

How Can We Use Verification and Validation (V&V) Techniques in Early Systems Engineering?

STEVEN H. DAM, PH.D., ESEP
CHRIS RITTER
SPEC INNOVATIONS
STEVEN.DAM@SPECINNOVATIONS.COM



Outline

1. V&V in the Early Stages of the Lifecycle?
2. Ontology for V&V
3. What's a Verifiable Requirement?
4. Developing a V&V Plan Using MBSE

1. V&V IN THE EARLY STAGES OF THE LIFECYCLE?



What Is Verification?

- Verification: “the process of establishing the truth, accuracy, or validity of something” [Google definition]
- Meets specification-level requirements
- Proves that the solution-dependent requirements are satisfied
- Proves that solution was or is being built according to agreed requirements

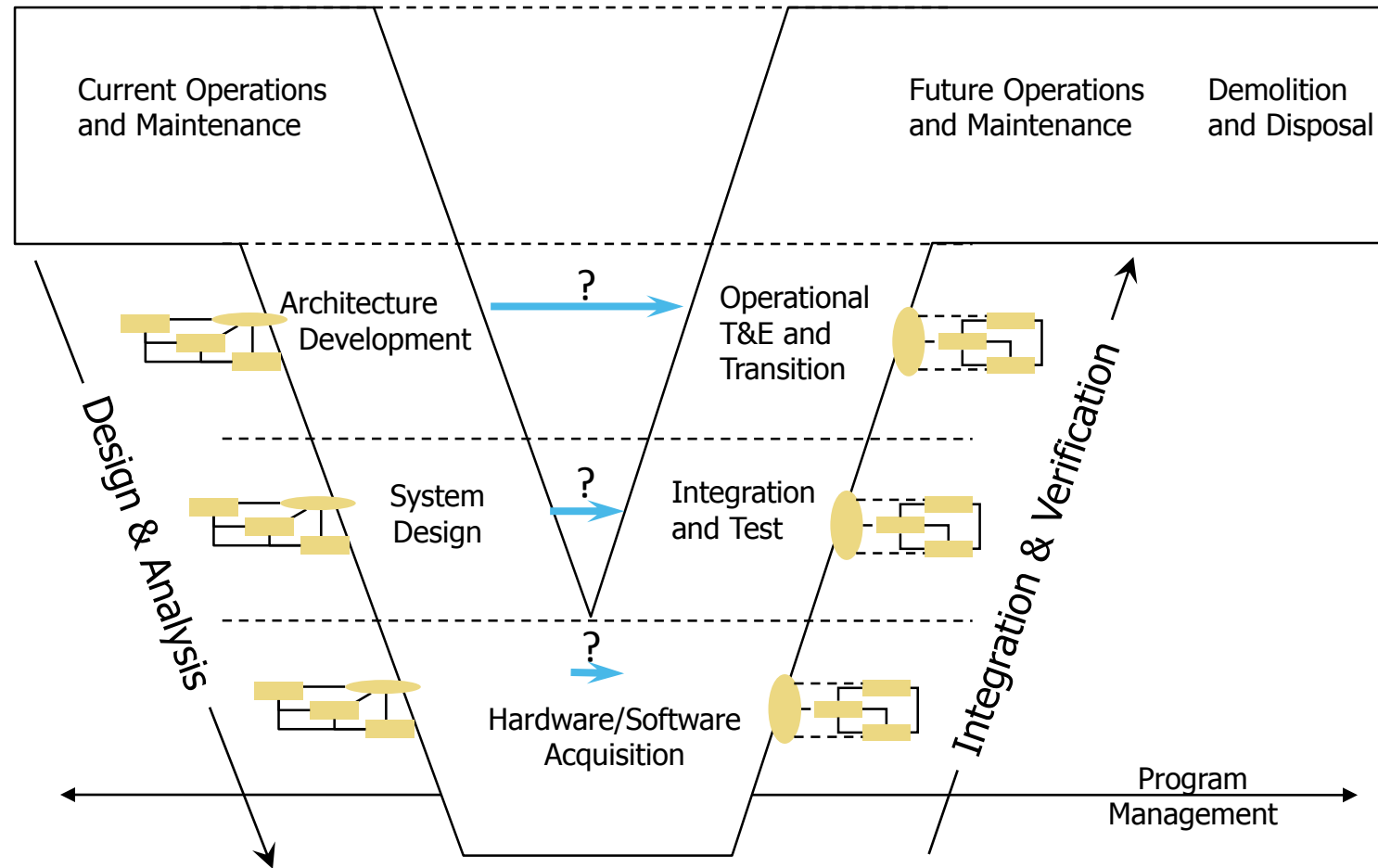
Frequently the terms “Unit Test” and “Developmental Test and Evaluation” apply to verification

What Is Validation?

- Validation: “the action of checking or proving the validity or accuracy of something” [Google definition]
- Relates to customer and other stakeholder satisfaction
- Proves solution-independent requirements are being satisfied
- Usually performed at the enterprise and/or system level
- In process, validation helps ensure system will ultimately be part of the accepted solution in the target environment

Frequently the term “Operational Test and Evaluation” applies to validation

What Do We Need to Do Early?



What Do We Need Early?

- Ontology that includes V&V information
- Verifiable Requirements
- V&V Plan

To do any of these things you need to understand how to prepare for V&V, conduct V&V activities, and report V&V results, so make sure an expert in these areas are part of the early phase

2. ONTOLOGY FOR V&V



Lifecycle Modeling Language's Primary Classes

- Action
- Artifact
- Asset
 - Resource
- Characteristic
 - Measure
- Connection
 - Conduit
 - Logical
- Cost
- Decision
- Input/Output
- Location
 - Physical, Orbital, Virtual
- Risk
- Statement
 - Requirement
- Time

See www.lifecyclemodeling.org
for LML specification

*Supports capturing information
throughout the lifecycle*

V&V Extension to LML

- In developing Innoslate's new Test Center capability, we discovered the need to add a subclass to Action: Test Case
- We used the Schema Editor to make these changes, but also we had to add views and reports
- You may discover that you want to add other classes, attributes, and relationships, as well and develop special reports and data entry screens using the SDK

Test Case (Subclass of Action)

- A Test Case entity represents a set of conditions utilized to determine whether a system works as intended
- Properties (Attributes)

Name	Type	Description
Status	ENUMERATION	Status represents the current state of this Test Case.
Actual Result	BIG_TEXT	Actual Results represents the results that are captured after executing a Test Case.
Expected Result	BIG_TEXT	Expected Result represents the result expected when executing this Test Case.
Set Up	BIG_TEXT	Set Up represents the prerequisites that must be fulfilled before executing this Test Case.

3. WHAT'S A VERIFIABLE REQUIREMENT?



Characteristics of Good Requirements

- Each individual requirement should be:
 - Correct: Describes the user's true intent and is legally possible
 - Complete: Express a whole idea
 - Clear: Unambiguous and not confusing
 - Consistent: Not in conflict with other requirements
 - **Verifiable: Provable (within realistic cost and schedule) that the system meets the requirement**
 - Traceable: Uniquely identified, and able to be tracked to predecessor and successor lifecycle items/objects
 - Feasible: Able to be implemented with existing technology, and within cost and schedule
 - Modular: Can be changed without excessive impact on other requirements
 - Design: Does not impose a specific solution on design; says "what", Independent not "how"

What Makes a Requirement Verifiable?

- You need to answer the following questions:
 - Can the requirement be met?
 - By analysis, demonstration, inspection, modeling & simulation, or test?
 - Will the user accept the results?
- Avoid words such as “excessive,” “sufficient,” “resistant,” etc.
 - Make the requirement quantifiable
- Even “suitability” can be quantified








Example Verification Requirements

MENU Dashboard **Requirements** Database Diagrams Test Center

Add After Add Child Auto Number Quality Check Move Open More Delete

Clear: Yes
 Complete: Yes
 Consistent: Yes
 Correct: No
 Design: Yes
 Feasible: No
 Traceable: Yes
 Verifiable: No

Potential ambiguities detected: [appropriate, all]

VR Verification Requirements	(Last Modified: 9/20/2017)	Rationale	Quality Score
VR.1 Space Vehicle First-mode Natural Frequency The space vehicle first-mode natural frequency shall be verified by analysis and test.	T V	Analysis and test shall be considered successful if the estimate and measured first mode is greater than 25 Hz.	89% 
VR.1.1 Natural Frequency Analysis The analysis shall develop a multi-node finite element model to estimate natural modes.	S T V		78% 
VR.1.2 Natural Frequency Test The test shall conduct a modal survey (since sweep) of the vehicle using a vibration table.	S V		67% 
VR.2 Appropriate Markings The appropriate markings on all system structural components shall be verified by inspection. The inspection shall determine if axes and identifications are properly indicated.		The verification shall be considered successful if all structural components are properly marked.	56% 
VR.3 Altitude Accuracy The accuracy of the altitude determination system estimates shall be verified by analysis. The analysis shall use Monte Carlo simulations of expected sensor accuracy, plus noise, to determine statistical distribution error.	V	The analysis shall be considered successful if the predicted error is less than or equal to 0.01 degrees (3 sigma).	56% 
VR.4 Battery GSE Charge Display Battery charge ground support equipment (GSE) state of charge display shall be verified by demonstration. The demonstration shall show that state of charge is indicated when connected to a representative load.	V	The demonstration shall be considered successful if the state of charge is displayed.	56% 
VR.5 Fastener Type Fastener type shall be verified by inspection. The inspection shall review the vendor's records to look for the type and size of fasteners used. The inspection shall also review the documentation on fastener material.	V	The verification shall be considered successful if all interface fasteners are 4-40 in size made from stainless steel.	56% 

Trace VRs to Test Cases

MENU ▾
Dashboard Requirements Database Diagrams Test Center
🔍
🗨️
Share
FireSAT Complete Demo ▾

Attributes Metadata

Requirement

Name

Appropriate Markings

Number

VR.2

Description

✚ ▾ **B** *I* U ~~S~~ ⋮

The appropriate markings on all system structural components shall be verified by inspection. The inspection shall determine if axes and identifications are properly indicated.

Quality Score

56%

Rationale

The verification shall be considered successful if all structural components are

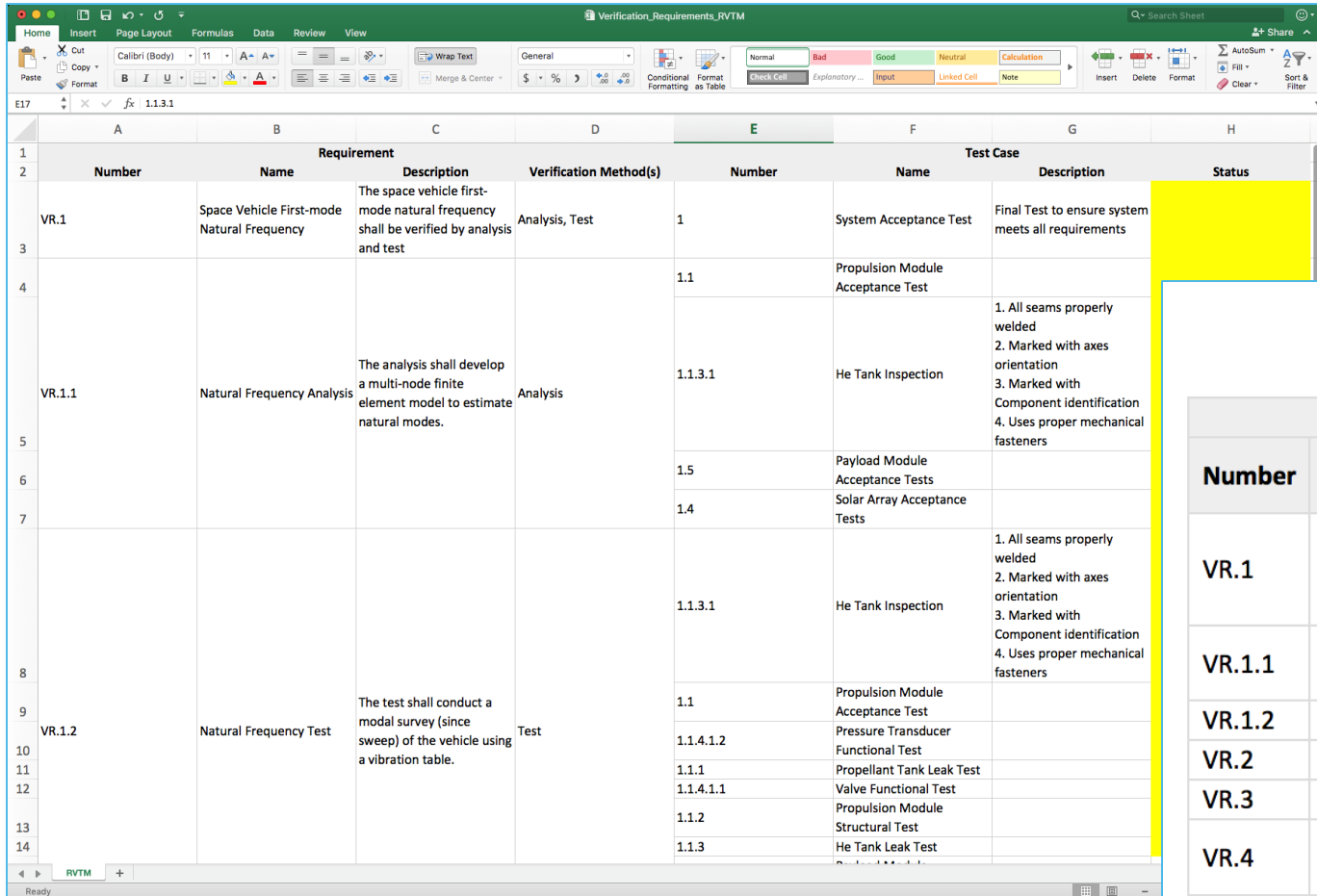
Clear ☰

🔍 Open ▾
Remove ▾

		1 System Acceptance Test	1.1 Propulsion Module Acceptanc...	1.1.1 Propellant Tank Leak Test	1.1.1.1 Propellant Tank Leak Test	1.1.2 Propulsion Module Inspection	1.1.3 He Tank Leak Test	1.1.3.1 He Tank Leak Test	1.1.4 Propellant Management Sub...	1.2 Baseplate Module Acceptanc...	1.3 Top Panel Module Acceptanc...	1.4 Solar Array Acceptance Tests	1.5 Payload Module Acceptance T...
VR.1 Space Vehicle First-mode Natural F...	X												
VR.1.1 Natural Frequency Analysis		X				X				X	X		
VR.1.2 Natural Frequency Test		X	X		X	X	X			X	X		
VR.2 Appropriate Markings		X		X	X	X	X	X	X	X	X	X	
VR.3 Altitude Accuracy	X												X
VR.4 Battery GSE Charge Display	X								X				X
VR.5 Fastener Type		X				X	X	X	X	X	X	X	

Tracing verification requirements to test cases early ensures all requirements are properly verified through inspection, analysis, simulation, demonstration, and/or test

Produce Key Reports and Archive Them



Requirement				Test Case			
Number	Name	Description	Verification Method(s)	Number	Name	Description	Status
VR.1	Space Vehicle First-mode Natural Frequency	The space vehicle first-mode natural frequency shall be verified by analysis and test	Analysis, Test	1	System Acceptance Test	Final Test to ensure system meets all requirements	
VR.1.1	Natural Frequency Analysis	The analysis shall develop a multi-node finite element model to estimate natural modes.	Analysis	1.1	Propulsion Module Acceptance Test		
				1.1.3.1	He Tank Inspection	1. All seams properly welded 2. Marked with axes orientation 3. Marked with Component identification 4. Uses proper mechanical fasteners	
				1.5	Payload Module Acceptance Tests		
				1.4	Solar Array Acceptance Tests		
VR.1.2	Natural Frequency Test	The test shall conduct a modal survey (since sweep) of the vehicle using a vibration table.	Test	1.1.3.1	He Tank Inspection	1. All seams properly welded 2. Marked with axes orientation 3. Marked with Component identification 4. Uses proper mechanical fasteners	
				1.1	Propulsion Module Acceptance Test		
				1.1.4.1.2	Pressure Transducer Functional Test		
				1.1.1	Propellant Tank Leak Test		
				1.1.4.1.1	Valve Functional Test		
1.1.2	Propulsion Module Structural Test						
1.1.3	He Tank Leak Test						

Add actual results and status as V&V occurs

Verification Cross-Reference Matrix

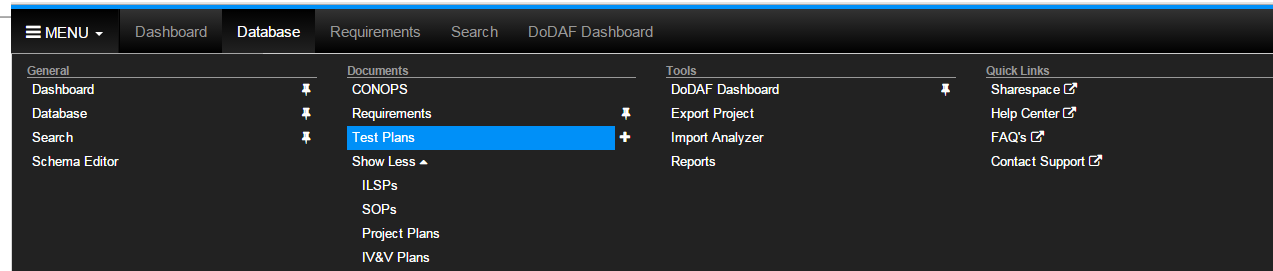
Requirement		Verification Method(s)				
Number	Name	Analysis	Demonstration	Inspection	Modeling & Simulation	Test
VR.1	Space Vehicle First-mode Natural Frequency	X				X
VR.1.1	Natural Frequency Analysis	X				
VR.1.2	Natural Frequency Test					X
VR.2	Appropriate Markings			X		
VR.3	Altitude Accuracy	X				
VR.4	Battery GSE Charge Display		X			
VR.5	Fastener Type			X		

4. DEVELOPING A V&V PLAN USING MBSE



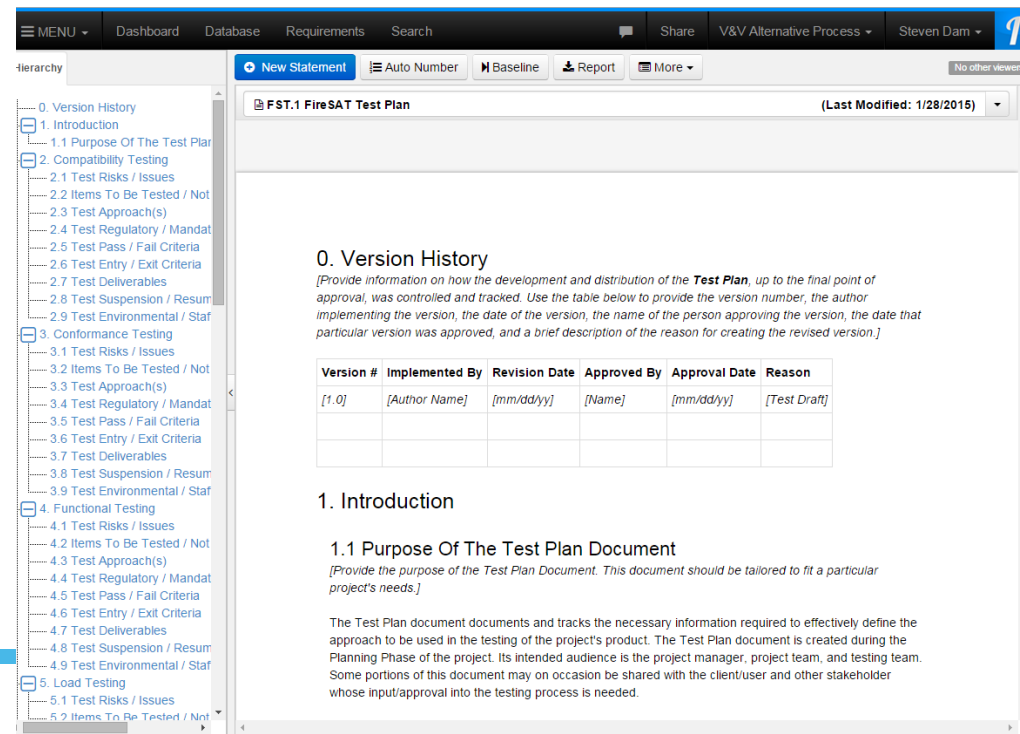
Create a Test Plan

1 Select Test Plans from Menu



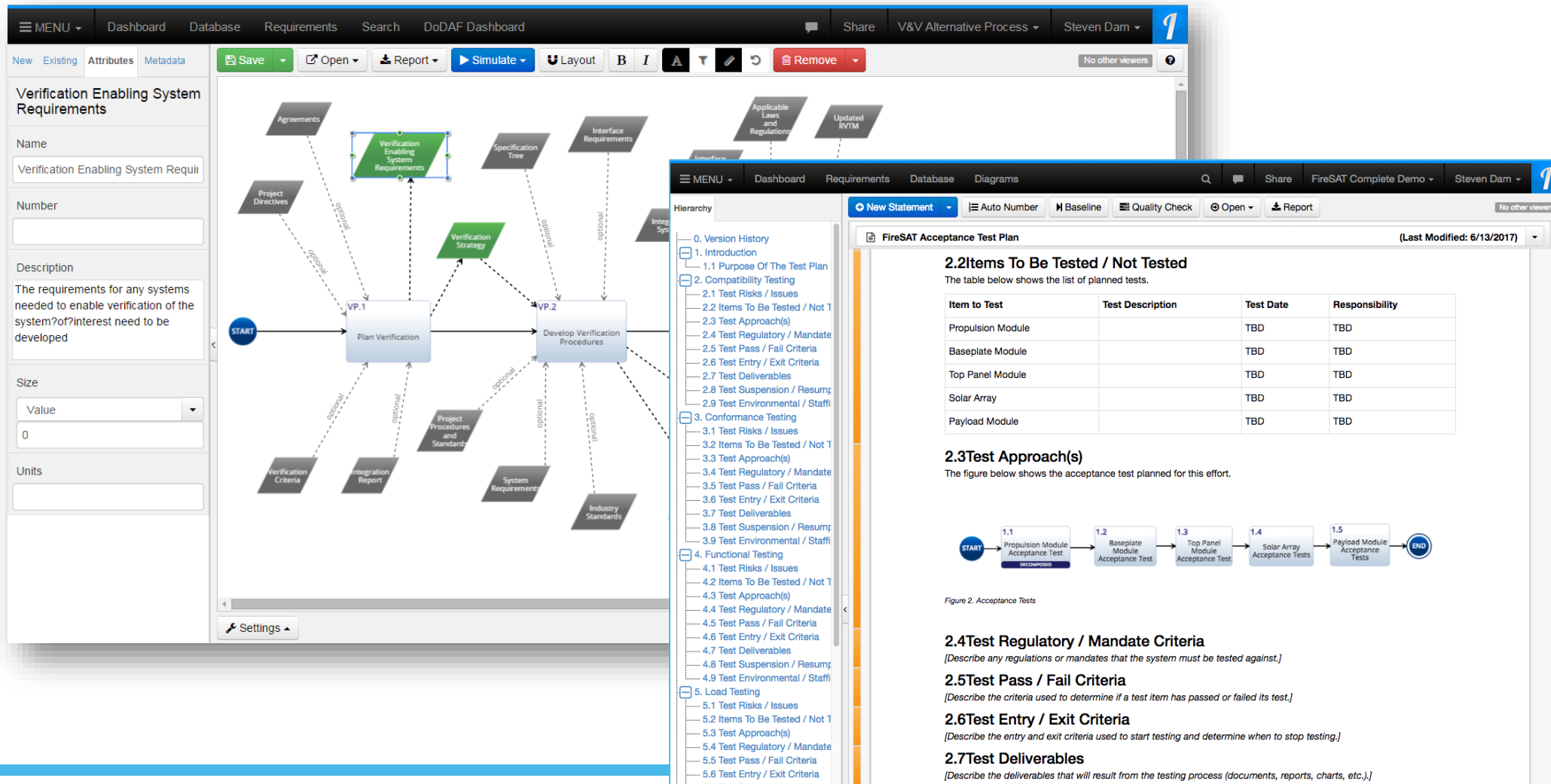
2 Answer questions (use our template or create your own)

3 Fill-in resulting template



Create Test Processes (Test Cases)

- Model processes
- Embed processes into test plan



The screenshot displays a software tool interface for creating test processes. The main window shows a flowchart with nodes for 'Plan Verification' (VP.1) and 'Develop Verification Procedures' (VP.2), connected by a solid arrow. Dashed arrows indicate dependencies from various inputs like 'Project Directives', 'Verification Criteria', 'Integration Report', 'Project Procedures and Standards', 'System Requirements', and 'Industry Standards' to the main processes. A 'Verification Enabling System Requirements' box is highlighted in green.

On the right, a detailed test plan for 'FireSAT Acceptance Test Plan' is shown. It includes a table of items to be tested and a flowchart of acceptance tests.

Item to Test	Test Description	Test Date	Responsibility
Propulsion Module		TBD	TBD
Baseplate Module		TBD	TBD
Top Panel Module		TBD	TBD
Solar Array		TBD	TBD
Payload Module		TBD	TBD

2.2 Items To Be Tested / Not Tested
The table below shows the list of planned tests.

2.3 Test Approach(s)
The figure below shows the acceptance test planned for this effort.

```

graph LR
    START((START)) --> 1.1[1.1 Propulsion Module Acceptance Test]
    1.1 --> 1.2[1.2 Baseplate Module Acceptance Test]
    1.2 --> 1.3[1.3 Top Panel Module Acceptance Test]
    1.3 --> 1.4[1.4 Solar Array Acceptance Tests]
    1.4 --> 1.5[1.5 Payload Module Acceptance Tests]
    1.5 --> END((END))
  
```

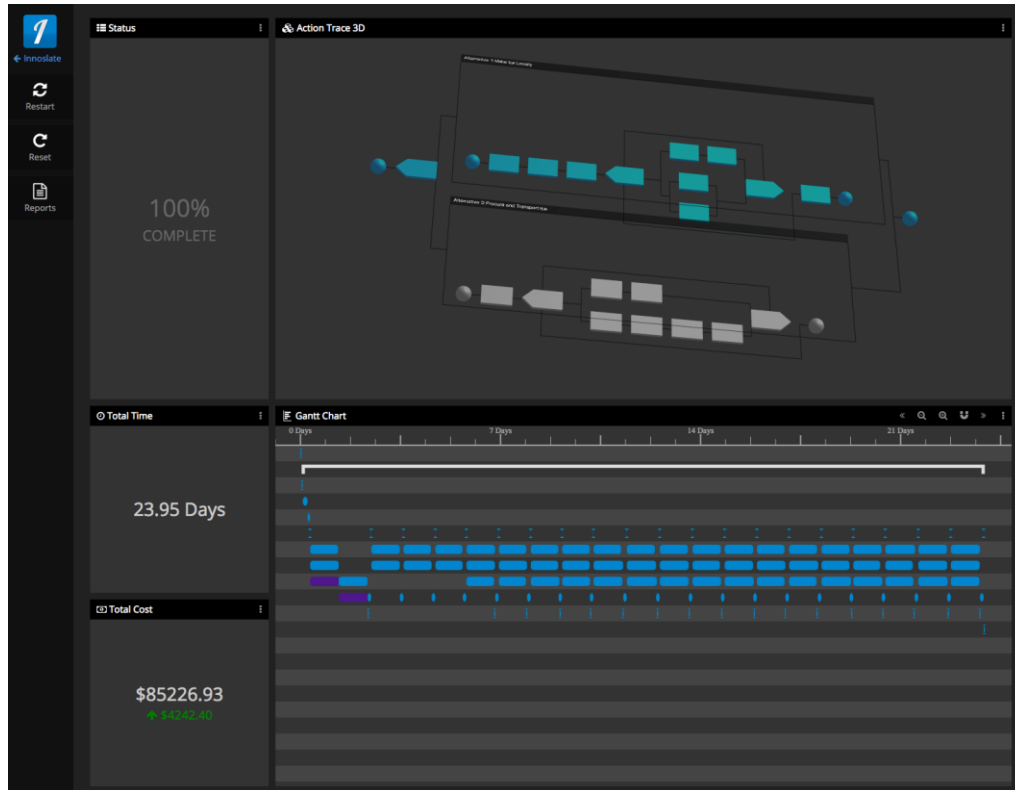
2.4 Test Regulatory / Mandate Criteria
[Describe any regulations or mandates that the system must be tested against.]

2.5 Test Pass / Fail Criteria
[Describe the criteria used to determine if a test item has passed or failed its test.]

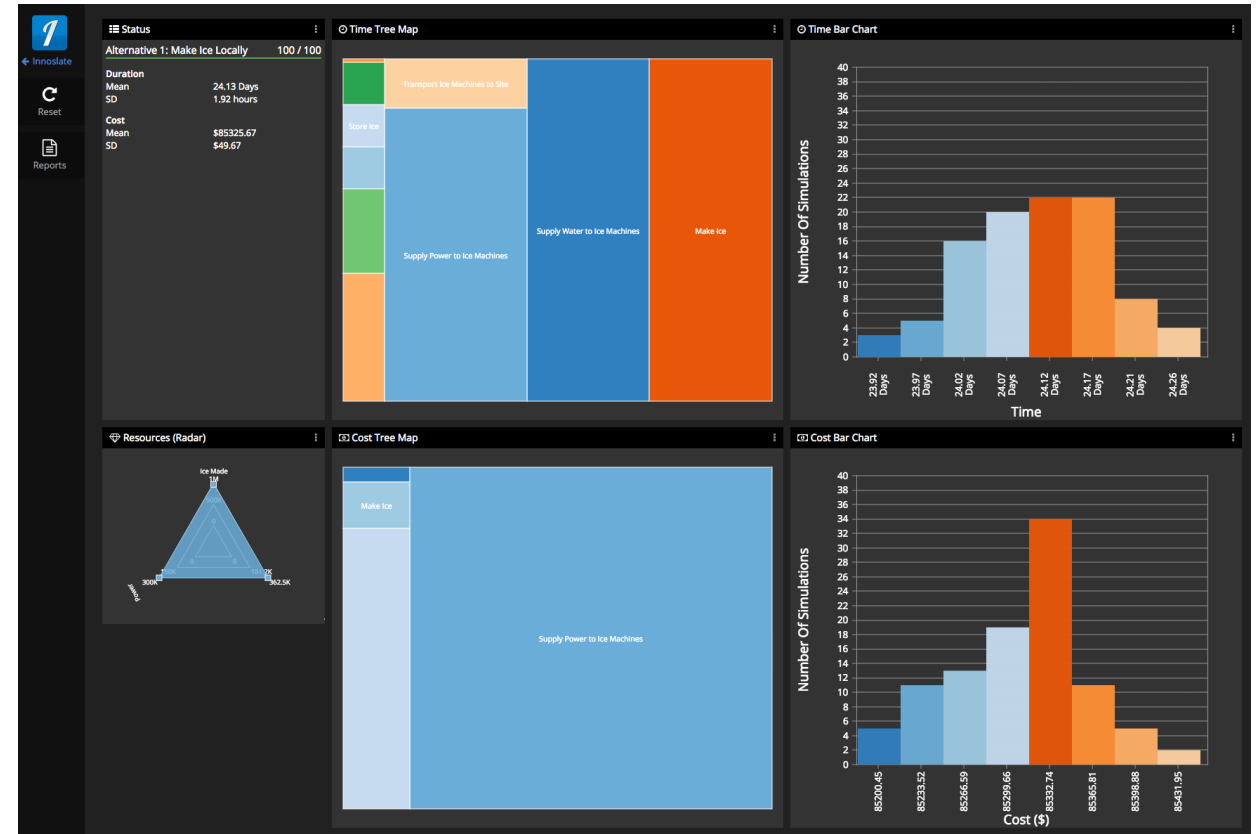
2.6 Test Entry / Exit Criteria
[Describe the entry and exit criteria used to start testing and determine when to stop testing.]

2.7 Test Deliverables
[Describe the deliverables that will result from the testing process (documents, reports, charts, etc.,)]

Make Sure the Test Cases Work Using Simulation



Watch test case execute at all levels using the Discrete Event Simulator











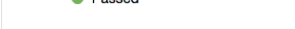
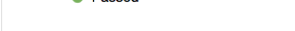






Explore the variation of individual steps to execute the model over many iterations using the Monte Carlo Simulator

You can add resources and costs to enhance your planning

Capture Actual Results and Status During V&V

- Capture actual results as part of test report

Hierarchy		Expected Result	Actual Result	Status	Status Roll-Up
<ul style="list-style-type: none"> 1 System Acceptance Test <ul style="list-style-type: none"> 1.1 Propulsion Module Acceptance Test <ul style="list-style-type: none"> 1.1.1 Propellant Tank Leak Test <ul style="list-style-type: none"> 1.1.1.1 Propellant Tank Inspection 1.1.1.2 Propulsion Module Structural Test 1.1.1.3 He Tank Leak Test <ul style="list-style-type: none"> 1.1.1.3.1 He Tank Inspection 1.1.1.4 Propellant Management Subassembly Acceptance Test <ul style="list-style-type: none"> 1.1.1.4.1 Line Inspection <ul style="list-style-type: none"> 1.1.1.4.1.1 Valve Functional Test 1.1.1.4.1.2 Pressure Transducer Functional Test 1.2 Baseplate Module Acceptance Test 1.3 Top Panel Module Acceptance Test 1.4 Solar Array Acceptance Tests 1.5 Payload Module Acceptance Tests 		Meets all acceptance criteria	TBD	In Progress	
1 System Acceptance Test Final Test to ensure system meets all requirements		Meets all acceptance criteria	TBD	In Progress	
1.1 Propulsion Module Acceptance Test		Meets all propulsion module acceptance criteria	TBD	In Progress	
1.1.1 Propellant Tank Leak Test		Less than 2 parts/million detected	Met all test criteria	Passed	
1.1.1.1 Propellant Tank Inspection		All seams appear complete	Met all test criteria	Passed	
1.1.1.2 Propulsion Module Structural Test		Must pass "shake and bake" test	Met all test criteria within expected tolerances	Passed	
1.1.1.3 He Tank Leak Test		Less than 10 parts/million He detected	5.7 parts/million detected	Passed	
1.1.1.3.1 He Tank Inspection		All seams appear complete	Met all test criteria	Passed	
1.1.1.4 Propellant Management Subassembly Acceptance Test		Meets all test criteria	Met all test criteria	Passed	
1.1.1.4.1 Line Inspection		Inspect line to ensure no breaks have occurred	Met all test criteria	Passed	
1.1.1.4.1.1 Valve Functional Test		Values function as designed	Met all test criteria within expected tolerances	Passed	
1.1.1.4.1.2 Pressure Transducer Functional Test		Pressures match levels used	Met all test criteria within expected tolerances	Passed	
1.2 Baseplate Module Acceptance Test		Full "shake and bake"	Inspection determined sufficient	Not Run	
1.3 Top Panel Module Acceptance Test		Meets all acceptance criteria	Awaiting results of lower level tests	Blocked	
1.4 Solar Array Acceptance Tests		Produces greater than 10.7 MWatts	Produced less than 8.9 MWatts	Failed	
1.5 Payload Module Acceptance Tests		Meets all acceptance criteria	Met all criteria	Passed	

Other Information Needed for V&V Activities

- Test Equipment and Facilities (Assets)
- Test Organization (Assets) and Roles/Responsibilities (Statements)
- Risks and mitigations (Risk and many others)
- Criteria (Characteristics/Measures)
- Schedule (Timeline and/or process simulation output)
- Costs (WBS linked to processes)
- Data capture (actual results as Measures and Times)
- Artifacts
- Location(s)
- Decisions (assumptions, issues, etc.)

BENEFITS OF EARLY V&V



Benefits of Early V&V

1. Well defined plan for V&V
 - We know what data we need to capture
 - We know what test facilities we will need
 - We have modeled test scenarios to derive expected results
 2. Well crafted verification requirements
 - Opportunity for early customer approval
 - Increase in stakeholder confidence
 3. Reduced costs
 - Fewer errors in design
 - Fewer tests may be needed
-