Cost Credibility Enhancements with SRL and MBSE Advanced Tools

May 17 - 20, 2021

Patrick Malone
MCR Space Programs
Topics

• Overview
• History
• Advanced Tools
• System Readiness Levels
• Model Based System Engineering
• Implementation
• Benefits
• Conclusions and Future Study
Agenda

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Overview

• GAO 2019 17th year review of Selected Defense Systems+ reveals
  • 51% of programs had cost growth, median of 35% growth*
  • Schedule delays averaged 27 months (2.3 yrs) or more to IOC
  • Decision makers confronted with difficult choices a) increasing program investments, or b) truncating the program and subsequently depriving warfighters of a needed capability.

• Problem
  • Limited use of Knowledge-Based Practices Continues to Undercut DoD’s Investments (GAO finding)
  • Attaining adequate knowledge prior to development start is difficult
  • Developing an objective assessment is needed
  • Over confidence in maturity assessment prevails
    • Leading to cost and schedule growth
    • Higher than expected defects
    • Less than optimized performance or capability
  • Optimistic estimates of cost and time to mature before Milestone B
  • Lack of a repeatable process

* 7 of the top 10 programs reviewed for the 2016 report

+Source: GAO-19-336SP

Getting on the list
– Graded high risk
– Five criteria
– Usually not met

Getting off the list
– Action plan
  • To fully meet
  • Partially met to minimize impacts

Source: GAO-15-290 High Risk Series
Overview

- DoD Lifecycle contains major milestones tied to system knowledge
- GAO Knowledge Point Framework supports the major milestones
- TRLs Historically follow a specific maturity requirement (TRL 6/7 by MS B)
- SRLs highlight maturity areas to focus resources
Overview (Cont.)

• **Solutions**
  • A early focus on system knowledge
  • Application of advanced tools
    • System Readiness Levels
    • Model Based System Engineering

• **Results**
  • Implementing best practices early
    • Accelerates knowledge attainment
    • Identifies risk areas to be mitigated
    • Significantly reduces potential system defects
  • Adds confidence meeting initial cost and schedule estimates
  • Enhances end-to-end modelling and simulation capability to assess system performance
  • Drives repeatable processes for future application

Knowledge Point Framework Contains in-depth queries to obtain a clear understanding of the System Development
• Historically 80% of program costs are committed when only 15% of costs are spent
• The later defects and system deficiencies are found the more costly to mitigate and resolve
Overview (cont.)

• Knowledge Point Requirements
  • KP1 – Resources and Requirements Match
  • KP2 – Product Design is Stable
  • KP3 – Manufacturing Processes are Mature

Knowledge Point Framework criteria

KP1 Practices
- Demonstrate all critical technologies are very close to final form, fit and function within a relevant environment
- Demonstrate all critical technologies are in form, fit and function within realistic environment
- Complete preliminary design review before system development start

KP2 Practices
- Release at least 90 percent of design drawings to manufacturing
- Test a system-level integrated prototype

KP3 Practices
- Demonstrate critical manufacturing processes are in statistical control
- Demonstrate critical processes on a pilot production line
- Test a production-representative prototype in its intended environment

Program best practice performance metrics
- 75 – 100 percent
- 50 – 74 percent
- 0 – 49 percent
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2009

2019
Top 10 DoD Programs Reviewed in 2019

Many MDAPs continue to experience cost and schedule growth
History

- Programs begin with limited information
  - Technical maturity may be lacking
  - Cost and schedules are often optimistic
- Less detailed knowledge leads to
  - Unexpected capability gaps
  - Cost and schedule growth
  - Nunn-McCurdy breaches

GPS III

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2019</th>
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<tbody>
<tr>
<td>Procurement Cost Growth</td>
<td>14.3%</td>
<td>50.1%</td>
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<tr>
<td>Program Unit Cost Growth</td>
<td>16.3%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Total Quantities Start/Current</td>
<td>8/8</td>
<td>8/10</td>
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</table>
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Advanced Tools

- **System Readiness Levels**
  - Evaluates Technology and Integrations
  - Provides a system level interpretation

- **Model Based System Engineering**
  - Models system early
  - Identifies latent issues for corrective action
  - Enables robust V&V
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System Readiness Levels - Method

- SRL: f(TRL, IRL)

\[
\text{SRL} = \text{IRL} \times \text{TRL}
\]

\[
\begin{pmatrix}
\text{SRL}_1 \\
\text{SRL}_2 \\
\text{SRL}_3
\end{pmatrix} =
\begin{pmatrix}
\text{IRL}_{11} & \text{IRL}_{12} & \text{IRL}_{13} \\
\text{IRL}_{12} & \text{IRL}_{22} & \text{IRL}_{23} \\
\text{IRL}_{13} & \text{IRL}_{23} & \text{IRL}_{33}
\end{pmatrix}
\times
\begin{pmatrix}
\text{TRL}_1 \\
\text{TRL}_2 \\
\text{TRL}_3
\end{pmatrix}
\]

Composite SRL = \(1/n(\text{SRL}_1/n + \text{SRL}_2/n + \text{SRL}_3/n)\)

= \(1/n^2(\text{SRL}_1 + \text{SRL}_2 + \text{SRL}_3)\)

SRL approach highlights strengths and weaknesses in trade space
# SRL – TRL and IRL Definitions

<table>
<thead>
<tr>
<th>TRL/IRL</th>
<th>TRL Definition</th>
<th>IRL Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic principles observed and reported</td>
<td>An <strong>Interface</strong> between technologies has been identified with sufficient detail to allow characterization of a relationship</td>
</tr>
<tr>
<td>2</td>
<td>Technology concept and/or application formulated</td>
<td>There is some level of specificity to characterize the <strong>Interaction</strong> (i.e. ability to influence) between technologies through their interface.</td>
</tr>
<tr>
<td>3</td>
<td>Analytical and experimental critical function and/or characteristic proof of concept</td>
<td>There is <strong>Compatibility</strong> (i.e. common language) between technologies to orderly and efficiently integrate and interact.</td>
</tr>
<tr>
<td>4</td>
<td>Component and/or breadboard validation in a laboratory environment</td>
<td>There is sufficient detail in the <strong>Quality and Assurance</strong> of the integration between technologies.</td>
</tr>
<tr>
<td>5</td>
<td>Component and/or breadboard validation in a relevant environment</td>
<td>There is sufficient <strong>Control</strong> between technologies necessary to establish, manage, and terminate the integration.</td>
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<td>System/subsystem model or prototype demonstration in a relevant environment</td>
<td>The integrating technologies can <strong>Accept, Translate, and Structure Information</strong> for its intended application.</td>
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<td>System prototype demonstration in an operational environment</td>
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</tr>
<tr>
<td>9</td>
<td>Actual system proven through successful mission operations.</td>
<td>Integration is <strong>Mission Proven</strong> through successful mission operations.</td>
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## SRL Maturity Compare and Contrast

<table>
<thead>
<tr>
<th>TRL Normalized</th>
<th>SRL</th>
<th>Acquisition Phase</th>
<th>Definitions</th>
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<tbody>
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<td>0.9</td>
<td>3.5</td>
<td>0.10 - 0.39</td>
<td>Concept Development</td>
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<td>0.40 - 0.59</td>
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<td>5.4</td>
<td>7.1</td>
<td>0.60 - 0.79</td>
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<td>7.2</td>
<td>8.0</td>
<td>0.80 - 0.89</td>
<td>Production</td>
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<td>8.1</td>
<td>9.0</td>
<td>0.90 - 1.00</td>
<td>Operations and Support</td>
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</table>
Maturity and Knowledge Across the Lifecycle

- Cross Referencing tools and techniques by program lifecycle guides analysis
  - Program Formulation
  - Development
  - Flight
  - Operations
- Lack of knowledge can impact performance metrics

<table>
<thead>
<tr>
<th>TRL/IRL</th>
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<th>SRL</th>
<th>GAO Knowledge Point</th>
<th>Acquisition Milestones</th>
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<tr>
<td>0.9</td>
<td>0.1</td>
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<td>Material Decision</td>
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<td>Milestone A</td>
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<td>Alternatives</td>
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<td>3</td>
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<td>3.5</td>
<td>SRR</td>
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<td>SFR</td>
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<td>5</td>
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<td>KP 1</td>
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<td>8.1</td>
<td>KP 3</td>
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<td>9</td>
<td>9</td>
<td>9.1</td>
<td>FOC</td>
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Cost and Time to Mature

- In a prior paper
  - Cost Corrections to mature technology were developed based on
    - NASA historical data
    - DoD historical data
  - Time to mature by technology group was also developed

- Expanding to SRLs
  - Application of TRL data
  - Shows consistent results
Cost to Mature

• Cost Correction Factor is normalized to TRL7
• Used as a basis for the analysis
• Work done by Dubos et al provide a range of time to mature
• Analysis of SAR data (Smoker) falls between the mean and upper limits
• Supports uncertainty boundary's
• Integrated with our analysis
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Document-based System Engineering
Many places for information

Model-based System Engineering
Single source for information

Trending
MBSE

- Starts at concept definition
- Consolidates numerous tool sets
  - Requirements, ICDs, SWaP
  - Cost, schedule
  - Document control
- Shows key integration points
- Continues throughout lifecycle
- Identifies risks early
- Reduces defects
MBSE (cont.)

- Complete thread
- Connected hubs to support decision points
- Interactive models
- SysML modeling language continues to mature
Why MBSE?

- Systems and SoS are becoming more complex
  - Higher part count
  - More Software
- Time to market (capability)
  - Increases significantly
  - Can be obsolete at release
  - Misses critical need dates
- Long-Range
  - Reduce time to market
  - Meet Affordability Goals

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Implementation

1. Define Mission Need
2. Identify key system attributes
3. Choose candidate technologies
4. Identify MBSE methodologies
5. Perform SRL assessment
6. Design system architecture
7. Detailed Design and Analysis
8. System development
9. Testing
10. Verification and Validation
11. Fielding (IOC)
12. O&S
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Benefits

• Compare and contrast
  • Classical SE
    • Limited cross communication
    • TRL limited to primary technology
    • Manual requirement updates
    • Defect identification later in lifecycle where cost can be extensive
  • MBSE/SRL
    • Integrates communication paths
    • Highlights risk areas
    • SRL highlights primary technology and Interfaces
    • Instant requirement updates
    • Defect identification early where cost are minimal
Benefits (cont.)

- Concept Development
- Concept Refinement
- Technology Development
- Engineering & Manufacturing Development
- Production & Deployment
- Operations & Sustainment

**Materiel Solution Analysis**
**TMRR**
**Pre-Systems Acquisition**
**MS-A**
**PDR**
**CDR**
**System Acquisition**
**MS-B**
**LRIP**
**FRP**
**Sustainment**
**MS-C**
**IOC**
**FOC**

**MBSE Defect Identification**

**MBSE Development Effort**

**Document-Based SE Classic Effort**

**Classical SE Defect Identification**

**Cost to Make Changes**
**Options to Make Changes**

**MBSE**
**Document-Based SE**
**Cost to Make Changes**
**Options to Make Changes**
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Systems and SoS complexity continues to grow fostering more effective Engineering Tools
Conclusions

• GAO Knowledge point Framework reduces risk
• Technology Readiness Levels serve as a guide
• System Readiness Levels
  • Add insight and visibility
  • Add fidelity to TRLs & Integrations
  • Provide Metrics to focus resources
• MBSE Methods
  • Enhance system definition
  • Open up communication paths
  • Minimize defects
  • Accelerate cost avoidance
  • Add capability confidence
Future Study

- Continue monitoring Modeling tools as they add capability across the lifecycle
- Evaluate figure of merit for cost avoidance early in the program lifecycle to
  - Measure MBSE to Document based SE
  - Estimate ROI when including cost avoidance at defect identification
- Research estimating relationship changes from classical SE approaches
Questions
References

1. GAO-09-326SP Assessments of Major Weapon Programs, 2009
2. GAO-19-336SP Assessments of Major Weapon Programs, May 2019
3. GAO-15-290 High Risk Series
4. INCOSE Guide to the Systems Engineering Body of Knowledge (SEBoK), version 2.2, 2019
Acronyms

- CCF  Cost Correction Factor
- CER  Cost Estimating Relationship
- DBSE  Document-based System Engineering
- DoD  Department of Defense
- EMD  Engineering Manufacturing Development
- FOC  Full Operational Capability
- GAO  Government Accountability Office
- GPS  Global Positioning System
- ICD  Interface Control Document
- INCOSE  International Council On Systems Engineering
- IOC  Initial Operational Capability
- IPT  Integrated Product Team
- IRL  Integration Readiness Level
- KP  Knowledge Point
- MBSE  Model-based System Engineering
- MDAP  Major Defense Acquisition Program
- MS  Milestone
- NASA  National Aeronautics and Space Administration
- NPV  Net Present Value
- NPW  Net Present Worth
- O&S  Operations & Sustainment
- ROI  Return on Investment
- SAR  Selective Acquisition Report
- SE  System Engineering
- SoS  System of Systems
- SRL  System Readiness Level
- SWaP  Size, Weight and Power
- TMRR  Technology Maturity and Risk Reduction
- TRL  Technology Readiness Level
- UL  Upper Limit
Backup
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<td>Component and/or breadboard validation in a laboratory environment</td>
<td>There is sufficient detail in the Quality and Assurance of the integration between technologies.</td>
<td>Technology Development</td>
<td>Reduce technology risks and determine appropriate set of technologies to integrate into a full system.</td>
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<td>There is sufficient Control between technologies necessary to establish, manage, and terminate the integration.</td>
<td>Technology Development</td>
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<td>System/subsystem model or prototype demonstration in a relevant environment</td>
<td>The integrating technologies can Accept, Translate, and Structure Information for its intended application.</td>
<td>Engineering Manufacturing Development</td>
<td>Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.</td>
<td>0.6</td>
<td>CDR</td>
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<td>Actual system completed and qualified through test and demonstration</td>
<td>Actual integration completed and Mission Qualified through test and demonstration, in the system environment</td>
<td>Production and Deployment</td>
<td>Achieve operational capability that satisfies mission needs.</td>
<td>0.8</td>
<td>IOC</td>
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<td>8.1</td>
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<td>Actual system proven through successful mission operations.</td>
<td>Integration is Mission Proven through successful mission operations.</td>
<td>Operations and Support</td>
<td>Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total lifecycle.</td>
<td>0.9</td>
<td>FOC</td>
</tr>
</tbody>
</table>