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hybrid event

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Model-Based Test & Evaluation (T&E) Framework

Introduction

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Kasey is a Systems Engineer with over 10 years of experience working in the defense industry. She has proven success in leading systems engineering and test teams to solve problems and achieve operational mission success. She has supported test programs for a variety of systems including Radars, Drones, and IoT systems. With specialties in Model Based Systems Engineering and Test and Evaluation, she enjoys optimizing tools and processes to make Systems Engineering and Testing more accurate and efficient.

Introduction

Goal: explore applying **Model-Based Systems Engineering (MBSE)** methodology to **Test and Evaluation (T&E)** to achieve a **more efficient and effective approach** to system testing

What is Model-Based T&E, and why would you want to use it?

Approach to a Model-Based T&E Framework

Example of applying a Model-Based T&E Framework to a real Test Program

Results, benefits, and lessons learned applying a Model-Based T&E approach

Challenges of Test & Evaluation

Challenge

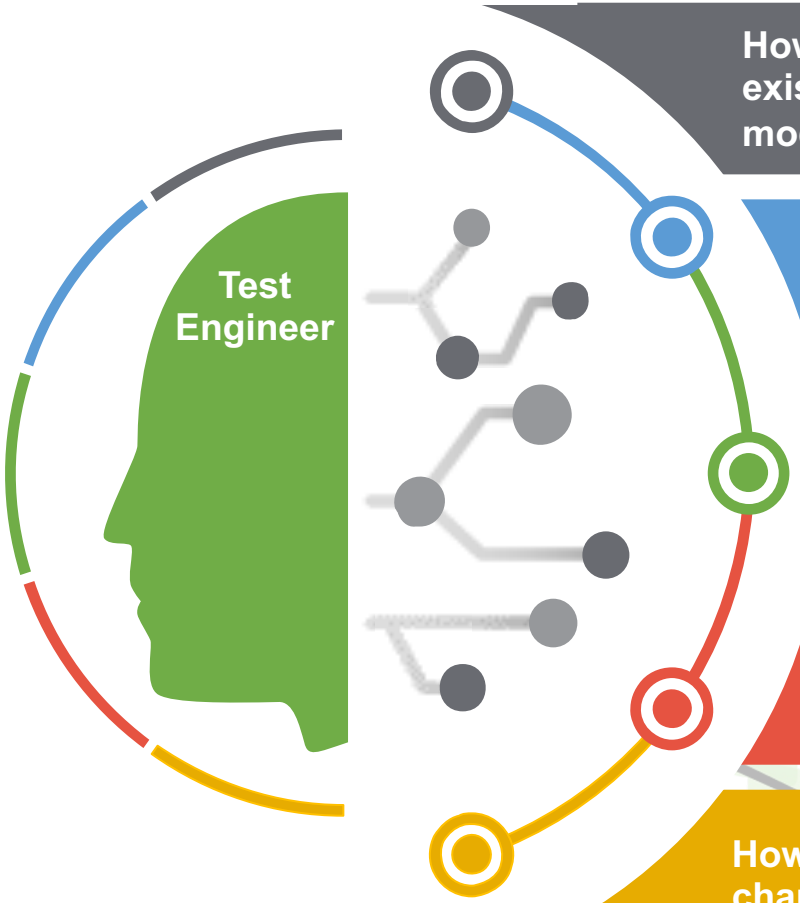
- Managing **competing stakeholder priorities** on test objectives, schedules, and resources leads to **frequent changes and re-work**
- Testing complex System of Systems (SoS) may require **development of complex scenarios,** making it **difficult to assess test coverage**
- Testing often requires **manual generation of detailed documents** such as test plans, procedures, and readiness reviews
- The system **may not work like the testers expected** it to perform, leading to significant redlining, retesting, and schedule delays

Opportunity

- Develop **dynamic models for test planning** that are **easier to update** as plans evolve over time
- Utilize **model-based traceability, metrics, and gap analysis** to assess test alignment to the requirements
- **Automate test document generation** to **save time** and **reduce human error**
- **Analyze system models** to **improve test procedure quality** and ensure that testing is feasible

A growing gap exists between digital systems engineering processes and manual document-based test processes

Model-Based Test and Evaluation

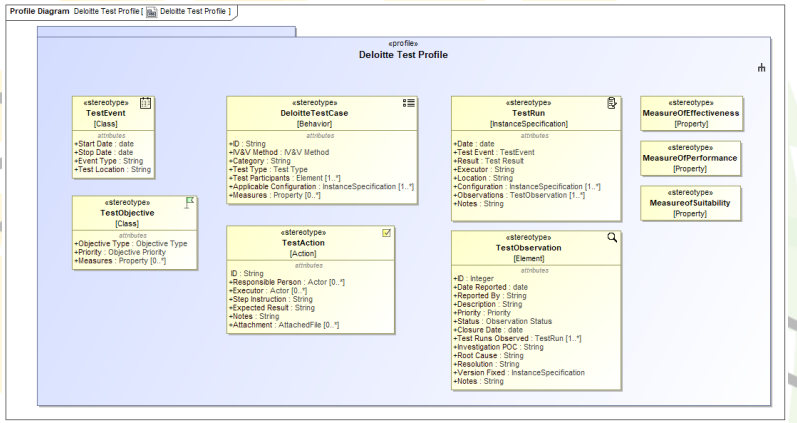


How can I utilize existing system models for testing?	Use the system MBSE model to help **capture** the **System Under Test (SUT) configuration**, **requirements**, and **behaviors to be executed** during testing
How can I ensure test coverage?	**Integrate** the **test model** with the **system design model** for **improved traceability** to ensure test coverage
How can I better understand how the system should work?	Use models to **facilitate more communication** between the test team and system design team
How can I spend less time on documentation?	Capture test planning and design information in **one location** instead of multiple disparate documents, and **automate generation of documents**
How can I manage change?	As the system definition changes, **use the model to identify** where **test changes** need to be made and look for gaps

Approach for Implementing Model-Based T&E

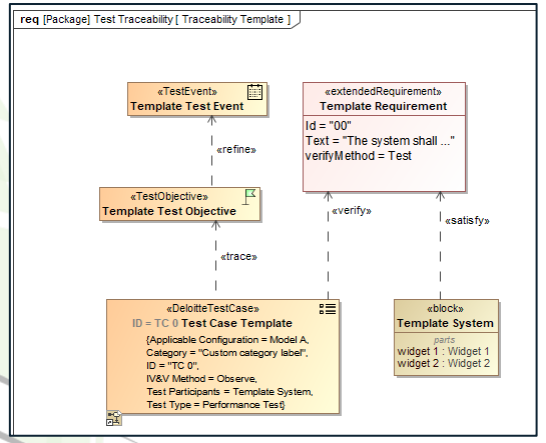
1

Developed **custom Cameo Profile** for T&E elements and additional test fields that need to be captured



2

Created **model schema** for planning how to interconnect test elements and connect the test model to the system model



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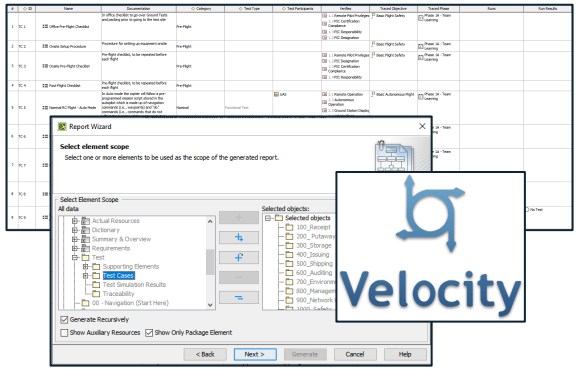
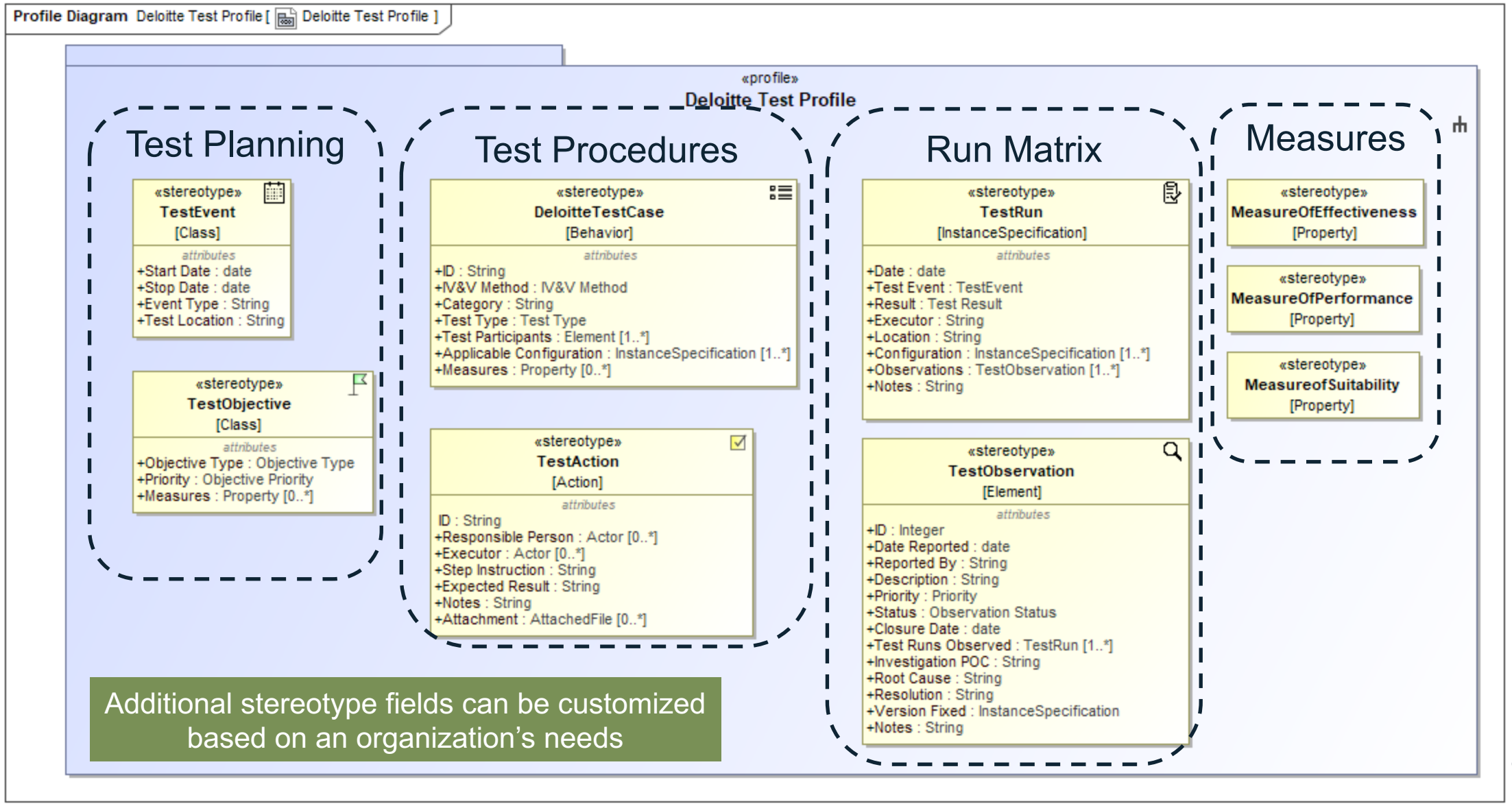
Built **templates** to **standardize and automate** model-based tables (RTVM) and exports (Test Procedures, Plans, etc.)



Stereotypes Overview



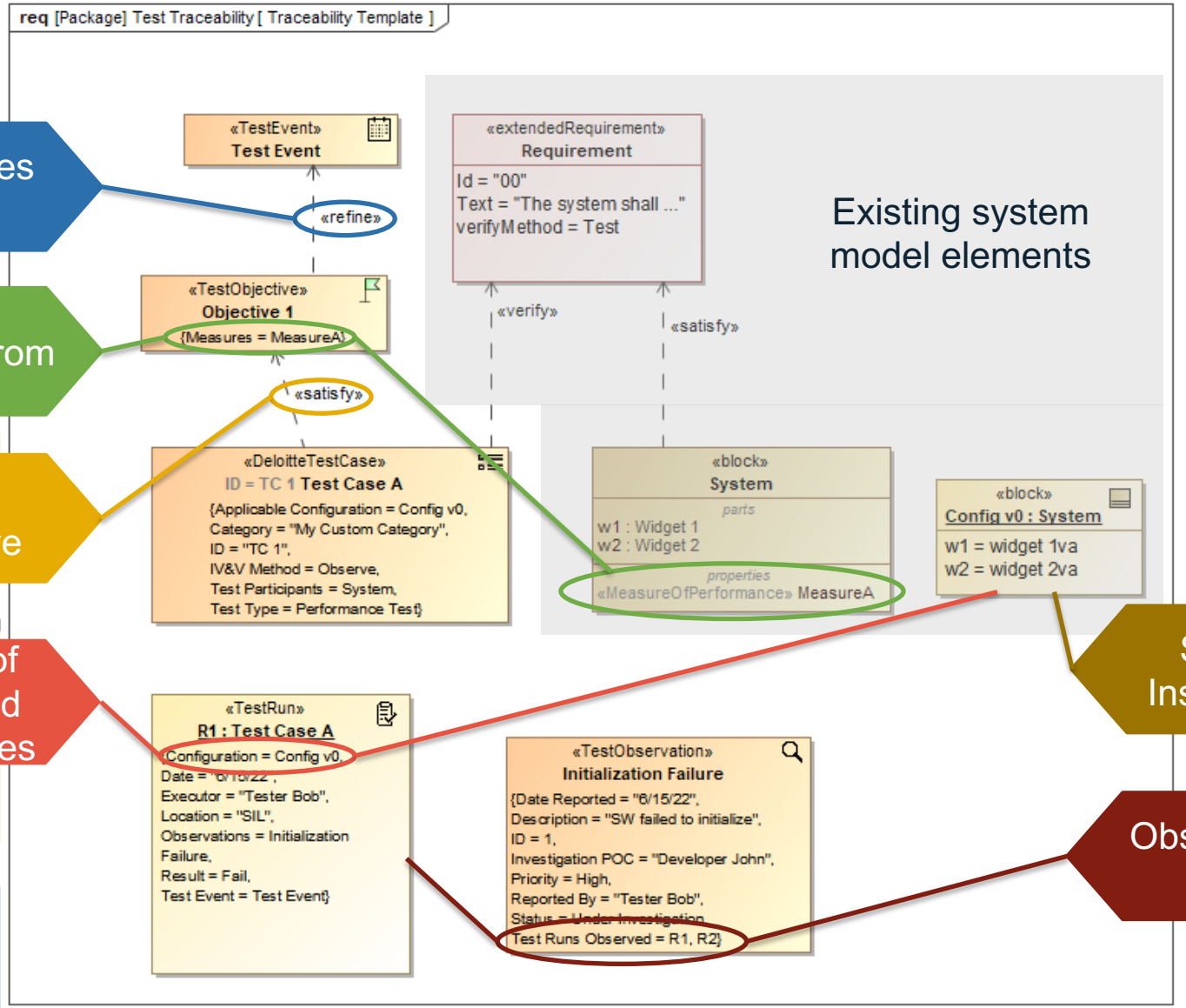
T&E Model Schema

One or more Test Objectives refine each Test Event

Test Objectives can be associated with Measures from System Blocks

One or more Test Cases Satisfy each Test Objective

Test Runs are instances of Test Cases and associated with system config Instances



SUT configurations are Instances of system blocks

Observations are associated with Test Runs

Model-Based Requirements Traceability Verification Matrix (RTVM)

RTVM by Requirement displays Requirement to Test Case traceability, snapshot of test run results, and Requirement details

#	Id	Name	Text	Verify Method	Verified By	Related Test Runs	Test Run Results
1	00	Requirement	The system shall …	Test	TC 1 Test Case A	R1 : Test Case A R2 : Test Case A R3 : Test Case A	Fail Pass with Exception Pass

RTVM by Test Case displays Test Case to Requirement traceability, snapshot of test run results, and Test Case details

#	ID	Name	Documentation	Category	Test Type	Test Participants	Verifies	Traced Objective	Traced Phase	Runs	Run Results
1	TC 1	Test Case A	Test Case Description	My Custom Category	Performance Test	System	00 Requirement	Objective 1	Test Event	R1 : Test Case A R2 : Test Case A R3 : Test Case A	Fail Pass with Exception Pass

Model-Based Run Matrix

- Run Matrix displays **Test Runs** (instances of Test Cases)
- Instances can be user-created or generated by Cameo if simulating a Test Case

Criteria

Classifier: Test Case A, Test Case B ... Scope (optional): Run Matrix ... Filter:

Result: Pass | Pass with Exception | Fail | No Test | Other

#	Name	Classifier	Date	Test Event	Result	Executor	Location	Configuration	Observations	Notes
1	R1	TC 1 Test Case A	6/15/22	Test Event	Fail	Tester Bob	SIL	Config v0 : System	Initialization Failure	
2	R2	TC 1 Test Case A	6/15/22	Test Event	Pass with Exception	Tester Sue	SIL	Config v0 : System	Data Recording Failure	Executed run but no data recorded
3	R3	TC 1 Test Case A	6/15/22	Test Event	Pass	Tester Sue	SIL	Config v1 : System		

Test Case is the classifier of each Test Run

Link run to specific System Configuration (SUT Instance)

Associate run with Observations (new or existing)

Model-Based Observations Tracker

- Observations are **color-coded by closure status**
- **Traceability**: observations are linked to specific Test Runs (instances of the Test Case) and the SUT Configuration (instances of the system blocks)

Status: New | Under Investigation | Fix in Work | Closed (Fixed) | Closed (Not an Issue) | Closed (Duplicate) | Deferred

#	ID	Name	Date Reported	Reported By	Description	Priority	Status	Closure Date	Test Runs Observed	Test Events Observed
1	1	Initialization Failure	6/15/22	Tester Bob	SW failed to initialize	High	Under Investigation		R1 : Test Case A R2 : Test Case A	Test Event
2	2	Data Recording Failure	6/16/22	Tester Sue	Run completed successfully but data log could not be recovered	Medium	Closed (Fixed)	6/22/22	R2 : Test Case A	Test Event

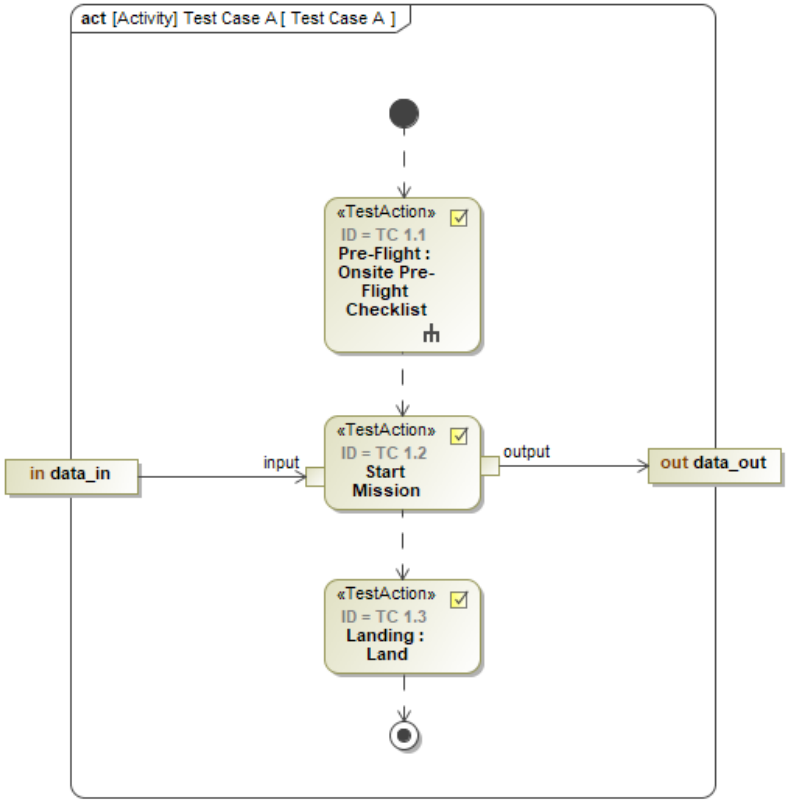
TCs Observed	Investigation POC	Root Cause	Version Identified	Resolution	Version Fixed	Notes
TC 1 Test Case A	Developer John		Config v0 : System			
TC 1 Test Case A	Developer Mary	Incorrect folder permissions	Config v0 : System	Updated procedure to add permissions check	Config v1 : System	

Link to one or more Runs

Link to System Config Observed / Fixed

Model-Based Test Procedures

- Model-Based Test Procedures are activities (Test Cases) with customized actions (Test Actions)
- Table format provides detailed steps for test team
  - Each step's behavior could be a **behavior in the system model** or another Test Procedure
  - Steps can have **inputs and outputs**, for data to be input or captured
  - **Actors** (test team members) who will execute each step are identified

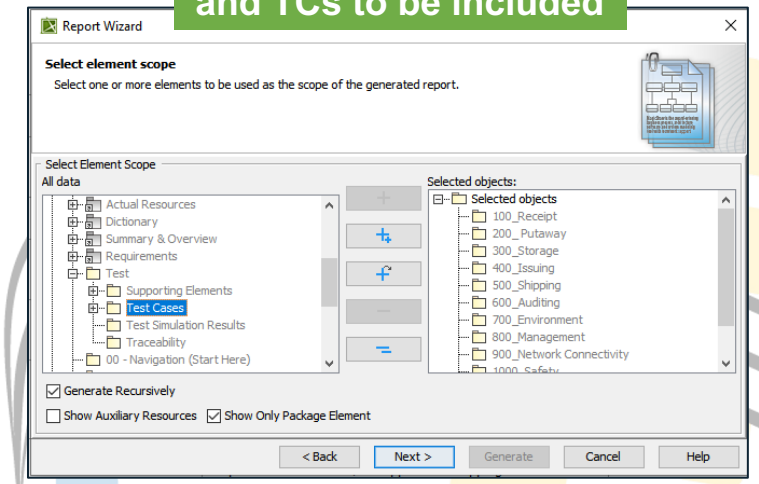


ID	Name	Behavior	Executor	Step Instruction	Expected Result	Notes	Responsible Person	Input	Output
TC 1.1	Pre-Flight	TC 3 Onsite Pre-Flight Checklist	Tester 1	Execute Pre-Flight Procedure	Successfully executed all steps in TC 3		Test Lead		
TC 1.2	Start Mission		Tester 2	Select mission in GUI and initiate takeoff.	Planned mission begins	Special case …	Test Lead	input	output
TC 1.3	Landing	Land	Tester 1 Tester 2	Use controller to initiate landing sequence.	Vehicle successfully lands		Test Lead		

Automated Test Procedure Exports

- Developed **Velocity-Based template** for **Cameo Report Wizard** to generate Test Procedure Document
- Output document includes **high-level test case information**, **traceability**, and **detailed table of procedure steps**

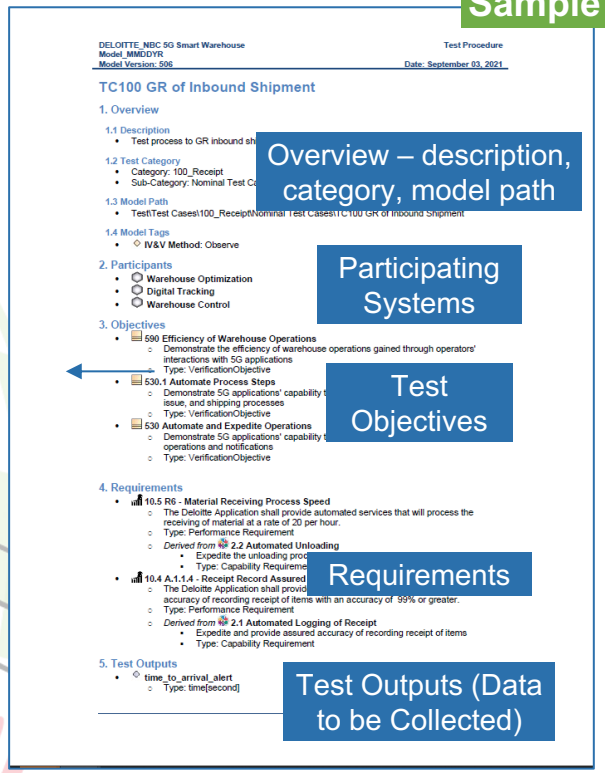
Select export template and TCs to be included

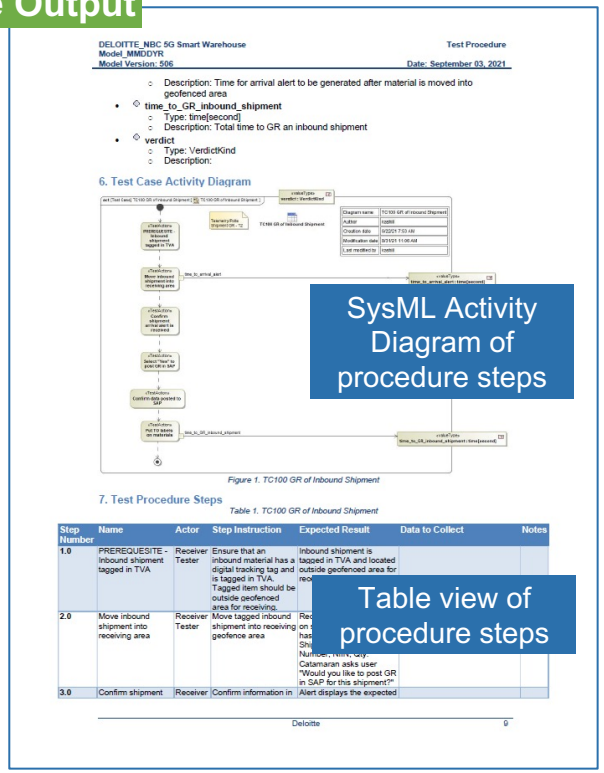


Velocity

Word Document Auto-Generated

Sample Output



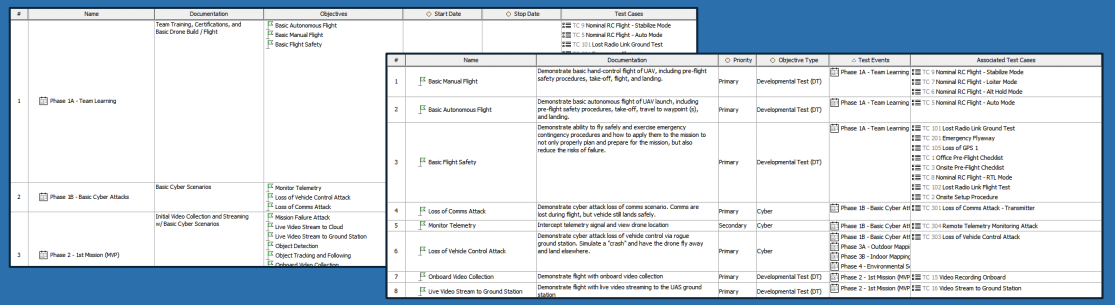


Example Test Program – Drone

- **Project was to design, build, and flight test a UAS system**
  - Integrating COTS parts for multiple missions
  - Test team of about 5 people
- **High emphasis on flight safety and pre-flight checklists**
  - Abiding by FAA Part 107 drone regulations
  - Structured test team with formal roles and reporting structures

Model-Based Test Planning Example

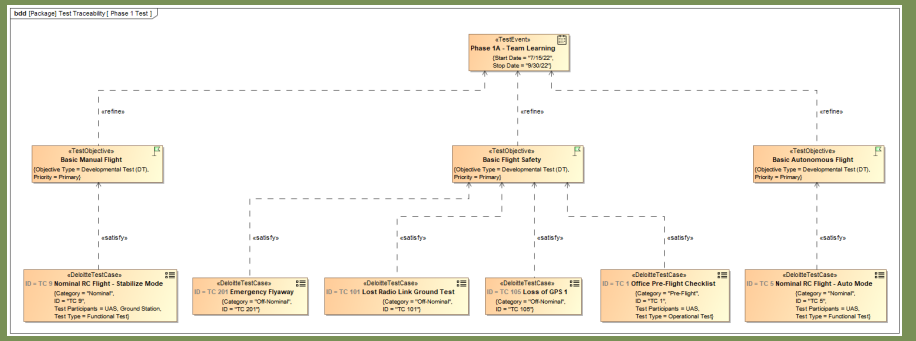
- Developed phased test approach with a Test Event element created for each test phase
- Created test objectives and mapped them to test events



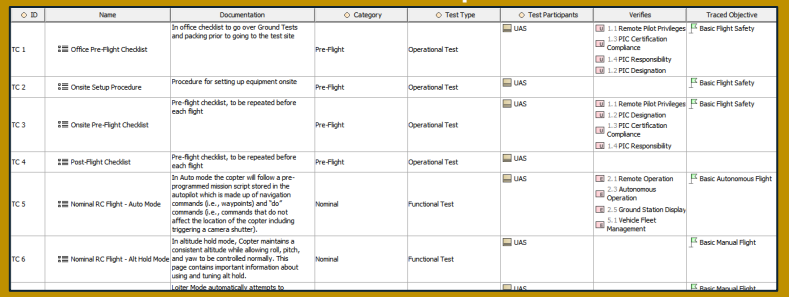
#	Name	Documentation	Objectives	Start Date	Stop Date	Test Cases
1	Phase 1A - Team Learning	Team Training, Certifications, and Basic Drone Build / Flight	Basic Autonomous Flight Basic Manual Flight Basic Flight Safety			TC 9 Nominal RC Flight - Stabilize Mode TC 5 Nominal RC Flight - Auto Mode TC 101 Lost Radio Link Ground Test
2	Phase 1B - Basic Cyber Attacks	Basic Cyber Scenarios	Monitor Telemetry Loss of Vehicle Control Attack Loss of Comms Attack			
3	Phase 2 - 1st Mission (MVP)	Initial Video Collection and Streaming w/ Basic Cyber Scenarios	Mission Failure Attack Live Video Stream to Cloud Live Video Stream to Ground Station Object Detection Object Tracking and Following Onboard Video Collection			

#	Name	Documentation	Priority	Objective Type	Test Events	Associated Test Cases
1	Basic Manual Flight	Demonstrate basic hand-control flight of UAV, including pre-flight safety procedures, take-off, flight, and landing.	Primary	Developmental Test (DT)	Phase 1A - Team Learning	TC 9 Nominal RC Flight - Stabilize Mode TC 7 Nominal RC Flight - Loiter Mode TC 6 Nominal RC Flight - Alt Hold Mode
2	Basic Autonomous Flight	Demonstrate basic autonomous flight of UAV launch, including pre-flight safety procedures, take-off, travel to waypoint (s), and landing.	Primary	Developmental Test (DT)	Phase 1A - Team Learning	TC 5 Nominal RC Flight - Auto Mode
3	Basic Flight Safety	Demonstrate ability to fly safely and exercise emergency contingency procedures and how to apply them to the mission to not only properly plan and prepare for the mission, but also reduce the risks of failure.	Primary	Developmental Test (DT)	Phase 1A - Team Learning	TC 101 Lost Radio Link Ground Test TC 201 Emergency Flyaway TC 105 Loss of GPS 1 TC 1 Office Pre-Flight Checklist TC 3 Onsite Pre-Flight Checklist TC 8 Nominal RC Flight - RTL Mode TC 102 Lost Radio Link Flight Test TC 2 Onsite Setup Procedure
4	Loss of Comms Attack	Demonstrate cyber attack loss of comms scenario. Comms are lost during flight, but vehicle still lands safely.	Primary	Cyber	Phase 1B - Basic Cyber Attacks	TC 301 Loss of Comms Attack - Transmitter
5	Monitor Telemetry	Intercept telemetry signal and view drone location	Secondary	Cyber	Phase 1B - Basic Cyber Attacks	TC 304 Remote Telemetry Monitoring Attack
6	Loss of Vehicle Control Attack	Demonstrate cyber attack loss of vehicle control via rogue ground station. Simulate a "crash" and have the drone fly away and land elsewhere.	Primary	Cyber	Phase 1B - Basic Cyber Attacks Phase 3A - Outdoor Mapping Phase 3B - Indoor Mapping Phase 4 - Environmental S	TC 303 Loss of Vehicle Control Attack
7	Onboard Video Collection	Demonstrate flight with onboard video collection	Primary	Developmental Test (DT)	Phase 2 - 1st Mission (MVP)	TC 15 Video Recording Onboard
8	Live Video Stream to Ground Station	Demonstrate flight with live video streaming to the UAS ground station	Primary	Developmental Test (DT)	Phase 2 - 1st Mission (MVP)	TC 16 Video Stream to Ground Station

- Built block definition diagrams to visually display test event / test objective / test case traceability for Test Readiness Reviews



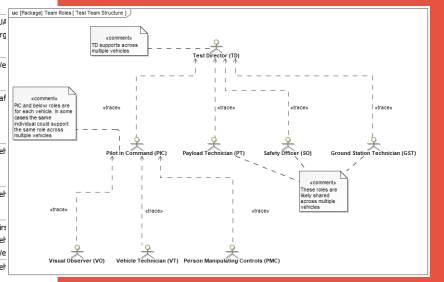
- Mapped Test Cases to Objectives satisfied and Requirements verified to build out model-based RTVM
- Developed reusable pre-flight and post-flight Test Cases, to be used as first and last step of other Test Cases



ID	Name	Documentation	Category	Test Type	Test Participants	Verifies	Traced Objective
TC 1	Office Pre-Flight Checklist	In office checklist to go over Ground Tests and packing prior to going to the test site	Pre-Flight	Operational Test	UAS	1.1 Remote Pilot Privileges 1.3 PIC Certification Compliance 1.4 PIC Responsibility 1.2 PIC Designation	Basic Flight Safety
TC 2	Onsite Setup Procedure	Procedure for setting up equipment onsite	Pre-Flight	Operational Test	UAS		Basic Flight Safety
TC 3	Onsite Pre-Flight Checklist	Pre-flight checklist, to be repeated before each flight	Pre-Flight	Operational Test	UAS	1.1 Remote Pilot Privileges 1.2 PIC Designation 1.3 PIC Certification Compliance 1.4 PIC Responsibility	Basic Flight Safety
TC 4	Post-Flight Checklist	Pre-flight checklist, to be repeated before each flight	Pre-Flight	Operational Test	UAS		
TC 5	Nominal RC Flight - Auto Mode	In Auto mode the copter will follow a pre-programmed mission script stored in the autopilot which is made up of navigation commands (i.e., waypoints) and "do" commands (i.e., commands that do not affect the location of the copter including triggering a camera shutter).	Nominal	Functional Test	UAS	2.1 Remote Operation 2.3 Autonomous Operation 2.2 Ground Station Display 2.1 Vehicle Fleet Management	Basic Autonomous Flight
TC 6	Nominal RC Flight - Alt Hold Mode	In altitude hold mode, Copter maintains a consistent altitude while allowing roll, pitch, and yaw to be controlled normally. This page contains important information about using and tuning alt hold.	Nominal	Functional Test	UAS		Basic Manual Flight
		Loiter Mode automatically attempts to			UAS		Basic Manual Flight

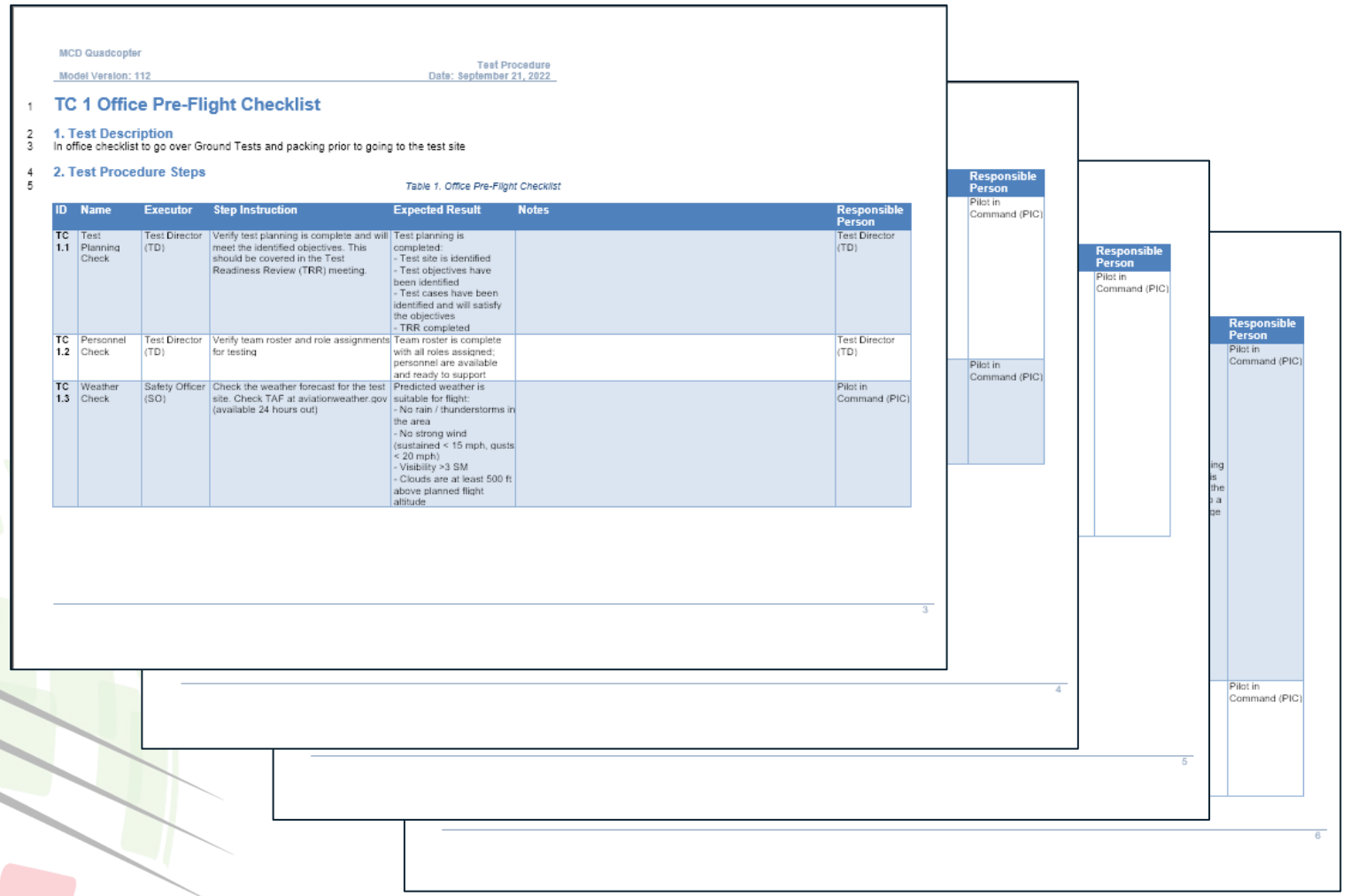
- Modeled test team roles as actor elements and developed reporting structure hierarchy

#	Name	Documentation	Reports To	Use Cases
1	Test Director (TD)	The Test Director (TD) manages team personnel and mission objectives across all drones, and TD has overall responsibility for safe execution of the test. The TD provides overall permission to proceed with the mission and makes the final go/no-go decision, with approval from the PIC. The TD cannot provide permission to fly without approval from the PIC.		
2	Pilot in Command (PIC)	The Remote Pilot in Command (PIC) is directly responsible for and is the final authority as to the operation of the UAS. The PIC must hold an FAA Remote Pilot Certification under 14 CFR Part 107. A separate PIC must be identified for each drone.	Test Director (TD)	Conduct UA Take Emerg
3	Person Manipulating Controls (PMC)	The Person Manipulating Controls (PMC), under direct supervision of the PIC, is responsible for manipulating the UAS flight controls using either the RC transmitter or ground station controls. A separate PMC must be identified for each drone.	Pilot in Command (PIC)	Operate Ve
4	Safety Officer (SO)	The Safety Officer (SO) is responsible for monitoring the area for weather, airspace, and radio comms for situational awareness. The SO will report any potential safety issues to the TD and the PIC. Any major issues should be communicated immediately to both the PIC and the TD. The SO role can be shared across multiple drones if each drone has a separate VO identified.	Test Director (TD)	Monitor Saf
5	Ground Station Technician (GST)	The Ground Station Technician (GST) is responsible for configuration, operation, and monitoring of the Ground Station software and associated communication hardware. If multiple drones are using the same ground station, the GST may be shared across multiple drones.	Test Director (TD)	Monitor Vel
6	Vehicle Technician (VT)	The Vehicle Technician (VT) is responsible for ensuring physical components of the drone are installed, configured, and operating nominally. The VT role may be shared across multiple drones.	Pilot in Command (PIC)	Monitor Vel
7	Visual Observer (VO)	The Visual Observer (VO) is responsible for visually tracking the drone and visually monitoring the area for any potential safety issues. A separate VO must be identified for each drone.	Pilot in Command (PIC)	Monitor Air Monitor Vel Monitor We
8	Payload Technician (PT)	The Payload Technician (PT) is responsible for configuring, running, and monitoring any payload devices such as cameras, sensors, etc. The PT is an optional role depending on mission complexity. The PT role may be shared across multiple drones.	Test Director (TD)	Monitor Vel



Test Procedure Export Example

- **Developed additional "Steps Only" Test Procedure export to reduce procedure page count for in the field**
  - After each test day, the team redlined the procedures and made updates in the model
  - Team would re-export the procedures before the next test event



MCD Quadcopter
Model Version: 112
Test Procedure
Date: September 21, 2022

TC 1 Office Pre-Flight Checklist

1. Test Description

In office checklist to go over Ground Tests and packing prior to going to the test site

2. Test Procedure Steps

Table 1. Office Pre-Flight Checklist

ID	Name	Executor	Step Instruction	Expected Result	Notes	Responsible Person
TC 1.1	Test Planning Check	Test Director (TD)	Verify test planning is complete and will meet the identified objectives. This should be covered in the Test Readiness Review (TRR) meeting.	Test planning is completed: - Test site is identified - Test objectives have been identified - Test cases have been identified and will satisfy the objectives - TRR completed		Test Director (TD)
TC 1.2	Personnel Check	Test Director (TD)	Verify team roster and role assignments for testing	Team roster is complete with all roles assigned; personnel are available and ready to support		Test Director (TD)
TC 1.3	Weather Check	Safety Officer (SO)	Check the weather forecast for the test site. Check TAF at aviationweather.gov (available 24 hours out)	Predicted weather is suitable for flight: - No rain / thunderstorms in the area - No strong wind (sustained < 15 mph, gusts < 20 mph) - Visibility >3 SM - Clouds are at least 500 ft above planned flight altitude		Pilot in Command (PIC)

Responsible Person
Pilot in Command (PIC)
Pilot in Command (PIC)

Responsible Person
Pilot in Command (PIC)

Responsible Person
Pilot in Command (PIC)
Pilot in Command (PIC)

Lessons Learned

Profile Tailoring

- Need to **develop custom fields** to be tracked to **align profile** with the organization's **existing terminology**
- Need to develop **customized exports** to **match existing document templates**
- **Level of T&E modeling appropriate** for each organization **can vary**

Model Fluency

- Test team members will need to learn **advanced modeling tool skills**, particularly to **build profile customizations** and **develop export templates**
- Stakeholders will need a basic understanding of MBSE to provide **buy-in** for the **model-based approach**

Tool Limitations

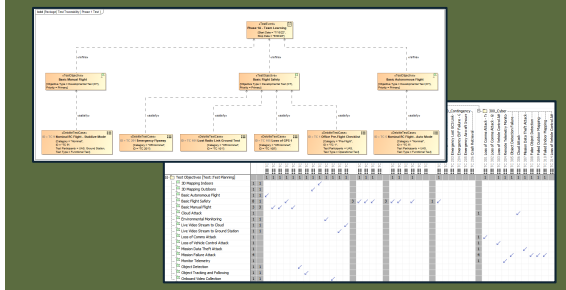
- **Difficult to manage** Test Case numbering and Test Procedure step numbering with **numbering scheme customizations**
- Tracking Test Results in Cameo **can be tedious**
- **Need tool licenses** for test team

Adopting a Model-Based T&E approach requires a **cultural shift** and **willingness to learn new skills** and **adopt new T&E processes**

Benefits and Results

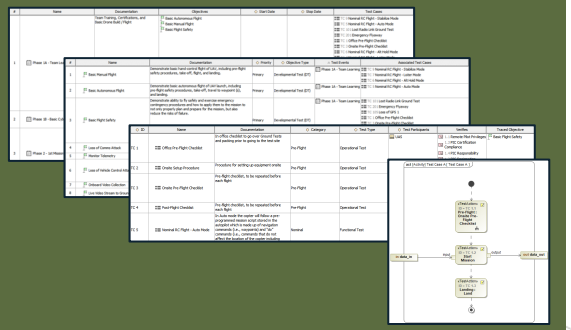
Model Traceability

- Traceability **ensured test coverage** of requirements and **provided confidence to stakeholders** in the test planning process
- It was **easy to re-map** objectives and test cases as **plans evolved over time**



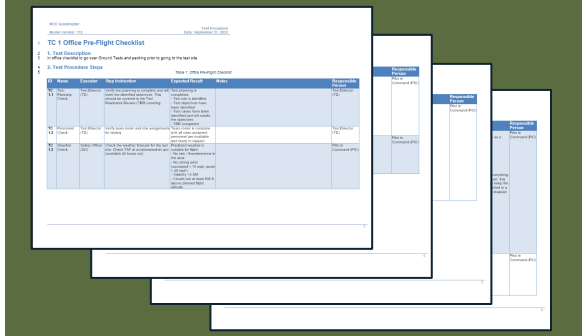
Improved Efficiency

- Modelling Test Events, Objectives, and Test Cases was **more efficient that writing multiple documents**
- Team was able to create **multiple stakeholder views** of the information for Test Readiness Reviews (TRRs)



High Quality Procedures

- Test team **understood the UAS design better**, leading to higher quality test procedures with **fewer redlines needed**
- **Automated Test Procedure Exports** were **easy to use** in the test field



Better Change Management

- Model provided **change control** to the entire **T&E Process**
- Team was able to **monitor the system model for changes** that would impact test
- **Changes propagated** to all affected model tables, diagrams, exports, etc.

Teamwork Cloud

Test Team successfully stood up a new UAS test program and **completed Phase 1 Testing ahead of schedule**

Thank you.

Deloitte.

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33rd Annual INCOSE international symposium

hybrid event

Honolulu, HI, USA
July 15 - 20, 2023

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