Advancing Systems Engineering Practice using Model Based Systems Development (MBSD)

Systems & Software Technology Conference

26-29 April, 2010

Sanford Friedenthal
Lockheed Martin
sanford.friedenthal@lmco.com
| 1. REPORT DATE | APR 2010 |
| 2. REPORT TYPE | |
| 3. DATES COVERED | 00-00-2010 to 00-00-2010 |
| 4. TITLE AND SUBTITLE | Advancing Systems Engineering Practice using Model Based Systems Development (MBSD) |
| 5a. CONTRACT NUMBER | |
| 5b. GRANT NUMBER | |
| 5c. PROGRAM ELEMENT NUMBER | |
| 5d. PROJECT NUMBER | |
| 5e. TASK NUMBER | |
| 5f. WORK UNIT NUMBER | |
| 6. AUTHOR(S) | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | Lockheed Martin, Cherry Hill, NJ, 08002 |
| 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | |
| 10. SPONSOR/MONITOR’S ACRONYM(S) | |
| 11. SPONSOR/MONITOR’S REPORT NUMBER(S) | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT | Approved for public release; distribution unlimited |
| 13. SUPPLEMENTARY NOTES | Presented at the 22nd Systems and Software Technology Conference (SSTC), 26-29 April 2010, Salt Lake City, UT. Sponsored in part by the USAF. U.S. Government or Federal Rights License |
| 14. ABSTRACT | |
| 15. SUBJECT TERMS | |
| 16. SECURITY CLASSIFICATION OF: | a. REPORT unclassified |
| | b. ABSTRACT unclassified |
| | c. THIS PAGE unclassified |
| 17. LIMITATION OF ABSTRACT | Same as Report (SAR) |
| 18. NUMBER OF PAGES | 23 |
| 19a. NAME OF RESPONSIBLE PERSON | |
Topics

- Model-based Systems Development (MBSD) Motivation and Scope
- System Modeling Using SysML
- System Model as an Integration Framework
- Deploying MBSD into your Organization
- Summary
MBSD Motivation and Scope
Practices for Describing Systems

**Past**
- Specifications
- Interface requirements
- System design
- Analysis & Trade-off
- Test plans

**Future**

Moving from Document centric to Model centric
Model-based Systems Development (MBSD)

- Formalizes the practice of systems development through use of models
- Broad in scope
  - Integrates with multiple modeling domains across life cycle from system of systems to component
- Results in quality/productivity improvements & lower risk
  - Rigor and precision
  - Communications among system/project stakeholders
  - Management of complexity
System Description

• **Document-Based System Engineering:**

  Where is truth?

  ![Document 1](A<B)
  ![Document 2](A=B)
  ![Document 3](A>B)

  Inconsistencies within and among documents

• **Model-Based System Engineering:**

  ![Model Repository]

  Model enforces consistency

© Copyright Lockheed Martin Corporation All Rights Reserved
System Modeling Using SysML
System Modeling

Requirements

Functional/Behavioral Model
- Start
- Shift
- Accelerate
- Brake

Performance Model
- Control Input
- Power Equations
- Vehicle Dynamics

System Model

Structural/Component Model
- Engine
- Transmission
- Transaxle

Other Engineering Analysis Models
- Mass Properties
- Structural Model
- Safety Model
- Cost Model

Integrated System Model Must Address Multiple Aspects of a System
What is SysML?

- A graphical modeling language in response to the UML for Systems Engineering RFP developed by the OMG, INCOSE, and AP233
  - a UML Profile that represents a subset of UML 2 with extensions

- Supports the specification, analysis, design, verification, and validation of systems that include hardware, software, data, personnel, procedures, and facilities

- Supports model and data interchange via XML Metadata Interchange (XMI®) and the evolving AP233 standard (in-process)

SysML is Critical Enabler for MBSE
SysML Diagram Taxonomy

- **SysML Diagram**
  - **Behavior Diagram**
  - **Requirement Diagram**
  - **Structure Diagram**
    - **Activity Diagram**
    - **Sequence Diagram**
    - **State Machine Diagram**
    - **Use Case Diagram**
    - **Block Definition Diagram**
    - **Internal Block Diagram**
    - **Package Diagram**

Legend:
- Same as UML 2
- Modified from UML 2
- New diagram type
4 Pillars of SysML – ABS Example

1. Structure

2. Behavior

3. Requirements

4. Parametrics
System Model as an Integration Framework
MBSD Must Integrate across Modeling Domains

- Ops/Mission Analysis
- Logistics Support
- Manufacturing
- Integration & Test
- Performance Simulation
- Engineering Analysis
- System Design
- Algorithm Development
- Software Design
- Hardware Design
- Human System Integration

© Copyright Lockheed Martin Corporation All Rights Reserved
Using System Architecture Model as an Integration Framework

- Analysis Models: $U(s) \rightarrow G(s) \rightarrow \int \rightarrow$ System Architecture Model
- Verification Models
- Req’ts Allocation & Design Integration
- Hardware Models
- Software Models

© Copyright Lockheed Martin Corporation All Rights Reserved
Using the System Architecture Model to Flowdown Requirements

System-of-System Level
- 1st Level Of Decompositions
- How Our System Contributes to the Overall Mission
  
  Mission Concept of Operations

System Level
- Derives Subsystems
- Allocates Requirements to Subsystems
  
  Trade Studies, Simulation, Specification Reviews, etc.

Element Level
- Derives Hardware and Software Components
- Allocates Requirements to Components

Component Design & Implementation Level

(from John Watson/LMC SysML Info Days presentation)
System Decomposition Process using SysML

1. Analyze System Level Requirements
2. Analyze System Services
3. Identify the Subsystem
4. Analyze Subsystem Collaboration to Satisfy the System Services
5. Incorporate Additional Analysis as Needed
6. Derive and Allocate Requirements to Subsystem

**Continue?**

Yes

- The Subsystem shall .... Derive Requirements

No

- Complete Subsystem Specs

**Trade Studies, R&D, Simulation, Specification Reviews, etc.**

(from John Watson/LMC SysML Info Days presentation)
System Architecture Model to Support Tradeoff Analysis

### Analysis Results

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>Sensor1</td>
<td>Sensor2</td>
<td>Sensor3</td>
</tr>
<tr>
<td>Processor</td>
<td>Processor1</td>
<td>Processor2</td>
<td>Processor3</td>
</tr>
<tr>
<td>Control</td>
<td>Control1</td>
<td>Control2</td>
<td>Control3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Alt 1</th>
<th>Alt 2</th>
<th>Alt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>0.5</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.2</td>
<td>4</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Cost</td>
<td>0.3</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Effectiveness</td>
<td></td>
<td>5.2</td>
<td>4.2</td>
<td>5.9</td>
</tr>
</tbody>
</table>

### Optimization

- **Objective Function**
  \[ E = \text{Sum} \left( w_1 u_1 P + w_2 u_2 R + w_3 u_3 C \right) \]

- **Effectiveness**

© Copyright Lockheed Martin Corporation All Rights Reserved
Integrating SysML with Simulation

GIT* Project

Modelica Lexical Representation
(auto-generated from SysML)

[Johnson, 2008 - Masters Thesis]

* Georgia Institute of Technology
Deploying MBSD into Your Organization
Deploying MBSD as part of Improvement Process

ASSESS
Assess the state of your practice

DEPLOY
Incrementally integrate changes into the current workflow

PLAN
Plan the improvement

PILOT
Pilot the practice and tailor the approach

CODIFY
Codify the practice

Infrastructure & Support Practices Tools Training

© Copyright Lockheed Martin Corporation All Rights Reserved
Transition from document-centric to model-centric is a cultural change

Well defined MBSE method is essential

Multiple tool vendors provide a range of price point, capability, and standards conformance

MBSE training should include language, method, and tools

Employ pilots to validate your MBSE approach

Need buy-in from program and customer on MBSE benefits, approach and deliverables

Scope model to support program objectives and within program constraints

A lot has been learned, but much more remains
Summary

- MBSD is a key practice to advance complex systems development
- Standards such as SysML and UML are critical enablers of MBSD
- Multiple tool vendors implementing SysML
- System architecture model and standards based approach facilitate integration across modeling domains
- Growing interest and application of MBSD
Acronyms

- MBSD – Model-based Systems Development
- MBSE – Model-based Systems Engineering
- OMG – Object Management Group
- SysML – Systems Modeling Language
- UML – Unified Modeling Language