AVSI's System Architecture Virtual Integration Program:

Proof of Concept Demonstrations

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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)

What is the Problem?

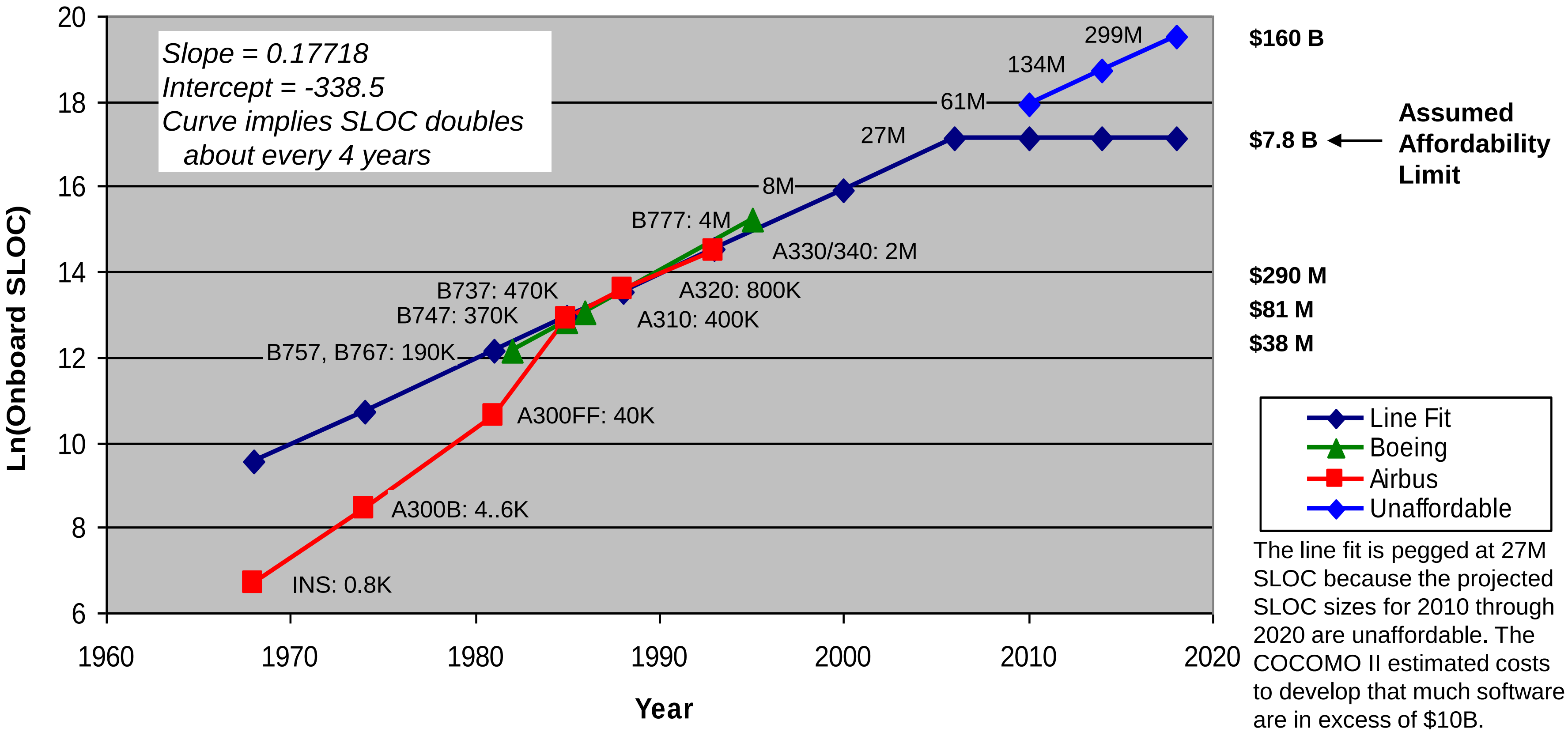
- **The trend is to add features / functionality**
  - ***Functionality is often implemented in software***
  - ***Size and complexity are growing exponentially***
    - **Software-based systems are becoming dominant**
    - **This marriage of hardware/software enables systems of systems**
  - ***Examples***

Portable phones

Airliner cockpits

One Measure of Complexity

Growth of Software Lines of Code



The line fit is pegged at 27M SLOC because the projected SLOC sizes for 2010 through 2020 are unaffordable. The COCOMO II estimated costs to develop that much software are in excess of $10B.

Airbus data source: J.P. Potocki De Montalk, Computer Software in Civil Aircraft, Sixth Annual Conference on Computer Assurance (COMPASS '91), Gaithersburg, MD, June 24-27, 1991.
Boeing data source: John J. Chilenski. 2009. Private email.

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

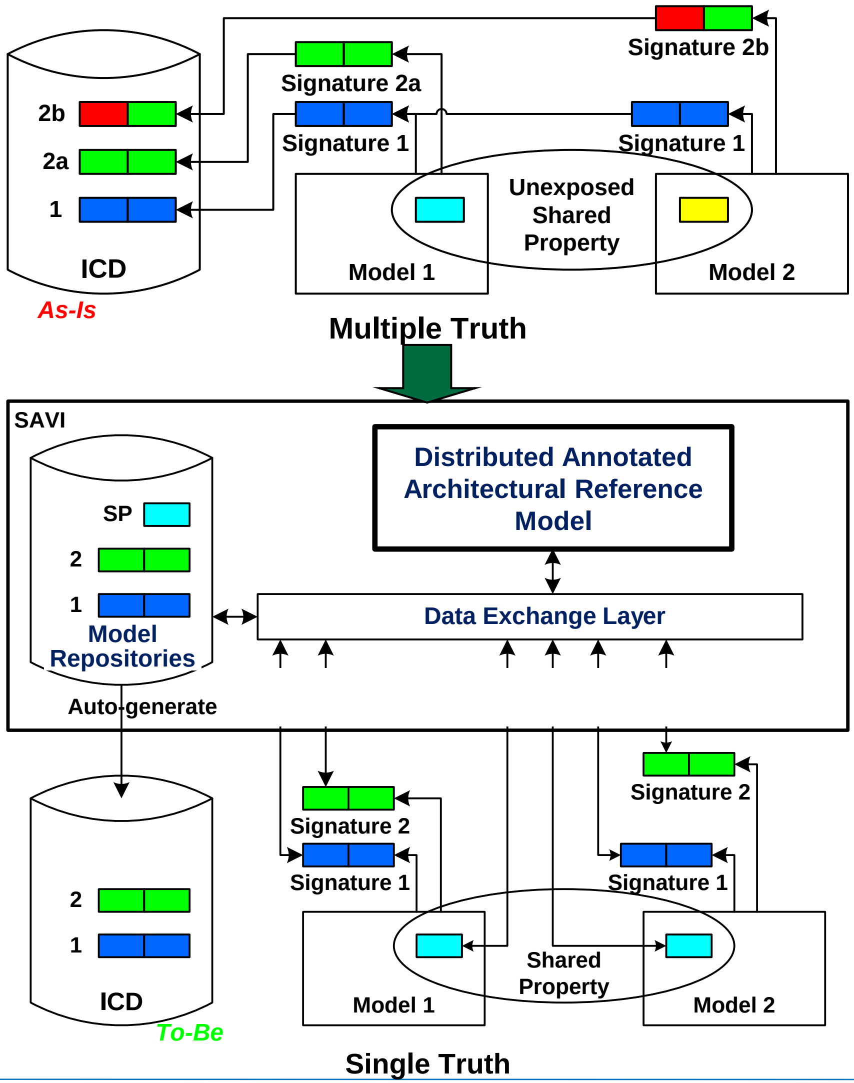
- **The complete Model Set for a system needs to be in compliance (i.e. consistent)**
  - ***with the top-level specification of what is intended/wanted/ required***
  - ***with the physics of the system environment***
- ***Do the Models within the Model Set need to be consistent with each other?***

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**

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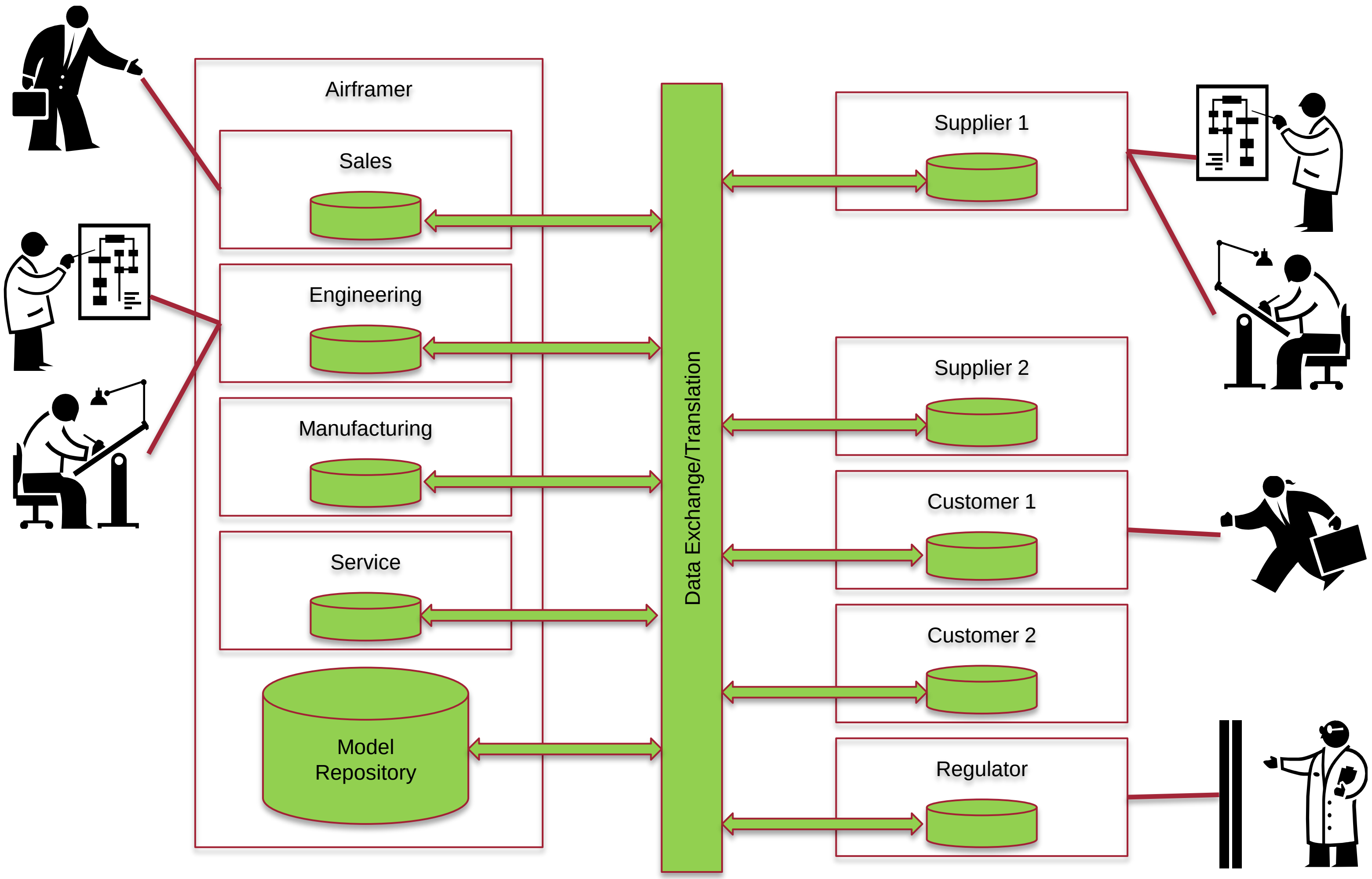
AVSI AEROSPACE VEHICLE SYSTEMS INSTITUTE

Multiple Groups/Tools/Repositories



Late Discovery of Problems

S-A-V-I

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

repair cost

Requirements Engineering

System Design

Software Architectural Design

Component

Acceptance Test

System Test

Integration Test

70%, 3.5% 1x

10%, 50.5% 16x
20-100x

0%, 9% 40x
500-1000x

20.5% 110x

20%, 16%
5x
3-6x

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

Rework and certification dominates development cost

Delivery delays not known until late into project schedule

Sources:

NIST Planning report 02-3, *The Economic Impacts of Inadequate Infrastructure for Software Testing,* May 2002.

D. Galin, *Software Quality Assurance: From Theory to Implementation*, Pearson/Addison-Wesley (2004)

B.W. Boehm, *Software Engineering Economics*, Prentice Hall (1981)

Where faults are introduced

Where faults are found

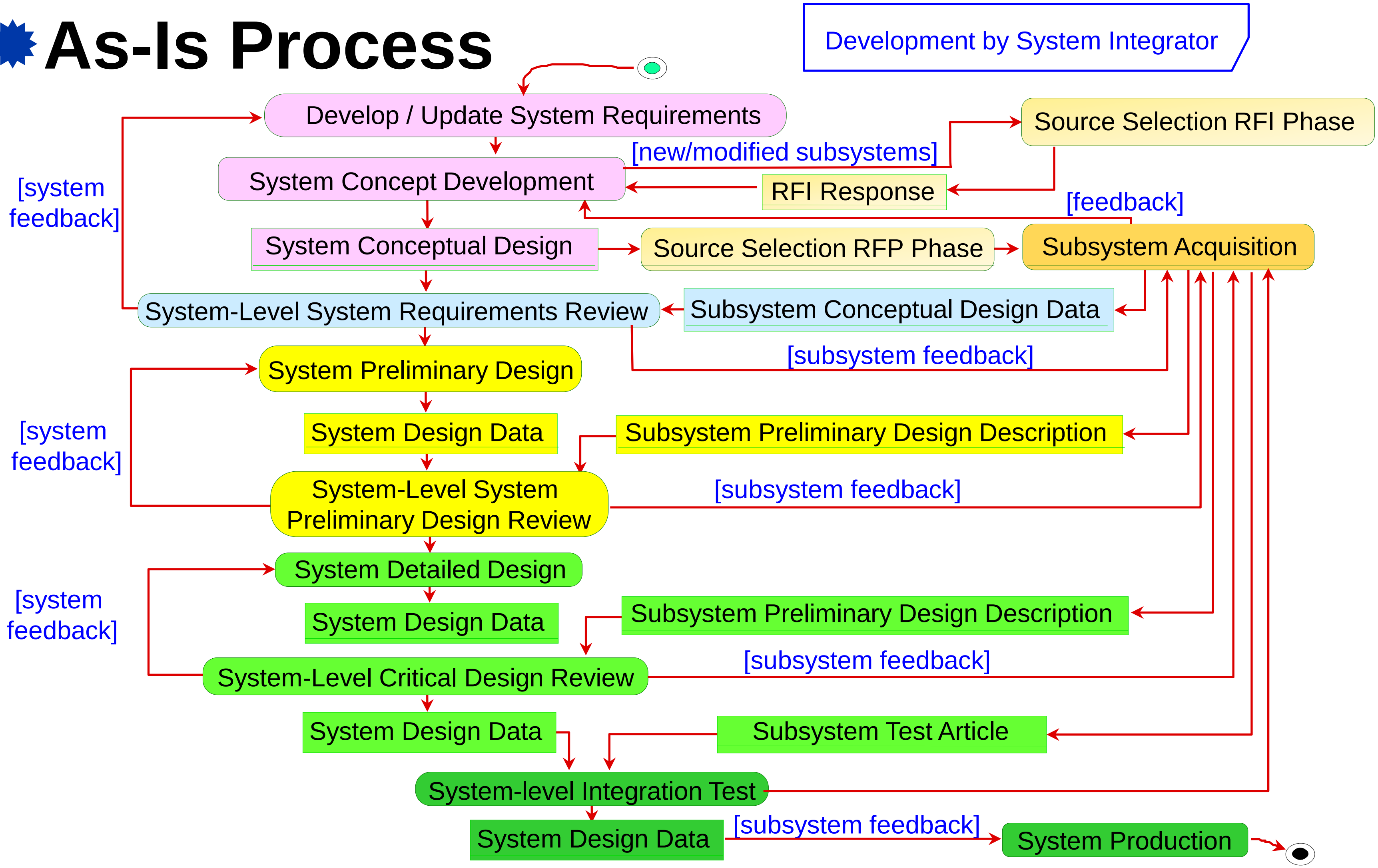
The estimated nominal cost for fault removal

INCOSE 2010

POC PHASE 1 RESULTS

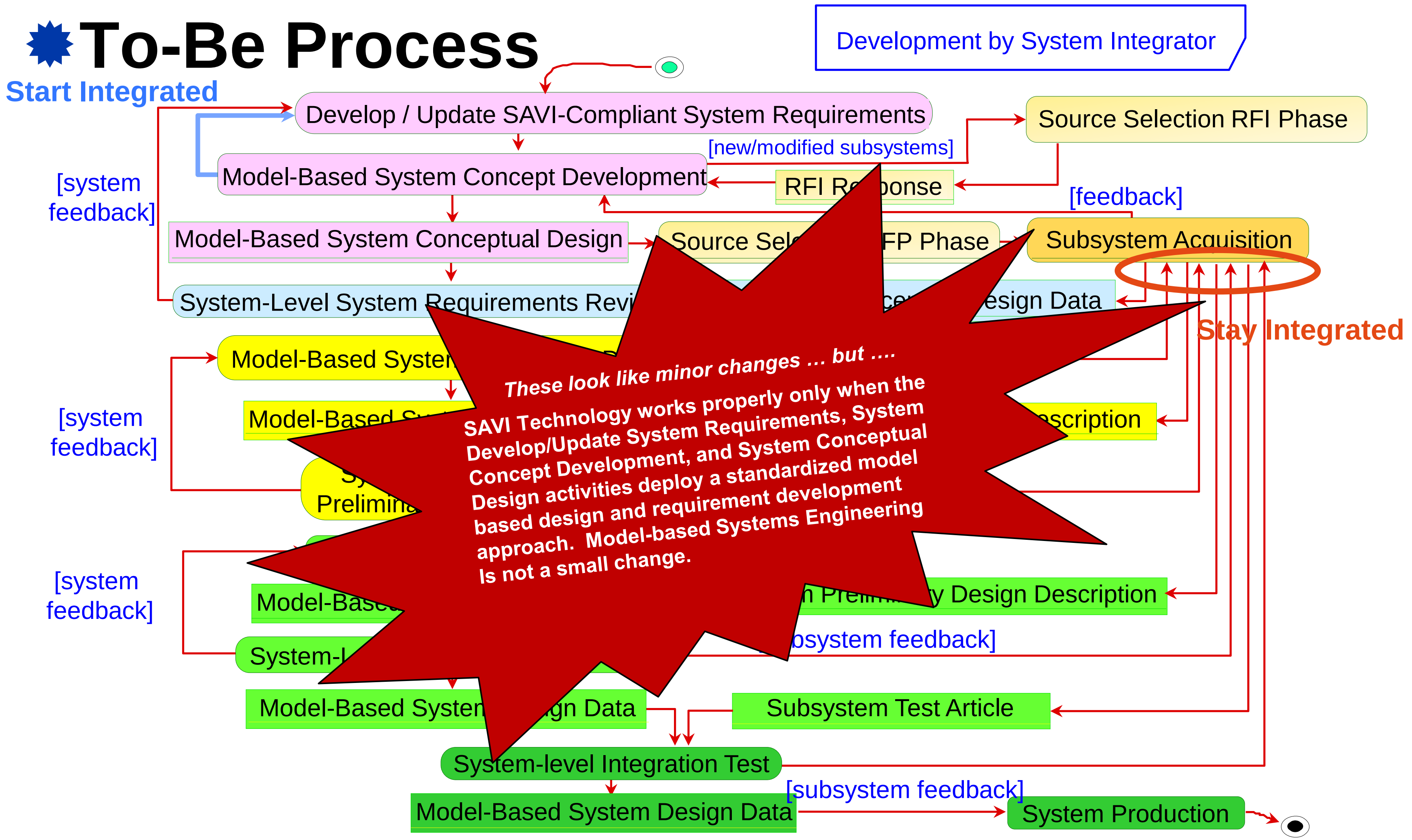
AFE 58 As-Is Acquisition Process

✸ As-Is Process



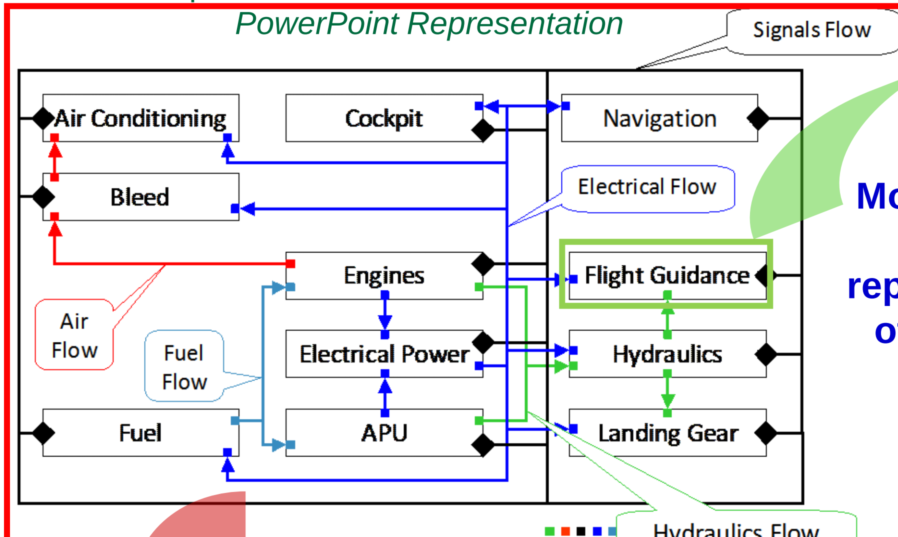
AFE 58 To-Be Acquisition Process

✸ To-Be Process

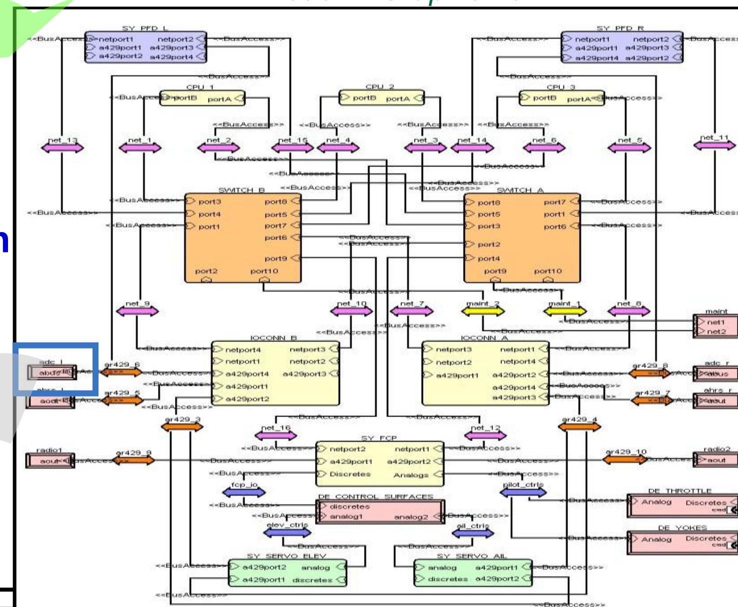


AFE 58 PoC Models

Top Level Abstraction: Tier1 A/C Model
PowerPoint Representation

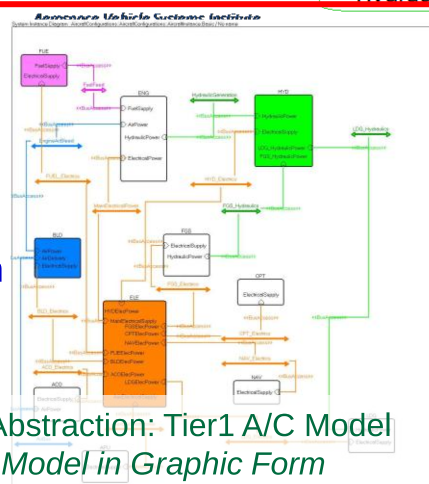


Second Level Abstraction:
Tier 2 Flight Guidance System
AADL Model in Graphic Form



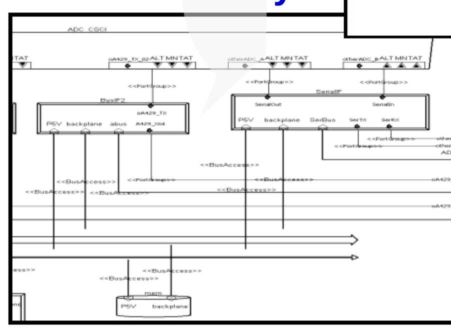
More detailed AADL representation of a system

AADL representation



Top Level Abstraction: Tier1 A/C Model
AADL Model in Graphic Form

AADL model hierarchy



Third Level Abstraction:
Tier 3 Air Data Subsystem

Multi levels ➔ all systems levels, single system level

Multi-criteria ➔ weight, power, …

Analysis based on the same hierarchical description

AFE 58 Models Based on AADL

Connection Consistency

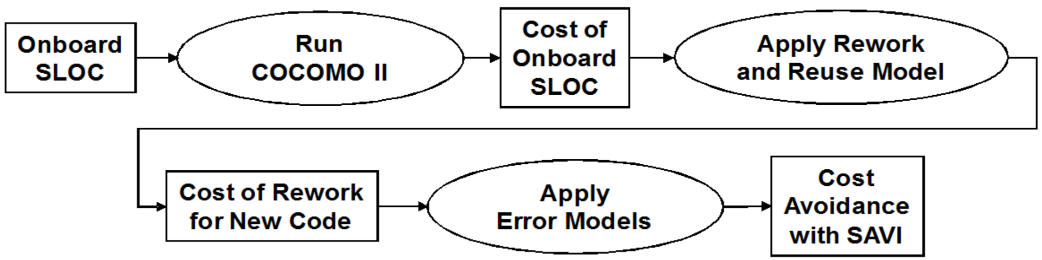
```
system Engines
  features
    ElectricalPower: requires bus access ElectricalPower
      { SAVI::PowerSupply => access 20000.0 W;};
    HydraulicPower: requires bus access HydraulicPressure
      { SAVI::PressureCapacity => access 5000.0 psi;};
    AirPower: requires bus access AirFlow;
    FuelSupply: requires bus access FuelFlow
      { SAVI::FuelBudget => access 5000.0 GalpH;};
    Signals: requires bus access SignalFlow;
properties
  SAVI::System_Tier => tier2;
  SEI::NetWeight => 15000.0 kg;
  SAVI::Requirement => "Req 2";
end Engines;
```

- ***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



2. Estimate the Cost

3. Estimate ROI

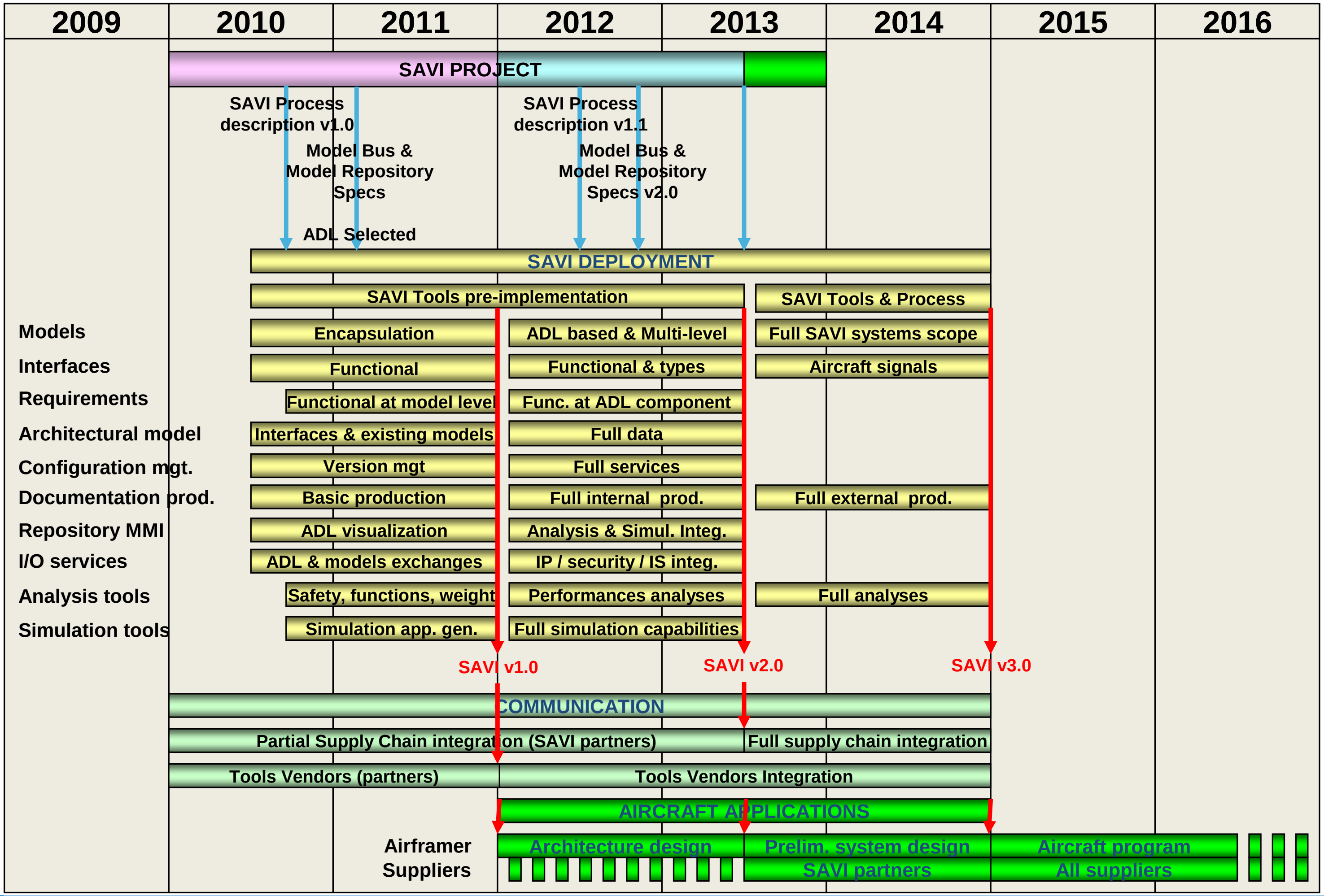
$$RoI = \frac{NPV(\text{Cost avoidance with SAVI implemented... discounted @ 10\%})}{NPV(\text{Cost to develop SAVI...discounted @ 10\%}) * \text{Years}}$$

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

	NPV (Cost Avoidance)	Total Cost Avoidance	NPV (Cost to Develop)	ROI % per year
Pessimistic	$64 M	$99 M	($85.7 M)	2%
Expected	$256 M	$398 M	($85.7 M)	40%
Optimistic	$768 M	$1.193 B	($85.7 M)	144%

AFE 58 Road Map

- Based on Assumptions Prior to 2008



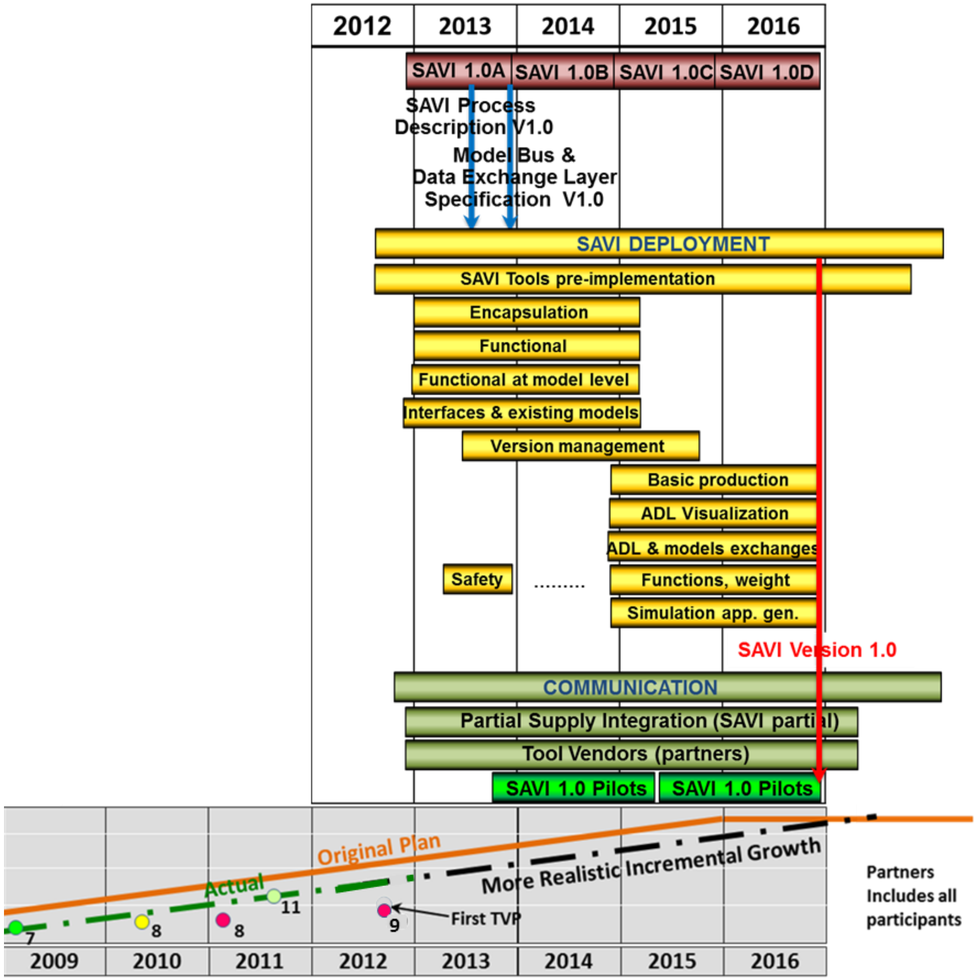
AFE 58 Assessment

- **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



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

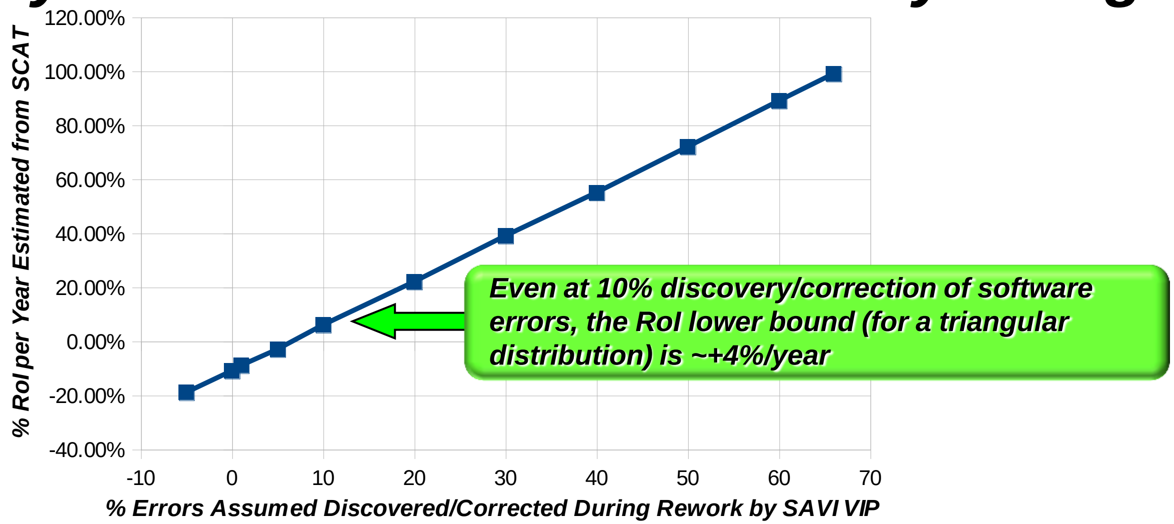
Still Using COCOMO II with SCAT Added

- ***RoI Estimates Still Very High***

Average RoI - average deviation for ten Monte Carlo runs		
30% new SLOC	40 % new SLOC	50 % new SLOC
78 % -- 0.81%	98 % -- 1.05%	115% -- 1.73%

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***

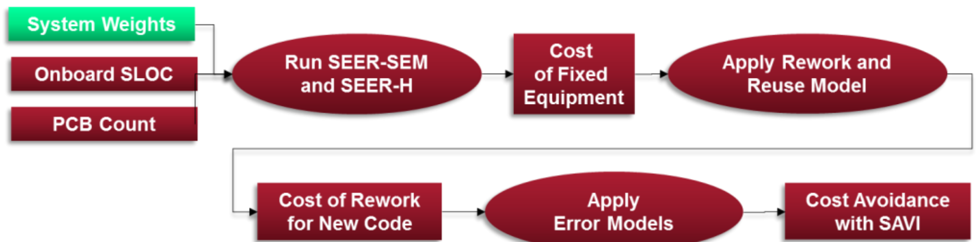


EPOC SHADOW PROJECT RESULTS

AFE 59S1 Return on Investment

Compared Estimates with SEER Results

1. Calculate the Benefit



2. Calculate the Cost

3. Calculate the ROI

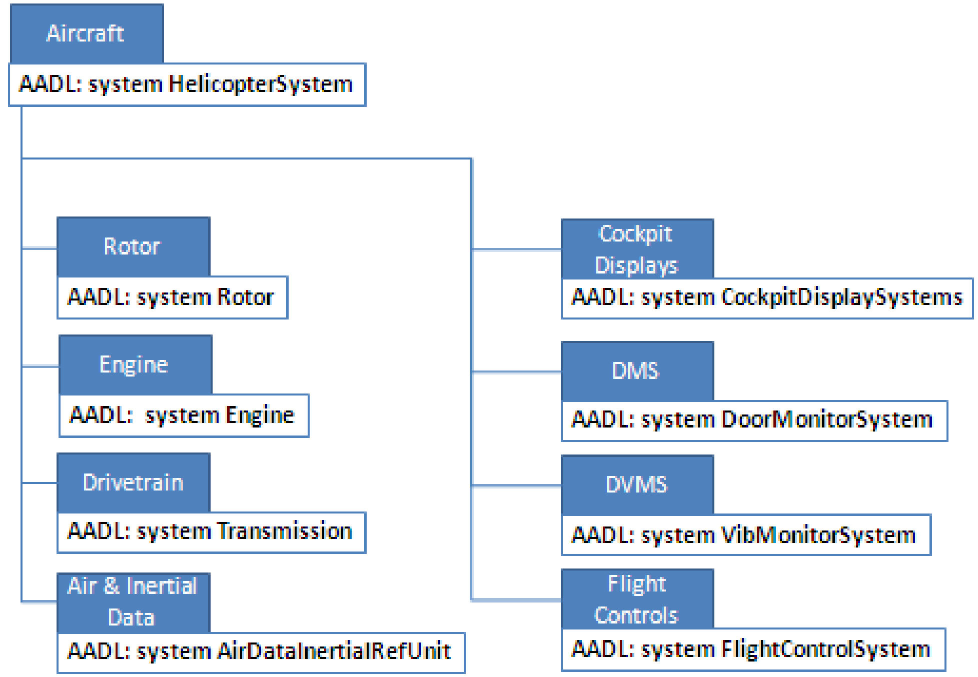
$$\text{ROI} = \frac{\text{net NPV (Net cost avoidance with SAVI discounted at 10\%)}}{\text{NPV (Cost to develop SAVI discounted at 10\%) * Years}}$$

SEER Model Shows Similar RoI

AP Systems	HW + SW		AP Systems	SW Only			Enter the rose-green-rose color block of values in I
No Rework			No Rework				Will need to do this twice, once with rework value
$7,433,252,909	$12,264,867,299	$17,034,537,916	$6,711,266,260	$11,073,589,329	$15,379,985,179	CDF Output	COCOMO II cost to develop this amount of new SLOC
						CDF Output	Labor months
With rework			With rework				
$9,737,561,310	$16,066,976,162	$22,315,244,669	$8,791,758,801	$14,506,402,021	$20,147,780,585	CDF Output	COCOMO II cost to develop this amount of new SLOC
						CDF Output	Labor months
$2,304,308,402	$3,802,108,863	$5,280,706,754	$2,080,492,541	$3,432,812,692	$4,767,795,406	Aircraft Summary	Cost of rework
	78.95%					Cost Escalation	% of cost of rework due to requirements errors
$1,819,350,545	$3,001,928,400	$4,169,344,999	$1,642,638,301	$2,710,353,197	$3,764,379,440	Aircraft Summary	Cost of requirements errors rework
	15.79%					Cost Escalation	% of cost of rework due to design errors
$363,941,505	$600,503,483	$834,032,616	$328,592,122	$542,177,001	$753,023,612	Aircraft Summary	Cost of design errors rework
	94.75%					Cost Escalation	% of rework due to requirements errors and design erro
$2,183,292,050	$3,602,431,883	$5,003,377,615	$1,971,230,423	$3,252,530,197	$4,517,403,052	Aircraft Summary	Cost of rework due to requirements and design errors
	10%					Benefit NPV	Discount rate
33%	66%	99%				Error Model	Triangular distribution of % of requirements & design er
52.53%	66.00%	79.47%				Triang. Distr.	Expected % of errors prevented
$1,146,835,422	$2,377,605,043	$3,976,293,944	$1,035,444,100	$2,146,669,930	$3,590,079,298	Aircraft Summary	Cost avoidance with SAVI
$373,409,832	$774,148,655	$1,294,682,066	$337,140,796	$698,956,138	$1,168,930,504	Aircraft Benefit NPV	NPV(Cost avoidance with SAVI)
($53,533,236)	($88,329,840)	($122,680,334)	($48,333,591)	($79,750,425)	($110,764,479)	Aircraft Total Cost NPV	Cost to develop SAVI
($1,161,965)	($1,161,965)	($1,161,965)	($1,049,104)	($1,049,104)	($1,049,104)	Aircraft Deploy Cost	Cost to deploy SAVI
($37,709,068)	($62,219,963)	($86,416,615)	($34,046,413)	($56,176,581)	($78,023,029)	Aircraft Total Cost NPV	NPV(Cost to develop SAVI) of 5.5 year development
($596,272)	($596,272)	($596,272)	($538,356)	($538,356)	($538,356)	Aircraft Total Cost NPV	NPV(Cost to deploy SAVI) after 5.5 year development
97%	126%	154%	97%	126%	154%	Summary	Arithmetic Rate of Return (ROI) over 9 years from 2

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;
```

CH-47 CAAS Upgrade (AMRDEC)

- **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

SAVI Proof of Concept Takeaways

- **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)**

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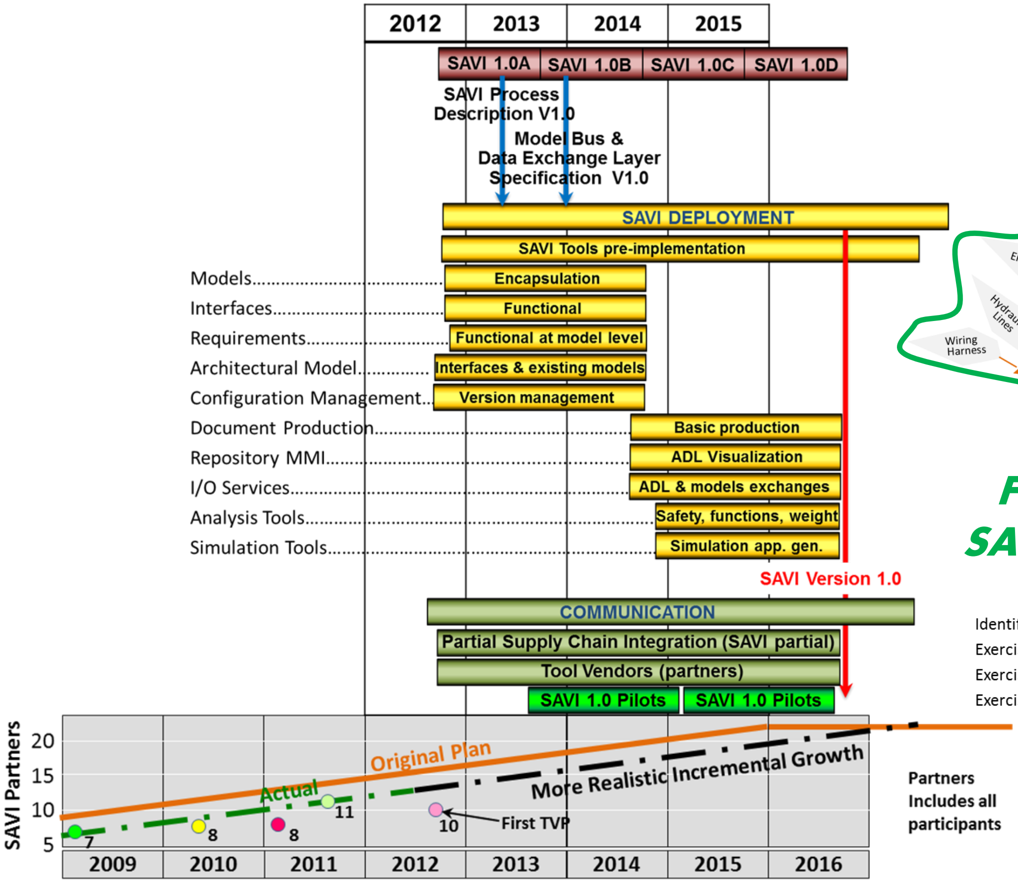
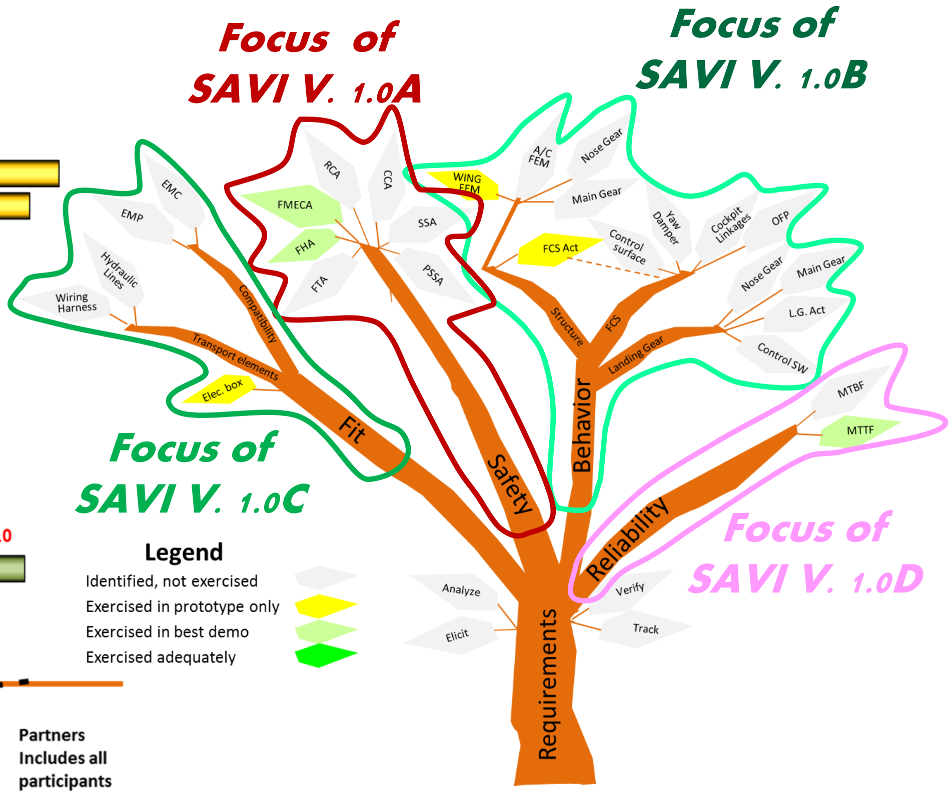
SAVI Roadmap for Next Stage

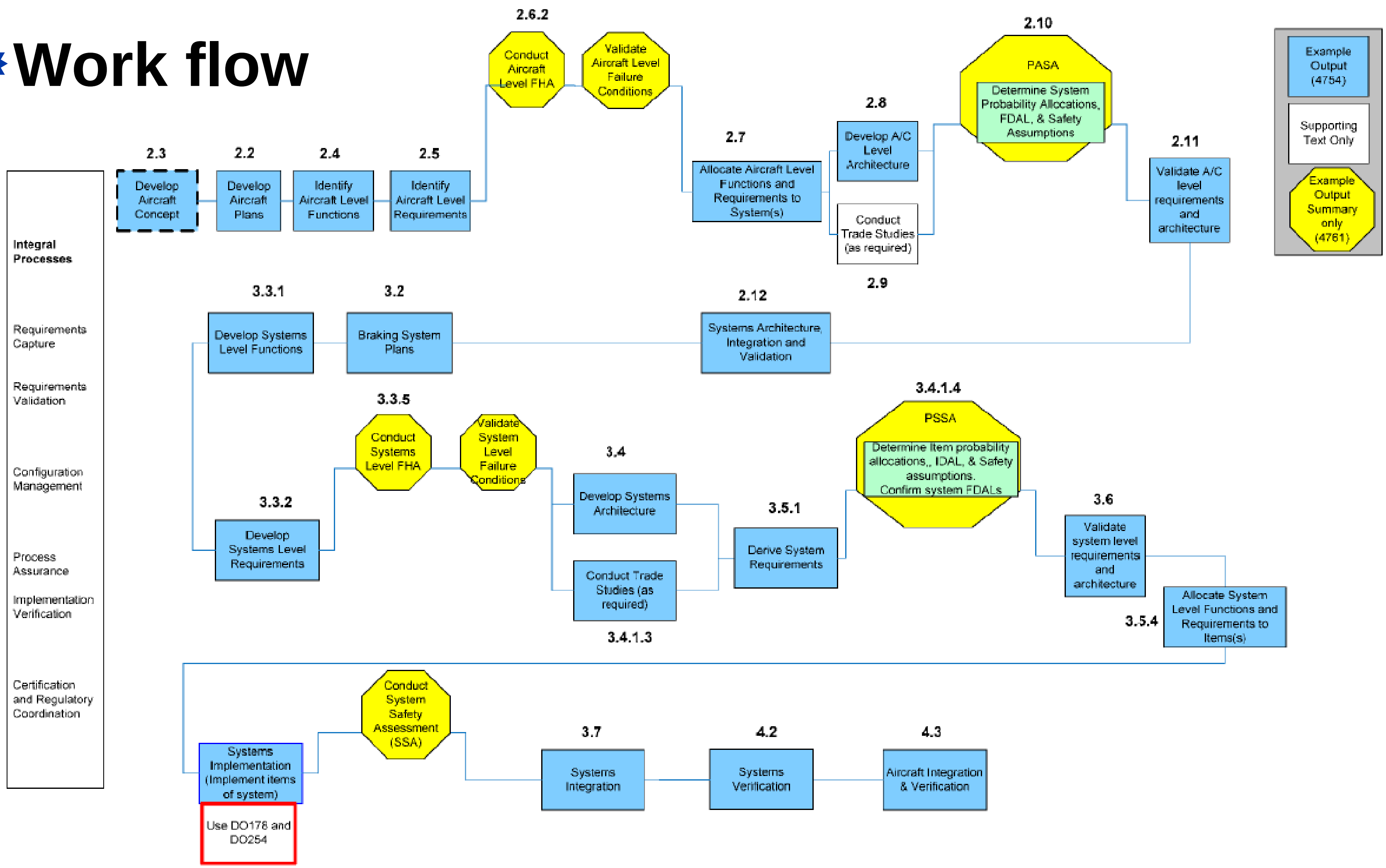




Aircraft Braking System Safety

S-A-V-I

Work flow



SAVI Version 1.0 Actions

- **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?

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