Using Model-Based System Engineering to Provide Artifacts for NASA Project Life-cycle and Technical Reviews

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My Background

My experience:

• 10+ years as a system engineer
• 8 years working with Model-Based System Engineering (MBSE)
• Utilized MBSE across various projects on multi-center teams
• Taught basic MBSE classes
What is Model-Based System Engineering

Model shows the interrelationship of the data defining the system.

Stand alone documents

SRD
ICD
ConOps
REQ

SRD
ConOps
NASA Glenn System Engineers have investigated MBSE through:

- Training
- Exploratory uses
- Working Groups
- Implementing on projects over the past 4+ years: multi-center
Realization of Gap

System Engineers are trained to use a modeling tool but still are asking themselves . . .

• How can I use this on my project?
• Where do I start?
• What information is required for the model?
• How do I capture the data within the model?
• How do I show this information?
• What types of products am I trying to produce from the model?
• How do I know that I have all the right information and at the correct level?

The guidelines provided help to answer the above questions for developing review products.
**Review Products**

NASA Procedural Requirements 7123.1B “NASA Systems Engineering Processes and Requirements,” which outlines:

- Required products
- Required reviews
- Maturity of the products

<table>
<thead>
<tr>
<th>Products</th>
<th>Formulation</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KDP 0</td>
<td>KDP 1</td>
</tr>
<tr>
<td></td>
<td>KDP 0</td>
<td>KDP 1</td>
</tr>
<tr>
<td>Projects and single Project Programs</td>
<td>Pre-Phase A</td>
<td>Phase A</td>
</tr>
<tr>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
</tr>
<tr>
<td>MCR</td>
<td>SRR</td>
<td>MDR/SDR</td>
</tr>
</tbody>
</table>

- Stakeholder identification and expectations definition: **Baseline**
- Concept definition: **Baseline**
- Measure of Effectiveness definition: **Approve**
- Cost and schedule for technical implementation:
  - Initial
  - Update
  - Update
  - Baseline
  - Update
  - Update
  - Update
  - Update
  - Update
  - Update
  - Update
  - Update

1. SEMP
2. SEMP

**Baseline** indicates a key milestone or critical review point; **Approve** indicates a decision point requiring review and approval.
# System Engineering Product Categories

<table>
<thead>
<tr>
<th>Concept &amp; Design</th>
<th>Requirements and Verification &amp; Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plans</td>
<td>Metrics</td>
</tr>
</tbody>
</table>
Metrics Category Product Listing

- Cost and Schedule for Technical Implementation
- Measures of Effectiveness (MOE)
- Measures of Performance (MOP)
- Required Leading Indicator Trends
- Technical Performance Measures (TPM)
Key Focus Areas

1. **Artifacts**
   - How the traditional SE products are seen as model artifacts in the modeling world.

2. **Model elements and relationship**
   - What model elements and relationships could be used to capture the project data in order to generate the artifacts.

3. **Model validation**
   - Common questions to evaluate if your modeling task are complete.

4. **More detail**
   - Extra information associated with the SE Product
Applicability

• **Who**
  – System Engineers
  – Project Managers
  – Customers
  – Review Board members
  – Other key project stakeholders

• **What it provides..**
  – Initial guidance on where to start in order to develop system engineering products using MBSE
  – Aid in translating document-centric products into model-centric products
  – Knowledge to non-modelers about what model can do for them
Functional Examples

Walk-thru 2 examples on how document-centric products can be captured in a model, using the previously mentioned focus areas:

1. Metrics: using a Mass Roll-up for demonstration which is typically a Technical Performance Measures (TPM)

2. Plan: using the System Engineering Management Plan which is a living document that changes throughout its life-cycle and information used in the plan may or may not be stored inside the model

At the bottom of each page will show what focus area that the information can be found in.
### Example 1: Product Artifacts: Metrics

<table>
<thead>
<tr>
<th>MOE/MOP/TPM Products</th>
<th>Model Artifact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metric</strong></td>
<td><strong>Instance</strong></td>
</tr>
<tr>
<td>Metric to Needs Goals and Objective(s) traceability</td>
<td><strong>Table</strong></td>
</tr>
<tr>
<td>Metric to requirements traceability</td>
<td><strong>Table</strong></td>
</tr>
<tr>
<td>MOE, MOP and TPM decomposition</td>
<td><strong>Relationship Matrix</strong></td>
</tr>
<tr>
<td>Tracking trends</td>
<td><strong>Instance Tables</strong></td>
</tr>
</tbody>
</table>

**Artifacts**

- Model Elements and Relationships
- Model Validation
- More Detail
Example 1: Mass Roll-up Instance

Instance Example

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>P_ML: mass limit</th>
<th>totalMass: kg</th>
<th>system 1:totalMass: kg</th>
<th>system 2:totalMass: kg</th>
<th>system 3:totalMass: kg</th>
<th>system 3a:totalMass: kg</th>
<th>system 3b:totalMass: kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>project 06-01-2016</td>
<td>pass</td>
<td>75.0</td>
<td>10.0</td>
<td>15.0</td>
<td>50.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
</tbody>
</table>
### Example 1:
**Model Elements and Relationships: Metrics**

<table>
<thead>
<tr>
<th>MOE, MOP and TPM</th>
<th>Model Element and Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>System &amp; subsystem</td>
<td>Block</td>
</tr>
<tr>
<td>Value used in calculating parameter(s)</td>
<td>Value attribute within the system/subsystem/component block it represents</td>
</tr>
<tr>
<td>Metric value associated with MOE/MOP/TPM</td>
<td>Parameter owned by a constraint block</td>
</tr>
<tr>
<td>Equation to calculate parameter(s)</td>
<td>Constraint block - The parametric diagram assigns the values for which the equation need to execute</td>
</tr>
<tr>
<td>Results from calculations</td>
<td>Instances (generated from the equations)</td>
</tr>
</tbody>
</table>

**Artifacts**
- Model Elements and Relationships
- Model Validation
- More Detail
Example 1: Mass Roll-up Equation

Equation:

\[ \text{MassSum : Total\_mass} \]
\[ \{ \text{total} = \text{parent} + \sum(\text{child}) \} \]

Parameter Values:

- \( \text{totalmass : kg} \)
- \( \text{mass : kg [1]} \)
- \( \text{totalmass : kg} \)
## Example 1: Mass Roll-up Instance Table for Trending

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>P_ML : mass limit</th>
<th>totalMass : kg</th>
<th>system 1.totalMass : kg</th>
<th>system 2.totalMass : kg</th>
<th>system 3.totalMass : kg</th>
<th>system 3 subsystem 3a.totalMass : kg</th>
<th>system 3 subsystem 3b.totalMass : kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>project 06-01-2016</td>
<td>pass</td>
<td>75.0</td>
<td>10.0</td>
<td>15.0</td>
<td>50.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>2</td>
<td>project 09-01-2016</td>
<td>pass</td>
<td>95.1</td>
<td>10.1</td>
<td>25.0</td>
<td>60.0</td>
<td>25.0</td>
<td>35.0</td>
</tr>
<tr>
<td>3</td>
<td>project 06-05-2017</td>
<td>pass</td>
<td>93.1</td>
<td>10.1</td>
<td>25.0</td>
<td>58.0</td>
<td>21.0</td>
<td>37.0</td>
</tr>
<tr>
<td>4</td>
<td>project 06-06-2017</td>
<td>pass</td>
<td>93.1</td>
<td>10.1</td>
<td>25.0</td>
<td>58.0</td>
<td>21.0</td>
<td>37.0</td>
</tr>
<tr>
<td>5</td>
<td>project 06-10-2017</td>
<td>fail</td>
<td>110.3</td>
<td>22.3</td>
<td>28.0</td>
<td>60.0</td>
<td>21.0</td>
<td>39.0</td>
</tr>
</tbody>
</table>
## Example 1: Model Validation Questions: Metrics

<table>
<thead>
<tr>
<th>Validation Question</th>
<th>Validation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which MOP or TPM satisfy a concern?</td>
<td>Table showing the MOP and TPM with their related model elements via the satisfy relationship.</td>
</tr>
<tr>
<td>Which MOP and TPM are related to a requirement, system or subsystem?</td>
<td>Table showing the MOP and TPM with their related model elements. The relationship used is dependent on the project.</td>
</tr>
<tr>
<td>Have the constraint equations been implemented correctly in the model?</td>
<td>Run a known configuration to show that the model configuration produces the expected results.</td>
</tr>
</tbody>
</table>
### Example 2: Product Artifacts: SEMP

<table>
<thead>
<tr>
<th>SEMP artifacts</th>
<th>Model Artifact</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMP Document</td>
<td>Output from the model using information from within the model, in addition to information that supplements model-generated content</td>
</tr>
<tr>
<td>System Decomposition</td>
<td>Block definition diagram</td>
</tr>
<tr>
<td>Work Breakdown Structure (WBS) Layout</td>
<td>Block definition diagram</td>
</tr>
<tr>
<td>Technical Summary of SEMP sections</td>
<td>Artifact</td>
</tr>
<tr>
<td>Responsibility and organizational structure</td>
<td>Block definition diagram and allocation matrix</td>
</tr>
<tr>
<td>External or NASA Standard</td>
<td>Block that contain attributes with external hyperlink</td>
</tr>
<tr>
<td>Processes</td>
<td>Activity diagrams</td>
</tr>
</tbody>
</table>
Example 2: SEMP Artifacts

WBS Structure

WBS Allocation Matrix
### Example 2:
**Model Elements and Relationships: SEMP**

<table>
<thead>
<tr>
<th>SEMP</th>
<th>Model Element and Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMP</td>
<td>Package or content diagram</td>
</tr>
<tr>
<td>Textual content</td>
<td>Artifact or comment</td>
</tr>
<tr>
<td>Personnel and organizations associated with the project</td>
<td>Actors</td>
</tr>
<tr>
<td>System component</td>
<td>Block</td>
</tr>
<tr>
<td>WBS structure</td>
<td>Block</td>
</tr>
<tr>
<td>Project process activities</td>
<td>Action block or call behavior action block</td>
</tr>
<tr>
<td>Organizational task allocation</td>
<td>Swim lanes</td>
</tr>
<tr>
<td>Data interactions</td>
<td>Activity parameter nodes and pins on the action block</td>
</tr>
</tbody>
</table>

**Artifacts**  
Model Elements and Relationships  
Model Validation  
More Detail
Example 2: SEMP Artifact Organization

SEMP Structure

- 1.0 Purpose & Scope
- 2.0 Applicable Documents
- 3.0 Technical Summary
  - 3.1 System Description
  - 3.2 System Structure
  - 3.3 Product Integration
- 4.0 Technical Effort Integration
- 5.0 Common Technical Processes Implementation
- 6.0 Technology Insertion
- 7.0 Additional SE Functions and Activities
  - 7.4 Technical Performance Measures
- 8.0 Integration with the Project Plan and Technical Resource Allocation
- 9.0 Compliance Matrices
**Example 2:**
**Model Validation Questions: SEMP**

<table>
<thead>
<tr>
<th>Validation Question</th>
<th>Validation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the model have all the processes that are required in a SEMP?</td>
<td>Package diagram or content diagram and verify that all required sections contain the pertinent information.</td>
</tr>
<tr>
<td>Do the WBS elements have allocations to an organization or role?</td>
<td>Matrix with all the WBS allocated to an organization or role.</td>
</tr>
</tbody>
</table>
Summary

• Gap between learning MBSE and the application of those skills is often significant

• The information and examples in this paper are intended to increase the use of MBSE

• Work presented is limited to the primary products for project life-cycle and technical reviews based on NPR 7123.1B

• A SysML system model can contain or generate most systems engineering products to a significant extent
QUESTIONS