
- Development labor costs
  - Consider cost in retaining experienced MBSE engineers
- Define team roles and responsibilities

SEER for SE personnel and team capabilities

SEER for SE development and productivity aids

SEER for SE project effort and/or costs, labor categories

How does MBSE establishment affect the lifecycle cost?

- Develop model user documentation
- Model development complexity factor
  - Define model requirements, architecture structure and environment, etc.
  - Develop model-based processes, including model V&V

Development phase changes in terms of cost (1 of 2)?

- Cost reduction with requirements engineering
- Most of the defects will be introduced during the early phases
- Cost reduction with design reuse when applicable while making tradeoffs

Development phase changes in terms of cost (2 of 2)?

- Sharp increase in the number of changes in interface requirements with new autogenerated SE artifacts
- Increase in SE labor hours overall
- Note: cost defect removal equates to a “large portion of development cost”

MSA = mission solution analysis

V&V = verification and validation

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SEER for Systems Engineering User Guide. Galorath Incorporated. https://seer-university.galorath.com/wp-content/uploads/2017/02/SEER-for-Systems-Engineering-User-Guide.pdf

Considerations for MBSE Life Cycle Costing

2 of 2

Production and deployment phase cost changes?

- Defect introduction will ideally gradually decrease to 0% when reaching system and acceptance testing stages
- Decrease in the total number of defects and total labor hours per requirement
- Addition of model release and updates, configuration and data management

Operations and maintenance phases cost changes? (1 of 2)

- Operations and maintenance is a large cost driver within the MBSE LCCE
- Model management is an important factor with proper application of model valuation and collection activities

Operations and maintenance phases cost changes? (2 of 2)

- Increase of model sustainment (database and tool interoperability)
  - Model updates, library and databases
- Internal and external model
  - Digital artifacts, user interfaces, visualizations, i.e., HTML files
  - Integration and collaboration

SEER for SE product and system complexity

What overhead and additional costs should be considered?

- Continuous training
- Conferences and/or collaborations
- Professional memberships
- Keeping updated with INCOSE visions and methods of the MBSE initiative
- Ongoing usage of the INCOSE Model-Based Capability Assessment

SEER for SE ongoing support

Are there any other factors and items to keep in mind?

- Yes, this is only a brief look into the MBSE LCCE
- MBSE is continuously evolving
- Note: MBSE may take five+ years to fully implement

DE = Digital Engineering
ROI = Return on Investment

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Findings, and Recommendations

Concluding Remarks on MBSE Costing

Findings

- Little information for costing analogies for MBSE on large programs
- Actual vs Theory: Effectiveness is dependent on systems engineers utilizing the tools effectively, tools cannot take the place of systems engineers (cost factor to skills of the systems engineers)
- MBSE culture and experience of execution inside of a company is a good indicator of efficient MBSE
- MBSE must be utilized throughout the System Engineering Life Cycle (SELC) of a program to be effective – configuration management must be sustained (and costed for)
- MBSE tools can't replace good systems engineering (watch item for contracts)
- MBSE process is ever changing and is not standardized yet across the government – costing is similar to paying for programmers at this time
- Evidence points to but cannot confirm MBSE costs up front reduce risk and standardize architectures across a program

Next Steps for the Study

- Looking for partners!!!
- Follow on work could focus on costing tools such as COSYSMO lineage of tools or SEER
- More research and interviews needed to find analogies for cost estimates and similarities

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MBSE is still nascent enough that rules apply to costing for the concept, but not many costing analogies exist

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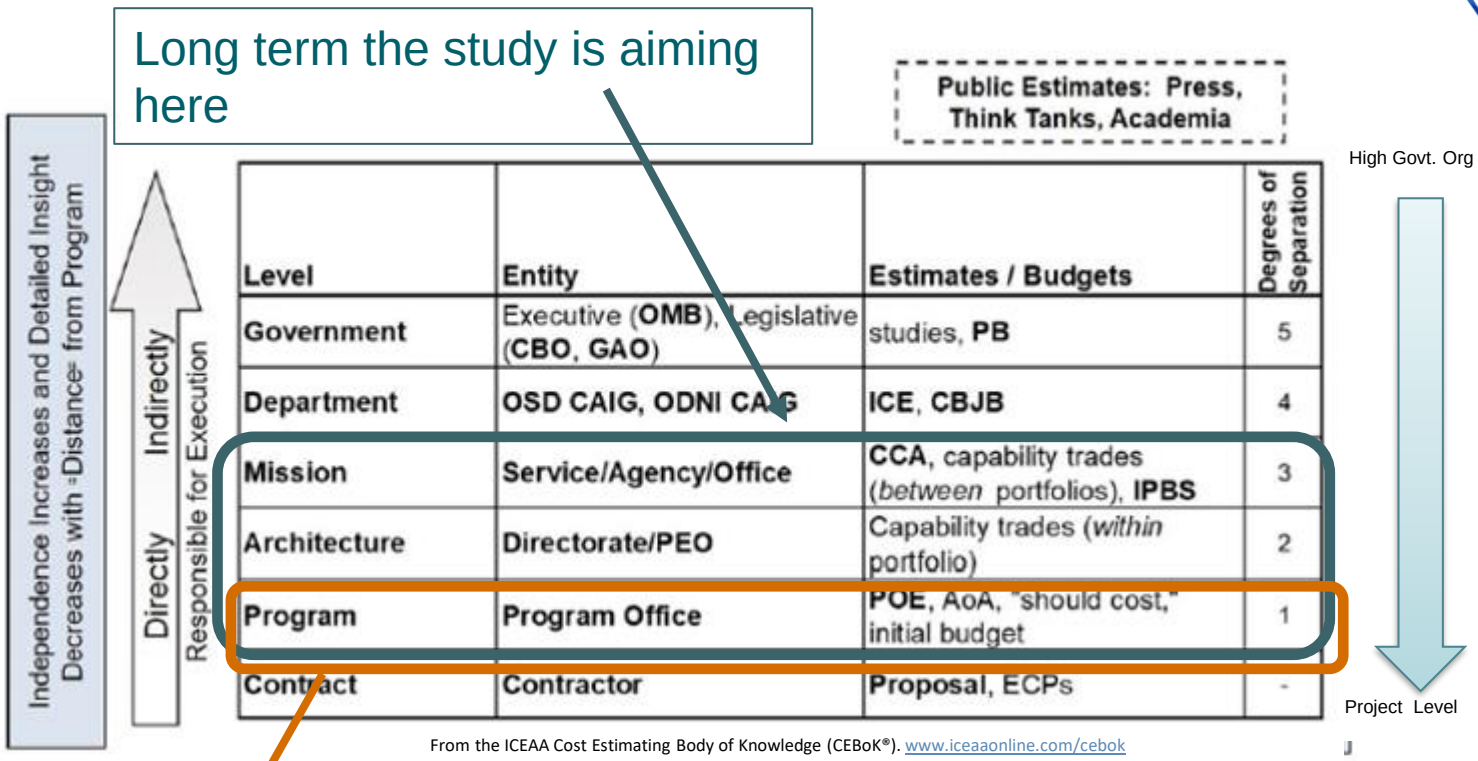
Estimating at the Level of the Program that Impacts the Enterprise

- We are identifying the problems at the program level and at an enterprise level (due to architecture)
- Too often, engineers want to solve a problem before assessing the problem fully
- For enterprise level problems at the Mission or Architecture level, we need to assess the scope of the problem before crafting a solution
- Many pieces to this puzzle – bite at a time



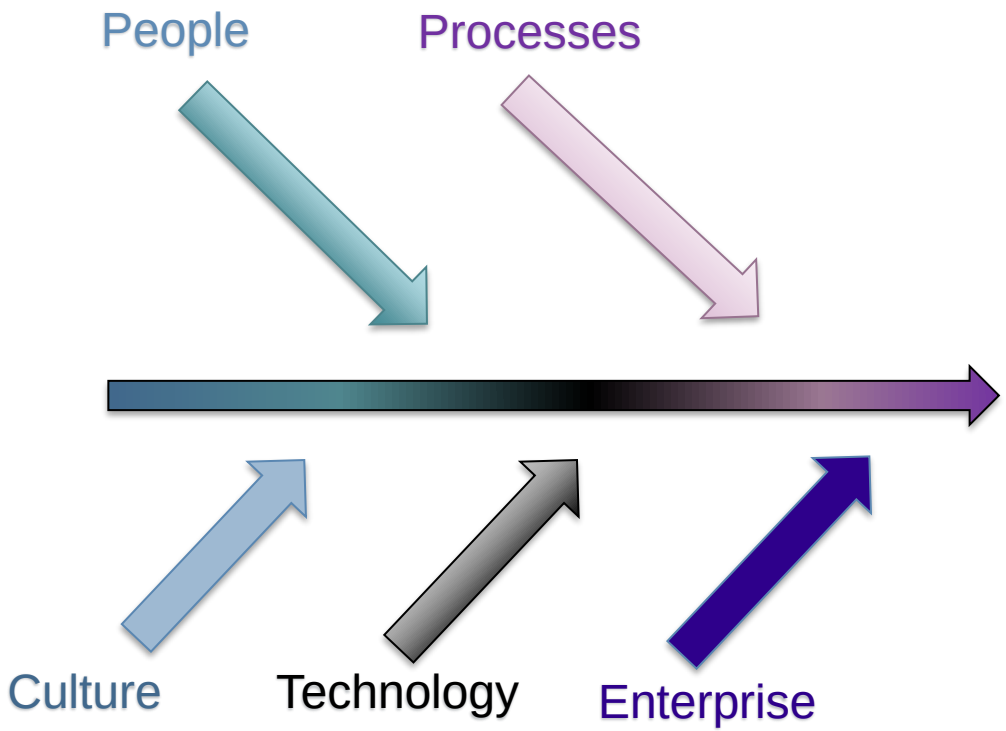
Most cost estimates are at the program level – and thus emphasize this part more than others at the start

We need to articulate the problem due to the newness of this engineering domain to Cost Estimation Paradigm

Root Cause Analysis

Ishikawa Diagrams

- Root Cause Analysis (RCA) aided in defining the right questions for the next step of panel discussions with MBSE subject matter experts and practitioners
- Summarized MBSE information extracted from literature research
- Focused on factors in connection to people, processes, culture, technology, and enterprise
- Brainstormed with main questions (see backup):
  - How does MBSE get mis-used?
  - What are the proper items/activities that must be done to create a good MBSE Program Team?
  - What are the taxes or barriers to effectively implementing MBSE?



RCA = Root Cause Analysis
SME = Subject Matter Expert

Additional reference used in RCA: McKelvin M. Model Based Systems Engineering (MBSE) Overview (Recording). The Aerospace Corporation. https://aerospace.csod.com/ui/lms-learning-details/app/video/d681b193-d946-4aa4-9d9a-09bbabd8a218

Connecting MBSE factors in relation to cost

Recommended Requirements for Effective MBSE Costing

Pre-made Requirements for utilizing MBSE in a SOW

The contractor shall utilize MBSE in addition to traditional INCOSE standard systems engineering practices.
The contractor shall adhere to the ISO 15288 framework with the addition of MBSE.
The contractor shall utilize the INCOSE Model-Based Capabilities Matrix and User's Guide as a reference and for guidance.
The contractor shall form a MBSE tool trade study.
The contractor shall produce and deliver an MBSE team training plan for the tools, licensing, access permissions, and modeling language choices.
The contractor shall produce and deliver an MBSE development and strategy plan.
The contractor shall define team roles and responsibilities specifically for MBSE implementation.
The contractor shall provide and distribute user documentation to stakeholders for models created.
The contractor shall develop a metamodel plan to standardize model structure, interface, elements, and relationships for model integration with all stakeholders.
The contractor shall establish, continuously update, and share MBSE databases and libraries to all stakeholders.
The contractor shall apply model configuration management for all models.
The contractor shall apply model data management for all models.
The contractor shall continuously produce and provide digital deliverables throughout the acquisition.
The contractor shall limit the use of document deliverables.
The contractor shall reuse models when applicable.
The contractor shall utilize configuration management best practices for inventorying and versioning models for MBSE
The contractor shall use standardized models that utilizes common vocabulary, interfaces, and ontologies between programs at the beginning of the program, used throughout the life of the program.
The contractor shall verify, validate, and utilize regression testing on models integrated with a system of system models cross contractor/programs.

Shea G. Appendix C: How to Write a Good Requirement. National Aeronautics and Space Administration. https://www.nasa.gov/seh/appendix-c-how-to-write-a-good-requirement
Wagner H. MBSE for the Gateway Program. National Aeronautics and Space Administration. https://ntrs.nasa.gov/api/citations/20190031738/downloads/20190031738.pdf

These requirements help bound the assumptions on how MBSE will be used by the contractor

Considerations for a MBSE Costing Checklist (1 of 2)

- What is included and categorized in the labor cost?
- What phases in the lifecycle do those labor costs contribute to?
- How cohesive is the stakeholder team?
- How capable is the personnel in terms of MBSE?
- What is the experience level and reliability of the team?
- Is ongoing labor support needed?
- How many system requirements can be identified for systems engineering? Complexity? See system specification.
- How many major interfaces can be identified?
  - *See context diagram, ICD, etc.*
- How many unique algorithms or business rules can be identified?
- How many operational scenarios can be identified?
  - *See number of end-to-end tests, use cases, etc.*
- Will any models be reused in association with systems requirements, major interfaces, unique algorithms, and operational scenarios?
- How knowledgeable are all the stakeholders regarding the requirements?
- How knowledgeable are all the stakeholders regarding the systems architecture?
  - *See "IP platforms, standards, components (COTS,GOTS/NDI/new), connectors (protocols), and constraints ... systems analysis, tradeoff analysis, modeling, simulation, case studies, etc."*
- How complex is the design in terms of ISO/IEC 15288?

ICD = Interface Control Documents
TRL = Technology Readiness Level

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Considerations for a MBSE Costing Checklist (2 of 2)

- How complex is the level of service requirements?
  - *See "security, safety, response time, interoperability, maintainability, Key Performance Parameters (KPPs)".*
- How complex is the migration of legacy systems? Is the contractor legacy?
- How complex and mature is the technology in terms of risk?
- How ready is the TRL?
- How complex and formal is the required documentation?
- How many platforms are required for system hosting and installation?
- What is the operating environment?
- How many site/installations are needed?
- How cohesive is the stakeholder team?
- How capable is the personnel in terms of MBSE?
- What is the experience level and reliability of the team?
- What process capability is needed for maturity in EIA/IS 731, SECMM, CMMI, etc.?
- Where will the stakeholders be located?
- Is travel required?
- How is stakeholder communication delivered? Any barriers?
- How complex is the MBSE tool support?

ICD = Interface Control Documents
TRL = Technology Readiness Level

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