Using a Model-Based Systems Engineering Approach For Exploration Medical System Development

J. Reilly, A. Hanson, J. Mindock, K. McGuire, B. Reyna

HRP Investigators’ Workshop
January 23, 2017
The needs identified by this work will drive future ExMC research.
Systems Engineering Recap

What is Systems Engineering?

• A methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system.

Systems Engineering Provides:

• a way of looking at the “big picture” when making technical decisions.
• a way of achieving stakeholder functional, physical, and operational performance requirements in the intended use environment over the planned life of the systems.
• the art and science of developing an operable system capable of meeting requirements within often opposed constraints.
• a holistic, integrative discipline, wherein the contributions of e.g.,
  – structural engineers
  – electrical engineers
  – mechanism designers
  – power engineers
  – human factors engineers
  – and many more disciplines (medical!) are evaluated and balanced...
• To produce a coherent whole that is not dominated by the perspective of a single discipline.¹

¹Comments on systems engineering throughout the handbook’s Chapter 2.0 are extracted from the speech “System Engineering and the Two Cultures of Engineering” by Michael D. Griffin, previous NASA Administrator.
Information to Communicate

To communicate with exploration mission development activities, we need to describe:

• Operational Needs
• Requirements
• Design Options
• Interfaces...

https://dasp.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=9c591ad6-8f69-49dd-a61d-4096e7b3086c
What is Model-Based Systems Engineering?

- The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.¹

**Emphasis is on controlling the model of the system rather than controlling documentation about the system**

1. INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02, Sep 2007)
What is a system model in this context?

- A logical model that describes a system’s structures, behaviors, interfaces and properties through multiple perspectives to:
  - Facilitate a common understanding of the system
  - Control, measure and report progress of technical solution throughout the project lifecycle including requirements, analysis, design, implementation, verification and operations of the system
  - Abstraction that contains only the details needed to address the intended use of the model
  - Not an analytical model

**A system model is like a building blueprint that specifies the system to be implemented**
System Modeling Language

- System Modeling Language (SysML) is a graphical modeling language for specifying, analyzing, designing and verifying complex systems that may include hardware, software, information, personnel, procedures and facilities.
- Better than document based
- Used by automobile, aerospace/defense, medical industries
- NASA Agency-wide support for adopting MBSE and SysML
- Enables technical communication with other disciplines regarding interfaces and design in common language
Modeling Process

System Scenarios

What is the scenario narrative?
What other systems are involved?

Activity Diagrams

How does the system behave?

Sequence Diagrams

What functions does the system need to provide?

Functional Decomposition (BDDs)

How does the system interact with other systems?

System Requirements

System Architecture

System requirements are allocated?

Subsystem Requirements

What parts does the system have?

Subsystem Scenarios

Allocated System Requirements

System level

Subsystem level

I see this more like the original simpler looking spiral with big, thick arrows, and then subsystem level is “inside”…will explain when we talk.

Can speak to how this is moving down the left side of the “V”
SysML Diagram Types

- Use of all diagram types is not required for a complete SysML model.
- Use as many as it takes to complete a model for each case.

Even though we’ll use pkg diagrams, and possibly other diagrams, I think we can just circle the 3 we’re using primarily to start.
The diagram is just a visualization of the model, not the model itself...
System Model

- Stakeholders’ needs and constraints
- System Allocations & DRMs
- ConOps
- Technical Management

- Requirements
- System Alternatives
- System Architecture
- Interfaces
- Verification & Validation

Analyses & Other Tools
- Simulations (e.g., risk assessments)
- Traceability assessments
- Design option characterizations
- Design option optimizations
- Analytical Model Data

- Technical Measures
- Risk
- Cost
- Schedule
- Documentation
- Research Prioritization
- Gap Closure Evidence
- Technical Measures
Model Development and Test-bed Integration

- Team from across Centers is building model content (blocks, activities, sequence diagrams)
  - Medical system function identification
  - Medical system architecture and characterization (e.g., mass)

- Will also use to support definition of integrated Habitat test in iPAS environment in Sept. 2017
  - e.g., medical data architecture to collect sensor data and interface with vehicle
  - Hab test team developing Hab SysML models – we will collaborate and share models
Keys to Success

• Commitment from management
• Training
• Tools
• Experienced Modelers

Why this is important:
• In-line with our SE approach of providing structured, integrative science and engineering
• Enables increased relevancy to exploration system maturation by communicating in common technical language
Questions?
Backup
ExMC SE Approach Recap

Define what/who is involved in operational activities

**Block Definition Diagrams**

Capture activities in scenarios

**Activity Diagrams**

Capture complementary and reference info

**Traditional documents**

Derive requirements and verification info

**Requirement “shall” statements**

Allocate functions to subsystems

**System ConOps**

- “scenario tree”
- Mission Phases

**Level of Care Definitions**

**System architecture description**

**Other Documents...**

**Medical System requirements**

- Ground support
- Crew-member: Patient
- Crew-member: Caregiver
- Medical System

**In-flight Health Data System**

**Medical Appliances**

**...**

**Subsystem scenarios**

**Docs as needed**

**Medical Subsystem requirements**
Organizational Context

1) Research
2) Risks
3) Design/techs
4) Standards
OMG SysML Specification

• SysML provides graphical representations with a semantic foundation for modeling requirements, behavior, structure and parametrics for knowledge capture and simulation model interoperability.

• INCOSE and Object Management Group (OMG) jointly charted Systems Engineering Domain Special Interest Group (SE DSIG) in 2001

• INCOSE, OMG and ISO AP 233 workgroup developed requirements for the modeling language that went into the UML for Systems Engineering RFP issued in 2003
Why use MBSE?

• Improve quality of the exploration medical system design and specification
• Reuse of system specification and system engineering artifacts
• Improves communication within the element and across engineering disciplines
• Finer control of information stored in the model
  • Information is spread across many documents making relationships unclear resulting in increased costs/errors regarding requirements management, verification and impact assessments
• Promotes rigor across all phases of the project lifecycle
• Change to one element propagates through the entire model
• Evolves over the course of the lifecycle
• Used early in the lifecycle to support evaluation of alternatives
• Later phases it is used for subsystem/component development
• Support system integration and verification activities

Potential Drawbacks to consider:
  • Steep learning curve for those new to modeling
  • Established culture / organizations entrenched in parochial approach to system design
  • Requires commitment from all levels of an organization from management to engineers
Document-Based Systems Engineering

Focus is on developing and maintaining a set of documents to capture various aspects of the system such as requirements, interfaces, design and verification.

Challenges include:

• Information being spread across several documents leading to data inconsistency
• Maintaining and reusing the information for an evolving system design
• Understanding particular aspects of system along with traceability and change impact assessment
• Progress of systems engineering effort is based, in part, on documentation status which does not necessarily reflect quality of requirements or technical solution
• Impacts to cost, schedule and quality often show up integration and testing or after the system is delivered to the customer
Why Use a System Model?

• Characterize and assess an existing system
• Specify and design a new or modified system
  • Represent a system concept
  • Specify and validate system requirements
  • Synthesize system designs
  • Specify component requirements
  • Maintain requirements traceability
• Evaluate the system
  • Conduct system design trade-offs
  • Analyze system performance requirements or other quality attributes
  • Verify that the system design satisfies the requirements
  • Assess the impact of requirements and design changes
• Train users on how to operate or maintain a system
• Support system maintenance and diagnostics

Why this is important:
• In-line with our SE approach of providing structured, integrative science and engineering
• Enables increased relevancy to exploration system maturation by communicating in common technical language
# Model-Based vs. Document-Based

<table>
<thead>
<tr>
<th></th>
<th>Model Based</th>
<th>Document Based</th>
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<tbody>
<tr>
<td><strong>Information</strong></td>
<td>• Integrated views from multiple perspectives</td>
<td>• Spread across multiple documents</td>
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<tr>
<td></td>
<td>• Standardized format improves accessibility, analysis and reusability</td>
<td>• Inconsistent format</td>
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<tr>
<td></td>
<td>• Improved communication due to shared understanding across HRP and engineering teams</td>
<td>• Duplication of information</td>
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<tr>
<td><strong>Quality</strong></td>
<td>• Improved traceability between requirements, design, analysis and verification</td>
<td>• Poor synchronization between requirements, design, interfaces and sub-system components</td>
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<td></td>
<td>• Improved impact analysis and design integrity</td>
<td>• Issues likely to be discovered during integration and testing</td>
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<td></td>
<td>• Enhanced ability to manage system complexity</td>
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<tr>
<td></td>
<td>• Automation</td>
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<tr>
<td><strong>Effectiveness</strong></td>
<td>• Improved agility</td>
<td>• Increased costs / risks</td>
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<td>• Reduced cost / lower risk</td>
<td>• Effort to maintain documents impacts design work</td>
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<td>• Reuse of system specification and SE artifacts</td>
<td>• Difficult to track progress of technical solution</td>
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<td>• Quick impact analysis for requirements and design changes</td>
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<td>• More comprehensive trade space analysis</td>
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Systems Engineering Modeling Process

(Model-Based)

- Use Cases
- Requirements
- Scenarios

System
- Architecture

Subsystem
- Architecture

Component Design and Verification

Deployment
- Sys. Integration
- Sys. Verification

Assemble Subsys:
- Subsys. Verification

Integration and Verification
Model Integration

- Understand operational needs and constraints from multiple perspectives (Medical, Crew, Flight Ops, Ground Support, Vehicle/system integration)
- Identify system functions and derive system requirements
- Decompose and allocate requirements to subsystems
- Conduct trade studies and system analysis on design concepts/system components
- Generate documentation
- Identify and track system interfaces
- Determine verification and validation plans
- Collaborate with medical system design team and engineering orgs to facilitate system design and integration
- Track mass properties of medical system
- Manage cost, schedule and risks
- Track and report on technical measures

- Modeling Language - SysML
- Modeling Tool – MagicDraw
- Model Repository - Teamwork Server
- Analysis Tools – IMM, MONSTR, Tableau, Centrifuge
- Requirements Management – TBD
- Project Management – MS Project, Excel and SharePoint
- 7 Modelers located at 4 different NASA Centers (ARC, GRC, JSC and LaRC)
Modeling Process

- What is the scenario narrative? What other systems are involved?
- How does the system behave?
- What functions does the system need to provide?
- How does the system interface with other systems?
- What parts does the system have?
- How are system requirements allocated?