How to Fail at MBSE
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Changes in Systems Engineering Practice

Change from Document centric to Model centric

Requirement Specifications
Interface Definitions
System Architecture
System Functionality
Trade-off Analysis
Test Specifications
Etc.

Old Approach

New Approach
Model-Based Engineering

Model-based Systems Engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing through-out development and later lifecycle phases.” (INCOSE, 2007).

Modeling is at the heart of all aspects of the development effort

– Covers the complete product and project lifecycle
– Has a direct effect on any generated artifacts.
– MBE encompasses architecture, systems and software development.
Modeling at Multiple Levels of the System

Architecture Models

Systems Models

Component Models
Modeling Language for these Multiple Levels of the System
System Modeling with SysML

System Model Must Include Multiple Aspects of a System

Behavioral Requirements
- Start → Shift → Accelerate → Brake

Performance Requirements
- Control Input
- Power Equations → Vehicle Dynamics

Structural Components
- Engine → Transmission → Drive Shafts

Other Engineering Analysis Models
- Mass
- Efficiency
- Safety
- Cost Model

System Model
Minimum Turn Radius: 24 ft.
Dry Pavement Braking Distance at 60 MPH: 110 ft.
Integrated Systems Engineering Vision

- Power Rating: 18 Amps
- Hydraulic Fluid: SAE 1340 not-compliant
- Thermal/Heat Dissipation: 780°F
- Ergonomic/Pedal Feedback: 34 ERGS
- Hydraulic Pressure: 350 PSI
- Sensor MTBF: 3000 hrs
- Minimum Turn Radius: 24 ft.
- Dry Pavement Braking Distance at 60 MPH: 110 ft., 90 ft.

- Used on a Safety Critical Rail Project
- Adopted an approach to MBSE for testing
- Leveraged a substantial body of UML/SysML models
- **Decreased validation costs by 75%!**
- Eliminates manual work
  - Excel files created automatically, which are used as evidence
- Reduces human errors
  - Originally the files were hand-coded
- Decreases the number of files used
- Enforces design standards
- Automatically produces documentation
Raytheon Findings on MBSE

- Presented at the Boston CTO Club meeting 30th May, 2012
  - Chief Software Engineer, Engineering Fellow, Integrated Defense Systems, Colorado
  - Engineering Fellow, Integrated Defense Systems Massachusetts

- They reported productivity increases from 150% to 700%, and defect rates of 10% to 50% of the same team's rates on previous projects.
Adopting MBSE can be hard

- Often there are a few ways to do something correctly
  - However, there are an infinite number of ways to do things wrong

- Used correctly, tools can help build systems more efficiently
  - Using the wrong end of a hammer to pound in a nail does not make the hammer a bad tool; it makes you a bad carpenter.
  - A fool with a tool is still a fool

- The following guidelines will help to guide managers with implementing an MBSE initiative
Things NOT to do when adopting MBSE

- Avoid Training and Mentoring
- Discourage Collaboration
- Avoid Professional and Standards Organizations
- Adopt an External Process Wholesale
- Duplicate your Work
- Avoid Configuration Management
- Stay Ignorant of Best Practice
- Ignore Metrics
- Conduct Paper-Based Reviews
- Abuse Lean and Agile Development
- Avoid Optimizing Your Process
- Model Too Much, Too Early
- Delay Building Documentation and Code Templates
- Use Incompatible Modeling Tools
- Adopt a Custom Notation
- Duplicate Paper-based Processes With Tools
- Buy a Tool First (Any tool)
Don’t Neglect Training and Mentoring

- The Problem: Modeling is an actively acquired skill
  - You can’t learn to swim by reading a book
  - A good FORTRAN programmer can do FORTRAN in any language
- The Solution: Adopting MBSE requires learning to solve problems differently
  - The same engineering techniques are used
  - You just do them using standardized models rather than just words
- Comprehensive training gets you started
  - Available from Atego and others
  - Books are essential, but not enough
    - You cannot ask a book a question
- Mentoring ensures that your techniques and processes are sound
  - “Course correction”
  - Model review
  - Process review
Encourage Collaboration

- The Problem: Project communication is difficult
  - It is common practice that software, hardware, and systems engineers only communicate with each other at the end of the project to blame each other for why they are late.

- The Solution: Models provide a force-multiplier for engineering work.
  - Models are developed using the different viewpoints
  - Each group develops it’s portion of the model, working towards a whole
  - Traceability can be added between the views to create a coherent whole
  - The model can then be examined for coherence, correctness, compliance, etc.
  - The model is used to communicate between disciplines
Engage with Professional and Standards Organizations

- The Problem: Sharing best practice is seen as “Giving information to the enemy”
  - IP is to be protected at all costs
  - Publishing papers only helps our competitors
- The Solution: Mankind has progressed over time through the ability to communicate and share information
  - Professional and standards bodies are a means to achieve this
- The International Council On Systems Engineering (INCOSE)
  - “Our mission is to share, promote and advance the best of systems engineering from across the globe for the benefit of humanity and the planet.”
- The Object Management Group (OMG)
  - “OMG’s mission is to develop, with our worldwide membership, enterprise integration standards that provide real-world value. OMG is also dedicated to bringing together end-users, government agencies, universities and research institutions in our communities of practice to share experiences in transitioning to new management and technology approaches.”
Don’t Adopt an External Process Wholesale

The Problem: Wholesale process adoption
- Confuses engineers
- Causes resentment
- Delays projects

The Solution: All processes MUST be customized
- Additional steps
- Redundant steps

Normal Process Improvement is:
- Start with your existing process
- Figure out where you would like to be
- Determine how you are going to arrive at your destination incrementally whilst ensuring that improvement can be measured
  - Start first with most effective ROI (Largest problem)
- Correct the process as required
Don’t Adopt an External Process Wholesale

- It is imperative that a well defined process be specified elaborating how quality checks fit into the overall process
  - Suggested vs. mandatory, and
  - How updates, modifications, variations, dispensations, etc. will be handled.

- Allow easy access to the process
  - Wiki/Intranet as opposed to paper or electronic documents

- Object Oriented Systems Engineering Methodology (OOSEM).
  - A good starting point for defining a process or integrating these concepts into an existing process
  - Successfully adopted by several major companies
  - More information is available at the OOSEM website http://syseng.omg.org
Don’t Look at MBSE as Duplicate Work

- The Problem: MBSE is often considered “Extra Work”
  - Visio/PowerPoint diagrams added to tick boxes
  - Models not integrated into the process
- The Solution: MBSE needs to be integrated into existing processes
  - Redundant tasks and I/O need to be identified early
  - MBSE needs to become “The Way Things are Done”
- Modeling needs to be at the center of the development effort
  - Covers the complete product and project lifecycle
  - The model contains the requirements, the strategy to meet the requirements, and the implementation of the requirements
  - Has a direct effect on any generated artifacts.
  - What goes in, should go out
- Adopt an “Agile” modeling approach for concept development
  - Avoids the need for “PowerPoint models”
Integrate MBSE with Configuration Management

- The Problem: Projects often view model CM like document CM
  - File based MBSE can easily lead to version skew

- The Solution: MBSE Configuration Management requires special attention
  - Model Versions
  - Model Variants
  - Component Versions
  - Component Variants
  - Error traceability and reporting across projects, models, and components

- Most companies have rigorous configuration management over code, documentation, artwork, architecture, versions, etc.

- Models are aggregations of interconnected data
  - The only solution is a whole model approach
Stay Informed of Best Practice

- The Problem: Companies become reliant on existing processes and tools
  - Projects stagnate due to lack of innovation
  - “We’ve always done it this way before.”
- The Solution: We need to adapt processes, tools, technology, etc. to keep pace with our competitors or risk falling behind
- New problems require a different approach
  - "We can't solve problems by using the same kind of thinking we used when we created them." Einstein
- The technology landscape is changing at an alarming rate
  - Technology
  - Engineering
  - Tools
  - Processes
  - Etc.
- Best practice from 5 years ago is now archaic
Integrate Metrics into Your Process

- The Problem: Collecting metrics is seen as a time-consuming, unnecessary, overhead
  - Often metrics that are collected are never analyzed

- The Solution: Metrics are an essential indicator as to whether or not your MBSE initiative is working
  - Integrate automated collection of metrics into your process

- “If you can measure it, you can manage it”
  - Consequently, if you aren’t measuring your process, productivity, error rates, defect rates, etc., how can they be managed?
  - Similar to a control loop with no feedback

- Prior to starting any process improvement initiative, start a metrics initiative
  - Process Improvement tells you how to get from A to B in your process
  - Metrics tell you if you are going in the right direction
  - “If you don’t know where you are, a map won’t help.”
Don’t Conduct Paper-Based Reviews

The Problem: When project documents were all words, all we reviewed were the words
– Often devolved into spelling and grammar checking
– Usually missed substantial issues
– Tedious and disheartening
– Lowering motivation and morale

The Solution: Model-based reviews provide substance
– Can include model execution, trade-off analysis, etc.
– Issues can be entered into the tool, traced and acted upon
– Automated checks can review the model for:
  – Correctness
  – Compliance to industry and company standards
  – Traceability
  – Completeness
  – Etc.
– Reduces tedium and busywork
Don’t Abuse Lean and Agile Development

The Problem: Agile development can be used to bypass process
– It becomes a “License to Hack”
– Loose requirements, traceability, and a lack of criteria against which to determine if the system is “correct”

The Solution: Agile development needs to be integrated into a process in an effective way
– Concept development
– Bid management
– Investigation of alternatives
– Prototyping
– Etc.

Agile development can be a powerful tool providing a fast and efficient way to build systems

Always develop your systems, processes and models to the “Right” level of quality
Optimize Your Process

- The Problem: We are often tempted to continue with existing broken processes
  - “If it ain’t broke don’t fix it”

- The Solution: Regular and Periodic Process Review
  - Learning from our mistakes improves the way we do things
  - Error correction needs to be built into our processes
  - One definition of madness is doing the same thing over and over again and expecting a different result

- Perform a process review at the start of the process to determine what is and is not required

- Meet with other teams during the project to identify common problems

- Perform a post-mortem after the project
  - Document what did and didn’t work
  - Capture and document reusable assets
  - Publicize success stories
  - Update the process to improve things the next time
Don’t Model Too Much, Too Early

■ The Problem: Modeling without a clear structure and plan
  – Adopting a “Mongolian Hoard” approach towards modeling creates a large amount of data that will be impossible to sort out.
■ The Solution: Establish a model structure early
  – This should support the Work Breakdown Structure as well as the process
  – Separate areas for specialist areas, project teams, project phases
■ Start by modeling the requirements
  – Helps establish a foundation on which to build the model
  – Add traceability from the requirements to the requirements model
■ Do investigative modeling in a separate area
  – Prototypes of designs, products, alternatives, processes, etc.
■ The best modeling tool is a whiteboard
  – Use the whiteboard to solve problems, make decisions
  – Use the tool to document those decisions
Build Documentation and Code Templates Early

- The Problem: A lack of standardized templates can be disastrous
  - Severely impacts project deadlines
  - Reduces standards compliance
  - Causes duplication of effort

- The Solution: Prototype the process prior to project start
  - Documentation generation
  - Code generation
  - Modeling standards
  - Model and project reviews
  - Configuration management
  - Etc.

- Have the tools available when people need them
  - Achieves “Just in Time” project documentation

- A model with no output capability is useless
  - What goes in, must come out
Don’t Use Incompatible Modeling Tools

■ The Problem: Use of project tools evolves over time
  – One tool for architecture (DoDAF), another for systems engineering, and a third for software engineering
  – Often the tools use different methodologies (IDEF-0/State/OO)
  – Traceability and interchange done through documents/RM Tools
  – Extremely difficult to manage and communicate between stages

■ The Solution: UML tools now cover the complete project lifecycle
  – DoDAF (UPDM)
  – Systems Engineering (SysML)
  – Software (UML)
  – Model Traceability across project phases
  – Direct impact analysis and traceability

■ Requirements integrated into the model
  – Direct connection to model elements
The Problem: A non-standard notation locks you into a single vendor, limits resources, reduces communication, and increases risk.

The Solution: Adopt International Proven Standards
- The Systems Engineering Modeling Language (SysML) was started in 2001 to provide a standardized means of communicating between systems engineers, stakeholders, and other project personnel.

Resources are now plentiful
- Multiple tools on the market
- Several books have been published
  - E.g. Holt, Friedenthal, Weilkiens
- Training courses from several sources
- Taught at university
- In wide use in industry
- Documented project success
- Etc.
Don’t Duplicate Paper-Based Processes with Tools

The Problem: Companies buy tools first and then use them in the same way as the existing paper-based process
− This gets the least out of tools, not the most

The Solution: Paper-based and model-based processes are different
− The inventors of the car did not start by inventing an electric horse
− Work practices need to adapt to the paradigm shift
− Processes need to adapt to make better use of tools

Project documents
− Originally large paper documents, then electronic documents
− Next, electronic documents with cut and paste diagrams
− Need to shift to automated document generation

Requirements traceability
− Originally large sheets of graph paper, then spreadsheets
− Next, Requirements Management (RM) tools
− Then, traceability links between RM tools and models
− Need to shift toward models integrated with reqts.
Don’t Start by Buying a Tool (Any Tool)

The Problem: Projects often buy the cheapest tool to minimize costs
- Models then expand to the point where converting to a different tool is too expensive
- Projects have no choice but to carry on
- Buying cheap can be very expensive

The Solution: People – Process – Tools

Tools must be fit for purpose
- As always, start with requirements
- What will the tool be used for?
- How does it fit into existing processes?
- Can it manage a complex, concurrent development environment?
- Will the tool scale to meet your needs?

Evaluate tools as you are going to use them on projects
- Tools are *Usually* evaluated by individuals
- *Always* used by groups
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]

Material Solution Analysis
- Material Development Analysis
- Material Development Decision

Technology Development
- Integrated System Design
- PDR
- Post PDR Assessment
- CDR

Engineering & Manufacturing Development
- System Capability & Manufacturing Process Demonstration
- Post CDR Assessment

Production & Deployment
- LRIP
- Full Rate Prod & Development
- FRP Decision Review

Operations & Support
- Life Cycle Sustainment

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]
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Material Solution Analysis

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- Earlier risk identification and mitigation [2, 4, 7]
- Early evaluation of manufacturing processes [2]
- More complete evaluation of trade space [8, Boeing 787]
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
5. Complex Product Family Modeling for Common Submarine Combat System MBSE, Lockheed Martin July 2010
10. Does a Model Based Systems Engineering Approach Provide Real Program Savings? Informal Symposium on Model-Based Systems Engineering DSTO, Edinburgh, South Australia, Steve Saunders, FIEAust CPEng, Raytheon
(2) NDIA Using M&S to Guide Producibility

- Several GAO studies conducted around acquisition cost overruns
  - Systemic issue was excessive design, technology, & manufacturing risk
  - Successful programs exhibited earlier design & producibility knowledge
  - Recommendation is adoption of knowledge-based decision processes

- Producibility analysis capability generates critical knowledge early
  - Influence and validate requirements feasibility
  - Identify, quantify, and proactively plan for risk
  - Provides manufacturing analysis capability comparable to engineering

- Producibility figure of merit provides means to quantify concerns
  - Quantify “hidden costs” during early design studies
  - Guide solutions and minimize risk
  - Provides means to conduct trade-off analysis
(3) NRAC Report on Software Intensive Systems

- The GAO and DoD CIO found the DoD spends 40% of its RDT&T budget on software
  - FY 2003 $21B, FY 2006 $30B
  - 40% was attributed to rework efforts ($8.4B and $12B)

- Recommendations included:
  - Increase awareness of software problems, technology, and opportunities
  - Develop real incentives to share specifications, interfaces, models, and software (e.g. ARCI program)
  - Apply emerging software engineering tools to appropriate problems
  - Deploy system engineering methods that enable specification, implementation, and testing to evolve together
  - Model driven tools can stimulate and enforce iterative systems engineering
A Product Family is a group of products derived from a common product platform.
- Chrysler K-cars, Boeing 747

LMCO Used MBSE to define product families, manage complexity, leverage reuse, and document commonality

Expect 13% additional savings to SE from MBSE
- 25% in Capability Definition
- Another 10% over DOORS in Baseline Management

Savings won’t be seen until 4th year
- 2 years to implement model
- 1 year transition overlap with current process
(7) Use of a Model Based Approach to Minimize System Development Risk and Time-to-Field for New Systems

- Concurrent development and implementation of the Test Environment model saves time by identifying errors before they can be propagated.
- Work flows provide the capability to standardize work products
- Don’t attempt this without training
  - Even with training, continued mentoring is vital
  - Training is necessary but not sufficient
  - This approach may not be cost effective if it is not institutionalized
- Must integrate model-based development activities into standard enterprise system engineering
- Time is saved when transitioning from Systems Engineering to SW Engineering by using a common modeling tool suite and language (SysML & UML)
(9) "Testing Solutions through SysML/UML" Hause, M. Richards, D. Stuart, A., INCOSE IS 2009, June, 2009

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- **Decreased validation costs by 75%!**
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- Decreases the number of files used.
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(10) Does a Model Based Systems Engineering Approach Provide Real Program Savings? – Lessons learned

- Programs are sensitive to errors during Requirements Definition
- Requirements Definition should first consider what the System does (its Functional Behavior)
- System Functional Behavior cannot be expected to be understood to the extent needed to create a complete/consistent Specification
  - System Functional Modeling must be undertaken
  - Functional Modeling should be linked to requirements
- **68% Reduction in Specification Defects since MBSE Practices Introduced**
- MBSE should not be constrained to commence with Requirements; Propose the model should link into Architectural Modeling
- Adoptions of elementary MBSE has demonstrated significant reductions in requirements errors
  - Similar results expected from more formal methods (SysML)
How MBSE Reduced Costs and Improved Productivity at “YOUR COMPANY NAME HERE”

■ Well? What are you waiting for?
Strategies and Lessons Learned

- There are many ways to do integrate MBSE into an organization
  - Some are helpful, others are not
  - Without metrics, it is difficult to know if things are improving

- MBE approaches and tools must be integrated with existing processes
  - Do not adopt a new process wholesale

- Leveraging MBSE requires investment in tools, training, and infrastructure
  - MBSE should be introduced incrementally
  - Start with a prototype project to streamline processes
  - Publish success stories and encourage adoption

- Training must be combined with mentoring and coaching

- Models will cross organizational / discipline boundaries
  - Reflects the nature of systems engineering
Questions and Answers

Thanks for your attention!