AVSI’s System Architecture Virtual Integration Program:

Proof of Concept Demonstrations

Don Ward, TEES SAVI Program Manager
Presentation to the INCOSE MBSE Workshop

January 27, 2013    Jacksonville, Florida
Outline

- SAVI Proof of Concept
  - Motivation for Virtual Integration
  - Phase 1 – Proof of Concept
  - Phase 2 – Expanded Proof of Concept
  - Phase 3 – Initial Shadow Projects
  - Results

- Program Status

- Next Steps
MOTIVATION FOR SYSTEMS ARCHITECTURE VIRTUAL INTEGRATION (SAVI)
The trend is to add features / functionality

- *Functionality is often implemented in software*
- *Size and complexity are growing exponentially*
  - Software-based systems are becoming dominant
  - This marriage of hardware/software enables systems of systems

**Examples**

Portable phones

Airliner cockpits
One Measure of Complexity

Growth of Software Lines of Code

*Slope = 0.17718
Intercept = -338.5
Curve implies SLOC doubles about every 4 years

Root Causes

New integration problems result from combining:
- Rapid technological advancement and obsolescence
- Increasingly complex hardware and software evolution
- Migration to increasingly software-based systems

Increased software → increased interfaces → increase in integration problems
- Software interfaces not as “transparent” as mechanical interfaces - goes beyond inputs and output
- Most complex system interfaces cross multiple suppliers (hardware and software)

Complicating Issues - It’s not going to get better, it’s only going to get worse
- Increased software lines of code
- Increased integration, verification and validation efforts
One Approach to the Problem

Industry is moving toward Model-Based

- Engineering
- Development
- Manufacturing
- Production
- Verification
- Validation
- Integration

For both Systems and Software

EXPLOSION IN MODELS
A Fundamental Concern

- The complete Model Set for a system needs to be in compliance (i.e. consistent)
  - with the top-level specification of what is intended/wanted/required
  - with the physics of the system environment
- Do the Models within the Model Set need to be consistent with each other?

*If they are not consistent, then there are multiple truths about the system in the Model Set*
SAVI Program Concepts

1. Start integrated, stay integrated
2. Integrate, analyze, *then* build
3. Architecture-centric, single truth – Model Repository
4. Distributed and Heterogeneous – Data Exchange Layer
5. Standards based
6. Semantically precise for quantitative analyses
7. Mixed maturity development – incremental V&V
8. Support the business case
9. Collaborate – leverage “Best-In-Class”
As-Is to To-Be → Single Truth

- Models from multiple design teams contain multiple interdependent properties
  - Each design team identifies multiple ways of modeling (abstracting) these common properties - multiple models and tools
    - Each team abstracts properties in different ways
    - Each team’s approach to modeling common properties may not be equivalent

- Results: multiple truths
Multiple Groups/Tools/Repositories

Airframer
Sales
Engineering
Manufacturing
Service
Model Repository

Data Exchange/Translation

Supplier 1
Supplier 2
Customer 1
Customer 2
Regulator

1/27/2013
Late Discovery of Problems

Where faults are introduced
Where faults are found
The estimated nominal cost for fault removal

80% of accidents due to operator error
High recertification cost of design error corrections leads to 75% of operator time spent in work-arounds

System-level fault propagation due to incomplete/inconsistent requirements and mismatched assumptions.

Rework and certification dominates development cost

20%, 16% 5x 3-6x

20.5% 110x

70%, 3.5% 1x

10%, 50.5% 16x

10%, 9% 40x

0%, 1% 20-100x

500-1000x

Venkat Mani


INCOSE 2010
POC PHASE 1 RESULTS
AFE 58 As-Is Acquisition Process

As-Is Process

1. Develop / Update System Requirements
2. System Concept Development
   - System Conceptual Design
     - System-Level System Requirements Review
       - System Preliminary Design
         - System Design Data
           - System-Level Critical Design Review
             - System Design Data
               - System-level Integration Test
                 - System Design Data
                   - System Production

3. Source Selection RFI Phase
4. RFI Response
5. Source Selection RFP Phase
6. Subsystem Acquisition

[system feedback]

- New/modified subsystems
- [feedback]
- [feedback]
- [feedback]
- [feedback]
- [feedback]
- [feedback]
AFE 58 To-Be Acquisition Process

To-Be Process

Start Integrated

- Develop / Update SAVI-Compliant System Requirements
  - Source Selection RFI Phase
  - Source Selection RFP Phase

Model-Based System Concept Development
- Model-Based System Conceptual Design
  - Subsystem Acquisition
  - System-Level System Requirements Review
  - System-Level Critical Design Review

Model-Based System Preliminary Design
- Subsystem Test Article
  - System-level Integration Test

Model-Based System Design Data
- System Production
  - Stay Integrated

Model-Based System Design Description
- System Detailed Design
  - Model-Based System Design Data

Model-Based System Concept Development [new/modified subsystems]

SAVI Technology works properly only when the Develop/Update System Requirements, System Concept Development, and System Conceptual Design activities deploy a standardized model-based design and requirement development approach. Model-based Systems Engineering is not a small change.

These look like minor changes ... but ...

[system feedback]
[system feedback]
[system feedback]
AFE 58 PoC Models

Top Level Abstraction: Tier1 A/C Model
*PowerPoint Representation*

- Air Conditioning
- Cockpit
- Navigation
- Engines
- Electrical Flow
- Flight Guidance
- Electrical Power
- Hydraulics
- Fuel
- APU
- Landing Gear
- Air Flow
- Fuel Flow
- Hydraulics Flow

Second Level Abstraction: Tier 2 Flight Guidance System
*AADL Model in Graphic Form*

Multi levels ➔ all systems levels, single system level
Multi-criteria ➔ weight, power, …
Analysis based on the same hierarchical description

More detailed AADL representation of a system

 Third Level Abstraction: Tier 3 Air Data Subsystem
*AADL Model in Graphic Form*
Connection Consistency

AADL is a strongly-typed Architectural Definition Language

- Generates code that supports analysis
- Allows consistency checking to be implemented
AFE 58 Return on Investment

*Estimation flow – software dominates*

1. Estimate the Benefit

   - Onboard SLOC
   - Run COCOMO II
   - Cost of Onboard SLOC
   - Apply Rework and Reuse Model
     - Cost of Rework for New Code
     - Apply Error Models
     - Cost Avoidance with SAVI

2. Estimate the Cost

   - WBS
   - Apply Estimates
   - Cost to Develop SAVI

3. Estimate ROI

   \[ \text{ROI} = \frac{NPV(\text{Cost avoidance with SAVI implemented discounted @ 10\%})}{NPV(\text{Cost to develop SAVI...discounted @ 10\%}) \times \text{Years}} \]

*COCOMO II Results* (Multiplier of 1.55 used to include hardware effects)

<table>
<thead>
<tr>
<th></th>
<th>NPV (Cost Avoidance)</th>
<th>Total Cost Avoidance</th>
<th>NPV (Cost to Develop)</th>
<th>ROI % per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pessimistic</td>
<td>$64 M</td>
<td>$99 M</td>
<td>($85.7 M)</td>
<td>2%</td>
</tr>
<tr>
<td>Expected</td>
<td>$256 M</td>
<td>$398 M</td>
<td>($85.7 M)</td>
<td>40%</td>
</tr>
<tr>
<td>Optimistic</td>
<td>$768 M</td>
<td>$1.193 B</td>
<td>($85.7 M)</td>
<td>144%</td>
</tr>
</tbody>
</table>
## AFE 58 Road Map

### Based on Assumptions Prior to 2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SAVI PROJECT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVI Process description v1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Bus &amp; Model Repository Specs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADL Selected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SAVI DEPLOYMENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVI Tools pre-implementation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encapsulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional at model level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interfaces &amp; existing models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version mgt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADL visualization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADL &amp; models exchanges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety, functions, weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulation app. gen.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SAVI v1.0</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SAVI v2.0</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SAVI v3.0</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COMMUNICATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial Supply Chain integration (SAVI partners)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tools Vendors (partners)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airframer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suppliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AIRCRAFT APPLICATIONS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Architecture design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prelim. system design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aircraft program</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVI partners</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All suppliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AFE 58 Assessment

- Will AFE 58 sufficiently evaluate the technical risks to know that SAVI is possible?
  - Yes: we have demonstrated the key concepts and technologies to a level that will reduce technical risk to an acceptable level for the participating member companies.

- Will the ROI development reasonably scope the financial commitment and potential return for participating member companies?
  - The ROI methodology is very conservative - built on accepted precedent and explicit assumptions and validated with multiple sources of data. It will allow participating companies to fine tune the ROI for their own, unique situations.

- Is the SAVI program too ambitious for AVSI?
  - Jury is out: member companies must individually assess the validity of the ROI and the level of technical risk in the context of their own business environments. AFE 58 demonstrates feasibility (it can be done) and points to mutually benefits with the right level of resource commitment. The upside potential benefits are very enticing, but it requires considerable investment to reap the benefits. We will need to be innovative in structuring the path forward to make this palatable to participants.
EPOC PHASE 2 RESULTS
Revised Road Map

Incremental Development Emphasized


SAVI 1.0A  SAVI 1.0B SAVI 1.0C SAVI 1.0D
SAVI Process Description V1.0
Model Bus & Data Exchange Layer Specification V1.0

SAVI DEPLOYMENT

SAVI Tools pre-implementation
Encapsulation
Functional
Functional at model level
Interfaces & existing models
Version management

Basic production
ADL Visualization
ADL & models exchanges
Functions, weight
Simulation app. gen.

SAVI Version 1.0

COMMUNICATION

Partial Supply Integration (SAVI partial)
Tool Vendors (partners)
SAVI 1.0 Pilots SAVI 1.0 Pilots

Original Plan

More Realistic Incremental Growth

Partners includes all participants


First TVP

2012

2013

Incremental Development Emphasized
AFE 59 Use Case Demonstrations

- “Fit” Demonstration
  - *Electronic Case Element*

- Reliability Demonstration
  - *MTBF Model*
  - *Interface with Moebis*

- Safety Demonstration
  - *FHA*
  - *FMECA*

- Behavior Demonstration
  - *Aeroelastic (FEM) Model of Lifting Surface*
  - *Hydromechanical Model of Control Elements*
AFE 59 Return on Investment

Still Using COCOMO II with SCAT Added

\textit{RoI Estimates Still Very High}

<table>
<thead>
<tr>
<th>Average RoI - average deviation for ten Monte Carlo runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% new SLOC</td>
</tr>
<tr>
<td>78 % -- 0.81%</td>
</tr>
</tbody>
</table>

Assumes 66\% of software defects are discovered and corrected during the SAVI VIP

Small Deviation in Results from Monte Carlo Runs

Sensitivity to Assumed Error Discovery Using SAVI

Even at 10\% discovery/correction of software errors, the RoI lower bound (for a triangular distribution) is \(~+4\%\)/year
EPOC SHADOW
PROJECT RESULTS
AFE 59S1 Return on Investment

**Compared Estimates with SEER Results**

1. Calculate the Benefit

   - **System Weights**
     - Onboard SLOC
     - PCB Count

   - **Run SEER-SEM and SEER-H**

   - **Cost of Fixed Equipment**

   - **Apply Rework and Reuse Model**

   - **Cost of Rework for New Code**

   - **Apply Error Models**

   - **Cost Avoidance with SAVI**

2. Calculate the Cost

   - **WBS**

   - **Net NPV (Net cost avoidance with SAVI discounted at 10%)**

3. Calculate the ROI

   - **SEER Model Shows Similar RoI**

   \[
   \text{ROI} = \frac{\text{NPV (Cost to develop SAVI discounted at 10\%)}}{\text{Years}}
   \]

   - **Table: AP Systems No Rework vs. SEER Results**

   - **CDF Output**
     - COCOMO II cost to develop this amount of new SLOC
     - Labor months

   - **CDF Output**
     - COCOMO II cost to develop this amount of new SLOC
     - Labor months

   - **Aircraft Summary**
     - Cost of rework
     - Cost Escalation
     - Cost of rework due to design errors

   - **Aircraft Summary**
     - Cost of rework due to requirements and design errors

   - **Aircraft Summary**
     - Benefit NPV
     - Discount rate

   - **Error Model**
     - Triangular distribution of % of requirements & design errors

   - **Aircraft Summary**
     - Cost avoidance with SAVI

   - **Aircraft Total Cost NPV**
     - Cost to deploy SAVI

   - **Aircraft Total Cost NPV**
     - Cost to deploy SAVI of 5.5 year development

   - **Aircraft Total Cost NPV**
     - NPV to deploy SAVI after 5.5 year development

   - **Summary**
     - Arithmetic Rate of Return (ROI) over 9 years from 2013
Aircraft Monitoring System

**AADL Model Structure**

**Interface uses AADL features structure**

- **Features**:
  - Signals: requires bus access SignalFlow;
  - Mountings: requires bus access MountPoints;
  - HydraulicPower: requires bus access HydraulicFlow;
  - ElectricPower: requires bus access ElectricPowerFlow;
  - Interfaces for other subsystems - added per 3/29/12 minutes
  - FCS_DMS: port group FCStoDMS;
  - FCS_CDS: port group FCStoCDS;
CAAS – “fully integrated flight and mission management capability…”

- Common digital architecture for U. S. Army rotary wing aircraft
- Fully open, non-proprietary system embracing commercial standards
- Consistent, intuitive user interface for displays that allows control of all avionics subsystems
NEXT STEPS
No Roadblocks

- **Architecture-centric Analysis Works**
  - Model-based Elements Feasible
    - Narrative elements were captured
    - Property exchanges were carried out
    - Inconsistencies were detected and quantified
  - Cyber-Physical Interfaces Were Demonstrated with AADL Model
    - MATLAB/Simulink, LISA (FEM) – simple scripts (need to be automated and verified)
    - Simple fit geometries (CATIA)
    - Safety and Reliability tools for FHA and FMECA; MTBF analysis

- **Major Lessons – Focus for SAVI Version 1.0**
  - “Single Truth” Does not Imply Single Language
    - AADL’s strong semantics facilitates architectural analyses
    - SysML graphical tools are helpful for data flow and to illustrate Use Cases
    - Two-way translations are available (Cofer’s work for DARPA – extended for SAVI)
    - Other translations will be needed
  - Repository Interfaces Are Complex
    - Must facilitate consistency checking
    - Must provide protection for intellectual property
    - Must provide automated configuration management
    - Must provide verification path
    - Must underpin and encourage formal analysis
    - Must spell out needed translators/converters for unique project requirements
  - Involve Tool Vendors and Standards Body (ies)
Aircraft Braking System Safety

**Work flow**

1. **2.3** Develop Aircraft Concept
2. **2.2** Develop Aircraft Plans
3. **2.4** Identify Aircraft Level Functions
4. **2.5** Identify Aircraft Level Requirements
5. **2.6.2** Conduct Aircraft Level PHA
6. **2.6.1** Validate Aircraft Level Failure Conditions
7. **2.7** Allocate Aircraft Level Functions and Requirements to Systems
8. **2.8** Develop AVC Level Architecture
9. **2.9** Conduct Trade Studies (as required)
10. **2.10** PASA
    - Determine System Probability Allocations, FDL, & Safety Assumptions
11. **2.11** Validate AVC level requirements and architecture
12. **2.12** Systems Architecture Integration and Validation
13. **3.2** Braking System Plans
14. **3.3.1** Develop Systems Level Plans
15. **3.3.2** Develop Systems Level Requirements
16. **3.3.5** Conduct Systems Level PHA
17. **3.4** Validate System Level Failure Conditions
18. **3.4.1.3** Develop Systems Architecture
19. **3.4.1.4** PSSA
    - Determine Lion probability allocations, IDAL & Safety assumptions
20. **3.5.1** Derive System Requirements
21. **3.5.4** Validate system level requirements and architecture
22. **3.6** Allocate System Level Functions and Requirements to (Interface)
23. **3.7** Systems Implementation
24. **3.7** Conduct System Safety Assessment (SSA)
25. **4.2** Systems Integration
26. **4.3** Systems Verification
27. **4.3** Aircraft Integration & Verification

---

**Notes:**
- Use DO-178 and DO-254
- Example Output (4/14)
- Supporting Text Only
- Example Output Summary (4/16)
SAVI Initial Capability Phase (Version 1.0A)

- Specify the SAVI Virtual Integration Process
  - Use AADL Requirements Annex
    - Requirements Generation
    - Requirements Validation
    - Requirements Traceability
  - Spell Out Multiple Language Interfaces
    - Define needed translators/mapping tools
    - Evaluate mapping and translators available
  - Document the VIP (set initial baseline)

- Specify Model Bus and Data Exchange Layer
  - Initiate Application of the VIP Process
    - Apply Analysis Techniques Used in SAVI
    - Illustrate Specification with Models
    - Implement translators
  - Description of Repository Interfaces
    - Capture Functionality of System
    - Encapsulate Consistency Checking
    - Set up Version Management Scheme
    - Illustrate Specification with Models
    - Implement translators
  - Involve Tool Vendors
    - Capture Inputs to Version 1.0 Specification
    - Encourage setting roadmaps for tool development
Conclusion

- The problems caused by escalating complexity are being felt the majority of large aerospace systems developments. Thus the need is immediate to develop the next generation of system design tools and processes.

- The SAVI Program is a collaborative, industry-led project developing the processes and technologies necessary to **enable virtual integration of complex systems**.
  - The problem space is large and diverse. An industry-consensus effort leading to a set of implementable standards is necessary for a viable solution.
  - The impact will be on the full product lifecycle. All stakeholders in the design, development, manufacture, distribution, operation, and maintenance of complex systems need to be engaged.

- A solution will require continued investment and direction from both government and industry and employ technology development with academic partners.
Questions?

Contacts:
Dr. Don Ward
Phone: (254) 842-5021
Mobile: (903) 818-3381
dward@avsi.aero

Dr. Dave Redman
Office: (979) 862-2316
Mobile: (979) 218-2272
dredman@avsi.aero