Maturity of the Model-Based Enterprise

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About Greg Pollari

- Principal Systems & Process Engineer at Rockwell Collins
- 30 years in product design and leadership roles
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- Industry co-sponsor for the MoSSEC ISO standardization effort





- How do we know we have robust design, development, and manufacturing process in a model-based environment?
- Do we know how we compare with our customers, suppliers, and partners when it comes to using models?
- TRL (Technical Readiness Level) and its associated assessment is one way to assess an enterprise maturity for technology
- The TRL framework has been adapted to process maturity
- A DoD tool (TMC) has been developed to support maturity assessments
- This presentation looks at using the TMC tool for the SAVI VIP (Virtual Integration Process) maturity assessment





AFRL TMC 3.6.0

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- TMC 3.6.0
- From AFRL (Air Force Research Laboratory)

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Configuration	Technology Maturity Calculator Process Maturity Level Achieved												
Analysis													
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Level 1													
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- The following questions in the TMC tool have been modified for the SAVI VIP
- Nine levels of maturity one for each TRL level
- Approximately 10 questions per level
- Must show evidence to support each "claim"
- SAVI notionally at TRL 4 6
 - Periodic assessment is underway



SAVI VIP Maturity Progression

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Level 1 to 9 (increasing maturity)

Are you thinking about using models?

Do you have a model-based concept in mind?

Have you done a proof-of-concept and feasibility study?

Is there a multi-domain model integration framework?

Is a relevant model management process established?

Are models used in a "near production" environment?

Are model-based processes applied in production?

Are measures in place for model-based processes?

Are model-based processes continuously improving?



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Level 1 Questions

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- L1-1: Is architecture-centric modeling research is being pursued through applied research activities?
- L1-2: Are needed mathematical formulations in development?
- L1-3: Is basic use of possible algorithms is understood?
- L1-4: Are basic principles observed and reported?
- L1-5: Have basic research activities started?
- L1-6: Have research articles, white papers, or point papers been reported in journals/conference proceedings or published in technical reports?
- L1-7: Have research articles, white papers, or point papers been reported in journals/conference proceedings or published in technical reports?
- L1-8: Do we know who, when, and where additional research will take place?
- L1-9: Does published research identify underlying principles?
- L1-10: Is scientific research beginning to be translated into applied research and development (R&D)?

Are you thinking about using models?





- L1-1: Is architecture-centric modeling research is being pursued through applied research activities?
 - Attempts to tie certification efforts to formal analysis and model-based engineering are underway (attempts to implement DO 178C, include DO 330 and DO 331, for example).
- L1-2: Are needed mathematical formulations in development?
 - Formal analysis options are being pursued. Integration efforts are underway (CRESCENDO, TOICA, MoSSEC in Europe, AVM from DARPA, ASSERT in Europe, SPEEDS) are all examples
- L1-3: Is basic use of possible algorithms is understood?
 - Algorithms for architecture-centric analysis are included in AADL. Error Model Annex and Behavior Annex are understood. Data exchange protocols (ISO 10303-239 and OSLC) are available.
- L1-4: Are basic principles observed and reported?
 - Several Architectural Definition Languages (SysML, AADL) defined by standards. Model checking principles discussed in the literature. Consistency is defined in several papers. INCOSE is pursuing use of models to improve Systems Engineering.
- L1-5: Have basic research activities started?
 - Proof of Concept studies are underway, rudimentary two-way translators between some ADLs are useable.
- L1-6: Have research articles, white papers, or point papers been reported in journals/conference proceedings or published in technical reports?
 - SEI, Georgia Tech, Vanderbilt, ESA and other academic and government agencies have published articles on using architecture-centric models in systems engineering.
- L1-7: Have research articles, white papers, or point papers been reported in journals/conference proceedings or published in technical reports?
 - SEI, Georgia Tech, Vanderbilt, ESA and other academic and government agencies have published articles on using architecture-centric models in systems engineering.
- L1-8: Do we know who, when, and where additional research will take place?
 - SAVI has a roadmap for completing three versions of an increasingly mature Virtual Integration Process.
- L1-9: Does published research identify underlying principles?
 - Principles of architecture-centric modeling and its Virtual Integration Process is spelled out in Proof of Concept studies.
- L1-10: Is scientific research beginning to be translated into applied research and development (R&D)?

Rudimentary means of interfacing domain analysis tools are being demonstrated. Classification of Use Cases to develop the VIP are laid out in outline form.



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Level 2 Questions

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- L2-1: Do publications provide analysis to support the concept?
- L2-2: Are examples limited to analytical studies using synthetic data?
- L2-3: Are papers comparing competing technologies completed?
- L2-4: Have small code units been completed?
- L2-5: Are preliminary technology concepts and/or applications formulated?
- L2-6: Have practical applications been envisioned and described?
- L2-7: Are applications speculative, that is, is there little or no proof or detailed analysis for assumptions made?
- L2-8: Are examples limited to analytical studies and Proof of Concept demonstrations?
- L2-9: Is the application adequately envisioned and described?
- L2-10: Is the concept of application adequately analyzed?

Do you have a model-based concept in mind?





- L2-1: Do publications provide analysis to support the concept?
 - Guiding principles for VIP set down in AFE 57. Initial development concepts set down in AFE 58 work breakdown structures for development, reuse concepts, need for business case identified.
- L2-2: Are examples limited to analytical studies using synthetic data?
 - Use cases outlined and enumerated. General areas to be tackled first postulated; need for cyberphysical (interconnections between hardware and software) identified.
- L2-3: Are papers comparing competing technologies completed?
 - Evaluation of ADLs and need for single language examined; papers describing Rol methodology located; papers on consistency checking read and evaluated.
- L2-4: Have small code units been completed?
 - Several versions of Proof of Concept modeling for aircraft systems (Flight Management System, for example) were made available during AFE 58 and later Proof of Concept phases.
- L2-5: Are preliminary technology concepts and/or applications formulated?
 - AADL component models for subsystems have been identified. Mechatronic models (Simulink) and FEM (in LISA) postulated.
- L2-6: Have practical applications been envisioned and described?
 - The SAVI VIP envisioned by John Chilenski as an AVSI project has the goal of reducing cost and schedule time of complex engineering systems. It was rather fully described during AFE 57.
- L2-7: Are applications speculative, that is, is there little or no proof or detailed analysis for assumptions made?
 - This VIP was highly speculative at the outset; Proof of Concept work began in AFE 58 and was competed in 1012.
- L2-8: Are examples limited to analytical studies and Proof of Concept demonstrations?
 - This limitation was true through AFE 59S1. Only analytical studies and subset demonstrations were carried out up to that point.
- L2-9: Is the application adequately envisioned and described?
 - John Chilenski, through the earlier work done in AFE 32 and AFE 57 (prior to 1958), gave clear vision of a path forward. Guiding principles set down were: (1) credible models, (2) proof-based analysis where feasible, and (3) component-based. VIP credo is: "integrate, analyzem, ... then build".
- L2-10: Is the concept of application adequately analyzed?
 - Initial feasibility studies tested for subsystems; architecture-centric concept was evaluated with small avionics and software subsystems in AFE 58 (2008-2009). Cost to develop the VIP was estimated and ROI evaluated with COCOMO II.







Level 3 Questions

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- L3-1: Do hardware and software (mechatronic) components of the process exist and are they fully • representative?
- L3-2: Have Proof of Concept demonstrations been completed? •
- L3-3: Have simulations and system analyses been performed that measure parameters of interest In a • distributed subversion environment?
- L3-4: Have comparisons of systems and components to analytical predictions for critical system • functionality in a a simulation laboratory?
- L3-5: Are a limited number and limited functionality Use Cases available to evaluate critical process • properties?
- L3-6: Has feasibility of the the VIP been demonstrated through demonstrations during the Proof of • **Concept phase?**
- L3-7: Have analytical predications been verified using partially integrated software components and • representative data sets?
- L3-8: Have algorithms been run on a surrogate processor in a laboratory environment? •
- L3-9: Do modeled components perform together as integrated subsystems in a laboratory environment? •
- L3-10: Do the results to date indicate feasibility of the architecture-centric concept? •
- L3-11: Have active Shadow projects been initiated? •
- L3-12: Has the critical functionality of semantically strong architectural models been empirically • confirmed?
- L3-13: Have analytical studies been performed to validate physical and analytical predictions of separate • elements of the VIP technologies?
- L3-14: Have attempts been made to scale up or extend concepts from lower level elements? •

Have you done a proof-of-concept and feasibility study?







- L3-1: Do hardware and software (mechatronic) components of the process exist and are they fully representative?
 - All components are not yet fully representative, though major groups of components have been identified for architecture-centric modeling. There are gaps, though the accomplishments were substantial during the Proof of Concept demonstrations.
- L3-2: Have Proof of Concept demonstrations been completed?
 - Yes, the demonstrations are not yet complete. Data exchange between different types of models has been demonstrated, but is not completely automated. Architectural analysis of system, both static and dynamic, has been exercised but not completely characterized and had manual linkages in some instances.
- L3-3: Have simulations and system analyses been performed that measure parameters of interest In a distributed subversion environment?
 - Architectural model repositories are in place and have been expanded to demonstrate representative OEMs and supplier interactions.
- L3-4: Have comparisons of systems and components to analytical predictions for critical system functionality in a a simulation laboratory?
 - To a limited degree this comparison mode was demonstrated during the Proof of Concept demonstrations.
- L3-5: Are a limited number and limited functionality Use Cases available to evaluate critical process properties? Use Cases are recognized as needed and prioritized ones have been chosen from a list first enumerated during AFE 58.
- L3-6: Has feasibility of the the VIP been demonstrated through demonstrations during the Proof of Concept phase? Small scale repository functionality between OEMs and suppliers was demonstrated during the Proof of Concept phase. Small scale integration demonstrations of hardware and software functions were carried out in this phase of development
- L3-7: Have analytical predications been verified using partially integrated software components and representative data sets? A limited set of Use Cases have been exercised to show system integrity for subsystem level components rather than a complete aircraft model.
- L3-8: Have algorithms been run on a surrogate processor in a laboratory environment?
 - Model sets operate together though they represent an incomplete integraion so far.
- L3-9: Do modeled components perform together as integrated subsystems in a laboratory environment? Model elements, though incomplete and/or simplified, do work together indicating feasibility of the approach.
- L3-10: Do the results to date indicate feasibility of the architecture-centric concept?
 - Elements of the architecture, though simplified for the Proof of Concept demonstrations, suggest strongly that the concept is feasible.
- L3-11: Have active Shadow projects been intitated? Subsystems, like the AIR 6110 wheel braking system, have been completed, though now full-scale aircraft system has been considered.
- L3-12: Has the critical functionality of semantically strong architectural models been empirically confirmed? Basic analyses have confirmed utility in such models at a component and subsystemd level only for a limited number of system elements.
- L3-13: Have analytical studies been performed to validate physical and analytical predictions of separate elements of the VIP technologies?
 - Emphasis on Model Repository functionality and data exchang has been demonstrated in a simulated environment. Models have been exercised for a limited number and size of overall system components.
- L3-14: Have attempts been made to scale up or extend concepts from lower level elements?
 - Extensibility of ADLs was demonstrated during Proof of Concept and a few different types of models have been connected in the same set of demonstrations.







Level 4 Questions

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- L4-1: Has a relatively complete set of subsystem models (including generation of models, system analyses, and consistency checks) been exercised in a laboratory environment?
- L4-2: Has a low level integration of components, perhaps including "ad hoc" hardware, been exercised in the laboratory environment?
- L4-3: Has a mechatronic module or subsystem (including both hardware and software components) been exercised in a laboratory environement?
- L4-4: Has development of an architecture-centric subsystem model been initiated to include interoperability, extensibility, scalability, and internal security (at least for IP issues)?
- L4-5: Are basic components of the SAVI VIP relatively primitive with regard to efficiency and robustness compared to the expected final process?
- L4-6: Have emulations been done with current/legacy elements as appropriate?
- L4-7: Have prototypes been developed to demonstrate different aspects (but not all aspects) of the eventual system?
- L4-8: Does the current level of architecture-centric system prototyping address a simple integration process?
- L4-9: Have the basic technical components been integrated to establish that the model sets will work together?
- L4-10: Has the architecture-centric subsystem been evaluated in a representative environment?
- L4-11: Has the producibility and cost effectiveness of an architecture-centric approach to virtual integration been carefully evaluated and quantified?

Is there a multi-domain model integration framework?







- L4-1: Has a relatively complete set of subsystem models (including generation of models, system analyses, and consistency checks) been exercised in a laboratory environment?
 - The AIR 6110 wheel braking system has been exercised in such an environement to carry out a Preliminary System Safety Assessment (PSSA) virtually.
- L4-2: Has a low level integration of components, perhaps including "ad hoc" hardware, been exercised in the laboratory environment?
 - The limited set of hardware and software components for the AIR 6110 wheel braking system as modified by SAVI (with no antiskid nor autobraking software) satisfies this question.
- L4-3: Has a mechatronic module or subsystem (including both hardware and software components) been exercised in a laboratory environement?
 - The SAVI modified AIR 6110 wheel braking system included architectural, geometry, and publisher/subscriber models have been exercised showing completeness for this limited model and with simple consistency checks carried out.
- L4-4: Has development of an architecture-centric subsystem model been initiated to include interoperability, extensibility, scalability, and internal security (at least for IP issues)?
 - The SAVI-modified AIR 6110 wheel braking system model set included a simulated SVN environment, with initial internal security considerations for OEMs, suppliers, and regulators has been exercised. Component models addressing dynamic performance has not yet been implemented.
- L4-5: Are basic components of the SAVI VIP relatively primitive with regard to efficiency and robustness compared to the expected final process?
 - At the time of this evaluation (end of AFE 61), the wheel braking model set is still lacking dynamic components (antiskid, and autobraking for example) and only system safety aspects have been addressed.
- L4-6: Have emulations been done with current/legacy elements as appropriate?
 - SAVI-modified AIR 6110 wheel braking system (with not antiskid nor autobraking) have been emulated in AFE 61.
- L4-7: Have prototypes been developed to demonstrate different aspects (but not all aspects) of the eventual system?
 - The AFE 61 prototype wheel braking system served as a basis for further work including emulation of the dynamic performance with added elements like antiskid and autobraking and hydraulic system transient behavior with failure states.
- L4-8: Does the current level of architecture-centric system prototyping address a simple integration process?
 - The AFE 61 wheel braking system illustrates a minimal subset of representative integration data for a virtual PSSA that is largely automated through the interfacing of model sets. Of course, dynamic data for transient responses still need to be demonstrated with a more complete model set and better automation of the virtual PSSA.
- L4-9: Have the basic technical components been integrated to establish that the model sets will work together? This type of integration has been carried in AFE 61 for the SAVI minimalist wheel braking system that still lacks dynamic performance elements.
- L4-10: Has the architecture-centric subsystem been evaluated in a representative environment?
 - The SAVI-modified AIR 6110 wheel braking system has been assessed against the system safety process during AFE 61, though the evaluation was limited to generation of static metrics pertinent to the virtual PSSA.

INTEROPERABILITY

- L4-11: Has the producibility and cost effectiveness of an architecture-centric approach to virtual integration been carefully evaluated and quantified?
 - The SAVI Rol studies completed during AFE 58, 59, and 59S1 (2008 through 2012) all showed a remarkable estimated return and each refinement of the Rol estimation methodologies led to even higher returns.







Level 5 Questions

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- L5-1: Have all basic modeling components of importance to subsystem level architectures been integrated • using reasonably realistic elements in the architecture-centric environment?
- L5-2: Have high fidelity architectural integrations of components across solid geometry models, SysML/AADL models, and interface documents been carried out with inter-model consistency checking?
- L5-3: Has the overall architecture been refined to more nearly meet the expected system goals?
- L5-4: Are differences between the architecture-centric virtual environment and the operation environment • being anticipated and discussed?
- L5-5: Is the architecture-centric system model set ready for virtual integration with existing data tools and other operational constraints for a VIP?
- L5-6: Do prototype model implementations conform to target environment/interfaces? •
- L5-7: Are tradeoffs completed utilizing the expanded example architecture-centric subsystem model set? •
- L5-8: Are interface interactions within the architecture-centric model set established for all model • elements?
- L5-9: Is the system architecture for the example subsystem (the SAVI-modified wheel braking system) established?
- L5-10: Have representative analytics (static and dynamic behavioral consistency checks) been run using • the architecture-centric model set?
- L5-11: Has a graphical interface for the ADLs (both SysML and AADL) been exercised and evaluated? •
- L5-12: Has the SAVI VIP been placed under Configuration Management? •
- L5-13: Are Architectural Definition Languages (ADLs) that are useable for an operational development in • place?
- L5-14: Have consistency checking tools been used to compare with expectations?
- L5-15: Has the process been tested in limited acquisition developments?
- L5-16: Has the producibility and cost of developing the virtual integration process been fully evaluated? •

Is a relevant model management process established?







 L5-1: Have all basic modeling components of importance to subsystem level architectures been integrated using reasonably releastic elements in the architecture-centric environment?

The AIR 6110 wheel braking system model set expanded to include antiskid elements and autobraking and with typical behavioral modeling tools (SCADE, Simulink, and Modelica) fits this description.

 L5-2: Have high fidelity architectural integrations of components across solid geometry models, SysML/AADL models, and interface documents been carried out with inter-model consistency checking?

The AFE 61S1 wheel braking system models included this kind of prototype virtual integration.

- L5-3: Has the overall architecture been refined to more nearly meet the expected system goals?
- Inclusion of antiskid elements and autobraking elements in the expanded AIR 6110 wheel braking system is a good example of this refinement. Another example is the emphasis on dynamic performance for this improved subsystem.
- L5-4: Are differences between the architecture-centric virtual environment and the operation environment being anticipated and discussed?
 Use Cases have been developed to illustrate how the operational environment and/or system modifications may affect dynamic performance of the SAVI-modified wheel braking system.
- L5-5: Is the architecture-centric system model set ready for virtual integration with existing data tools and other operational constraints for a VIP?

The MR/DEL models and data exchange supporting elements are in advanced prototype stages at the end of AFE 61; translators are also in place for at least two-way SysML and AADL mappings.

- L5-6: Do prototype model implementations conform to target environment/interfaces?
 The SAVI -modified AIR 6110 wheel braking system with additional components (antiskid braking, autobraking, hydraulic and electrical system transient interfaces) will allow evaluations at this level.
- L5-7: Are tradeoffs completed utilizing the expanded example architecture-centric subsystem model set?
 - Consistency checking Use Cases with the expanded AIR 6110 wheel braking system model set promote exactly this kind of tradeoff evaluations.
- L5-8: Are interface interactions within the architecture-centric model set established for all model elements?
 The expanded SAV AIR 6110 wheel braking system models will allow demonstration of these interface interactions in the VIP scheme of model-based integration.
- L5-9: Is the system architecture for the example subsystem (the SAVI-modified wheel braking system) established? The virtual PSSA illustrates how this architecture is being established; this demonstration was completed in AFE 61. But the model set is still being expanded for purposes of showing a more complete subsystem model and bringing in more behavioral elements.
- L5-10: Have representative analytics (static and dynamic behavioral consistency checks) been run using the architecture-centric model set?
 AFE 61 established the ability to do a virtual PSSA with dynamic consistency checking. Dynamic behavior with the final model set for the SAVI wheel braking system are still to be carried out. Model repository structure is laid out and appropriate tools identified for handling data with internal security are likewise identified but not yet fully exercised.
- L5-11: Has a graphical interface for the ADLs (both SysML and AADL) been exercised and evaluated?
 - Both SysML and AADL graphical interfaces have been exercised and evaluated as satisfactory in multiple tools (EA, SCADE System) at the end of AFE 61. Suggested improvements have been passed on and in many cases are already implemented in the tools.
- L5-12: Has the SAVI VIP been placed under Configuration Management?
 - Rudimentary CM has been exercised through AFE 61 (use of SVN repositories for models) but more complete CM is a focus for Model Repository development in AFE 62 (emphasis on internal security). Later versions of the SAVI VIP (Version 2.0 is a likely appropriate time for more complete CM implementation) must include much more complete CM with emphasis on external security.
- L5-13: Are Architectural Definition Languages (ADLs) that are useable for an operational development in place? The SAVI-expanded AIR 6110 wheel braking system model set was developed with the two most promising ADLs - SysML and AADL - and improvements to each of them were identified. Better graphical interfaces were sought, AADL added the Error Management Annex, and better handling of requirements for each of these ADLs was promoted through the SAVI-efforts through AFE 61.
- L5-14: Have consistency checking tools been used to compare with expectations? AADL now includes simple consistency checks in its menus, though at the end of AFE 61 these checks are largely static checks. Work is progressing on dynamic behavior consistency checking as the SAVI wheel braking model set is further expanded to include such elements.
- L5-15: Has the process been tested in limited acquisition developments?
 - Shadow projects like the modification upgrade to the CH-47 CAAS have been carried out, as well as other small scale projects as of the end of AFE 61. The US Army is planning a SAVI-like architecture-centric approach to model based engineering for the MSAD effort which feeds the JMR family of vehicles. This demonstration could be the largest and perhaps most immediate of uses of the SAVI approach to virtual integration.
- L5-16: Has the producibility and cost of developing the virtual integration process been fully evaluated?
 - The SAVI team believes their three iterations off work to establish a predicted Rol (all with very positive results) is as good an evaluation of the business case for implementing the SAVI VIP as can be constructed until a full up aircraft development is done using the SAVI VIP.



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Level 6 Questions

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- L6-1: Has a representative architecture-centric system model prototype been integrated in a near production environment?
- L6-2: Has a high-fidelity virtual environment been used to evaluate representative subsystems with alternative elements?
- L6-3: Is the demonstration model set for the VIP near the desired configuration in terms of its ability to illustrate how the process activities should be carried out in a larger scale shadow project?
- L6-4: Architecture-centric example system model facilitates comparison of tradeoffs and system limitations with competing elements?
- L6-5: Does the architecture-centric example model set along with the ADL tools available support iterative consistency checks at all levels in the system hierarchy and provide automated documentation for the traceability matrix?
- L6-6: Have differences between the simulated operational (virtual) integration and the actual operational environment been identified, discussed, and documented as assumptions and limitations for the virtual integration?
- L6-7: Do relevant architectural model sets facilitate comparison of changes to software modules and/or subelements (hardware or software) in a virtual end-to-end setting?
- L6-8: Has a full virtual integration for a full set of the SAVI-expanded wheel braking system (including antiskid and autobraking, hydraulic system interactions, and electrical power interactions) been carried out?
- L6-9: Does the extended SAVI wheel braking model set include sufficient number and types of integrated hardware/software models to describe how to complete consistency checks that detect typical anomalies at interactions?
- L6-10: Does the SAVI expanded wheel braking system model set provide enough complexity in the model set to expose performance issues and physical, logical, and security anomalies during a virtual integration?
- L6-11: Does the work bench for the SAVI VIP provide adequate ability to compare virtual and real-world performance and give direction to analysis that can be easily provided to decision-makers early in the life cvcle?
- L6-12: Can the architecture-centric SAVI expanded wheel braking system model set provide predictions about systemwide throughput, timing, scalability, and reliability interactions?
- L6-13: Have efforts to analyze the human-computer interfaces been started with the SAVI expanded wheel braking system?

Are models used in a "near production" environment?







- L6-1: Has a representative architecture-centric system model prototype been integrated in a near production environment?
 Example: "Representative" at this level of maturity likely should include at least three interrelated subsystems (electrical power, hydraulic power, flight control system, flight management system, or wheel braking system or some combination of these elements). The SAVI expanded wheel braking system (with antiskid and autobraking evaluated) along with the interfaces with hydraulics and electrical power is a minimal example of such a "representative" system.
- L6-2: Has a high-fidelity virtual environment been used to evaluate representative subsystems with alternative elements? The SAVI expanded wheel braking system Use Cases planned for AFE 61S1 and AFE 62 seem to fit this kind of evaluation and examination of more than one element for given functions is planned. The work plan through AFE 61 is planned around such a credible set of demonstrations but the work has not yet been completed. (Simulink, SCADE, Modelica, solid geometry, and publisher/subscriber interfaces should all be available for these evaluations.)
- L6-3: Is the demonstration model set for the VIP near the desired configuration in terms of its ability to illustrate how the process activities should be carried out in a larger scale shadow project?
 - The current plans for AFE 61S1 and AFE 62 should provide static and dynamic behavioral performance consistency checks and allow analsis of interactions between hardware and software.
 - L6-4: Architecture-centric example system model facilitates comparison of tradeoffs and system limitations with competing elements? While there are system analysis tools in ADL that promote such tradeoff comparisons, the SAVI VIP needs a fuller set of consistency checking tools and should further emphasize formal analysis tools. The VIP provides a quantitative means of comparing options or actions that resolve problems are clarified.
- L6-5: Does the architecture-centric example model set along with the ADL tools available support iterative consistency checks at all levels in the system hierarchy and provide automated documentation for the traceability matrix?

 The tools are evolving rapidly at the end of AFE 61 but more effort needs to be applied to expand their coverage and to better automate them into the graphical interface.
- L6-6: Have differences between the simulated operational (virtual) integration and the actual operational environment been identified, discussed, and documented as assumptions and limitations for the virtual integration?
 - These discussions are ongoing and are fairly well documented through AFE 61 in the detailed reports. Summary final reports are not as complete in spelling out assumptions and constraints.
- L6-7: Do relevant architectural model sets facilitate comparison of changes to software modules and/or subelements (hardware or software) in a virtual end-to-end setting?
 - Consistency checking (though done at every level as well) is one of the primary end-to-end objectives. Such checks have been carried out for the original AIR 6110 wheel braking system, but the fuller model set is essential to assess the first steps in scaling up the SAVI process to more complex systems. So far the development effort has shown considerable flexibility in the tools chosen for demonstrations. Nonetheless, scalability is a key issue for further maturation of the SAVI VIP.
- L6-8: Has a full virtual integration for a full set of the SAVI-expanded wheel braking system (including antiskid and autobraking, hydraulic system interactions, and electrical power interactions) been carried out?
 - The full SAVI braking system has not been carried through a complete virtual process at the end of AFE 61. That is planned for AFE 62, though that effort will likely still demonstrate a relatively immature VIP; that level of maturity is still likely short of what a major development program manager would like to see. That is why the SAVI Integrated Program Plan has always anticipated the need for additional development of Version 2.0 and Version 3.0 of the VIP.
- L6-9: Does the extended SAVI wheel braking model set include sufficient number and types of integrated hardware/software models to describe how to complete consistency checks that detect typical anomalies at interactions?
- L6-10: Does the SAVI expanded wheel braking system model set provide enough complexity in the model set to expose performance issues and physical, logical, and security anomalies during a virtual integration?
 A model set that includes dynamic elements (like antiskid, autobraking, hydraulic presseure failure states and transient behavior) should allow these types of assessments with consistency checking tools now available and expected by or shortly after
- L6-11: Does the work bench for the SAVI VIP provide adequate ability to compare virtual and real-world performance and give direction to analysis that can be easily provided to decision-makers early in the life cycle?

Autogeneration of inter-model dependencies revealed sources of safety defects as early as AFE 61, though a more complete set of automated generation of such reports is highly desirable.

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L6-12: Can the architecture-centric SAVI expanded wheel braking system model set provide predictions about system-wide throughput, timing, scalability, and reliability interactions?

Except for scalability, all these metrics have been demonstrated (albeit with simpler models) in demonstrations completed during AFE 61 or earlier.

• L6-13: Have efforts to analyze the human-computer interfaces been started with the SAVI expanded wheel braking system? Except for the use of the control and displays for COM-MON Use Cases examined early in AFE 61 (and before), there has been little or not work addressing human-computer interfaces.







Level 7 Questions

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- L7-1: Has an actual system modification or development (with a set of interacting subsystems) integration been carried out with the SAVI VIP?
- L7-2: Have adequate comparisons between the VIP and the "as-is" (or classical) integration process been carried out? Have any problems with use of the VIP in such a shadow project been documented? Are there planned actions to resolve problems or issues with use of the VIP?
- L7-3: Was the operating environment realistic (of high fidelity) for any shadow project completed that sought to assess the VIP versus "as-is" integration?
- L7-4: Was the feasibility of utilizing the VIP to integrate either new or modified software for a system of interest adequately demonstrated for a system of interest in a high fidelity operational environment?
- L7-5: Has a prototype software implementation been carried out in an operational environment where critical technical risk functionality (where this is risk associated with any defects in the VIP-compliant process) is involved?
- L7-6: Were there specific instances of where software technology was not "wellintegrated" whenever the VIP was utilized in the development?
- L7-7: Was it possible to measure and/or identify critical technological properties against requirements in a virtual (simulated) operational environment?

Are model-based processes applied in production?





- L7-1: Has an actual system modification or development (with a set of interacting subsystems) integration been carried out with the SAVI VIP?
 - The CH-47 CAAS upgrade was the closest to this kind of shadow project that has been during through AFE 61. That was not complete enough to guite meet the needs of this level of maturity.
- L7-2: Have adequate comparisons between the VIP and the "as-is" (or classical) integration process been carried out? Have any problems with use of the VIP in such a shadow project been documented? Are there planned actions to resolve problems or issues with use of the VIP?
 - The MSAD project might be an example of this kind of comparison, but the results of that SAVI-like effort are not likely to be shared completely with all SAVI members. The CH-47 CAAS upgrade was an attempt to generate a shadow project with a real modification project, but the comparisons are not complete enough and also could not be shared with all SAVI members.
- L7-3: Was the operating environment realistic (of high fidelity) for any shadow project completed that sought to assess the VIP versus "as-is" integration?
 - This question alludes to the environment for the system under development, not the VIP per se. It will, of course, be very difficult to measure the benefits of using the VIP rather than a classical integration process since that would imply parallel development tracks for identical or near-identical systems - not a realistic hope for any system used in the real world. This fact makes assessing the fidelity of the operational environment for a shadow project of great importance.
- L7-4: Was the feasibility of utilizing the VIP to integrate either new or modified software for a system of interest adequately demonstrated for a system of interest in a high fidelity operational environment?
 - This guestion focuses on the software integration but it again is intertwined between a realistic environment for operating a system of interest but is primarily concerned with the maturity of the VIP as a process for carrying out this software integration.
- L7-5: Has a prototype software implementation been carried out in an operational environment where critical technical risk functionality (where this is risk associated with any defects in the VIP-compliant process) is involved?
 - This guestion demands that "critical technical risk functionality" be defined unambiguously. Again, this maturity guestion is aimed at the software functionality it appears; hence, hardware is not addressed, though it is guestionable whether or not the guestion should apply only to software.
- L7-6: Were there specific instances of where software technology was not "well-integrated" whenever the VIP was ٠ utilized in the development?
 - Were these instances at least partly generated because of defects in the VIP or were they purely associated with flaws in the system of interest itself?
- L7-7: Was it possible to measure and/or identify critical technological properties against requirements in a virtual (simulated) operational environment?
 - Were such measurements/identifications useful and credible to decision-makers? Again, this guestion applies to the system under development but the ramifications of interest to VIP developers and evaluators is whether or not the VIP-compliant process (the virtual elements) provided additional useful and credible information at an earlier time than such information would have been available using the classical integration approach.







Level 8 Questions

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- L8-1: Has the VIP been proven to work in its "final" form and under expected conditions?
- L8-2: Does the VIP conform to all integration needs for completing verification that the system of interest meets its design specifications?
- L8-3: Does the VIP facilitate systems testing in the system's final configuration under the expected range of environmental conditions in which the system will operate?
- L8-4: Does the VIP and its architecture-centric model (continuously updated as the development testing progresses) provide useful information for planning operational assessments (validation testing)?
- L8-5: Does the VIP adequately auto-generate documentation of problems encountered both the system of interest and with the VIP itself?
- L8-6: Does VIP facilitate planning for additional testing and broader trade studies to support options that add capability, or actions to resolve either problems with the system of interest or with the VIP itself?
- L8-7: Does the VIP quantify how well software in the system is integrated with the operating hardware and all other elements?
- L8-8: Does the VIP architecture-centric model set remain continuously synchronized with system of interest completion and conformance with system requirements throughout the verification test and early validation testing (IOT&E for DoD users)?
- L8-9: Does auto-generated documentation from the VIP produce complete software documentation that conforms to the planned configuration management (CM) planning?
- L8-10: Does the VIP result in all planned software functionality completed using up to date software model sets with all consistency checks passed (or modifications analyzed at least)?
- L8-11: Does the VIP facilitate tracking of software resource reserves and measure how well the process operates to stay within allowable reserve limits?

Are measures in place for model-based processes?





- L8-1: Has the VIP been proven to work in its "final" form and under expected conditions?
 - This level (8) is the end process development. A full aircraft system can be integrated using this process, which is fully documented. The process must have all process elements completed for standards bodies to write specifications to the VIP.
- L8-2: Does the VIP conform to all integration needs for completing verification that the system of interest meets its design specifications?
 - The VIP should show results better (less development time, fewer defects, lower cost) than that of a classical physical/logical system integration (the "as-is" type of integration).
- L8-3: Does the VIP facilitate systems testing in the system's final configuration under the expected range of environmental conditions in which the system will operate?
 - The VIP should expedite verification testing of the end item by reducing defects found at the later stages of system synthesis.
- L8-4: Does the VIP and its architecture-centric model (continuously updated as the development testing progresses) provide useful information for planning operational assessments (validation testing)?
- L8-5: Does the VIP adequately auto-generate documentation of problems encountered both the system of interest and with the VIP itself?
 - VIP auto-generation of documents should be evident as the documentation is updated as both hardware and software testing progresses. This auto-generated documentation should be clearly superior (in completeness, substantiating reports, and in earler availability) to documentation produced after an "as-is" integration process.
- L8-6: Does VIP facilitate planning for additional testing and broader trade studies to support options that add capability, or actions to resolve either problems with the system of interest or with the VIP itself?
- L8-7: Does the VIP quantify how well software in the system is integrated with the operating hardware and all other elements?
 - The VIP should have fewer defects occurring in the verification and in the validation phases of testing than a comparable "as-is" or classical physical/logical integration approach.
- L8-8: Does the VIP architecture-centric model set remain continuously synchronized with system of interest completion and conformance with system requirements throughout the verification test and early validation testing (IOT&E for DoD users)?
- L8-9: Does auto-generated documentation from the VIP produce complete software documentation that conforms to the planned configuration management (CM) planning?
 - All VIP-generated documents should accurately reflect system software that meets the system specification.
- L8-10: Does the VIP result in all planned software functionality completed using up to date software model sets with all consistency checks passed (or modifications analyzed at least)?
 - Software testing that follows a SAVI-compliant VIP should have fewer defects than software that follows a classical physical/logical integration approach.
- L8-11: Does the VIP facilitate tracking of software resource reserves and measure how well the process operates to stay within allowable reserve limits?
 - Analysis of system-wide performance (end-to-end latency, offending elements in latency of computing threads) is essential to the success of the virtual enhancements to the
 integration process.







Level 9 Questions

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- L9-1: Does the actual system of interest prove successful in operational missions; that is, is virtual integration validated to provide operational success as defined by the user?
- L9-2: Have end item operational tests been completed successfully for the system of interest that was integrated using the VIP?
- L9-3: Does completed configuration management documentation provide complete traceability of the development?
- L9-4: Is there an integrated technology reuse methodology indicated through the use of the VIP?
- L9-5: Is the system of interest software readily repeatable and shown to be reusable?
- L9-6: Has the software in the system of interest passed a full range of consistency checks suggested by user-generated Use Cases?
- L9-7: Is sustainment of software engineering support in place and synchronized with the VIP configuration management traceability documentation?

Are model-based processes continuously improving?







- L9-1: Does the actual system of interest prove successful in operational missions; that is, is virtual integration validated to provide operational success as defined by the user?
 - This level of maturity for the VIP is the final proof of the process. A positive answer here suggests an integration done using this process for a full aircraft system satisfies customer needs and the process is standardized in a way to be useful to all stakeholders. The actual system has been validated in its final form and under mission conditions, as encountered in OT&E.
- L9-2: Have end item operational tests been completed successfully for the system of interest that was integrated using the VIP?
 - The OT&E reports should provide quantitative results to corroborate cost savings and time savings due to the virtual integration. The validated system of interest capabilities must compare favorable and quantitatively with predictions.
- L9-3: Does completed configuration management documentation provide complete traceability of the development?
 - The VIP auto-generated documentation effort must support this level of configuration management and allow appropriate value-added modifications to be pursued readily.
- L9-4: Is there an integrated technology reuse methodology indicated through the use of the VIP?
 - The VIP documentation (updated specifications, completely validated MR/DEL scheme, and proven consistency checking) should provide a framework for further MBSE inputs to improving operations and maintenance of the system of interest.
- L9-5: Is the system of interest software readily repeatable and shown to be reusable?
 - Use of formal proofs where appropriate are one way to support positive answers to this question, but empirical evidence from validation testing with the user (OT&E) may also lead to confident reuse of software components.
- L9-6: Has the software in the system of interest passed a full range of consistency checks suggested by user-generated Use Cases?
 - A VIP that supports this kind of user interaction in software validation is mature in this sense.
- L9-7: Is sustainment of software engineering support in place and synchronized with the VIP configuration management traceability documentation?
 - This maturity question strongly suggests that the VIP itself collects reliability information and that such data are to be continuously collected throughout the life cycle of the system of interest.







Conclusion

- The TMC tool is useful for establishing a maturity assessment for MBE processes
- SAVI has tailored the TRL levels for virtual system integration processes
- SAVI has advanced from TRL 1 to "upper mid-range" TRL levels
- SAVI continues to mature with commercial tools a re-assessment is underway







































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Questions?





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6