ABSTRACT

Title of Thesis:	FORMALIZED APPLICATION OF SYSTEMS ENGINEERING PROCESSES TO THE DEVELOPMENT OF THE PURPLE LINE SHAREPOINT TEST TRACKING TOOL
	Hanish Gaurang Mehta, Master of Science in Systems Engineering, 2020
Thesis Directed By:	Professor John S. Baras, Institute for Systems Research

Testing & Commissioning (T&C) for a $2 Billion project generally consists of more than ten thousand tests, and the Purple Line Light Rail system being constructed in Maryland is no exception. The Purple Line Light Rail is expected to have at least twenty thousand tests conducted in its T&C phase over the next 3-4 years. Given the number of tests, their pre-requirements, resources (manpower, equipment, facilities) and the test reporting procedures to be used to comply with the Maryland Transit Administration (MTA), the Purple Line Transit Constructors (PLTC) felt a need for an online system that could be used to log and track tests. This Thesis focuses on the formalized application of Systems Engineering processes, in accordance with ISO/IEC/IEEE 15288:2015, to the development of this test tracking tool. The Stakeholder requirements given by MTA and PLTC are converted to System requirements, and a Test Plan for the tool is developed in parallel. The tool is designed by PLTC in collaboration with a subcontractor to meet the System requirements and will be tested before going live.

FORMALIZED APPLICATION OF SYSTEMS ENGINEERING PROCESSES TO THE DEVELOPMENT OF THE PURPLE LINE SHAREPOINT TEST TRACKING TOOL

By

Hanish Gaurang Mehta

Thesis submitted to the Faculty of the Graduate School of the
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Advisory Committee:
Dr. John S. Baras, Chair/Advisor
Dr. Jeffrey Herrmann
Dr. Timothy Eveleigh

Dedication

This thesis is dedicated to my grandfather, Mr.Chandubhai Sanjanwala (Daddu), who has been watching over me since May 2016.

Acknowledgements

I sincerely thank my advisor Dr. John S. Baras and Purple Line Transit Constructors (PLTC) for giving me the opportunity to work on this live project of high importance.

I take great pleasure in acknowledging the support given to me by my friends and fellow PLTC colleagues – Brian, Alex, Connor, Abuzar, and Umesh. During the last two years at the University of Maryland, I met and became friends with exceptional people. I would like to thank them for their cooperation and being my family away from home.

Last but not the least; I would like to thank my parents for their unquestioning support. They have always been extremely supportive and taught me to focus on the things that really matter.

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List of Symbols and Abbreviations

T&C	Testing & Commissioning	IBD	Internal Block Diagram
MTA	Maryland Transit Administration	RAM	Requirements Allocation Matrix
PLTC	Purple Line Transit Constructors	RVM	Requirements Verification Matrix
ISO	International Standards Organization	MBSE	Model Based Systems Engineering
TP	Technical Provisions	SysML	Systems Modelling Language
PL	Purple Line	SOI	System of Interest
TTT	Test Tracking Tool	IDS	Inspire Data Solutions
RVM	Requirements Verification Matrix	UI	User Interface
OMF	Operations and Maintenance Facility	MOE	Measure of Effectiveness
LRV	Light Rail Vehicle	BDD	Block Definition Diagram
TCS	Train Control System	UCN	Use Case Narrative
TPS	Traction Power Substations		
OCS	Overhead Contact Systems		
COM	Communication Systems		
CMS	Control and Monitoring System		
FSS	Fire & Security Systems		
FMS	Fire Management Systems		
FAC	Fare Collection		
CCG	Corrosion Control & Grounding		
V&V	Verification & Validation		
POC	Proof-of-Concept		
SSS	System Safety & Security team		
UCD	Use Case Diagram		

Chapter 1: Overview

1.1. Contribution of Thesis

The main contribution of the thesis is the development of a one-of-a-kind SharePoint-based Test Tracking Tool (TTT) tailored to the T&C process of Light-Rail transit systems. This tool will not be a stand-alone spreadsheet, but will actually be utilized by the Purple Line Transit Constructors (PLTC) as the T&C management tool for the $2 Billion Purple Line project.

Another contribution of this thesis is the tailoring of Systems Engineering processes and Model Based Systems Engineering (MBSE) to the development of the TTT. Unlike in an academic environment, the application of standardized processes in an industrial setting is not straightforward. As some of the technical solutions for the TTT were already selected when I joined the project, the work performed in this thesis helps assure that the solution selected more completely matches the stakeholder requirements. The application of the processes ensure that the right thing is built, and the application of MBSE ensures that it is built the right way, thus following a "middle-out" approach.

Fluor, PLTC's parent company, is also working on the Chicago Transit Authority's Red and Purple Line modernization program [1], and the Massachusetts Bay Transportation Authority's Green Line Light Rail Extension [2]. Both these projects are similar in nature to the Maryland Purple Line, and the Test Tracking Tool

being developed may serve as the tracking tool for those projects, as well, and any additional railway projects that Fluor may undertake in the future.

1.2. The Purple Line

Today, with the world's population increasing, cities shrinking, and road traffic getting denser, Light Rail and Metro systems are fast gaining popularity. Some of the major reasons to push forward rail-based mass transit systems are to reduce traffic congestion, reduce harmful emissions, make travel easier for people in the low-income bracket, and boost economic development along the alignment. One of such upcoming systems is the Purple Line, which shall be owned by the Maryland Transit Administration (MTA).

The current Metro system run by Washington Metropolitan Area Transit Authority (WMATA) primarily focuses on transit into and out of Washington DC, with the rail lines mainly running through and radially away from Washington's city centre. In the populous suburban Montgomery County and northern Prince Georges County that surround Washington, DC to the north, this arrangement supports a mostly North-South passenger flow. This layout makes it very time consuming for commuters travelling East-West in an annular fashion, who first have to travel South into DC and then North back out of DC towards their destination. Thus, the need was felt in this part of Maryland for a dedicated mass-transit corridor that facilitates a more annular East-West flow vs the north-south radial flow in and out of DC. In accordance, the overall purpose of the PL as stated in the Technical Provisions (TPs) released by the MTA is to:

"**Provide faster, more direct, and more reliable east-west transit service connecting the major activity centres in the Purple Line at Bethesda, Silver Spring, Takoma/Langley Park, College Park and New Carrollton"** [3].

The Purple Line (PL) is Maryland's second light rail line, the first one being the Baltimore Light Rail that began operations in 1992. PL is a 16-mile light rail line connecting Bethesda in Montgomery County to New Carrolton in Prince George's County, Maryland. The rail line will consist of 21 stations and will connect the WMATA Metrorail Red, Green, and Orange Lines. The PL will also connect to the Maryland Area Regional Commuter (MARC), Amtrak, and local bus services at various points along the alignment. The project is expected to carry 69,000 daily riders in 2030 and 74,000 daily riders in 2040 [3]. Figure 1 shows the planned Purple Line Alignment.

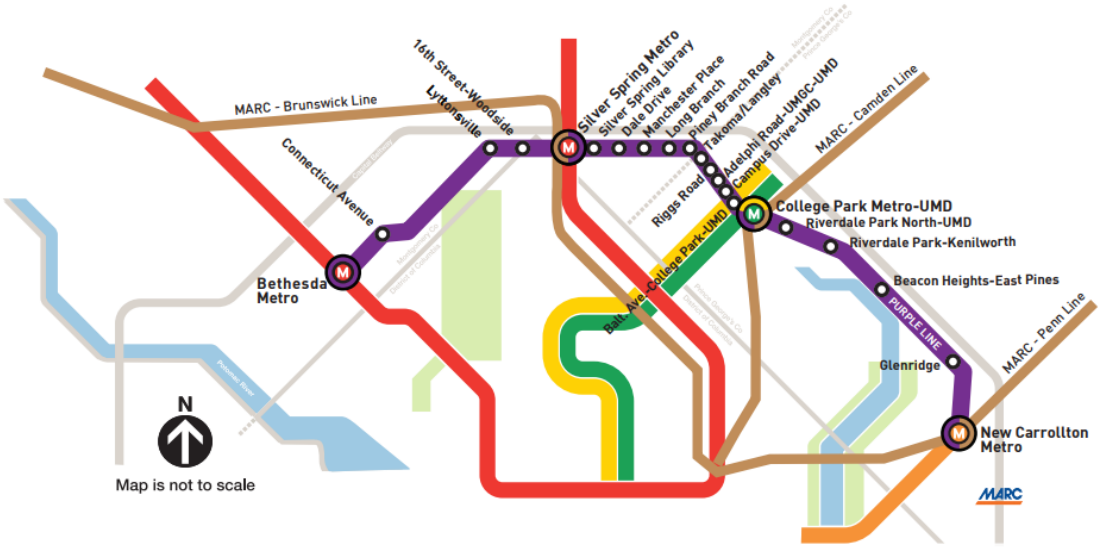


Figure 1: Purple Line Alignment [4]

1.2.1. Public-Private Partnership (P3) [5]

Unlike the DC Metro systems that are owned and operated by WMATA, the PL utilizes a Public-Private Partnership (P3). A P3 is where a public entity contracts a single private entity (the Concessionaire) to design, construct, operate, and maintain the project. This approach was chosen by the MTA as it provides incentive for the Concessionaire to deliver a reliable, high-quality project as it has a vested financial interest during the Operations & Maintenance phase. In 2016, Purple Line Transit Partners (PLTP) was declared as the Concessionaire for the project, responsible for designing, constructing, operating, and maintaining the PL, while partly financing a part of the project. The Concessionaire is comprised of three main teams:

- Purple Line Transit Partners (PLTP): Responsible for the overall project, including the financing and management of:
    - Purple Line Transit Constructors (PLTC): Responsible for the design and construction of the PL.
    - Purple Line Transit Operators (PLTO): Operate & maintain the PL for 30 years after commissioning.

Figure 2 below shows the P3 structure adopted by MTA for the Purple Line.

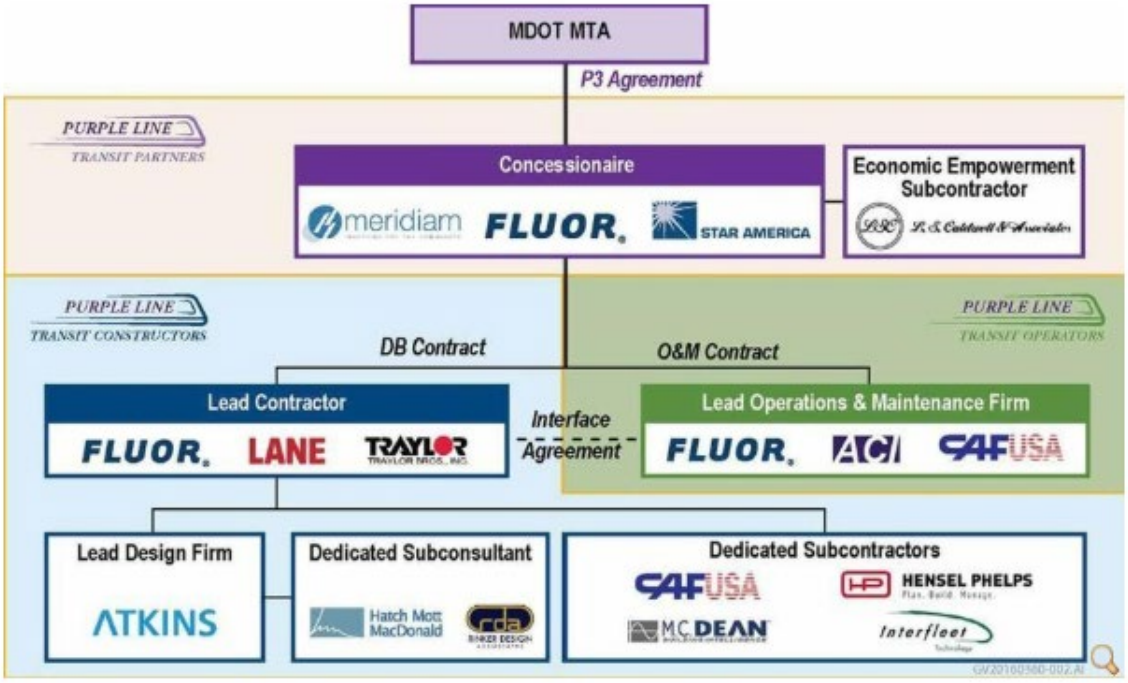


Figure 2: Purple Line P3 Structure [5]

1.2.2. System Layout and Technical Descriptions

Light rail systems are railway systems that operate short trains along mixed right-of-way. Unlike most mass transit systems that run on a dedicated corridor, light rail systems are designed to operate in exclusive, dedicated or mixed-traffic alignment.

To better understand the complexity of the system and appreciate the need for a dedicated test tracking tool, it is necessary to know the sub-systems that the Purple Line Light Rail is divided into.

The PL System is composed of the *major* sub-systems listed below [6]:

1. Operations & Maintenance Facility (OMF): The OMF is the primary maintenance facility for the Purple Line system, and houses the Operation Control Center (OCC) that is used to monitor and control the entire light rail network. The OMF has multiple maintenance bays for the trains along with designated areas for washing and repainting the trains.

2. Light Rail Vehicles (LRV): The LRV is the most critical part of the Purple Line, with each LRV expected to ferry 300 passengers during peak hours. Each LRV is 140 ft long and consists of five different sections. The PL is supposed to have 26 LRVs, of which a certain number shall be running during revenue service, and the rest will be undergoing maintenance or shall be in storage.
3. Train Control System (TCS): Train Control System includes wayside and car-borne Automatic Train Protection (ATP) including systems for train detection, route setting and locking, vehicle maximum speed enforcement, highway-light rail transit grade crossing warning, railroad worker secondary warning system, and an interface to highway traffic signal controllers.
4. Traction Power Substations (TPS): TPS includes everything related to supplying traction power (1500 V AC) to the LRV.
5. Overhead Contact System (OCS): OCS refers to the overhead power system that is used to supply power to the LRV. OCS includes the poles, pole foundations, wire support assemblies, messenger and contact wires, feeder cables, duct banks etc.
6. Communication Systems (COM): COM includes the communication subsystems such as Supervisory Control and Data Acquisition (SCADA), Radio System, Telephone System, Wi-Fi for LRV Operations, Passenger Information Systems, and the Communication Infrastructure Backbone (CIB).
7. Control and Monitoring System (CMS): CMS includes all subsystems that are necessary to control and monitor train movements, set routes for normal

operations and respond to emergency conditions, control and monitor the TPS and the MEP, and to respond efficiently to equipment failures or service disruptions.

8. Fire & Security System (FSS): FSS is composed of the following major subsystems:
    - Fire Management System (FMS): Detects hazardous conditions caused by fire, smoke, chemical hazards, and bio-hazards; issues local and remote alarms, and interfaces with other systems to activate immediate responses to the detected conditions.
    - Access Control System (ACS): Permits only authorized staff into non-public areas and records identity of each staff member that was granted access.
    - CCTV System: Observes and records conditions in public spaces, egress areas, and critical equipment spaces.
9. Fare Collection (FAC): The FAC includes equipment such as the ticket vending machines, central servers, workstations, communication network devices and fare validation devices for fare inspectors.
10. Corrosion Control & Grounding (CCG): The CCG includes equipment and materials required to minimize corrosion including stray current control and cathodic protection.

The TTT that this thesis aims to implement is designed to store a Requirements Verification Matrix (RVM) for each of the sub-systems mentioned above, and help the Purple Line successfully clear the Testing & Commissioning phase.

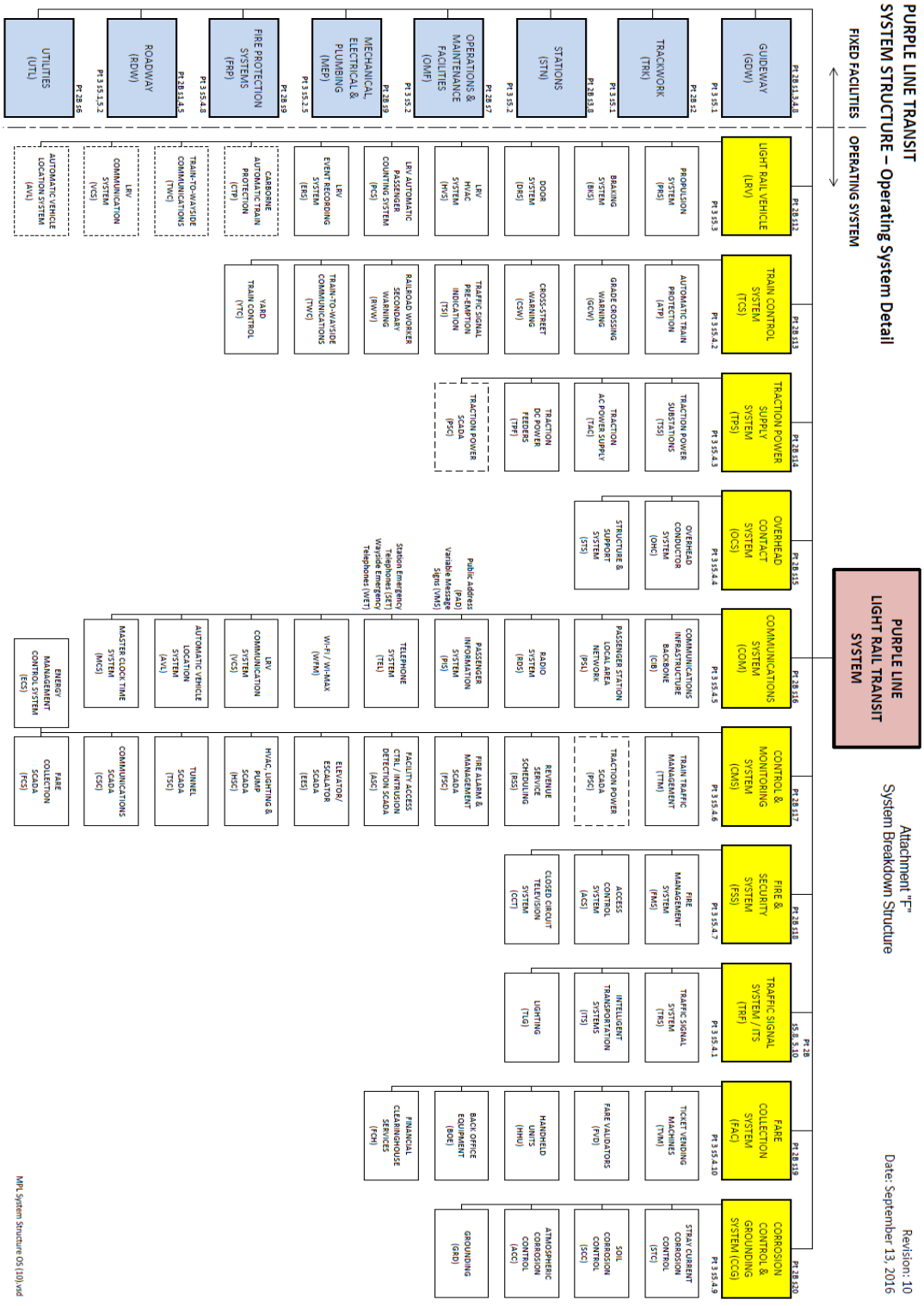


Figure 3: Purple Line System Breakdown Structure [7]

1.3. ISO/IEC/IEEE 15288:2015

ISO/IEC/IEEE 15288:2015 (Systems and software engineering – System life cycle processes) [8] is a standard that has been set by the International Standards Organization (ISO) to baseline a framework for describing the technical and managerial processes for developing man-made systems. It defines a set of technical processes as shown in Figure 4 below, aligned with their relative positions on Mooz and Forsberg's (1991) classic "Vee" model. These processes can be applied at any level in the system's hierarchy, and can be tailored to the level of detail required. The primary focus of this standard is to ensure that the customer is satisfied, and it does so by involving all stakeholders from the very beginning of a project. It also emphasizes the need for systems engineers to work on a Verification & Validation (V&V) test plan in parallel with the requirements processes.

For the scope of this project, although I shall be going through nearly all the ISO/IEC/IEEE 15288 technical processes, the major focus will be on developing system requirements, the technical architecture, and the Implementation, Integration, and the Verification and Validation (V&V) processes (the processes most associated with ISO/IEC TR 24748-1's Development lifecycle stage). The Stakeholder Needs and Requirements Definition process associated with the ISO/IEC TR 24748-1's Concept stage are not the focus of this thesis because the stakeholder requirements were already provided by the Maryland Transit Administration (the project owner), and the initial solution architecture was already decided by PLTC when I joined the project. A V&V strategy will be written and implemented, but a formal Unit and Element level test plan will not be written owing to time constraints.

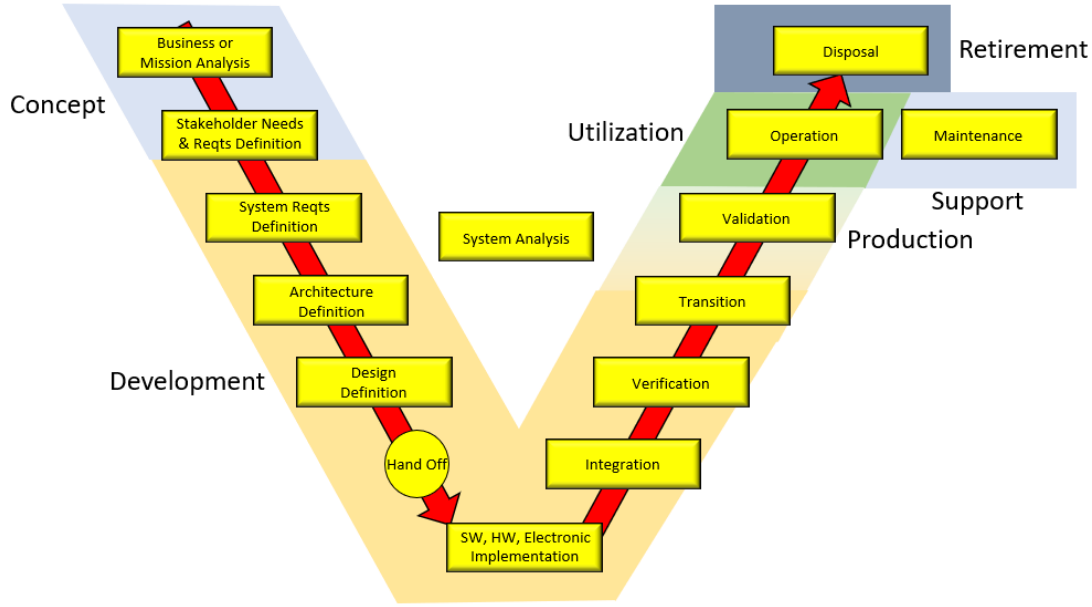


Figure 4: V Development Life Cycle Model [9]

1.3.1. Why ISO/IEC/IEEE 15288:2015?

ISO/IEC/IEEE 15288 is categorized as an Acquisition Life Cycle Model (LCM) that covers the entire "birth to death" life cycle. 15288 was deemed as the best way forward for this project because once imposed on a Vee model (refer to Figure 4), it:

- Indicates system development activities on the left side to an increasing level of detail (from stakeholder requirements to system requirements to system architecture and element design).
- Indicates integration and verification activities on the right side to an increasing scope.
- Implies that engineers need to think about the development of test scenarios while developing the requirements.
- Implies that verification criteria for testing should come from the requirements developed in the associated development stage.

Beyond the reasons identified above, 15288 also offers users the ability to tailor the processes for application to a variety of projects and scenarios, and ensures that the product delivered is high-quality because [10]:

- It stresses the application of a formal framework to guide the project.
- Defines the stakeholder's expectations in the form of stakeholder requirements.
- Defines the supplier's (PLTC) scope in the form of system requirements, thus reducing any ambiguity in the scope of work.
- Ensures a means for the supplier to demonstrate compliance with those requirements by focusing on Verification & Validation.

1.4. Scope of Work

Testing & Commissioning (T&C) for railway projects generally consists of over ten thousand tests, and the Purple Line Light Rail system being constructed in Maryland is no exception. The Purple Line Light Rail is expected to have at least twenty thousand tests conducted in its T&C phase over the next 3-4 years. Given the number of tests, their pre-requirements, resources (manpower, equipment, facilities), and the test reporting procedures to be used to comply with the Maryland Transit Administration (MTA) requirements, the Purple Line Transit Constructors (PLTC) felt the need for an online system that could be used to log and track tests.

The thesis focuses on the formalized application of Systems Engineering processes, in accordance with ISO/IEC/IEEE 15288:2015, to the development and delivery of this test tracking tool. The stakeholder requirements given by MTA are converted to system requirements, and a Test Plan for the tool is developed in parallel.

The tool is designed by PLTC in collaboration with a subcontractor, with the subcontractor's scope being limited to providing the T&C SharePoint domain/website, and coding the advanced backend logic for the T&C SharePoint site.

1.5. Document Overview

This section provides an outline of the thesis. Chapter 1 starts with an overview of the Purple Line project that includes the system layout. It goes on to discuss ISO/IEC/IEEE 15288:2015 and its relevance to this project. This is followed by the Scope of Work and the Contribution of the Thesis. Chapter 2 describes the approach adopted by the author in the execution of this project. Chapter 3 begins by providing a background of the SharePoint TTT that is to be developed, the Stakeholder and System requirements, the design of the TTT, which includes the different views, Automated Workflows, PowerBI integration and Dashboard design. Chapter 4 describes the Verification & Validation activities performed on the TTT.

Chapter 2: Development Approach

This Thesis focuses on the formalized application of Systems Engineering processes, in accordance with ISO/IEC/IEEE 15288:2015, to the development and delivery of the TTT. The approach adopted is outlined below:

- Identify stakeholder requirements for the Test Tracking Tool (TTT) from a set of Purple Line stakeholder requirements (Technical Provisions).
- Derive system requirements for the TTT from the stakeholder requirements identified. This shall include a Requirements Allocation Matrix (RAM) and a Requirements Verification Matrix (RVM).
- Since the concept/layout of the TTT had already gone through a formal review, the "design" of the tool was largely considered final. However, the Proof-of-Concept (POC) spreadsheet developed by a PLTC engineer was evaluated against the stakeholder and system requirements, and any unnecessary columns were removed, and lacking columns added.
- Develop a high-level system architecture in SysML using Cameo (a systems modeling tool) to capture the design.
- Implement the TTT in Microsoft SharePoint.
- Verify and Validate (V&V) the TTT in accordance with the Requirements Verification Matrix developed in the system requirements development process.

Chapter 3: Purple Line Test Tracking Tool (TTT)

3.1. Background

The T&C phase is used to close interface requirements and verify compliance of the Purple Line system with stakeholder requirements. While a major chunk of the tests conducted in the T&C phase will be performed on the Purple Line alignment (physical tracks), a lot of the sub-system tests will be performed at a subcontractor/vendor's facility either in the United States or overseas. Owing to the Owner's (MTA) contractual requirements, PLTC is required to formally log each verification event (when relevant to the requirements), regardless of the level and location at which it occurs. Given the reporting requirements, the number of tests and the geographically distributed nature of subcontractor facilities, traditional document-based test tracking systems are not feasible for the Purple Line. A need was felt for a web-based, affordable, easy-to-use and low-maintenance tool that could be used to track the test events, and upload test results and reports, thus giving rise to the Purple Line Test Tracking Tool.

3.2. TTT System Concept Description

3.2.1. TTT System Stakeholders and Roles

Table 1 identifies the Stakeholders for the TTT, their roles and their priority.

ID	Stakeholder	Role(s)	Priority
SH1	Maryland Transit Administration (MTA)	Customer, User	Primary
SH2	Purple Line Transit Constructors Systems Team	User, Maintainer	Primary
SH3	Purple Line Quality Team	User	Secondary
SH4	Purple Line System Safety & Security Team	User	Secondary
SH5	Subcontractors	User	Secondary

Table 1: System Stakeholders and Roles

3.2.2. TTT System Capabilities

Table 2 shows the primary end-user capabilities of the Test Tracking Tool, along with their priority.

ID	Subsystem Area	System Capability	Priority
C1	Sub-system RVM Database	Store Sub-system RVMs, test reports and other documents	1
C2	Sub-system RVM Database	Allow users to populate fields in the RVMs and upload documents	1
C3	Sub-system RVM Database	Allow users to review and approve/reject tests	1
C4	Workflow Automation Software	Automate the test (report) approval flow	1
C5	Workflow Automation Software	Notify users of any potential issues by providing indicators and flags	2
C6	Dashboard	Display the status of system-wide testing on the Purple Line project	1

Table 2: System Capability List

3.2.3. TTT System Operational Concept

The system operational concept as predetermined by the PLTC Systems team, before I joined the team, describes the TTT and outlines the types of interaction between the users, the environment, and the system. The TTT is to be implemented in SharePoint, a document management and storage system offered by Microsoft. Further information about SharePoint is provided in Section 3.7.1.

- A partial Sub-system RVM is received as an Excel file from the Subcontractor.
- The PLTC Systems team creates a SharePoint "List" (individual page) on the TTT for that specific sub-system.
- The PLTC Systems team uploads data from the Sub-system RVM Excel file to the Sub-system List on the TTT.
- The Subcontractor logs test results and uploads test reports as each test is conducted.
- The TTT autonomously sends the test reports and results to a group of reviewers.
- The reviewers will either review and pass the test, reject it or flag it for potential issues.
- Simultaneously, a set of tabular and graphical reports is generated from the Sub-system Lists on the TTT.
- The tabular and graphical reports are collectively organized as a "Dashboard" showing the status of system-wide testing on the Purple Line.
- The dashboard is viewed by all stakeholders, who may use it to make managerial decisions.

3.2.4. TTT System Maintenance Concept

Since the TTT is not a physical product, but a cloud-based platform, it does not require the kind of corrective and preventative maintenance that a physical system warrants, and the maintenance largely constitutes of administrative duties of providing access, cleaning up bad data, and monitoring the line items for accurate information.

3.2.5. TTT Context-Level Use Case Diagram and Use Case Narratives

This section identifies and describes the principal high-level use cases for the TTT. The stakeholders provided in Table 1 are allocated a corresponding SysML Actor ID, as shown below in Table 3:

ID	Stakeholder	SysML Actor ID
SH1	Maryland Transit Administration	MTA_Reviewer
SH2	Purple Line Transit Constructors Systems Team	Tool_Maintainer
SH2	Purple Line Transit Constructors Systems Team	PLTC_Reviewer
SH3	Purple Line Quality Team	Quality_Reviewer
SH4	Purple Line System Safety & Security Team	System Safety_Reviewer
SH5	Subcontractors	Test_Performer

Table 3: SysML Actor IDs for Stakeholders

Figure 5 below shows the context-level Use Case Diagram (UCD) for the system. The UCD identifies the high-level use cases, the actors and the environmental elements the system interfaces with.

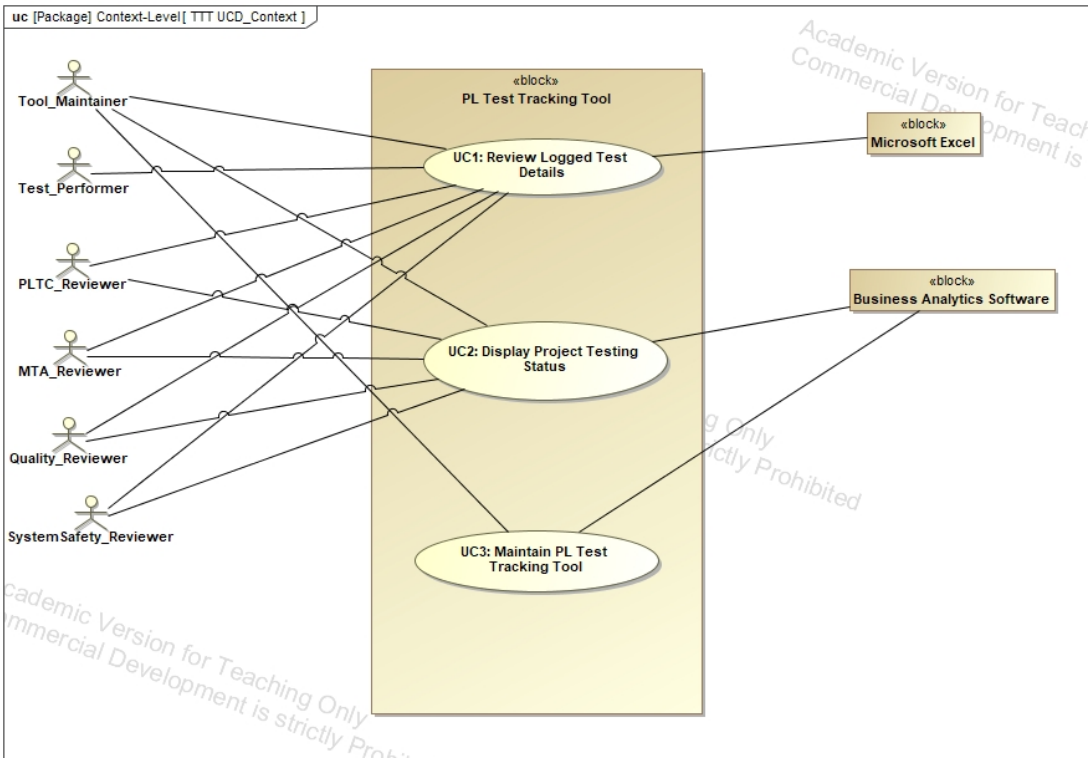


Figure 5: TTT Context-level UCD

Use Case Narratives (UCNs) describe in detail the scenarios that take place for a use case execution to be successful, along with the triggers for the use case. The Context-level UCNs for the TTT are given below.

Use Case ID: UC 1
Use Case Name: Review Logged Test Details
Level: Context-Level
Actor(s):
1) Tool_Maintainer
2) Test_Performer
3) PLTC_Reviewer
4) MTA_Reviewer
5) Quality_Reviewer
6) System Safety_Reviewer
Precondition(s):
1)The Test_Performer has provided a partially populated Sub-system RVM as an Excel file to the Tool_Maintainer.
Trigger(s):
1) A test is performed, and the results are awaiting upload.

Post-condition(s):
1) The test is passed/approved by all concerned reviewers.
Main Success Scenario:
1) The Tool_Maintainer uploads data from the Sub-system RVM Excel file to the respective Sub-system RVM on the TTT.
2) The Test_Performer uploads the test results and reports to the TTT, either from the Sub-system RVM Excel file or by directly typing into the Sub-system RVM on the TTT.
3) The TTT sends the report to PLTC_Reviewer and MTA_Reviewer for review.
4) The TTT send the report to System Safety_Reviewer if the test is marked as System Safety critical. [Done concurrently with Step 2]
5) The Quality_Reviewer may randomly review a report to ensure quality standards are being met.
6) All the reviewers approve the test.
7) End.

Use Case ID: UC 2
Use Case Name: Display Project Testing Status
Level: Context-Level
Actor(s):
1) Tool_Maintainer
2) PLTC_Reviewer
3) MTA_Reviewer
4) Quality_Reviewer
5) System Safety_Reviewer
Precondition(s):
1) A business analytics software is available for data analysis.
2) The TTT can host the project testing status dashboard.
Trigger(s):
1) On-going activity.
Post-condition(s):
1) The testing status dashboard can be viewed by all reviewers.
Main Success Scenario:
1) The Tool_Maintainer interfaces each Sub-system RVM on the TTT with a business analytics software.
2) The Tool_Maintainer creates a central dashboard with tabular and graphic reports, using the business analytics software.
3) The Tool_Maintainer links/uploads the dashboard to the TTT, such that anyone with access to the TTT can view the dashboard.
4) The reviewers view the testing status dashboard.
5) End.

Use Case ID: UC 3
Use Case Name: Maintain PL Test Tracking Tool
Level: Context-Level
Actor(s):
1) Tool_Maintainer
Precondition(s):
1) The Sub-system RVM is available on the TTT.
2) A business analytics software is available and linked with the Sub-system RVMs on the TTT.
3) A workflow automation software is available and linked with the Sub-system RVMs on the TTT.
Trigger(s):
1) On-going activity.
Post-condition(s):
1) The TTT functions normally.
Main Success Scenario:
1) The Tool_Maintainer checks each Sub-system RVM on the TTT once a week to review items like the number of line items/rows on each list, test performed dates, test status, reviews etc.
2) The Tool_Maintainer shall rectify any errors, if found.
3) The Tool_Maintainer provides access privileges to users, as and when necessary.
4) The Tool_Maintainer checks the status reports on a weekly basis to ensure that the dashboard is representing the project testing status accurately.
5) The Tool_Maintainer shall rectify any errors in the reports, if found.
5) End.

3.2.6. TTT Context-Level System Architecture

An important part of the application of systems engineering processes is the development of formal system architecture. The International Standards Organization (ISO) Standard 42010 defines Architecture as the fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution [11]. This architecture generally consists of a set of models that define the system's structure, behaviour, and interactions to the level required to successfully realize, operate, and maintain the system [12].

To generate the system architecture, this project makes use of the Model Based Systems Engineering (MBSE) approach. MBSE is the formalized application of

modelling to support system requirements, design, analysis, verification and validation activities, beginning in the conceptual design process and continuing throughout development and later life cycle processes [13]. This project implements MBSE by using the Systems Modelling Language (SysML) to generate the schematic models desired.

This section provides the system's context-level architecture. Section 3.2.6.1 defines the system domain using a Block Definition Diagram (BDD). Section 3.2.6.2 provides an Internal Block Diagram (IBD) that shows the primary system interfaces and an Interface BDD to define each interface.

3.2.6.1. TTT Context-Level Domain Definition

Figure 6 shown below provides the BDD indicating the structure of the Test Tracking Tool's domain. The purpose of this BDD is to identify the constituent elements of the system, the users, and the environment.

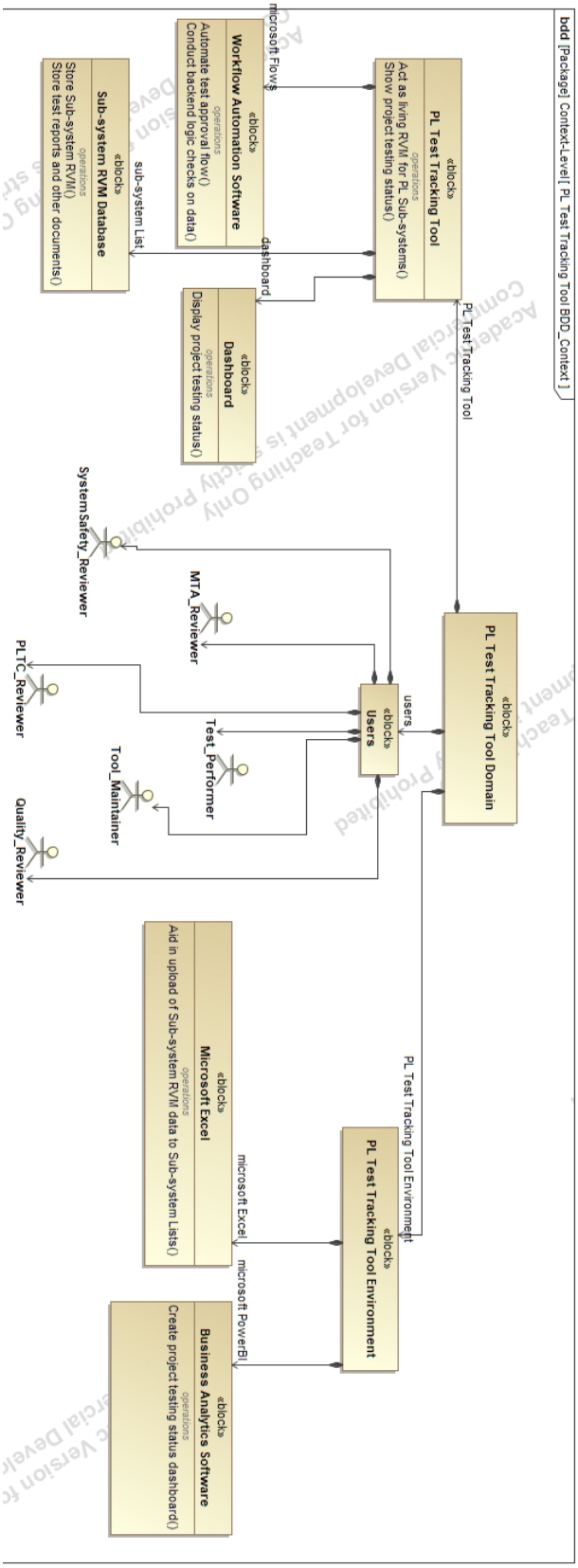


Figure 6:TTT Domain Definition BDD

3.2.6.2. TTT System Domain Interface Definition

Figure 7 shown below provides the IBD for the TTT, indicating the system, the users and the environmental elements that it interfaces with, along with the information that is transferred over those interfaces.

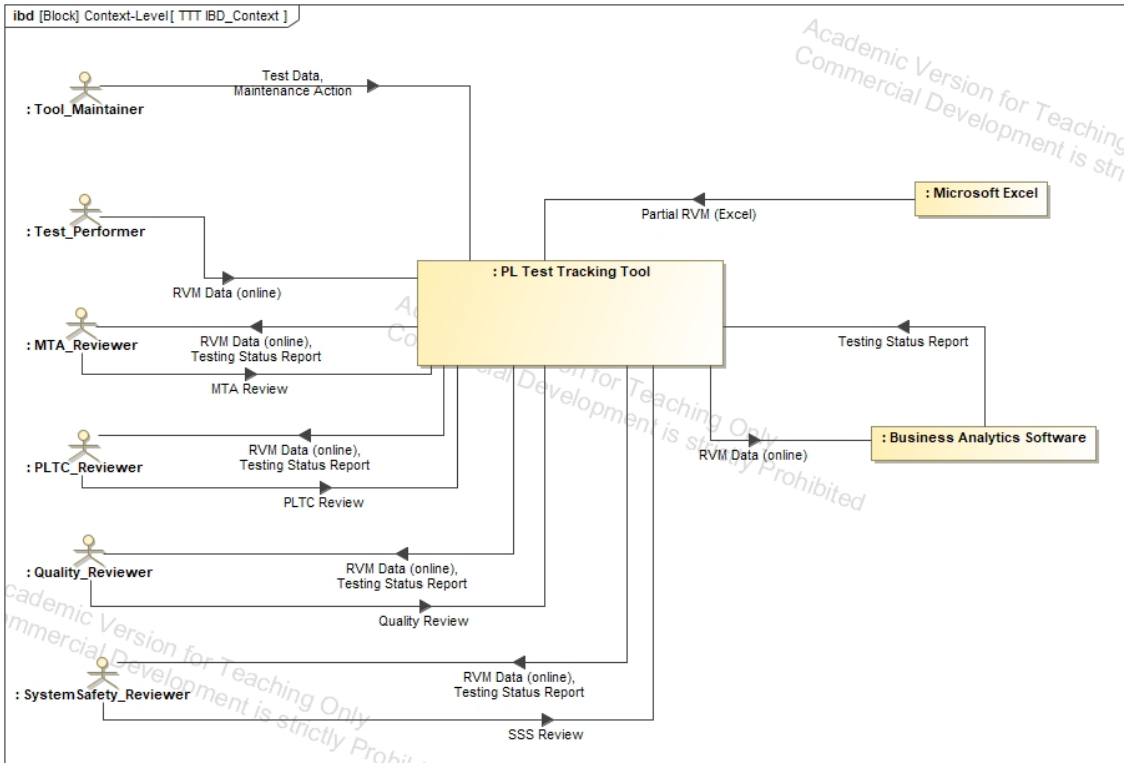


Figure 7:TTT Context-Level IBD

Figure 8 shown below provides the Interface Flow BDD that defines the information flowing over the interfaces shown in the TTT Context IBD.

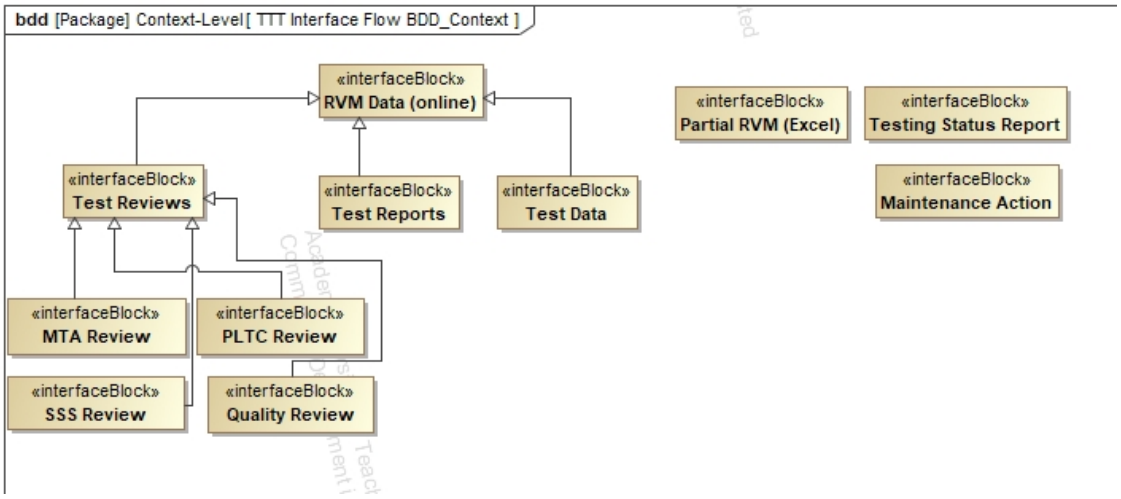


Figure 8: Interface Flow BDD for the TTT Context-Level IBD

3.2.6.3. TTT System Behavior Definition

Figures 9, 10, and 11 provide a schematic representation for each individual Use Case using an Activity Diagram. They show the main actions taken by the users, the TTT and external systems in accomplishing the Main Success Scenarios of UC1, UC2 and UC3.

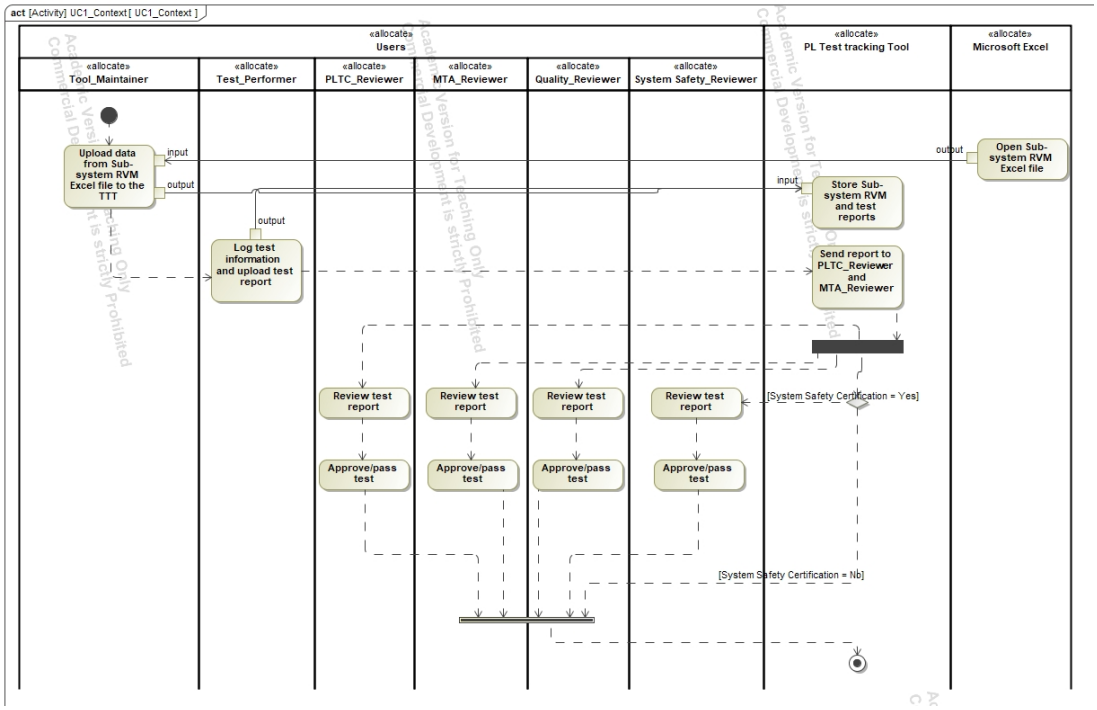


Figure 9: Activity Diagram for Context-Level UC1

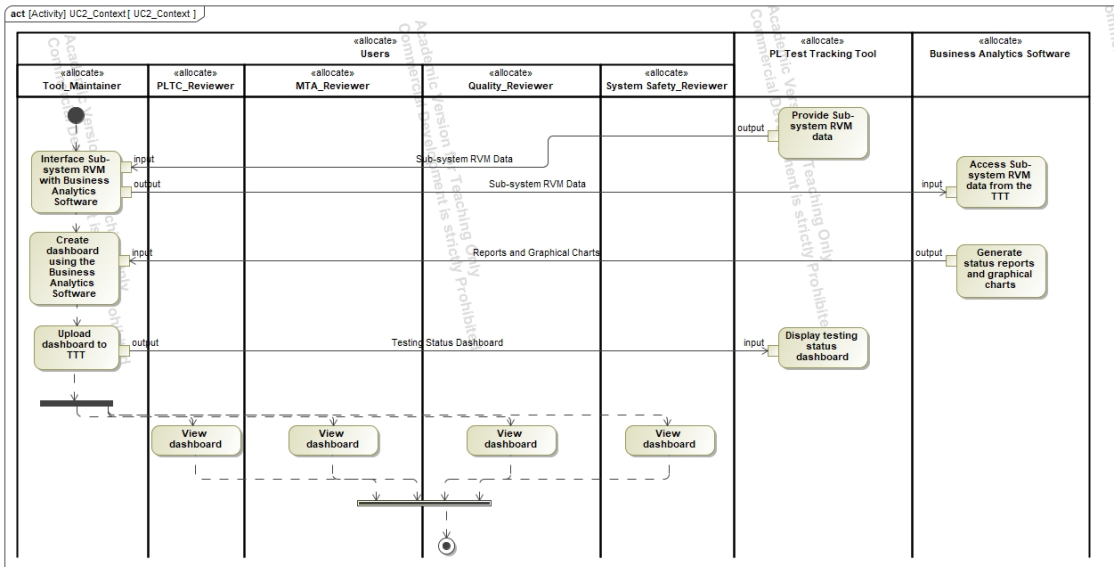


Figure 10: Activity Diagram for Context-Level UC2

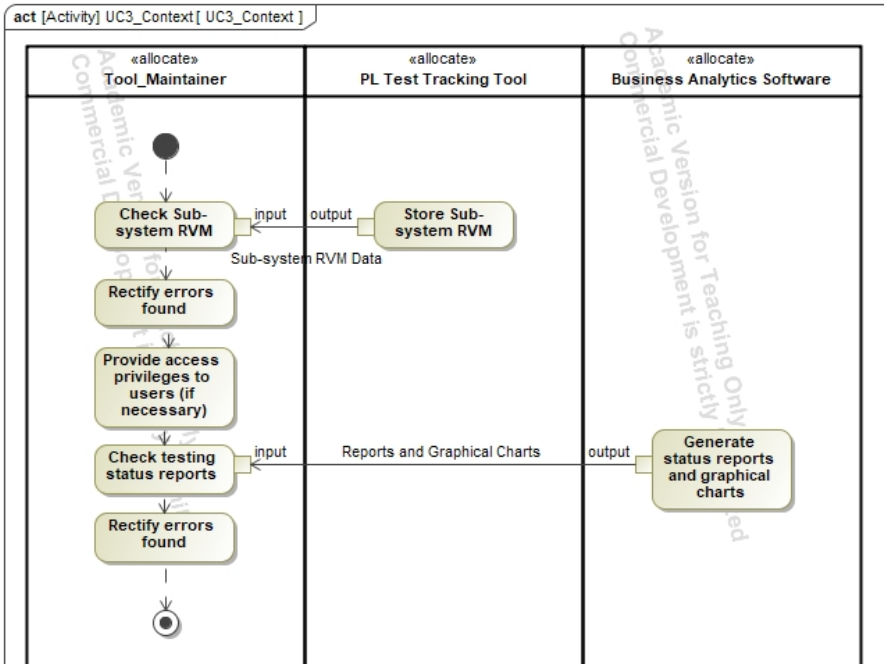


Figure 11: Activity Diagram for Context-Level UC3

3.3. TTT Stakeholder Requirements

The stakeholder requirements for the entire Purple Line project are provided in three different "books" called the Technical Provisions (TPs), which are issued by the State of Maryland. Each requirement given in the TPs is logged as a stakeholder requirement in TraceCloud, the Purple Line's requirements management tool.

TraceCloud contains more than 20,000 requirements, and the small number of requirements specific to the TTT had to be filtered from this large set. In order to narrow down the list, first, requirements specific to the Testing & Commissioning phase were exported as an Excel file. These exported requirements were then manually analysed to check if they were relevant to the TTT in any way. This analysis yielded approximately fifty requirements.

The requirements identified largely fall under the categories listed below [14]:

- **Functional**: Describe qualitatively the system functions or tasks to be performed in operation.
- **Technical**: Defines any specific columns that must be included in the system, specific formats each column must have etc.
    - Interface: Defines any requirements that require the user or any personnel to manually interface with the system to upload or modify any information.

Performance requirements were not provided by the stakeholder in the TPs, and thus, the Validation process uses a system acceptance (usability) test to assess system efficacy, along with engineering judgement by the PLTC Systems team.

The functional stakeholder requirements for the Purple Line Test Tracking Tool are given below in Table 4.

SHR	**Technical Provisions** [6]	**Stakeholder Requirements**
SHR 1.2	The Test Program shall at a minimum:	
SHR 1.2.1	As more fully described below, these inspections and tests shall progress from the component to the Subsystem level, to the System level, to the Purple Line System level.	The TTT shall store RVMs for the major Purple Line Sub-systems.
SHR 1.2.2	Tests shall also include tests of all interfaces identified in the Interface Control Matrix described in Part 2.A, Section 3.9.7.2 of the Technical Provisions.	The TTT shall serve as an RVM for interface tests.
SHR 1.2.3	As individual Systems and Fixed Facilities become operational, Integration Tests shall be performed to confirm operational readiness, reliability, safety and operational capabilities.	The TTT shall serve as an RVM for integration tests.
SHR 1.2.4	All such inspections and testing shall be documented and reported by Concessionaire in accordance with Part 2C, Sections 1.4.2 through 1.4.4 of the Technical Provisions.	The TTT shall allow the user to log test information.
SHR 1.4	Concessionaire shall develop a means to record and store the relationship between each performance requirement and interface and the tests that will be used to verify their correct operation. Concessionaire is encouraged to support the interface control matrix, requirements traceability and the verification cross reference matrix from a common database.	The TTT shall store the Purple Line Requirement number for each test performed.
SHR 1.5	All such tests to be performed shall be identified in a Project Test Program	The TTT shall store the Project Test Program Plan.

	Plan or the Integration Test Program Plan.	
SHR 1.7	Concessionaire shall review, evaluate and approve all successfully completed Test Reports documenting test results in accordance with the Quality Program prior to submitting them to Owner for Review and Comment. After Concessionaire has approved the successfully completed Test Reports and no later than 15 days after completion of each test, Test Reports shall be submitted for Review and Comment.	The TTT shall send the submitted test reports and information to a set of reviewers for review and comment.
SHR 1.8	All inspection records and Test Reports documenting successful completion of an inspection or test shall be utilized to support either the Safety and Security Certification and the similar process that Concessionaire implements to record all inspections and Test Reports that are not required for the Safety and Security Certification.	The TTT shall have a field that identifies whether the test is security critical or not.
SHR 1.9.1	Inspection and Test Reports that are required for Safety and Security Certification shall be checked, catalogued and utilized as required by the Safety and Security Certification Program.	If a test is identified as safety critical, the TTT shall require the Safety & Security team to review the test report.
SHR 1.9.2	For those tests failing to meet the test criteria, Concessionaire shall document the test discrepancy, implement appropriate corrective action and repeat the test.	The TTT shall have fields that allow the user to document test discrepancies and discrepancy resolutions.
SHR 1.9.3	All Test Records for a test failing to meet the test criteria shall be submitted to Owner for Review and Comment.	The TTT shall notify the owner if a test performed has failed.

Table 4: Functional Stakeholder Requirements

The technical stakeholder requirements for the Purple Line Test Tracking Tool are given below in Table 5.

SHR	**Technical Provisions** [6]	**Stakeholder Requirements**
SHR 2.1	To support the Test Program, Test Program Plans, Test Procedures and Test Reports, Concessionaire shall maintain the following as part of Record Documents:	NA
SHR 2.1.1	requirements traceability;	The TTT shall store the Purple Line requirement number for each test being logged.
SHR 2.1.2	test discrepancies; and test verification;	The TTT shall store the verification status for each test being logged.
SHR 2.2	Concessionaire shall develop a means to record and store all discrepancies identified by the Test Program. Concessionaire shall document, track and ensure that all discrepancies are rectified. The information recorded for each discrepancy shall include the following:	The TTT shall store the test discrepancy for each test being logged.
SHR 2.2.1	test number assigned to facilitate tracking and monitoring;	The TTT shall assign each test a unique identifier.
SHR 2.2.2	interface reference number assigned to facilitate tracking and monitoring;	The TTT shall have a field identifying the Interface Control Form (ICF) number.
SHR 2.2.3	date that the discrepancy originated;	The TTT shall have a field identifying the date the test was performed.
SHR 2.2.4	Test Report that identifies the original discrepancy;	The TTT shall store test reports uploaded by the user.
SHR 2.2.5	description of test;	The TTT shall have a field that stores the description of the test.
SHR 2.2.6	description of discrepancy, include any supporting/conflicting references to documentation; Concessionaire's representative in responsible charge of resolution of the discrepancy;	The TTT shall have a field for the Contractor's representative and the Sub-system Supplier's representative.

SHR 2.2.7	decisions made and description of actions to resolve discrepancy including any supporting documents including meeting minutes, telephone conversations, emails, and drawings.;	The TTT shall have a field that stores the discrepancy resolution.
SHR 2.2.8	sign-off when discrepancy is closed out; and date the discrepancy is closed out.	The TTT shall have a field that allows users to sign-off on discrepancies and close them.
SHR 2.3	Concessionaire shall develop a means to record and store all tests completed. The information recorded for each test shall include the following:	The TTT shall store the test information for all tests performed.
SHR 2.3.3	name of test;	The TTT shall have a field that stores the name of the test.
SHR 2.3.4	date of test performance;	The TTT shall have a field that stores the date the test is performed.
SHR 2.3.5	date that test is closed out; and	The TTT shall have a field that stores the date that test is closed out.
SHR 2.3.6	list of reference documents used to confirm that the interfaces have been implemented as required.	The TTT shall store documents uploaded by the user.
SHR 2.4	For each test activity, Concessionaire shall identify in each Test Program Plan the verification method that shall be used. Concessionaire shall use the following verification methods:	The TTT shall have a field that stores the verification method that will be used for the test.
SHR 2.5	All such tests to be performed shall be identified in a Project Test Program Plan or the Integration Test Program Plan.	The TTT shall store the RVM for multiple sub-systems.
SHR 2.6	Each Test Program Plan shall at a minimum be developed by Concessionaire so that when Concessionaire executes the Test Program Plan, it:	NA
SHR 2.6.1	identifies the verification method for each test;	The TTT shall have a field that stores the verification method that will be used for the test.
SHR 2.6.2	identifies key LRV, System, Fixed Equipment, Fixed Facility and human interfaces;	The TTT shall have a field that stores the equipment number that will be used for the test.

SHR 2.6.3	identifies all specific tests to be conducted and provides a brief description of the purpose of each test;	The TTT shall have a field that stores the description of each test.
SHR 2.6.4	identifies whether or not each test is required for Safety and Security Certification;	The TTT shall have a field that identifies whether the test is safety critical.
SHR 2.6.5	identifies Concessionaire's required manpower resources, including the Concessionaire's representative in responsible charge and the person leading the test;	The TTT shall have a field that identifies the Contractor's representative.
SHR 2.6.6	identifies test schedules and the dependence of each test on the prior completion of other tests.	The TTT shall have a field that stores the pre-requirements for each test.
SHR 2.7	The Verification Cross Reference Matrix shall include at a minimum the following:	The TTT shall contain the following fields:
SHR 2.7.1	test number - assigned to facilitate tracking and monitoring;	Test Number
SHR 2.7.2	interface reference number - assigned to facilitate tracking and monitoring;	Interface Control Form (ICF) number
SHR 2.7.3	specification number/referenced paragraph - the location where testing requirements appear in Concessionaire's specifications;	Specification Reference number
SHR 2.7.4	Systems and/or Fixed Facilities involved in the test;	Lead Sub-system
SHR 2.7.5	test type – to include Subsystem, System, Fixed Facility, and Project level integration/operational tests;	Test Type
SHR 2.7.6	test location - the location of the Systems and/or Fixed Facilities to be tested; System test lead - the portion of Concessionaire's organization, including the Concessionaire's representative in responsible charge and the person leading the test; and	Test Location
SHR 2.7.7	dates - Test Procedure submitted and reviewed by Owner; test scheduled, actually performed, and Test Report submitted and reviewed by Owner.	Submitted to Owner Date, Document Acceptance Date, Test Scheduled Date, Test Completion Date, Test Closed Date

Table 5: Technical Stakeholder Requirements

3.4. System Requirements

In order to create system requirements from the stakeholder requirements, I first had to learn how to write requirements in accordance with INCOSE's Guide for Writing Requirements. Since the Guide for Writing Requirements is tedious for a beginner to understand, I elected to take an online course called "Requirements Writing" through Coursera, and received the Certificate of Completion from the University of New South Wales [15].

Per the INCOSE's Guide for Writing Requirements [16], listed below are some characteristics individual requirements statements must adhere to:

- *Necessary*: Every requirement statement is necessary.
- *Implementation Independent*: A requirement statement must only state what is required, not how the requirement will be met.
- *Unambiguous*: A requirement statement must not be ambiguous or open to interpretation.
- *Complete*: An individual requirement statement is complete by itself.
- *Singular*: A requirement statement addresses a single thought.
- *Feasible*: A requirement statement expresses something that is realistic and achievable.
- *Verifiable*: A requirement statement is verifiable.
- *Correct*: A requirement statement is a correct expression of the stakeholder need
- *Conforming*: A requirement statement conforms to standards applicable to any specific organization.

In addition to the characteristics mentioned above, a *set* of requirement statements must also adhere to additional characteristics:

- *Complete*: A set of requirement statements must represent a complete definition of the stakeholder expectations. This is to ensure that all stakeholder needs are met.
- *Consistent*: A set of requirement statements represents a consistent expression of the stakeholder expectations. This is to prevent any inconsistent use of terms and abbreviations that may give rise to ambiguity.
- *Feasible*: A set of requirement statements represents a feasible expression of the stakeholder expectations. Similar to the feasibility characteristic for individual requirement statements, a set of requirement statements must also be realistic and achievable within governing constraints.
- *Bounded*: A set of requirement statements is within a well-defined scope. This is to ensure that only necessary requirements are included and that the scope of work is well-defined.

Listed below in Table 6 are the system requirements that were developed for the Purple Line Test Tracking Tool. The requirements listed below apply to each of the Sub-systems RVMs/ Lists being created for the ten primary Purple Line Sub-systems.

System Req. Title/ID	Description
System Column Requirements	
1.1	The TTT shall contain a column titled "Indicator/I1".
1.1.2	If the test report on a line item is both, rejected and flagged, the Indicator/I1 column shall display "FL-RJ"

1.1.3	If the [test report on a line item is rejected and flagged] and [the letter in the Document Revision column is greater than the letter in the Test Procedure Revision Used column] , the Indicator/I1 column shall display "REV-FL-RJ"
1.2	The TTT shall contain a column titled "Attachments".
1.2.1	The Attachments column shall allow each user to upload multiple attachment in any format.
1.2.2	If the Attachments column contains an attachment, the Attachments column shall display a paper clip icon.
1.3	The TTT shall contain a column titled "ID #".
1.3.2	The ID# column shall be editable by PLTC and the sub-system supplier.
1.3.3	The ID# column shall be a free text box that the user can type into.
1.4	The TTT shall contain a column titled "Document Type".
1.4.2	The Document Type column shall be editable by PLTC and the sub-system supplier.
1.4.3	The Document Type column shall be a drop down menu featuring the following options: Test Program Plan, Test Procedure, Test Report.
1.4.4	The Document Type column shall only hold one value from the options listed under it.
1.5	The TTT shall contain a column titled "Document Name"
1.5.2	The Document Name column shall be editable by PLTC and the sub-system supplier.
1.5.3	The Document Name column shall be a free text box that the user can type into.
1.6	The TTT shall contain a column titled "Document Revision"
1.6.2	The Document Revision column shall be editable by PLTC and the sub-system supplier.
1.6.3	The Document Revision column shall be a free text box that the user can type into.
1.7	The TTT shall contain a column titled "Test Purpose".
1.7.2	The Test Purpose column shall be editable by PLTC and the sub-system supplier.
1.7.3	The Test Purpose column shall be a free text box that the user can type into.
1.8	The TTT shall contain a column titled "Sub-System Supplier's Document ID".
1.8.2	The Sub-System Supplier's Document ID column shall be editable by PLTC and the sub-system supplier.

1.8.3	The Sub-System Supplier's Document ID column shall be a free text box that the user can type into.
1.9	The TTT shall contain a column titled "Owner Submittal ID (DRC)".
1.9.2	The Owner Submittal ID (DRC) column shall be editable by PLTC and the sub-system supplier.
1.10	The TTT shall contain a column titled "Submitted to Owner Date".
1.10.2	The Submitted to Owner Date column shall be editable by PLTC and the sub-system supplier.
1.10.3	The Submitted to Owner Date column shall accept values in a *mm/dd/yyyy* date format.
1.11	The TTT shall contain a column titled "Document Acceptance Date".
1.11.2	The Document Acceptance Date column shall be editable by PLTC and the sub-system supplier.
1.11.3	The Document Acceptance Date column shall accept values in a *mm/dd/yyyy* date format
1.12	The TTT shall contain a column titled "Test Type".
1.12.2	The Test Type column shall be editable by PLTC only.
1.12.3	The Test Type column shall be a drop down menu featuring the test type options as listed under the Purple Line Test Program Plan Template.
1.12.4	The Test Type column shall only hold one value from the options listed under it.
1.13	The TTT shall contain a column titled "Test-Type (Sub-System Supplier)".
1.13.2	The Test Type (Sub-System Supplier) column shall be editable by PLTC and the sub-system supplier.
1.13.3	The Test-Type (Sub-System Supplier) column shall be a free text box that the user can type into.
1.14	The TTT shall contain a column titled "Lead Sub-System / Facility".
1.14.2	The Lead Sub-System / Facility column shall be be editable by PLTC only.
1.14.3	The Lead Sub-System / Facility column shall be a drop down menu featuring the sub-system/facility options as listed under the Purple Line System Structure.
1.14.4	The Lead Sub-System / Facility column shall only hold one value from the options listed under it.
1.15	The TTT shall contain a column titled "Lead Sub-System Supplier"

1.15.2	The Lead Sub-System Supplier column shall be be editable by PLTC only.
1.15.3	The Lead Sub-System Supplier column shall be a free text box that the user can type into.
1.16	The TTT shall contain a column titled "Lead Sub-Sub-System".
1.16.2	The Lead Sub-Sub-System column shall be editable by PLTC and the sub-system supplier.
1.16.3	The Lead Sub-Sub-System column shall be a drop down menu featuring the sub-sub-system options as listed under the Purple Line System Structure.
1.16.4	The Lead Sub-Sub-System column shall only hold one value from the options listed under it.
1.17	The TTT shall contain a column titled "Equipment ID"
1.17.2	The Equipment ID column shall be editable by PLTC and the sub-system supplier.
1.17.3	The Equipment ID column shall be a free text box that the user can type into.
1.18	The TTT shall contain a column titled "Equipment Supplier".
1.18.2	The Equipment Supplier column shall be editable by PLTC and the sub-system supplier.
1.18.3	The Equipment Supplier column shall be a free text box that the user can type into.
1.19	The TTT shall contain a column titled "Partner Sub-System".
1.19.2	The Partner Sub-System column shall be editable by PLTC and the sub-system supplier.
1.19.3	The Partner Sub-System column shall be a drop down menu featuring the sub-system options as listed under the Purple Line System Structure.
1.19.4	The Partner Sub-System column shall only hold one value from the options listed under it.
1.20	The TTT shall contain a column titled "Partner Sub-System Supplier".
1.20.2	The Partner Sub-System Supplier column shall be editable by PLTC only.
1.20.3	The Partner Sub-System Supplier column shall be a drop down menu featuring the sub-system options as listed under the Purple Line Test Program Plan template.
1.20.4	The Partner Sub-System column shall only hold one value from the options listed under it.
1.21	The TTT shall contain a column titled "Verification Method".

1.21.2	The Verification Method column shall be editable by PLTC only.
1.21.3	The Verification Method column shall be a drop down menu featuring the verification methods as listed under the Purple Line Test Program Plan Template
1.21.4	The Verification Method column shall allow the user to choose only one option from the options listed under it.
1.22	The TTT shall contain a column titled "Test Location".
1.22.2	The Test Location column shall be editable by PLTC and the sub-system supplier.
1.22.3	The Test Location column shall be a free text box that the user can type into.
1.23	The TTT shall contain a column titled "Segment".
1.23.2	The Segment column shall be editable by PLTC and the sub-system supplier.
1.23.3	The Segment column shall be a drop down menu featuring the Segments as listed under the Purple Line Segment Breakdown.
1.23.4	The Segment column shall allow the user to choose multiple values from the options listed below.
1.24	The TTT shall contain a column titled "Workzone".
1.24.2	The Workzone column shall be editable by PLTC and the sub-system supplier.
1.24.3	The Workzone column shall be a drop down menu featuring the Segments as listed under the Purple Line Segment Breakdown.
1.24.4	The Workzone column shall allow the user to choose multiple values from the options listed below.
1.25	The TTT shall contain a column titled "Stationing".
1.25.2	The Stationing column shall be editable by PLTC and the sub-system supplier.
1.25.3	The Stationing column shall be a free text box that the user can type into.
1.26	The TTT shall contain a column titled "Requirement ID".
1.26.2	The Requirement ID column shall be editable by PLTC and the sub-system supplier.
1.26.3	The Requirement ID column shall be a free text box that the user can type into.
1.27	The TTT shall contain a column titled "Specification Reference (Section)".
1.27.2	The Specification Reference (Section) column shall be editable by PLTC and the sub-system supplier.

1.27.3	The Specification Reference (Section) column shall be a free text box that the user can type into.
1.28	The TTT shall contain a column titled "Specification Reference (Subsection)".
1.28.2	The Specification Reference (Subsection) column shall be editable by PLTC and the sub-system supplier.
1.28.3	The Specification Reference (Subsection) column shall be a free text box that the user can type into.
1.29	The TTT shall contain a column titled "System Safety and Security Certification Test".
1.29.2	The System Safety and Security Certification Test column shall be editable by PLTC only.
1.29.3	The System Safety and Security Certification Test column shall be a drop down menu featuring the options: *Yes, No.*
1.29.4	The System Safety and Security Certification Test column shall allow the user to choose only one option from the options listed under it.
1.29.5	If the System Safety and Security Certification Test column contains a "Yes", the TTT shall send the report to the System Safety and Security team for review.
1.30	The TTT shall contain a column titled "Interface Control Form".
1.30.2	The Specification Reference (Subsection) column shall be editable by PLTC and the sub-system supplier.
1.30.3	The Specification Reference (Subsection) column shall be a free text box that the user can type into.
1.31	The TTT shall contain a column titled "Predecessor Test ID".
1.31.2	The Predecessor Test ID column shall be editable by PLTC only.
1.31.3	The Predecessor Test ID column shall be a free text box that the user can type into.
1.32	The TTT shall contain a column titled "Predecessor Test ID (Sub-System Supplier)".
1.32.2	The Predecessor Test ID (Sub-System Supplier) column shall be editable by PLTC and the sub-system supplier.
1.32.3	The Predecessor Test ID (Sub-System Supplier) column shall be a free text box that the user can type into.
1.33	The TTT shall contain a column titled "Test Scheduled Date".
1.33.2	The Test Scheduled Date column shall be editable by PLTC and the sub-system supplier.

1.33.3	The Test Scheduled Date column shall accept values in a *mm/dd/yyyy* date format.
1.33.4	The Test Scheduled Date Column shall be used to populate 60-day "Lookahead" reports for the project owner.
1.34	The TTT shall contain a column titled "Sub-System Supplier's Test Manager".
1.34.2	The Sub-System Supplier's Test Manager column shall be editable by PLTC and the sub-system supplier.
1.34.3	The Sub-System Supplier's Test Manager column shall be a free text box that the user can type into.
1.35	The TTT shall contain a column titled "Contractor's Test Manager".
1.35.2	The Contractor's Test Manager column shall be editable by PLTC only.
1.35.3	The Contractor's Test Manager column shall be a drop down menu featuring the names of PLTC personnel as listed under the Purple Line Project Organization Plan.
1.35.4	The Contractor's Test Manager column shall allow the user to choose only one option from the options listed under it.
1.36	The TTT shall contain a column titled "Test Completion Date".
1.36.2	The Test Completion Date column shall be editable by PLTC and the sub-system supplier.
1.36.3	The Test Completion Date column shall accept values in a *mm/dd/yyyy* date format.
1.37	The TTT shall contain a column titled "Test Result".
1.37.2	The Test Result column shall be editable by PLTC and the sub-system supplier.
1.37.3	The Test Result column shall be a drop down menu featuring the options: *Passed, Passed with Discrepancies, Failed.*
1.37.4	The Test Result column shall allow the user to choose only one option from the options listed under it.
1.38	The TTT shall contain a column titled "Test Status".
1.38.2	The Test Status column shall be editable by PLTC and the sub-system supplier.
1.38.3	The Test Status column shall be a drop down menu featuring the options: *Scheduled, Pending, Conducted, Complete, Retest, Void.*
1.38.4	The Test Status column shall allow the user to choose only one option from the options listed under it.

1.40	The TTT shall contain a column titled "Test procedure Revision Used".
1.40.2	The Test Procedure Revision Used column shall be editable by PLTC and the sub-system supplier.
1.40.3	The Test Procedure Revision Used column shall be a free text box that the user can type into.
1.40.4	If the Test Procedure Revision Used column is lower than the Procedure's Revision, the Indicator/I1 column shall display a "REV".
1.41	The TTT shall contain a column titled "PLTC Review".
1.41.2	The PLTC Review column shall be editable by PLTC only.
1.41.3	The PLTC Review column shall be a drop down menu featuring the options: *Reviewed, Flagged, Rejected.*
1.41.4	The PLTC Review column shall allow the user to choose only one option from the options listed under it.
1.41.5	If the PLTC Review column contains a "Flagged", the Indicator/I1 column shall display a "FL".
1.41.6	If the PLTC Review column contains a "Rejected", the Indicator/I1 column shall display a "RJ".
1.42	The TTT shall contain a column titled "System Safety and Security Review".
1.42.2	The System Safety and Security Review column shall be editable by PLTC and the System Safety and Security team.
1.42.3	The System Safety and Security Review column shall be a drop down menu featuring the options: *Reviewed, Flagged, Rejected.*
1.42.4	The System Safety and Security Review column shall allow the user to choose only one option from the options listed under it.
1.42.5	If the System Safety and Security Review column contains a "Flagged", the Indicator/I1 column shall display a "FL".
1.42.6	If the System Safety and Security Review column contains a "Rejected", the Indicator/I1 column shall display a "RJ".
1.43	The TTT shall contain a column titled "MTA Review".
1.43.2	The MTA Review column shall be editable by PLTC and MTA team.
1.43.3	The MTA Review column shall be a drop down menu featuring the options: *Reviewed, Flagged, Rejected.*

1.43.4	The MTA Review column shall allow the user to choose only one option from the options listed under it.
1.43.5	If the MTA Review column contains a "Flagged", the Indicator/I1 column shall display a "FL".
1.43.6	If the MTA Review column contains a "Rejected", the Indicator/I1 column shall display a "RJ".
1.44	The TTT shall contain a column titled "Quality Review".
1.44.2	The Quality Review column shall be editable by PLTC and the quality team.
1.44.3	The Quality Review column shall be a drop down menu featuring the options: *Reviewed, Flagged, Rejected.*
1.44.4	The Quality Review column shall allow the user to choose only one option from the options listed under it.
1.44.5	If the Quality Review column contains a "Flagged", the Indicator/I1 column shall display a "FL".
1.44.6	If the Quality Review column contains a "Rejected", the Indicator/I1 column shall display a "RJ".
1.45	The TTT shall contain a column titled "Discrepancy Description".
1.45.2	The Discrepancy Description column shall be a free text box that the user can type into.
1.46	The TTT shall contain a column titled "Discrepancy Resolution".
1.46.2	The Discrepancy Resolution column shall be editable by PLTC and the sub-system supplier.
1.46.3	The Discrepancy Resolution column shall be a free text box that the user can type into.
1.47	The TTT shall contain a column titled "Contractor's Representative".
1.47.2	The Contractor's Representative column shall be editable by PLTC only.
1.47.3	The Contractor's Representative column shall be a free text box that the user can type into.
1.48	The TTT shall contain a column titled "Contractor's Sign Off".
1.48.2	The Contractor's Sign Off column shall be editable by PLTC only.
1.48.3	The Contractor's Sign Off column shall be a free text box that the user can type into.
1.49	The TTT shall contain a column titled "Date Closed".
1.49.2	The Date Closed column shall be editable by PLTC only.

1.49.3	The Date Closed column shall accept values in a *mm/dd/yyyy* date format.
Security Requirements	
2.1	The TTT shall not be accessible to anyone that the TTT has not been shared with.
Data Storage and Access Requirements	
3.1	The TTT shall store the Requirements Verification Matrix (RVM) for each subsystem.
3.2	The TTT shall store data for each Integration Test for the Purple Line system.
3.3	The TTT shall store attachments such as test reports and test procedures.
3.4	The TTT shall be shareable with personnel from any company with a valid company email ID.
User Interface Requirements	
4.1	The TTT shall be accessible from any commercial web-browser.
4.2	The TTT shall be accessible from any PC.
4.3	The TTT shall be accessible from mobile devices such as cellphones.
4.4	The TTT shall display a T&C status dashboard in accordance with the TTT Proof-of-Concept.
4.5	The TTT shall display a list of all Purple Line subsystem in a site navigation bar.
4.6	The TTT shall provide Subcontractors with a Supplier View for each subsystem RVM.
4.7	The TTT shall provide PLTC with a PLTC View for each subsystem RVM.
4.8	The TTT shall provide MTA with an Owner View for each subsystem RVM.
4.9	The TTT shall provide PLTC and Subcontractors a "Quick edit" option for each subsystem RVM.
4.10	The TTT shall provide the ability to filter for specific data for each subsystem RVM.
4.11	The TTT shall provide PLTC and Subcontractors the ability to create a new line-item for each subsystem RVM.
Maintainer Interface Requirements	

5.1	The TTT shall provide the system administrator the ability to share the TTT with required personnel.
5.2	The TTT shall have an "Export to Excel" icon for each subsystem RVM.
5.3	The TTT shall provide the Administrator the option to bulk edit each subsystem RVM.
Environment Interface Requirements	
6.1	The TTT shall be able to export each subsystem RVM as a MS Excel file.
6.2	The TTT shall be able to import data from a MS Excel file.
Workflow Requirements	
7.1	If a document is attached to a line-item for a test report, the TTT shall trigger a test approval flow.

Table 6: System Requirements

The Requirements Allocation Matrix (RAM) provides a matrix that identifies what system requirements are allocated to each element. This is used to ensure that system-level decomposition has been achieved. It also serves as the basis for Verification & Validation, and is used as a tool in creating the Requirements Verification Matrix (RVM). The RAM is provided in Appendix A.

3.5. TTT System Architecture

This section provides the system-level architecture for the TTT. Section 3.5.1 defines the system domain using a BDD. Section 3.5.2 provides an IBD that shows the primary system interfaces and an Interface Flow BDD to define each interface. Section 3.5.3 shows the system-level UCD, followed by the related UCNs in Section 3.5.3.1. Section 3.5.4 shows the ADs for each of the Use Cases.

3.5.1. Domain Definition BDD

The SysML domain definition BDD identifies the principal structural entities that serve as the context for the PL Test Tracking Tool. Figure 12 shown below shows the structure of the TTT domain:

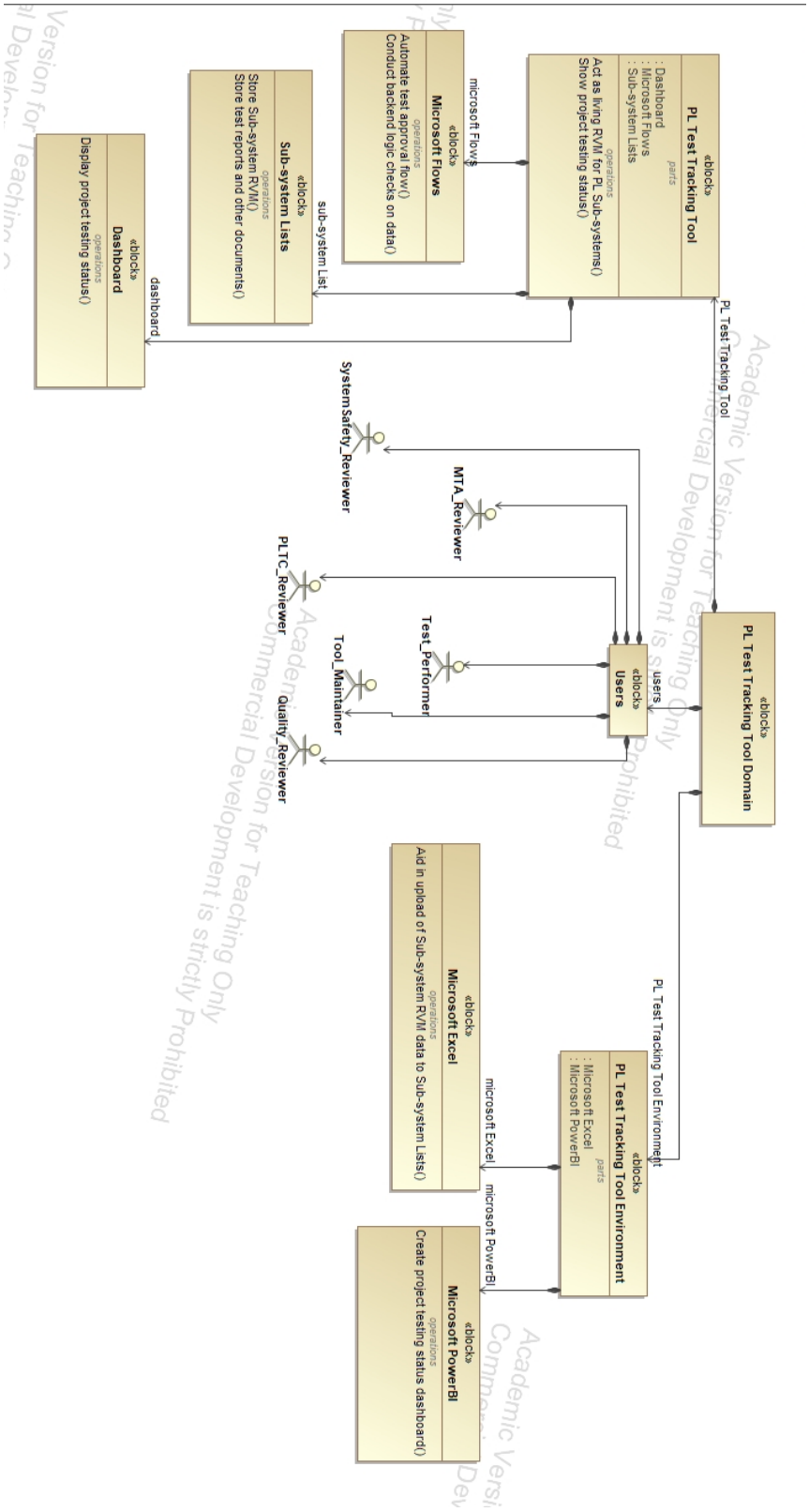


Figure 12: TTT Domain Definition BDD

3.5.2. System-Level IBD and Interface Flow BDD

The system-level IBD shown in Figure 13 below indicates the TTT, the users, and the environmental elements. The purpose of the system-level IBD is to show the information that is flowing between the system elements, users, and external elements.

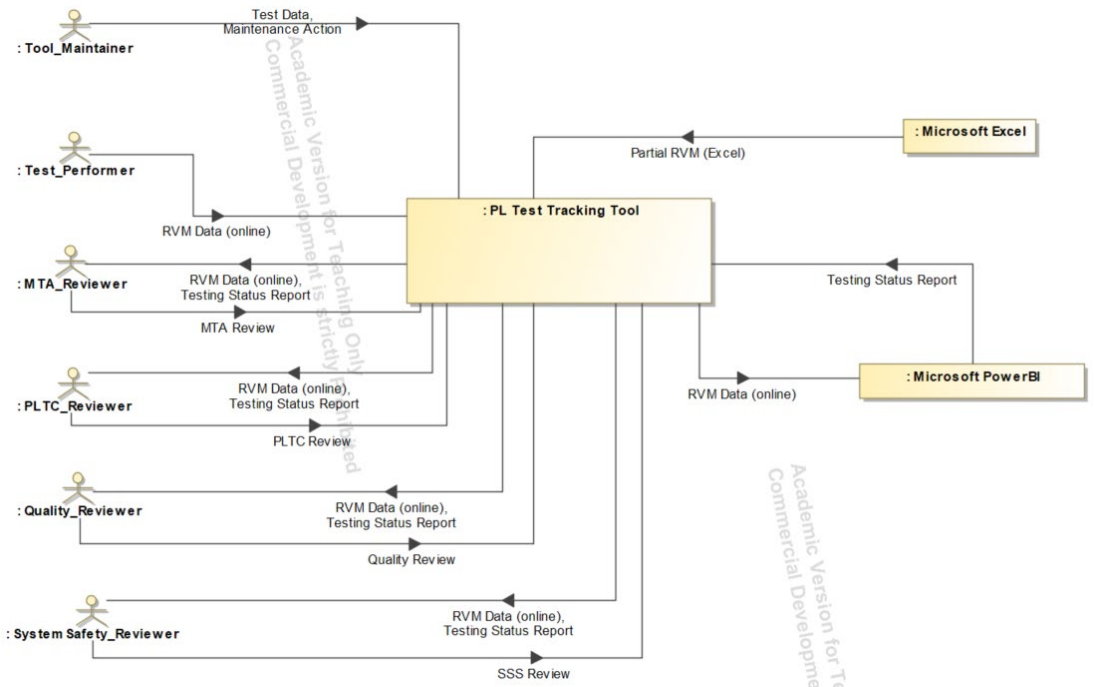


Figure 13: TTT System-Level IBD

The system-level Interface Flow BDD shown in Figure 14 defines the information that is carried from one interface to another.

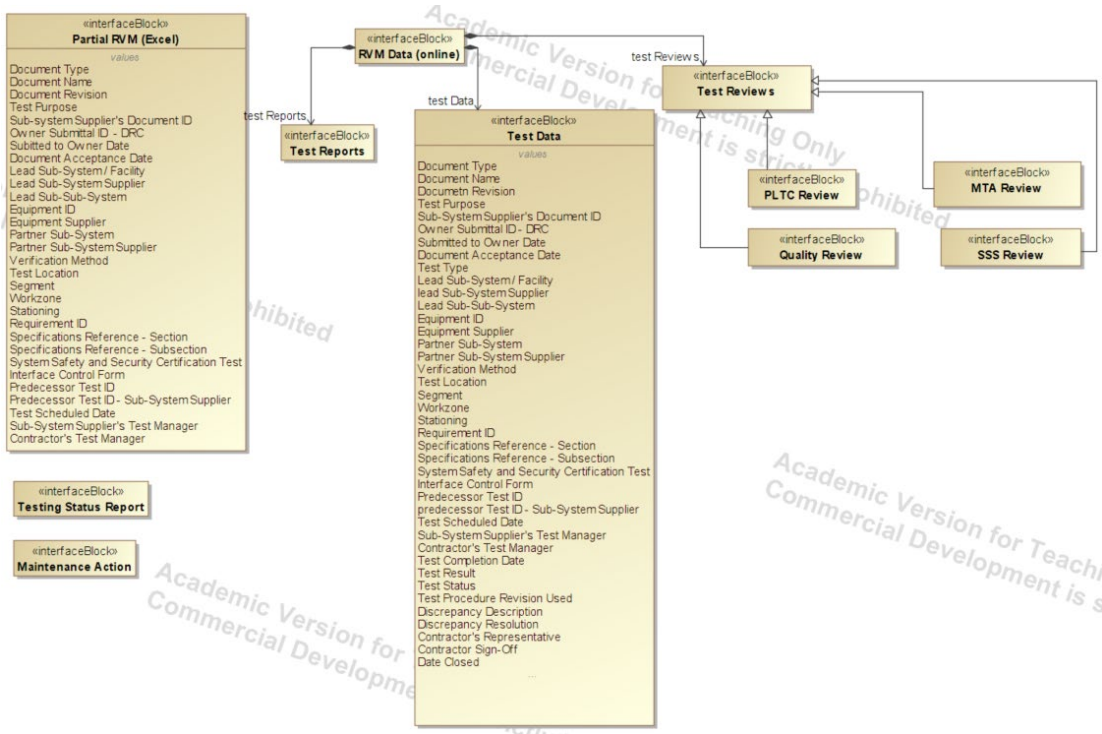


Figure 14: TTT System-Level Interface Flow BDD

3.5.3. System-Level Use Case Diagrams

The system-level UCD identifies the principal capabilities that the system is expected to provide the user. In the UCD, the left side illustrates the actors of the use-cases and the blocks on the right-hand side illustrate the environment. The TTT has five Use Cases, as shown in Figure 15 below.

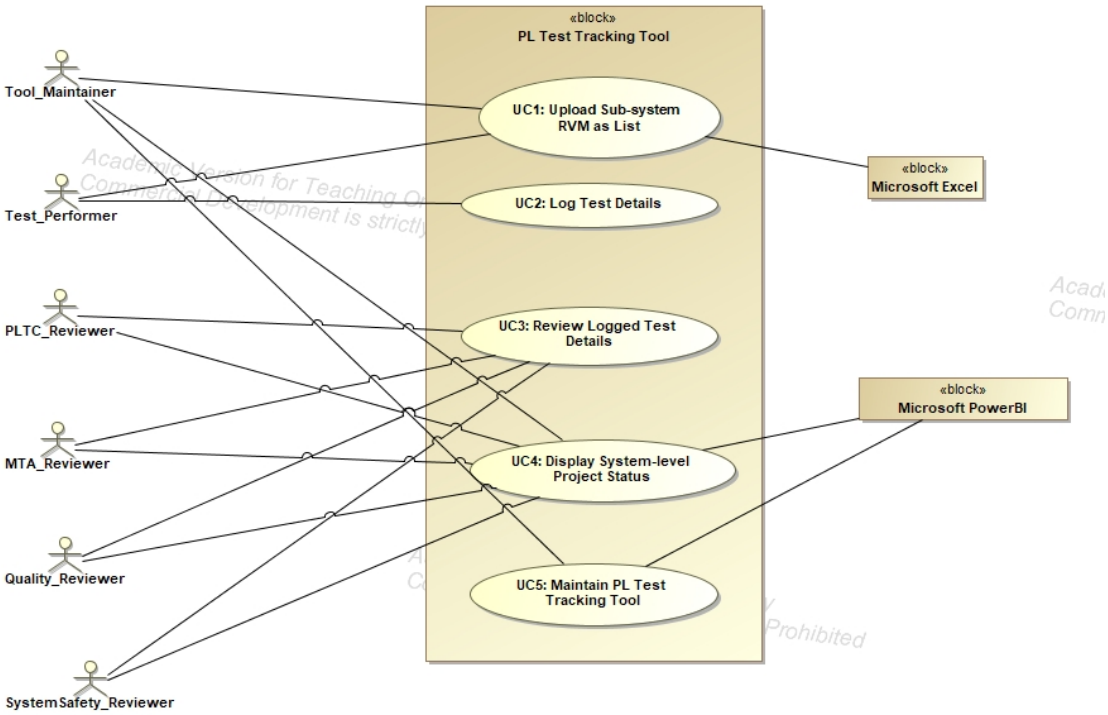


Figure 15:TTT System-Level Use Case Diagram

3.5.3.1. System-Level Use Case Narratives

The purpose of Use Case Narratives (UCNs) is to identify the activities that must be accomplished by the TTT, the users and the environmental elements in order for the system to perform the required tasks. They convey the narrative that unfolds when an actor invokes a Use Case. The UCN identifies the following [17]:

- The lower level activities that must be accomplished by the System of Interest (SOI), the user and other external actors in order for the system to provide the desired service indicated by the use case title.
- The flow of information between the SOI, primary actors and the external systems that must occur for the use case title to be accomplished.
- The flow of control between users, the SOI and environmental elements.

The Purple Line Test Tracking Tool has five major Use Case Narratives [18]:

Use Case ID: UC 1
Use Case Name: Upload Sub-system RVM as List ("List" is further described in Section 3.6.1).
Level: System-Level
Actor(s):
1) Tool_Maintainer
2) Test_Performer
Precondition(s):
1) The Sub-system RVM Excel file has been partially populated and verified by the Test_Performer (Refer to *Figure 14: TTT System-Level Interface Flow BDD* for more information).
2) The partially populated Sub-system RVM Excel file has been verified by the Tool_Maintainer.
3) A baselined template exists for creation of new SharePoint Lists on the TTT.
4) The Tool_Maintainer has full administrative access to the TTT.
Trigger(s):
1) The Sub-system RVM is officially submitted as a Microsoft Excel file to PLTC, for data transfer to the TTT.
Post-condition(s):
1) The Sub-system RVM is stored as a SharePoint List on the TTT.
2) The Sub-system List can be edited/viewed by concerned stakeholders per the given permissions.

Main Success Scenario:
1) The Tool_Maintainer creates a SharePoint List for the Sub-system RVM using a pre-existing baselined template.
2) The Tool_Maintainer manually copies data from the Sub-system RVM Excel file to the newly created list.
3) The Tool_Maintainer verifies the presence and accuracy of the Owner View, PLTC View and Supplier View in the Sub-system List (automatically generated from the baselined template).
4) The Tool_Maintainer provides the appropriate access privileges for the list, including view/edit access, to the concerned stakeholders.
5) The Test_Performer verifies that they have edit access to the Sub-System List.
6) End.

Use Case ID: UC 2
Use Case Name: Log Test Details
Level: System-Level
Actor(s):

1) Test_Performer

Precondition(s):

1) The Sub-system RVM is a SharePoint List on the TTT.
2) The Sub-system List can be edited/viewed by concerned stakeholders per the given permissions.

Trigger(s):

1) The Test_Performer has performed a test which is included in the Sub-system RVM, and needs to log the outcome.

Post-condition(s):

1) The test results are available on the Sub-system List.
2) The relevant test reports are available as attachments for each test performed.

Main Success Scenario:

1) The Test_Performer logs the test information in the Sub-system List for a specific test performed.
2) The Test_Performer creates a formal test report for the test performed.
3) The Test_Performer uploads the test report as an attachment to the line item/row for the specific test.
4) The Test_Performer logs the test result as “Passed”, “Passed with Discrepancies”, or “Failed”.
4) End.

Use Case ID: UC 3

Use Case Name: Review Logged Test Details

Level: System-Level

Actor(s):

1) MTA_Reviewer
2) PLTC_Reviewer
3) Quality_Reviewer
4) System Safety_Reviewer

Precondition(s):

1) The test results are available on the Sub-system List.
2) The relevant test reports are available as attachments for each test performed.
3) The Test_Performer has logged the test result as “Passed” or “Passed with Discrepancies”.
4) Microsoft Flows is operational and linked with the TTT.

Trigger(s):

1) Microsoft Flows triggers the Test Approval Flow (described further in Section 3.6.1.1) if a test report has been attached to a specific test and the Document Type for that test is a “Test Report”.

Post-condition(s):

1) Test (including reports) is approved by PLTC_Reviewer.
2) Test (including reports) may be approved by Quality_Reviewer.
3) Test (including reports) is approved by MTA_Reviewer.
4) Test (including reports) may be approved by the System Safety_Reviewer.

Main Success Scenario:

1) The Test Approval Flow directs the attached test report to the PLTC_Reviewer and MTA_Reviewer for approval.
2) If the System Safety and Security Certification Test contains a “Yes” for the test, the TTT sends the test report to the System Safety_Reviewer for approval (performed in parallel with Step 2).
3) The Quality_Reviewer may randomly elect to review a test to ensure that it meets PLTC quality standards (performed in parallel with Step 2).
4) The test report is reviewed (approved/passed) by all the reviewers, without any issues reported.
5) End.

Use Case ID: UC 4
Use Case Name: Display System-level Testing Status
Level: System-Level
Actor(s):
1) Tool_Maintainer
2) MTA_Reviewer
3) PLTC_Reviewer
4) Quality_Reviewer
5) System Safety_Reviewer
Precondition(s):
1) All Sub-system RVMs are available on the TTT as a SharePoint List.
2) Microsoft PowerBI is available and activated on the Tool_Maintainer’s computer.
3) A baselined dashboard template exists for reporting the test status.
Trigger(s):
1) The first Sub-system List is created on SharePoint
Post-condition(s):
1) There is a system-level test status dashboard displaying data consolidated from all the Sub-system RVMs, and can be viewed by the MTA_Reviewer, PLTC_Reviewer, Quality_Reviewer and System Safety_Reviewer.
Main Success Scenario:
1) The Tool-Maintainer creates a PowerBI project, and interfaces it with each of the Sub-system Lists on the TTT to create a consolidated dataset.
2) The Tool_Maintainer creates a system-level dashboard in the PowerBI project containing status reports and graphical charts, in accordance with the baselined dashboard template.
3) The Tool_Maintainer exports the system-level dashboard as a Microsoft PowerPoint presentation on a weekly basis.
4) The Tool_Maintainer uploads the PowerPoint presentation to the TTT website’s Dashboard page on a weekly basis.
5) The system-level dashboard is viewed by all the reviewers to decide which tests they want to witness in the future or make management decisions.
6) End.

Use Case ID: UC 5
Use Case Name: Maintain PL Test Tracking Tool
Level: System-Level
Actor(s):
1) Tool_Maintainer
Precondition(s):
1) The Sub-system RVM is available on the TTT as a SharePoint List.
2) Microsoft PowerBI is available and activated on the Tool_Maintainer's computer.
3) Microsoft Flows is operational and linked with the Sub-system Lists.
4) The Tool_Maintainer has full administrative access to the TTT.
Trigger(s):
1) On-going activity.
Post-condition(s):
1) The TTT functions normally.
Main Success Scenario:
1) The Tool_Maintainer checks each Sub-system List once a week to review items like the number of line items/rows on each list, test performed dates, test status, reviews etc.
2) The Tool_Maintainer shall rectify any errors, if found.
3) The Tool_Maintainer maintains a log containing details of all users that have been given access to the TTT.
4) The Tool_Maintainer provides access privileges to required users, as and when necessary.
5) The Tool_Maintainer revokes access to the TTT for any users that leave the project.
6) The Tool_Maintainer checks the PowerBI reports on a weekly basis to ensure that the dashboard is representing the project test status accurately.
7) End.

3.5.4. System-Level Activity Diagrams

The purpose of an Activity Diagram is to specify the behaviour of a system, with a focus on the flow of control and transformation of inputs into outputs through a sequence of actions. The TTT has five primary Activity Diagrams, each linked to its respective Use Case Narrative. Figures 16 – 20 below show the Activity Diagrams.

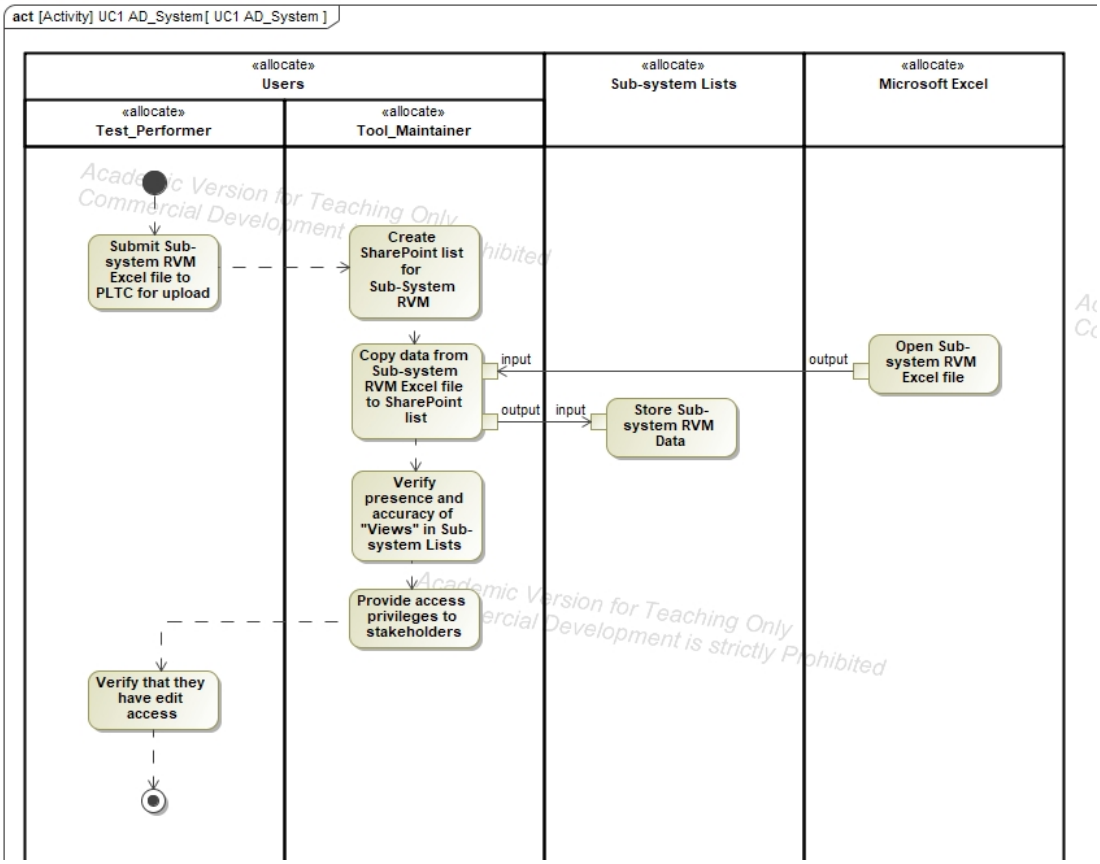


Figure 16: Activity Diagram for System-Level UC1

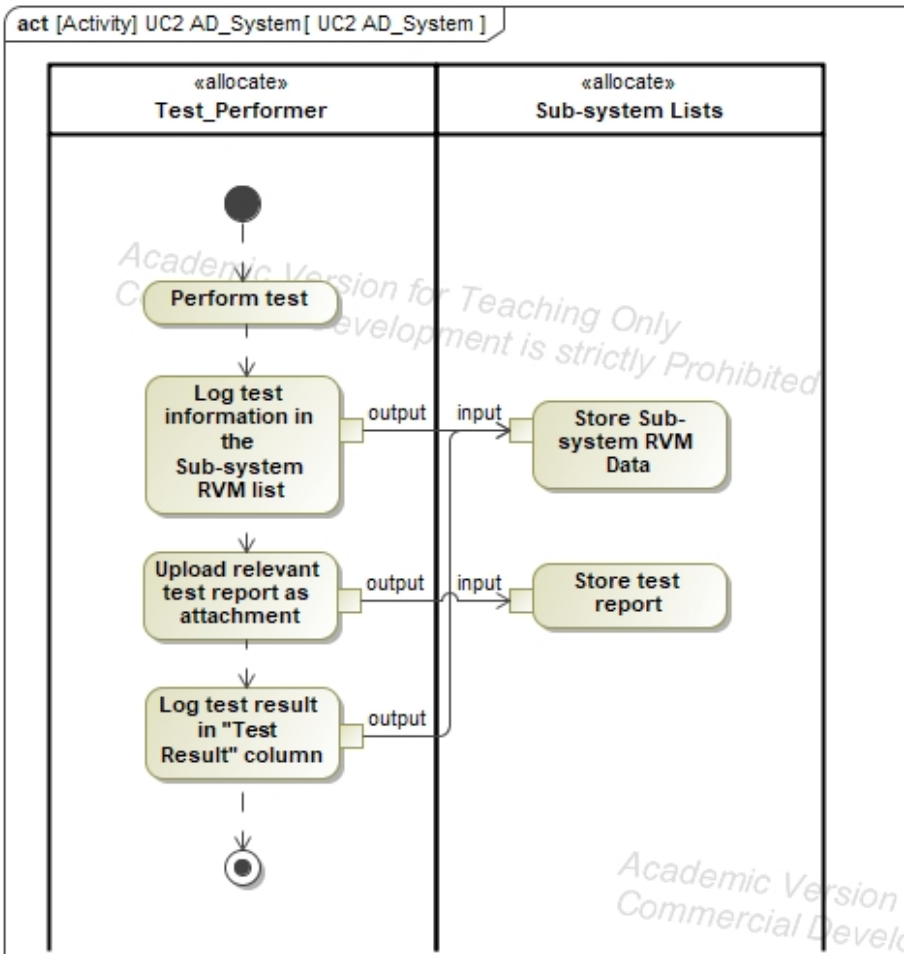


Figure 17: Activity Diagram for System-Level UC2

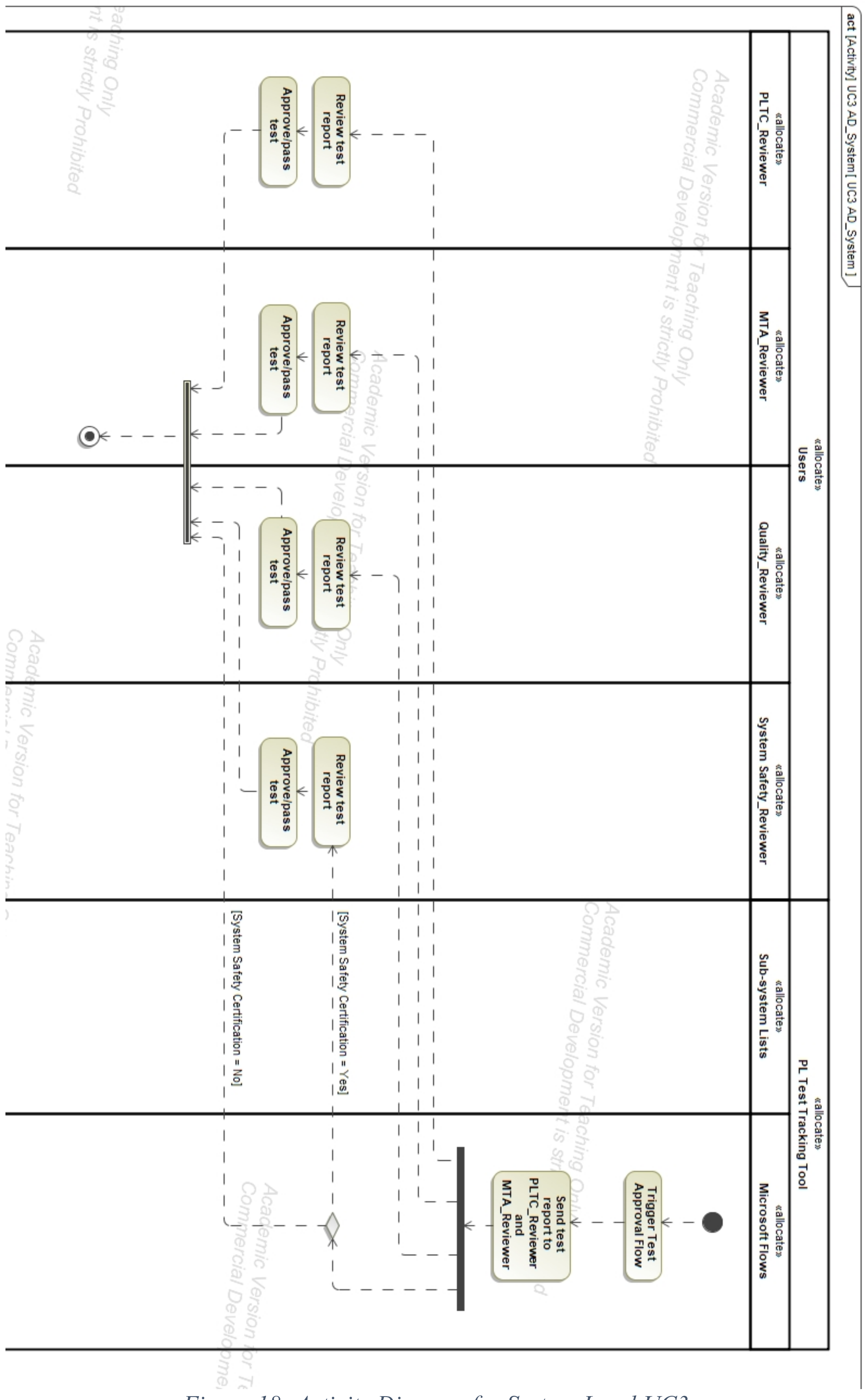


Figure 18: Activity Diagram for System-Level UC3

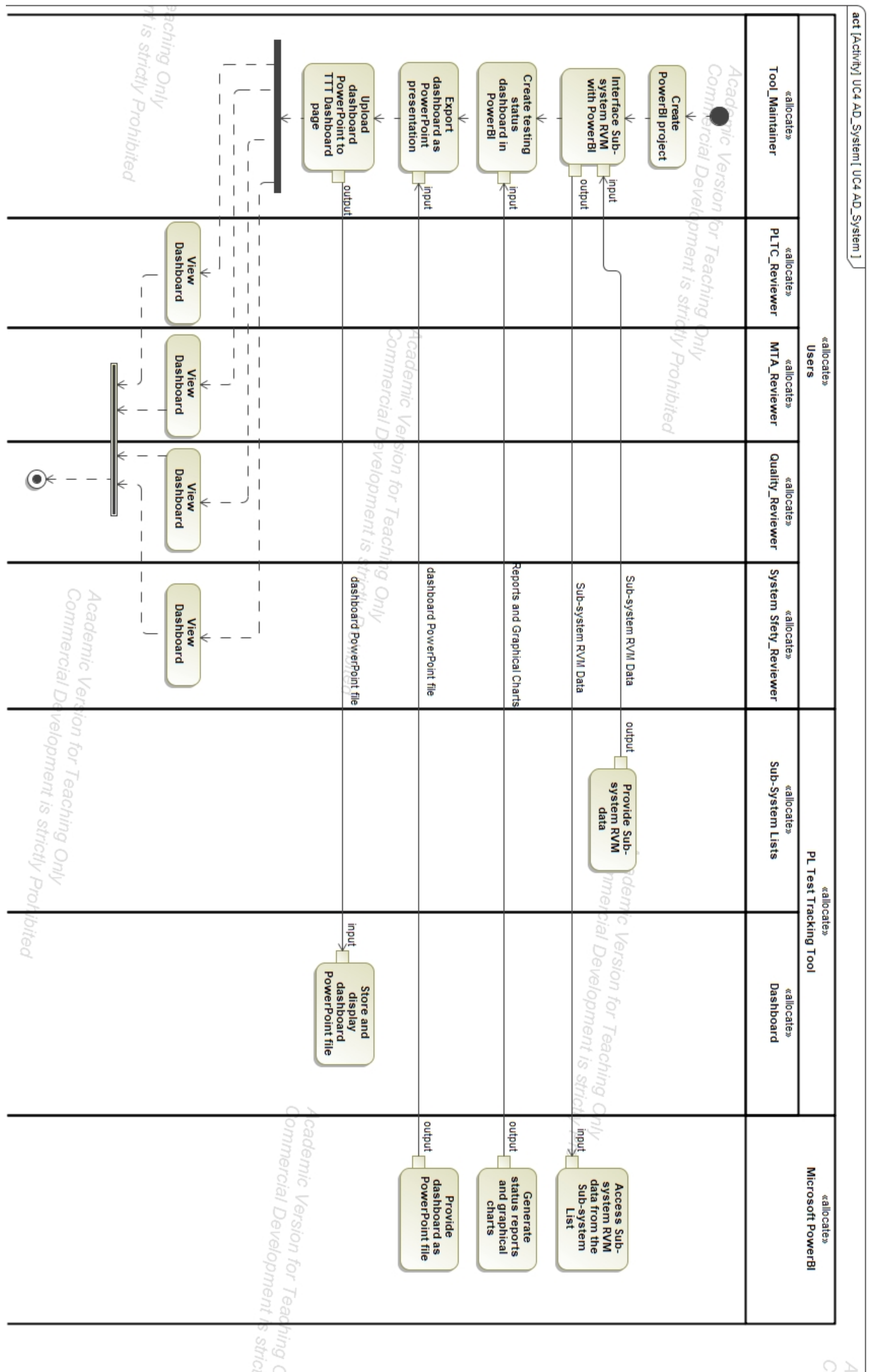


Figure 19: Activity Diagram for System-Level UC4

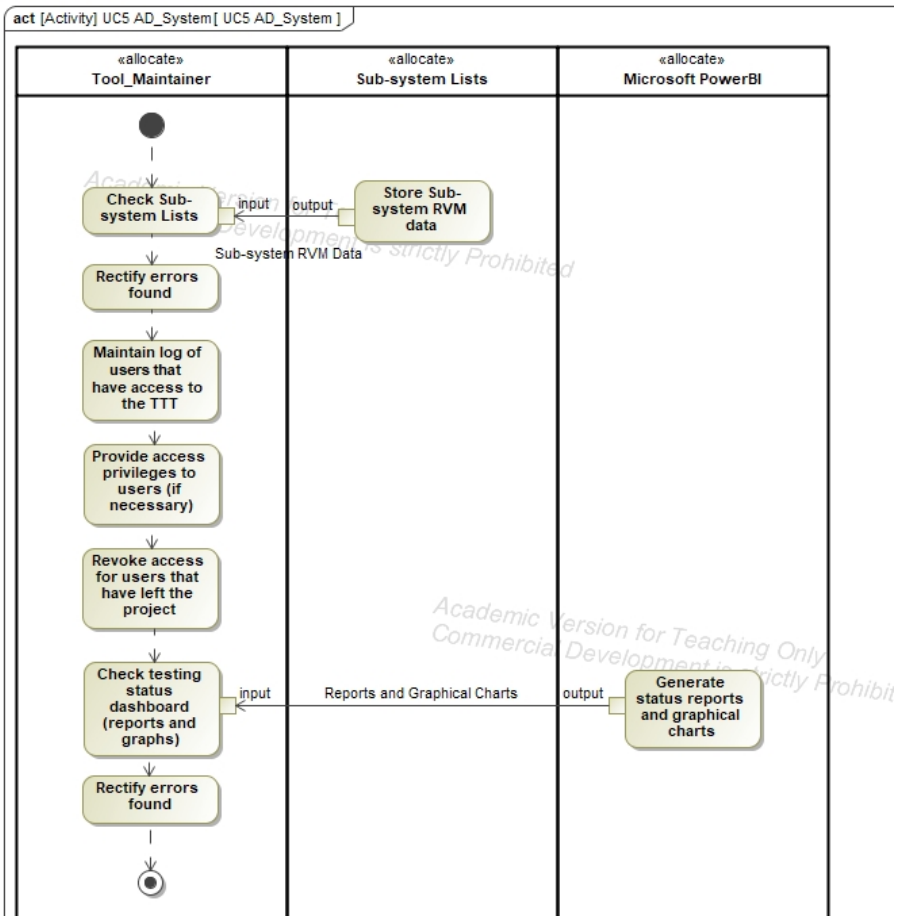


Figure 20: Activity Diagram for System-Level UC5

3.6. Tracking Tool Design

The design of the TTT was approved by PLTC through an informal review in April 2019. The design was created in MS Excel because a SharePoint license was not held by PLTC at the time. The Excel file contains four sheets:

- Matrix: A mock RVM containing dummy data for the train supplier. It is intended to show the reader what a Sub-system RVM may look like once it goes live on the TTT.

- Legend: This sheet provides technical information regarding the functionality and interface for Sub-system RVMs on the TTT. This includes:
    - Edit/View privileges for each field.
    - Whether or not a field must be mandatorily populated, and by which user.
    - The field type: *Drop Down, Free Text, Date, Checkboxes, Automatic* etc.
    - If the field type is a "Drop Down", the options provided for each field.
- Reporting: This sheet shows the type of dashboard that PLTC would like to use for reporting the status of all tests that are to take place during the Testing & Commissioning period. This dashboard includes infographics and tables providing high-level information.
- Workflow: This sheet shows the flow of test artifacts (reports) through the review process.

A description of each column/attribute contained in a typical Sub-system RVM is given in the Table 7. The "Remarks" column in Table 7 identifies the stage in which data is uploaded for a respective column/attribute; these stages are derived from the System requirements provided in Table 6, and are described as follows:

- Stage 1: The Sub-system Supplier submits a *partially populated* RVM (Excel file) to PLTC for review. After review by PLTC and System Safety & Security, the RVM is submitted to the MTA for review, as part of each sub-

system's TPP. Once the Sub-system Supplier addresses MTA's comments, the RVM proceeds to Stage 2.

- Stage 2: The PLTC Systems team finalizes the RVM and uploads it to SharePoint as a list. This stage includes the upload of data that was required in Stage 1, but the Sub-system Supplier may have not provided at that point.

- Stage 3: The Sub-system Supplier populates the SharePoint-based RVM. The Sub-system Supplier remains responsible for the upkeep of the technical data, and the PLTC team reviews test reports and shall work to close out issues concerned with rejected or flagged reports.

Attribute	Explanation	Remarks
Indicator	Displays a "REV" if the Document Revision of the Test Procedure is alphabetically greater than the Test Procedure Revision used. Displays a "FL" if the test (report) is flagged by any of the reviewers. Displays a "RJ" if the test (report) is rejected by any of the reviewers. Displays a combination of the above indicators if multiple scenarios exist.	The user should leave this column blank since SharePoint will automatically populate it.
ID#	Displays the line item ID number.	The Sub-system Supplier or PLTC should provide this information in Stage 1.
Document Type	Drop down menu of what type of document the line item pertains to. The options include: *Test Program Plan, Test Procedure, Test Report.*	Refer to the Purple Line TPP template for a description of each of the options given. The Sub-system Supplier should provide this information in Stage 1.

Document Name	The name of the document that the line item pertains to.	The Sub-system Supplier should provide this information in Stage 1.
Document Revision	Revision number of the document uploaded.	The Sub-system Supplier should provide this information in Stage 1, Stage 2 and Stage 3.
Test Purpose	Details what subsystem is being tested and the functions being verified.	The Sub-system Supplier should provide this information in Stage 1.
Sub-system Supplier's Document ID	The supplier's ID for the document.	The Sub-system Supplier should provide this information in Stage 1 and/or Stage 2.
Owner Submittal ID (DRC)	Contains the submittal number.	The Sub-system Supplier or PLTC should provide this information in Stage 1 and Stage 3.
Submitted to Owner Date	The date PLTC submitted the TPP or Test Procedure to MTA.	This must be in a mm/dd/yyyy format. The Sub-system Supplier or PLTC should provide this information in Stage 1 and Stage 3.
Document Acceptance Date	The date that all reviewer comments were closed.	This must be in a mm/dd/yyyy format. The Sub-system Supplier or PLTC should provide this information in Stage 1 and Stage 3.
Test Type	Drop down menu that lists out the types of tests per the Purple Line Test Program Plan (TPP).	The Sub-system Supplier must select any one when logging a test procedure or report. This information should be provided in Stage 3.
Lead Sub-System / Facility	Identifies the primary sub-system that is being tested.	The Sub-system Supplier must select any one when logging a test procedure or report.

	Drop down menu that lists out the sub-systems and facilities per the Purple Line System Structure.	This information should be provided in Stage 1.
Lead Sub-system Supplier	Identifies the name of the Sub-system Supplier.	The Sub-system Supplier should provide this information in Stage 1.
Lead Sub-Sub-System	Identifies the sub-sub-system that the test is validating. Drop down menu that lists out the sub-sub-systems per the Purple Line System Breakdown Structure.	The Sub-system Supplier must select any one when logging a test procedure or report. This information should be provided in Stage 1.
Equipment ID	Identifies the equipment that the test is validating using the equipment Asset ID.	The Sub-system Supplier should provide this information in Stage 1 and/or Stage 3.
Equipment Supplier	Identifies the Sub-system Supplier.	The Sub-system Supplier should provide this information in Stage 1 and/or Stage 3.
Partner Sub-System	Identifies the partner system involved in an interface test. Drop down menu that lists out the sub-systems per the Purple Line System Breakdown Structure.	Only applicable to Interface testing. The Sub-system Supplier must select any one when logging a test procedure or report. The Sub-system Supplier should provide this information in Stage 1 and/or Stage 3.
Partner Sub-system Supplier	Identifies the partner system supplier. Drop down menu that lists out the Sub-system Suppliers.	Only applicable to Interface testing. The Sub-system Supplier should provide this information in Stage 1 and/or Stage 3.
Verification Method	Identifies the method that is used to verify that the test passes. Drop down menu that lists out the sub-systems per the TPP.	The Sub-system Supplier should provide this information in Stage 1.
Test Location	Identifies where the test will be conducted.	The Sub-system Supplier should provide this information in Stage 1 and/or Stage 3.

Segment	Identifies the segment along the project alignment where the test will be conducted. Drop down menu that lists out the Segments per the TPP.	The Sub-system Supplier may select one or more Segments when logging a test procedure or report. The Sub-system Supplier or PLTC should provide this information in Stage 1 and/or Stage 3.
Workzone	Identifies the workstation along the alignment where the test will be conducted. Drop down menu that lists out the Workzones per the TPP.	The Sub-system Supplier may select one or more Workzones when logging a test procedure or report. The Sub-system Supplier or PLTC should provide this information in Stage 1 and/or Stage 3.
Stationing	Identifies the project stationing where the test will be conducted.	The Sub-system Supplier or PLTC should provide this information in Stage 1 and/or Stage 3.
Requirement ID	Identifies the TraceCloud ID for the requirements the line-item is closing out.	The Sub-system Supplier should provide this information in Stage 1. Requirements (hyperlink or FR #) shall be separated by comma.
Specifications Reference (Section)	Identifies the Specifications section calling for this test.	The Sub-system Supplier should provide this information in Stage 1.
Specifications Reference (Subsection)	Identifies the specific subsection of the Specification Section.	The Sub-system Supplier should provide this information in Stage 1.
System Safety and Security Certification Test	Identifies whether or not this test is safety related.	System Safety & Security will review the TPPs for agreement on this classification.

		The Sub-system Supplier or PLTC should provide this information in Stage 1 and/or Stage 3.
Interface Control Form	Identifies whether this test is an interface test, and if yes, what the IF-## is.	The Sub-system Supplier or PLTC should provide this information in Stage 1.
Predecessor Test ID	Identifies the tests that must be performed prior to this test.	The Sub-system Supplier should provide this information in Stage 1.
Predecessor Test ID (Sub-system Supplier)	Identifies the supplier's ID for the predecessor test.	The Sub-system Supplier should provide this information in Stage 1.
Test Scheduled Date	Identifies the date that the test is scheduled to be performed.	This must be in a mm/dd/yyyy format. The Sub-system Supplier should provide this information in Stage 1 and/or Stage 3.
Sub-system Supplier's Test Manager	Identifies the person responsible for the test performance.	This must be in a (First Last) name format. The Sub-system Supplier should provide this information in Stage 1 and/or Stage 3.
Contractor's Test Manager	Identifies PLTC's person responsible for the test.	PLTC should provide this information in Stage 1 and/or Stage 3. The contractor's test manager is subject to change based on the organizational chart.
Test Completion Date	Identifies the date the test is actually performed.	This must be in a mm/dd/yyyy format. The Sub-system Supplier should provide this information in Stage 3.
Test Result	Identifies the result of the test. Drop down menu that lists out the Test Result options. The options include:	The Sub-system Supplier can select only one option when logging a test report.

	Passed, Passed with Discrepancies, Failed.	The Sub-system Supplier should provide this information in Stage 3.
Test Status	Identifies the status of the test. Drop down menu that lists out the Test Status options. The options include: *Scheduled, Pending, Conducted, Complete, Retest, Void.*	The Sub-system Supplier can select only one option when logging a test report. The Sub-system Supplier should provide this information in Stage 3.
Test Procedure Revision Used	Identifies the revision that the test procedure was at when the test was performed.	The Sub-system Supplier should provide this information in Stage 3.
PLTC Review	Identifies whether a review of the logged test report has been performed by PLTC. Drop down menu that lists out the options: *Reviewed, Flagged, Rejected.* The default value is set to *Pending Test Result* for all Test Report line-items, and to *N/A* for everything else.	PLTC, typically the Contractor's Test Manager, may select one option when reviewing a test report. PLTC should provide this information in Stage 3.
System Safety and Security Review	Identifies whether a review of the logged test report has been performed by System Safety and Security (SSS). Drop down menu that lists out the options: *Reviewed, Flagged, Rejected.* The default value is set to *Pending Test Result* for all Test Report line-items, and to *N/A* for everything else.	This is only required for tests that have been flagged as safety-critical. Each SSS reviewer may select one option when reviewing a test report. SSS should provide this information in Stage 3.
MTA Review	Identifies whether a review of the logged test report has been performed by MTA Drop down menu lists out the options: *Reviewed, Flagged.* The default value is set to *Pending Test Result* for all Test Report line-items, and to *N/A* for everything else.	Each MTA reviewer may select one option when reviewing a test report. MTA should provide this information in Stage 3
Quality Review	Identifies whether a review of the logged test report has been performed by the Quality team. Drop down menu lists out the options: *Reviewed, Flagged.* The default	This is an optional review. Each Quality reviewer may select one option

	value is set to *Pending Test Result* for all Test Report line-items, and to *N/A* for everything else.	when reviewing a test report. Quality should provide this information in Stage 3.
Discrepancy Description	Provides a description of the discrepancy present, if a test report has been flagged as "Passed with Discrepancies" under the "Test Result" column.	The Sub-system Supplier should provide this information in Stage 3.
Discrepancy Resolution	Provides a description of the decisions and actions taken to resolve the discrepancy. Can include meeting minutes, emails, drawings and telephone conversations.	Mandatory if a test report has been flagged as "Passed with Discrepancies" under the "Test Result" column. The Sub-system Supplier should provide this information in Stage 3, after agreement with PLTC on path forward.
Contractor's Representative	Identifies the person responsible for resolving the discrepancy.	Mandatory if a test report has been flagged as "Passed with Discrepancies" under the "Test Result" column. PLTC should provide this information in Stage 3, after the discrepancy has been resolved.
Contractor Sign-Off	Contains a "Yes" if the discrepancy has been resolved and a "No" if the discrepancy has not been resolved.	Mandatory if a test report has been flagged as "Passed with Discrepancies" under the "Test Result" column. PLTC should provide this information in Stage 3, after the discrepancy has been resolved.
Date Closed	Identifies the date the discrepancy is closed.	Mandatory if a test report has been flagged

		as “Passed with Discrepancies” under the “Test Result” column. PLTC should provide this information in Stage 3, after the discrepancy has been resolved.

Table 7: Line-Item Attributes in the Test Tracking Tool

3.6.1. Test Tracking Tool Views

The TTT consists of different “views”, each displaying a certain set of columns to different users (MTA_Reviewer, Quality_Reviewer, PLTC_Reviewer, System Safety_Reviewer, Test_Performer and Tool_Maintainer).

The columns shown by each view, and the view users are provided in Table 8.

View Title	View User	Columns (Attributes) Included
Supplier View	Test_Performer (Subcontractor)	Indicator, ID, Name, Revision, Equip ID, Test Location, Test Scheduled Date, Test Completion Date, Test Result, Test Procedure Revision Used, PLTC, SSS, MTA, Quality Reviews.
PLTC View	PLTC_Reviewer, System Safety_Reviewer, Quality_Reviewer	Indicator, ID, Name, Revision, Equip ID, Test Location, Test Scheduled Date, Test Completion Date, Test Result, Test Procedure Revision Used, PLTC, SSS, MTA, Quality Reviews.
Owner View	MTA_Reviewer	Indicator, ID, Name, Revision, Equip ID, Test Location, Test Scheduled Date, Test Completion Date, Test Result, Test Procedure Revision Used, Owner Submittal ID, Submitted to Owner Date, Doc Accepted Date, MTA Review.
All Items View	Tool_Maintainer	All

Table 8: Test Tracking Tool Views and View Users

3.7. Implementation

The implementation of the TTT required working with three main software elements, each of which is described in the section below, along with images of their user interface.

3.7.1. SharePoint

As the host website for the TTT, PLTC opted to use Microsoft's SharePoint. Although primarily designed as a document management and storage system [19], SharePoint was chosen because of some major factors mentioned below:

- The ability to create large matrices that are to serve as the database for the test events.
- The ability it offers the administrator to easily review and manipulate data fields after uploading.
- The ability it offers to automate the document workflow, thus automating the process of document review and acceptance.
- The ability to bulk upload data using multiple methods.
- The ability to bulk export data as Excel spreadsheets.
- The seamless integration it offers with PowerBI, a powerful data analytics software offered by Microsoft. PowerBI was deemed necessary as the analytics engine owing to its ability to consolidate data from multiple datasets, and to create "Dashboards" for various stakeholders.

Although SharePoint is offered in different versions, SharePoint Online was chosen for the TTT as it allowed PLTC to simply upload the RVM data to the SharePoint website and share the website with all the stakeholders, while still

providing the core functionality of storing large amounts of data, automating document review flow, incorporating backend logic, and integrating with PowerBI etc.

The primary feature of SharePoint that forms the backbone of the TTT is the SharePoint List. A SharePoint List is a collection of data that gives the user an open-ended way to store and modify information. Lists function much like an Excel spreadsheet, allowing the user to add columns for different data types (drop-down menus, free text boxes, dates, and checkboxes), and sorting, formatting, or filtering lists as required. Lists permit the creation of "views" which help the user to tailor the columns a specific user category can see/edit. Lastly, Lists are also compatible with Microsoft Flows, which can help automate workflows and add backend logic. such as providing notifications, collecting data, and synchronizing files etc. using a predetermined trigger. [20]

In order to kickstart the project, Inspire Data Solutions, a Microsoft product vendor, was contracted to setup the initial SharePoint website and work on the more technically advanced features of the TTT such as programming backend logic in SharePoint and implementing complicated flows that are beyond the technical scope and knowledge of the author and other PLTC engineers.

Shown in Figure 21 is what the Homepage for the Test Tracking Tool looks like when a user accesses it using a web browser. The Homepage also serves as the point of display for the testing status Dashboard that is further discussed in Section 3.7.2. A zoomed-in view of the section boxed in red is shown in Figure 22, along with the options provided when the user clicks on the "Suppliers" drop down.

The “Suppliers,” “PLTC Reviewers,” and “MTA Reviewers” drop-downs contain icons linked to each Sub-system List that are tailored to show specific views (“PLTC View,” “Owner View,” and “Supplier View” as described in Table 8). Users from each category (Suppliers, PLTC, and MTA/Owner) click on the respective drop-down icons whenever they need to access a Sub-system List.

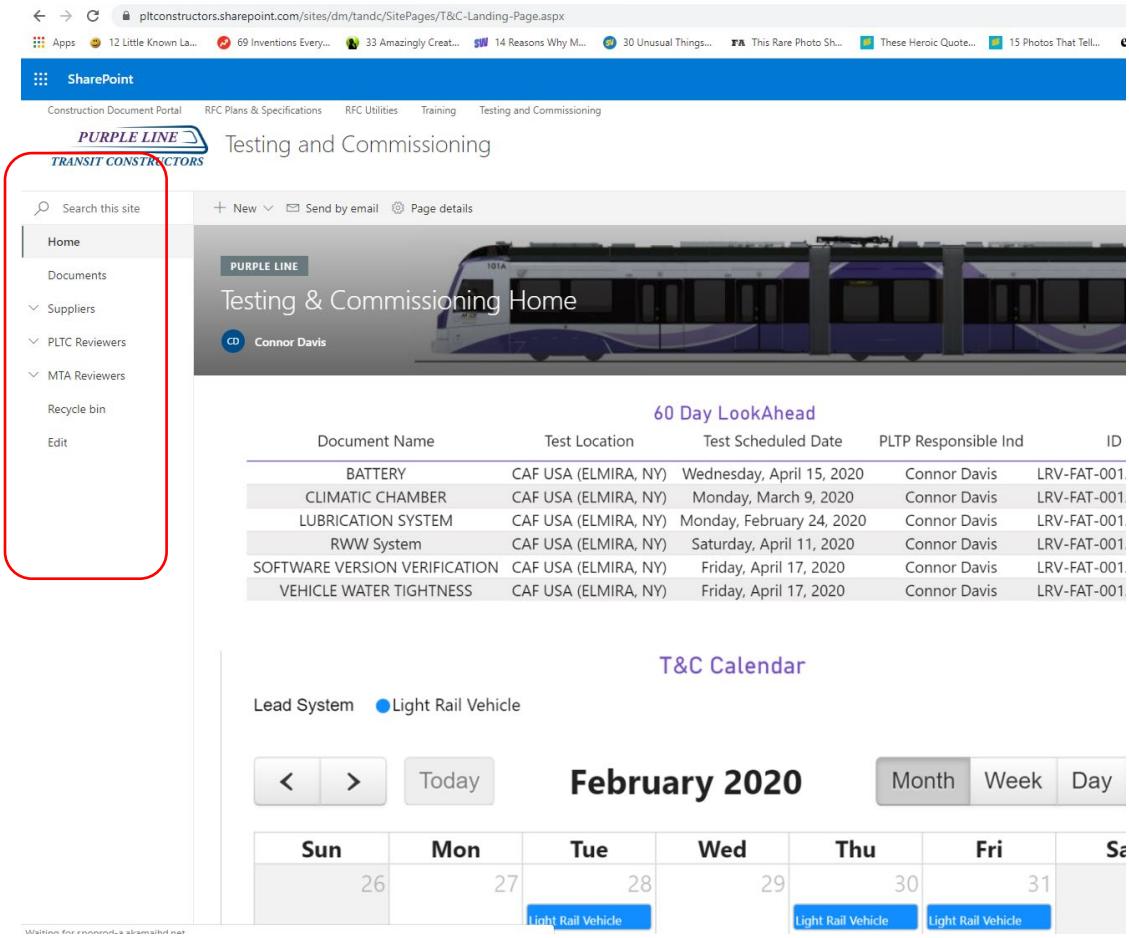


Figure 21: TTT Homepage

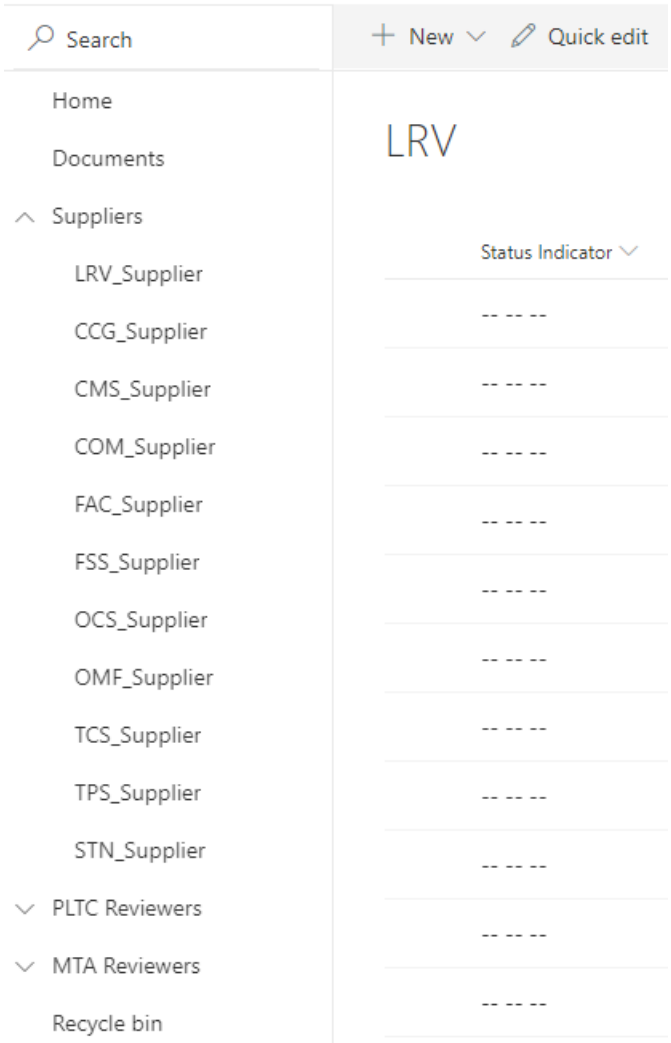


Figure 22: Zoomed-in View of the Homepage with "Suppliers" Expanded

Clicking on a particular sub-system icon in the navigation bar on the left side takes the user to that Sub-system List, showing the user a screen similar to the one shown in Figure 23. The Sub-system List contains all the columns that are described in the system requirements table (Table 6) and line-item attributes table (Table 7), and incorporates the functional requirements provided in the system requirements.

To create a new line-item, the user must click the "+ New" icon, shown in the top-right quadrant of Figure 23. In order to edit a single row / line-item in the List,

the user can either double click on it or, single click and then click “Edit” as shown in Figure 24. Performing either of these actions launches a form on the right side of the screen, as shown in Figure 25, where the user can scroll to the field required and add or edit information.

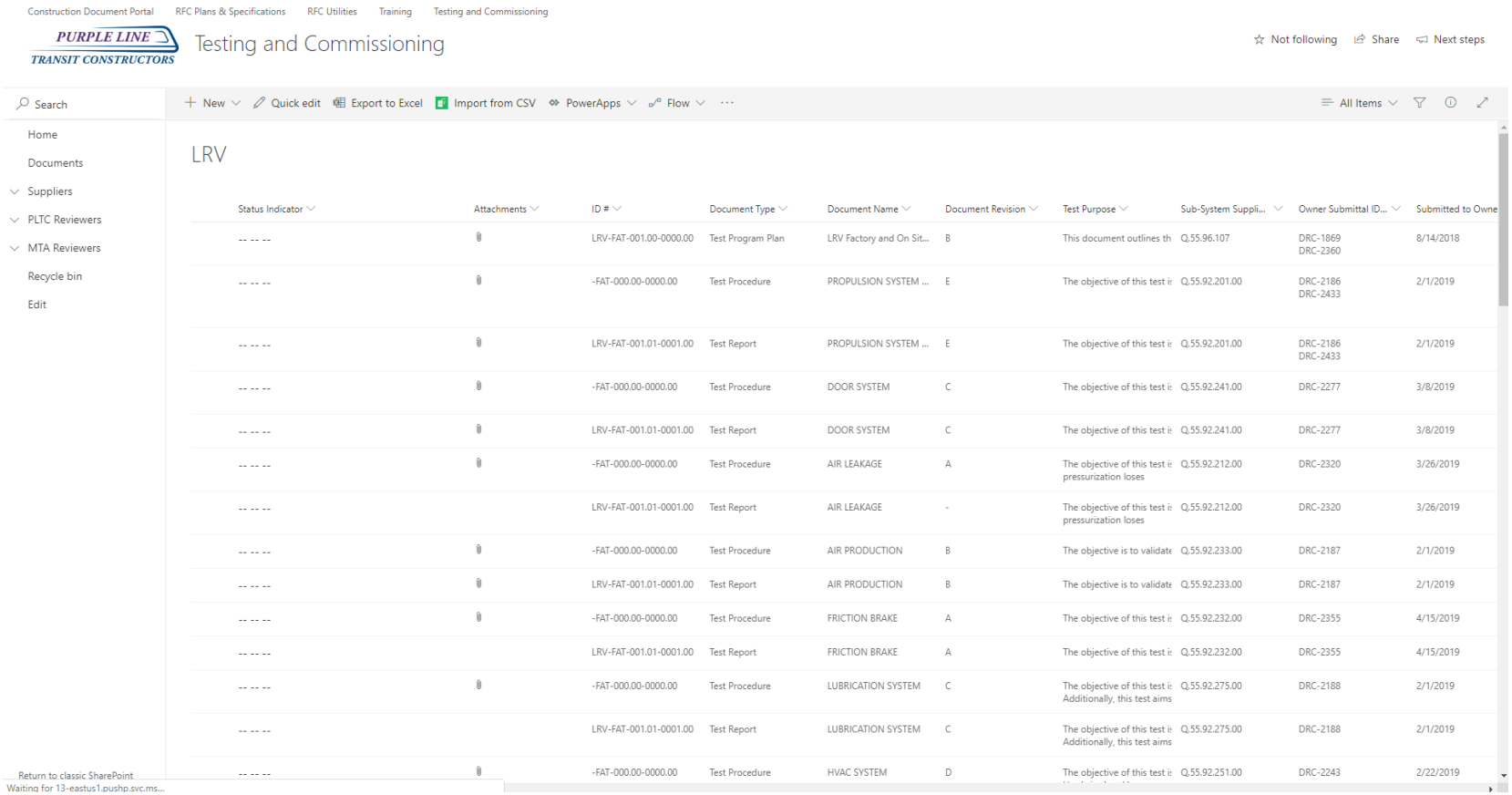


Figure 23: Tool Maintainer's Sub-System List View

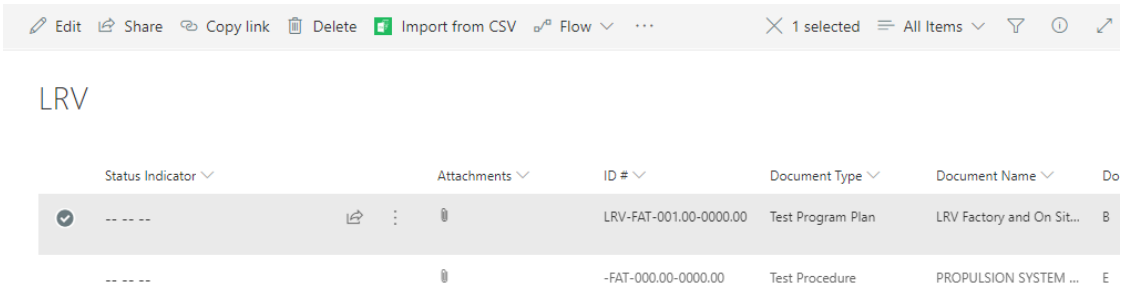


Figure 24: Selecting a Line-Item

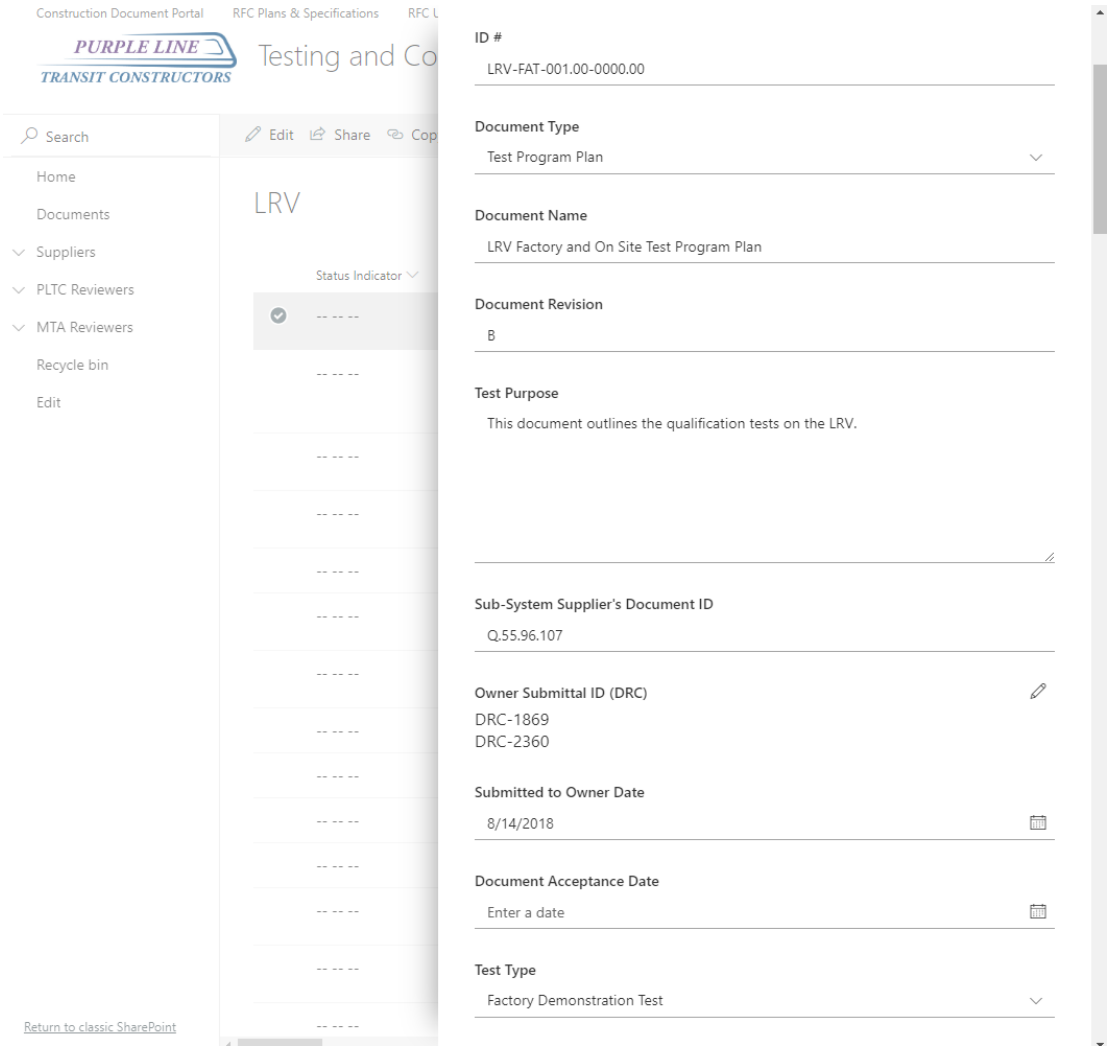


Figure 25: Line-Item Form

In case large amounts of data need to be added or edited to any Sub-system List, SharePoint offers a “Quick edit” option that the user can utilize. The user can click on the “Quick edit” icon shown in Figure 26 to enter the mode, and use it like an Excel spreadsheet to copy-paste bulk data or drag a value up or down the sheet. Figure 27 shows what the List looks like in the Quick Edit mode.

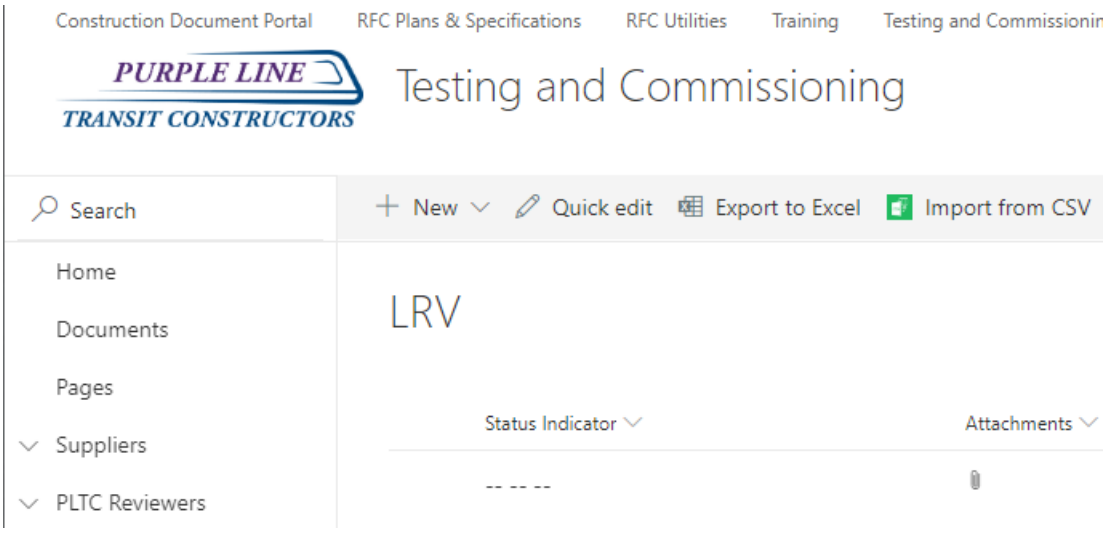
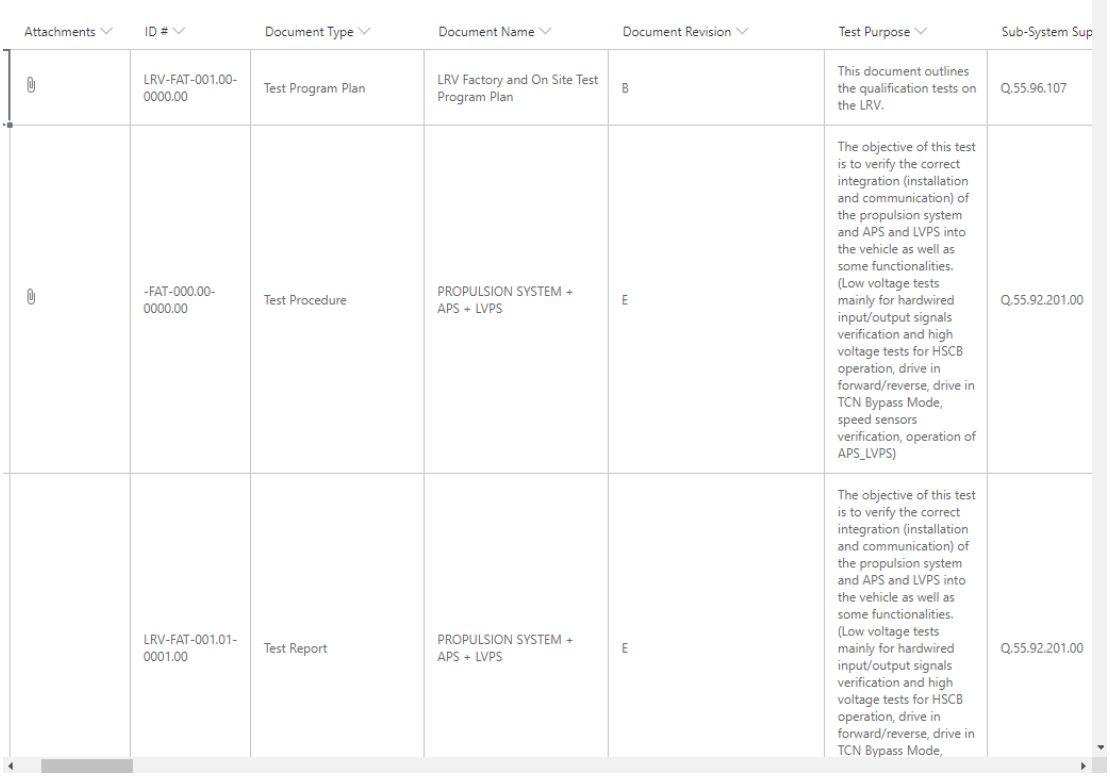


Figure 26: Entering Quick Edit



Attachments	ID #	Document Type	Document Name	Document Revision	Test Purpose	Sub-System Sup
	LRV-FAT-001.00-0000.00	Test Program Plan	LRV Factory and On Site Test Program Plan	B	This document outlines the qualification tests on the LRV.	Q.55.96.107
	-FAT-000.00-0000.00	Test Procedure	PROPULSION SYSTEM + APS + LVPS	E	The objective of this test is to verify the correct integration (installation and communication) of the propulsion system and APS and LVPS into the vehicle as well as some functionalities. (Low voltage tests mainly for hardwired input/output signals verification and high voltage tests for HSCB operation, drive in forward/reverse, drive in TCN Bypass Mode, speed sensors verification, operation of APS_LVPS)	Q.55.92.201.00
	LRV-FAT-001.01-0001.00	Test Report	PROPULSION SYSTEM + APS + LVPS	E	The objective of this test is to verify the correct integration (installation and communication) of the propulsion system and APS and LVPS into the vehicle as well as some functionalities. (Low voltage tests mainly for hardwired input/output signals verification and high voltage tests for HSCB operation, drive in forward/reverse, drive in TCN Bypass Mode,	Q.55.92.201.00

Figure 27: Quick Edit View

SharePoint offers the user the ability to upload multiple attachments to a line-item. In order to access attachments or upload attachments, the user can double-click on a line-item to enter the form view and scroll to the bottom of the form. Under the "Attachments" field, the user can click on the attached documents to view/download them, and an "Add attachments" icon to upload any documents, as shown in Figure 28.

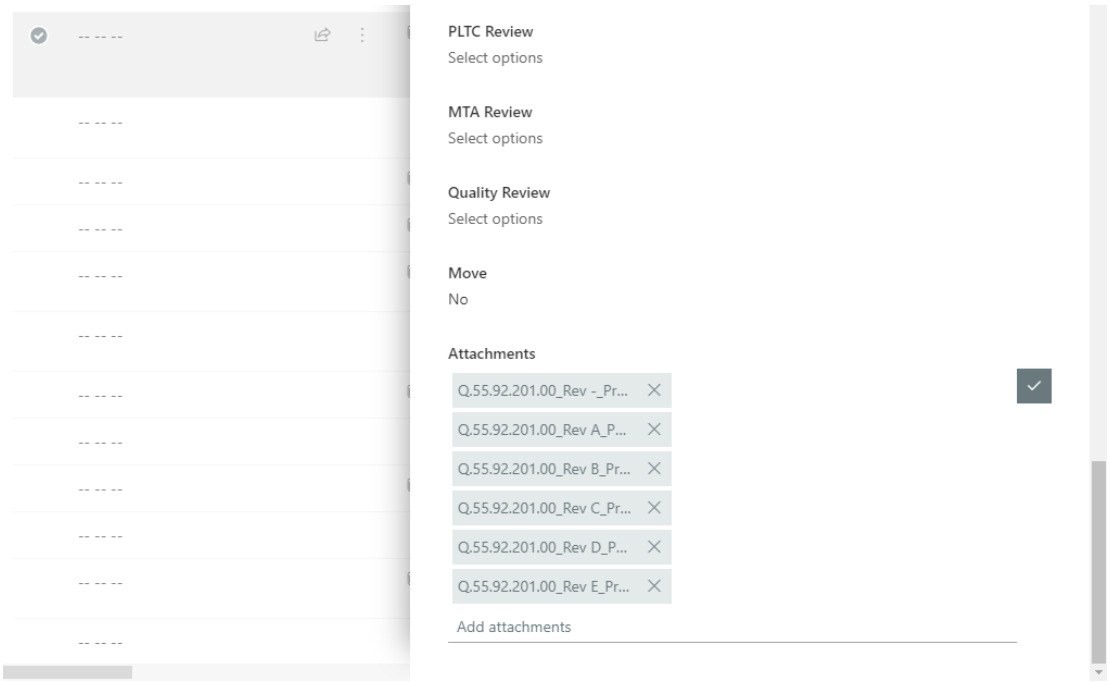


Figure 28: Adding Attachments

Fields that may be typed into (free text) can be sorted A – Z, Z – A, or filtered as needed depending on the data in the column. The user can click on the drop-down arrows located adjacent to the name of the fields, and filter the data as needed. Fields containing fixed options (drop-down menus) can be sorted as ascending, descending, grouped by, or filtered to show the line-items containing a certain value for that specific field. Similarly, fields containing dates can be sorted as older to newer, newer to older, filtered by, or grouped by [Column/Field Name], as desired. Figure 29, Figure 30, and Figure 31 show the three filtering variations mentioned.

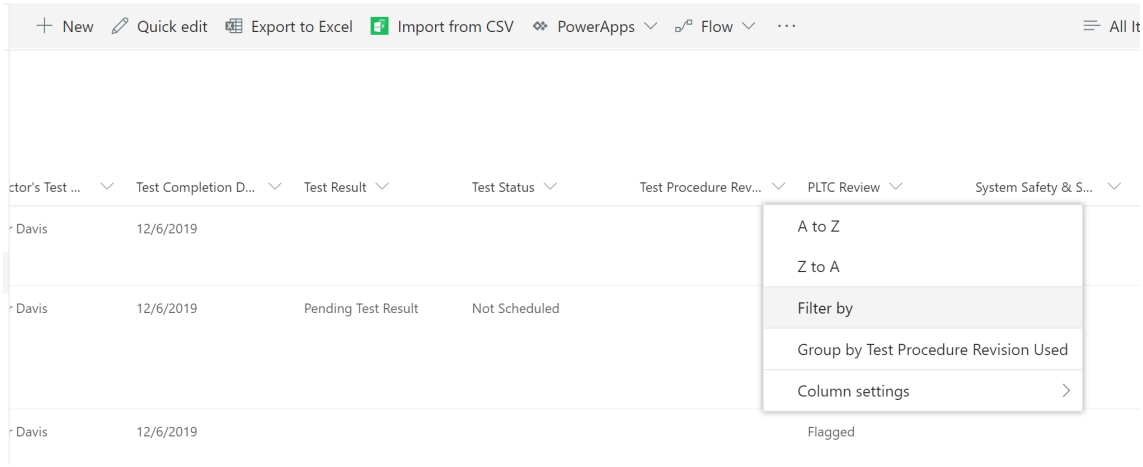


Figure 29: Filtering for Free Text Fields

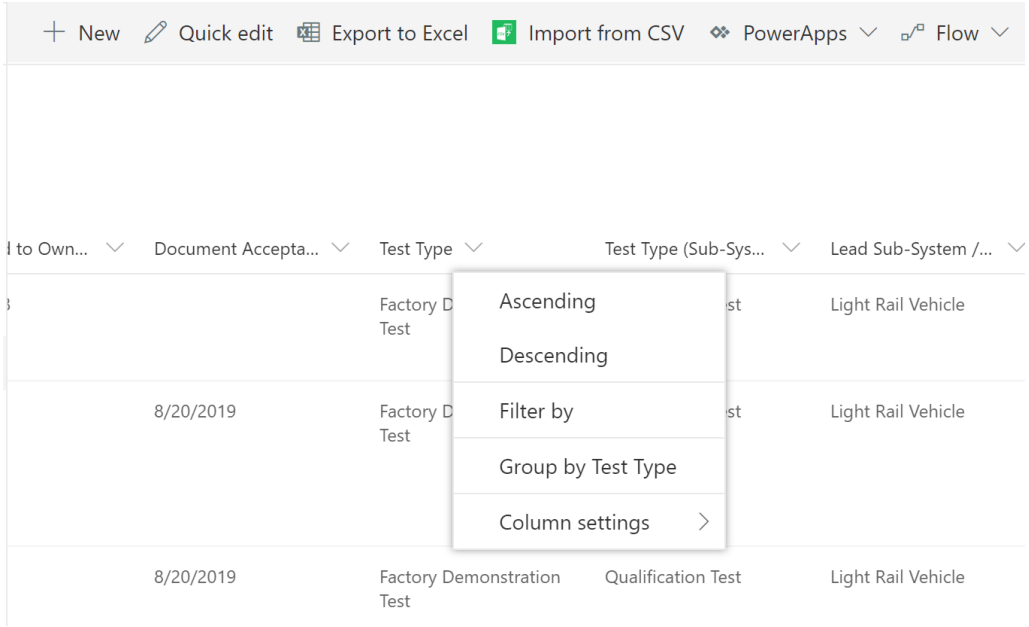


Figure 30: Filtering for Drop-down Fields

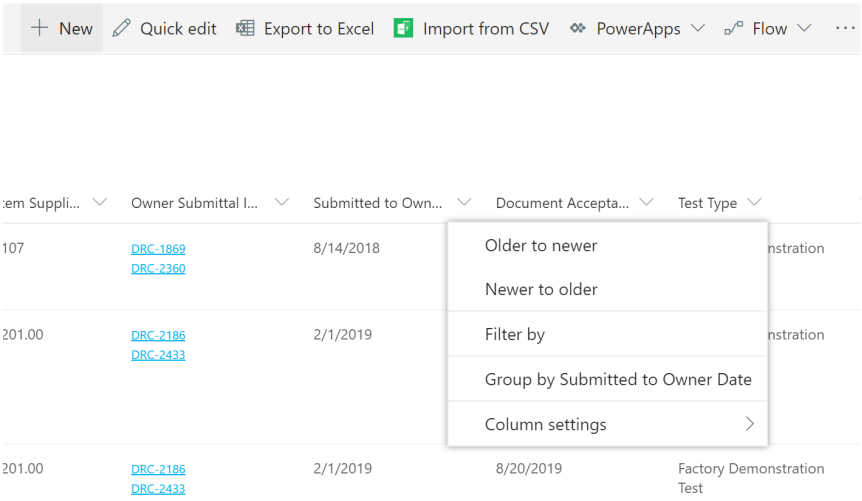


Figure 31: Filtering for Date Fields

3.7.1.1. Flows

Flows, also known as Power Automate, is a no-code software from Microsoft that is used for workflow and process automation [21] in other compatible software.

There are two workflows that are active on the TTT, with each performing a specific function. They are described in Table 9 below.

Flow ID	Flow Description	Trigger Condition
F1	Test Report Notification	When a line-item on a Sub-system List is modified
F2	Status Indicator	When a line-item on a Sub-system List if modified

Table 9: Workflows Implemented in the TTT

Figure 32 shows the logic implemented to execute F1. F1 is used to notify the PLTC reviewers, MTA reviewers and System Safety & Security reviewers about a test being conducted and a test report being logged. Figure 33 shows a partial view of the logic implementation for F1 in Microsoft Flows.

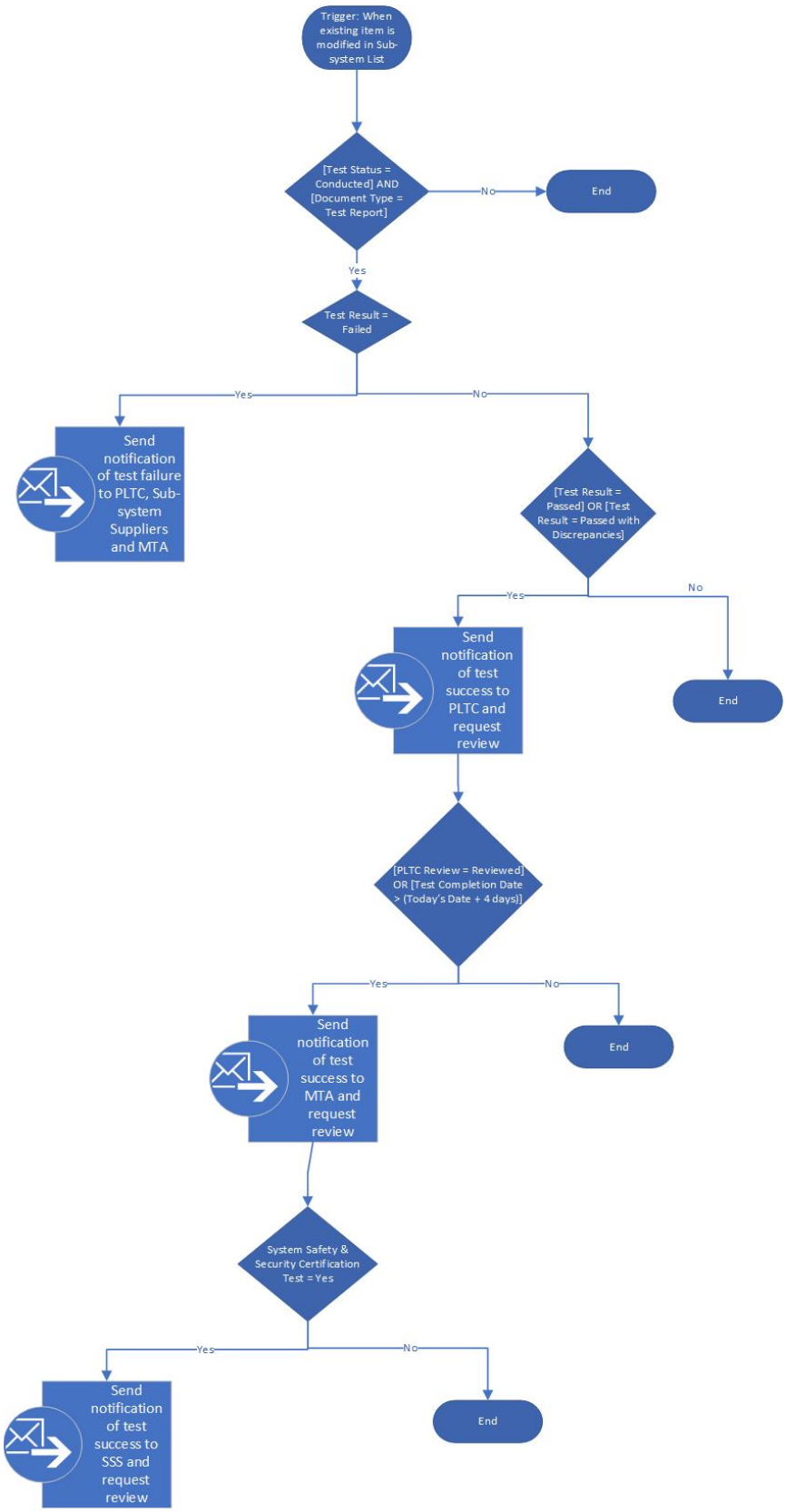


Figure 32: Test Report Notification Logic Flow

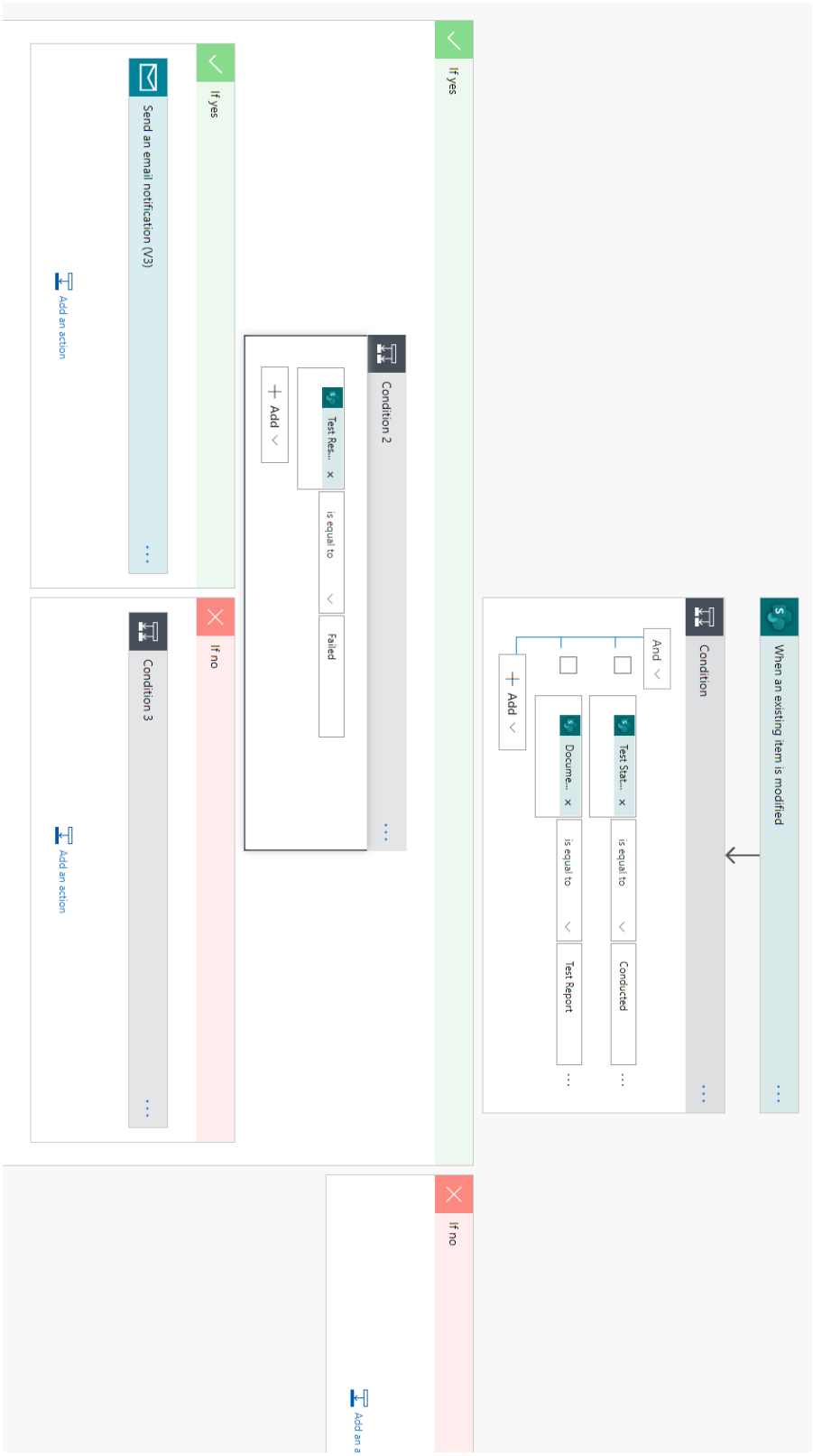


Figure 33: Implementation of F1 in Microsoft Flows

If the guard conditions for the decision branches are met, either a predetermined action takes place or control flows to another decision branch. For F1, if the first and second guard conditions are met, SharePoint sends an email to all the reviewers. Figure 34 shows the template that PLTC created for SharePoint to use to notify reviewers of a test being passed or failed. The green boxes ("Test Result Value", "ID#" etc.) are values that SharePoint extracts from the Sub-system List and the specific line-item for which the test has been logged. Figure 35 shows the email that reviewers receive for a test that has been logged as "Passed" or "Passed with Discrepancies" by the Sub-system Supplier.

The Status Indicator flow (F2) is used by SharePoint to populate the "Status Indicator" column for each Sub-system List. F2 extracts data from multiple columns in a Sub-system List ("PLTC Review", "System Safety & Security Review", "MTA Review", "Quality Review"), consolidates the data in a hidden column, and displays in the "Indicator" column a "FL" if a test has been flagged by any of the reviewers and a "RJ" is a test has been rejected by any of the reviewers. Inspire Data Solutions was tasked with the development of F2 because of its technically complex nature, and thus, is not discussed further in this thesis.

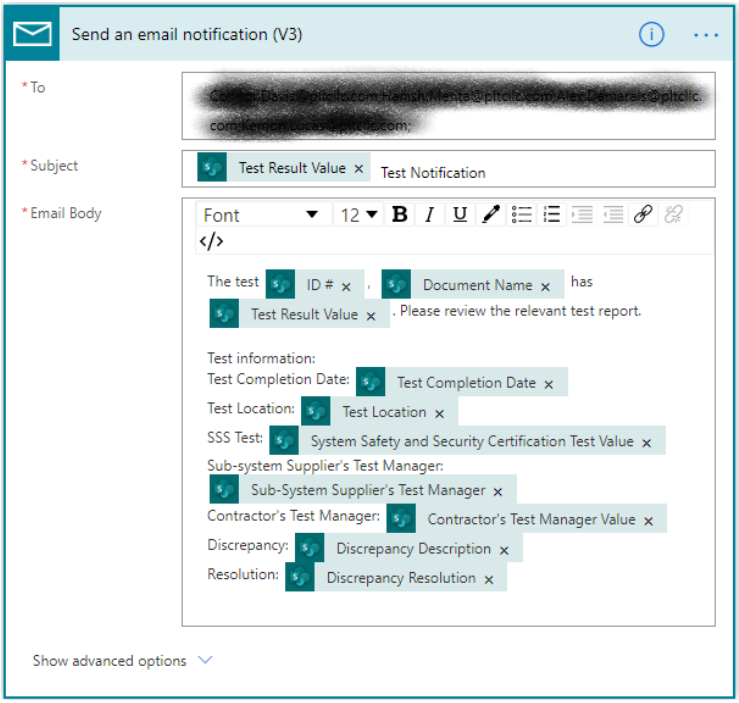


Figure 34: SharePoint Test Report Notification Template

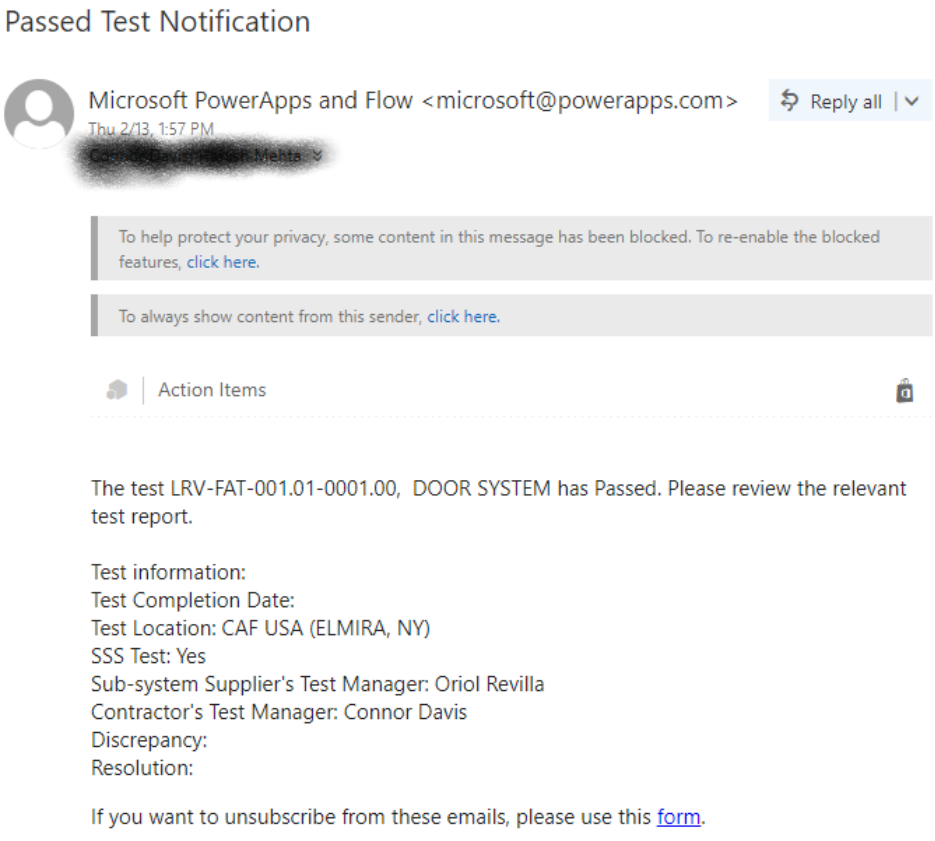


Figure 35: Typical Test Report Notification Received by Reviewers

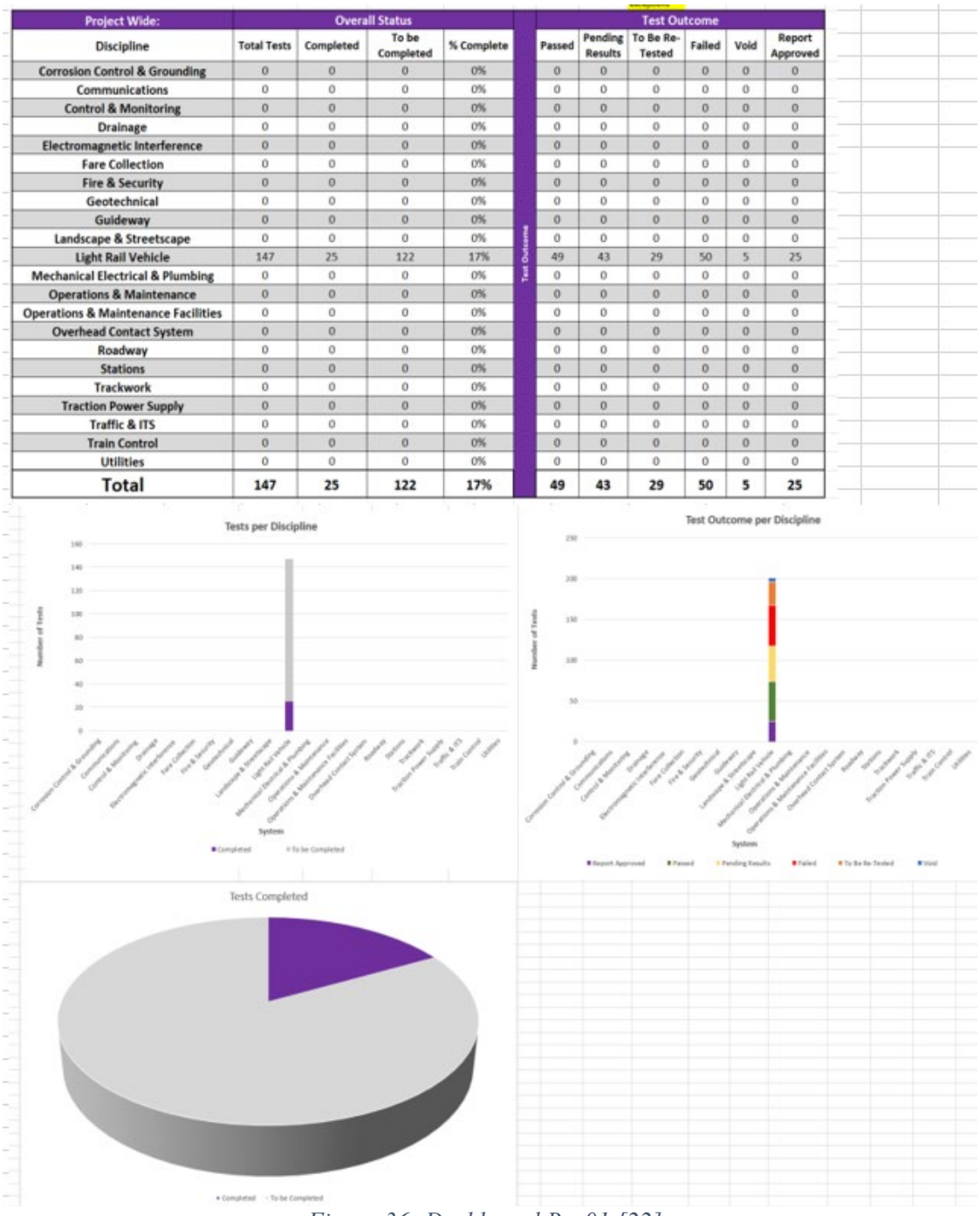
3.7.2. Reporting and Dashboards

Although not formally required by the Project Technical Provisions (TPs), the Systems Team at PLTC decided to create a centralized, system-level "Dashboard" that could be used to monitor the overall status of the project, and quickly show specific requested information at meetings with various entities.

3.7.2.1. Status Reporting Dashboard

A primary dashboard is used to report the status of testing on the Purple Line. The System-level Dashboard is a system-level status reporting dashboard that is created to help the MTA and PLTC monitor and witness the progress of testing on the entire Purple Line system. This dashboard will be a consolidated dashboard, using data from all the Sub-system Lists together.

Shown in Figure 36 is what the dashboard model looked like when it was first envisioned.



Project Wide:	Overall Status				Test Outcome					
Discipline	Total Tests	Completed	To be Completed	% Complete	Passed	Pending Results	To Be Re-Tested	Failed	Void	Report Approved
Corrosion Control & Grounding	0	0	0	0%	0	0	0	0	0	0
Communications	0	0	0	0%	0	0	0	0	0	0
Control & Monitoring	0	0	0	0%	0	0	0	0	0	0
Drainage	0	0	0	0%	0	0	0	0	0	0
Electromagnetic Interference	0	0	0	0%	0	0	0	0	0	0
Fare Collection	0	0	0	0%	0	0	0	0	0	0
Fire & Security	0	0	0	0%	0	0	0	0	0	0
Geotechnical	0	0	0	0%	0	0	0	0	0	0
Guideway	0	0	0	0%	0	0	0	0	0	0
Landscape & Streetscape	0	0	0	0%	0	0	0	0	0	0
Light Rail Vehicle	147	25	122	17%	49	43	29	50	5	25
Mechanical Electrical & Plumbing	0	0	0	0%	0	0	0	0	0	0
Operations & Maintenance	0	0	0	0%	0	0	0	0	0	0
Operations & Maintenance Facilities	0	0	0	0%	0	0	0	0	0	0
Overhead Contact System	0	0	0	0%	0	0	0	0	0	0
Roadway	0	0	0	0%	0	0	0	0	0	0
Stations	0	0	0	0%	0	0	0	0	0	0
Trackwork	0	0	0	0%	0	0	0	0	0	0
Traction Power Supply	0	0	0	0%	0	0	0	0	0	0
Traffic & ITS	0	0	0	0%	0	0	0	0	0	0
Train Control	0	0	0	0%	0	0	0	0	0	0
Utilities	0	0	0	0%	0	0	0	0	0	0
Total	**147**	**25**	**122**	**17%**	**49**	**43**	**29**	**50**	**5**	**25**

Figure 36: Dashboard Rev01 [22]

After further discussion within PLTC, a new, more user-friendly dashboard was designed as shown in Figure 37. The major reports that this version focused on are:

- 60 Day LookAhead: shows in a tabular form which tests are to be performed, and where over the next 60 days.

- Overall Project Status: shows in a graphical form how many tests have been scheduled, completed, are pending, are being retested, and/or are open with discrepancies.
- Calendar: shows on a calendar which sub-systems are being tested, on what date and where.

This Dashboard is generated using Microsoft PowerBI, which is further discussed in Section 3.7.2.2.

Figure 37: Dashboard Rev02

3.7.2.2. PowerBI

Owing to PLTC's decision to create a centralized T&C dashboard and graphic & tabular reports of various types, a database analytics software was needed that could be used to generate these reports. Since SharePoint is a Microsoft product, the consultant hired by PLTC suggested we look into PowerBI.

PowerBI is a business analytics tool offered by Microsoft. It provides cloud-based business intelligence service known as "PowerBI Services," along with a desktop software called "PowerBI Desktop." After some research on my part regarding PowerBI's ability and integration with SharePoint, a decision was made to move forward with PoweBI as the analytics engine for the TTT.

After downloading and installing PowerBI, the first step was to upload/link the SharePoint RVM data with PowerBI. Based on some initial discussions, PLTC narrowed down to two ways the data could be uploaded:

- Option 1: Downloading the SharePoint RVM/List as an Excel file, followed by importing the Excel file in PowerBI to access and utilize the data.
- Option 2: Connecting the SharePoint List to PowerBI directly through the "Online Services" option provided by PowerBI. An image of this capability is shown in Figure 38.

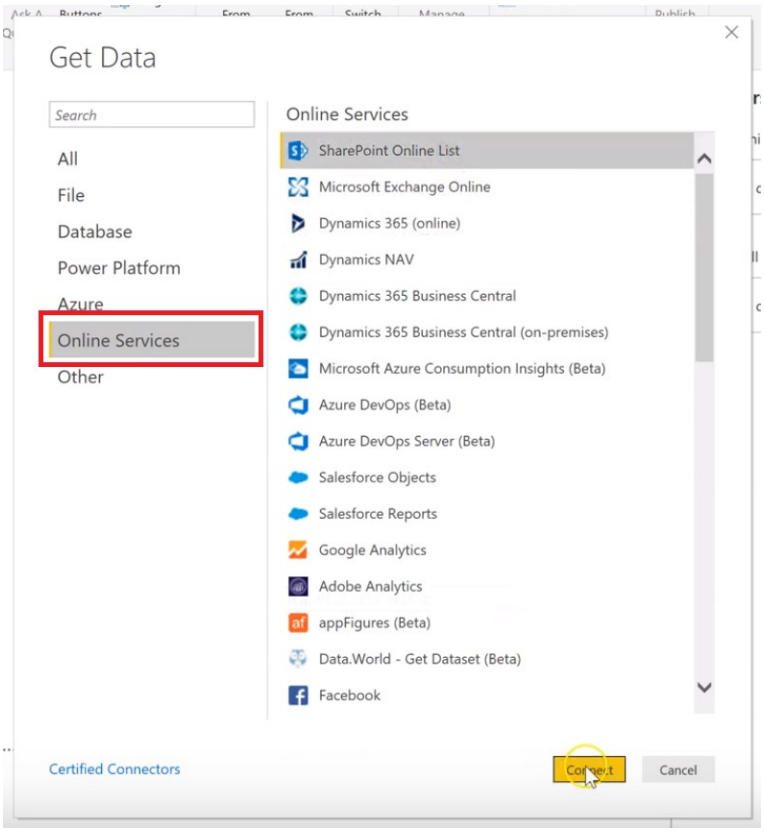


Figure 38: Linking SharePoint Lists with PowerBI [23]

After further research, Option 2 was chosen as the path forward. This option was chosen owing to the factors listed below:

- Since PowerBI is linked to the live SharePoint List/RVM, all the reports (discussed in Section 3.6.2) created update automatically.
- Since the reports generated are system-level, the information from all the SharePoint Lists needs to be consolidated in one database. Option 2 offers the user the ability to have PowerBI link with multiple SharePoint Lists and create a custom database extracting only the information needed from the various Lists. This custom database is then used to generate the reports desired.

Figure 39 shows what the PowerBI User Interface (UI) looks like. The report being worked on in the screenshot is the T&C LookAhead Calendar. The different

reports being created in the project are shown in different tabs at the bottom of the UI. The “VISUALIZATIONS” tab permits the user to add the data they need to visualize on the report, and other related formatting tools. The “Filters” tab allows the user to filter the data to be represented, as necessary. The filter feature works like the filter feature in Excel. The “FIELDS” tab allows the user to see what data is available from the database connected, and which data fields are being used in the report (by means of a checkmark). Other reports are created in a similar fashion.

All the reports generated in a project are “pinned” (linked) to a newly created Dashboard (one-time only), following which the Dashboard is exported as a PowerPoint Presentation and uploaded to the TTT Homepage. Based on internal discussions, it was deemed sufficient to download the Dashboard presentation and upload it to the TTT once every two weeks.

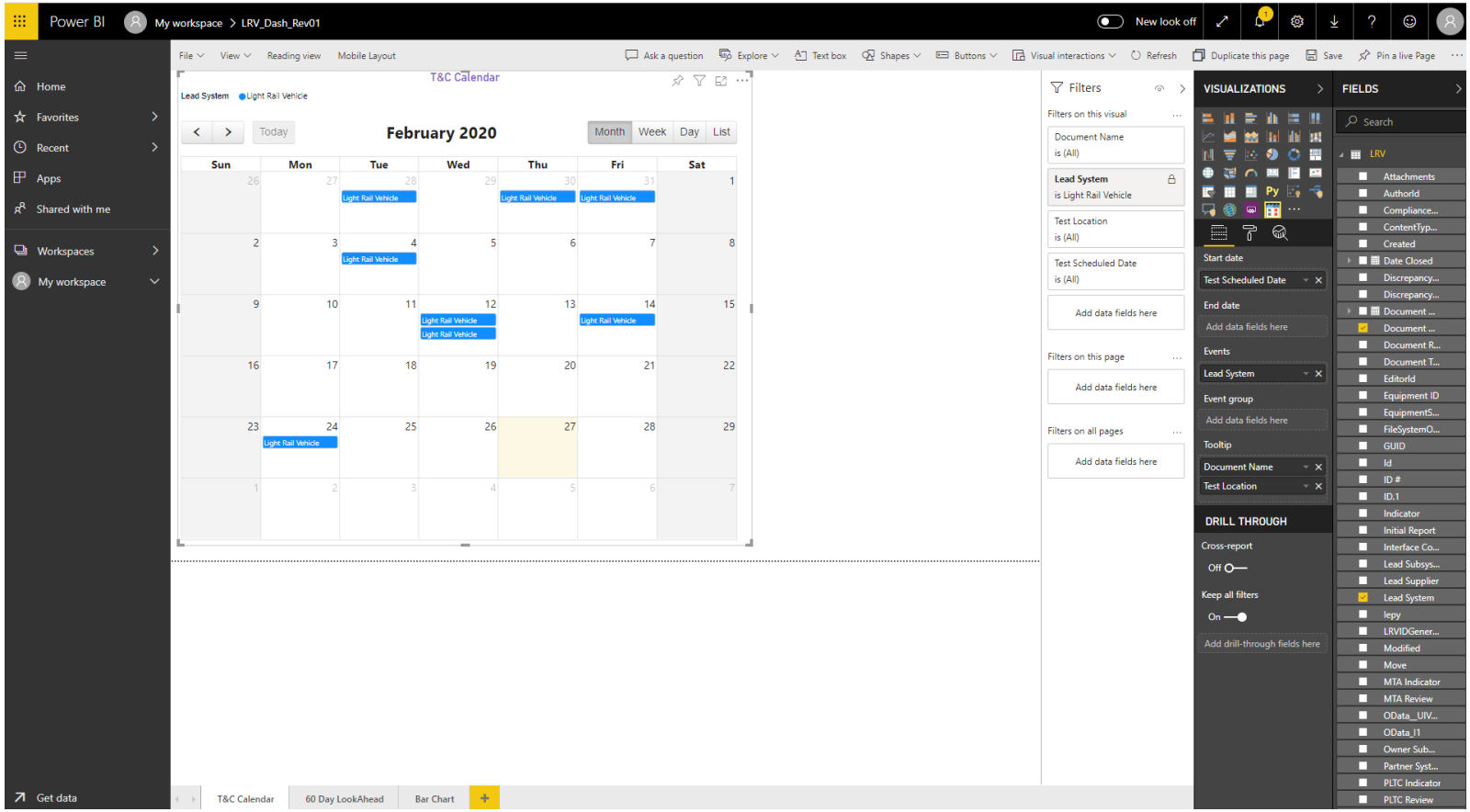


Figure 39: PowerBI User Interface

Chapter 4: TTT Verification and Validation

4.1. Test and Evaluation Approach

The testing approach adopted follows the V-lifecycle used in the development of the TTT. The first step is to test the Sub-system Lists to verify compliance with the system requirements, followed by the testing of the workflows and the testing of the Dashboard. After the initial verification is complete, the Sub-system Lists, Microsoft Flows, and the Dashboard (through PowerBI) will be integrated together to form the TTT "system". Once the integration is complete, the TTT will undergo a Black-box verification test to ensure that all the interfaces are working correctly.

A system acceptance test is planned to be performed in late-April 2020 to validate if the TTT meets the stakeholder requirements. In the case of the TTT, the system will be considered accepted or validated when the TTT is successfully utilized by the user(s) to log and review a test report. The results for the acceptance testing will not be known until after the defense of this thesis and therefore, will not be covered in this thesis.

4.1.1. Test Methodology

The following bullets describe the general test methodology that is used for testing the TTT.

1. Generate a Requirements Verification Matrix (RVM) identifying the columns listed below. The RVM is provided in Section 4.3.
    - System Requirement ID
    - Description

- System Element
- Verification Method
- Verification Event
- Verification Date
- Successfully tested?
- Verification Results
- Verification Status

2. Execute the test.
3. While executing the test:
    - Collect data in accordance with the test case tables, if available.
    - Identify record and report defects.
    - Correct any defects, if found, and retest.
    - Identify and note any defects that remain uncorrected.
4. After executing the test, populate the RVM columns for the requirement being verified by the test conducted.

4.1.2. Evaluation MOEs

The TTT will be evaluated with respect to the Measures of Effectiveness (MOEs) shown below in Table 10.

MOE	Definition	Criteria
System Completeness	The percentage of the TTT requirements that have been implemented and verified.	90%
System Usability	A score from 1 – 100 will be awarded by the PLTC Systems team during the system acceptance test.	95

Table 10: TTT V&V MOEs

4.1.3. Evaluation Approach

The evaluation approach adopted consists of the following [24]:

1. VE1: Element-level Black-box Verification testing of the Sub-system Lists, the Dashboard, and the workflows implemented using Microsoft Flows.
2. VE2: Black-box verification testing of the integrated TTT.
3. VAL: Acceptance testing of the integrated TTT.
    a. For the purpose of this thesis, the TTT is considered validated when it is successfully utilized to log and approve a test from each Sub-system List.

The sections below describe how each of the verification tests will be performed.

4.1.3.1. Black-Box Verification Test

Test ID: VE1
Test Name: Element-Level Black-Box Verification Test
Test Purpose: Verify that the elements of the TTT meet the System requirements.
Test Level: Element-level
Test Type: Black-box
Success Criteria:

1. All required inputs are accepted by the elements.
2. Backend logic/flows, if any, are executed successfully.
3. Required outputs (and actions) are accurate and formatted properly.

4.1.3.2. Integrated TTT Black-Box Verification Test

Test ID: VE2
Test Name: Integrated TTT Black-Box Verification Test
Test Purpose: Verify that the integrated TTT meets the System requirements.
Test Level: System-level
Test Type: Black-box
Success Criteria:

1. The primary user interface (Sub-system Lists) accepts the user input (including files).

2. Microsoft Flows successfully triggers and executes a workflow if the trigger conditions are met.
3. Microsoft PowerBI is able to generate a report for the Dashboard.
4. All required outputs (and actions) are accurate and formatted properly.

4.1.3.3. User Acceptance Test

Test ID: VAL1
Test Name: TTT Acceptance (Validation) Test
Test Purpose: Validate the high-level functionality of the TTT.
Test Level: System-level
Test Type: Black-box
Success Criteria:

1. Demonstrate that the TTT may be used to log a test result and upload the relevant test report.
2. Demonstrate that the test report and results submitted are automatically sent to appropriate reviewers for approval.
3. Show the testing status Dashboard to reflect the updated information.

4.2. Verification Strategy

This section describes the verification objectives and approach, the testing sequence used for verification and the requirements to be tested.

4.2.1. Verification Objectives and Approach

1. Test Objectives:
    - Verify that the TTT meets its system requirements.
    - Identify and document defects in the TTT.
2. Requirements to be verified:
    - All TTT system requirements given in Section 3.4 are to be verified.

      The Requirements Verification Matrix for the TTT is provided in Section 4.3.
3. Success criteria:

- The success criteria for the verification tests is that the requirement being verified is met 100% by the test.
- Interface requirements are considered verified if the user inputs are accepted and the output generated/action performed is as expected.
- Defects in the TTT are identified and documented.

4.2.2. Testing Sequence

The testing sequence used to verify the TTT (using the RVM) is as follows:

1. All requirements being verified with a VE1 event and method "Inspection" will be tested.
2. All requirements being verified with a VE1 event and method "Demonstration" will be tested.
3. All requirements being verified with a VE2 event and method "Inspection" will be tested.
4. All requirements being verified with a VE2 event and method "Demonstration" will be tested. This category of requirements (VE2 + Demonstration) all utilize Microsoft Flows, and thus need to be tested using certain test cases. These test cases are provided in Section 4.3.1.

4.3. Requirements To Be Tested

Two primary methods are used to perform system verification. They are:

1. Inspection: This technique is based on visual or dimensional examination of an element, and the verification relies on the human senses or uses simple

methods of measurement and handling. This method doesn't require the tester to stimulate the system in any way and is used mainly to check characteristics best determined by observation [25].

2. Demonstration: This technique is used to demonstrate correct operation of the submitted element against operational and observable characteristics without using quantitative measurements. This technique is also referred to as "field testing." It consists of the tester performing a set of tests for a predetermined factors (inputs) and observing the system's response to compare against an expected response [25].

Owing to space constraints, the Requirements Verification Matrix (RVM) used for the Verification of the TTT is provided in Appendix B.

4.3.1. VE2 Demonstration Test Case Table

This section provides the test cases that have been identified for performance on the respective TTT elements. The expected outcome for each of these test cases is known and has been entered into the Test Case Results Table for each TTT element. Table 11 shows the Test Case Table that is used for VE2.

Test Case		Test Case Factors						Expected Action	Observed Action	Verified
	Document Attached?	Document Revision	Test Procedure Revision Used	PLTC Review	System Safety Review	MTA Review	Quality Review			
TC1		C	A					"REV" displayed	"REV" not displayed	No
TC2				Flagged				"FL" displayed	"FL" displayed	Yes
TC3					Flagged			"FL" displayed	"FL" displayed	Yes
TC4						Flagged		"FL" displayed	"FL" displayed	Yes
TC5							Flagged	"FL" displayed	"FL" displayed	Yes
TC6				Rejected				"RJ" displayed	"RJ" displayed	Yes
TC7					Rejected			"RJ" displayed	"RJ" displayed	Yes
TC8				Flagged	Flagged			"FL" displayed	"FL" displayed	Yes
TC9				Flagged	Rejected			"FL-RJ" displayed	"FL-RJ" displayed	Yes
TC10				Flagged		Flagged		"FL" displayed	"FL" displayed	Yes
TC11				Flagged			Flagged	"FL" displayed	"FL" displayed	Yes
TC12				Rejected	Flagged			"FL-RJ" displayed	"FL-RJ" displayed	Yes
TC13					Flagged	Flagged		"FL" displayed	"FL" displayed	Yes
TC14					Flagged		Flagged	"FL" displayed	"FL" displayed	Yes
TC15				Flagged	Flagged	Flagged	Flagged	"FL" displayed	"FL" displayed	Yes
TC16				Rejected	Rejected	Flagged	Flagged	"FL-RJ" displayed	"FL-RJ" displayed	Yes
TC17	Yes							Flow F1 executed	Flow F1 executed	Yes

Table 11: VE2 Test Cases

4.4. Verification Results

Table 12 provides the results of the Verification process and compares them against the criteria listed in Table 10 (TTT V&V MOEs). Table 11 provides the observed values for all the Verification events. Detailed information about which requirements have passed or failed is provided in the Appendix B (RVM).

During the Verification process, approximately two hundred tests were performed out of which three were considered failures, thus establishing the System Completeness at 98% (rounded-off). The system is considered successfully Verified because it surpasses its requirement of 90%.

MOE	Definition	Criteria	Observed
System Completeness	The percentage of the TTT requirements that have been implemented and verified.	90%	98%
System Usability	A score from 1 – 100 will be awarded by the PLTC team during the system acceptance test.	95	NA (To be performed)

Table 12: Verification Results

Chapter 5: Conclusion

5.1 Summary

This thesis walked the reader through the entire development cycle of the Purple Line Test Tracking Tool, from the stakeholder requirements process to the Verification & Validation process. We started off by filtering the Purple Line Technical Provisions (TP) documents to identify a set of stakeholder requirements and developed a set of system requirements from them. Once the system requirements were created, a partial Requirements Verification Matrix (RVM) and Requirements Allocation Matrix (RAM) were created. The functional mock-up (Proof-of-Concept) spreadsheet created by PLTC was modified to meet the system requirements. A system architecture was created using SysML, and was updated regularly to reflect the project's actual structure. In collaboration with Inspire Data Solutions, PLTC's subcontractor, the TTT was implemented in SharePoint along with the PowerBI and Microsoft Flows functionality. The TTT was then put through a Verification & Validation process where each system requirement was closed out (tested) by a test, and the results for these tests were logged in the RVM.

5.2 Lessons Learned

After going through the project, I learned some important lessons. Implementing a standardized process such as ISO/IEC/IEEE 15288 in an industry setting proved challenging because the process had not been followed from the start of the TTT project. Meetings were not held by PLTC during the development phase of the TTT, but should have been in order to clarify the initial stakeholder requirements. System requirements developed should have been verified by the stakeholders before

proceeding with system developments; this would have ensured clarity in expectations of the TTT.

The TTT should have been treated as a project in itself from the very start, and not simply as a tool. A more thorough SE approach should have been adopted in the initial stages of the project, and this would have saved valuable development time, thus reducing the development costs. Although an essential requirements management tool, Requirements Trace Matrices (RTM) were not considered value-add in the project because a number of system requirements created by PLTC were not created from stakeholder requirements.

The biggest lesson I learned was that ISO/IEC/IEEE 15288 and the Vee Model aren't the same. 15288 provides a set of processes from which only the Technical Processes are used in the Vee Model. The Vee Model on the other hand provides a sequential flow for the 15288 technical processes, while emphasizing the need for a testing/verification plan to be developed in parallel with the requirements and development stages.

15288 also prescribes the generic lifecycle model that should be adopted for a project, and the technical processes that should be used for them. This thesis focused on the application of the 15288 Technical Processes specifically to the Concept, Development, and the Production stages of the lifecycle model. Since the project was already in the Architecture Definition process when I joined, counter-intuitively, I first had to work my way up the left-hand side of the Vee model (instead of going down the Vee) to Stakeholder Needs & Requirements Definition and then go down again towards System Requirement Definition, Architecture Definition, Design Definition etc. correcting/modifying the work that was already performed. Owing to manpower and

time constraints, the Implementation process further relied on the use of a "Spiral" approach, where the TTT was created incrementally, incorporating one feature after another. This approach was used because it allowed a single engineer working 10 hrs/week to build the tool one function at a time, which over a span of seven months, culminated in a fully-functional system that met nearly all system requirements.

5.3 Future Work

The work to be performed in the immediate future includes the Validation testing of the TTT, which was not feasible to perform given the submission deadline for this thesis. The TTT's Validation test is expected to be performed late-April 2020. Extensions will also be added to the system-level Use Case Narratives after additional stakeholder elicitation in the coming months.

The work to be performed in the following months includes the uploading of RVM data to the TTT for the various Sub-systems. This can and will only be done once the Sub-system RVM Excel files are received from the Sub-system Suppliers and verified by the PLTC Systems team. Once all the Sub-system RVMs are uploaded to the TTT, the Flows (F1 and F2) will be activated for each Sub-system List. Once all flows are activated, instructions will be sent to the Sub-system Suppliers, and Reviewers who will then start using the TTT officially.

Appendix A: Requirements Allocation Matrix (RAM)

Figure 40 shows an excerpt from the TTT RAM. The full RAM can be accessed using this link: http://bit.ly/33GLgNb

System Req. Title/ID	Description	Sub-system Lists	Microsoft Flows	Dashboard	Chk Sum
System Column Requirements					
1.1	The TTT shall contain a column titled "Indicator/I1".	1			1
1.1.2	If the test report on a line item is both, rejected and flagged, the Indicator/I1 column shall display "FL-RJ"	1	1		2
1.1.3	If the [test report on a line item is rejected and flagged] and [the letter in the Document Revision column is greater than the letter in the Test Procedure Revision Used column], the Indicator/I1 column shall display "REV-FL-RJ"	1	1		2
1.2	The TTT shall contain a column titled "Attachments".	1			1
1.2.1	The Attachments column shall allow each user to upload multiple attachment in any format.	1			1
1.2.2	If the Attachments column contains an attachment, the Attachments column shall display a paper clip icon.	1			1
1.3	The TTT shall contain a column titled "ID #".	1			1
1.3.2	The ID# column shall be editable by PLTC and the sub-systems supplier.	1			1
1.3.3	The ID# column shall be a free text box that the user can type into.	1			1
1.4	The TTT shall contain a column titled "Document Type".	1			1
1.4.2	The Document Type column shall be editable by PLTC and the sub-system supplier.	1			1
1.4.3	The Document Type column shall be a drop down menu featuring the following options: Test Program Plan, Test Procedure, Test Report.	1			1
1.4.4	The Document Type column shall only hold one value from the options listed under it.	1			1

Figure 40: TTT Requirements Allocation Matrix

Appendix B: Requirements Verification Matrix (RVM)

Figure 41 shows an excerpt from the TTT RVM. The full RVM can be accessed using this link: http://bit.ly/2Qru8oT

System Req. ID	Description	System Element	Verification Method	Verification Event	Verification Date	Successfully Tested?	Verification Results	Verification Status
System Column Requirements								
1.1	The TTT shall contain a column titled "Indicator/I".	Sub-system Lists	Inspection	VE1	2/20/2020	Y	Passed	Completed
1.1.2	The Indicator/I column shall display "REV" if the letter in the Document Revision column is greater than the letter in the Test Procedure Revision Used column.	Sub-system Lists, Microsoft Flows	Demonstration	VE1, VE2	3/20/2020	Y	Failed	Completed
1.1.3	If the test report on a line item is flagged during a review, the Indicator/I column shall display "FL.".	Sub-system Lists, Microsoft Flows	Demonstration	VE1, VE2	3/20/2020	Y	Passed	Completed
1.1.4	If the test report on a line item is rejected during a review, the Indicator/I column shall display "RJ.".	Sub-system Lists, Microsoft Flows	Demonstration	VE1, VE2	3/20/2020	Y	Passed	Completed
1.1.2	If the test report on a line item is both, rejected and flagged, the Indicator/I column shall display "FL-RJ"	Sub-system Lists, Microsoft Flows	Demonstration	VE1, VE2	3/20/2020	Y	Passed	Completed
1.1.3	If the [test report on a line item is rejected and flagged] and [the letter in the Document Revision column is greater than the letter in the Test Procedure Revision Used column], the Indicator/I column shall display "REV-FL-RJ"	Sub-system Lists, Microsoft Flows	Demonstration	VE1, VE2	3/20/2020	Y	Failed	Completed
1.2	The TTT shall contain a column titled "Attachments".	Sub-system Lists	Inspection	VE1	2/20/2020	Y	Passed	Completed
1.2.2	If the Attachments column contains an attachment, the Attachments column shall display a paper clip icon.	Sub-system Lists	Demonstration	VE1	2/20/2020	Y	Passed	Completed

Figure 41: TTT Requirements Trace Matrix

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