Maintenance Aware Design Environment Training Course

Fundamentals & Application

For MADe 3.8.2

PHM Technology

Introduction: MADe Training

Prerequisites

Computer

- ✓Does it meet recommended requirements?

MADe installation & license

- ✓Does everyone have a license?
- ✓Is the license floating network or node-locked?

Training PowerPoint

- ✓Basis for presentation

Additional Material

- ✓Guides & Workflows in MADe Help
- ✓Tutorials available online

Minimum System Requirements
Windows® XP Service Pack 2
AMD Athlon II X2 or Intel Core i3. 2.8 GHz or better
4 GB RAM
30 GB available HDD space
1366x768 HD screen resolution or better
Java 8 SE

Introduction: MADe Training

Meet & Greet

- What is your name?
- What is your current position & responsibilities?
- How do you see the MADe software being used in your organization?

Introduction: MADe Training

COURSE OUTLINE

Introduction: MADe Training

Session 1: MADe Modeling

Session 2: Failure Simulation

Session 3: Safety Analyses

Session 4: Reliability Analyses

Session 5: Maintainability Analyses

Session 6: PHM Analyses

Conclusion: Using MADe

Introduction: MADe Training

DISCUSSION – WHAT IS MADE?

- MADe is a modeling tool that allows users to generate a variety of analyses across different engineering domains
- The main objective in MADe is to create a suitable model of a platform/system that contains enough detail to achieve the analyses/outputs the user requires
- MADe currently has four modules:
    - Modeling: System and Mission Modeling
    - SRA: Safety and Risk Assessment
    - RAM: Reliability, Availability and Maintainability
    - PHM: Prognostics and Health Management

Introduction: MADe Training

Discussion – MADe Modules

What can be done in each module?

- Modeling: System and Mission Modeling
  - Functional Hazard Assessment, Functional system modeling, Mission Profile Definition, Dependency mapping
- SRA: Safety and Risk Assessment
  - Failure Mode Effects Analysis (FMEA), Common Mode Analysis (CMA), Critical Item Analysis, Fault Trees
- RAM: Reliability, Availability and Maintainability
  - Reliability Block Diagrams (RBD), Reliability Allocation, Reliability Centred Maintenance, Maintenance Cost Estimates, Markov Analysis, Failure Rate Prediction
- PHM: Prognostics and Health Management
  - Sensor set design, Diagnostic rule generation, Sensor Set trade study

Session 1: MADe Modeling

Modeling of Mission Profile and System Architecture

Session 1: MADe Modeling

Session 1 Outline

1.1: Navigation

1.2: Project Creation

1.3: Mission Profile Definition (Solution-independent)

1.4: Functional Modeling (Functional Hazards Assessment)

1.5: System Modeling (Logical & Physical)

1.6: System Modeling (Functions)

1.7: MADe Library

Session 1: MADe Modeling

<u>SESSION 1 DISCUSSION</u>

Session 1 will take place in the MADe module

Session 1 is focussed on building a functional mode

Session 1.1: Navigation

Session 1.1 Outline

1.1.1: Launching MADe

1.1.2: MADe Workbench Layout

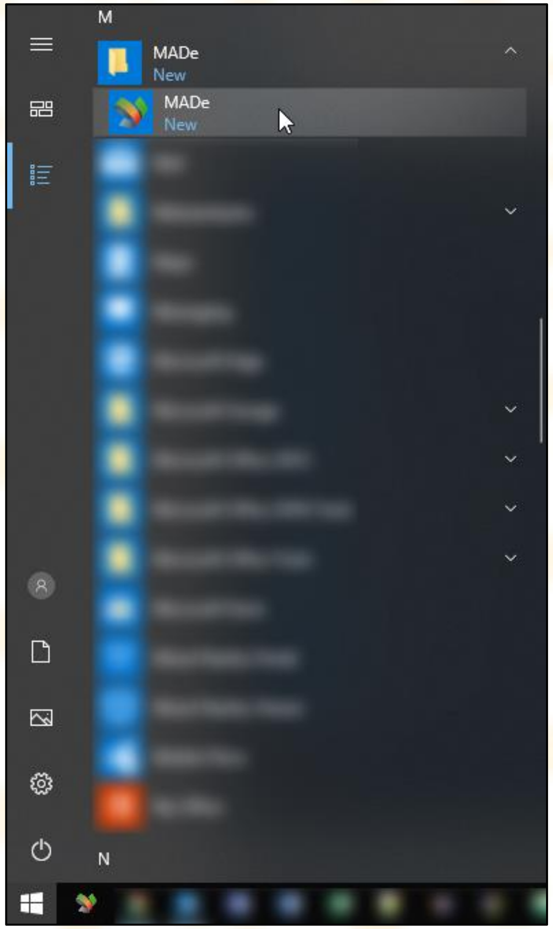
1.1.3: Default Viewers

1.1.4: MADe Modules

Session 1.1: Navigation

Exercise 1.1.1 Launching MADe

- Method 1:
  - Select **Windows Start**
  - Select **All Programs/Apps**
  - Select the **MADe folder**
  - Select **MADe**
- Method 2:
  - Double-click an existing MADe project file

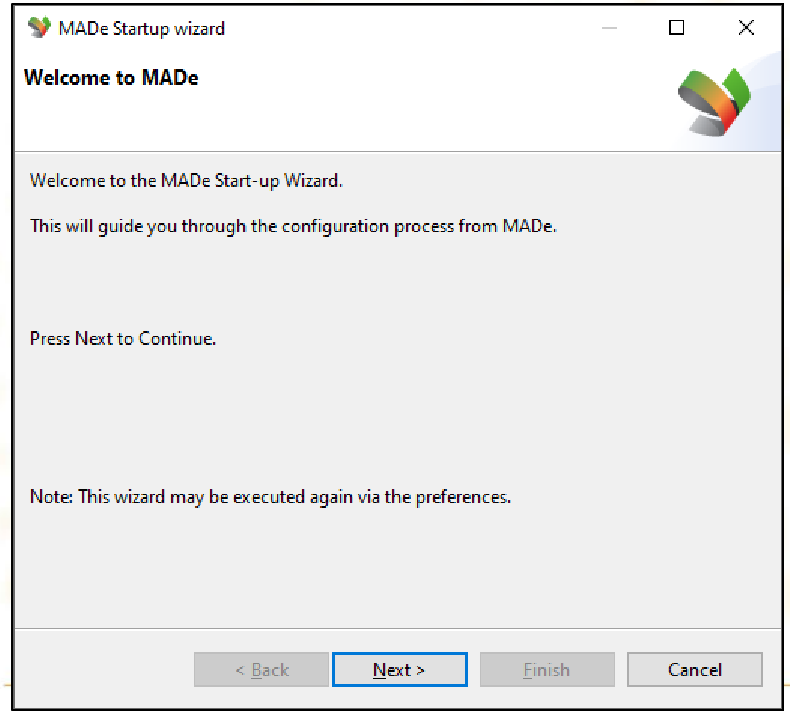


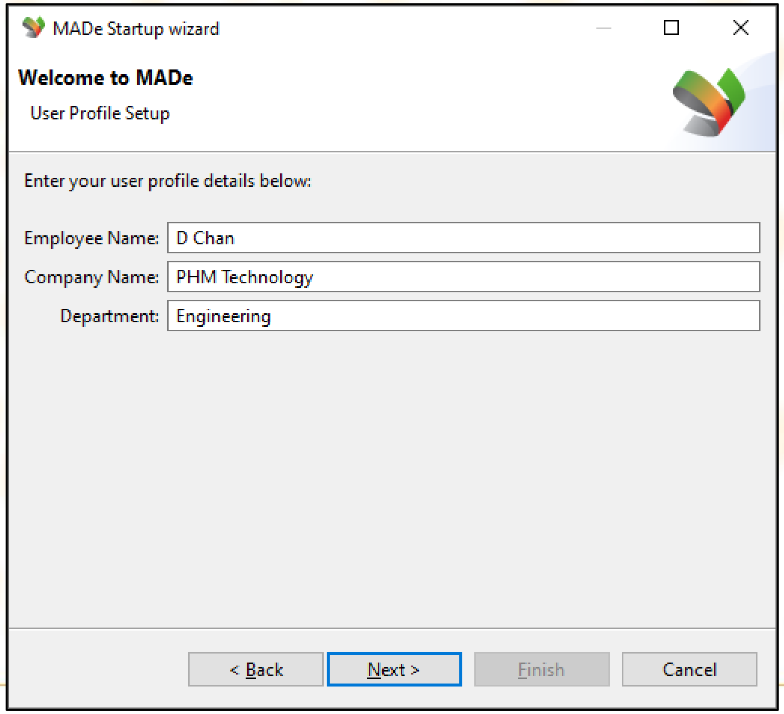
❖ Note: Create a desktop shortcut, or pin MADe to the taskbar/start menu for easy access

Session 1.1: Navigation

<u>EXERCISE 1.1.1 LAUNCHING MADE</u>

- When first launching MADe you will encounter a window to set up user preferences
- Select Next > to proceed to the next screen where we will input User details
- Enter your **Name**, **Company** and **Department** in their respective fields

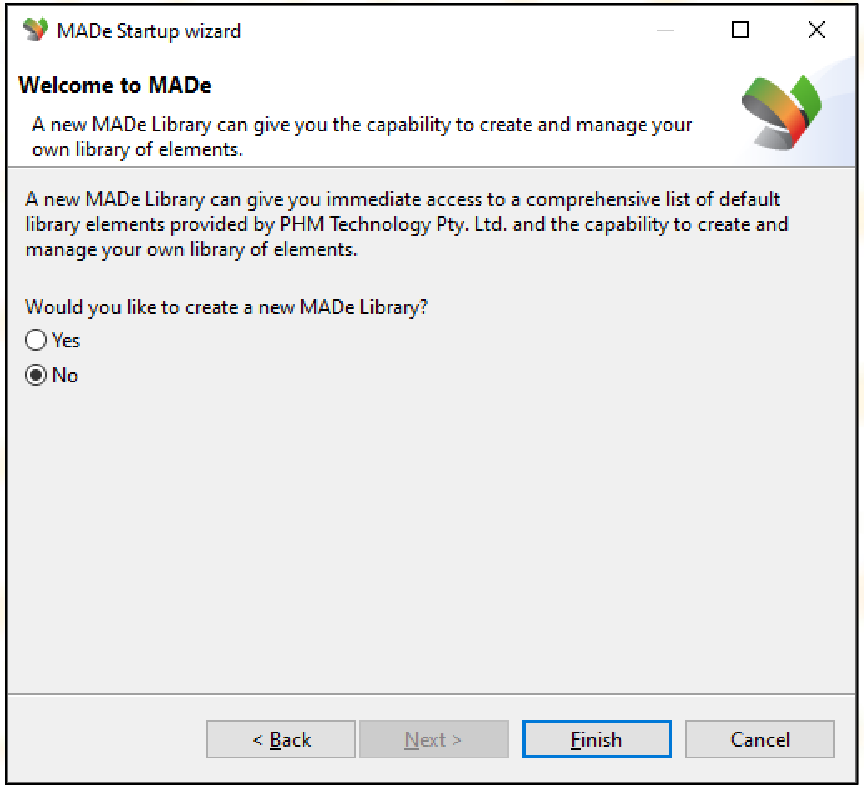




Session 1.1: Navigation

EXERCISE 1.1.1 LAUNCHING MADE

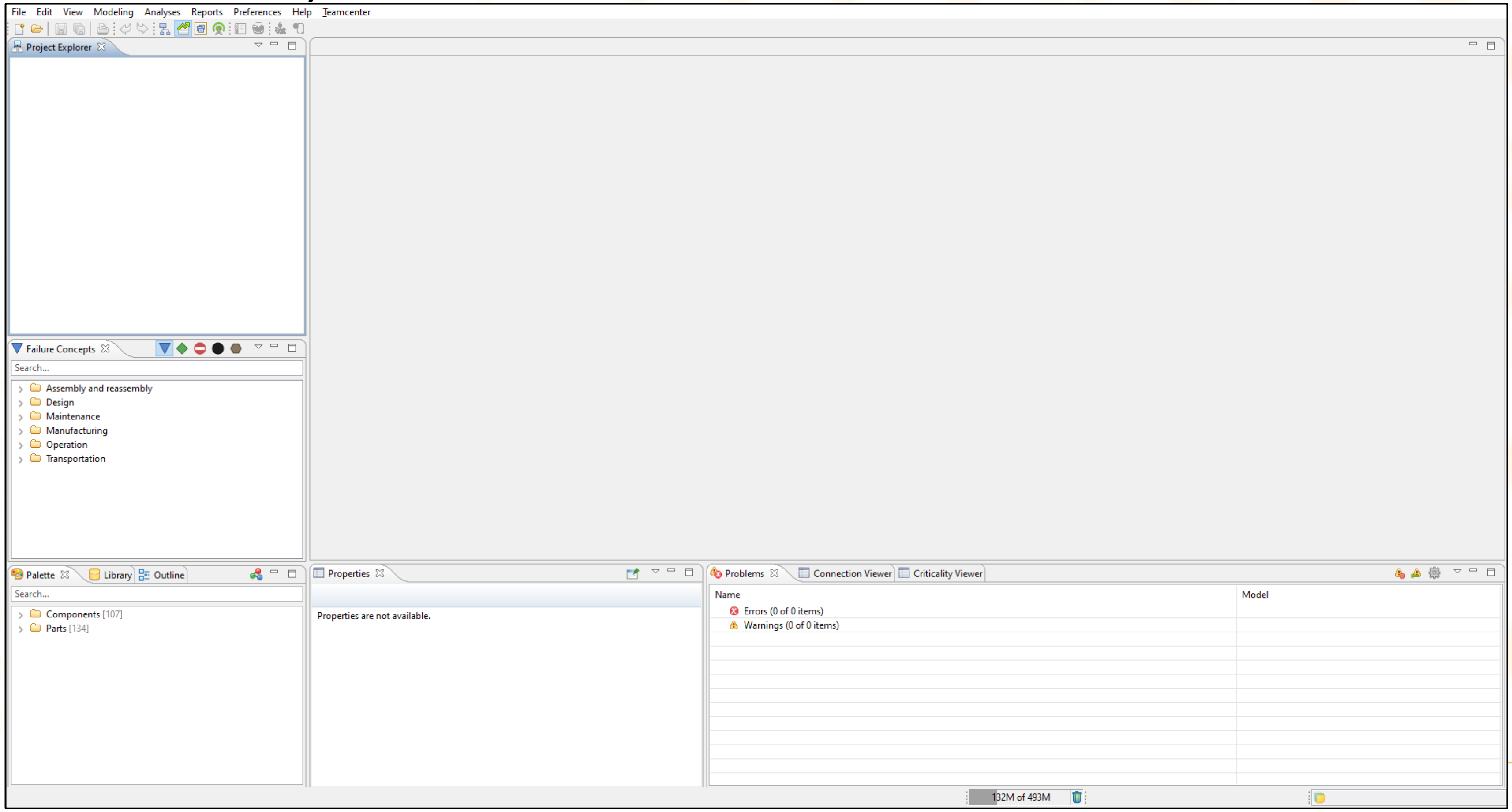
- When first launching MADe you will encounter a window to set up a library
- Select the **No** radio button
  - We will set the library in a later session
- Select Finish to continue



Session 1.1: Navigation

Discussion 1.1.2 MADe Workbench Layout

- Default MADe Workbench Layout shown below:



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Session 1.1: Navigation

Taxonomy 1.1.3 MADe Workbench Layout

- A list of sections in the MADe Workbench are shown below:

Taxonomy	Definition
Menu	The menu consists of a series of drop down boxes that allow navigation throughout the MADe software. The main menu allows access to all of the key features in MADe.
Toolbar	The toolbar provides access to key features in MADe via icons. These icons provide a shortcut to commonly used features for convenience.
Diagram	A diagram is one of the main windows in the MADe software. A diagram allows editing of content via a graphical representation.
Editor	An editor is another main window in MADe. An editor allows the user to write information to the model.
Viewer	A viewer is used to display or provide information to the user. Generally viewers allow reading or access of data but no ability to edit.
Dialog	A pop-up window used to provide additional information.
Wizard	A pop-up window used to provide additional information and perform an action.

Session 1.1: Navigation

Taxonomy 1.1.3 Default Viewers

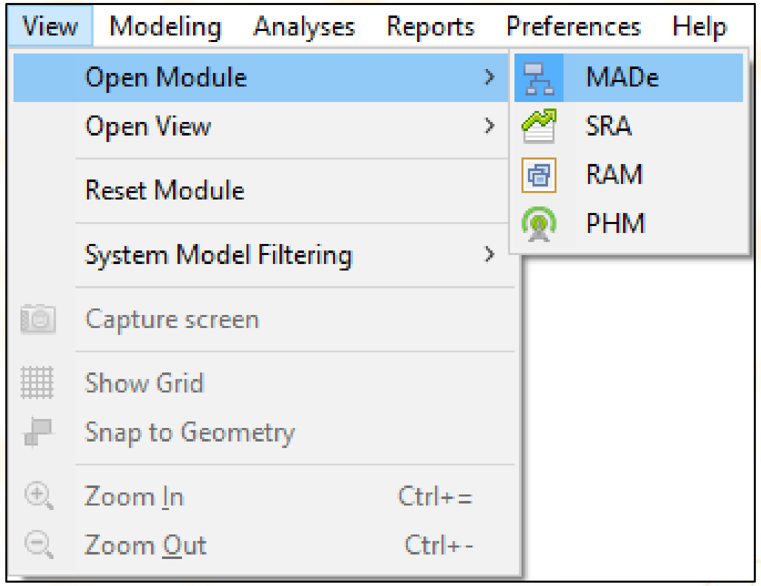
- Table below lists default viewers when opening MADe for the first time:

Taxonomy	Definition
Project Explorer	Displays system model hierarchy. This may be used to navigate through the system model.
Failure Concepts	Contains the complete failure taxonomy in the MADe software.
Library	Contains a list of all of the user modelled parts, components and systems.
Outline	Contains a list of exemplar PHM modelled parts, components and systems.
Palette	Contains a list of exemplar PHM modelled parts, components and systems.
Problems	Displays all of the current warnings and errors associated with the model.
Properties	Contains a concise list of the most used properties of the selected item and provides limited editing capability.

Session 1.1: Navigation

Discussion 1.1.4 MADe Modules

- What is a Module?
  - Modules are groupings of different perspectives or tool-sets in MADe
- Why is it important to select the MADe module?
  - Each module is used to conduct specific types of analyses
  - Access is enabled/disabled depending on the current active module
- What modules do I have access to?
  1. Maintenance Aware Design Environment (MADe) Modeling
  2. Safety & Risk Assessment (SRA)
  3. Reliability, Availability & Maintainability (RAM)
  4. Prognostics & Health Management (PHM)



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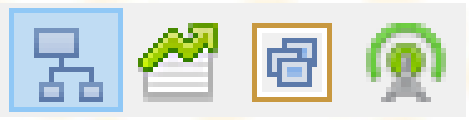
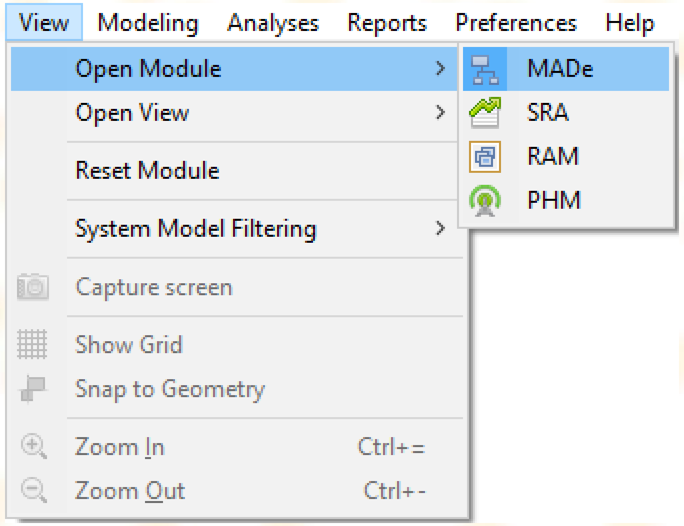
Session 1.1: Navigation

<u>Exercise 1.1.4 MADe Modules</u>

To select a module:

- ➢ Method 1:
  - ➢ Locate the main toolbar
  - ➢ Select the required module
- ➢ Method 2:
  - ➢ Select View → Open Module → MADe





❖ Note: Hover over a module icon in the main toolbar for a tool-tip

Session 1.1: Navigation

Session 1.1 Summary

- ✓ 1.1.1: Opening MADe
- ✓ 1.1.2: Layout Types in MADe
- ✓ 1.1.3: Default Layouts
- ✓ 1.1.4: Select MADe module

Session 1.2: Project Creation

Session 1.2 Outline

1.2.1: Creating a MADe Project

1.2.2: Project Properties

1.2.3: Project & Application Preferences

1.2.4: Annotation

Session 1.2: Project Creation

Discussion 1.2.1 Creating a MADe Project

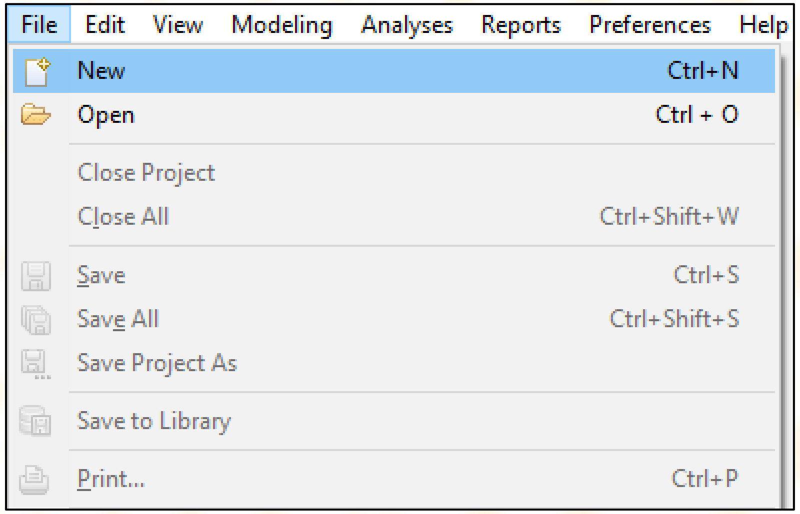
- What is a Project?
  - Projects are the MADe file (or archive) that stores the MADe model and information relevant to a model
  - Users can edit and save this file – similar to how a CAD file is updated
- What is the difference between a project and a system?
  - A system is the top level item within a project

Session 1.2: Project Creation

EXERCISE 1.2.1 CREATE A NEW PROJECT

To create a new MADe project:

- Select **File** from the main menu
- Select New

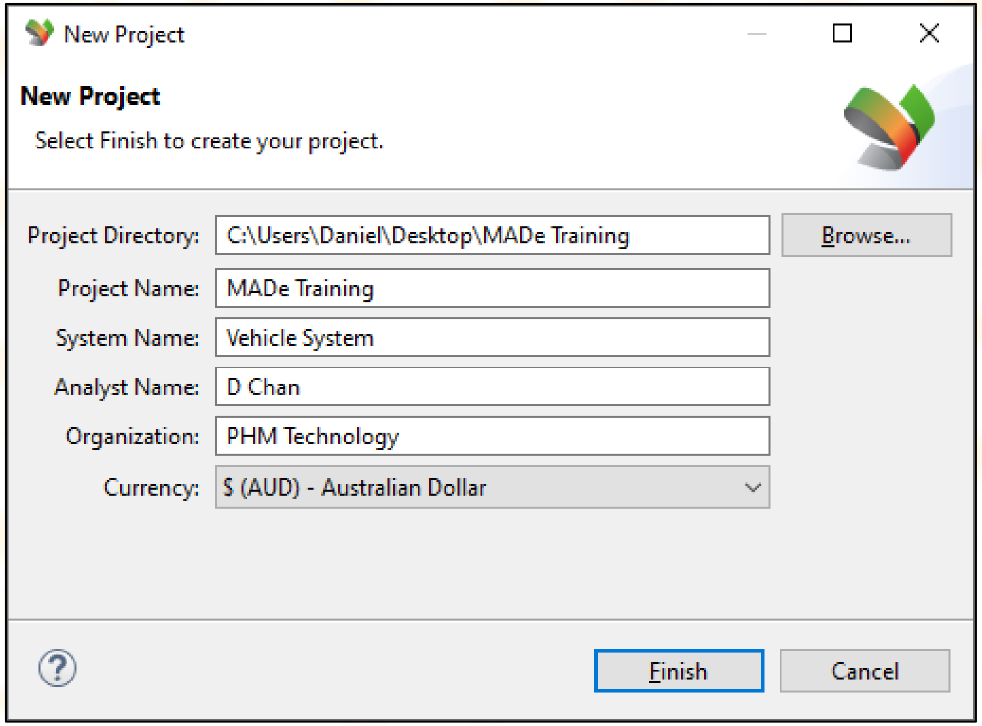


❖ Note: You can open an existing project by selecting **File → Open** in the main menu or from the icon toolbar

Session 1.2: Project Creation

EXERCISE 1.2.1 CREATE A NEW PROJECT (CONTINUED)

- In the New Project dialog, select Browse... to select a directory to save the model (e.g. Desktop)
- Complete the dialog with the following information:
  - Project Name: **MADe Training**
  - System Name: **Vehicle System**
  - Your Name & Organization
- Select the appropriate currency from the drop down menu
- Select Finish



Session 1.2: Project Creation

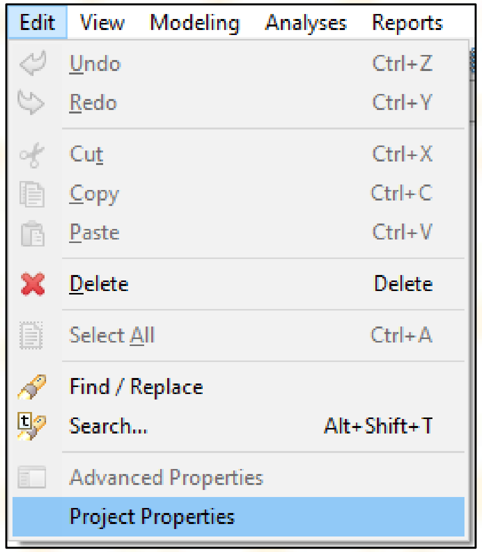
Discussion 1.2.2 Project Properties

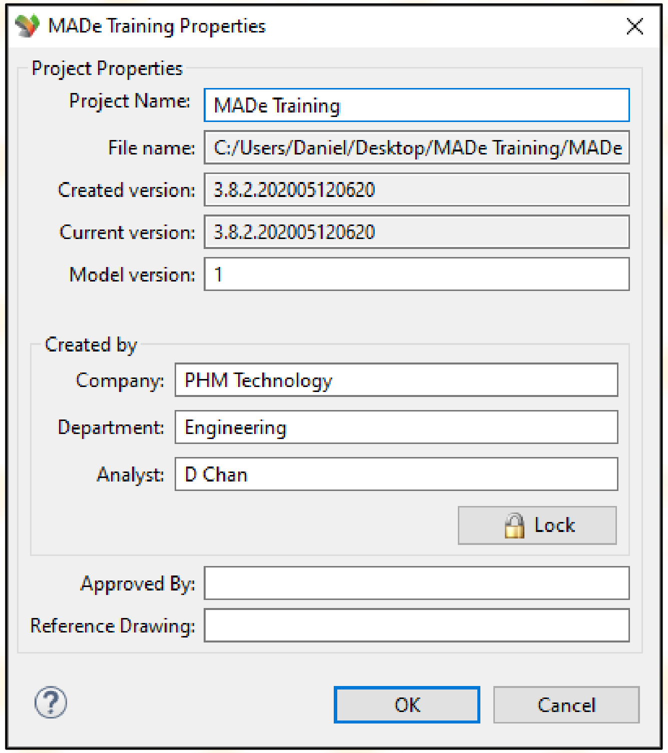
- What can be edited in the project properties?
- How is version control accomplished in MADe?

Exercise 1.2.2 Project Properties

To access & edit the Project Properties dialog:

- ➢ Select **Edit** → **Project Properties** from the main menu
- ➢ Populate the following fields:
  - ➢ Model Version: **1**
  - ➢ Department: **Engineering**
- ➢ Select OK





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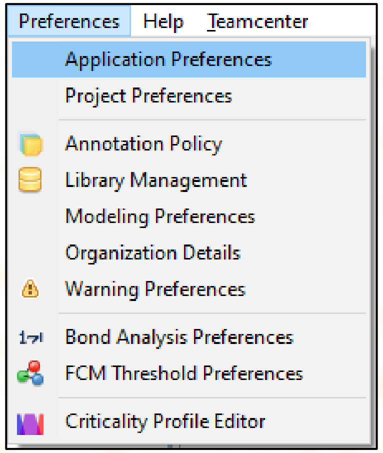
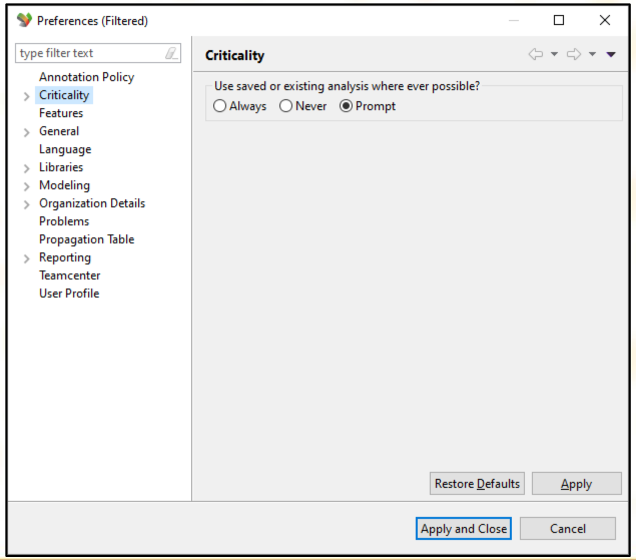
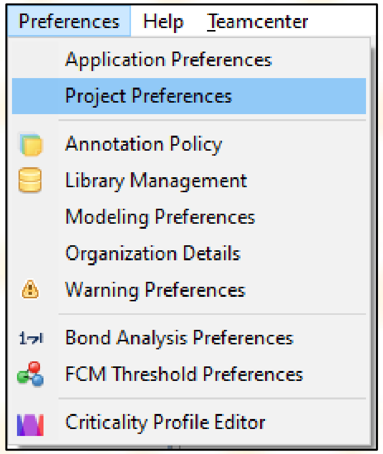
Session 1.2: Project Creation

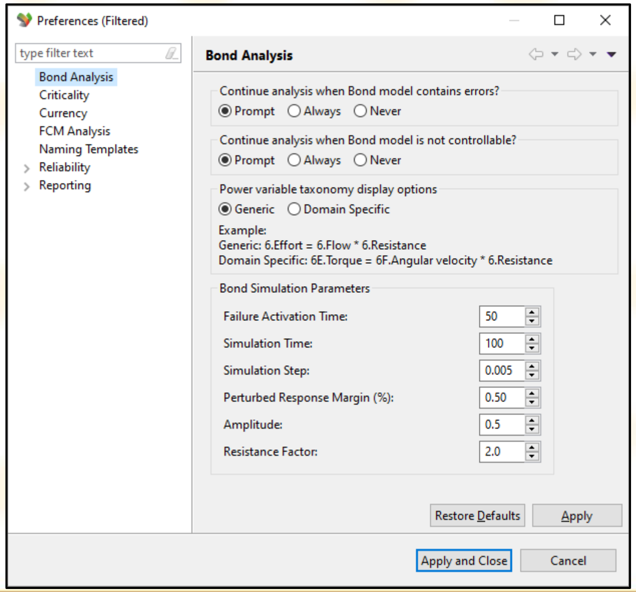
DISCUSSION 1.2.3 PROJECT & APPLICATION PREFERENCES

- What is the difference between project and application preferences?
  - **Application preferences**: Settings applied to all projects opened by a specific user profile
  - **Project preferences**: Applied only to a specific or individual MADe Project
- What are the preferences used for?
  - Save settings for reuse in future MADe instances









Session 1.2: Project Creation

Discussion 1.2.3 Project Preferences

- Bond Analysis: Bond properties
- Criticality: Used to adjust default values for criticality
- Currency: Used to change currency for the project
- FCM Analysis: Used to select the FCM Threshold Type
- Naming Templates: Used to customize naming for Functions, Failure Concepts and Flow Property
- Reliability: Used to adjust reliability precision
- Reporting: Reporting information for AIAG/SAE Template

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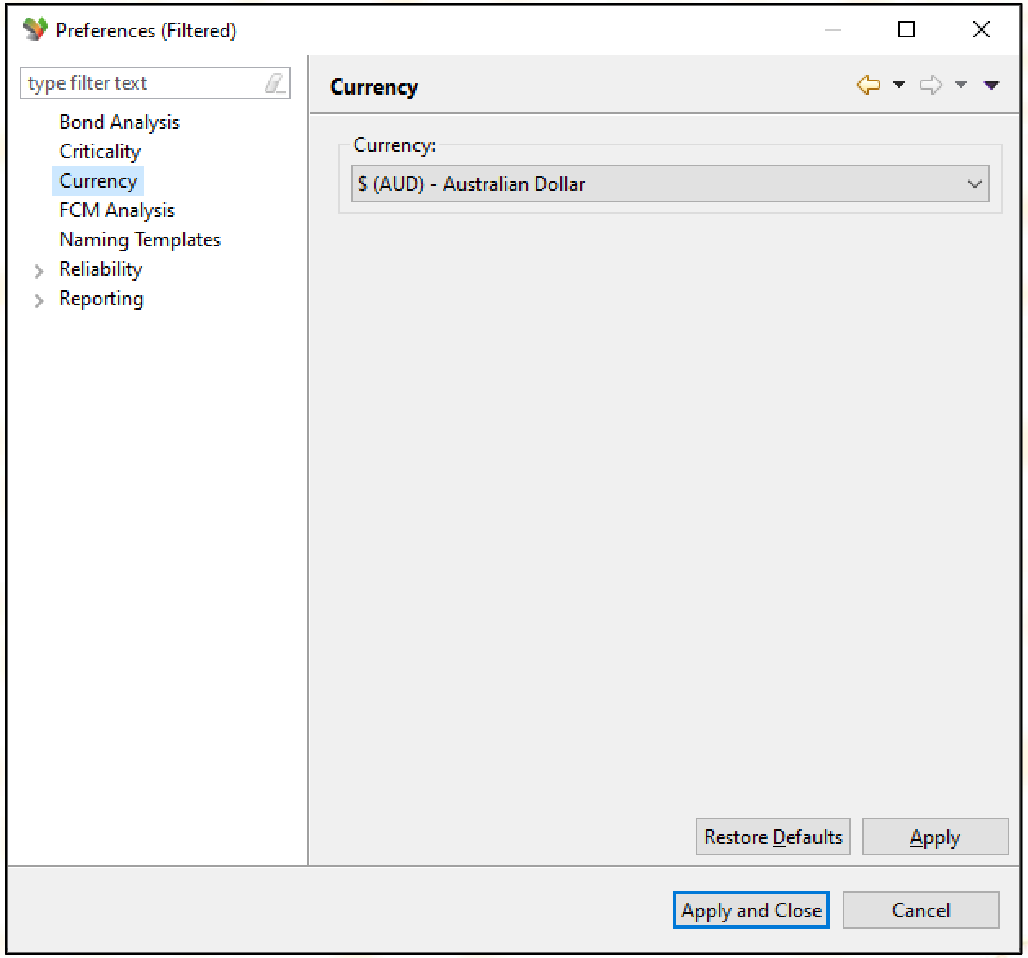
Session 1.2: Project Creation

Exercise 1.2.3 Project Preferences

To edit currency in the Project Preferences:

- Select **Preferences** → **Project Preferences** from main menu
- Select **Currency** tab in the left column
- Set or verify currency settings
- Select Apply and Close



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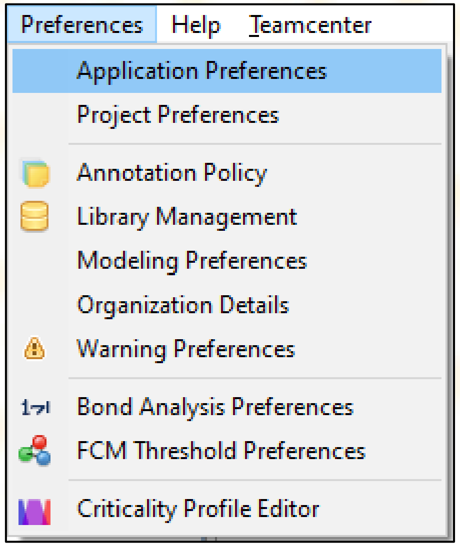
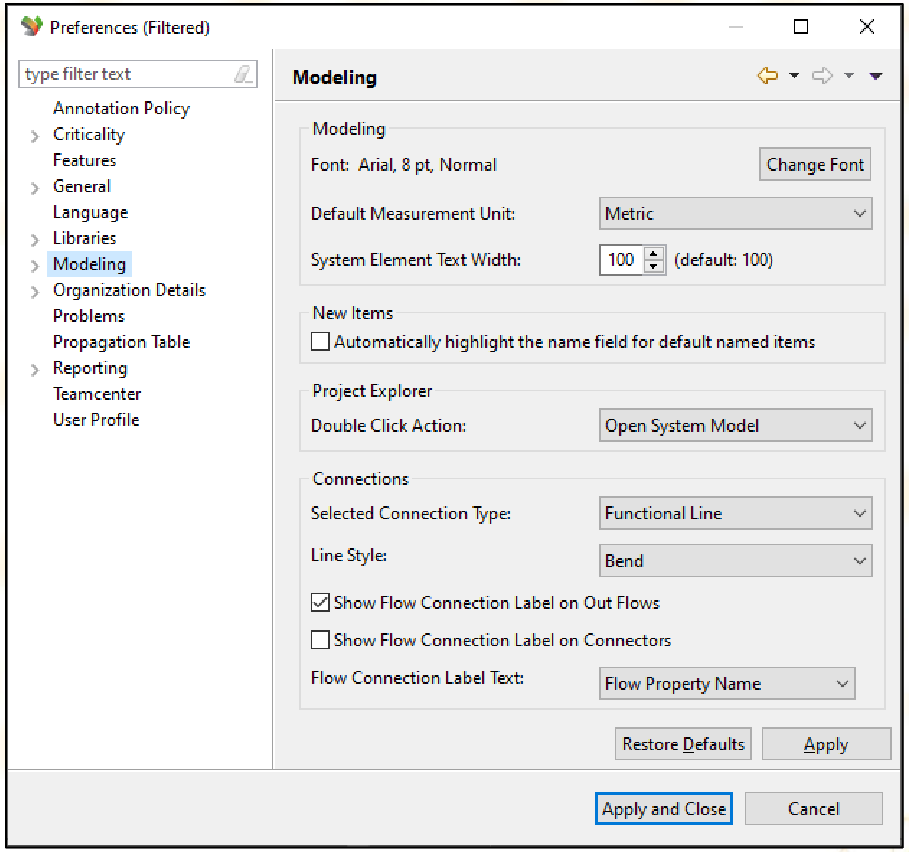
Session 1.2: Project Creation

EXERCISE 1.2.3 APPLICATION PREFERENCES

To display flow labels on the system diagram:

- Select **Preferences** → **Application Preferences** from main menu
- Select **Modeling** in the left column
- Select **Show Flow Connection Label on Out Flows**
- Select Apply and Close





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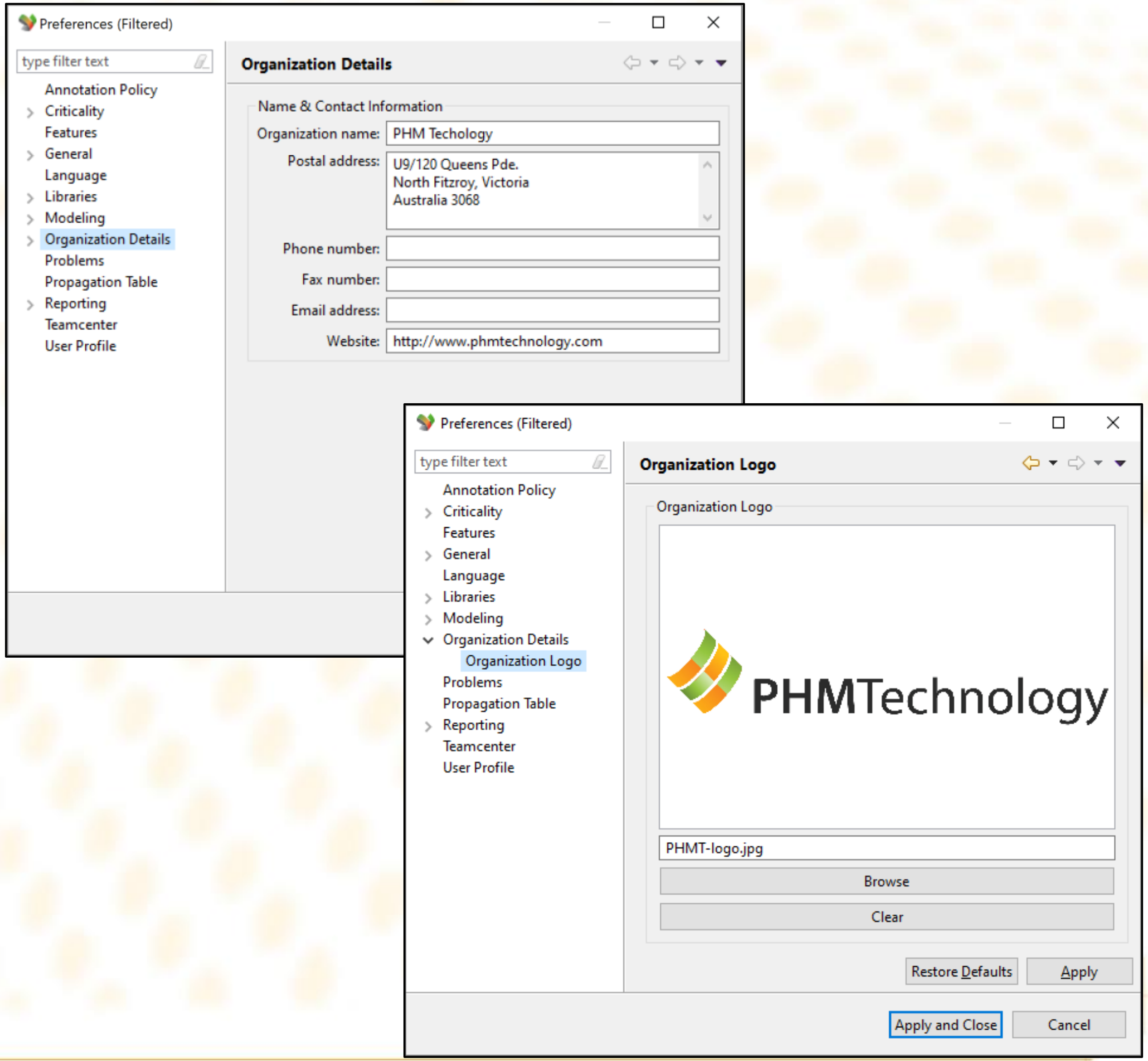
Session 1.2: Project Creation

Exercise 1.2.3 Organization Preferences

To edit Organization details:

- Select **Preferences** → **Application Preferences** from the main menu
- Select **Organization Details** tab in the left column
- Input the Organization details
  - Organization name, Postal address, Phone number, Fax number, Email address, Website
- Expand the **Organization Details** in the tree to show 'Organization Logo'
  - Upload your Organization Logo which will be used in the reports



Session 1.2: Project Creation

Discussion 1.2.4 Annotations

- Annotations are used to source and trace model decisions and information
- Annotations can be used to review data quality
- Annotations can be used to trace what work was done, when, and by who

Session 1.2: Project Creation

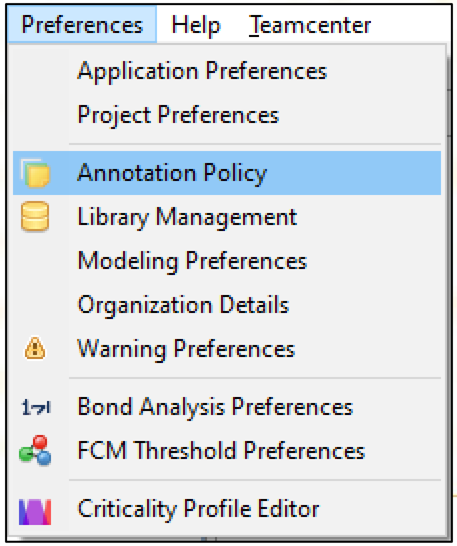
Exercise 1.2.4 Annotations Preferences

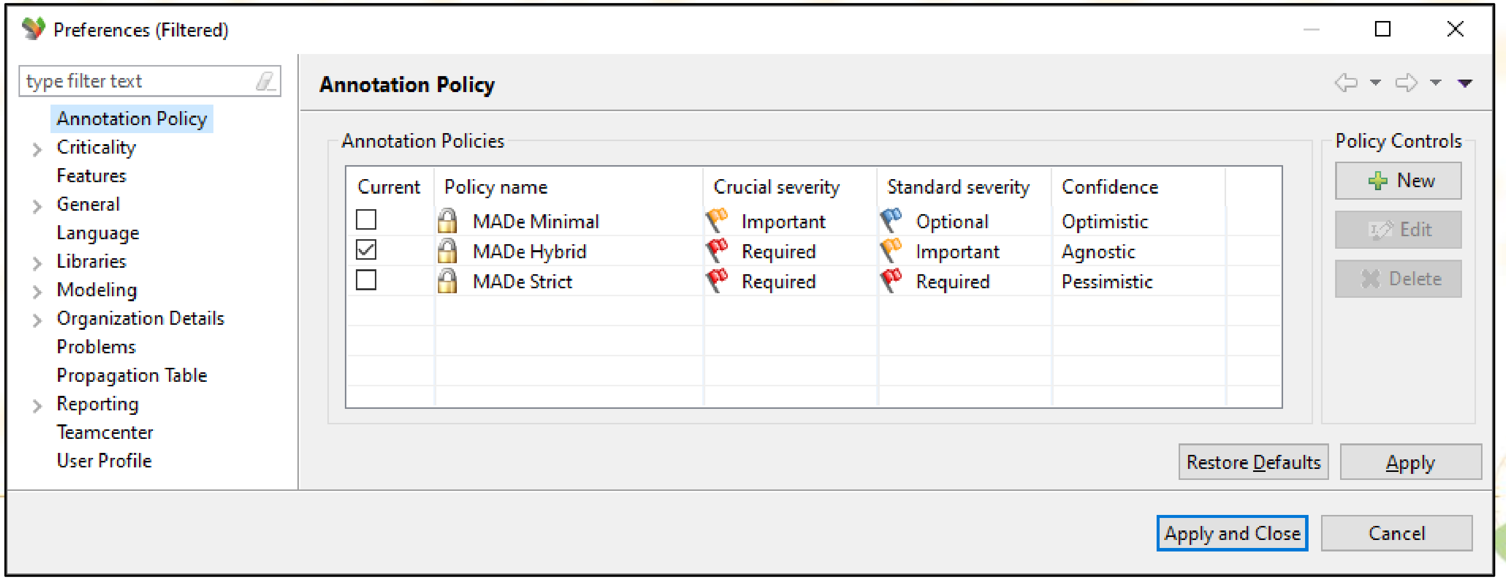
Annotation policies can be set to adjust confidence in the model

Custom policies can be created to exclude parameters which users may not want to track

To open the Annotations policy preference page:

- Select **Preferences → Annotation Policy** from the main menu
  - Three default policies are provided and MADe Hybrid is set as default





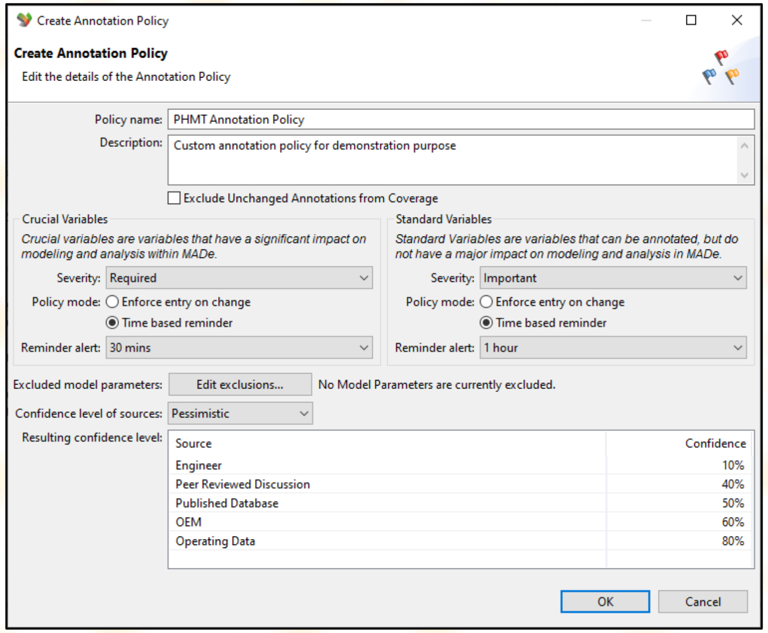
Session 1.2: Project Creation

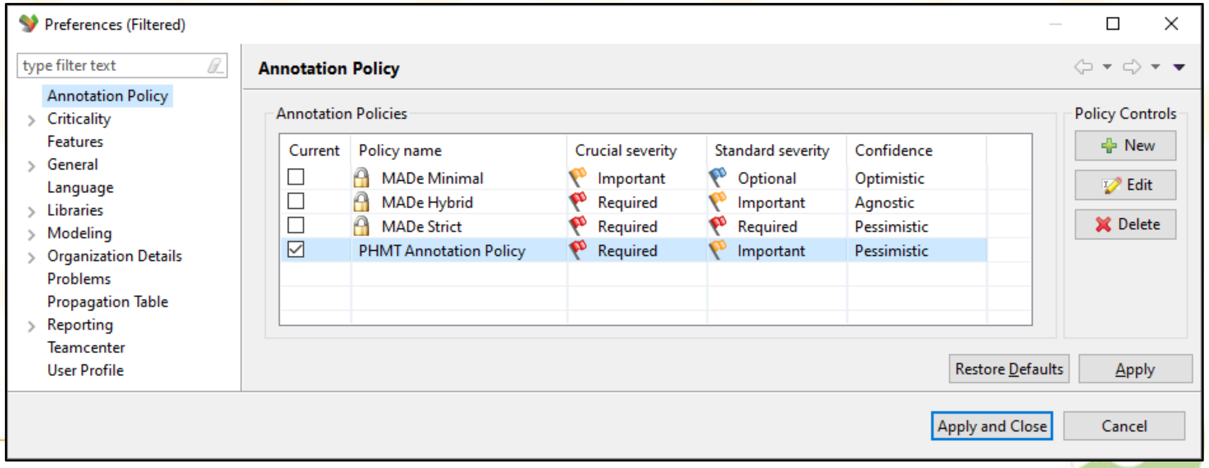
made
decisions better MADe...

Exercise 1.2.4 Annotations Preferences

To create a custom Annotations policy:

- Select **Preferences → Annotation Policy** from the main menu
- Select New
- Populate the fields with data as below:
  - Policy name: **PHMT Annotation Policy**
  - Description: **Custom annotation policy for demonstration purpose**
  - Confidence level of source: **Pessimistic**
- Select OK to save policy and close the window
- Check the PHMT Annotation Policy check box
- Select Apply and Close





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Session 1.2: Project Creation

SESSION 1.2 SUMMARY

- ✓ 1.2.1: Creating a MADe Project
- ✓ 1.2.2: Project Properties
- ✓ 1.2.3: Project & Application Preferences
- ✓ 1.2.4: Annotation Preferences

Session 1.3: Mission Profile Definition

<u>Session 1.3 Outline</u>

1.3.1: Mission Profile Overview

1.3.2: Mission Profile Editor

1.3.3: Overview / Management Page

1.3.4: Mission Profile Landing Page

1.3.5: Mission Phases and Segments

1.3.6: Mission Success Metrics

Session 1.3: Mission Profile Definition

Discussion 1.3.1 Mission Profile Overview

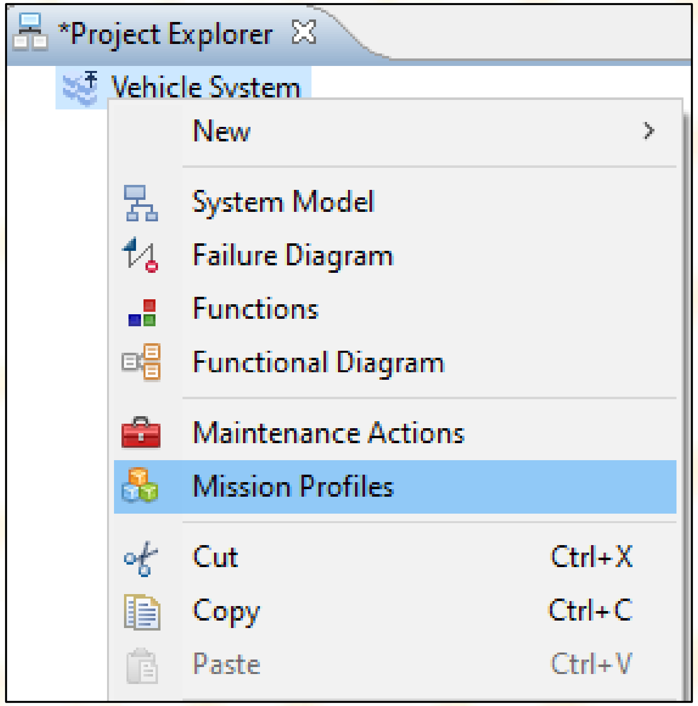
- What is the Mission Profile?
- How does this relate to the System / Project?
- Why do Mission Profile before the Model?
- What does solution-independent Mission Profile mean?

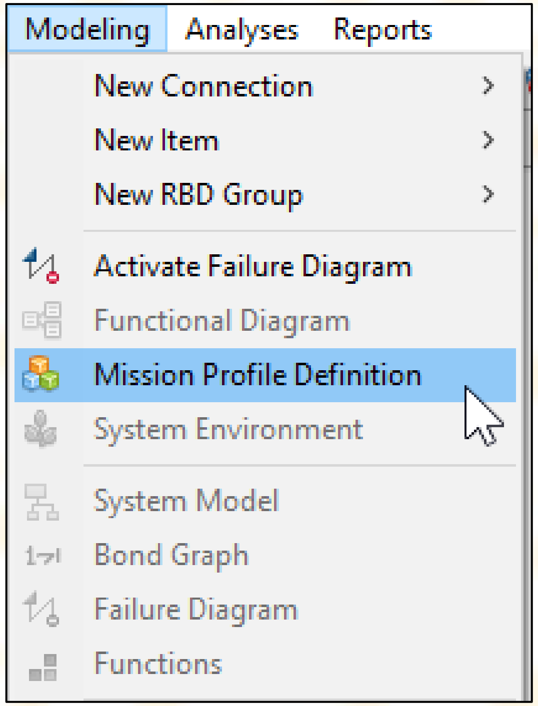
Session 1.3: Mission Profile Definition

Exercise 1.3.2 Mission Profile Editor

To open the Mission Profile Editor:

- Method 1:
  - Select **Modeling → Mission Profile Definitions** from the menu bar
- Method 2:
  - Right-click system in the Project Explorer viewer
  - Select **Mission Profiles** from the menu

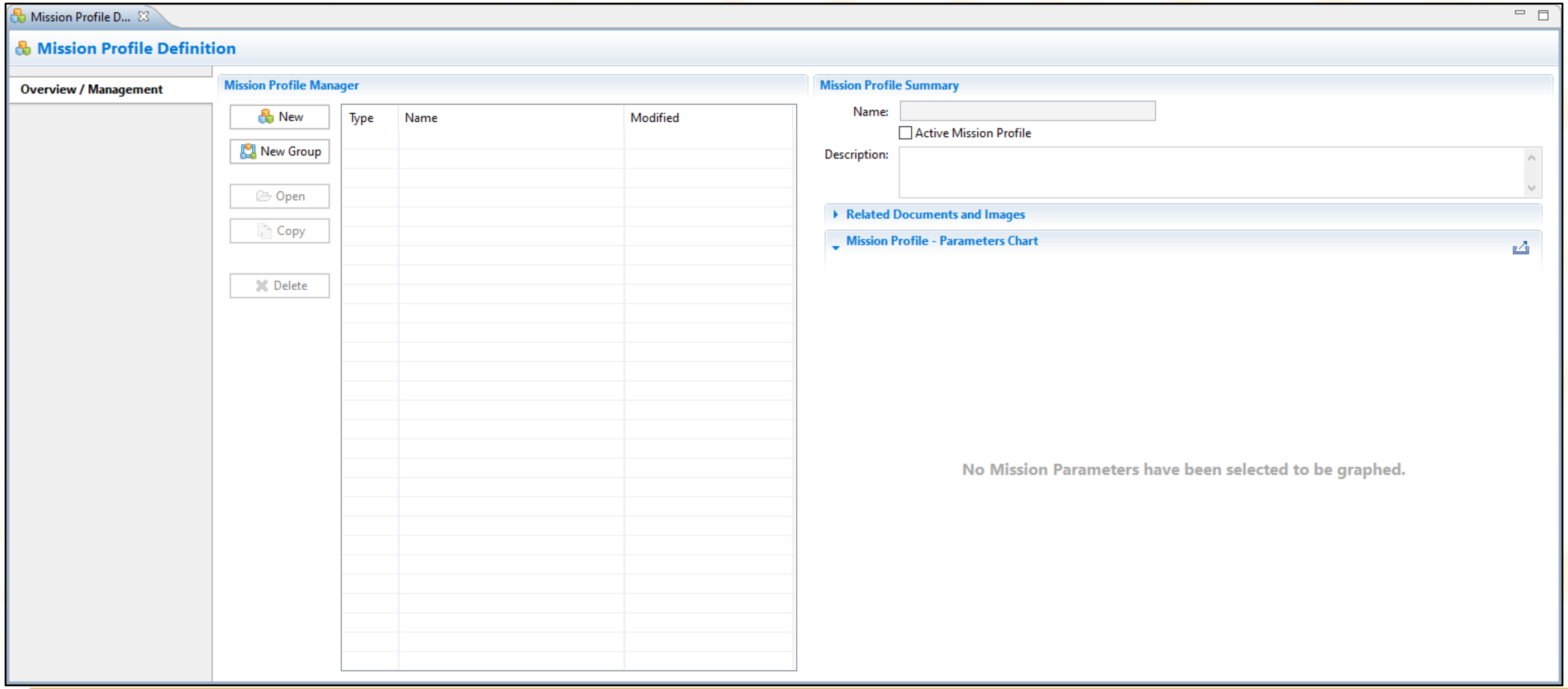




Session 1.3: Mission Profile Definition

Discussion 1.3.3 Overview/Management Page

- The Mission Profile Overview page is where missions are defined
- It also provides a summary of the profile as it is built

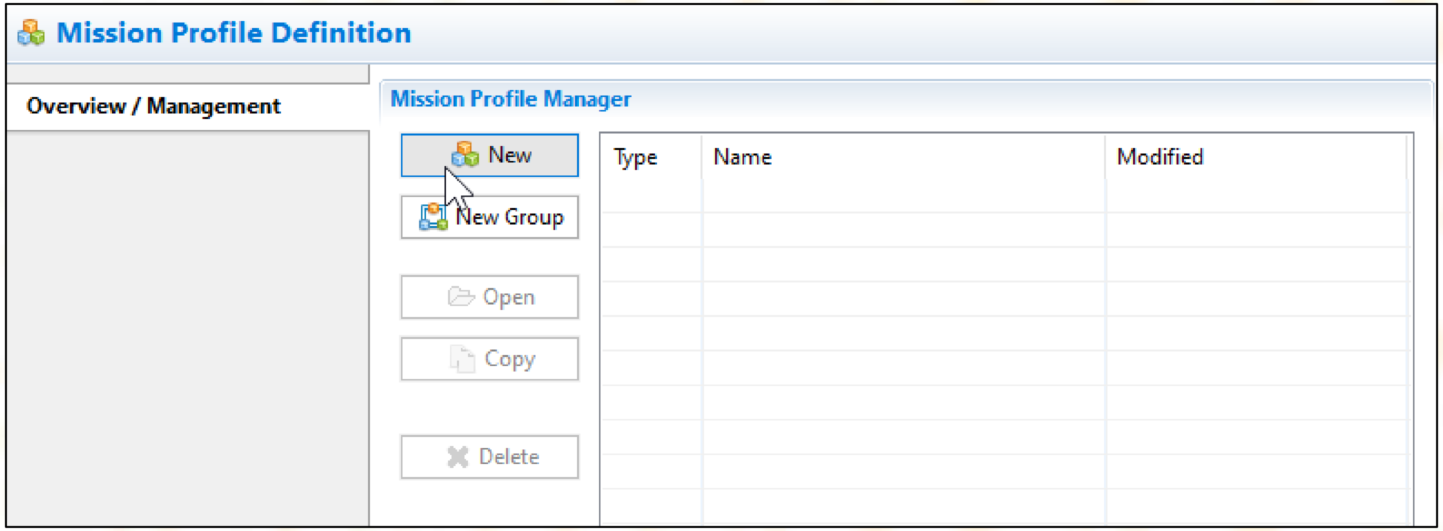


Session 1.3: Mission Profile Definition

EXERCISE 1.3.3 OVERVIEW/MANAGEMENT PAGE

To create and begin defining a new mission profile:

- Select [New] to create a new mission profile in the **Mission Profiles** list
- Once a new mission profile is created this will automatically load the **New Mission Profile** page

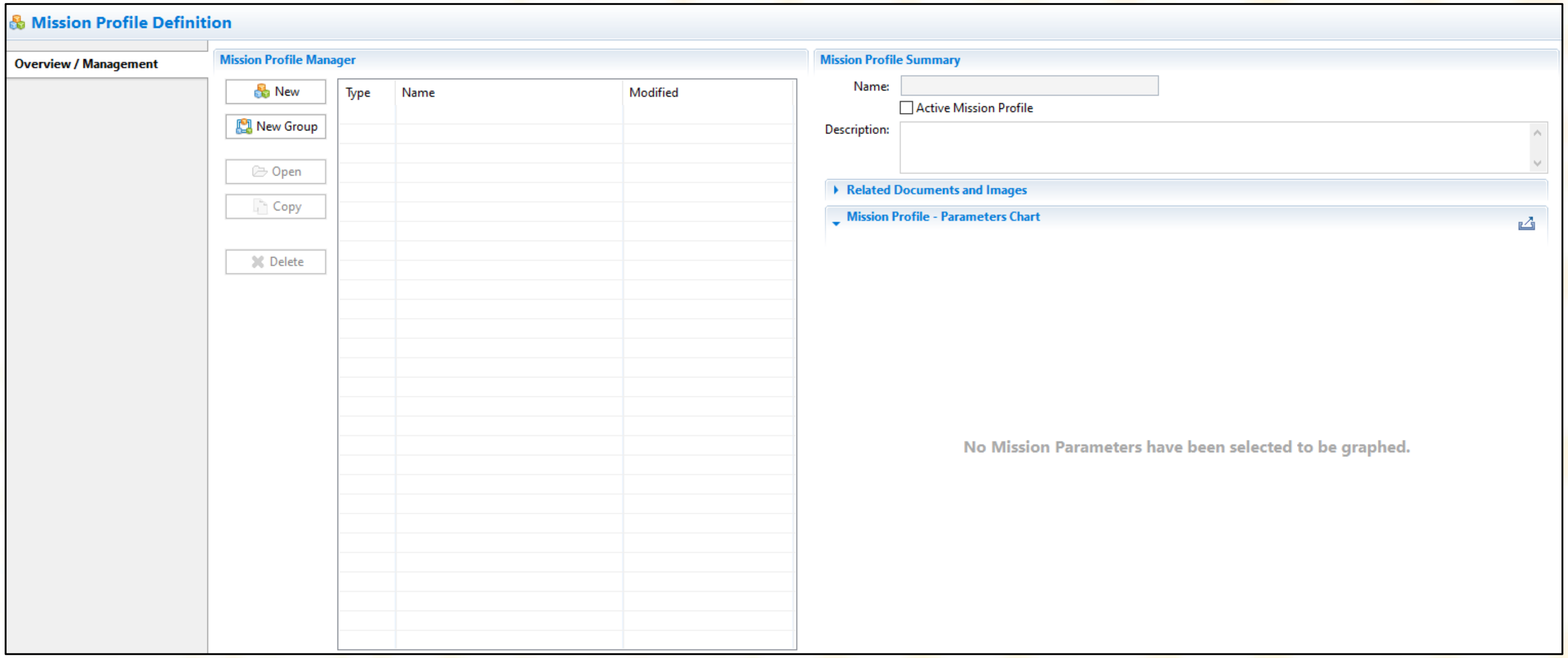


- Note: You can also open a mission profile/group by double-clicking the item in the table

Session 1.3: Mission Profile Definition

Discussion 1.3.4 Mission Profile Landing Page

- This page is used to add Mission Details, Documents/Images and define key Mission Parameters



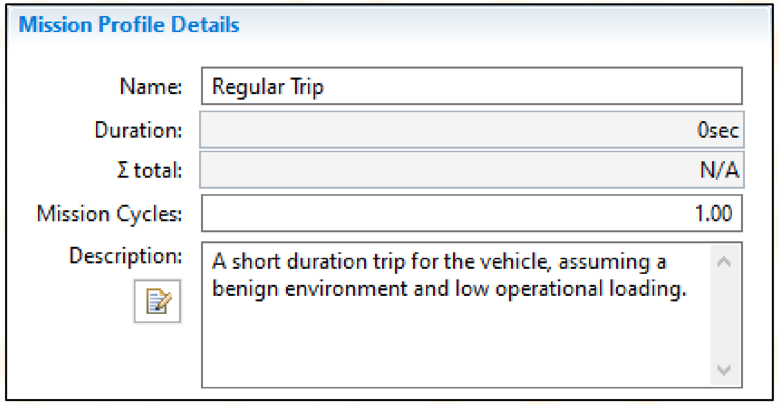
❖ Note: An **Active Mission Profile** refers to one currently assigned to the model

Session 1.3: Mission Profile Definition

EXERCISE 1.3.4 MISSION PROFILE LANDING PAGE

To enter Mission Profile Definition Details, in the **Mission Profile Details** section:

- Edit Mission Profile name to: **Regular Trip**
- Verify Number of Mission Cycles as: **1.00**
- Enter mission profile description: **A short duration trip for the vehicle, assuming a benign environment and low operational loading.**

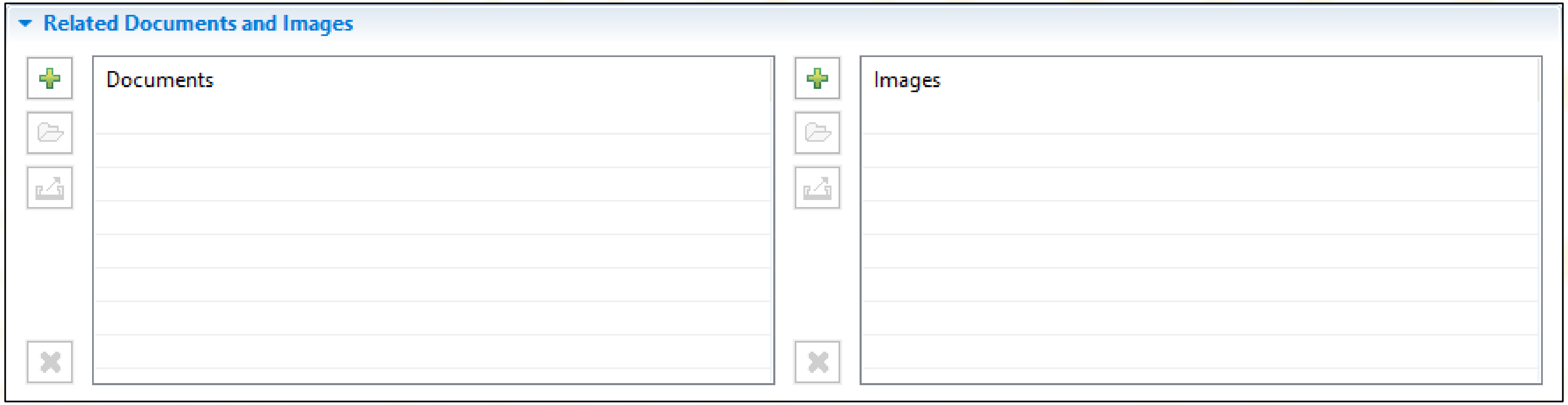


Session 1.3: Mission Profile Definition

Exercise 1.3.4 Mission Profile Landing Page (Continued)

To attach documents/images under the **Related Documents and Images** section:

- Select the add button to attach a document file
- Select the open button to open an attached file
- Select the export button to export an attached file
- Select the delete button to delete a selected file

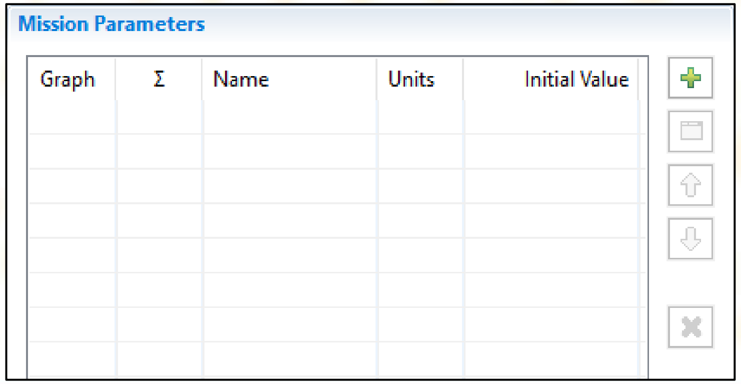


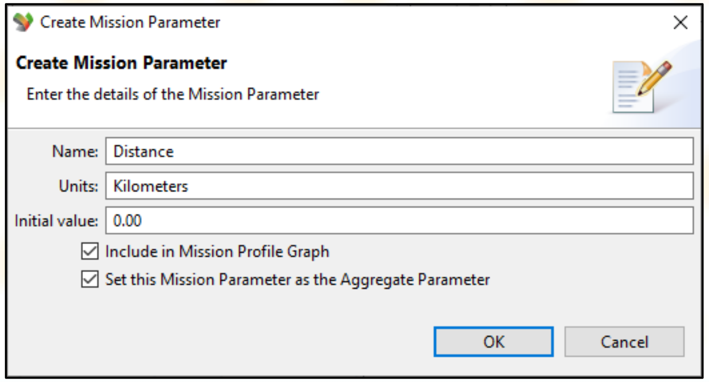
Session 1.3: Mission Profile Definition

Exercise 1.3.4 Mission Profile Landing Page (Continued)

To create a Mission Parameter from the Mission Parameters section:

- Select the add button to create a new Mission Parameter
- Enter a Mission Parameter name: **Distance**
- Enter units as: **Kilometers**
- Enter Initial value as: **0.00**
- Select the **Include parameter in Mission Profile Graph** check box
- Select the **Set this Mission Parameter as an Aggregate Parameter** check box
- Select OK





Session 1.3: Mission Profile Definition

Discussion 1.3.5 Mission Phases & Segments

- Phases & Segments are defined to divide a mission profile into smaller blocks of time
- Item Duration of Operation is defined based on durations of Phases/Segments & Duty Cycle allocation
- Used to allocate Environment & Environmental Characteristics to Phase/Segments
- Used to track and edit Mission Parameters for each Phase/Segment

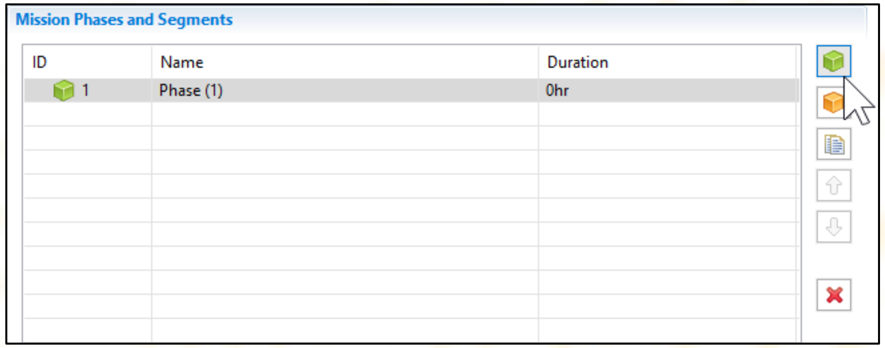
t = 0hr	t = 5sec	t = 1min 5sec	t = 16min 5sec	t = 17min 5sec	t = 1hr 17min 5sec	t = 1hr 18min 5sec	t = 1hr 18min 10sec
Phase / Segment:	1: Start-up	2: Acceleration	3: Cruise	4: Turning	5: Cruise 2	6: Deceleration	7: Shut-down
	1.1: Ignition						
	5sec						
Duration:	5sec	1min	15min	1min	1hr	1min	5sec

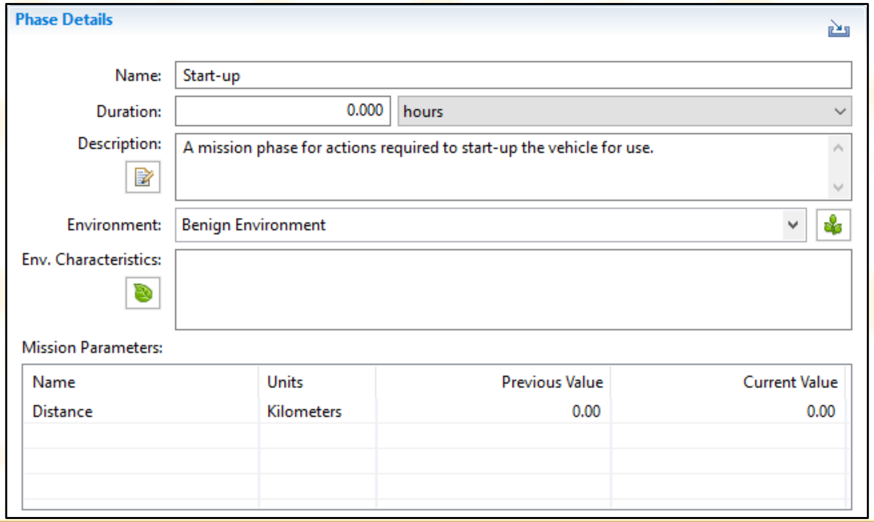
Session 1.3: Mission Profile Definition

<u>EXERCISE 1.3.5 MISSION PHASES & SEGMENTS</u>

To define Phases, in the **Mission Phases and Segments** table:

- Select to create a new phase
- Enter a phase name: **Start-up**
- Verify Duration is **0.000 minutes** (will be inherited from Segment)
- Enter description: **A mission phase for actions required to start-up the vehicle for use.**





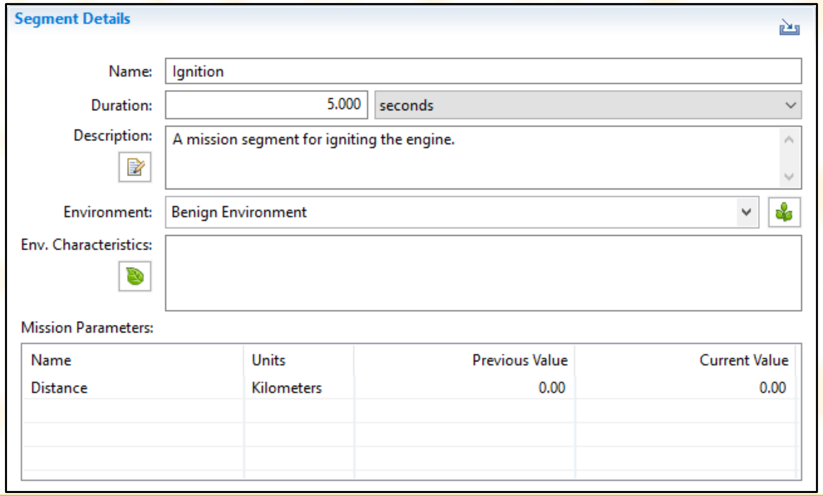
Session 1.3: Mission Profile Definition

Exercise 1.3.5 Mission Phases & Segments (Continued)

To define a Segment, in the **Mission Phases and Segments** table:

- Select **Start-up** Phase in Mission Phases & Segments Table
- Select to create a new segment
- Enter a Phase name as: **Ignition**
- Enter duration as **5 seconds** (verify Start-up phase inherits duration)
- Enter description: **A mission segment for igniting the engine.**

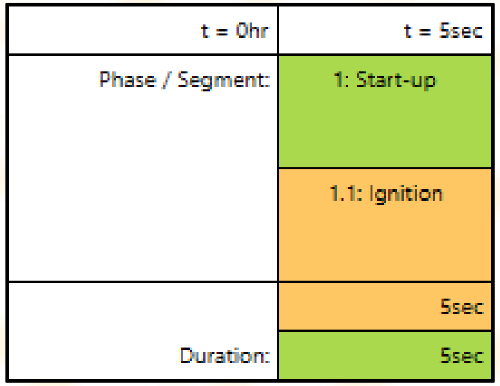
t = 0hr	t = 5sec
Phase / Segment:	1: Start-up
	1.1: Ignition
	5sec
Duration:	5sec

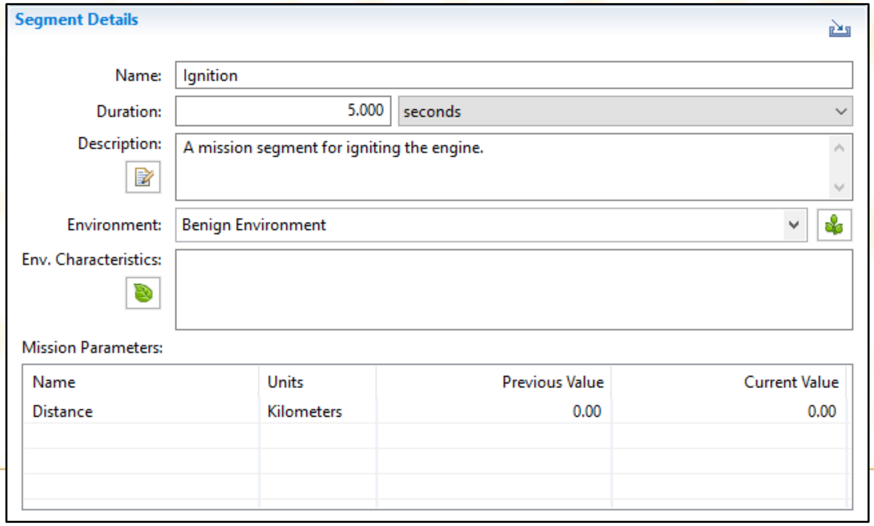


Session 1.3: Mission Profile Definition

EXERCISE 1.3.5 MISSION PHASES & SEGMENTS (CONTINUED)

- Verify Environment as **Benign Environment**
- Verify Environmental Characteristics field is empty
  - This will be covered in Session 2.3: MPD Groups
- Verify Mission Parameters **Current Value** is **0.00**
  - Reasoning: No distance is travelled during startup/ignition.
- Verify Time Profile Graph shows Phase & Segment details





Session 1.3: Mission Profile Definition

Exercise 1.3.5 Mission Phases & Segments (Continued)

- Create additional Phases and Segments using the table below to complete this mission profile:
    - Current Distance can be modified in the Mission Parameters section

Phase	Segment	Duration	Current Distance
Start-up			0.00 km
	Ignition	5 seconds	0.00 km
Acceleration		1 minute	0.50 km
Cruise		15 minutes	10.50 km
Turning		1 minute	11.00 km
Cruise 2		1 hour	111.00 km
Deceleration		1 minute	112.00 km
Shut-down		5 seconds	112.00 km

Session 1.3: Mission Profile Definition

EXERCISE 1.3.5 MISSION PHASES & SEGMENTS (CONTINUED)

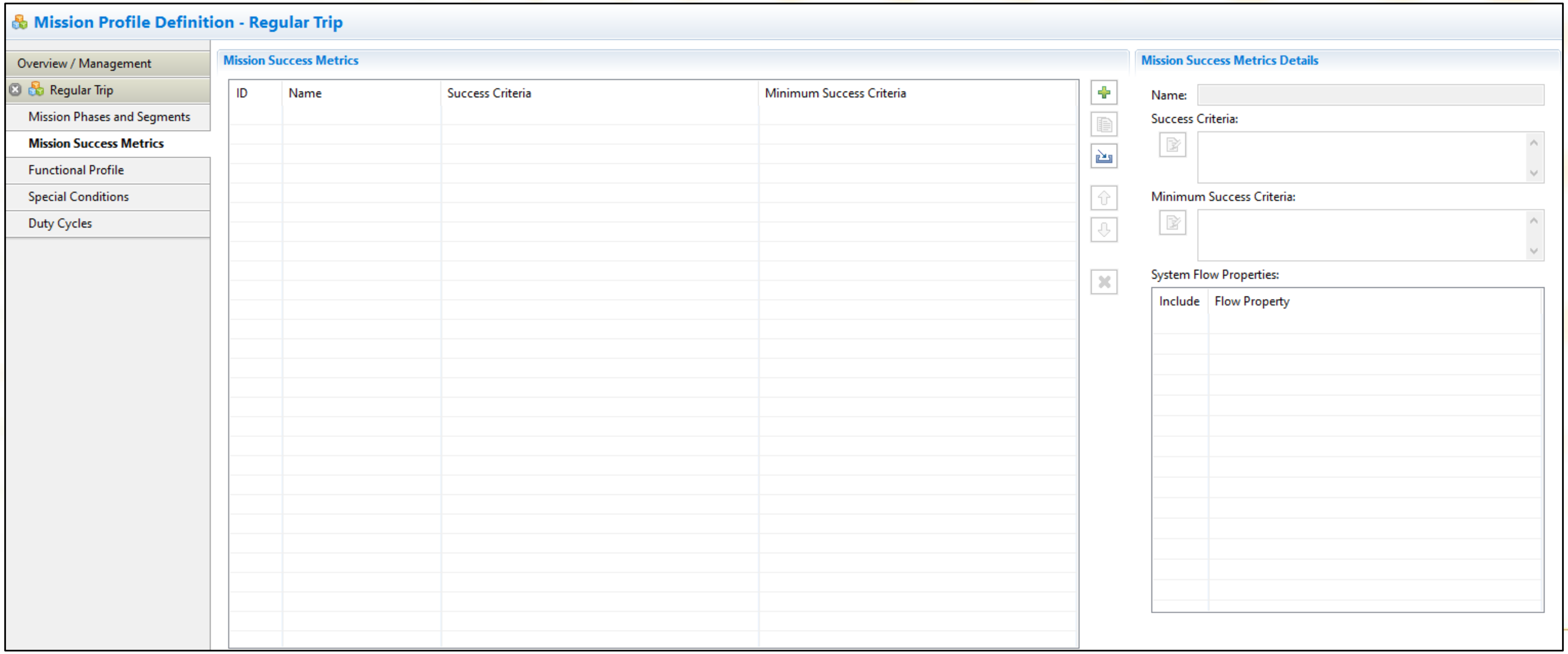
- Verify that the Time Profile graph has the layout & details below:

t = 0hr	t = 5sec	t = 1min 5sec	t = 16min 5sec	t = 17min 5sec	t = 1hr 17min 5sec	t = 1hr 18min 5sec	t = 1hr 18min 10sec
Phase / Segment:	1: Start-up	2: Acceleration	3: Cruise	4: Turning	5: Cruise 2	6: Deceleration	7: Shut-down
	1.1: Ignition						
	5sec						
Duration:	5sec	1min	15min	1min	1hr	1min	5sec

Session 1.3: Mission Profile Definition

DISCUSSION 1.3.6 MISSION SUCCESS METRICS

- Mission Success Metrics refer to requirements or targets that need to be fulfilled for the given mission
- These can be used to identify & map system functions (flow properties) in a completed system model

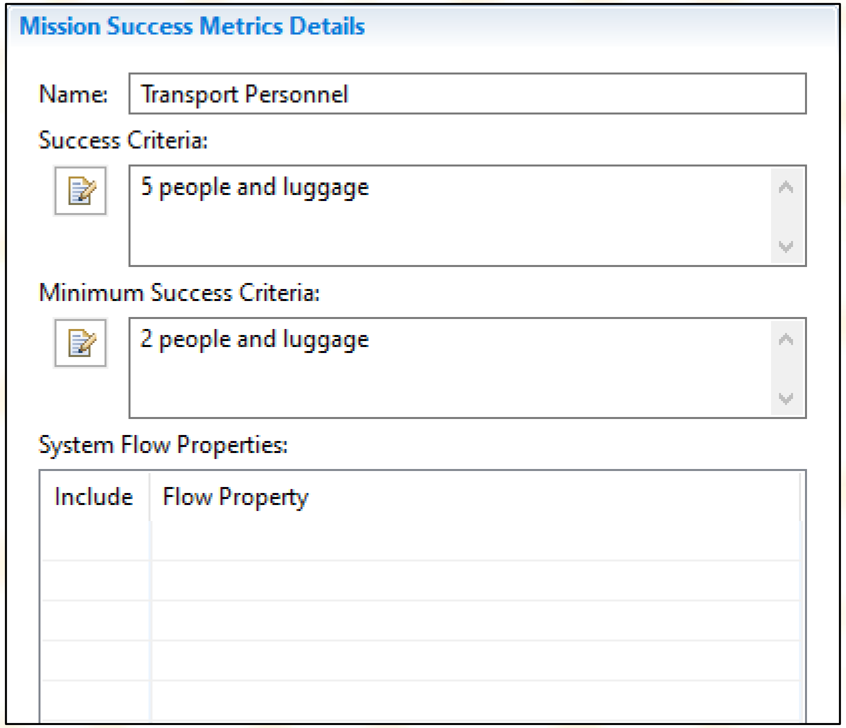


Session 1.3: Mission Profile Definition

EXERCISE 1.3.6 MISSION SUCCESS METRICS

To create a new Mission Success Metric:

- Select the Mission Success Metrics tab to open the page
- Select to create a new mission success metric
- Populate the following details:
  - Name: **Transport Personnel**
  - Success criteria: **5 people and luggage**
  - Minimum success criteria as: **2 people and luggage**

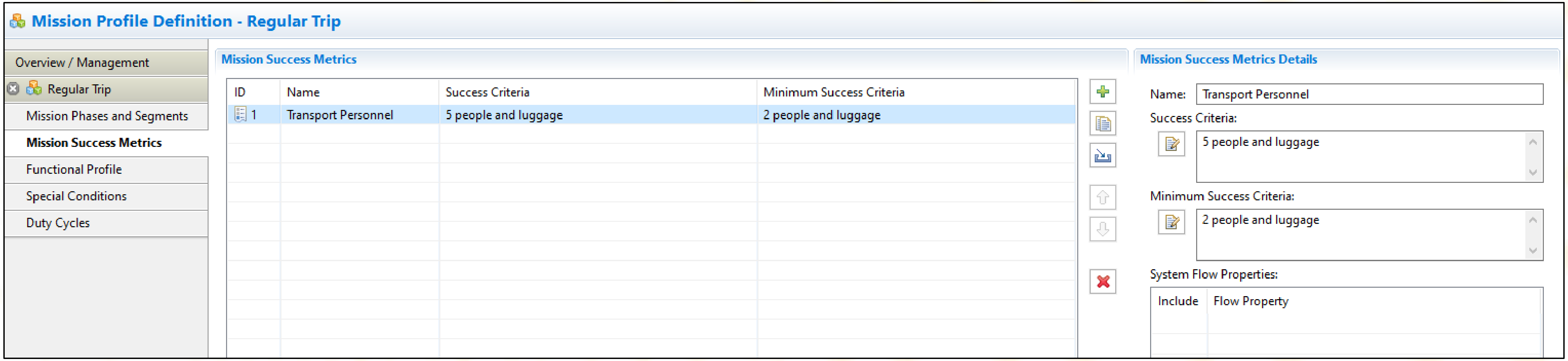


❖ Note: System Flow Properties table shows flow properties only when a system model with system-level function and flows are created

Session 1.3: Mission Profile Definition

EXERCISE 1.3.6 MISSION SUCCESS METRICS (CONTINUED)

- Verify that the newly created Metric is displayed in the **Mission Success Metrics** table



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Session 1.3: Mission Profile Definition

Session 1.3 Summary

- ✓ 1.3.1: Mission Profile Overview
- ✓ 1.3.2: Mission Profile Editor
- ✓ 1.3.3: Overview/Management Page
- ✓ 1.3.4: Mission Profile Landing Page
- ✓ 1.3.5: Mission Phases and Segments
- ✓ 1.3.6: Mission Success Metrics

Session 1.4: Functional Modeling (FHA)

Session 1.4 Outline

1.4.1: Functional Hazards Assessment (FHA) in ARP4761 Context

1.4.2: Opening Functional Modeling Editor

1.4.3: Functional Model Editor Layout

1.4.4: Creating Functions

1.4.5: Creating Connections

Session 1.4: Functional Modeling (FHA)

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Discussion 1.4.1 Functional Hazards Assessment (FHA) in ARP4761 Context

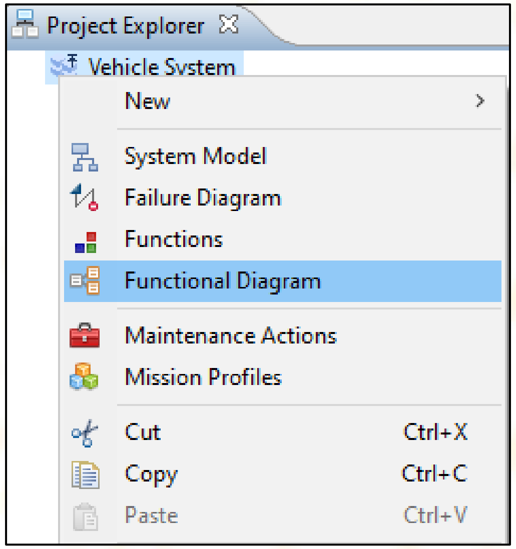
- ARP4761 Standard: Guidelines & methods of performing safety assessment for certification of civilian aircraft
- FHA Definition: A Functional Hazard Assessment is defined as a systematic, comprehensive examination of functions to identify and classify failure conditions of those functions according to their severity
  - Identify Functions
  - Identify Failure Conditions related to each Function
  - Classify Failure Conditions by Severity
- Performed during Concept and Preliminary Design Stages
- FHA is performed at 2 levels: Platform (e.g. Aircraft) Level & System Level
- Functions are assigned Development Assurance Levels (DALs) to classify the severity of failure effects or development errors

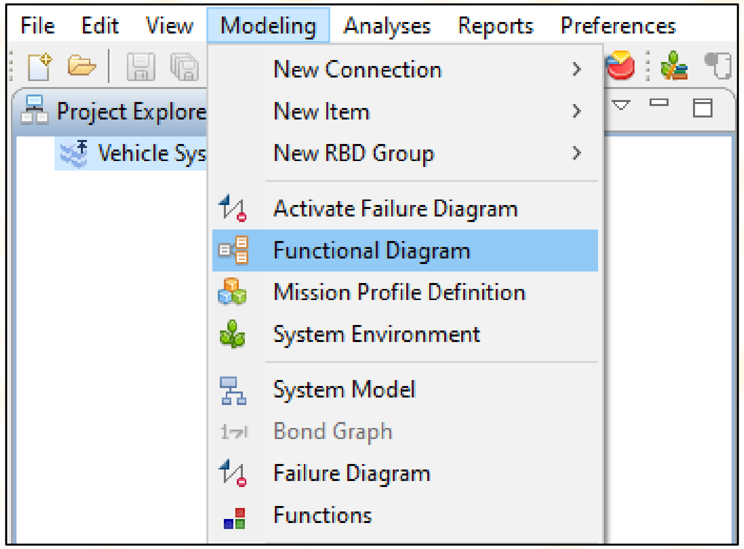
Session 1.4: Functional Modeling (FHA)

EXERCISE 1.4.2 OPENING FUNCTIONAL MODELING EDITOR

To access Functional Diagram:

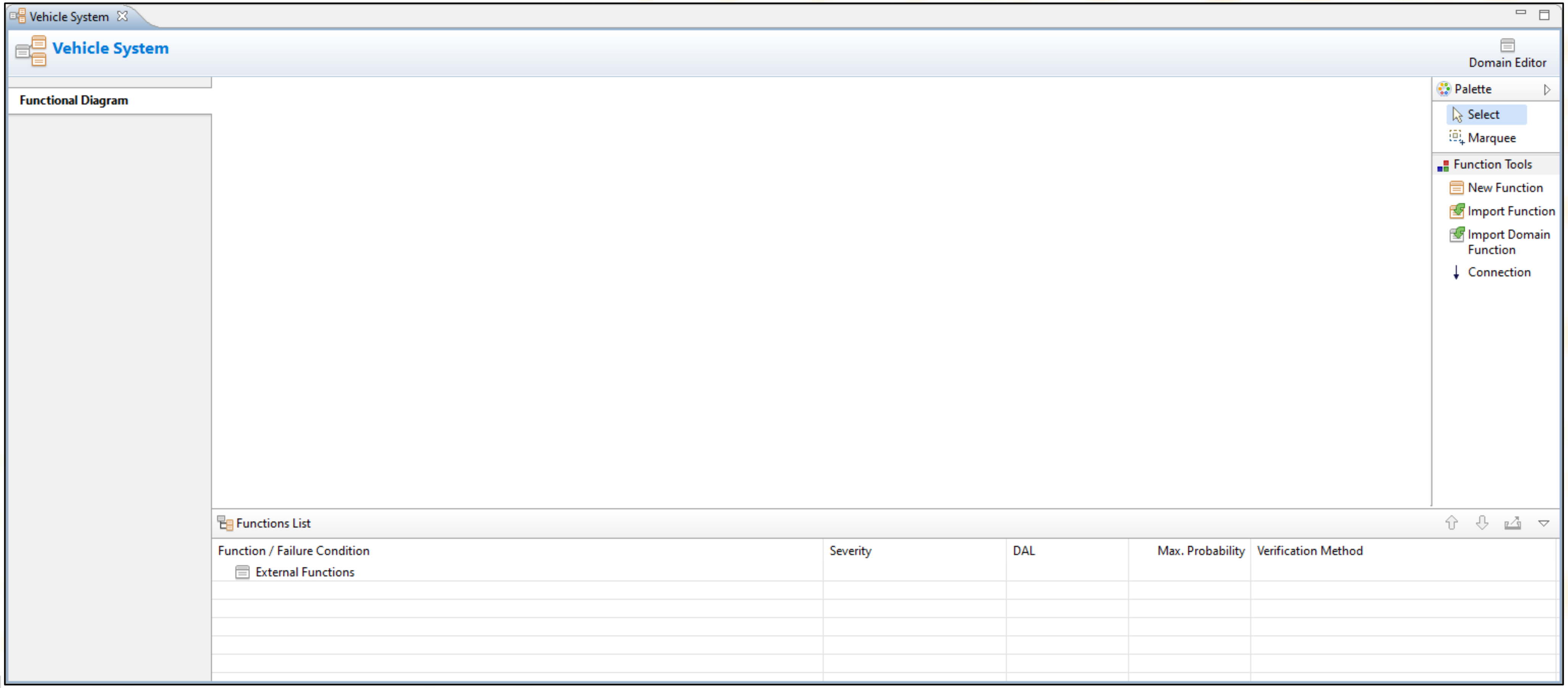
- Select **‘Vehicle System’** in the Project Explorer
- Select **Modeling → Functional Diagram** from main menu
- Alternatively, right-click **‘Vehicle System’** in Project Explorer then select **Functional Diagram**





Session 1.4: Functional Modeling (FHA)

Discussion 1.4.3 Functional Model Editor Layout



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Session 1.4: Functional Modeling (FHA)

DISCUSSION 1.4.3 FUNCTIONAL MODEL EDITOR LAYOUT

The default layout of the Functional Model editor consists of:

- Vertical Tabs (Left): Show Functional Model & active Failure Condition pages
- Functional Model canvas (Centre): The main area where Functions and Functional connections are defined
- Palette (Right): Contains a list of modeling tools, functional connections and function types
- Functions List (bottom): A collapsible area where functions & function details are summarised
- Domain Editor: Option to add external events relating to the functional model

Session 1.4: Functional Modeling (FHA)

Discussion 1.4.3 Functional Model Editor Layout

There are two types of function blocks in the Functional Model:

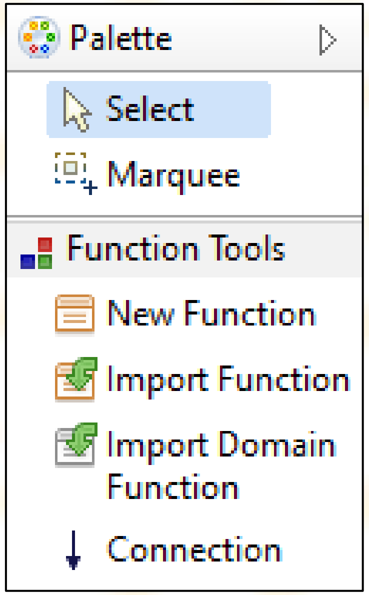
- **Function:** Represents a description of an operation to be performed by the system
- **External event**: An occurrence which has its origin distinct from the aircraft of the system

Session 1.4: Functional Modeling (FHA)

Discussion 1.4.3 Functional Model Editor Layout

There are 6 selections in the Palette view of FHA:

- **Select** – used to select items on the Functional model canvas
- **Marquee** – used to select multiple items on the Functional model canvas
- **New Function** – used to create new functions
- **Import Function** – used to import functions from a different hierarchy
- **Import Domain Function** – imports external functions onto the Functional model canvas
- **Connection** – creates connections and link functions



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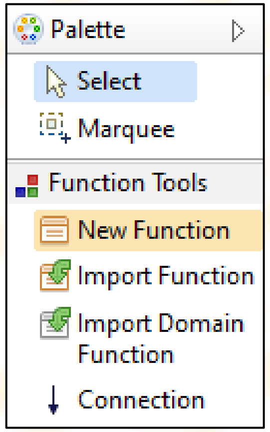
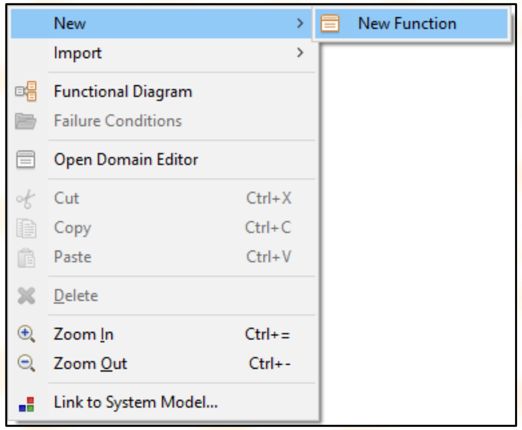
Session 1.4: Functional Modeling (FHA)

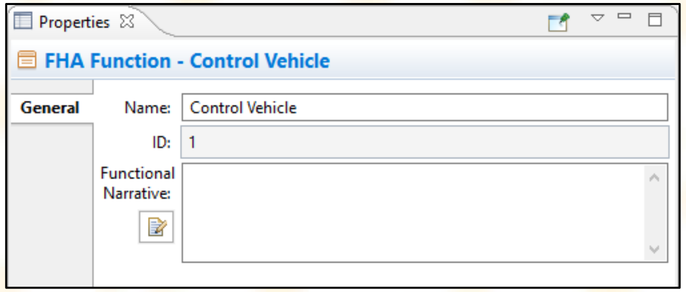
EXERCISE 1.4.4 CREATE FUNCTIONS

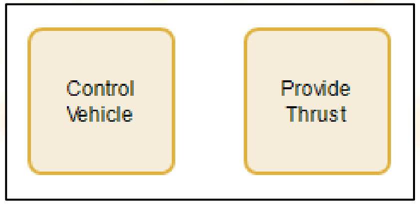
There are two methods to create a function:

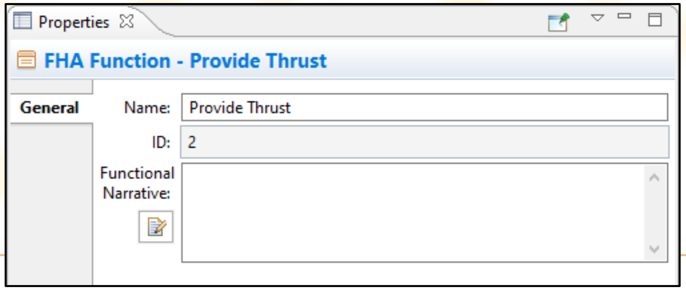
- Method 1:
  - Select **New Function** from the Palette
  - Select on the Functional model canvas to create a Functions on this level
  - Using the Properties viewer, rename the function to **Control Vehicle**
- Method 2:
  - Right click on the Functional model canvas
  - Select **New → New Function**
  - Using the Properties viewer, rename the function to **Provide Thrust**











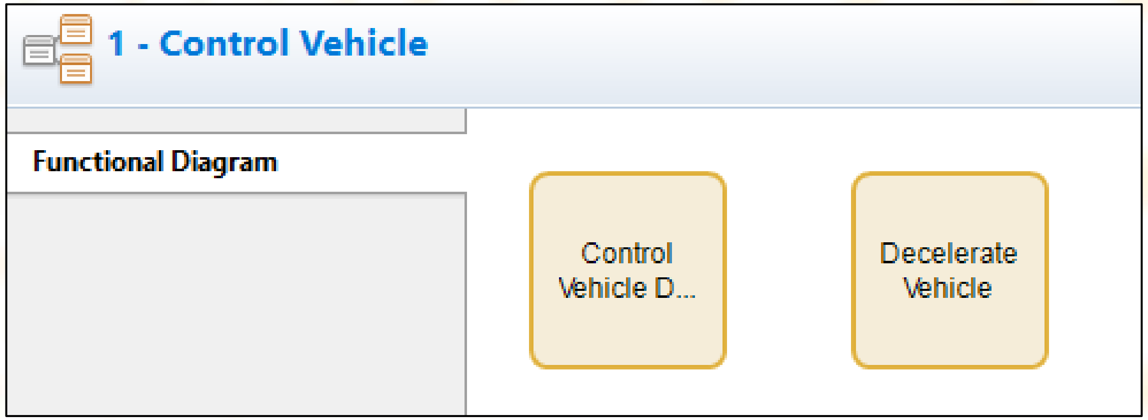
Session 1.4: Functional Modeling (FHA)

Exercise 1.4.4 Create Functions

The FHA Model is a hierarchical model. Functions can be created beneath the higher level functions.

To access the lower level FHA Model:

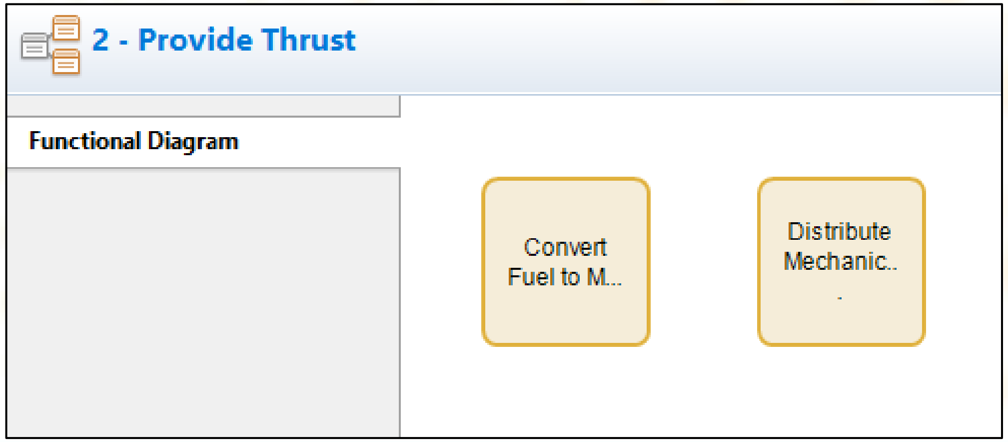
- Double click on the **Control Vehicle** function to view the lower level Functional Diagram
- Create the following functions under the Control Vehicle function:
    - Control Vehicle Direction
    - Decelerate Vehicle

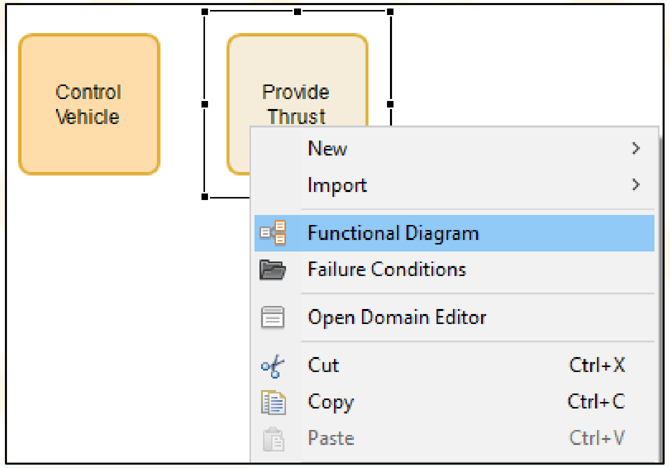


Session 1.4: Functional Modeling (FHA)

EXERCISE 1.4.4 CREATE FUNCTIONS (CONTINUED)

- On the Vehicle System Functional Diagram, right click on the Provide Thrust function
- Select **Functional Diagram**
- Create the following functions under the **Provide Thrust** function:
  - Convert Fuel to Mechanical Motion
  - Distribute Mechanical Motion

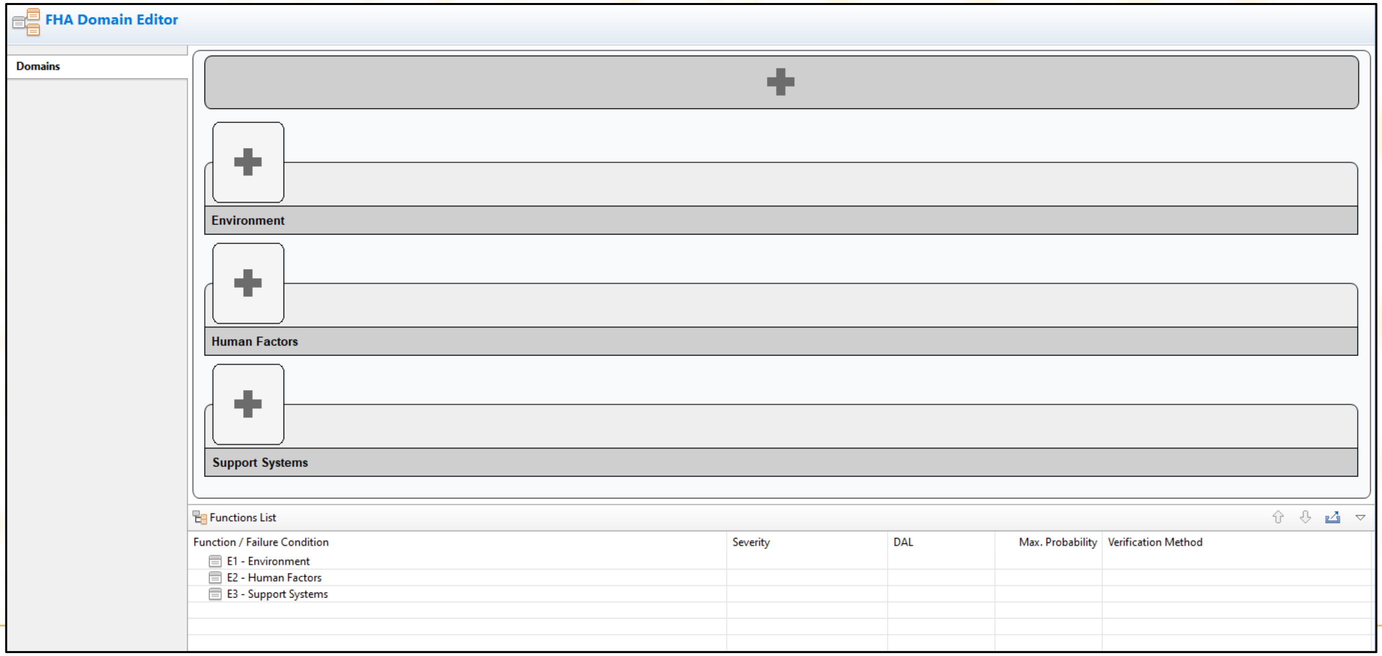




Session 1.4: Functional Modeling (FHA)

Discussion 1.4.5 External Function

- External functions can be captured using the Domain editor. This can be accessed by selecting Domain Editor button in the top right corner of the FHA window.
- The external functions can be assigned to various domains.
  - By default, Environment, Human Factors and Support Systems are provided.

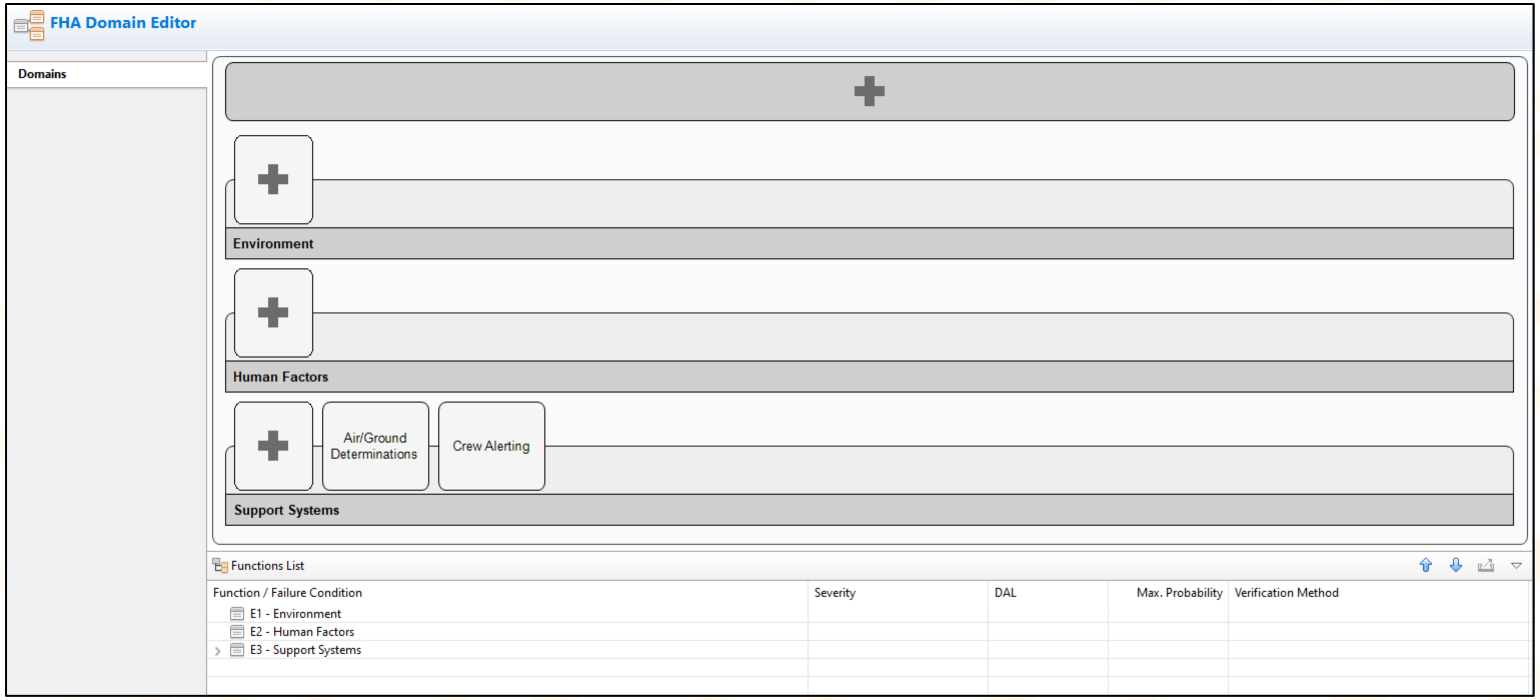


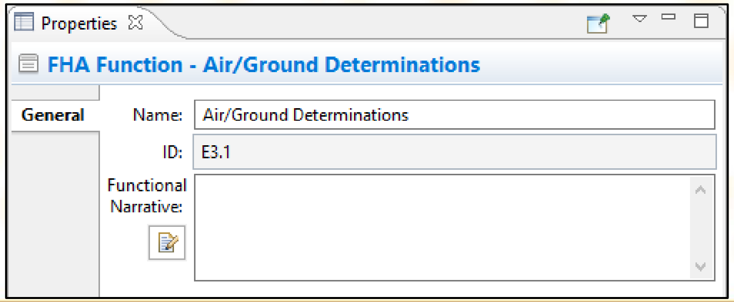
Session 1.4: Functional Modeling (FHA)

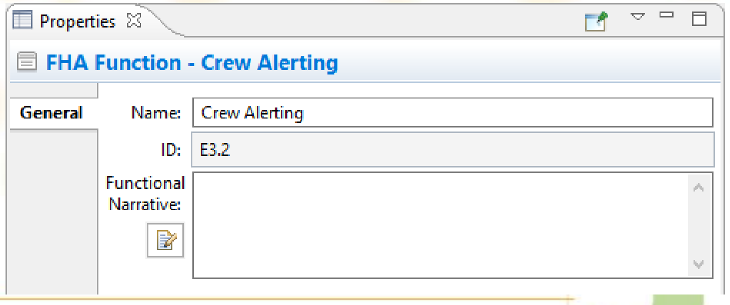
EXERCISE 1.4.5 EXTERNAL FUNCTION

To input External Functions:

- Select Domain Editor
- Within the Support Systems list select + to add 2 external functions
- Rename the external functions using the **Properties** viewer
  - Air/Ground Determinations
  - Crew Alerting







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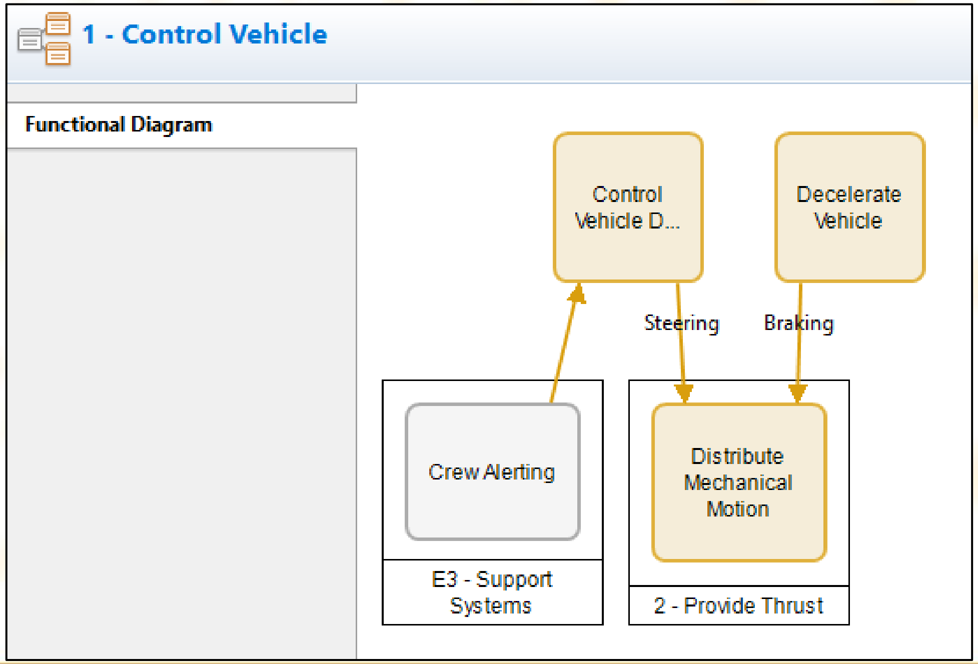
Session 1.4: Functional Modeling (FHA)

Discussion 1.4.4 Import Functions

- When functions are not located in the same Functional diagram, they can be imported and linked to other functions.
- Functions and External functions can be linked using Import Function and Import Domain Function



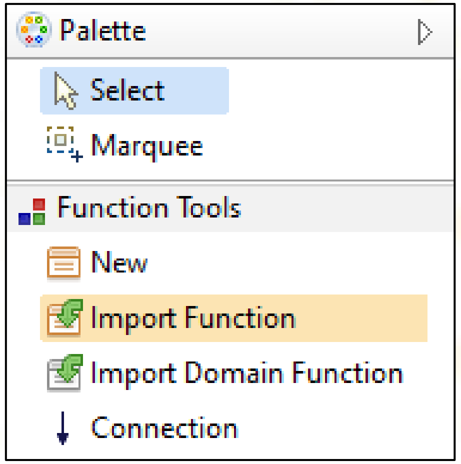
Session 1.4: Functional Modeling (FHA)

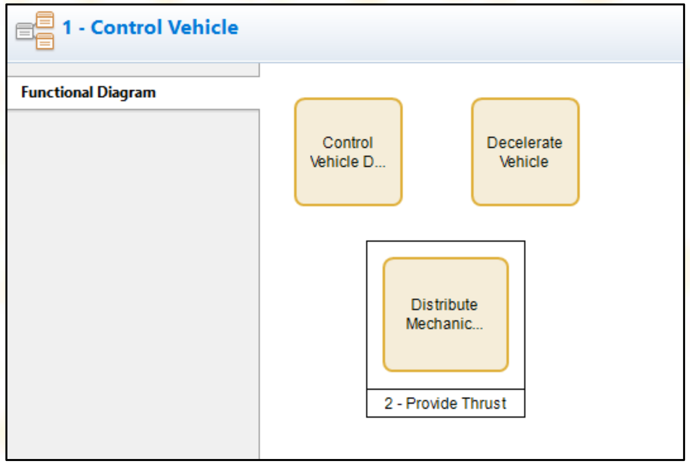
Exercise 1.4.5 Importing Functions

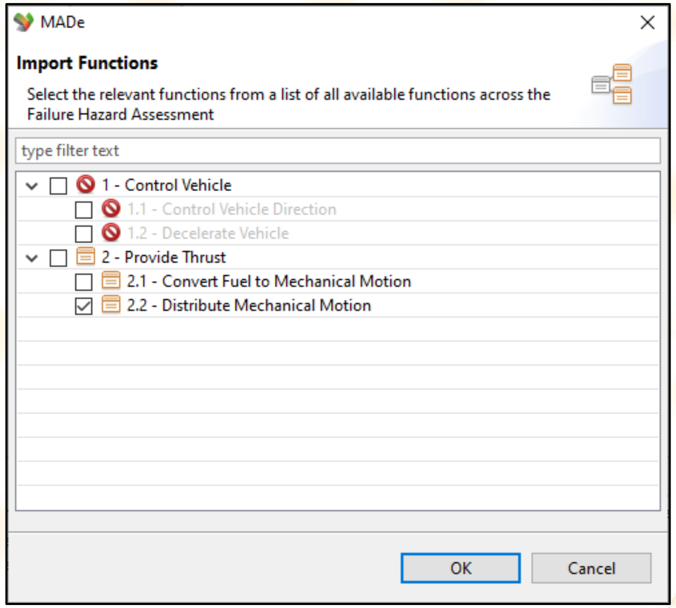
We can import both functions and external functions to associate them to a function block.

In the **Control Vehicle** function, to import a function:

- Select Import Function
- Select the **Distribute Mechanical Motion** check box
- Select OK
- Select on the canvas to add the Function to the diagram





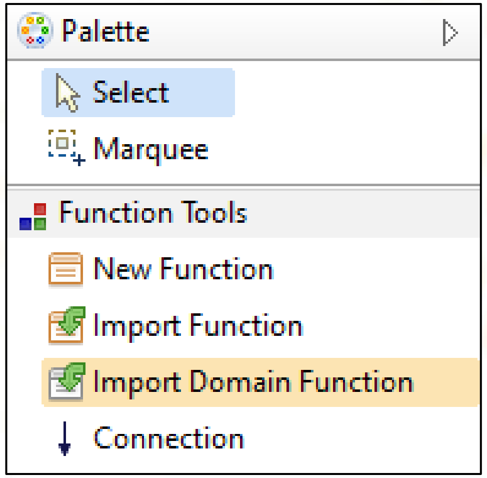


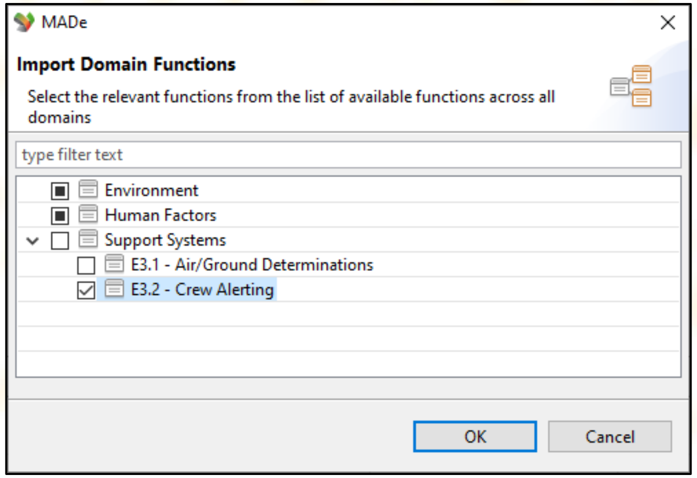
Session 1.4: Functional Modeling (FHA)

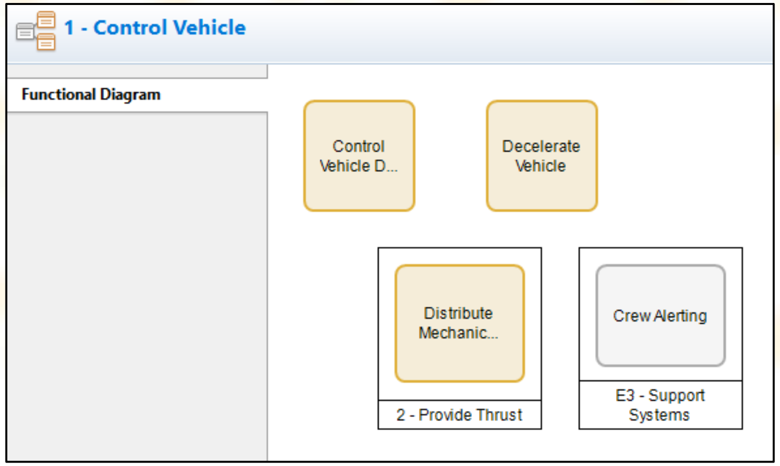
EXERCISE 1.4.5 IMPORTING FUNCTIONS (CONTINUED)

To import an external function:

- In the **Control Vehicle** functional diagram, select Import Domain Function
- Check the **Crew Alerting** box
- Select OK
- Select on the canvas to add the External Function to the diagram





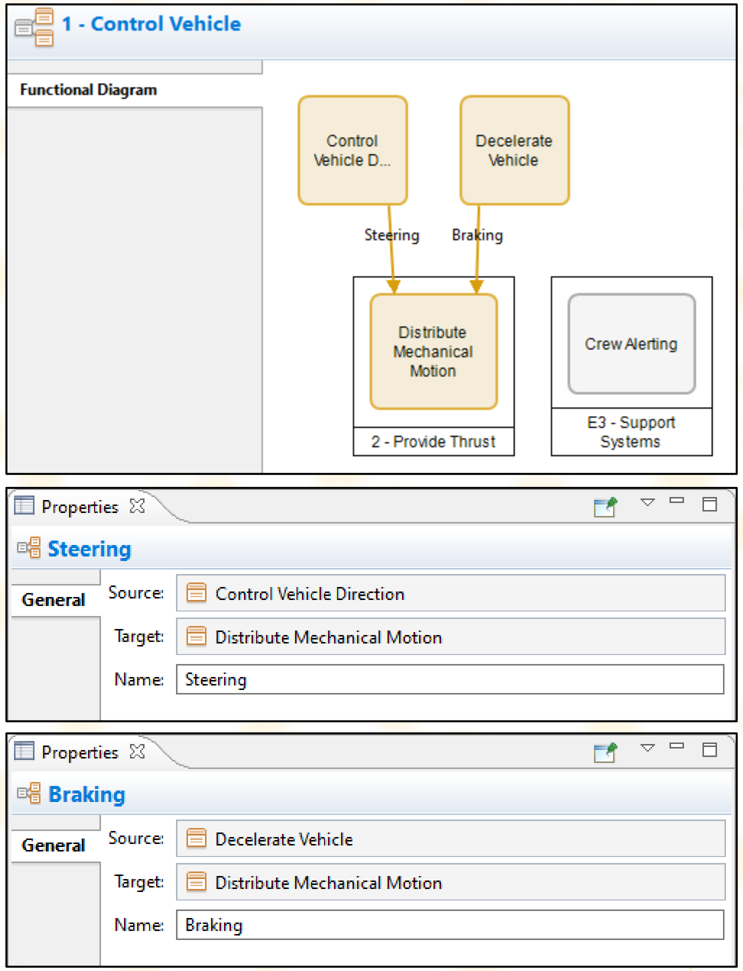


Session 1.4: Functional Modeling (FHA)

Exercise 1.4.5 Create Connections

To create a connection, select Connection from the Palette then click and drag from one function to another (including external functions).

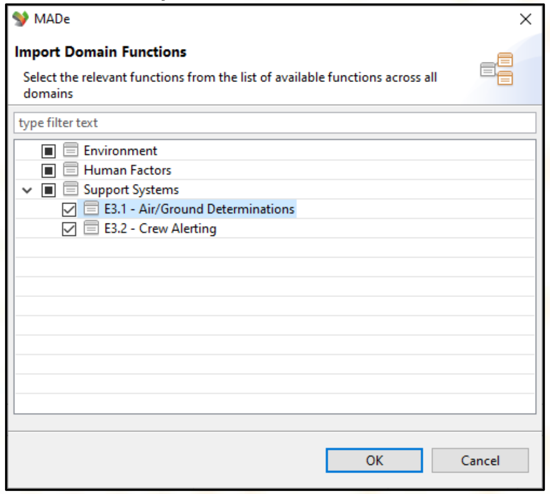
- In the **Control Vehicle f**unctional diagram, create connections to relate:
  - Control Vehicle Direction to Distribute Mechanical Motion
    - Select Connection and link **Control Vehicle Direction** and **Decelerate Vehicle** to **Distribute Mechanical Motion**
    - Select the connection between **Control Vehicle Direction** to **Distribute Mechanical Motion** and using the **Properties** viewer, rename the connection name to **Steering**
  - Decelerate Vehicle to Distribute Mechanical Motion
    - Select on the connection between **Decelerate Vehicle** to **Distribute Mechanical Motion** and using the **Properties** viewer, rename connection name to Decelerate Vehicle to **Braking**

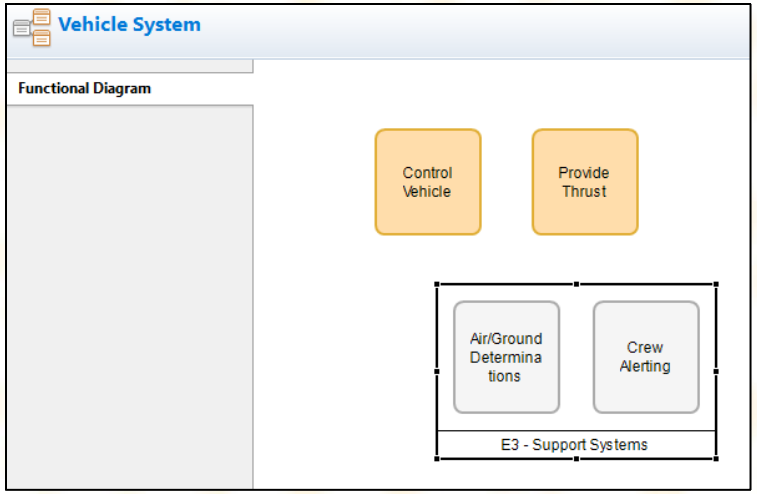


Session 1.4: Functional Modeling (FHA)

Exercise 1.4.5 Create Connections (Continued)

- Create connections to relate:
  - **Air/Ground Determinations** to **Control Vehicle**
    - In the **Vehicle System** functional diagram where **Control Vehicle** is located, select Import Domain Function
    - Select **Air/Ground Determinations** and **Crew Alerting**
    - Select on the system canvas to add to the diagram





❖ Note: If you import multiple external functions, you may need to extend the Domain window to see all imported external functions

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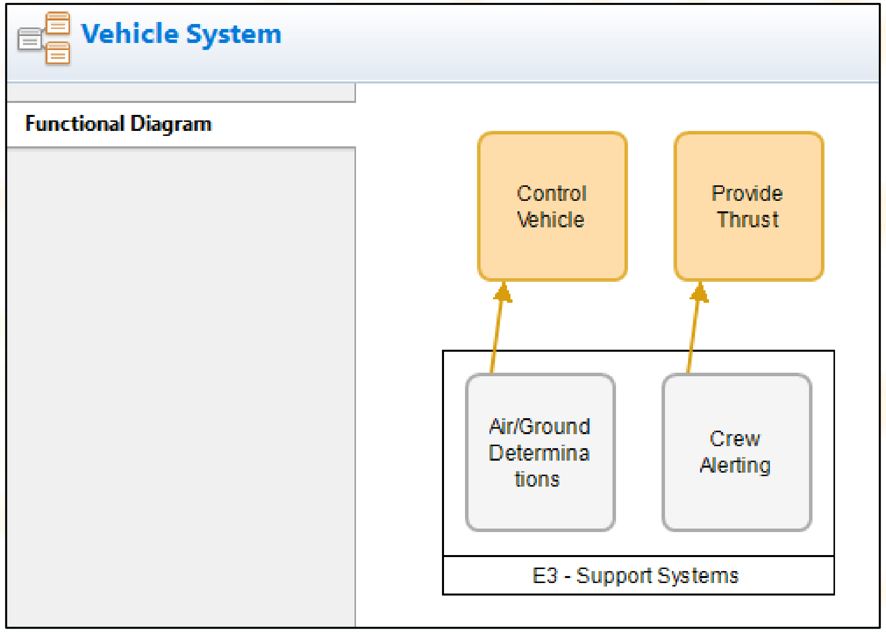
Session 1.4: Functional Modeling (FHA)

EXERCISE 1.4.5 CREATE CONNECTIONS (CONTINUED)

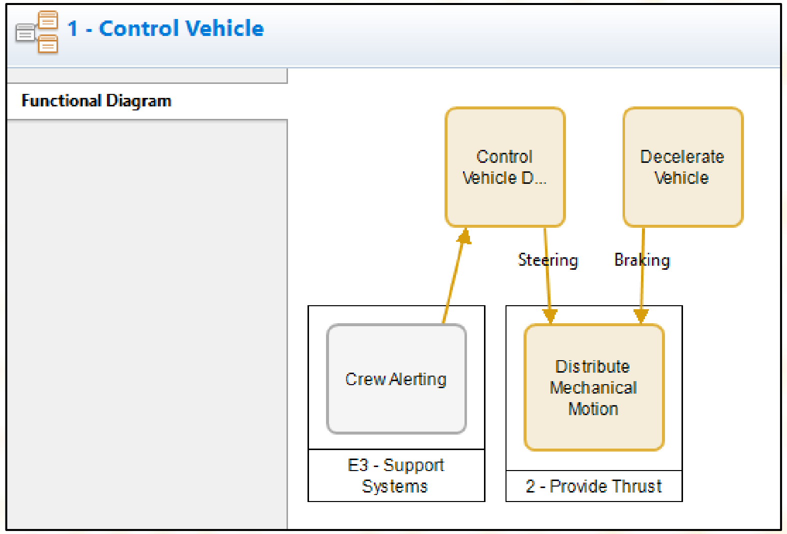
- Create connections to relate:
  - In the **Vehicle System** functional diagram
    - Select ↓ Connection and link **Air/Ground Determinations** to **Control Vehicle** (click on the source and link to target)
    - Create a connection between **Crew Alerting** and **Provide Thrust**

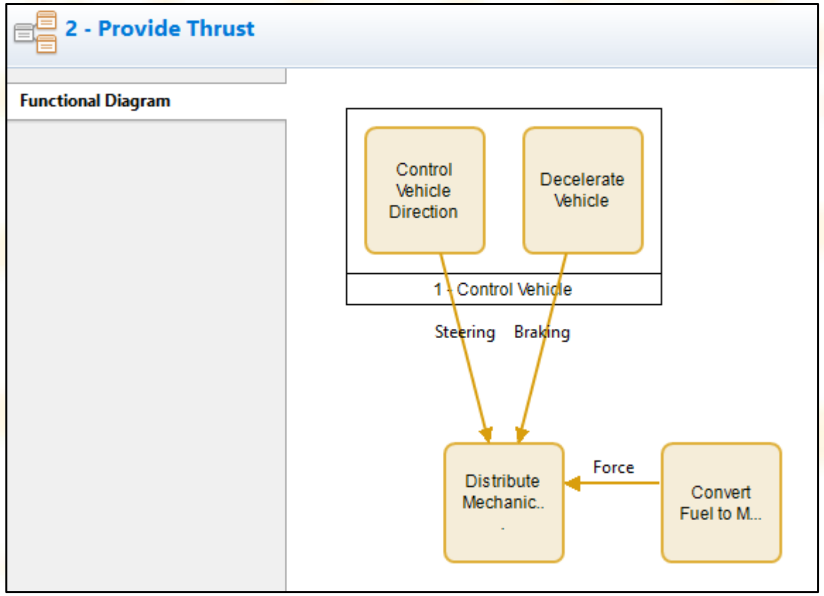


Session 1.4: Functional Modeling (FHA)

EXERCISE 1.4.5 CREATE CONNECTIONS (CONTINUED)

- In the Provide Thrust functional diagram, create a connection to relate:
  - **Convert Fuel to Mechanical Motion** to **Distribute Mechanical Motion**
    - Rename connection label to **Force**
- In Control Vehicle functional diagram, connect **Crew Alerting** to **Control Vehicle Direction**





Session 1.4: Functional Modeling (FHA)

SESSION 1.4 SUMMARY

✓ 1.4.1: Functional Hazards Assessment (FHA) in ARP4761 Context

✓ 1.4.2: Opening Functional Modeling Editor

✓ 1.4.3: Functional Model Editor Layout

✓ 1.4.4: Creating Functions

✓ 1.4.5: Creating Connections

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Session 1.5: System Modeling (Logical & Physical)

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Session 1.5 Outline

1.5.1: Advanced Properties

1.5.2: System Model & Boundary

1.5.3: Modeling Subsystems & Components (Logical Blocks)

1.5.4: Modeling Parts (Physical Blocks)

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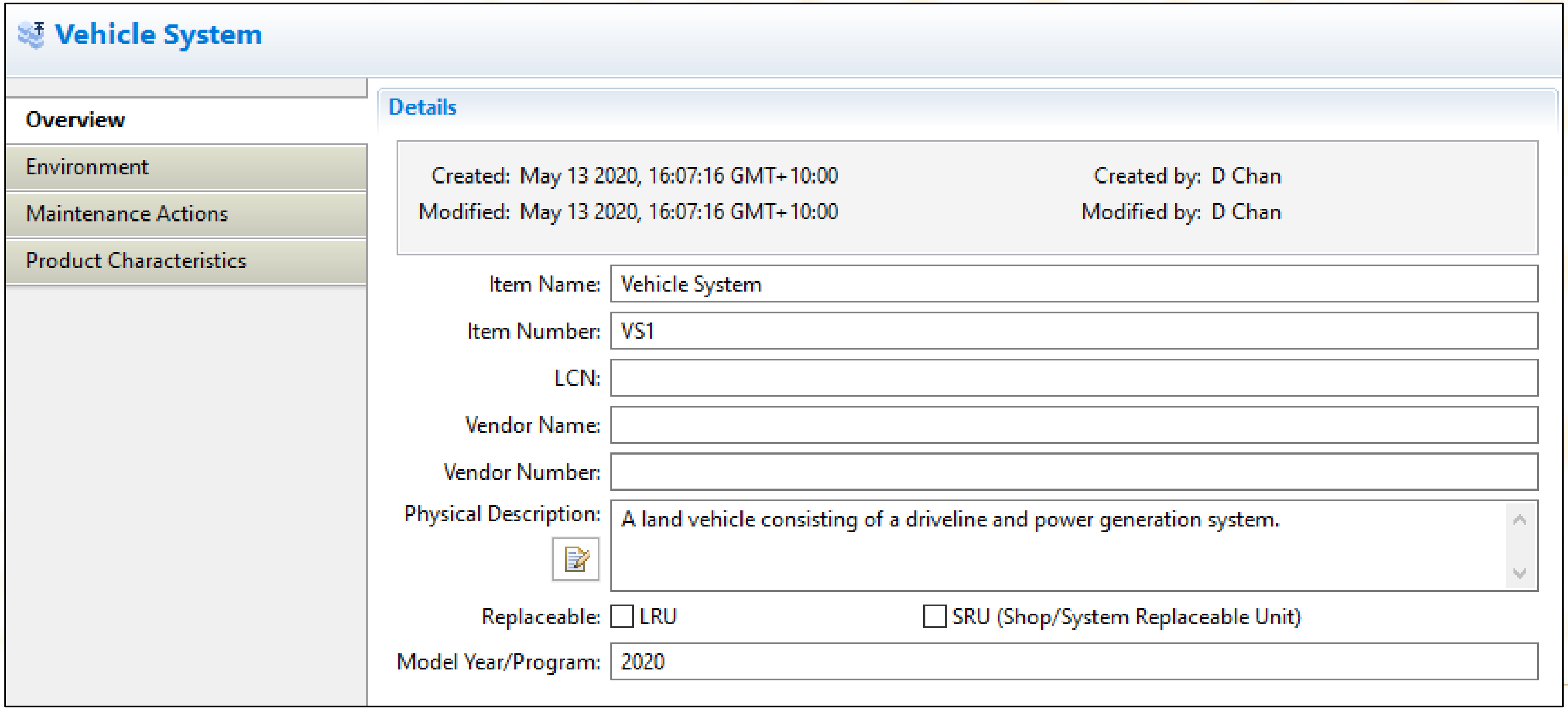
Session 1.5: System Modeling (Logical & Physical)

Discussion 1.5.1 Advanced Properties

- The Advanced Properties Overview page shows where high-level/detailed information of a system or item can be stored.

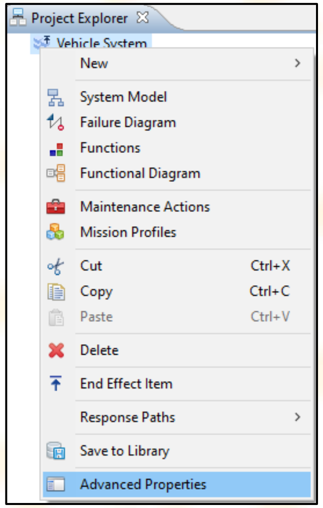


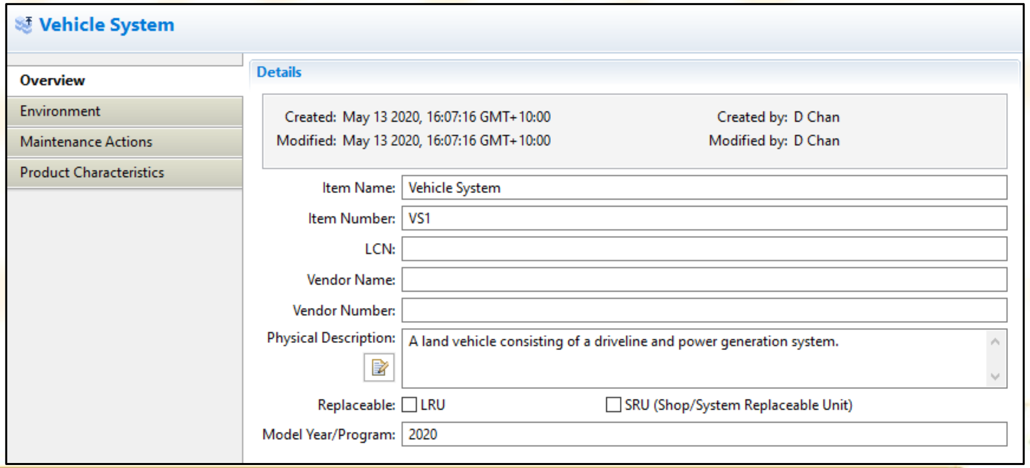
Session 1.5: System Modeling (Logical & Physical)

EXERCISE 1.5.1 ADVANCED PROPERTIES

To open the Advanced Properties editor:

- Right-click **'Vehicle System'** in the Project Explorer
- Select **Advanced Properties**
- Populate the following fields:
  - Item Number: **VS1**
  - Physical Description: **A land vehicle consisting of a driveline and power generation system.**
  - Enter a Model Year/Program: **2020**

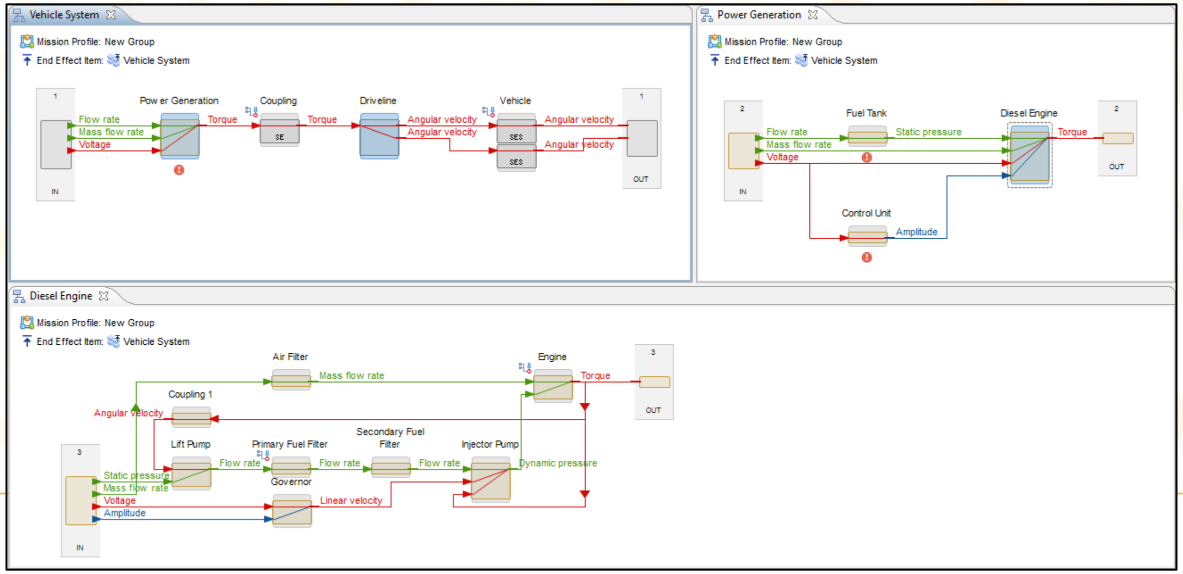




Session 1.5: System Modeling (Logical & Physical)

Discussion 1.5.2 System Model & Boundary

- System Model is the canvas for all MADe modeling work
- Shows the contents (children) of an item and the boundary MUX bars for that item
- Defines the scope of the system
- Represented by Input and Output MUX bars
- MUX Bars define the input and output flows for the item

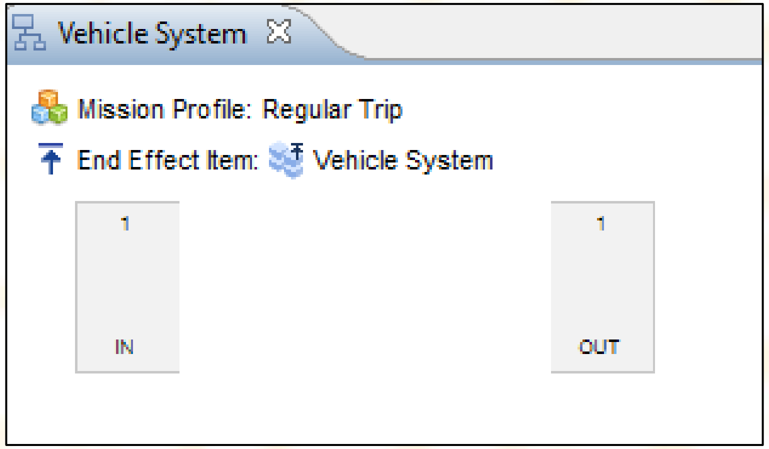


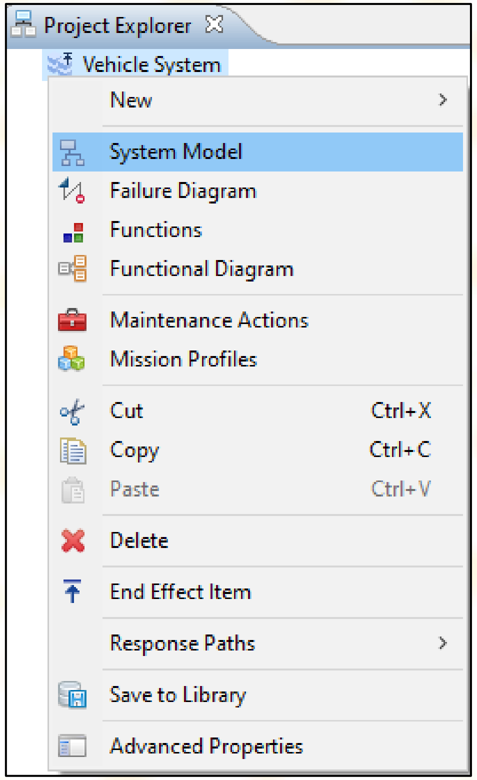
Session 1.5: System Modeling (Logical & Physical)

EXERCISE 1.5.2 SYSTEM MODEL & BOUNDARY

To open the System Model:

- Right-click the **‘Vehicle System’**
- Select **System Model**
- Select the **IN** & **OUT** MUX bars
- Shift it away from End Effect Item text





❖ Note: Double-clicking **‘Vehicle System’** will also open the System Model

❖ Note: Select the grid icon in the toolbar to show gridlines

Session 1.5: System Modeling (Logical & Physical)

Discussion 1.5.3 Modeling Subsystems & Components (Logical Blocks)

- What does system modeling involve?
  - Representing the structure and functionality of system of interest in MADe
- Does system modeling require defined hardware?
  - Before beginning modeling the user should decide how detailed the model needs to be based upon
    - System complexity
    - Required analyses
- How does system modeling differ from functional modeling?
  - A functional model is a simplistic model outlining the functions a system should achieve
  - System modeling in MADe includes a hierarchical structure of items
  - Items have functions associated with them and interact with one another via causal relationships between the functions

Session 1.5: System Modeling (Logical & Physical)

Discussion 1.5.3 Modeling Subsystems & Components (Logical Blocks)

- A taxonomy of system elements in the System Model is shown in the table below:

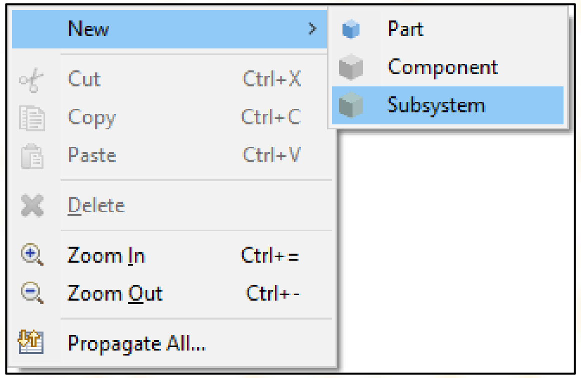
Term	Icon	Definition
System		A grouping of sub-systems, components and parts which interact to fulfil a common function. A system is the highest level of indenture within a MADe project.
Subsystem		A grouping of components or parts that work together to fulfil a common function.
Component		A model item that performs a function and forms part of a larger system.
Pair		The combination of two parts, created by assigning a physical connection between them. A pair possesses functions and failures, and may be connected up to the failure of a component.
Part		The lowest possible level of hierarchy in MADe. A part on its own cannot perform a function.

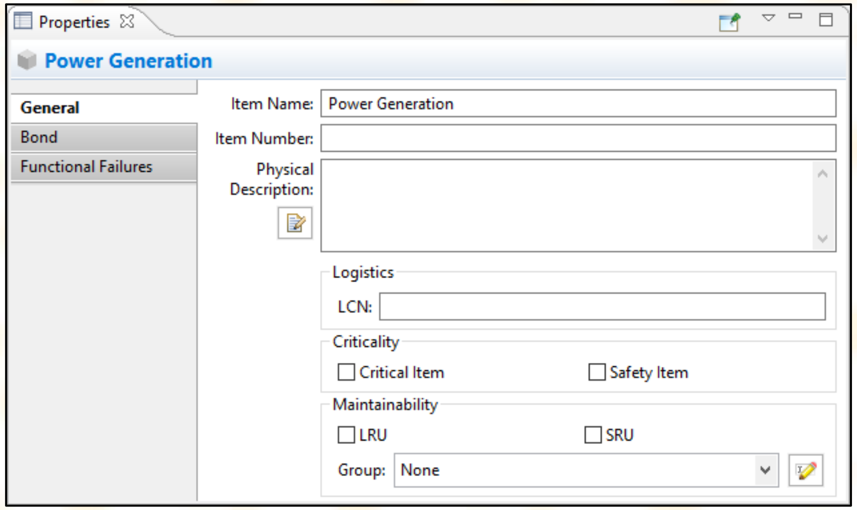
Session 1.5: System Modeling (Logical & Physical)

EXERCISE 1.5.3 MODELING SUBSYSTEMS & COMPONENTS (LOGICAL BLOCKS)

To model Subsystems:

- Right-click on the white-space on the system model
- Select **New → Subsystem**
- Select the Subsystem and using the Properties viewer, Rename the Item name to **Power Generation**



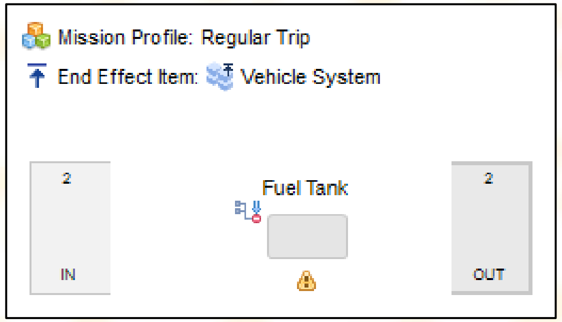


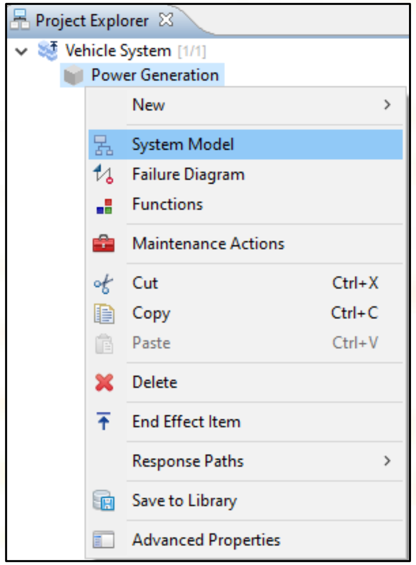
❖ Note: You can move a model item by clicking and dragging it

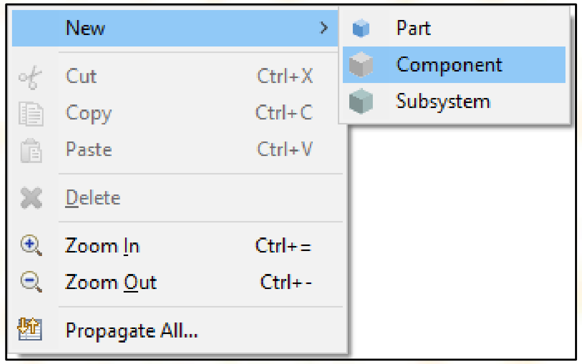
Session 1.5: System Modeling (Logical & Physical)

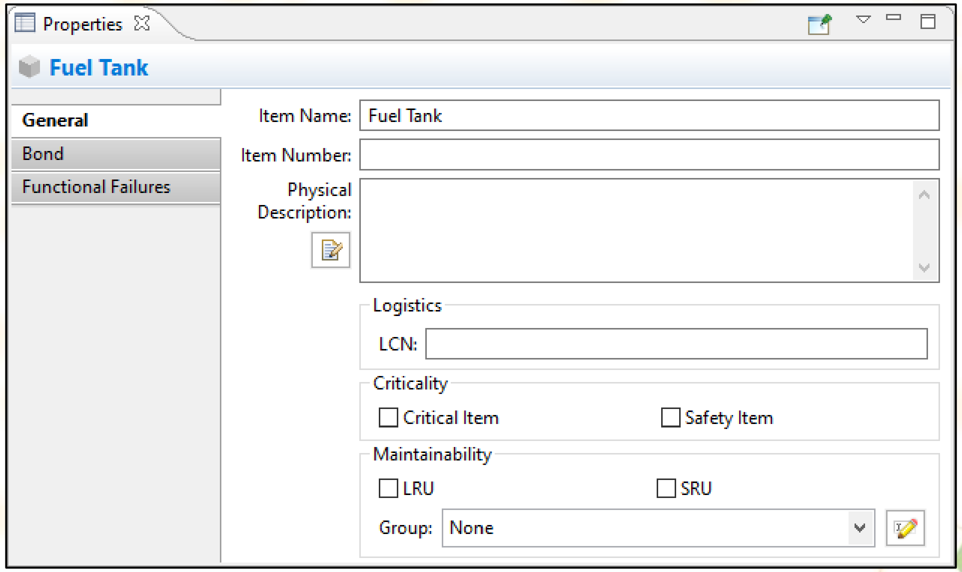
EXERCISE 1.5.3 MODELING SUBSYSTEMS & COMPONENTS (LOGICAL BLOCKS) (CONTINUED)

- Right-click the **‘Power Generation’** and select **System Model**
- Right-click the system canvas and select **New → Component**
- Select the new component and using the **Properties** viewer edit the name to **‘Fuel Tank’**







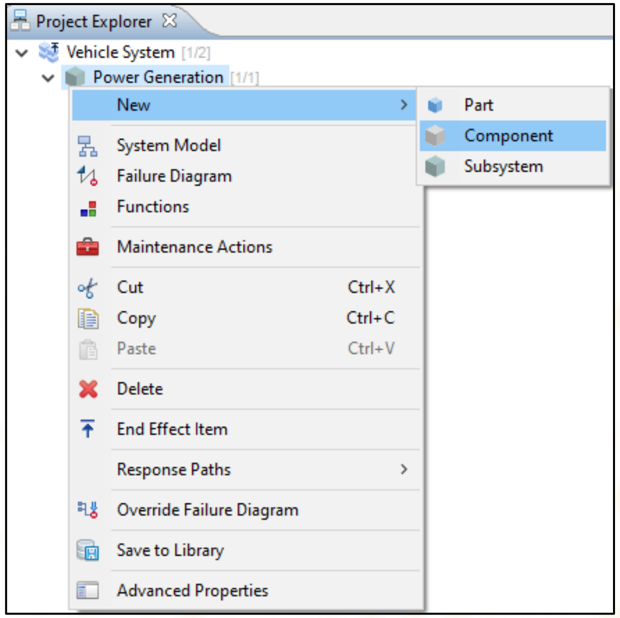


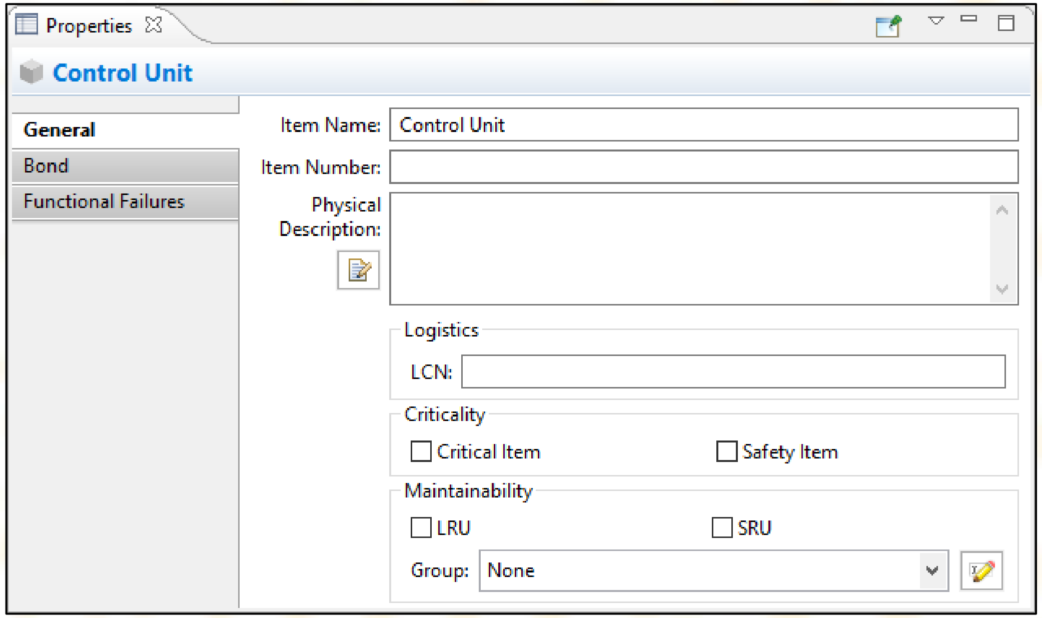
Session 1.5: System Modeling (Logical & Physical)

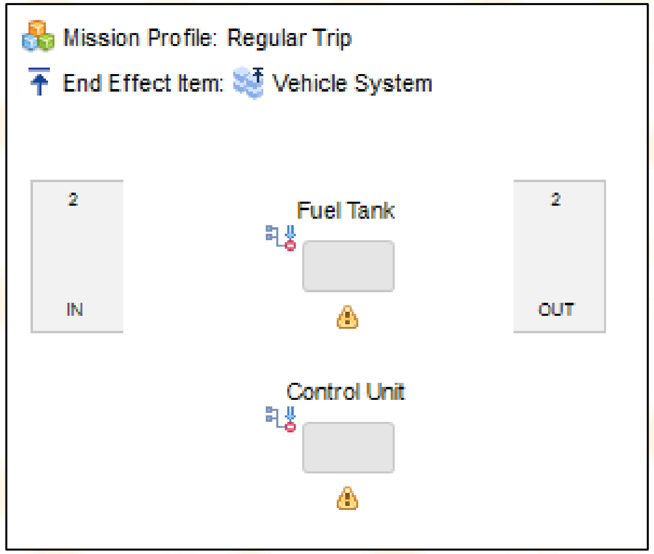
Exercise 1.5.3 Modeling Subsystems & Components (Logical Blocks) (Continued)

➢Right-click the **‘Power Generation’** subsystem in the project explorer and select: **New → Component**

➢Using the Properties viewer, edit the name to **‘Control Unit’**





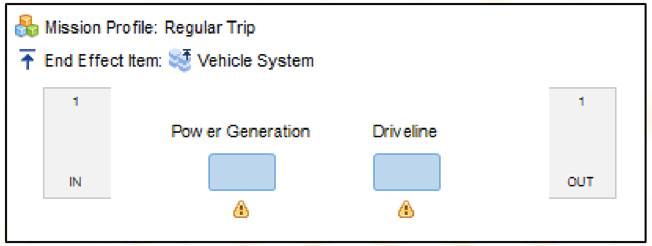


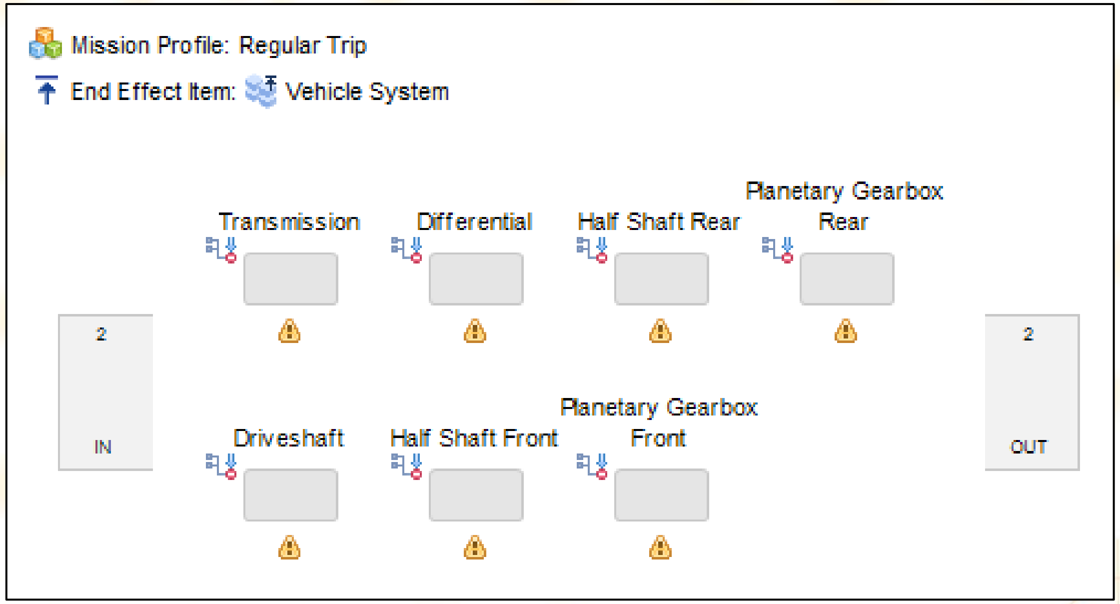
❖ Note: You can create a new component by selecting in the icon toolbar

Session 1.5: System Modeling (Logical & Physical)

EXERCISE 1.5.3 MODELING SUBSYSTEMS & COMPONENTS (LOGICAL BLOCKS) (CONTINUED)

- Create a new subsystem in **‘Vehicle System’**
- Rename the subsystem to **‘Driveline’**
- Open the **‘Driveline’** system model and create the following 7 driveline components:
  - **Transmission**
  - **Driveshaft**
  - **Differential**
  - **Half Shaft Front**
  - **Half Shaft Rear**
  - **Planetary Gearbox Front**
  - **Planetary Gearbox Rear**

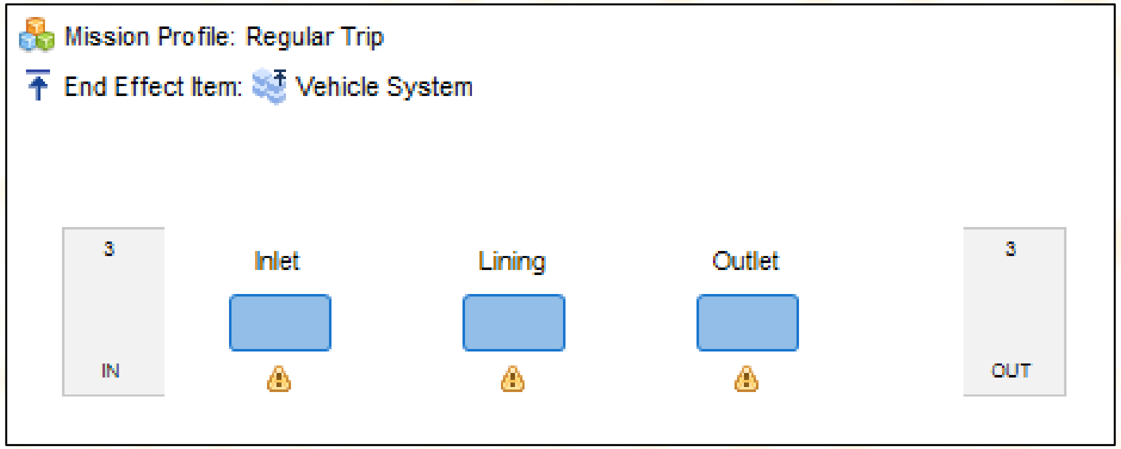




Session 1.5: System Modeling (Logical & Physical)

Discussion 1.5.4 Modeling Parts (Physical Blocks)

- Parts represent the most granular, physical level of detail in a MADe System Model
- Loading characteristics, features and environmental factors are attributed to part-level items
- Parts do not perform individual functions – instead part-pairs perform a function
- Parts interact with the logical model via failure diagram – do not connect directly to MUX bars

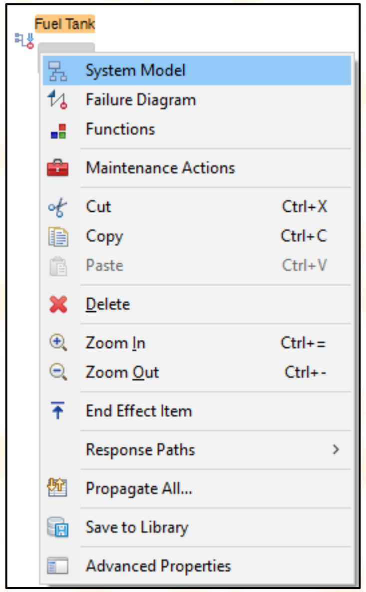


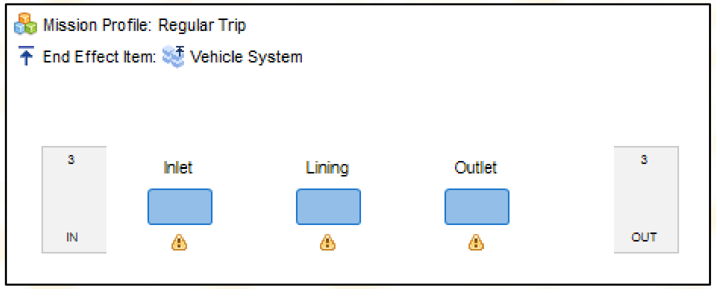
Session 1.5: System Modeling (Logical & Physical)

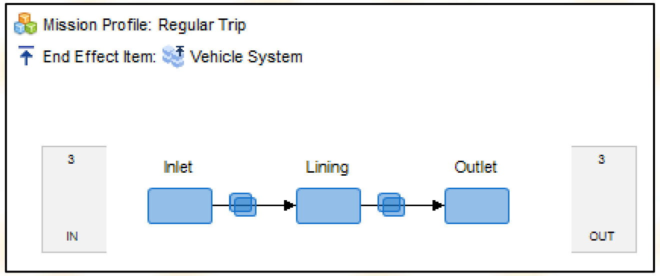
EXERCISE 1.5.4 MODELING PARTS (PHYSICAL BLOCKS)

To create parts:

- ➢ Open the **'Fuel Tank'** System Model
- ➢ Create two new parts
- ➢ Edit the names of the parts to: **'Inlet'** and **'Outlet'**
- ➢ Use the Palette window and search for **'Lining'**
- ➢ Drag this Palette part onto the canvas

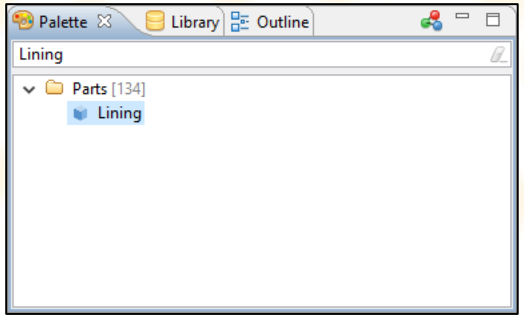






To create a part-pair Connection:

- ➢Select ↓ from the toolbar to create a connection
- ➢Left-click from the **'Inlet'** to the **'Lining'**
- ➢Repeat for the **'Lining'** and **'Outlet'**



Session 1.5: System Modeling (Logical & Physical)

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Session 1.5 Summary

- ✓ 1.5.1: Advanced Properties
- ✓ 1.5.2: System Model & Boundary
- ✓ 1.5.3: Modeling Subsystems & Components (Logical Blocks)
- ✓ 1.5.4: Modeling Parts (Physical Blocks)

Session 1.6: System Modeling (Functions)

Session 1.6 Outline

1.6.1: Functional Modeling

1.6.2: System & Subsystem Functions and Flows

1.6.3: Component Functions and Flows

1.6.4: Pair Functions and Flows

1.6.5: Connecting Model Items

Session 1.6: System Modeling (Functions)

Discussion 1.6.1 Functional modeling

- **Objective**: Defining the functions and flows for a system and its items

MADe has a defined functions taxonomy to assist modeling and increase model repeatability

- **Functions**: A description of an operation to be performed by a device, artifact or item, expressed as a verb
- A list of MADe function categories found is listed below:

Category	Definition
Branch	To cause a material or energy to no longer be joined or mixed.
Channel	To cause a material or energy to move from one location to another location.
Connect	To bring two or more energies or materials together.
Control	To alter or govern the size or amplitude of material, signal or energy.
Convert	To change from one form of energy or material to another.
Provide	To accumulate or provide material or energy.
Signal	To provide information.
Stop	To cease, or prevent, the transfer of a material, signal or energy.
Support	To firmly fix a material into a defined location, or secure an energy into a specific course.

Session 1.6: System Modeling (Functions)

DISCUSSION 1.6.1 FUNCTIONAL MODELING (CONTINUED)

- MADe has a defined flows taxonomy to assist modeling and increase model repeatability
- **Flow**: A change in material, energy or signal with respect to time, expressed as the object of a function
- Flows represent the interfaces throughout the system
- A list of MADe flow categories is listed below:

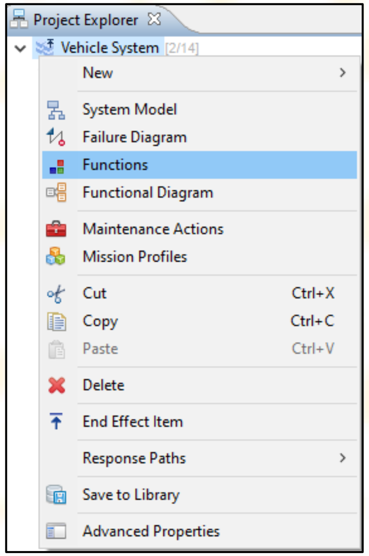
Category	Definition
Energy	Any flow that is characterized by the exchange of energy.
Material	Any flow that is characterized by the exchange and/or interaction of material.
Signal	Any flow that is characterized by the exchange of information.

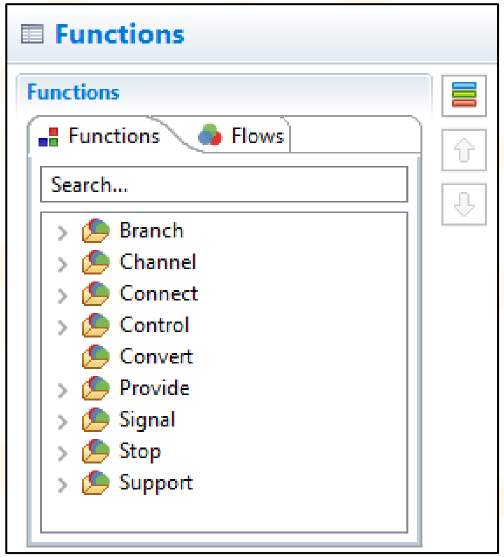
Session 1.6: System Modeling (Functions)

EXERCISE 1.6.2 SYSTEM & SUBSYSTEM FUNCTIONS AND FLOWS

To assign functions and flows:

- Right-click on the **'Vehicle System'** in the Project Explorer and select **Functions**
- This action will open the Functions window where the following are defined:
  - System Function
  - Flow Property (In Flows and Out Flows)

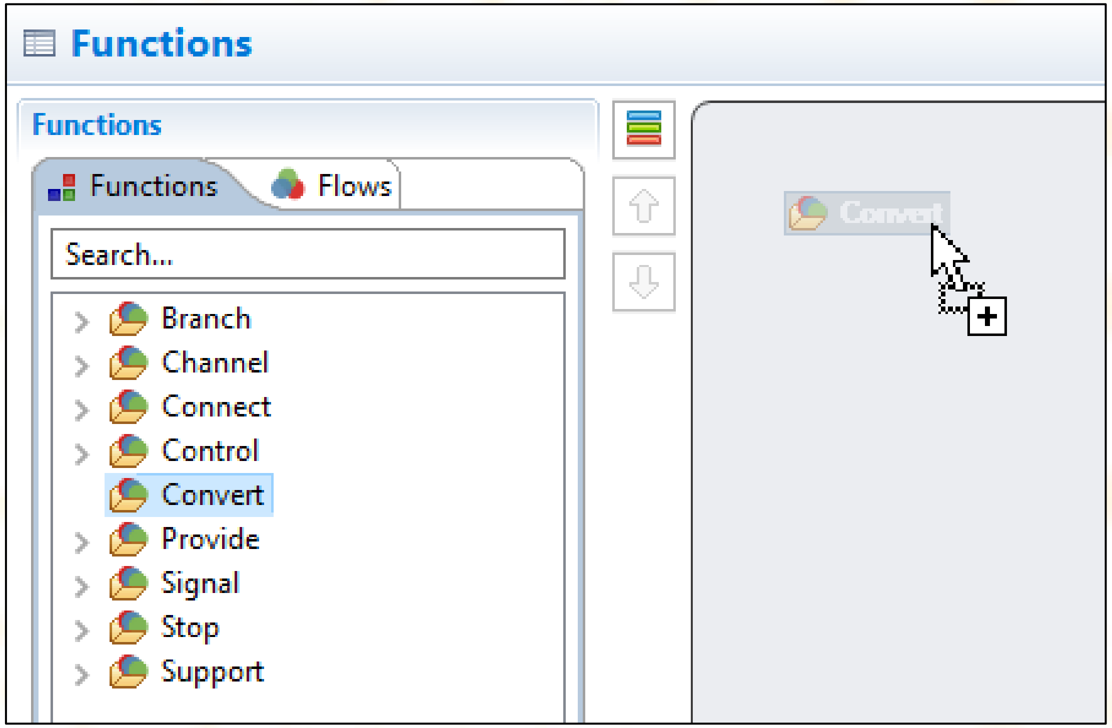




Session 1.6: System Modeling (Functions)

Exercise 1.6.2 System & Subsystem Functions and Flows (Continued)

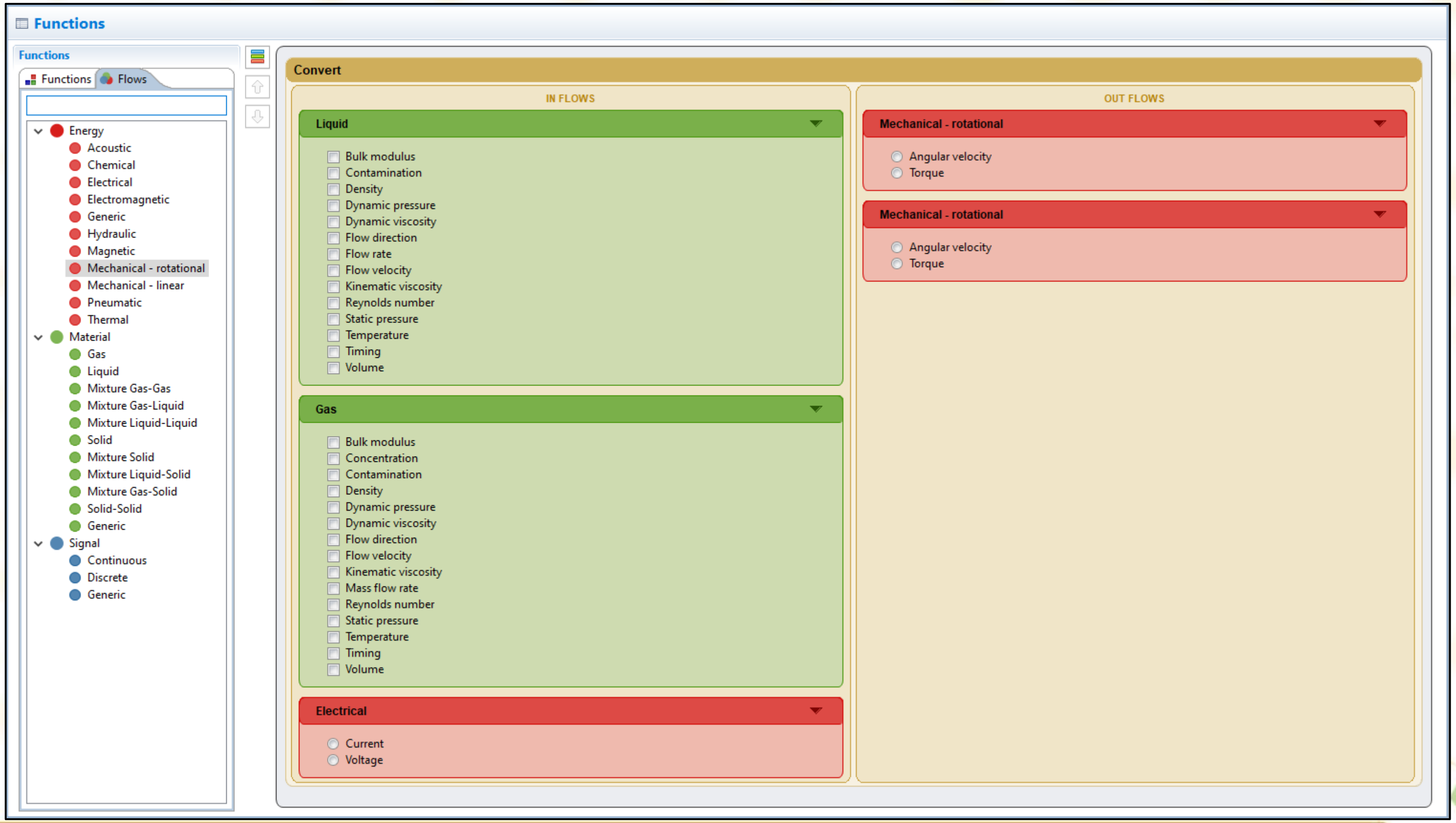
- Locate the **Convert** function
- Click-and-drag to grey area to assign function



Session 1.6: System Modeling (Functions)

EXERCISE 1.6.2 SYSTEM & SUBSYSTEM FUNCTIONS AND FLOWS (CONTINUED)

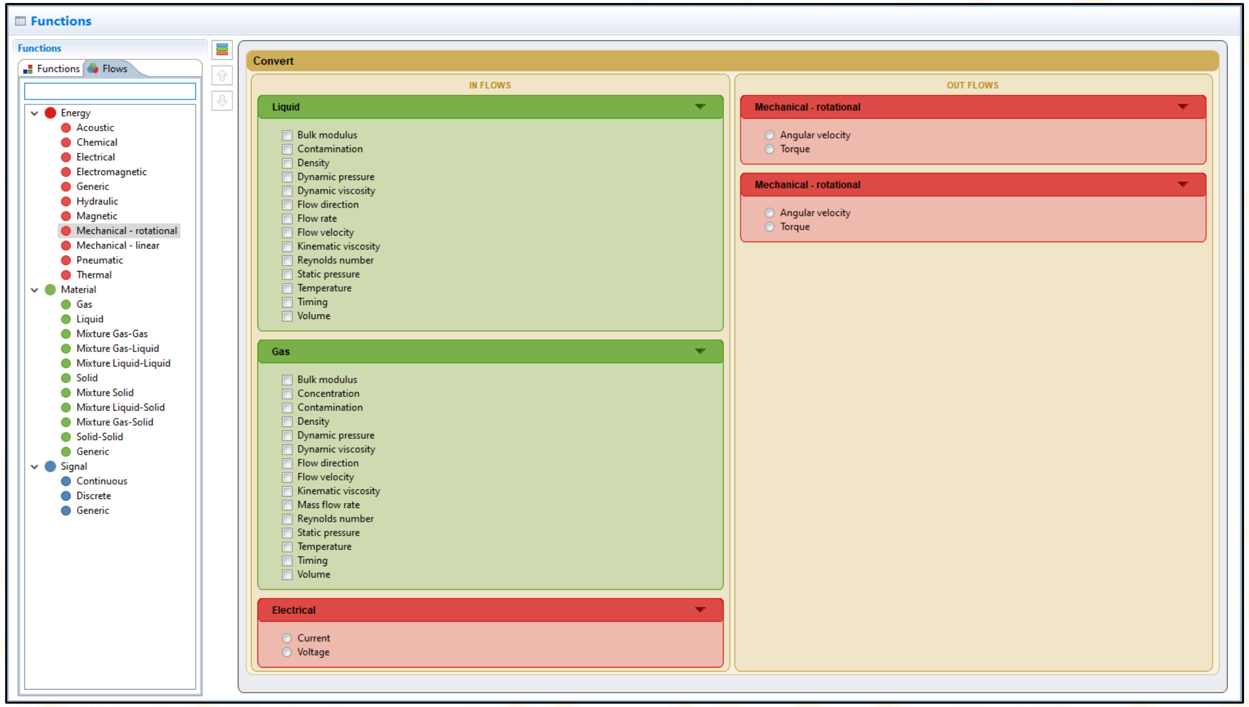
- Locate and select the Flows tab (this will be automatic selected after adding the first function)
- Click-and-drag into the **In Flows**:
  - **Liquid** (Material)
  - **Gas** (Material)
  - **Electrical** (Energy)
- Click-and-drag into the **Out Flows**:
  - **Mechanical – rotational** (Energy) (x2)

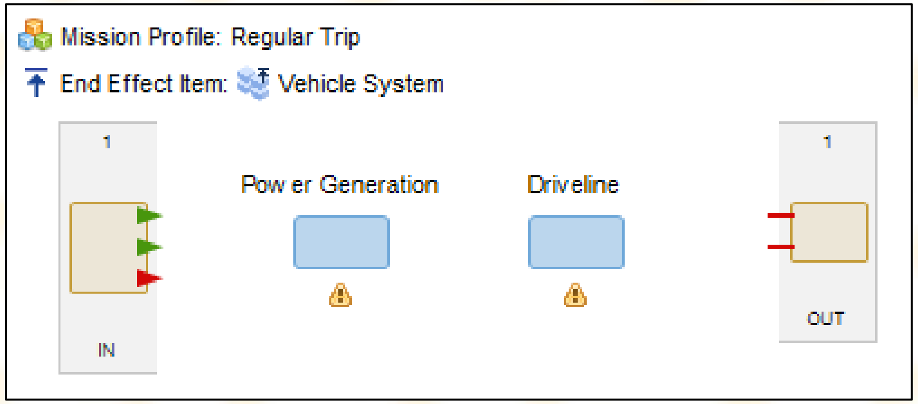


Session 1.6: System Modeling (Functions)

Exercise 1.6.2 System & Subsystem Functions and Flows (Continued)

- The completed functions editor should look like the image on the left
- System Model shows IN/OUT mux bars with a function and input & output flows





Session 1.6: System Modeling (Functions)

Exercise 1.6.2 System & Subsystem Functions and Flows (Continued)

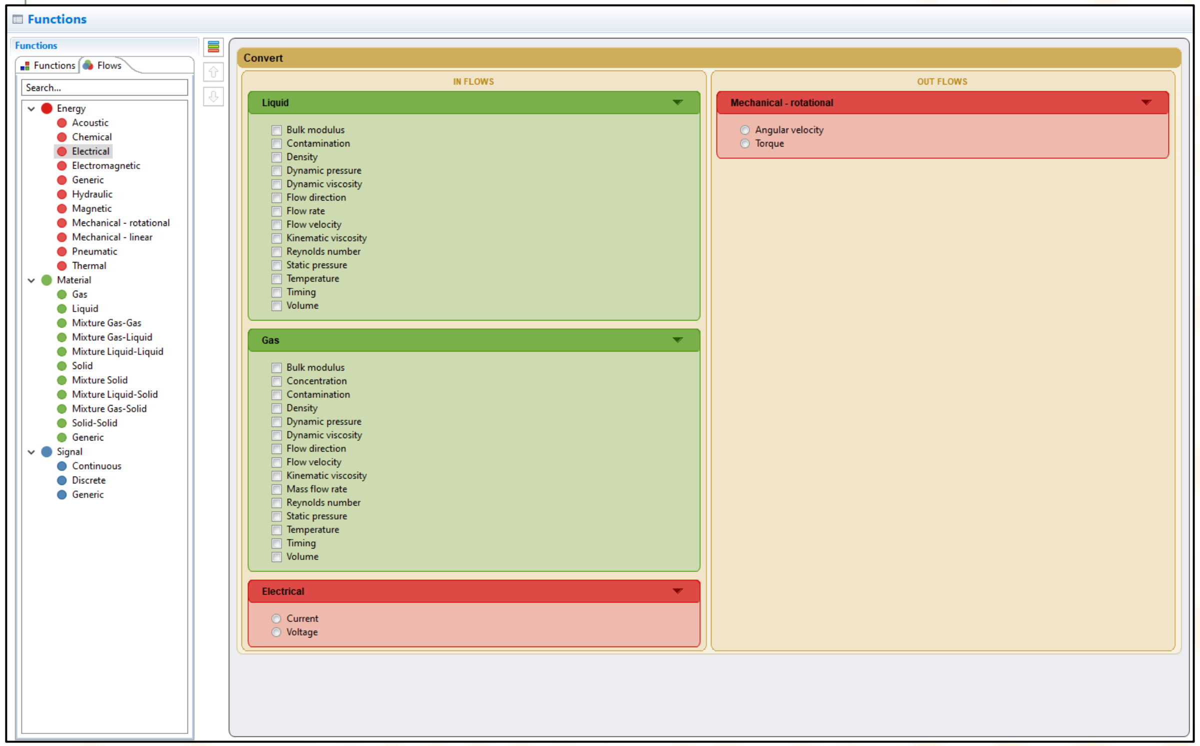
- Repeat function editor steps for the **'Power Generation'** & **'Driveline'** subsystem using the table below

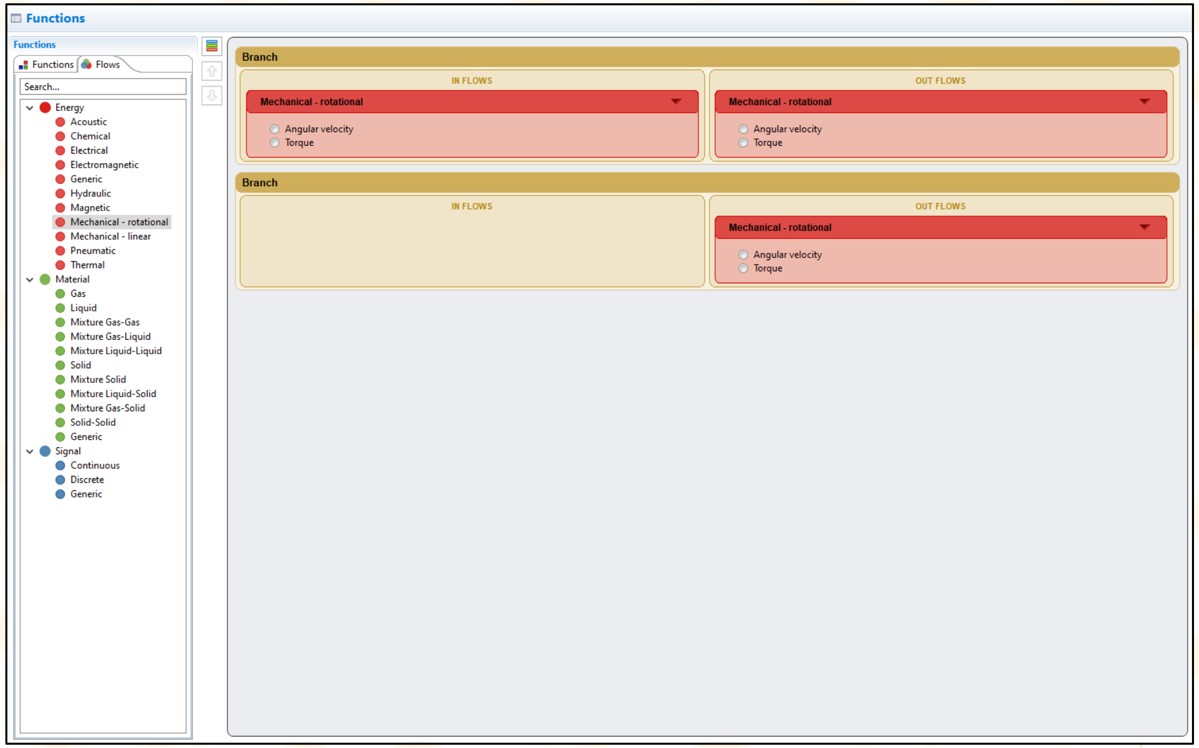
Subsystem	Functions	Input Flows	Output Flows
Power Generation	Convert	Liquid	Mechanical – rotational
		Gas	
		Electrical	
Driveline	Branch	Mechanical – rotational	Mechanical – rotational
	Branch		Mechanical – rotational

Session 1.6: System Modeling (Functions)

EXERCISE 1.6.2 SYSTEM & SUBSYSTEM FUNCTIONS AND FLOWS (CONTINUED)

➢Completed functions editors for **‘Power Generation’** & **‘Driveline’** subsystems are shown below





Session 1.6: System Modeling (Functions)

DISCUSSION 1.6.3 COMPONENT FUNCTIONS AND FLOWS

- Functional modeling is a top-down process however connecting flows are a bottom-up process
  - E.g. Define System Functions, then Subsystem, then Components etc.
  - E.g. Flows between components are connected, then subsystem flows, then flows to the system
- Component functions should relate to subsystem functions
  - E.g. If a subsystem function is to ‘provide torque’, then a component function could be to ‘convert torque’
- Flow properties represent the measurable attributes of a flow
- Causality is defined in components based on the relationship between input and output flows
- Once connected together a subsystem will inherit flow paths from its children items

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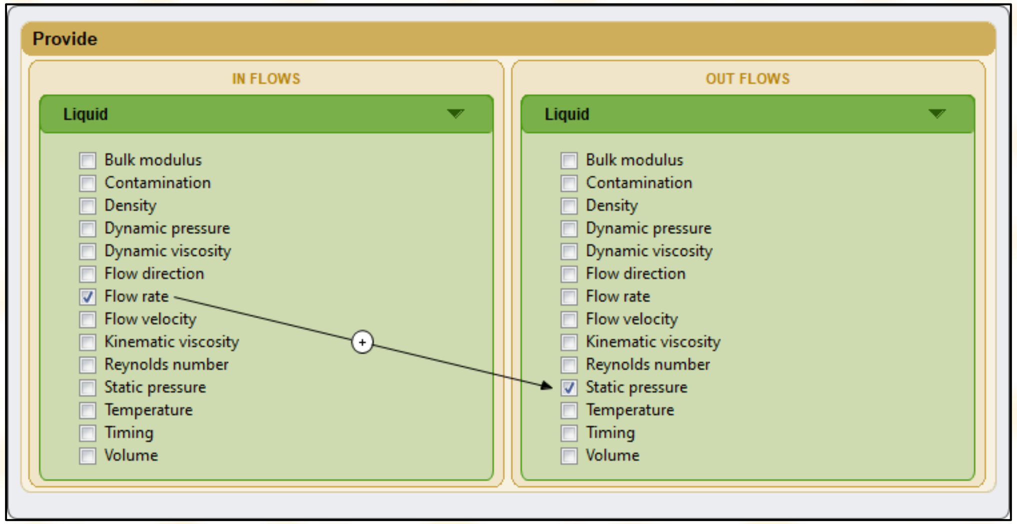
Session 1.6: System Modeling (Functions)

Exercise 1.6.3 Component Functions and Flows

- Open the system model for the **'Power Generation'** subsystem
- Right-click the **'Fuel Tank'** and select **Functions**
- Assign the **Provide** Function
- Assign the **Material - Liquid** flow into the **In Flows**
- Assign the **Material - Liquid** flow into the **Out Flows**
- Left-click and drag the **Flow rate** property in the In Flows to the **Static pressure** property in the Out Flows



- Note: The functional description will read as **Provide Liquid Static pressure**

Session 1.6: System Modeling (Functions)

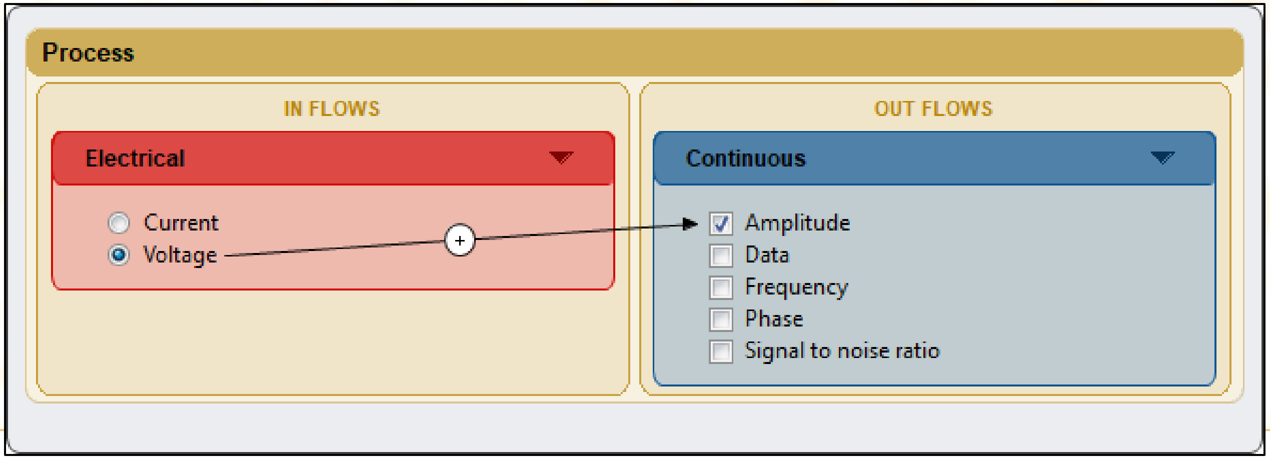
EXERCISE 1.6.3 COMPONENT FUNCTIONS AND FLOWS (CONTINUED)

- Right-click the **'Control Unit'** from the Project Explorer and select **Functions**
- Assign the flows as indicated in the table:

Subsystem	Functions	In Flows	Out Flows
Control Unit	Process	Energy - Electrical	Signal - Continuous

❖ Note: The Process function is located within the **Signal** folder. Alternatively, use the Search bar to search for **Process**

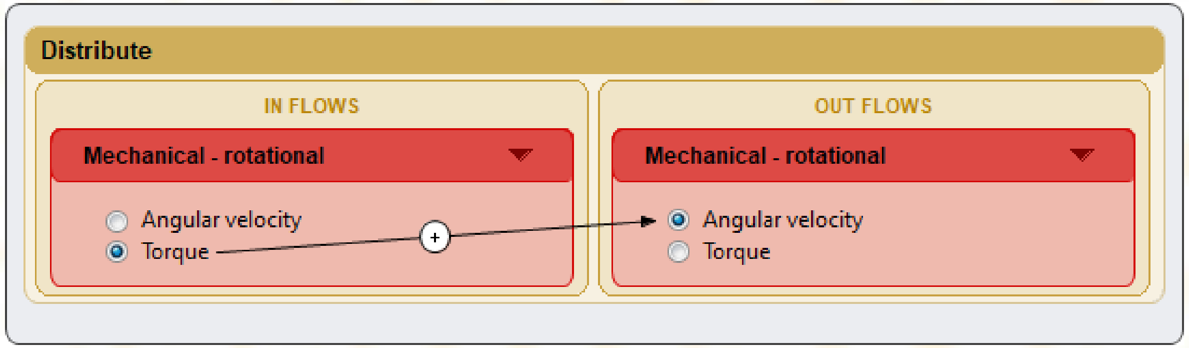
- Connect the **Electrical – Voltage** input flow to the **Continuous – Amplitude** output flow



Session 1.6: System Modeling (Functions)

Exercise 1.6.3 Component Functions and Flows (continued)

- Right-click the **'Transmission'** from the Project Explorer and select **Functions**
- Assign the **Distribute** function
- Assign **Energy – Mechanical - rotational** flow into the **In Flows**
- Assign **Energy – Mechanical - rotational** flow into the **Out Flows**
- Connect the **Torque In Flow** property to **Angular Velocity Out Flow** property



- Note: This will read as **Distribute – Mechanical – rotational Angular velocity**

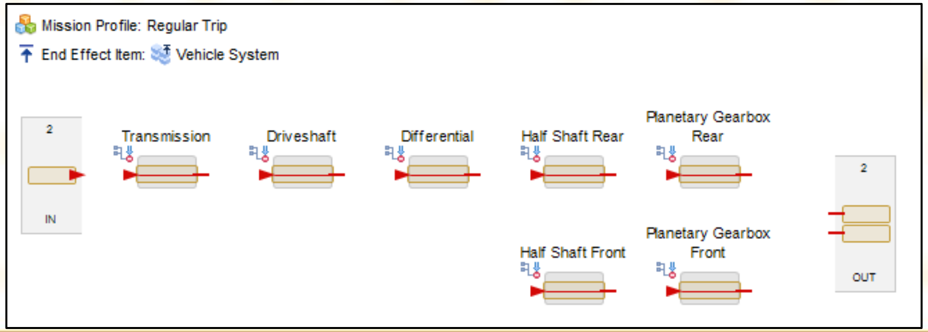
Session 1.6: System Modeling (Functions)

EXERCISE 1.6.3 COMPONENT FUNCTIONS AND FLOWS (CONTINUED)

To model the **'Driveline'** subsystem:

- Create components in the **'Driveline'** subsystem using the table below:

Component	Function	In Flow	Out Flow
Transmission	Distribute	Mechanical – Rotational Torque	Mechanical – Rotational Angular Velocity
Driveshaft	Support	Mechanical – Rotational Angular Velocity	Mechanical – Rotational Torque
Differential	Divide	Mechanical – Rotational Torque	Mechanical – Rotational Angular Velocity
Half Shaft (2 instances)	Transmit	Mechanical – Rotational Angular Velocity	Mechanical – Rotational Torque
Planetary Gearbox (2 instances)	Store	Mechanical – Rotational Torque	Mechanical – Rotational Angular Velocity



Session 1.6: System Modeling (Functions)

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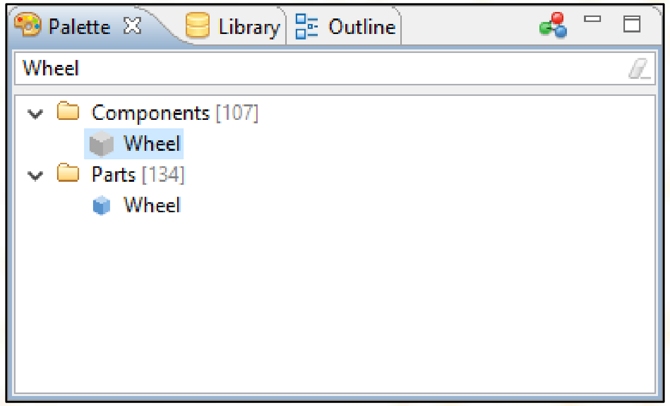
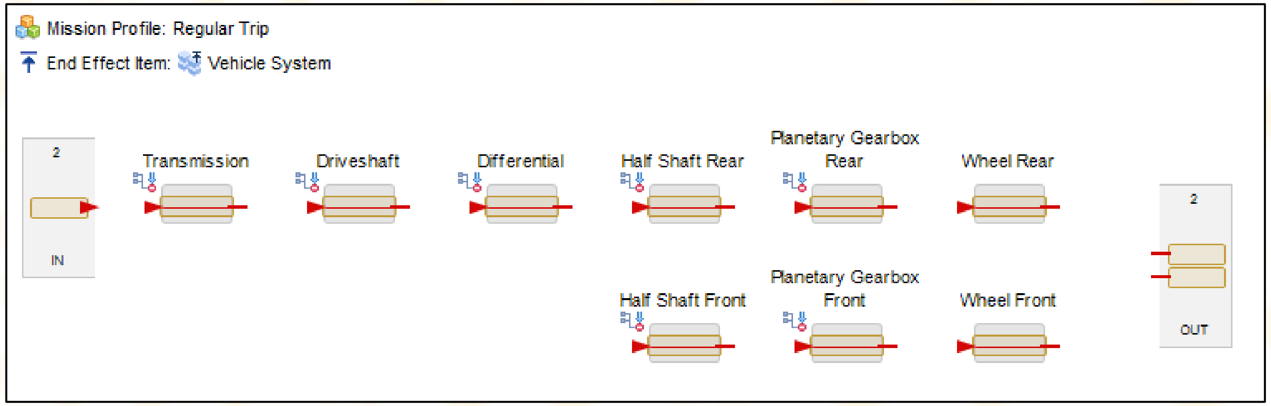
Exercise 1.6.3 Component Functions and Flows (Continued)

- Additional components required for the driveline: 2x **Wheel** components
- This requires accessing the Palette viewer:
  - Search for the **Wheel** component
  - Drag out two **Wheel** components to the **'Driveline'** system model
  - Rename them as **'Wheel Front'** & **'Wheel Rear'**





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Session 1.6: System Modeling (Functions)

Discussion 1.6.4 Pair Functions and Flows

- How are functions assigned for a pair?
  - A part is a discrete singular unit that cannot by itself work functionally. It needs to work in combination with one or more other parts
- Why are pair functions necessary?
  - A pair is the functional use of two parts
- How do pair functions relate to a component?
  - Unlike the relationship between components and subsystems, part-pair functions aren't directly connected to their parent component's functions
  - Parts represent the physical base units of a system, whereas components and above are representing the logical structure of the system

❖ Note: The failure diagram (later session) will further explore relationship between parts and components

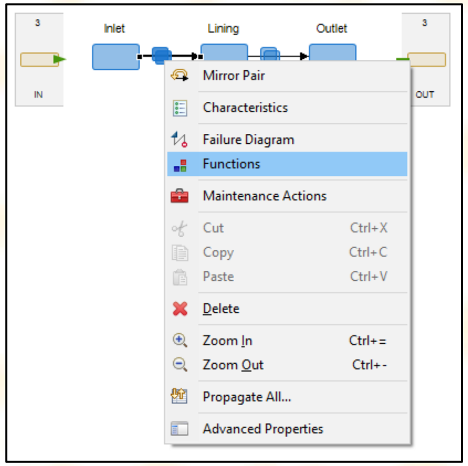
Session 1.6: System Modeling (Functions)

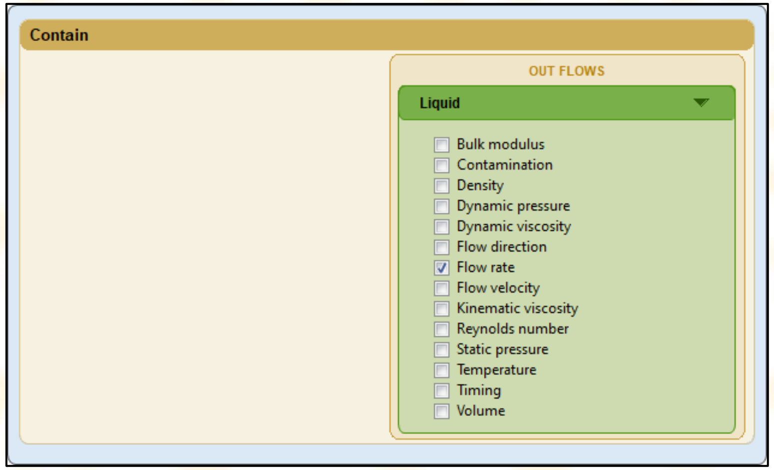
EXERCISE 1.6.4 PAIR FUNCTIONS AND FLOWS

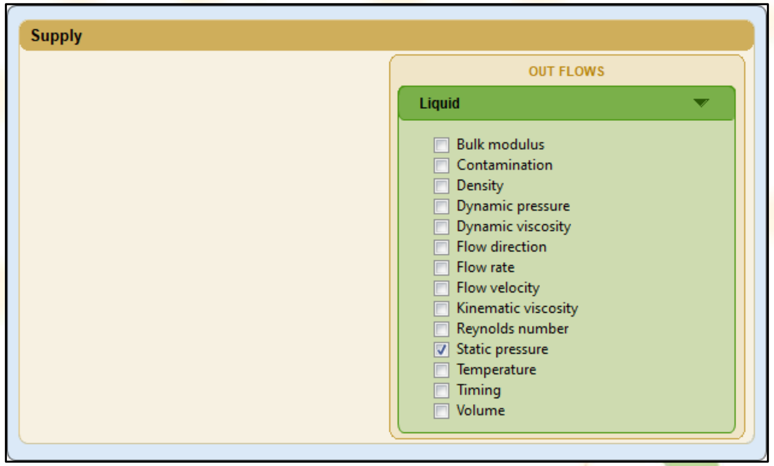
To assign a Pair Function & Flow:

- Open the system model for the **'Fuel Tank'** component
- Right-click the **Inlet-Lining** pair and select **Functions**
- Assign a function: **Contain**
- Assign a flow: **Material – Liquid**
- Select the property: **Flow rate**

- Right-click the **Lining-Outlet** pair and select **Functions**
- Assign a function: **Supply**
- Assign a flow: **Material – Liquid**
- Select the property: **Static Pressure**



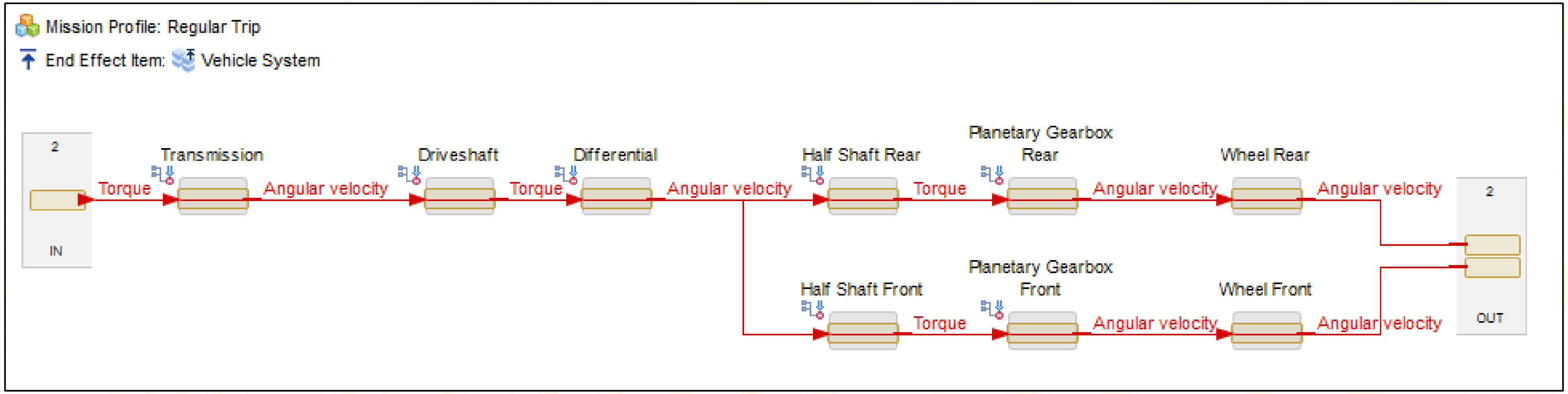




Session 1.6: System Modeling (Functions)

Discussion 1.6.5 Connecting Model Items

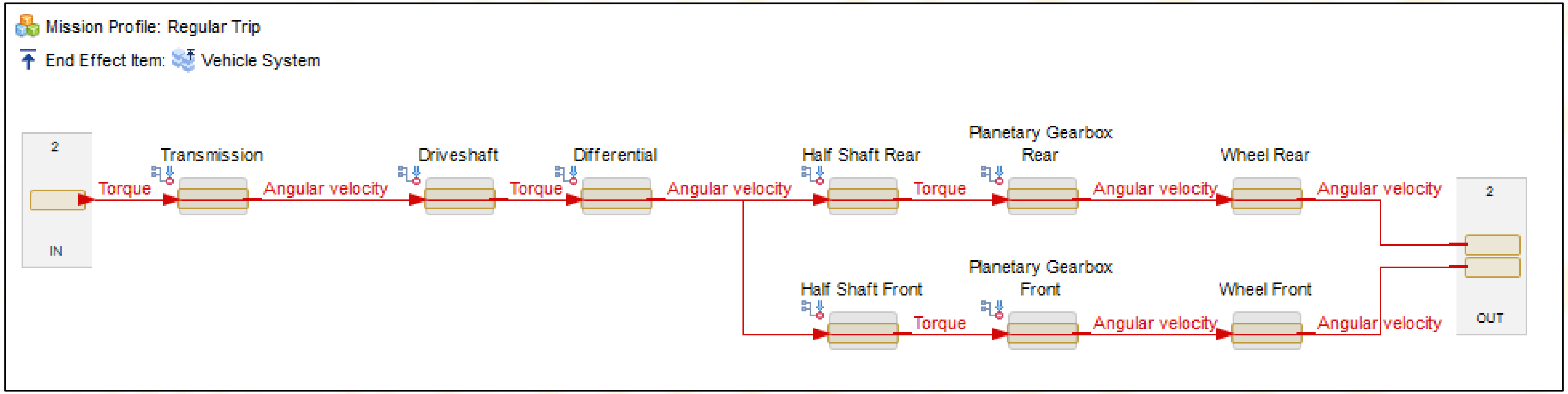
- Connecting items in the system model is used for:
  - Propagation of an injected failure
  - Path analysis of failures for reporting outputs e.g. FMEA, FMECA
  - Simulating dependencies between items using Bond Graph or FCM simulation methods



Session 1.6: System Modeling (Functions)

Exercise 1.6.5 Connecting Model Items

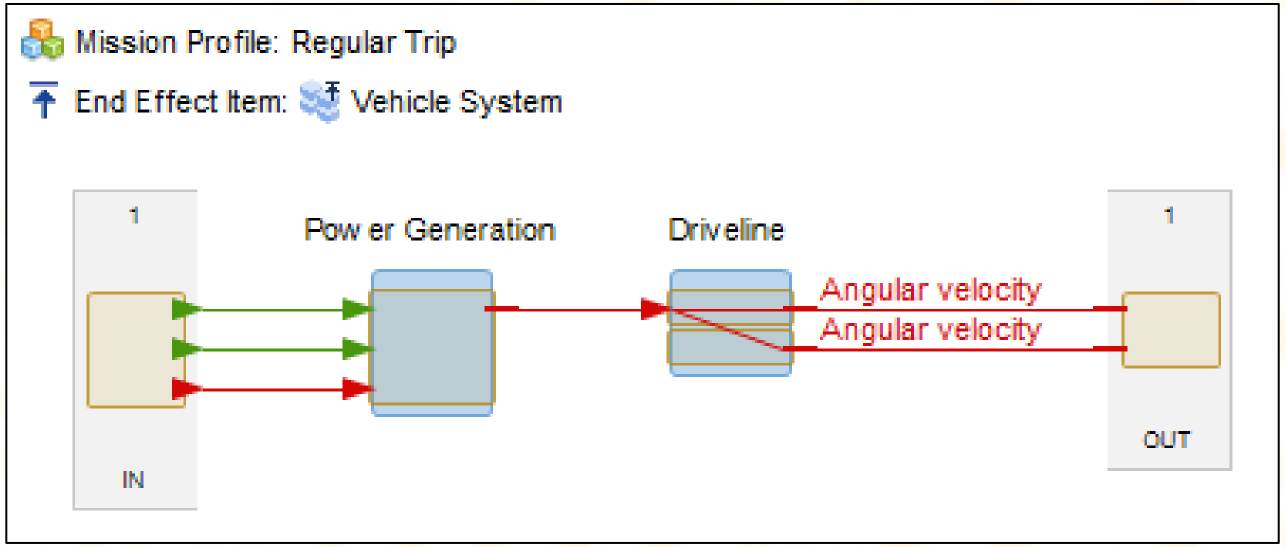
- Connect the **'Driveline'** components as shown in the diagram below:
  - The connection between the **'Planetary Gearbox'** and **'Wheel'** components can not be made due to mismatched flow properties
  - To resolve this, change the **'Wheels'** in flow properties to **Angular velocity** to connect the model



Session 1.6: System Modeling (Functions)

Exercise 1.6.5 Connecting Model Items (Continued)

- Connect the **'Power Generation'** & **'Driveline'** subsystems in the first Level of Indenture



Session 1.6: System Modeling (Functions)

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Session 1.6 Summary

- ✓ 1.6.1: Functional Modeling
- ✓ 1.6.2: System & Subsystem Functions and Flows
- ✓ 1.6.3: Component Functions and Flows
- ✓ 1.6.4: Pair Functions and Flows
- ✓ 1.6.5: Connecting Model Items

Session 1.7: MADe Library

SESSION 1.7 OUTLINE

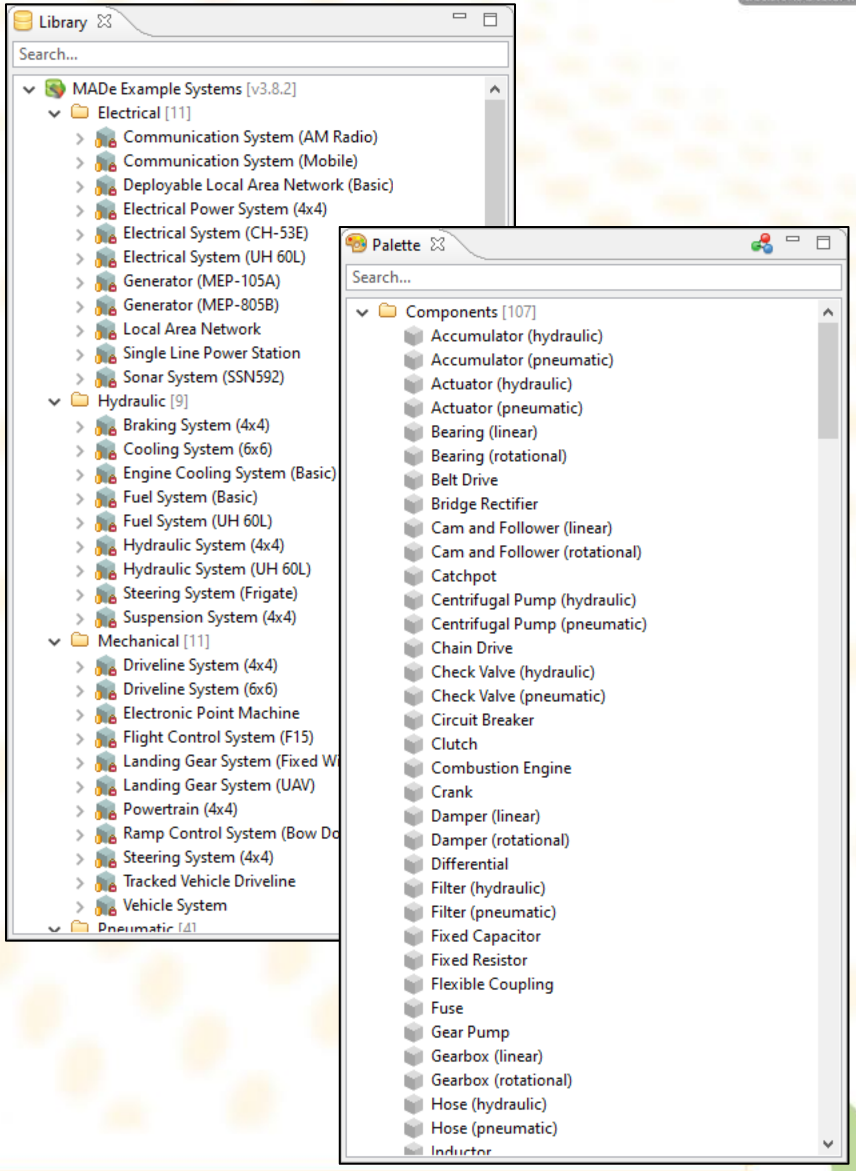
1.7.1: MADe Library

1.7.2: Setting up a new MADe User Library

Session 1.7: MADe Library

Discussion 1.7.1 MADe Library

- What does the MADe Example library contain?
  - MADe example library contains example systems modelled by PHMT
  - Used as guides for how to model and accelerate the modeling process
- How should the MADe Example library be used?
  - Repeatability
  - Transferability
- What does the Palette contain?
  - The palette contains a database of exemplar components and parts
  - Used to speed up modeling
  - Suggest correct function for an item



Session 1.7: MADe Library

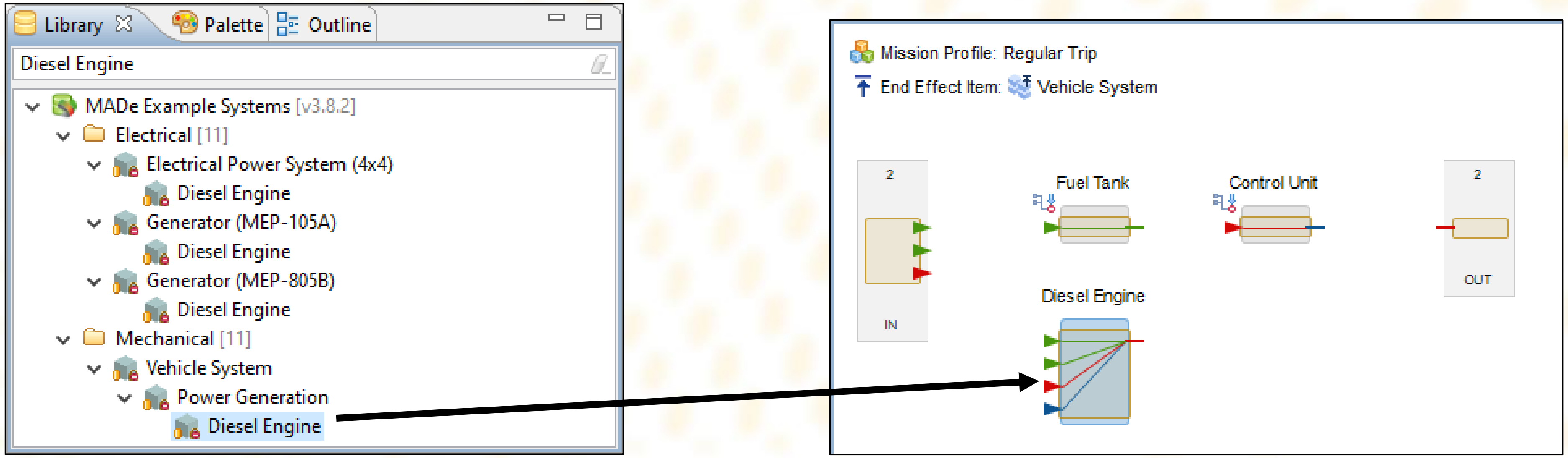
EXERCISE 1.7.1 MADE LIBRARY

To complete the **'Power Generation'** subsystem:

➢Select Library viewer and search for the **'Diesel Engine'**

➢Select the **'Diesel Engine'** under **MADe Example Systems → Mechanical → Vehicle System**

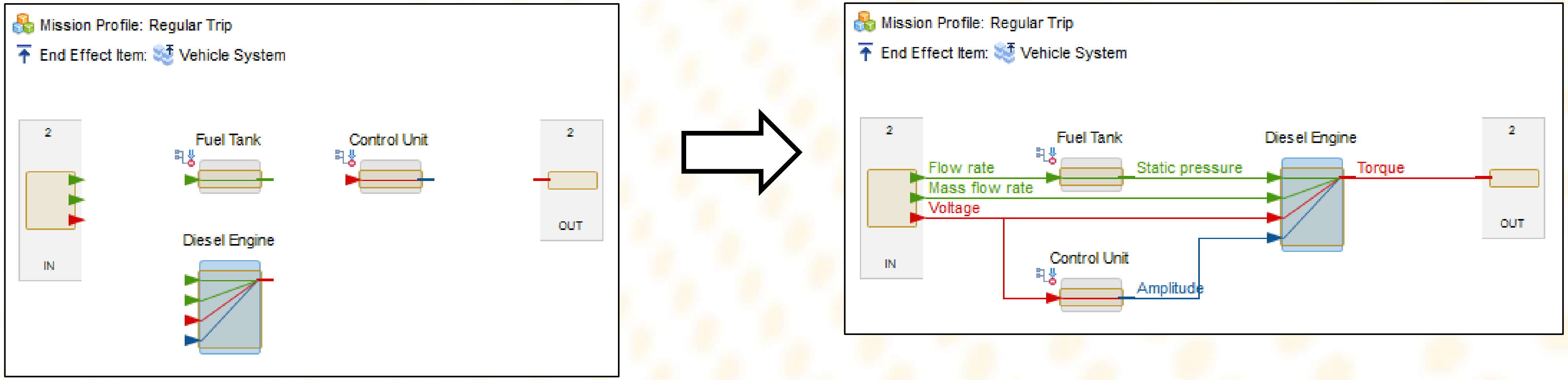
➢Drag this item into the **'Power Generation'** system model



Session 1.7: MADe Library

EXERCISE 1.7.1 MADE LIBRARY (CONTINUED)

➢ We can now connect all items in the **'Power Generation'** subsystem.

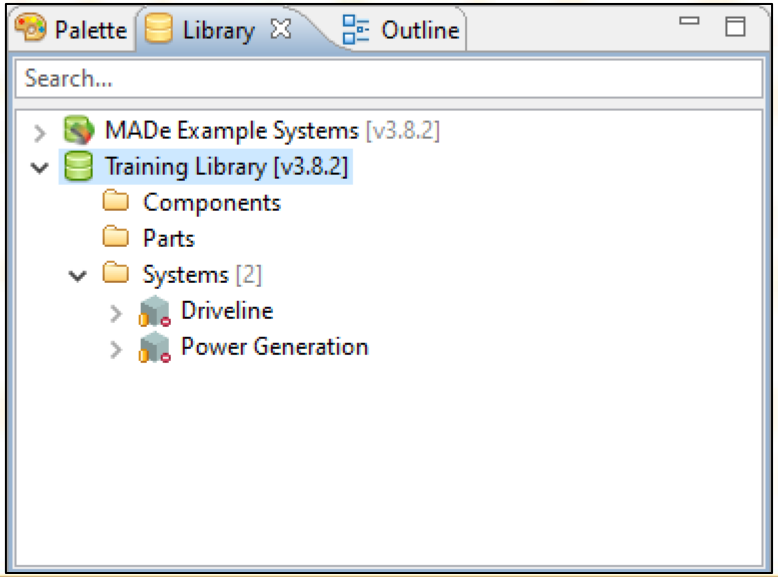


❖ Note: MADe will automatically prevent connection of dissimilar flows

Session 1.7: MADe Library

Discussion 1.7.2 Setting Up a New MADe User Library

- A user library is used to save MADe model items for re-use in future projects
- Libraries are created and managed in the preferences
- Once a model is complete any number of items can be saved to a library
- Companies may choose to establish company or project specific libraries

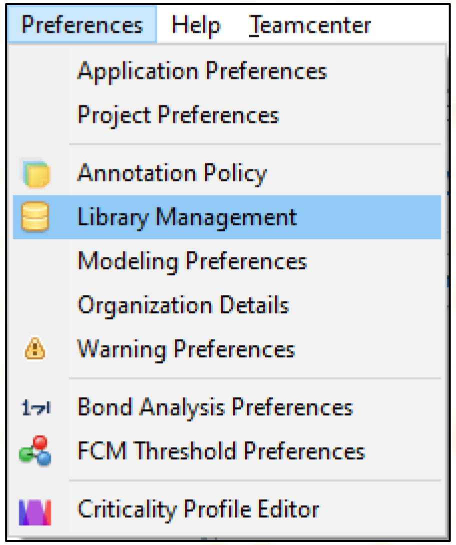


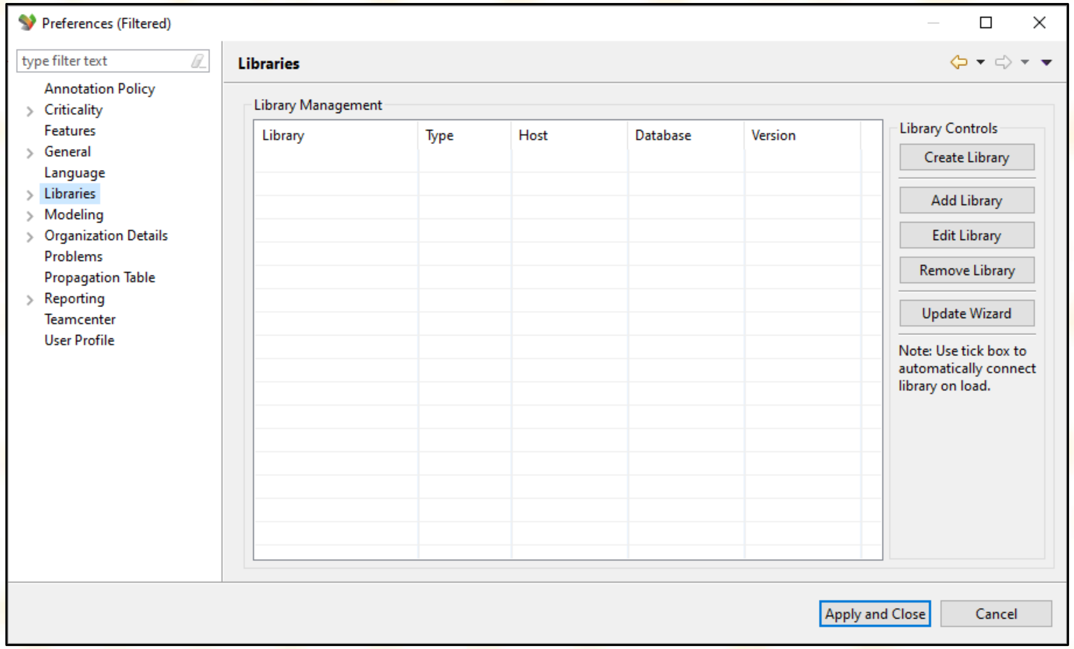
Session 1.7: MADe Library

EXERCISE 1.7.2 SETTING UP A NEW MADE USER LIBRARY

To set up a new MADe User Library:

- Select **Preferences → Library Management**
- Select Create Library
- Choose a location to save the library

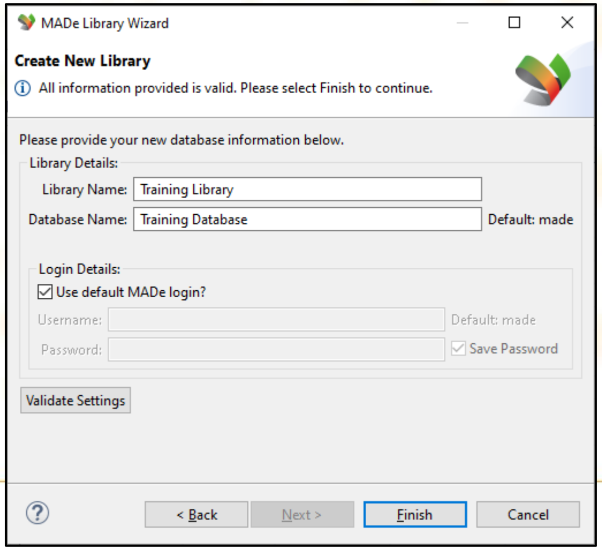


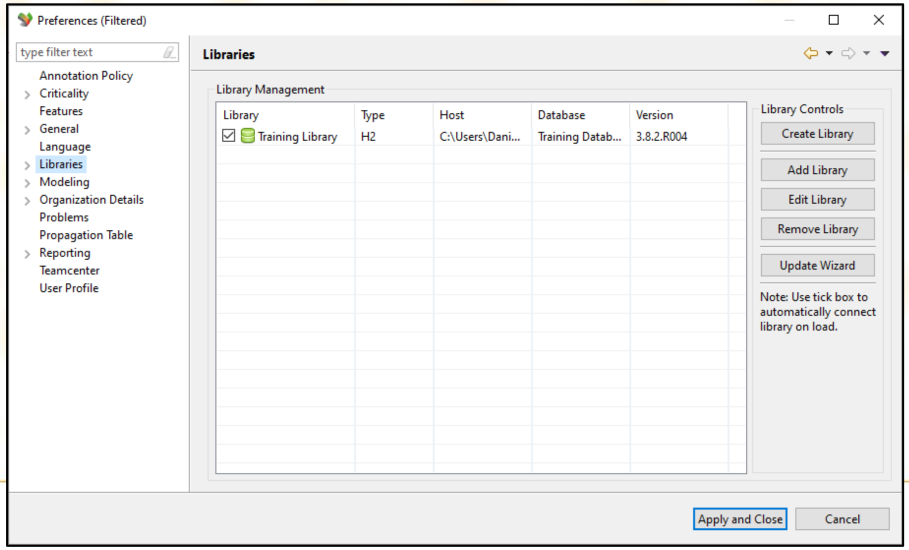


Session 1.7: MADe Library

Exercise 1.7.2 Setting Up a New User Library (Continued)

- Set the library name as: **Training Library**
- Set the database name as: **Training Database**
- Validate the settings to ensure no duplication with existing database name
- Select Finish
- Select the checkbox next to the new library to set it to automatically connect on starting MADe
- Select Apply and Close





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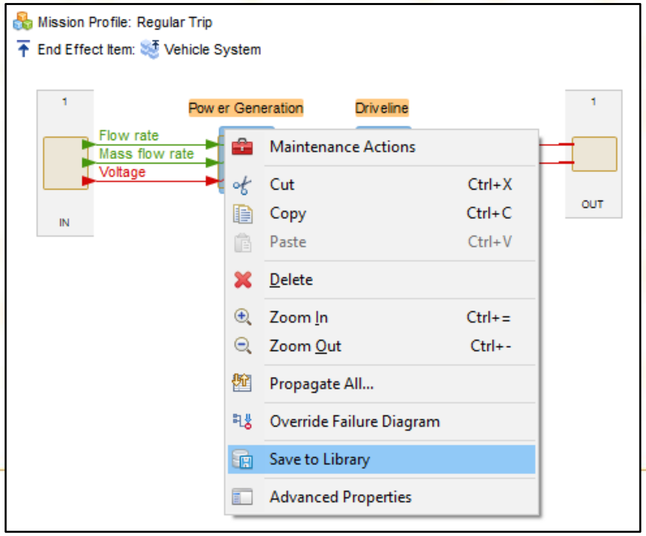
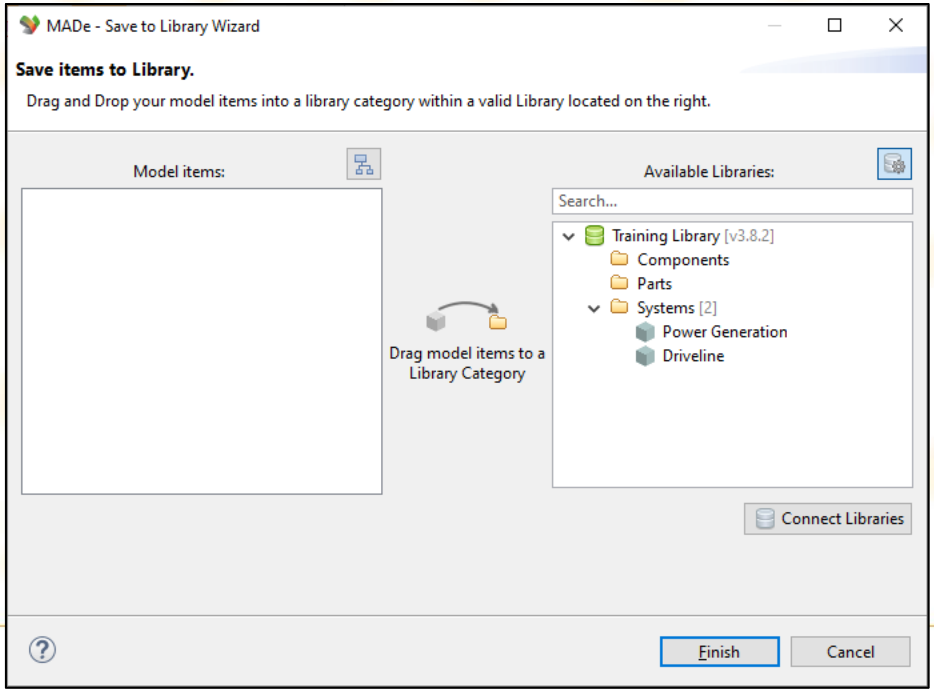
Session 1.7: MADe Library

EXERCISE 1.7.2 SETTING UP A NEW USER LIBRARY (CONTINUED)

To save items to the new User Library:

- Click-and-drag to select the **'Power Generation'** and **'Driveline'** subsystems
- Right-click on a highlighted item and select **Save to Library**
- Expand the **Training Library** folder to reveal the folders
- Click-and-drag the subsystems into the **Systems** folder
- Select Finish





Session 1.7: MADe Library

Session 1.7 Summary

✓ 1.7.1: MADe Library

✓ 1.7.2: Setting up a new MADe User Library

Session 1: MADe Modeling

Session 1 Summary

- ✓ 1.1: Navigation
- ✓ 1.2: Project Creation
- ✓ 1.3: Mission Profile Definition (Solution-independent)
- ✓ 1.4: Functional Modeling (Functional Hazards Assessment)
- ✓ 1.5: System Modeling (Logical & Physical)
- ✓ 1.6: System Modeling (Functions)
- ✓ 1.7: MADe Library

Session 2: Failure Simulation

Verifying the MADe model & Analysing Failure Modes and Effects

Session 2: Failure Simulation

Session 2 Outline

2.2: Failure Simulation

2.3: Mission Profile (Solution-dependent) & Groups

2.4: Failure Analysis

2.5: Features & Characteristics

Session 2: Failure Simulation

SESSION 2 DISCUSSION

- Session 2 will take place in the MADe module.
- This session will focus on:
  - Annotations
  - Mission Profile
  - Additional part level modeling
  - Failure simulation

Session 2.1: Annotations

Session 2.1 Outline

2.1.2: Dashboard

2.1.3: Model Parameters

2.1.4: Narratives

2.1.5: Assumptions

2.1.6: Comments

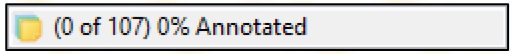
2.1.7: Annotations Report

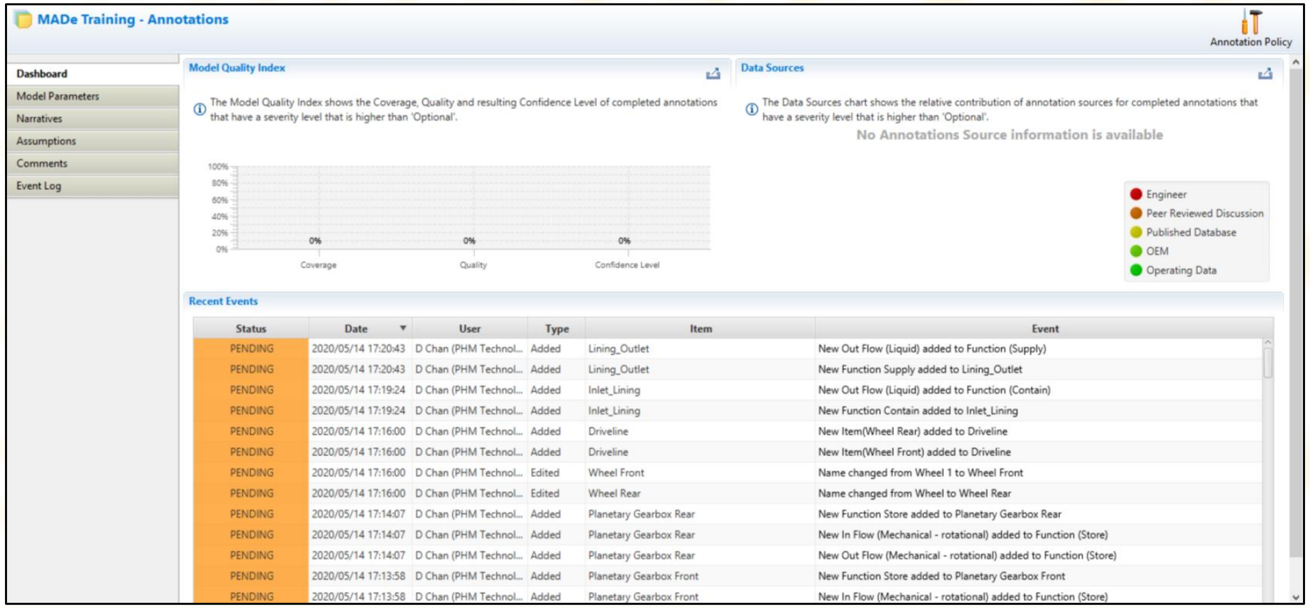
Session 2.1: Annotations

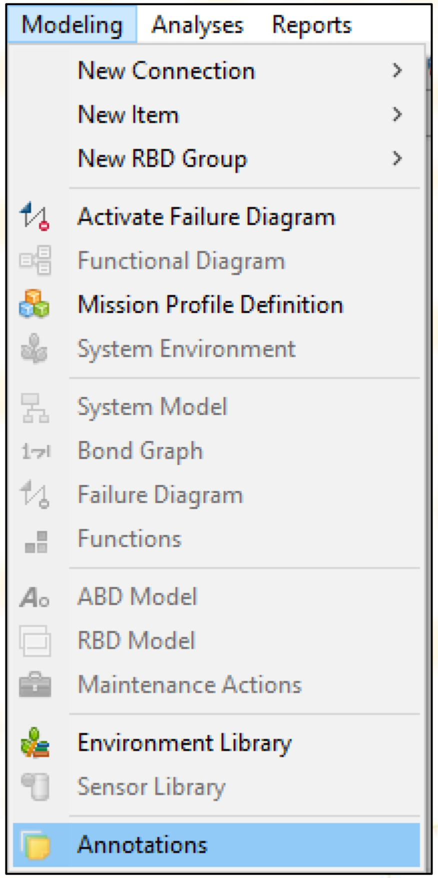
EXERCISE 2.1.1 ANNOTATIONS

Top open the Annotations Editor:

- ➢ Method 1: To open the Annotations editor, select **Modeling → Annotations** from the main menu
- ➢ Method 2: Double-click **Annotations** icon in bottom left corner of MADe







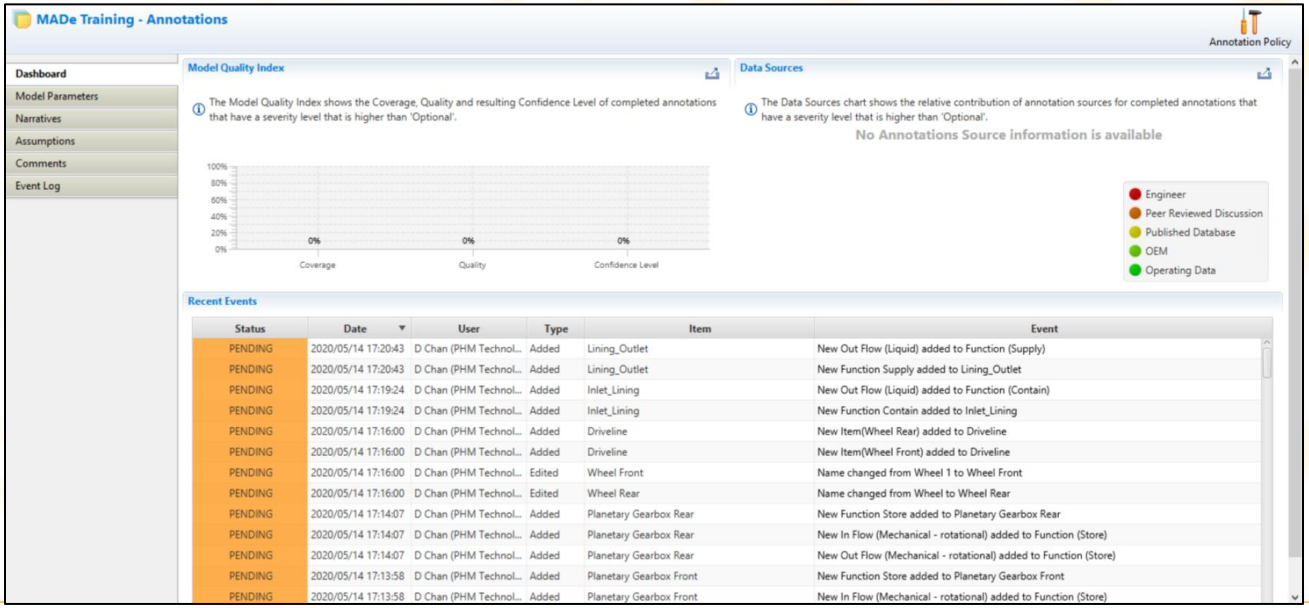
Session 2.1: Annotations

made
decisions better MADe...

Discussion 2.1.2 Dashboard

The Dashboard shows the following metrics:

- **Analysis Quality Index**: Coverage, Quality and resulting Confidence level of the model output
- **Data sources**: Visual breakdown of the types of data sources
- **Recent Events**: Changes to parameters in a model that are tracked



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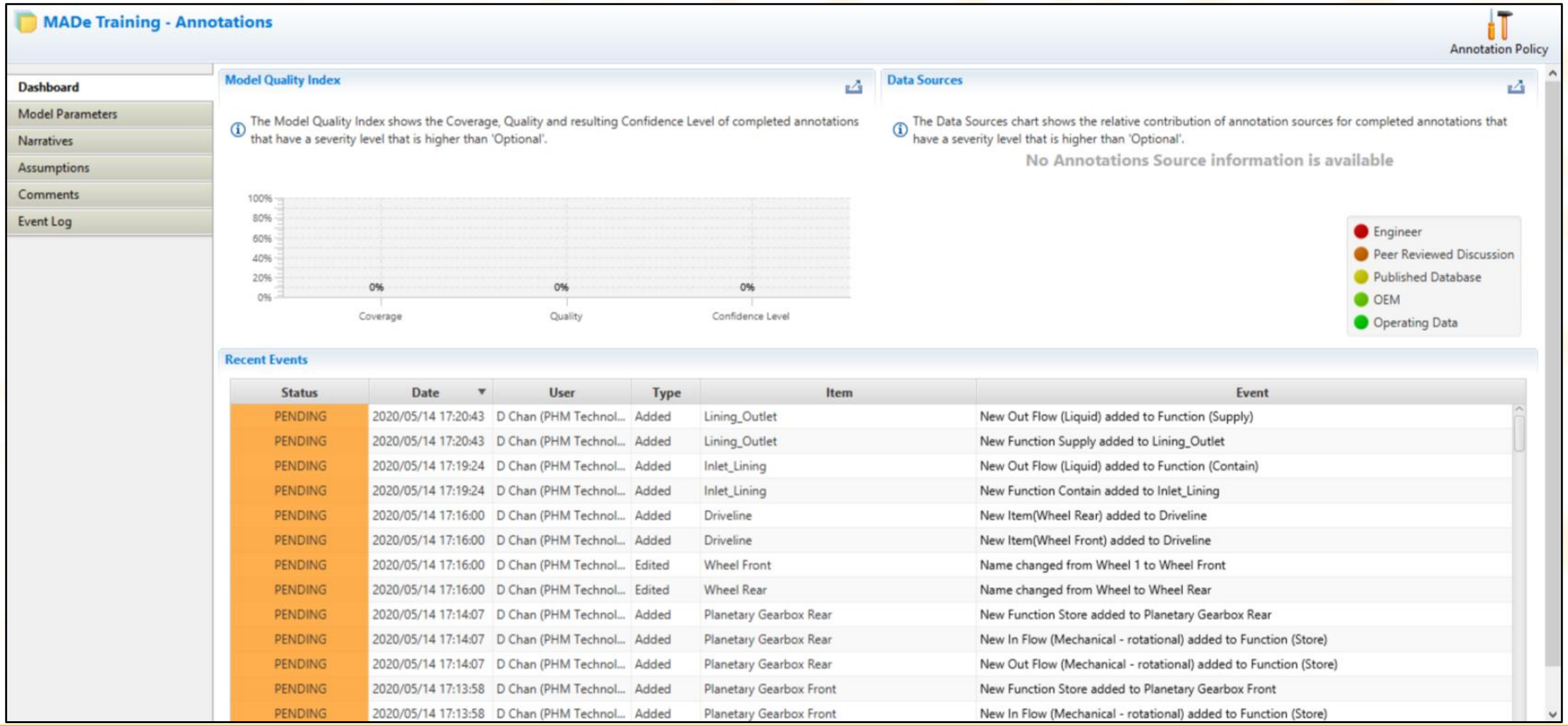
Session 2.1: Annotations

DISCUSSION 2.1.3 MODEL PARAMETERS

- Used to annotate any changes in the model
- Can also be used to search for annotations and filter by various properties

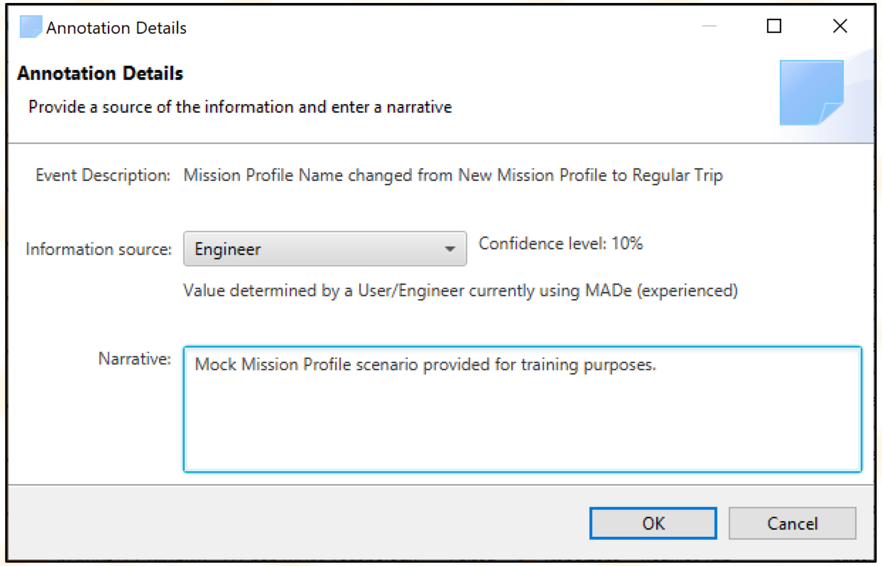


Session 2.1: Annotations

EXERCISE 2.1.3 MODEL PARAMETERS

To search for a model parameter:

- Enter **Mission Profile** into the **Item/Event Description** search box
- Find the event **Mission Profile Name Changed**
- Double-click on the **Mission Profile Name Changed** annotation event in the table
  - This opens the **Annotation Details** editor
- Select **Engineer** from the Information Source drop down menu
- Enter the following narrative: **Mock Mission Profile scenario provided for training purposes.**
- Select OK

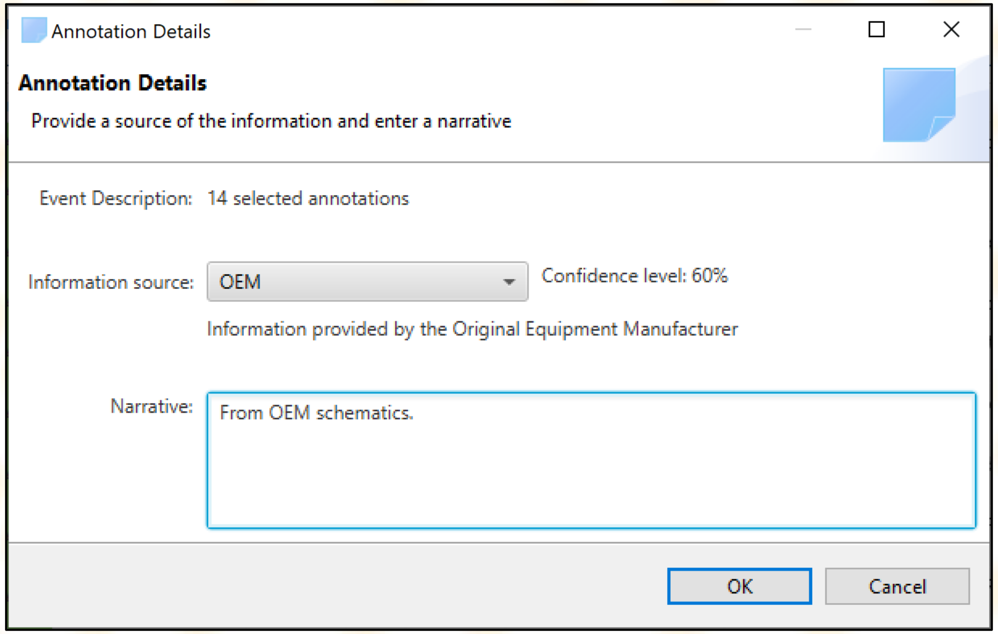


Session 2.1: Annotations

EXERCISE 2.1.3 MODEL PARAMETERS (CONTINUED)

To enter annotations for multiple model parameters:

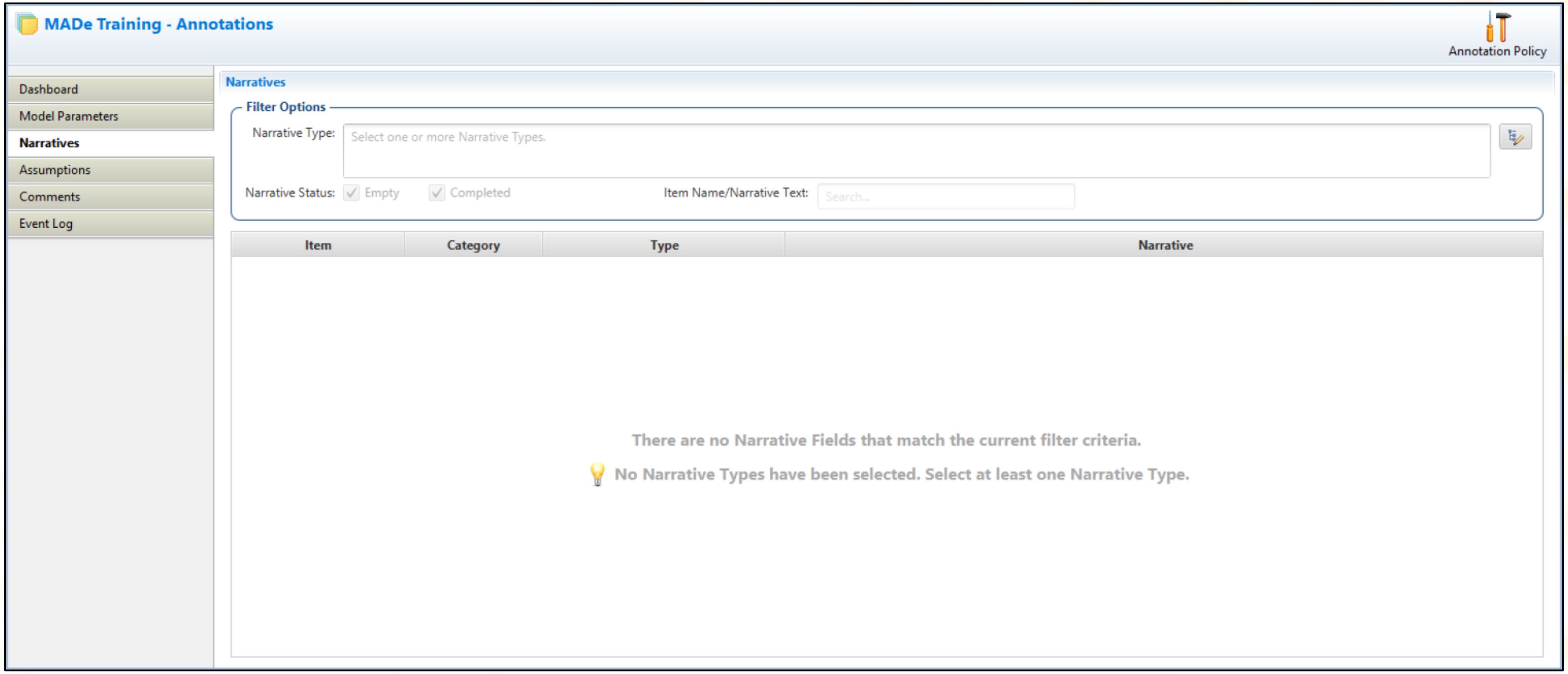
- Type **Item** into the **Item/Event Description** field
- Left-click the top result then shift-click the bottom result
- Right-click a highlighted change
- Select Annotate...
- Select the source as: **OEM**
- Enter the source as: **From OEM schematics.**
- Select OK



Session 2.1: Annotations

Discussion 2.1.4 Narratives

- Used to add additional information to the model e.g. Functional Narrative

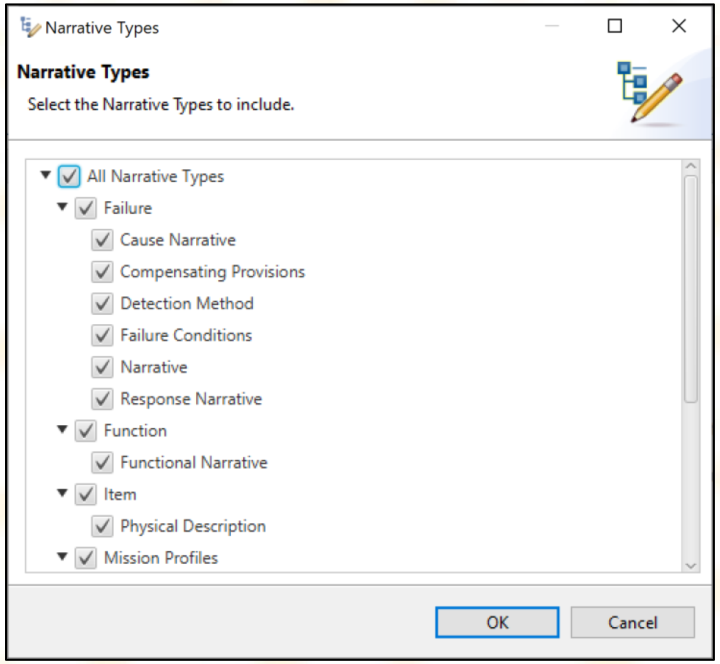


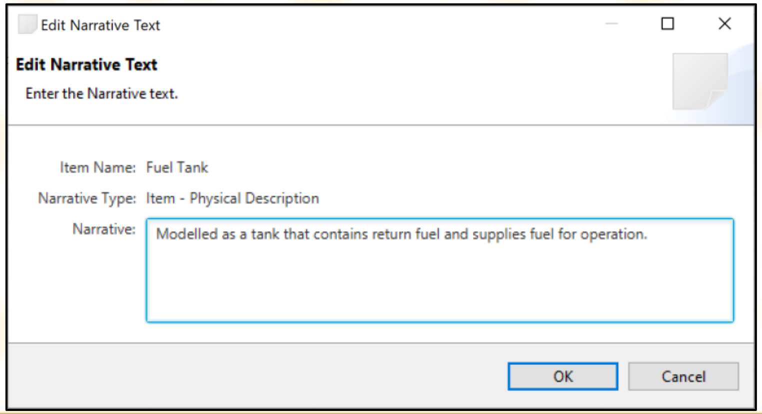
Session 2.1: Annotations

EXERCISE 2.1.4 NARRATIVES

To enter a new narrative:

- Select to open the **Narrative Types** editor
- Ensure all narratives are selected, then select OK
- Enter into the Item Name/Narrative Text search box: **Fuel Tank**
- Double-click the Fuel Tank with the Category **Item** to open the **Edit Narrative Text** editor
- Enter the following text: **Modelled as a tank that contains return fuel and supplies fuel for operation.**
- Select OK

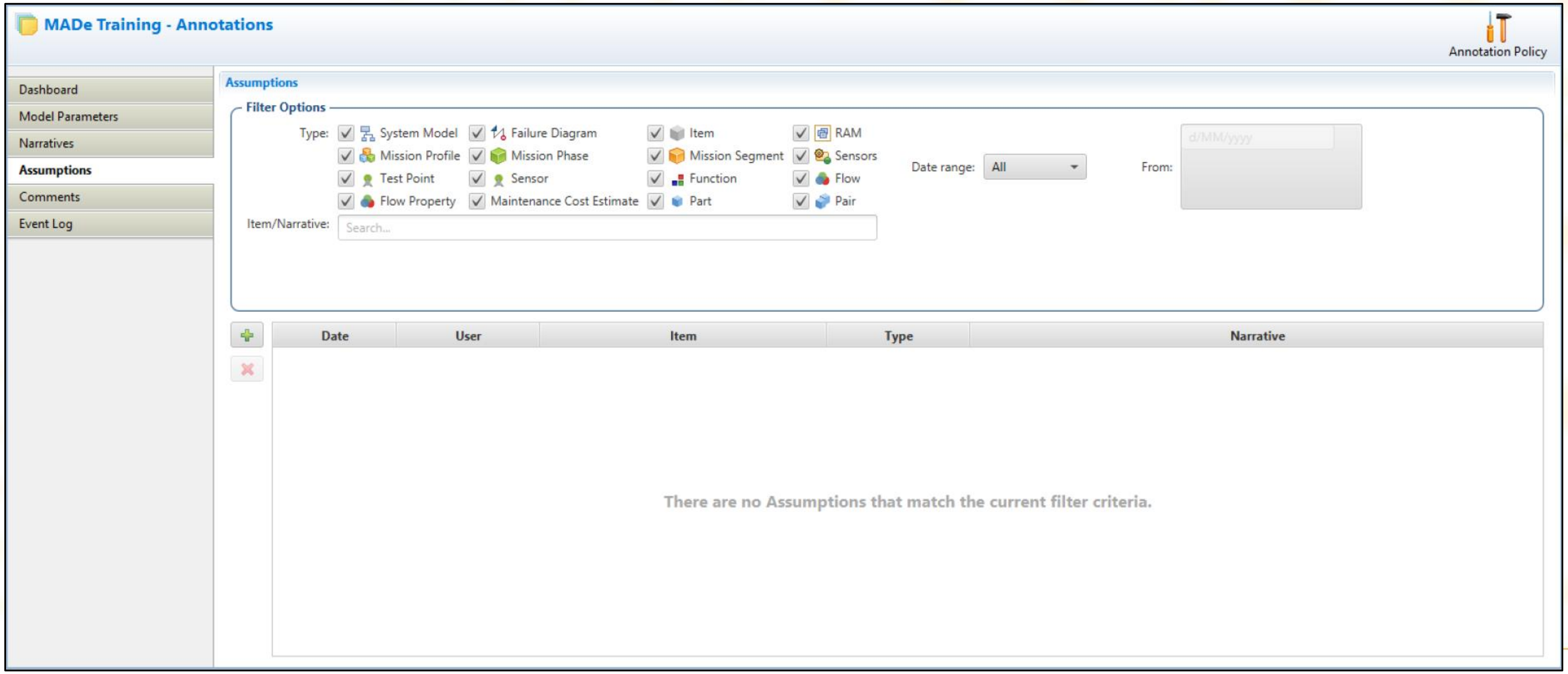




Session 2.1: Annotations

DISCUSSION 2.1.5 ASSUMPTIONS

- Used to capture any assumptions or constraints of the model
- Can be used to document modeling decisions

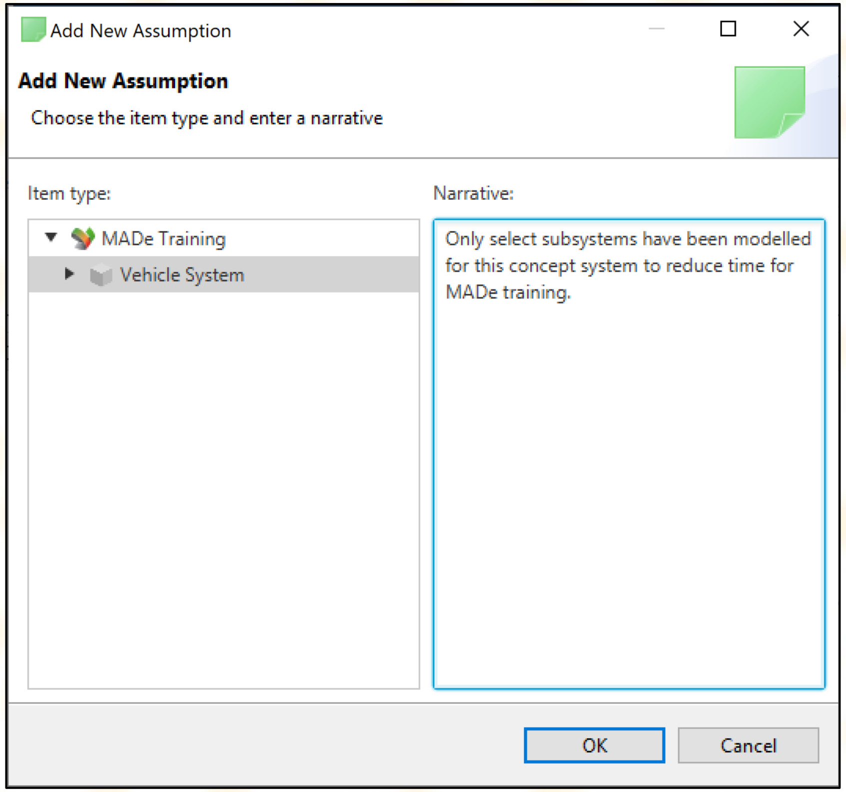


Session 2.1: Annotations

EXERCISE 2.1.5 ASSUMPTIONS

To enter a new assumption:

- ➢Select the button to the left of the table to open the **Add New Assumptions** editor
- ➢Expand the Item Type tree to **MADe Training → Vehicle System**
- ➢Select the **Vehicle System**
- ➢Enter the narrative: **Only select subsystems have been modelled for this concept system to reduce modeling time for MADe training.**
- ➢Select OK



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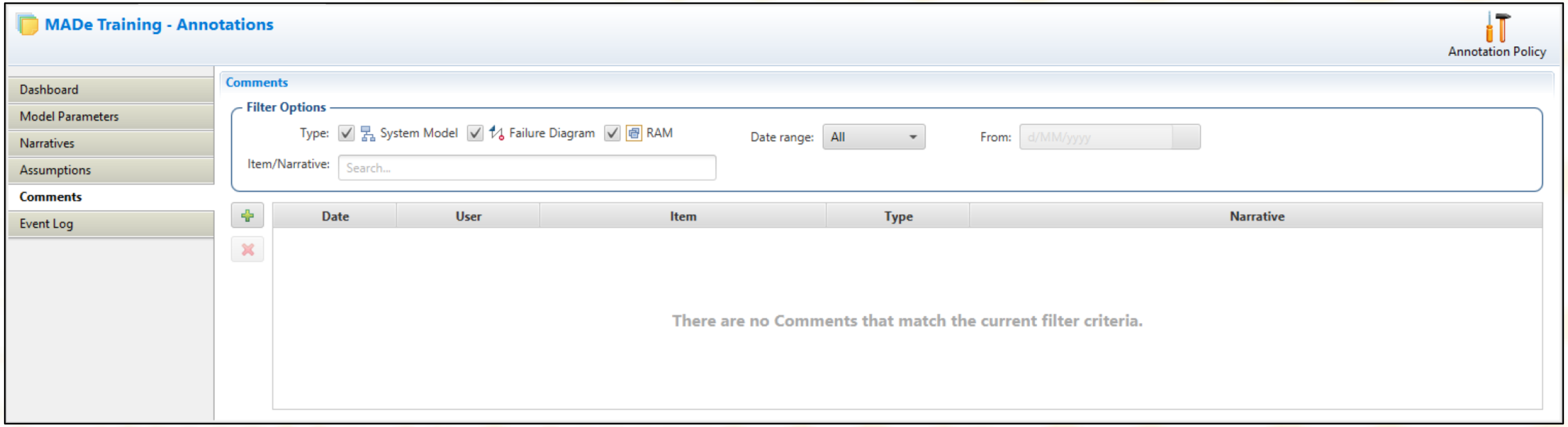
Session 2.1: Annotations

<u>Discussion 2.1.5 Comments</u>

- Used to pass general information to other modellers/users
- Used as notes/reminders for the modeling tasks

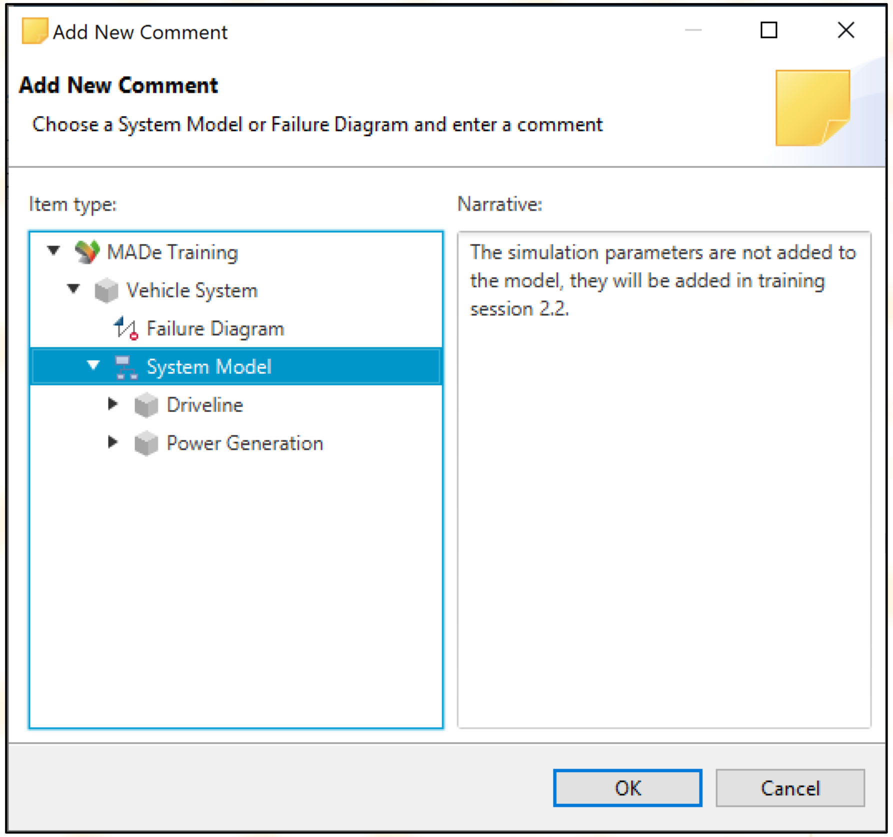


Session 2.1: Annotations

EXERCISE 2.1.5 COMMENTS

To add comments:

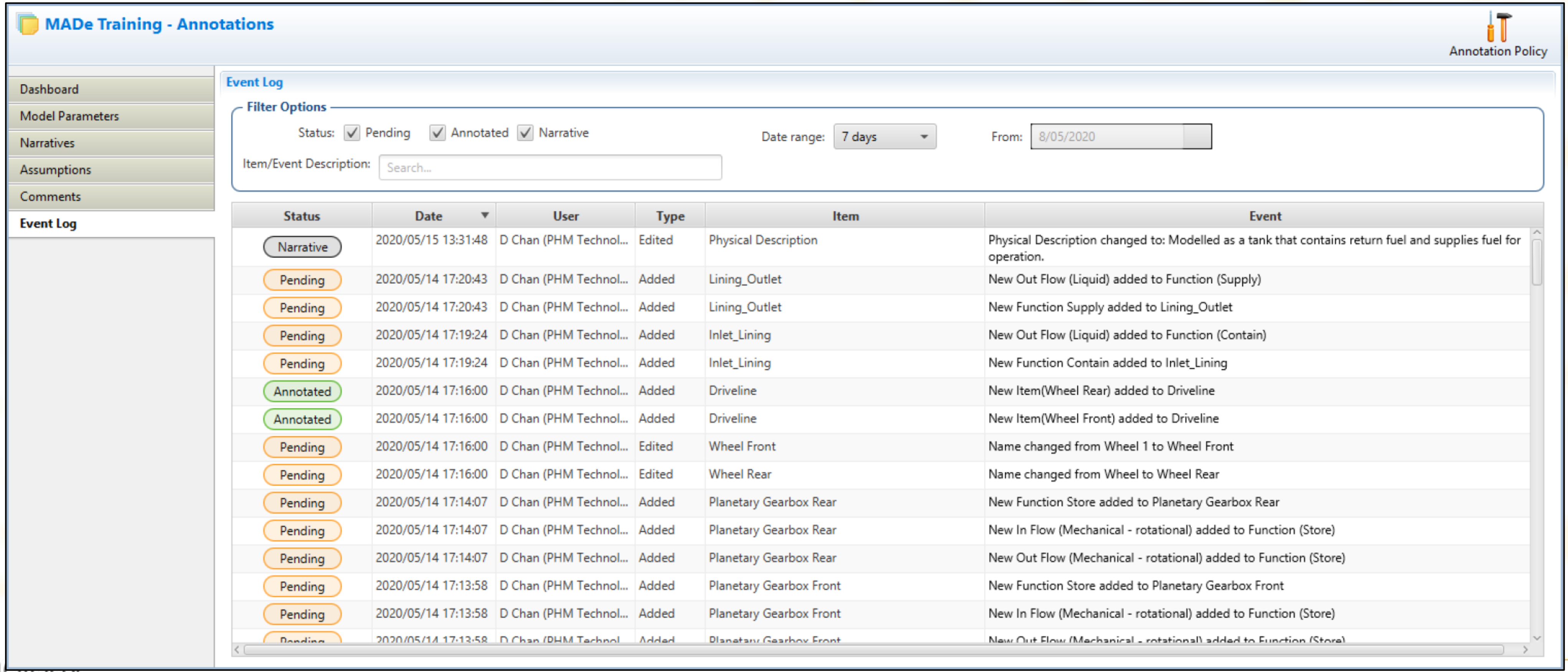
- Select the ✚ button to the left of the table to open the **Add New Comment** editor
- Expand the Item Type tree to **MADe Training → Vehicle System → System Model**
- Select the **System Model**
- Enter the narrative: **The simulation parameters are not added to the model, they will be added in training session 2.2.**
- Select OK



Session 2.1: Annotations

<u>Discussion 2.1.6 Event Log</u>

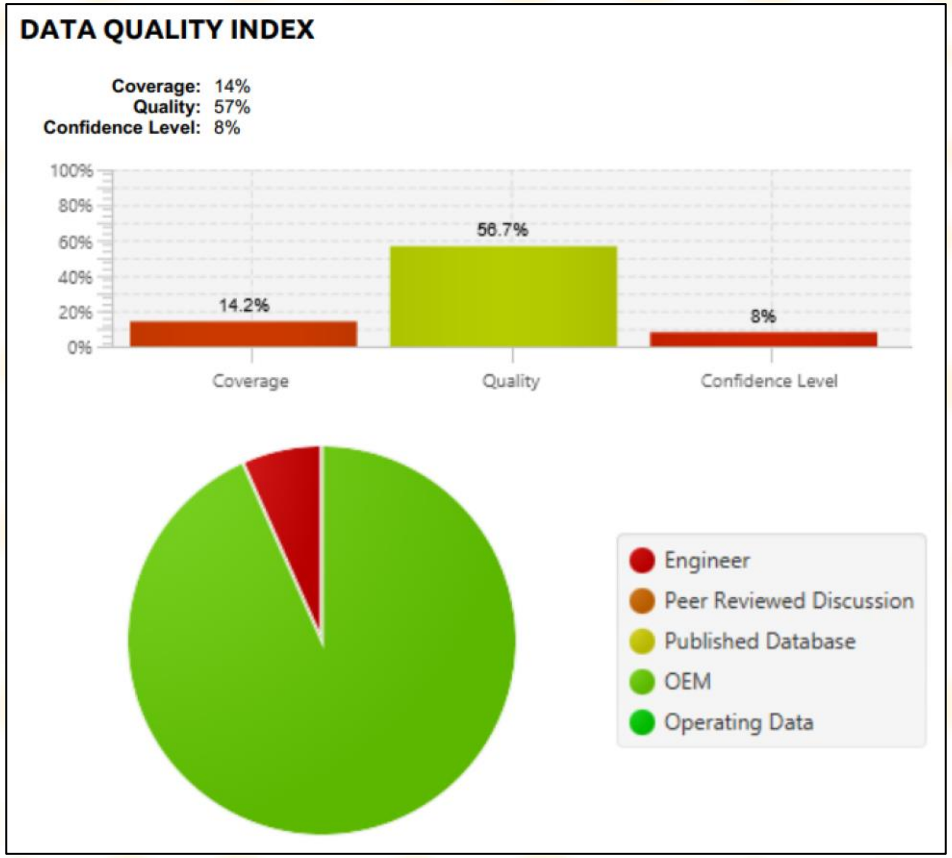
- Lists all annotation actions based on a date range



Session 2.1: Annotations

<u>Discussion 2.1.7 Annotations Report</u>

- Summarises annotations by item, type, status and source
- Displays information from:
  - Dashboard
  - Model Parameters Table

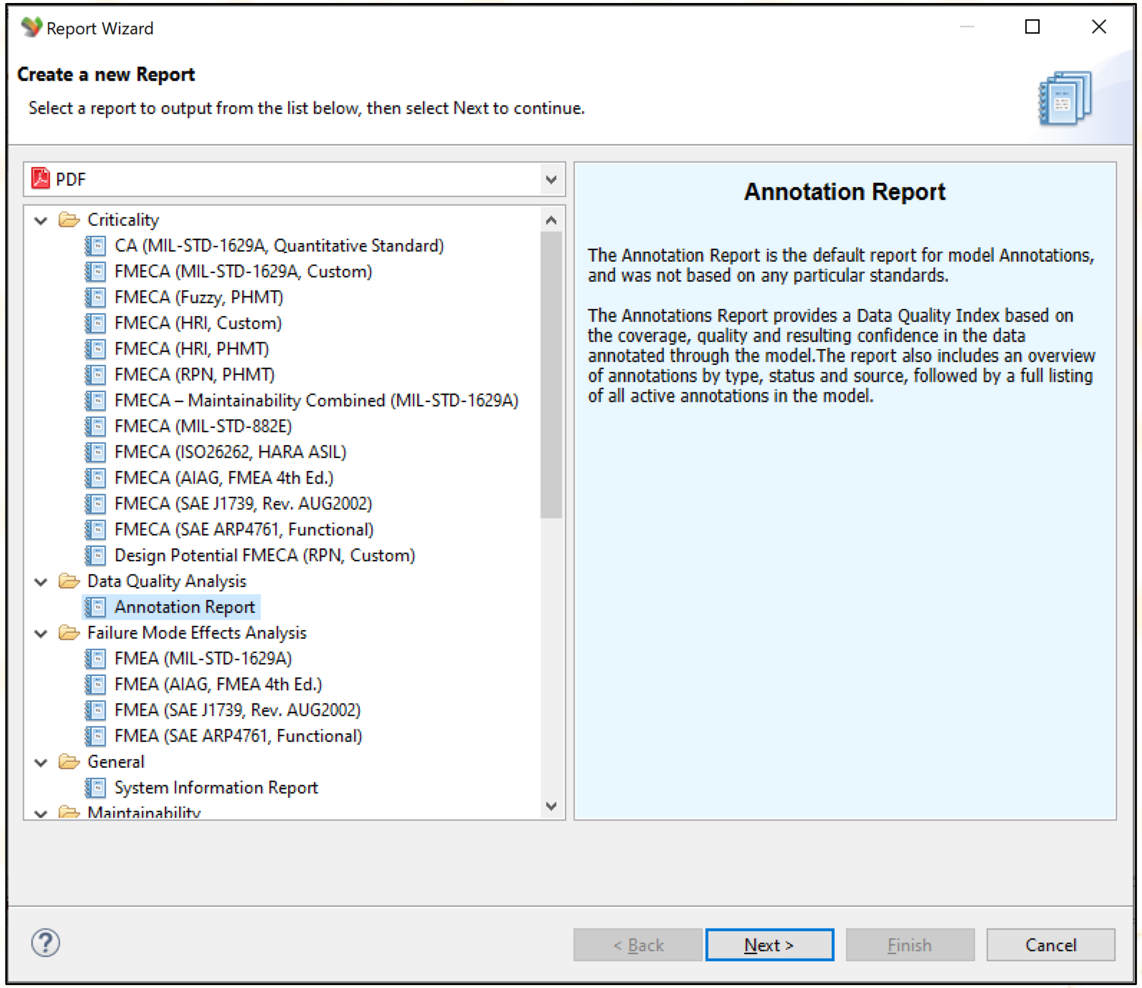


Session 2.1: Annotations

EXERCISE 2.1.7 ANNOTATIONS REPORT

To generate an Annotations report:

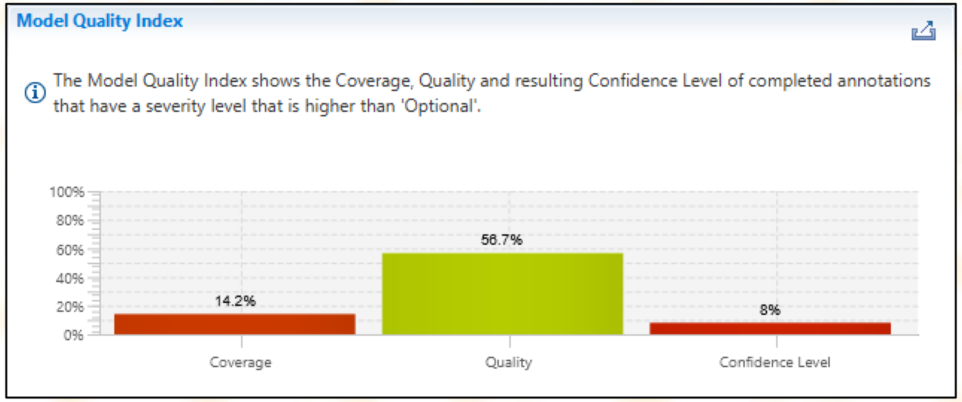
- Select **Reports → Report Wizard** from the main menu
- Under **Data Quality Analysis** select **Annotation Report**
- Select Next > to proceed to item selection page
- Select **'Vehicle System'** item
- Select Next > to set report formatting
- Select Finish to run report

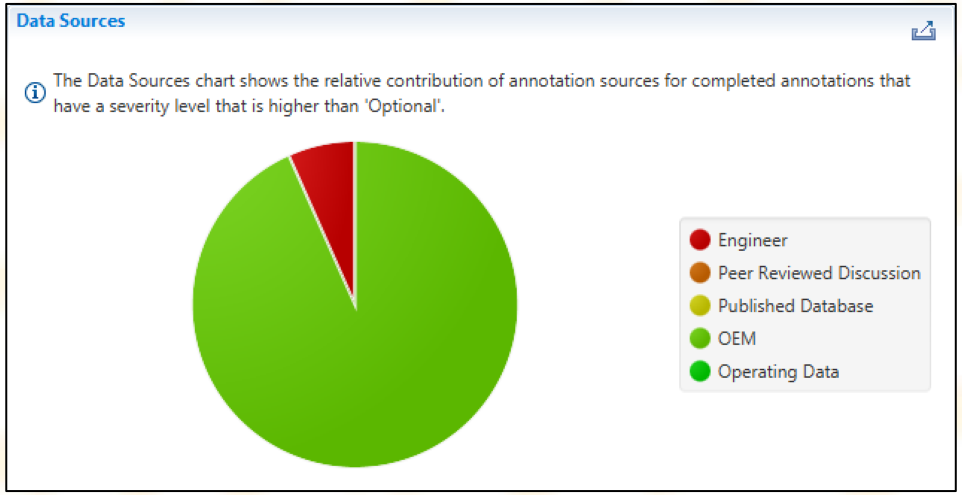


Session 2.1: Annotations

Session 2.1 Summary

- ✓ Understand the Annotations dashboard
- ✓ Search and create annotated events
- ✓ Create a narrative for more model information
- ✓ Create an assumption on a model item
- ✓ Create a comment on the system model
- ✓ Understand how to review the event log





Session 2.2: Failure Simulation

Session 2.2 Outline

2.2.1 Introduction to Failure Simulation in MADe

2.2.2 FCM Simulation Parameters

2.2.3 FCM Simulation

2.2.4 FCM Step Table

2.2.5 Response Simulation Viewer

2.2.6 FCM Simulation Threshold Types

2.2.7 Bond Graph Simulation

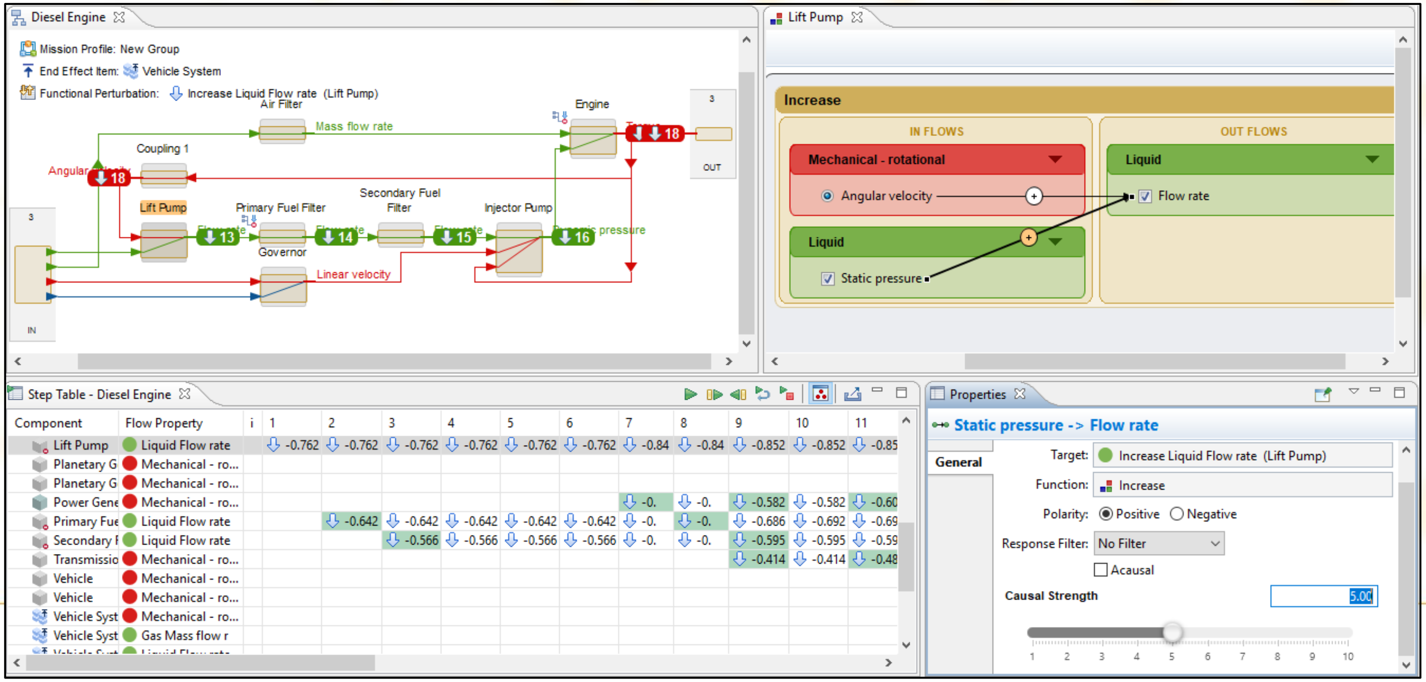
2.2.8 Bond Graph Model

2.2.9 Bond Graph Response Simulation

Session 2.2: Failure Simulation

Discussion 2.2.1 Introduction to Failure Simulation in MADe

- Failure simulation involves editing simulation-specific properties in the model
    - E.g. Causal Strength, Initial Value, Internal Damping for FCM Simulation
    - E.g. Bond Types & Passive Variables for Bond Simulation
- These properties are used to simulate the effects and failure propagation in the system model



Session 2.2: Failure Simulation

Discussion 2.2.1 Introduction to Failure Simulation in MADe

MADe utilises two response simulation methods that allow analysis of failures and performance:

- **Fuzzy Cognitive Maps (FCM)**

  - Uni-directional flow of information (failure is propagated downstream only)

  - Signal, material, and energy flows incorporated into model

- **Power bond modeling (Bond)**

  - Bi-directional flow of information (failure is propagated both upstream and downstream of an item)

  - Energy (power) flows incorporated into model

Session 2.2: Failure Simulation

Discussion 2.2.1 Introduction to Failure Simulation in MADe

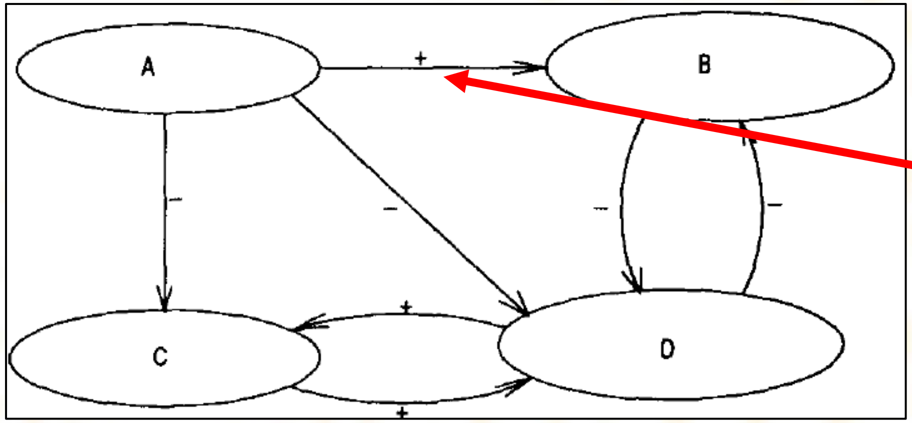
Which simulations should be used for a system model? Questions to ask include:

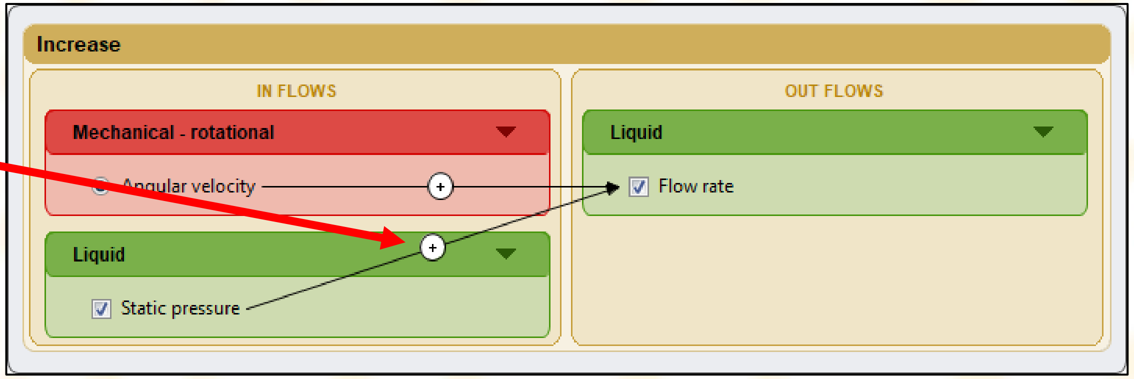
- What type of system behaviour is being represented?
  - Bond graphs model bi-directional information exchange typical of energy relationships
  - FCM model unidirectional information exchange typical of signal relationships
- What is/are the engineering domains in the system?
  - Bond allows multiple energy domains to be analyzed and integrated into the same model
    - E.g. Power transfer between energy flow types such as mechanical, electrical, hydraulic etc.
  - FCM allows different flow domains to be analysed
    - E.g. Energy, Material & Signal flow types
- What is the analysis being undertaken?
  - FCM is ideal for FMEA / FMECA reports or as the basis for reliability analysis
  - Bond is ideal when undertaking PHM analysis

Session 2.2: Failure Simulation

Discussion 2.2.2 FCM Simulation Parameters

- Fuzzy Cognitive Mapping (FCM) uses **causal strength** & **polarity** to define causality between two items
- FCM is used to define the relationship between input and output of an item
  - E.g. A drop in Fuel flow rate inflow affecting the fuel flow rate output of an item





❖ Note: For more information refer to FCM Simulation & Theory Guide in MADe Help

Session 2.2: Failure Simulation

Discussion 2.2.2 FCM Simulation Parameters

To perform an FCM analysis, FCM parameters need to be edited in the MADe model

- FCM parameters are accessed from several locations:
  - Causal connection between input and output flow properties (Functions Editor)
  - Output Flow Properties (Functions Editor)
  - Right-click menu in the system model

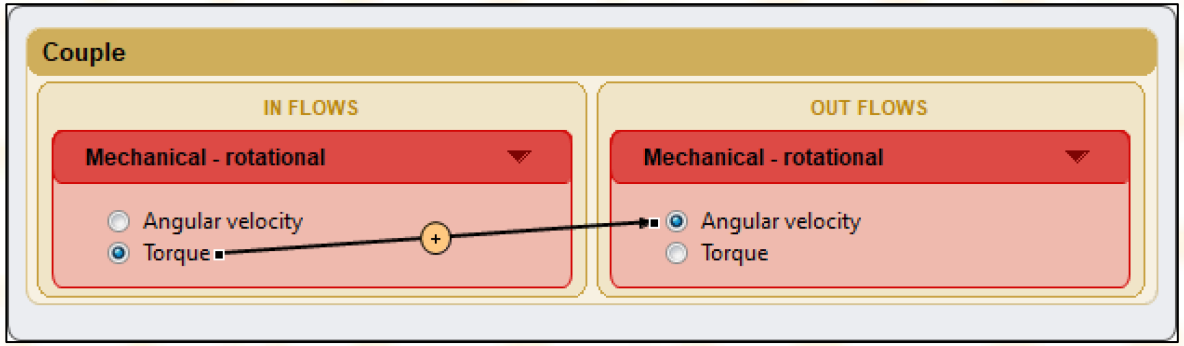
FCM Parameter	Location in MADe	Description
Initial Value	Output Flow Property	Augments the nominal value of a flow during a simulation
Internal Damping	Output Flow Property	Internal feedback of an item (Resistance, damping, friction)
Polarity	Causal Connection	Relationship between a cause and effect (in and out flow)
Causal Strength	Causal Connection	The likelihood that an input flow perturbs the connected output flow
Response Filter	Causal Connection	A filter applied to internal flow perturbations
Perturbation/Failure Injection	Item (Right-click menu)	An introduced failure response (high or low) from the nominal state

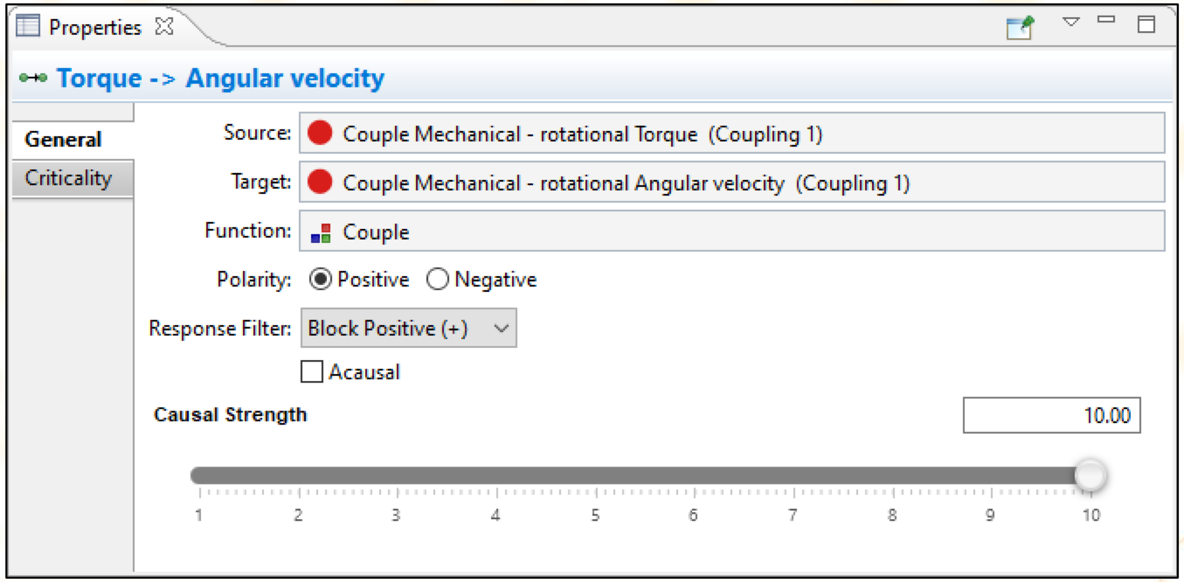
Session 2.2: Failure Simulation

Exercise 2.2.2 FCM Simulation Parameters

To edit FCM Parameters:

- Open the **'Power Generation'** system model
- Open the **'Diesel Engine'** system model
- Open the Functions editor of **'Coupling 1'**
- Select the causal connection between **Torque** & **Angular Velocity**
- Add a **Block Positive** response filter in the Properties Viewer

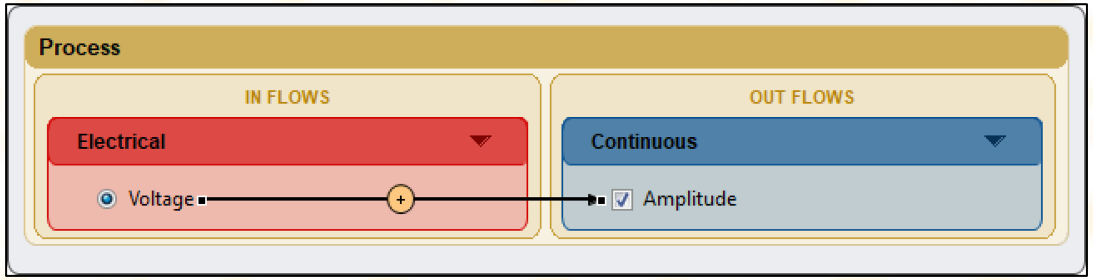


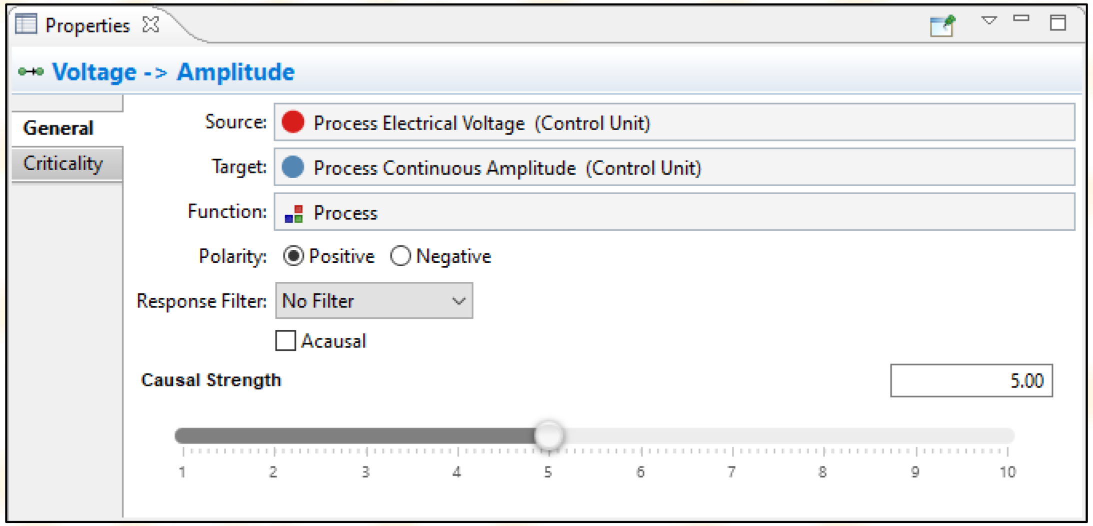


Session 2.2: Failure Simulation

EXERCISE 2.2.2 FCM SIMULATION PARAMETERS (CONTINUED)

- Open the **'Control Unit'** Functions editor (**'Power Generation'** subsystem)
- Toggle the **Enabled flow properties** icon
- Select the **Voltage** to **Amplitude** causal connection
- Set Polarity to **Negative**
- Set the Causal strength to **5.00**



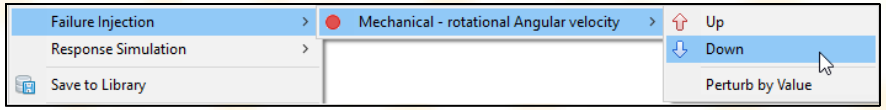


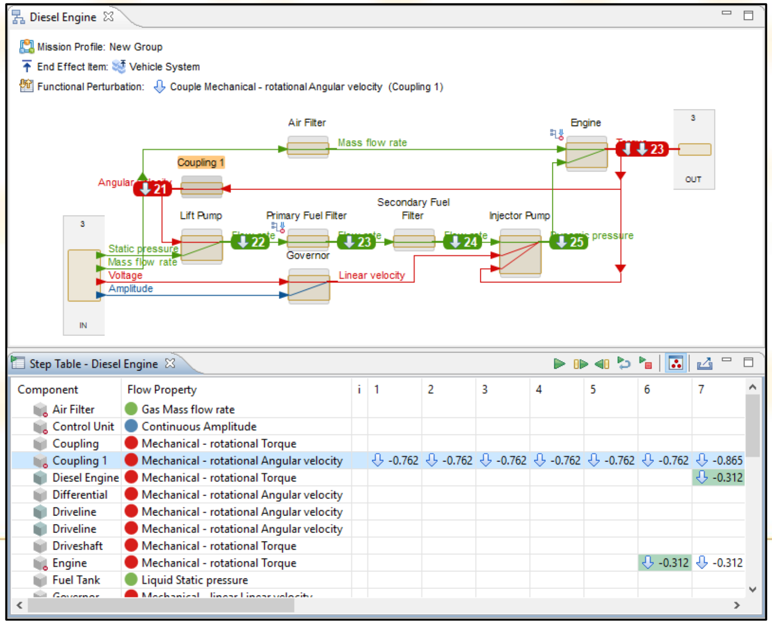
❖ Next section will demonstrate the results of these parameters

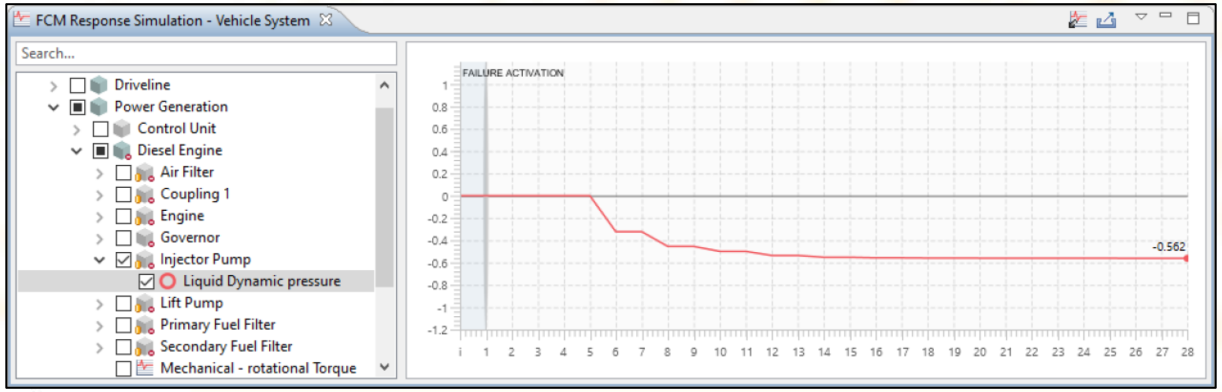
Session 2.2: Failure Simulation

DISCUSSION 2.2.3 FCM SIMULATION

- FCM Simulation looks at the propagating effects of a simulated failure due to an initiating failure introduced by the user
- A failure must first be 'injected' in the system model before FCM Simulation can occur
- System response is observed using methods below:
  - Sequentially (System Model or Step Viewer – see right)
  - Graphically for all time steps (Response Simulation Viewer below)



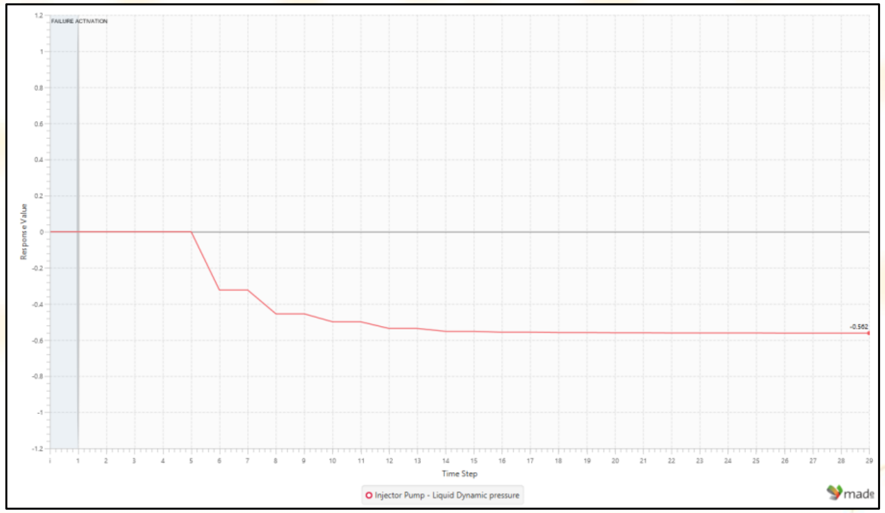




Session 2.2: Failure Simulation

DISCUSSION 2.2.3 FCM SIMULATION

- Failures in MADe are classified deviations from an item's nominal behaviour/state
  - E.g. A Pump provides a flow rate for an operating mode – flow rate outside of this range is considered a failure
  - Nominal behaviour/state is represented as a 'zero' value
- Magnitude of a deviation (per step) is calculated from 3 parameters:
  - Causal Strength (Weighting Matrix, W)
  - Initial Value (Initial State Vector, A^0)
  - Perturbation (Perturbation Vector, P)
- System State Vector* is expressed as: $A^t = A^{t-1} \cdot W + P$



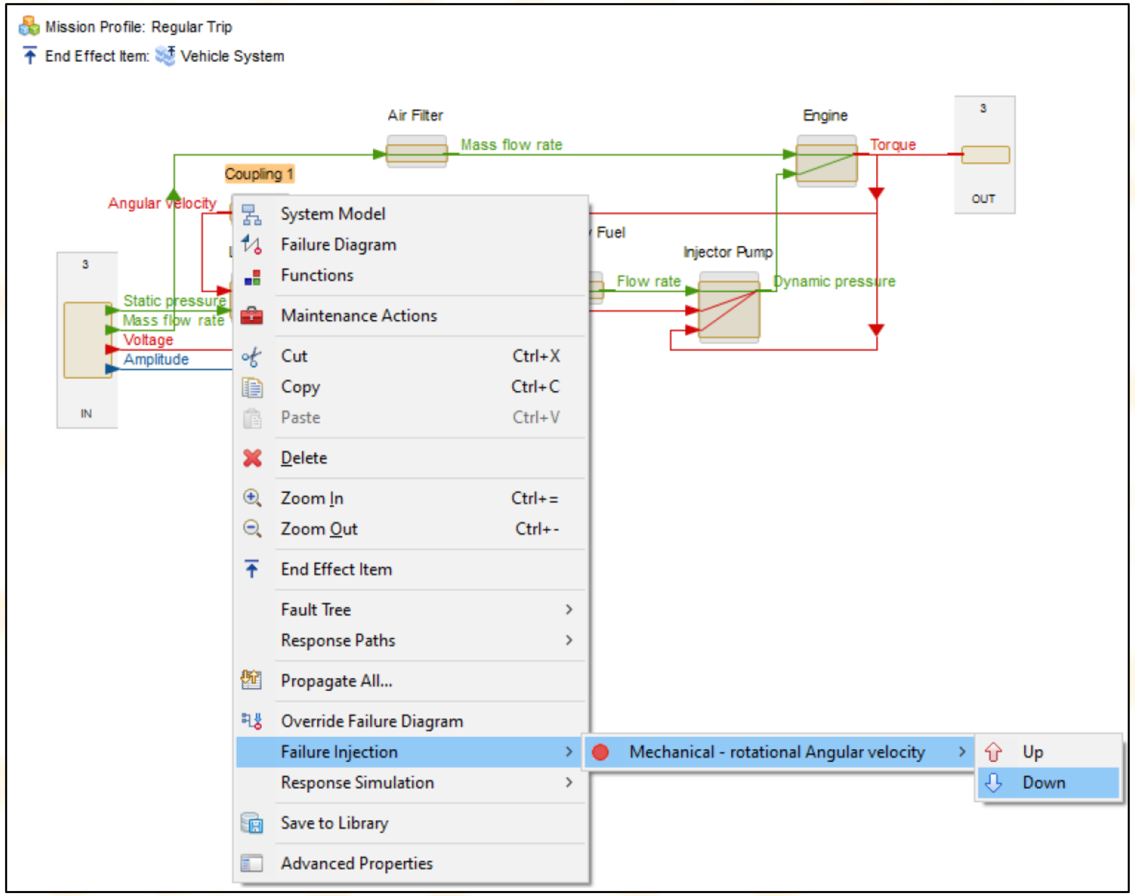
Reference*: FCM Simulation & Theory User Guide in MADe Help

Session 2.2: Failure Simulation

Exercise 2.2.3 FCM Simulation

To inject a Failure:

- Open the **‘Diesel Engine’** system model
- Right-click **‘Coupling 1’**
- Select **Failure Injection → Mech…Angular Velocity → Down**
- Verify Functional Perturbation is injected into the system model with text string: **↓ Couple Mechanical – rotational Angular Velocity (Coupling 1)**



Mission Profile: Regular Trip
End Effect Item: Vehicle System
Functional Perturbation: ⇩ Couple Mechanical - rotational Angular velocity (Coupling 1)

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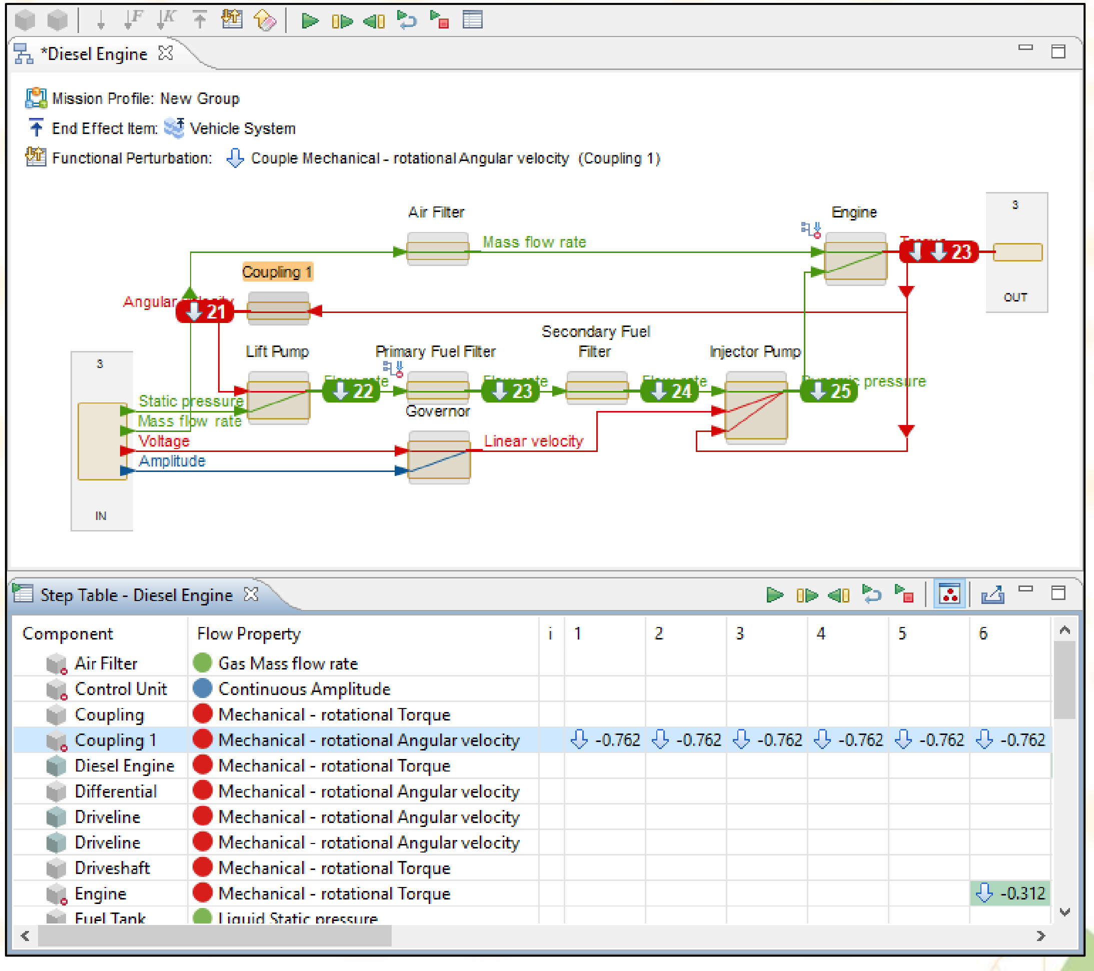
Session 2.2: Failure Simulation

Discussion 2.2.4 FCM Step Table

- Injected Failures are displayed in the system model
- Item State Vectors are listed in the Step Table viewer
- Step Table Icons  are used to control the failure propagation
- Failure Propagation 'Steps' can be traced throughout the system once a failure is fully propagated



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Session 2.2: Failure Simulation

EXERCISE 2.2.4 FCM STEP TABLE

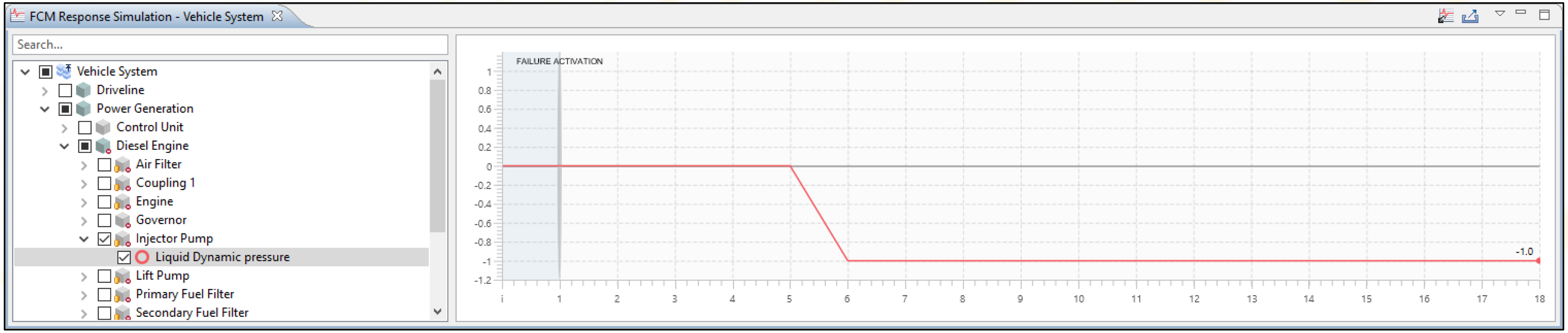
To step a failure through the system:

- Select to move forwards one step & repeat until system reaches equilibrium
    - When last column '=' in Step Viewer is filled out
- Select to go back one step
- Select to reset stepping to its initial state
- Select to run all steps automatically until system equilibrium
- Select to clear all steps and injected failure in system

Session 2.2: Failure Simulation

Discussion 2.2.5 Response Simulation Viewer

- Response Simulation Graph displays the response of failure/s at each step until equilibrium
- Shows the change over time (steps) due to failure
- Graph consists of 3 parts:
    1. Initial Equilibrium Region (Blue region on left)
    2. Failure Activation (Vertical line) representing steps where perturbation is introduced
    3. Post-Failure Response Region (White region)

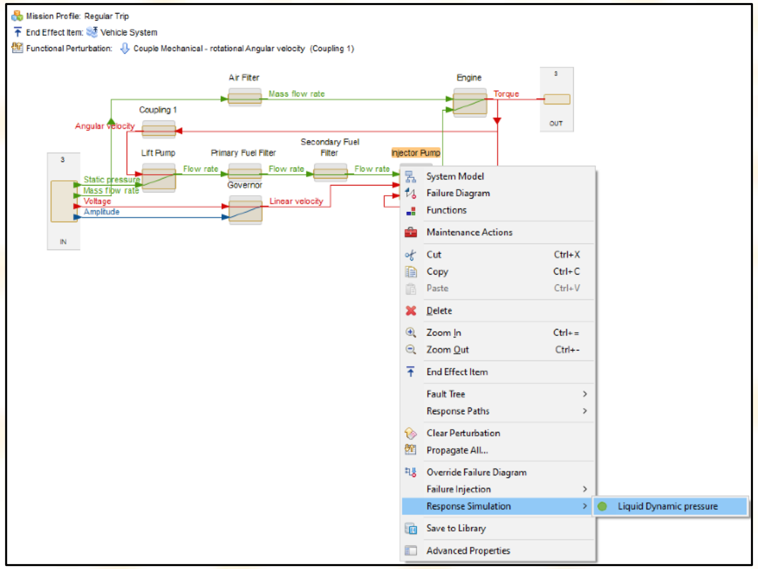


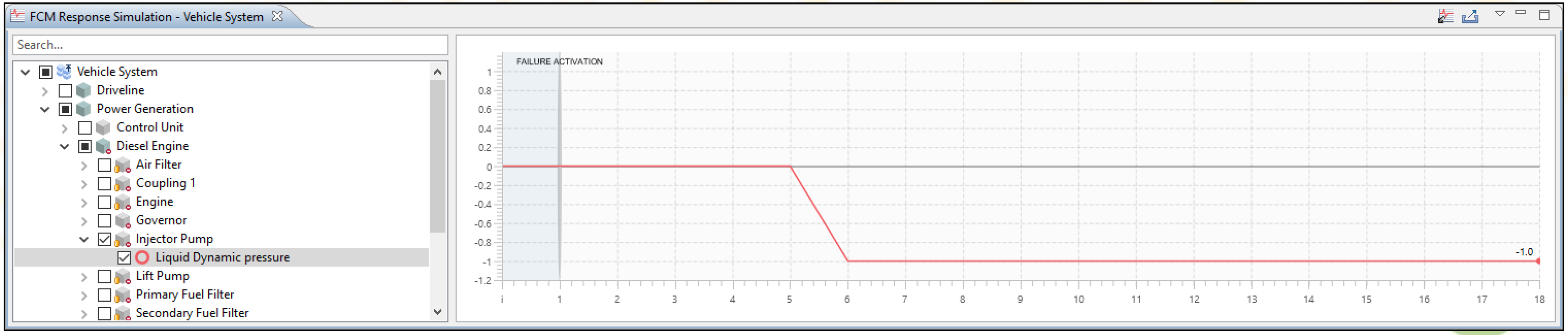
Session 2.2: Failure Simulation

EXERCISE 2.2.5 RESPONSE SIMULATION VIEWER

To view response simulation of the Injector Pump component:

- Right-click the **'Injector Pump'**
- Select **Response Simulation → Liquid Dynamic pressure**
- Verify response graph transitions from nominal (0) to a 'low' failure (-1.0)
- Select other flows to see additional graph overlays





Session 2.2: Failure Simulation

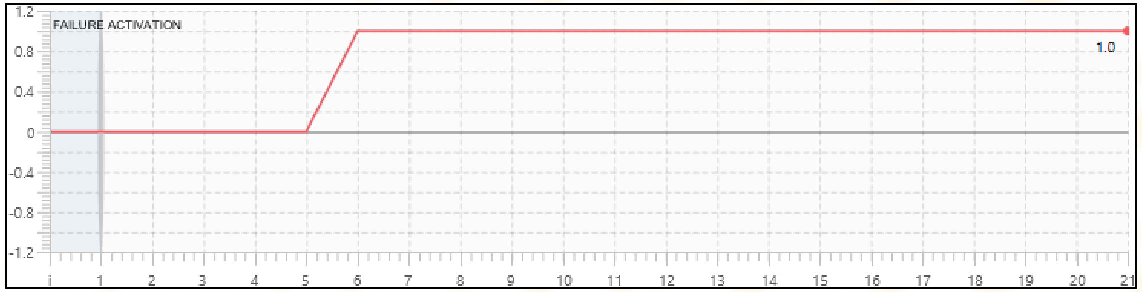
Discussion 2.2.5 FCM Simulation Threshold Types

- FCM Simulation Thresholds are used to ensure:
  - Failure simulation graphs are not divergent (unstable response)
  - Amplitude detail resolution is maintained
- There are currently 5 Threshold Types:
  - Bivalent: Graph results range between nominal (0) and high (+1)
  - Bivalent Sigmoid: Graph results range between nominal (0) and high (+1) with a sigmoid curve acting as a smoothing function
  - Trivalent: Graph results range between nominal (0) and low (-1) to high (+1)
  - Trivalent Sigmoid: Graph results range between nominal and low (-1) to high (+1) with a sigmoid curve acting as a smoothing function
  - No Threshold: User can set a specified limit value to the graph

Session 2.2: Failure Simulation

DISCUSSION 2.2.6 FCM SIMULATION THRESHOLD TYPES (CONTINUED)

- 5 Threshold Types Graphed:
  - Bivalent

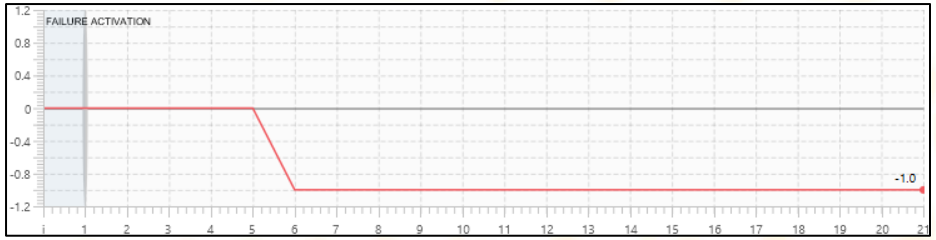


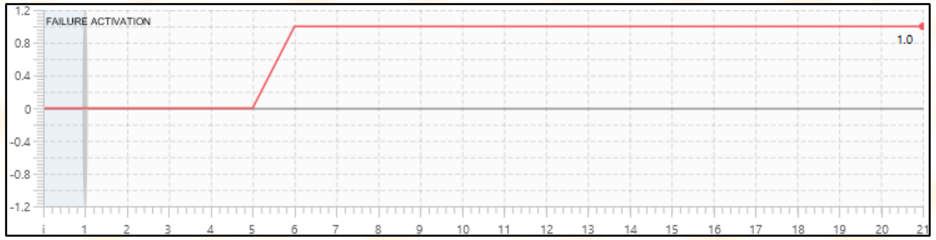
  - Bivalent Sigmoid

Session 2.2: Failure Simulation

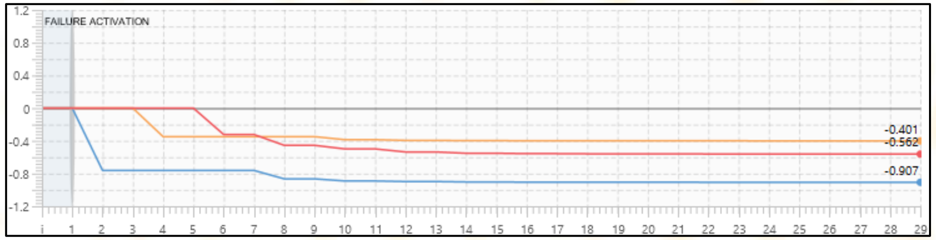
Discussion 2.2.6 FCM Simulation Threshold Types (Continued)

- Trivalent

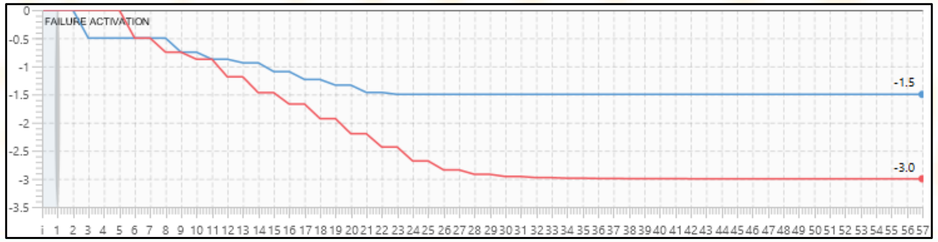




- Trivalent Sigmoid



- No Threshold

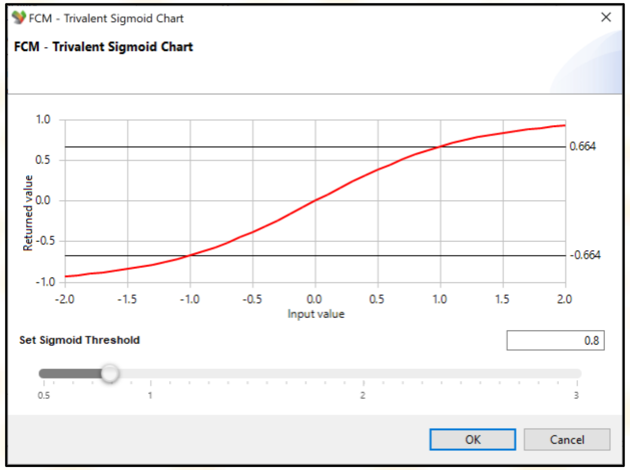


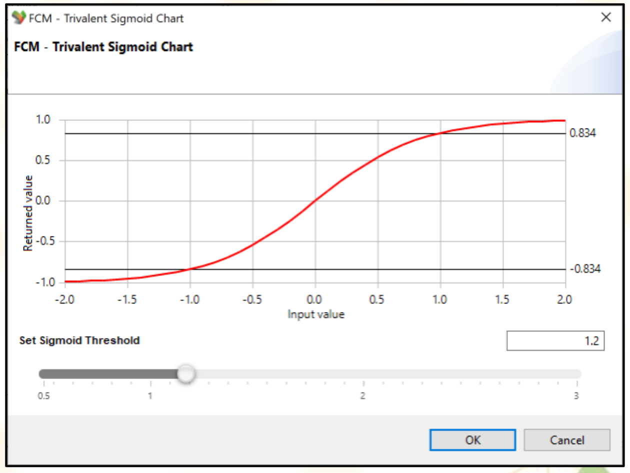
Session 2.2: Failure Simulation

Discussion 2.2.6 FCM Simulation Threshold Types (Continued)

Notes on Sigmoid Charts (Bivalent & Trivalent):

- Accessed from FCM Analysis page in Project Preferences by selecting Evaluate
- Sigmoid curve is adjusted by setting the sigmoid threshold value
    - Smaller Sigmoid Threshold equates to a lower returned value for input value <1
        - E.g. For a Threshold of 1.1, Input Value of 1.0 gives a returned value of 0.8
    - Larger Sigmoid Threshold equates to a higher returned value for input value <1
        - E.g. For a Threshold of 2.0. Input Value of 1.0 gives a returned value of 0.964
- Trivalent curve looks at returned value ranges between -1.0 and 1.0
- Bivalent curve looks at returned value ranges between 0.0 and 1.0



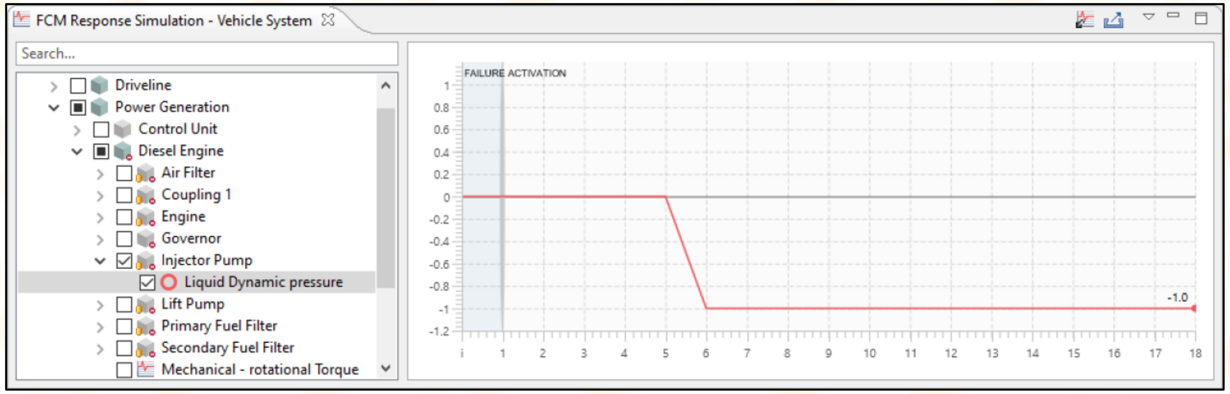


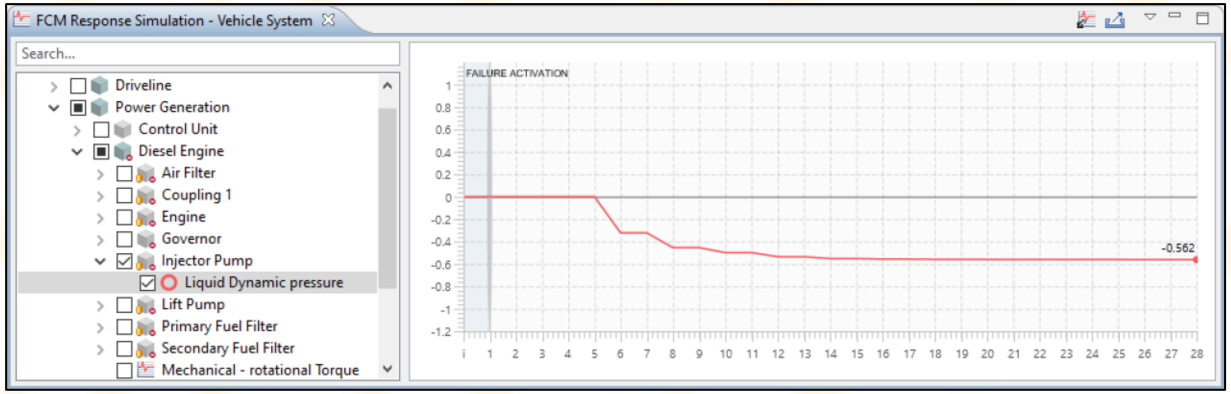
Session 2.2: Failure Simulation

Exercise 2.2.6 FCM Simulation Threshold Types

To set FCM Threshold:

- Select **Preferences → FCM Threshold Preferences**
- Set Threshold Type to **Trivalent Sigmoid 1.0**
- Repeat Failure Injection for **'Coupling 1'**
  - Clear all failure injections (Select)
  - Right-click **'Coupling 1'**
  - Select **Failure Injection → Mech…Angular Velocity → Down**
- Right-click the **'Injector Pump'**
- Select **Response Simulation → Liquid Dynamic pressure**





- Note difference between Trivalent & Trivalent Sigmoid responses – what does this mean?

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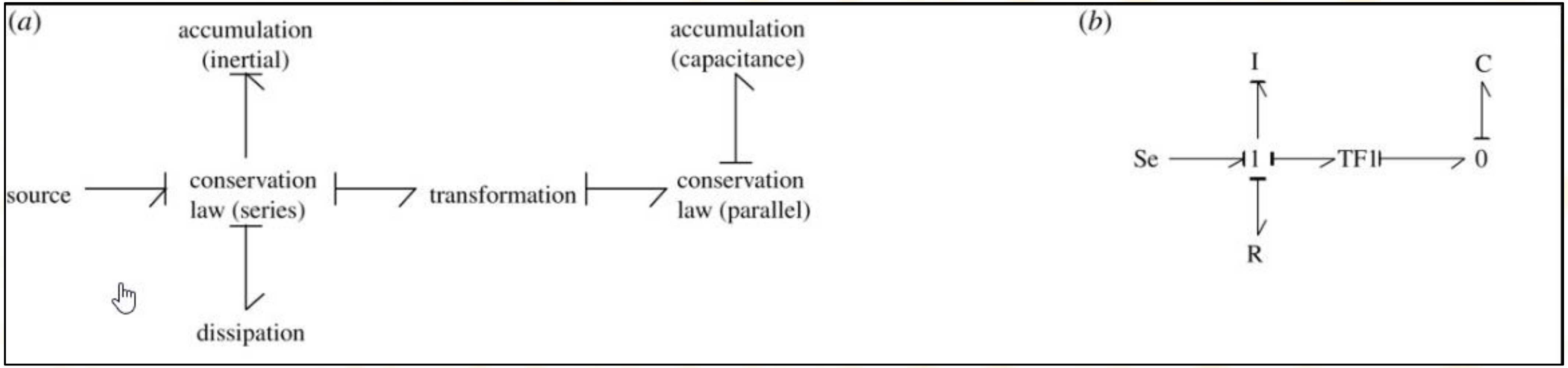
Session 2.2: Failure Simulation

Discussion 2.2.7 Bond Graph Simulation

- A Bond graph is an energy model of a dynamic system
- Bond graph modeling represents bi-directional exchange of energy
- Bond graph models use equations for each item to determine the net change in energy
- Power bonds are used to link different elements together



Session 2.2: Failure Simulation

Discussion 2.2.7 Bond Graph Simulation

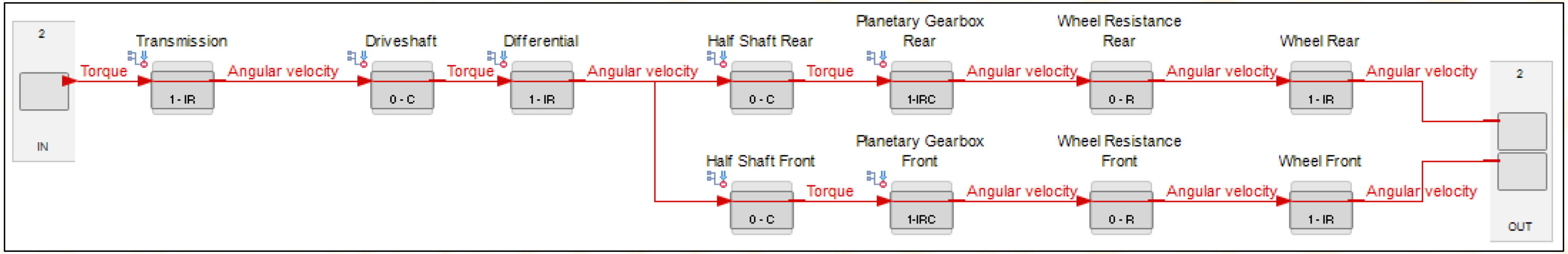
- Bond graph analysis requires editing of Bond graph properties
- These are accessed from the Properties viewer when selecting an item
- In MADe the user needs to:
  - Define the system model configuration
  - Assign bond groups to items
- Taxonomy for Bond Graph parameters is in the table below:

Bond Graph Parameter	Location	Description
Bond Type	Properties Viewer → Bond tab	Selection of bond type and junction represented by each item
Passive Variables	Properties Viewer → Bond tab	Contains fields for setting capacitor, inductor and resistor values & effort limits

Session 2.2: Failure Simulation

DISCUSSION 2.2.7 BOND GRAPH SIMULATION

- Modeling system model items for Bond simulation is the same process for FCM simulation
- The only limitation is that all flows used must be energy flows



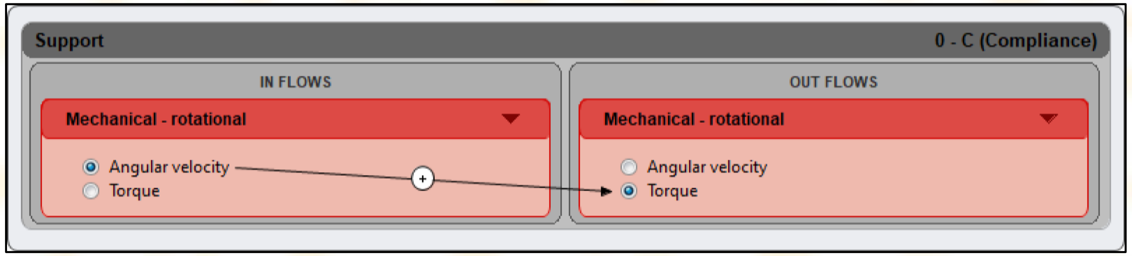
Session 2.2: Failure Simulation

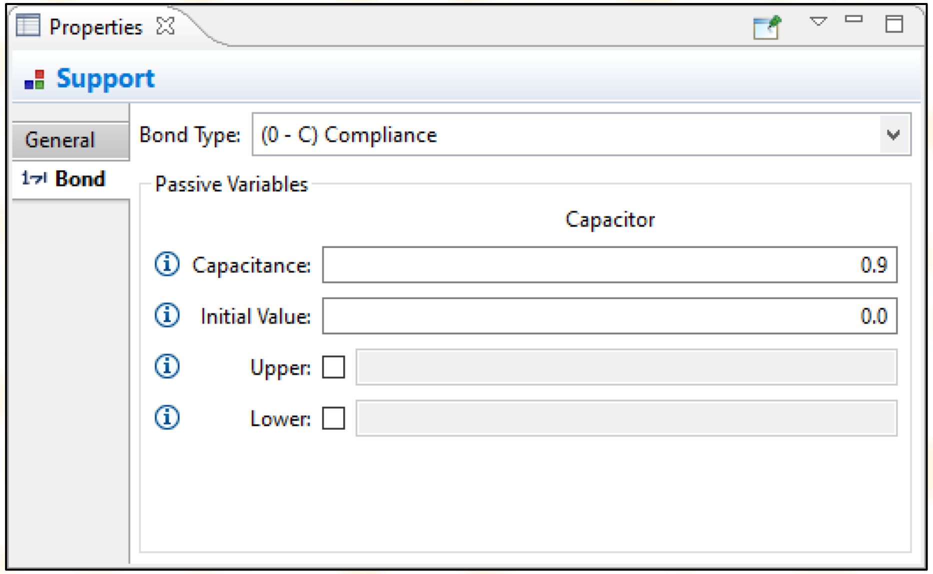
EXERCISE 2.2.7 BOND GRAPH SIMULATION

There are two methods of assigning Bond Types:

Method 1:

- Open the functions editor for the **'Driveshaft'** component (in the **'Driveline'** subsystem)
- Select the function **Support**
- Select **Bond** tab the **Properties** viewer
- Select Bond type **(0 – C) Compliance** from drop down menu
- Verify Capacitance and Initial Value are set to **0.90** & **0.00** respectively



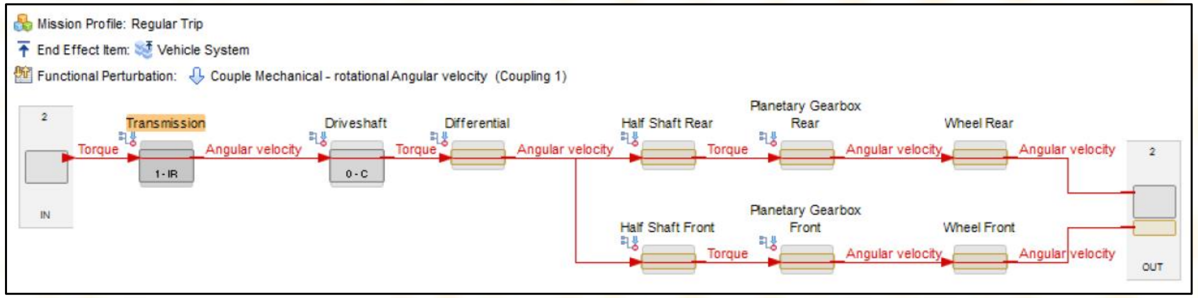


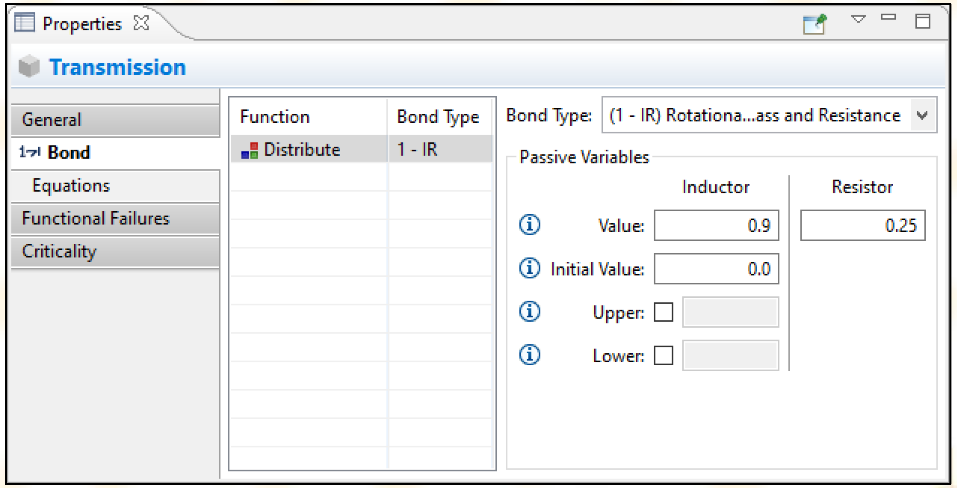
Session 2.2: Failure Simulation

Exercise 2.2.7 Bond Graph Simulation (Continued)

Method 2:

- Select the **‘Transmission’** (in the **‘Driveline’** subsystem)
- Navigate to the **Properties** viewer and select the **Bond** tab
- Select the function **Distribute**
- Select Bond Type: **(1 - IR) Rotational Inertia Mass and Resistance**
- Verify Values for Inductor is set to **0.90**
- Verify Values for Resistor is set to **0.25**
- Verify Inductor Initial Value is set to **0.00**





Session 2.2: Failure Simulation

EXERCISE 2.2.7 BOND GRAPH SIMULATION (CONTINUED)

- Assign the remaining components according to the table below with the appropriate Bond Type:

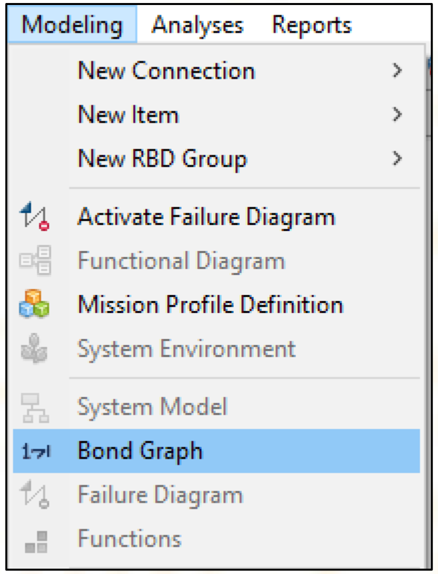
Item	Bond Type
Transmission	Rotational Inertia Mass and Resistance (1-IR)
Driveshaft	Compliance (0-C)
Differential	Rotational Inertia Mass and Resistance (1-IR)
Half Shaft (Front & Rear)	Compliance (0-C)
Planetary Gearbox (Front & Rear)	Rotational Inertia Mass, Compliance and Resistance (1-IRC)
Wheel (Front & Rear)	Rotational Inertia Mass and Resistance (1-IR)

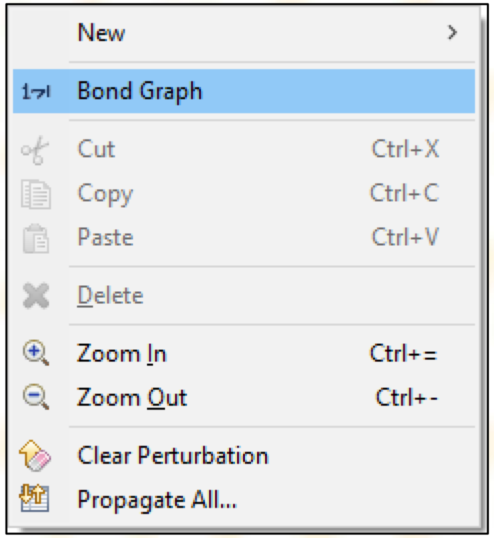
Session 2.2: Failure Simulation

EXERCISE 2.2.8 BOND GRAPH MODEL

There are 2 ways of generating the Bond Graph model:

1. From main menu: **Modeling → Bond Graph**
2. Right-click the system model, then select **Bond Graph**

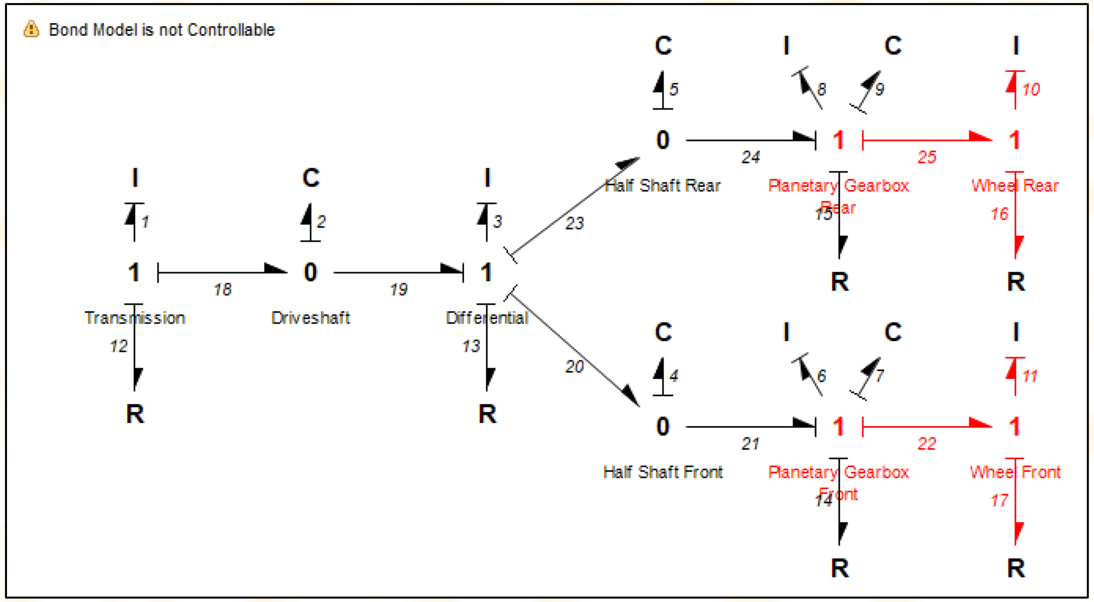




Session 2.2: Failure Simulation

EXERCISE 2.2.8 BOND GRAPH MODEL (CONTINUED)

- Verify that there are 4 junction errors & 6 causal stroke errors due to incompatible causal strokes (bond types)
- These are indicated by red lines/numbers on the Bond Graph
- You may also find these in the Problems window under Errors
    - Causal strokes do not match the bond graph assigned to …



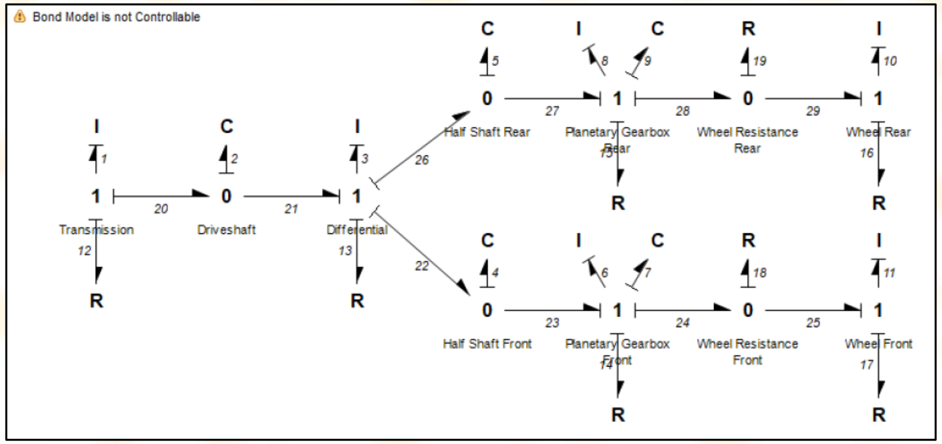
Problems

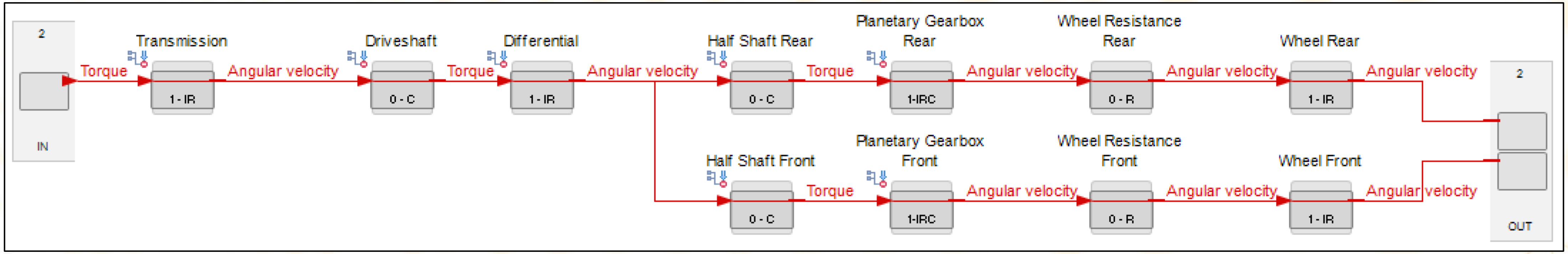
Name	Model
Errors (2 of 2 items)	
Causal strokes do not match the bond group assigned to 1 - IR (Wheel Front)	Wheel Front -> Rotate -> 1 - IR
Causal strokes do not match the bond group assigned to 1 - IR (Wheel Rear)	Wheel Rear -> Rotate -> 1 - IR
Warnings (13 of 13 items)	

Session 2.2: Failure Simulation

EXERCISE 2.2.8 BOND GRAPH MODEL (CONTINUED)

- To fix the error, split each **'Wheel'** component into two components: '**Wheel Resistance'** & **'Wheel'** by copying the **'Wheel'** components and renaming accordingly
- Set **'Wheel Resistance'** function: **Rotate Mechanical – Rotational Angular Velocity**
- Set **'Wheel Resistance'** & **'Wheel'** Bond Types as **(0 – R)** & **(1 – I)** respectively
- Re-run Bond Graph model to verify no causality errors are present

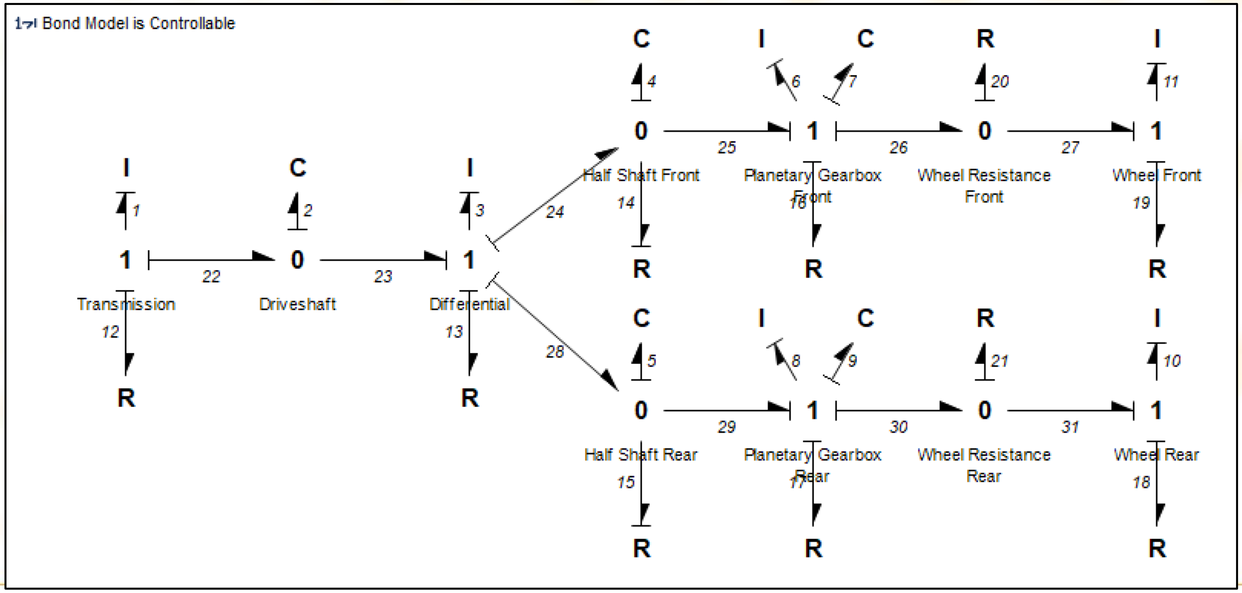




Session 2.2: Failure Simulation

Exercise 2.2.8 Bond Graph Model (Continued)

- The current Bond Graph model shows 3 warnings:
  1. Bond Model is not Controllable (Bond Graph editor)
  2. Vehicle system has no defined Sources (Problems viewer under Warnings)
  3. Vehicle system has no defined Sinks (Problems viewer under Warnings)
- To resolve the first warning, convert both the **Half Shaft Front** and **Half Shaft Rear** components to a **(0 – CR)** Bond Type

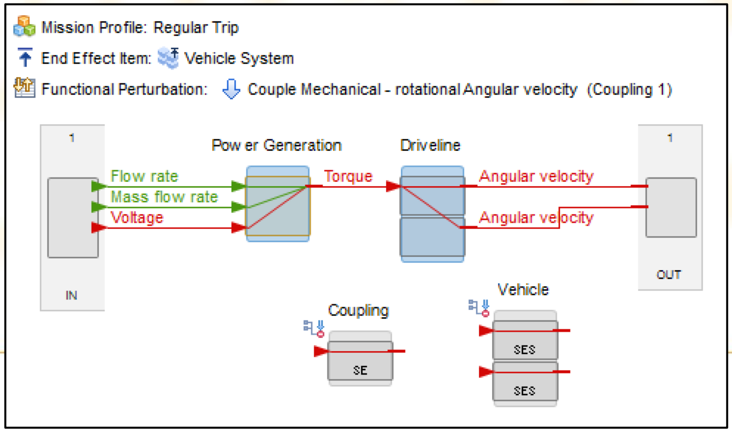


Session 2.2: Failure Simulation

Exercise 2.2.8 Bond Graph Model (Continued)

- To resolve warning regarding sources & sinks, create two new components at the top level of indenture:
  - **'Coupling'** component, set as an **Effort Source (SE)** Bond type
  - **'Vehicle'** component set as an **Effort Sink (SES)** Bond type
- Details of the component functions & flows are listed in the table below:

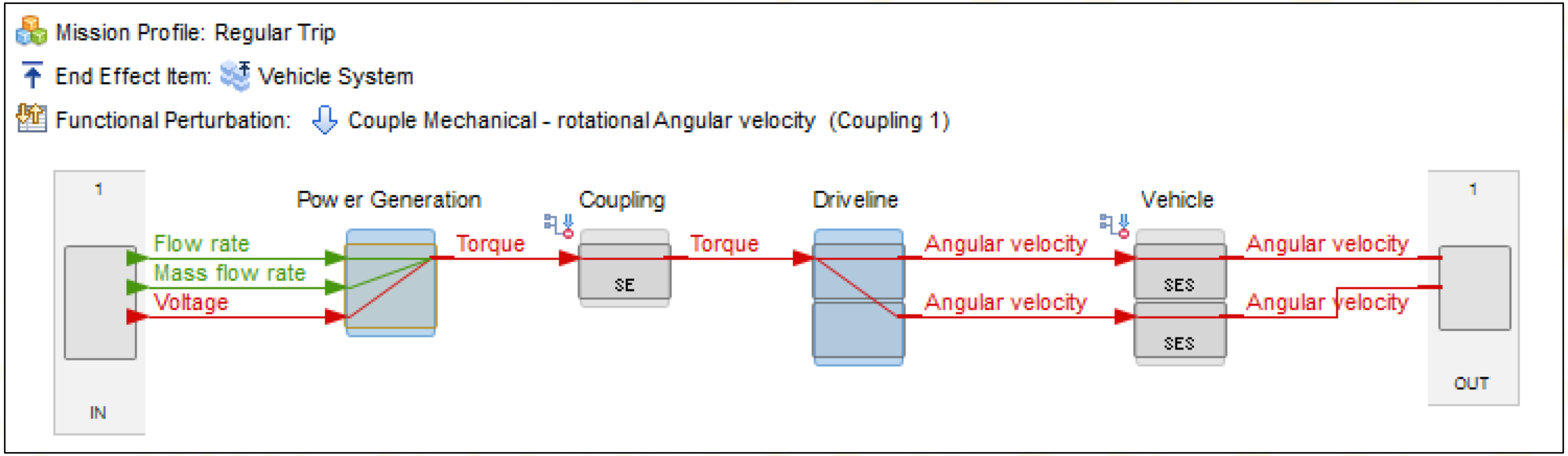
Component	Function	In Flow	Out Flow	Bond Type
Coupling	Couple	Mechanical – rotational Torque	Mechanical – rotational Torque	Effort Source
Vehicle	Connect	Mechanical – rotational Angular velocity	Mechanical – rotational Angular velocity	Effort Sink
	Connect	Mechanical – rotational Angular velocity	Mechanical – rotational Angular velocity	Effort Sink



Session 2.2: Failure Simulation

Exercise 2.2.8 Bond Graph Model (Continued)

- Connect the model as shown below



Session 2.2: Failure Simulation

Discussion 2.2.9 Bond Graph Response Simulation

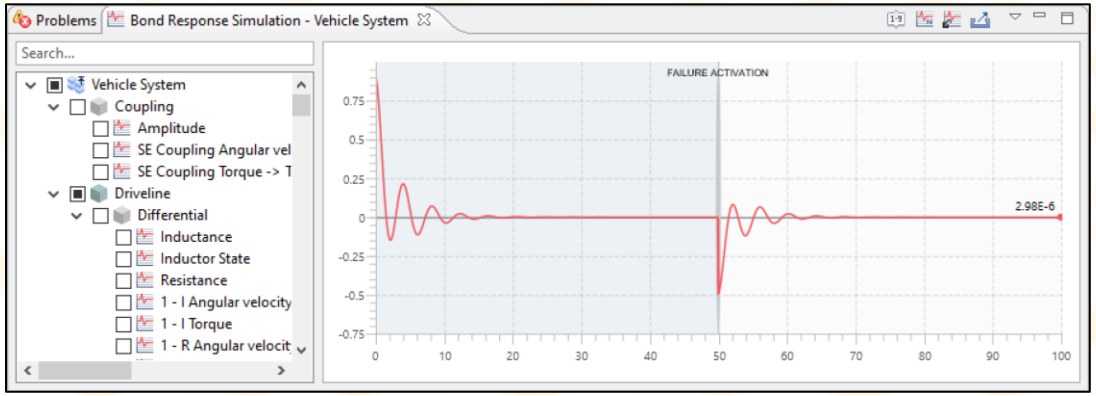
- Bond graph response simulation is similar to FCM but only uses Bond properties
- Bond graph simulation provides more accuracy in terms of model behaviour due to equations and bi-directional feedback (leading to more detailed responses)
- Bond graph response simulation is used to validate the Bond graph model
- Bond graph simulation can be tested against quantitative simulations, such as:
  - AMESIM
  - MATLAB Simulink

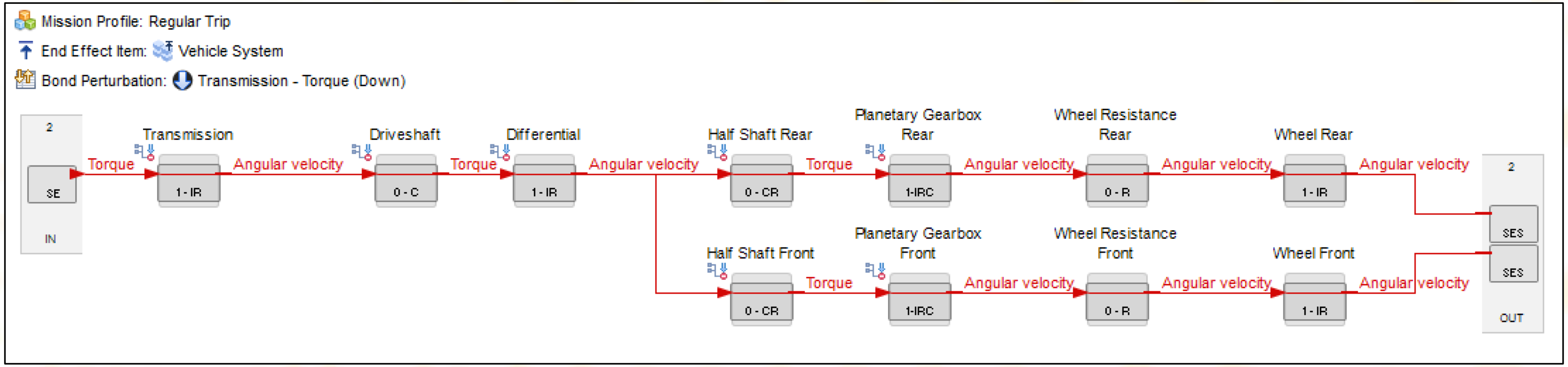
Session 2.2: Failure Simulation

EXERCISE 2.2.9 BOND GRAPH RESPONSE SIMULATION

To inject a failure in a Bond Graph model:

- ➢ Right-click the **'Transmission'** component
- ➢ Select **Failure Injection → Torque differential → Down**

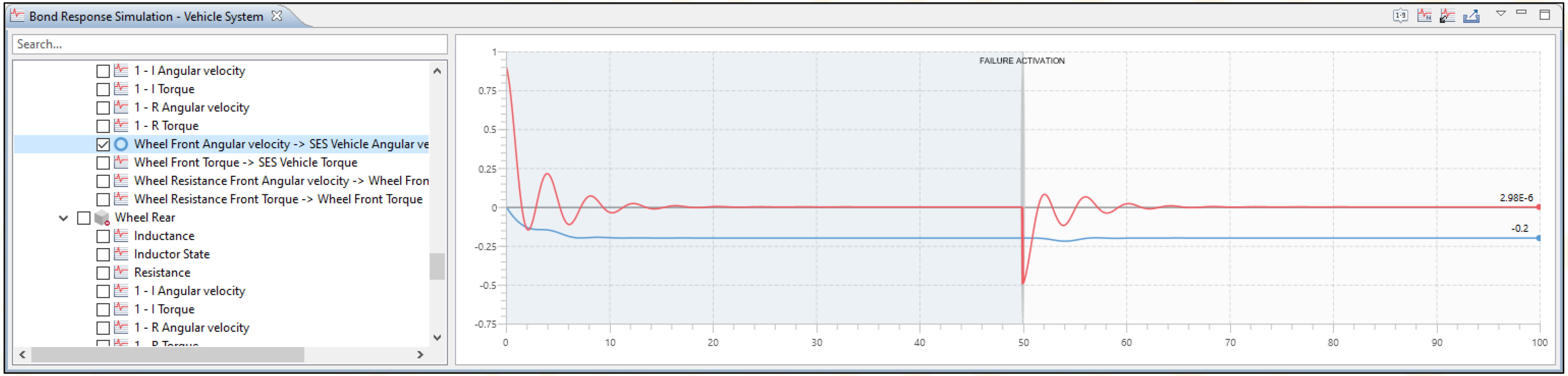




Session 2.2: Failure Simulation

EXERCISE 2.2.9 BOND GRAPH RESPONSE SIMULATION (CONTINUED)

- In the Response Simulation viewer locate **‘Wheel Front’**
- Select check box for **Wheel Front Angular Velocity → SES Vehicle Angular Velocity**
- Review the graph: Wheel Angular Velocity drops momentarily as a result of Transmission loss
- Try other perturbations & corresponding simulation responses



Session 2.2: Failure Simulation

Session 2.2 Summary

- ✓ 2.2.1 Introduction to Failure Simulation in MADe
- ✓ 2.2.2 FCM Simulation Parameters
- ✓ 2.2.3 FCM Simulation
- ✓ 2.2.4 FCM Step Table
- ✓ 2.2.5 Response Simulation Viewer
- ✓ 2.2.6 FCM Simulation Threshold Types
- ✓ 2.2.7 Bond Graph Simulation
- ✓ 2.2.8 Bond Graph Model
- ✓ 2.2.9 Bond Graph Response Simulation

Session 2.3: Mission Profile & Groups

Session 2.3 Outline

2.3.1 Environment Profiles: System Baseline

2.3.2 Mission Phase/Segment-specific Environments

2.3.3 Mission Success Metrics: System Flow Properties

2.3.4 Functional Profile

2.3.5 Special Conditions

2.3.6 Duty Cycles

2.3.7 Mission Profile Groups

2.3.8 Mission Profile Definition Reports

Session 2.3: Mission Profile & Groups

Discussion 2.3 Mission Profile & Groups

This session will focus on aspects of the Mission Profile that are solution-specific :

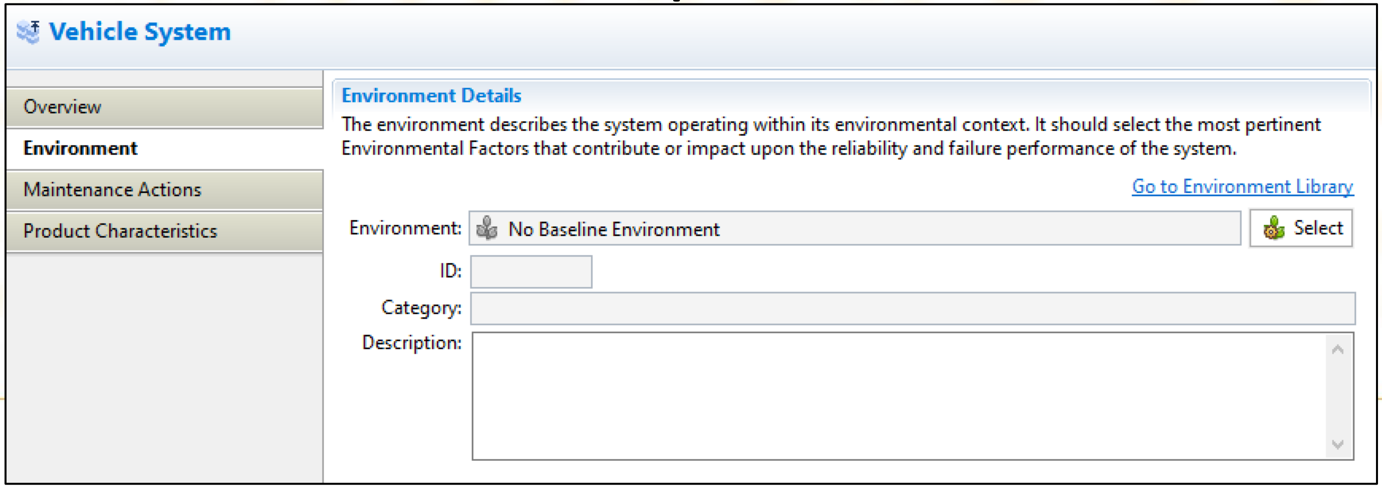
1. Operating environment
2. Functional Profile for each Mission Profile
3. Duty Cycles
4. Mission Groups

- Since the system model is now defined the mission profile from Session 1.3 can be further developed and applied to the system

Session 2.3: Mission Profile & Groups

Discussion 2.3.1 Environmental Profiles: System Baseline

- Environmental profiles are divided into System Baseline & Mission Phase / Segment-specific
  - System Baseline: Intended environment that the system is designed to operate within
  - Mission-Based: Actual environment experienced during a Mission Profile
- Each environmental profile includes the impact of environmental factors likely to be encountered
  - E.g. Acceleration, Pressure, Contamination etc.
  - This information is useful in determining the system susceptibility to these factors
- System Baseline is accessed from the **Advanced Properties** editor but relates to MPD



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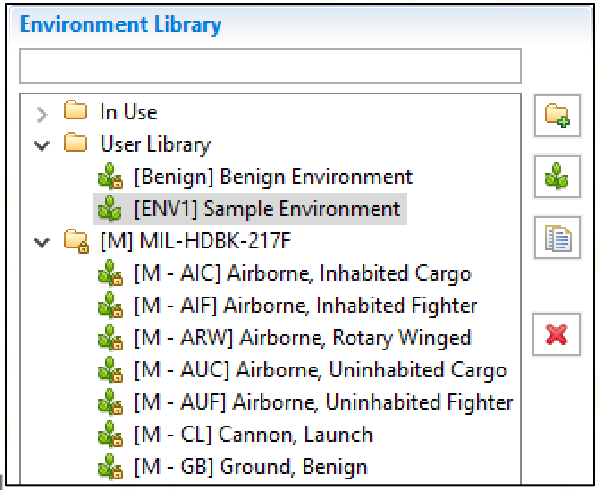
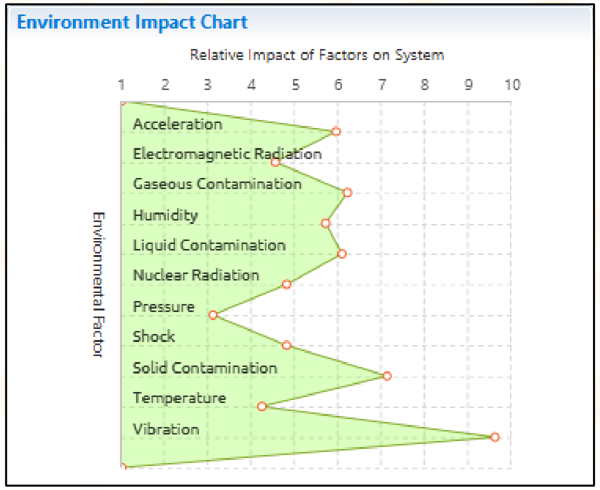
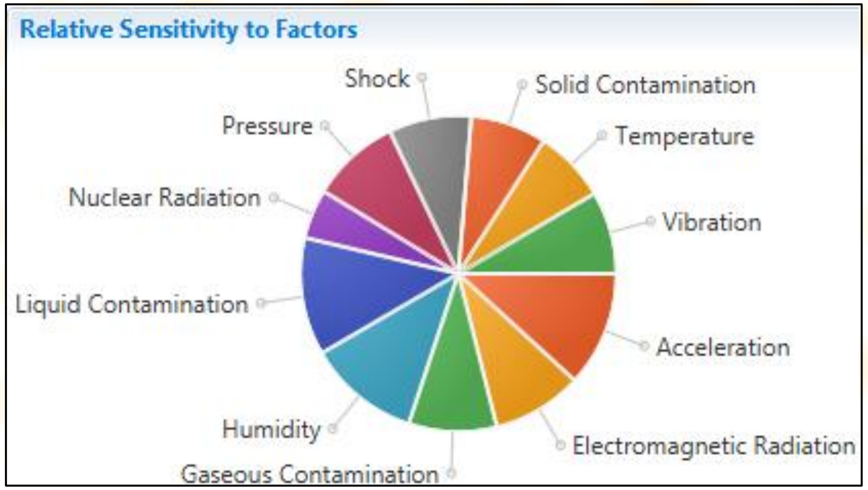
Session 2.3: Mission Profile & Groups

Discussion 2.3.1 Environmental Profiles: System Baseline (Continue)

- Environmental Profiles are stored in the Environmental Library
- Environmental Library contains:
  - Pre-defined Library: MIL-HDBK-217F, Telcordia
  - User-defined Category & Profiles
  - System Sensitivity to define relative impact of one environmental factor to another



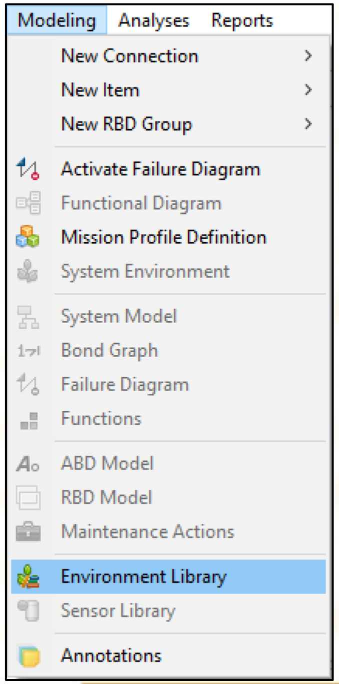


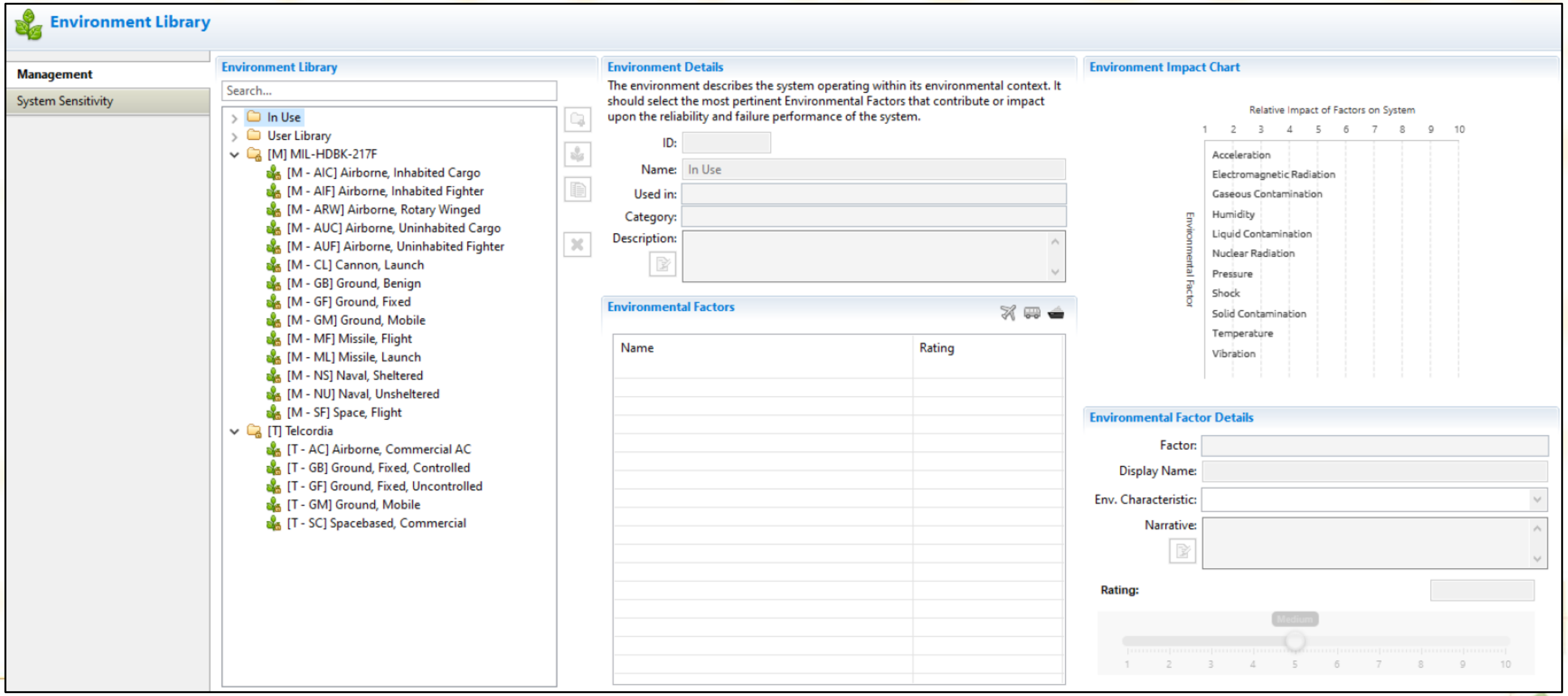


Session 2.3: Mission Profile & Groups

EXERCISE 2.3.1 ENVIRONMENTAL PROFILES: SYSTEM BASELINE

- To create a new Environmental Profile in the Environmental Library:
  - Select **Modeling → Environment Library** from the main menu
  - Select from the icon toolbar

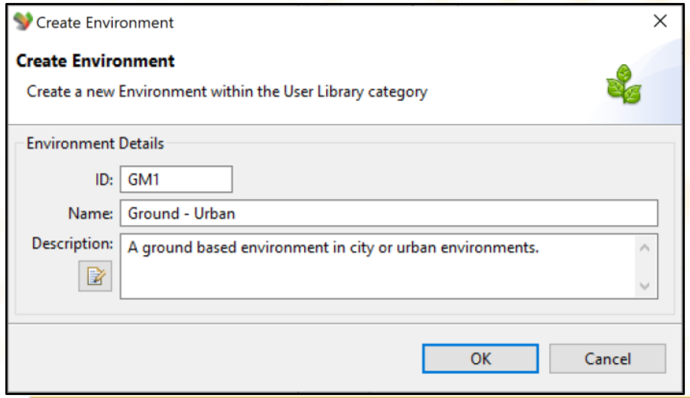


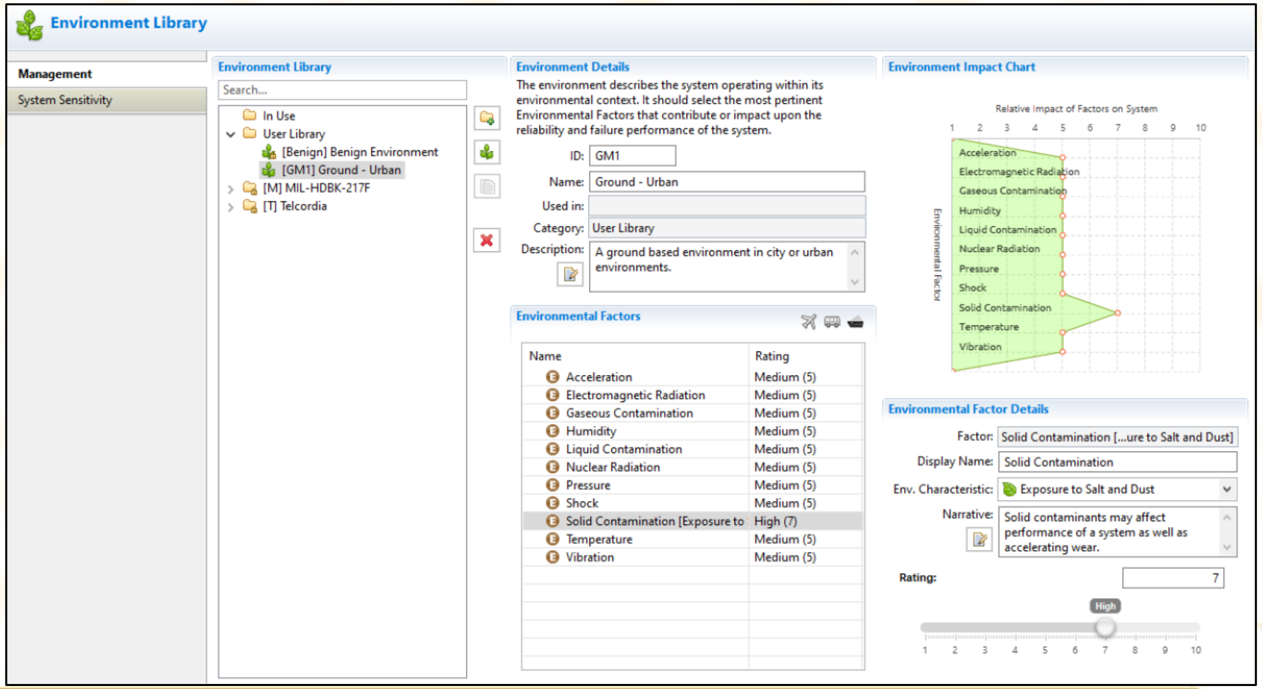


Session 2.3: Mission Profile & Groups

EXERCISE 2.3.1 ENVIRONMENTAL PROFILES: SYSTEM BASELINE (CONTINUE)

- Select **User Library** folder then select **Add an Environment** icon
- Enter ID & Name: **GM1, Ground – Urban**
- Enter Description: **A ground based environment in city or urban environments.**
- Select OK
- Select **Solid Contamination** Environmental Factor
  - Set rating to **High (7.0)**
  - Select Env. Characteristic: **Exposure to Salt and Dust**

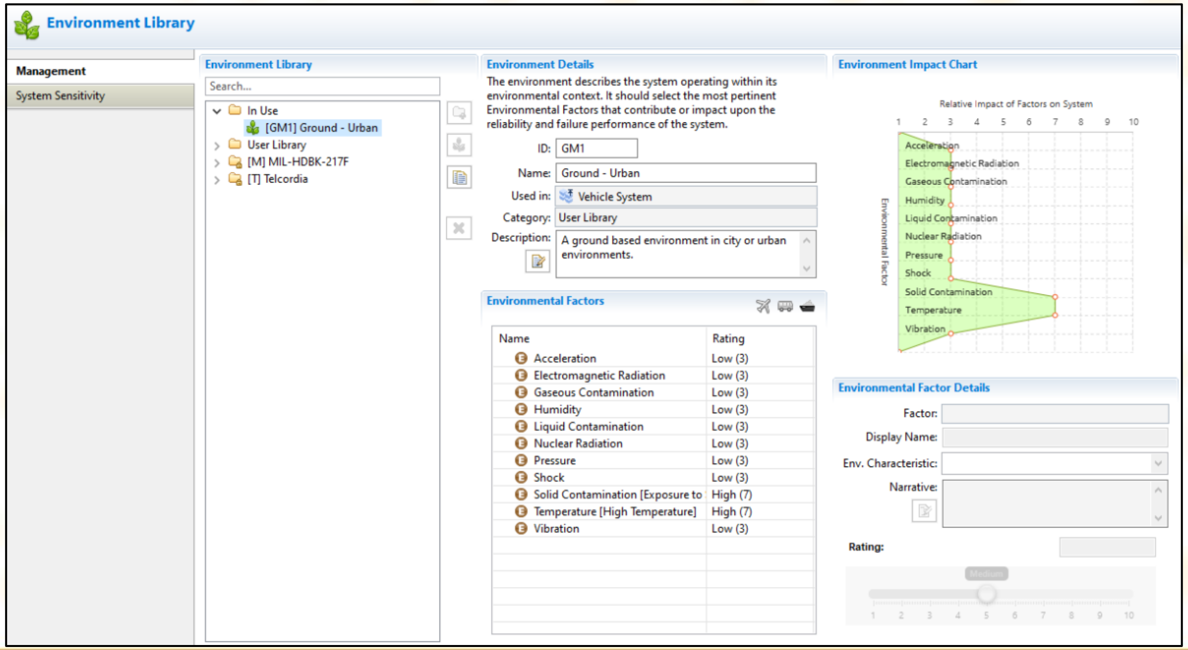




Session 2.3: Mission Profile & Groups

EXERCISE 2.3.1 ENVIRONMENTAL PROFILES: SYSTEM BASELINE (CONTINUE)

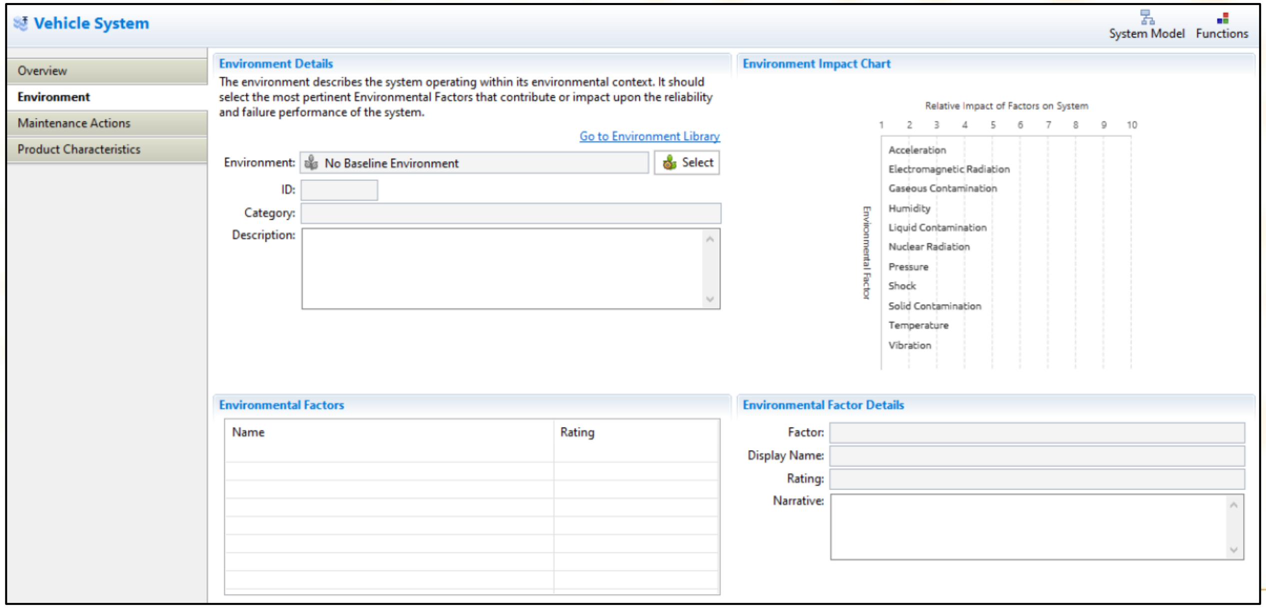
- Select **Temperature** Environmental Factor
  - Set rating to **High (7.0)**
  - Select Env. Characteristic: **High Temperature**
- Set all other Environmental Factor Ratings to **Low (3.0)**

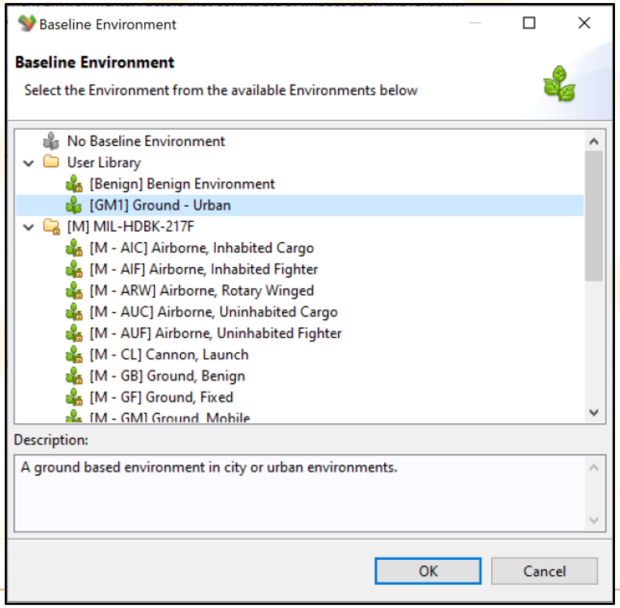


Session 2.3: Mission Profile & Groups

Exercise 2.3.1 Environmental Profiles: System Baseline (Continued)

- Right-click on **‘Vehicle System’** and select **Advanced Properties**
- Select the **Environment** tab
- Select [Select] to set a baseline environment
- Expand the **User Library** folder and select **[GM1] Ground – Urban**





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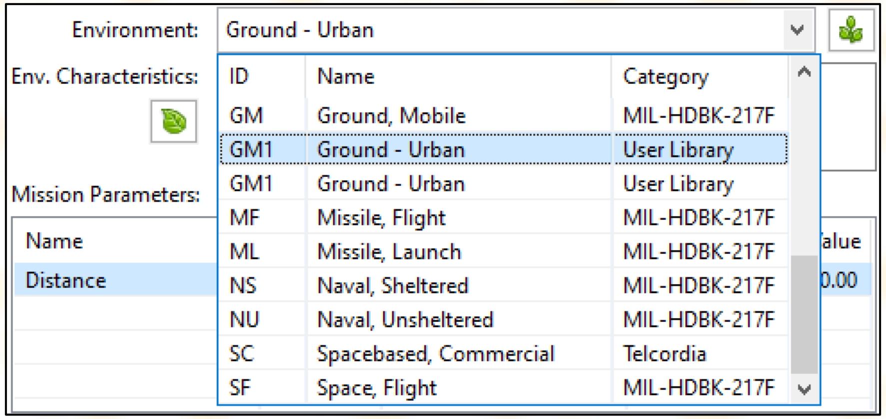
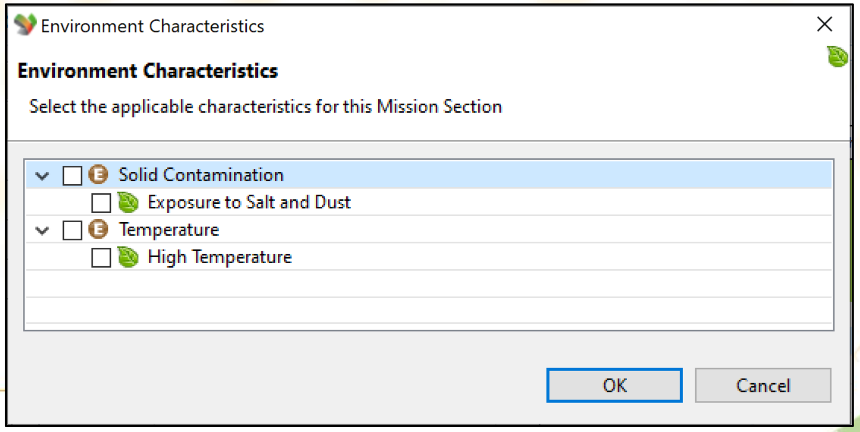
Session 2.3: Mission Profile & Groups

Exercise 2.3.2 Mission Phase/Segment-specific Environments

Now that we have set up environmental profiles, we can assign them to specific mission phases or segments.

- Open **Regular Trip** in the Mission Profile Editor
- Open the **Mission Phases and Segments** page
- Select the **Ignition** Segment
- From the Segment Details section:
  - Select **Ground – Urban** Environment from the drop down menu
  - Select the Environment Characteristics icon
  - Select **Exposure to Salt and Dust** & **High Temperature**
  - Select OK
- Repeat previous steps for **Acceleration** & **Shut-down** Phases

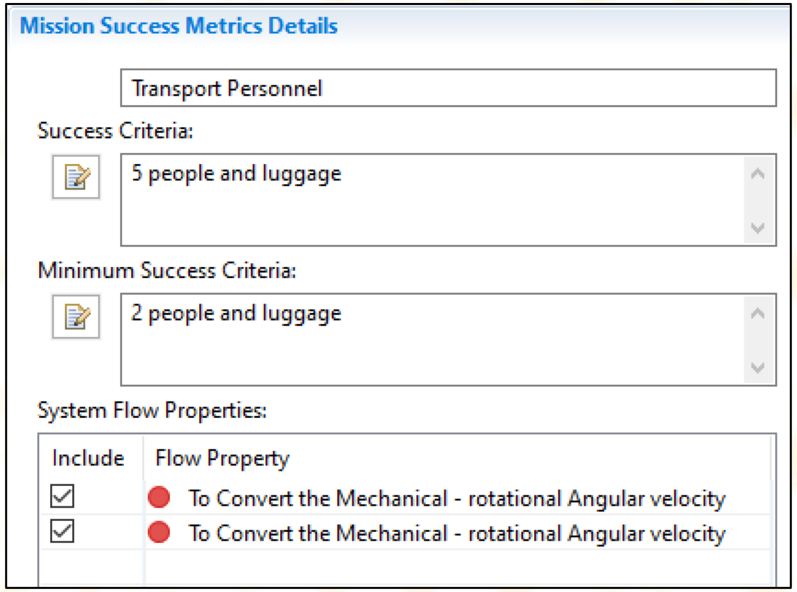




Session 2.3: Mission Profile & Groups

EXERCISE 2.3.3 MISSION SUCCESS METRICS: SYSTEM FLOW PROPERTIES

- Navigate to the **Mission Success Metrics** page
- Select check boxes for both **Convert Mechanical – rotational Angular velocity** functions

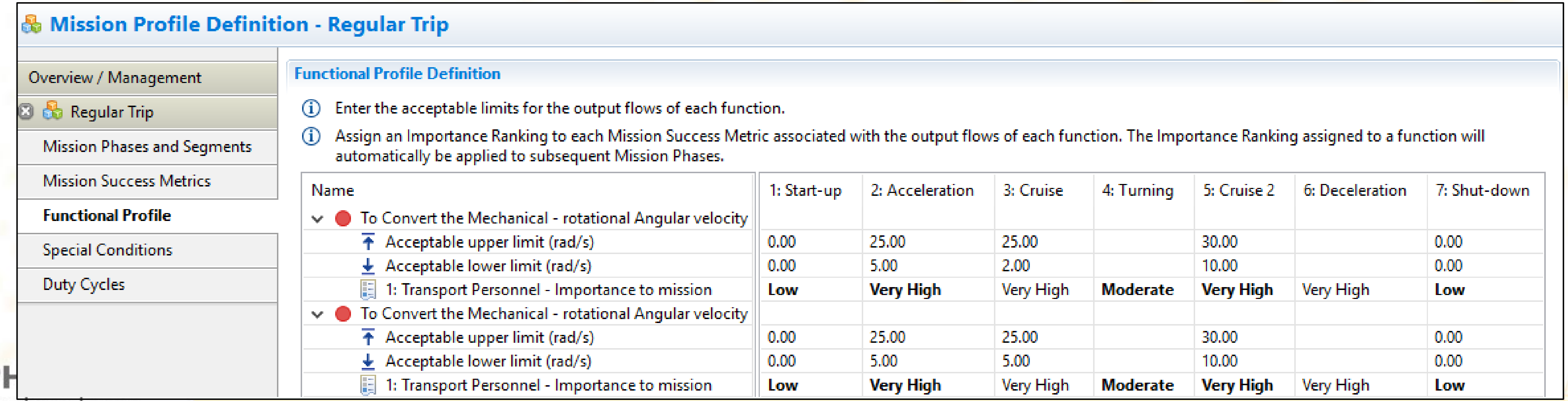


❖ Note: Selected flow properties are included in the Functional Profile page

Session 2.3: Mission Profile & Groups

Discussion 2.3.4 Functional Profile

- This page associates system functions to mission success metrics – both related to mission phases
- Acceptable upper/lower limits for each individual function per phase
- This page is used to determine importance of each success metric is for each mission phase
- This page is output in the Mission Profile & Mission Effective Functions List (MEFL) reports



Name	1: Start-up	2: Acceleration	3: Cruise	4: Turning	5: Cruise 2	6: Deceleration	7: Shut-down
To Convert the Mechanical - rotational Angular velocity							
Acceptable upper limit (rad/s)	0.00	25.00	25.00		30.00		0.00
Acceptable lower limit (rad/s)	0.00	5.00	2.00		10.00		0.00
1: Transport Personnel - Importance to mission	**Low**	**Very High**	Very High	**Moderate**	**Very High**	Very High	**Low**
To Convert the Mechanical - rotational Angular velocity							
Acceptable upper limit (rad/s)	0.00	25.00	25.00		30.00		0.00
Acceptable lower limit (rad/s)	0.00	5.00	5.00		10.00		0.00
1: Transport Personnel - Importance to mission	**Low**	**Very High**	Very High	**Moderate**	**Very High**	Very High	**Low**

Session 2.3: Mission Profile & Groups

EXERCISE 2.3.4 FUNCTIONAL PROFILE

To set the Functional Profile:

- Navigate to the **Functional Profile** tab
- Enter the acceptable limit values below
- Set functional importance for each phase as shown below

Mission Profile Definition - Regular Trip

- Overview / Management
- Regular Trip
  - Mission Phases and Segments
  - Mission Success Metrics
  - **Functional Profile**
  - Special Conditions
  - Duty Cycles

Functional Profile Definition

Enter the acceptable limits for the output flows of each function.

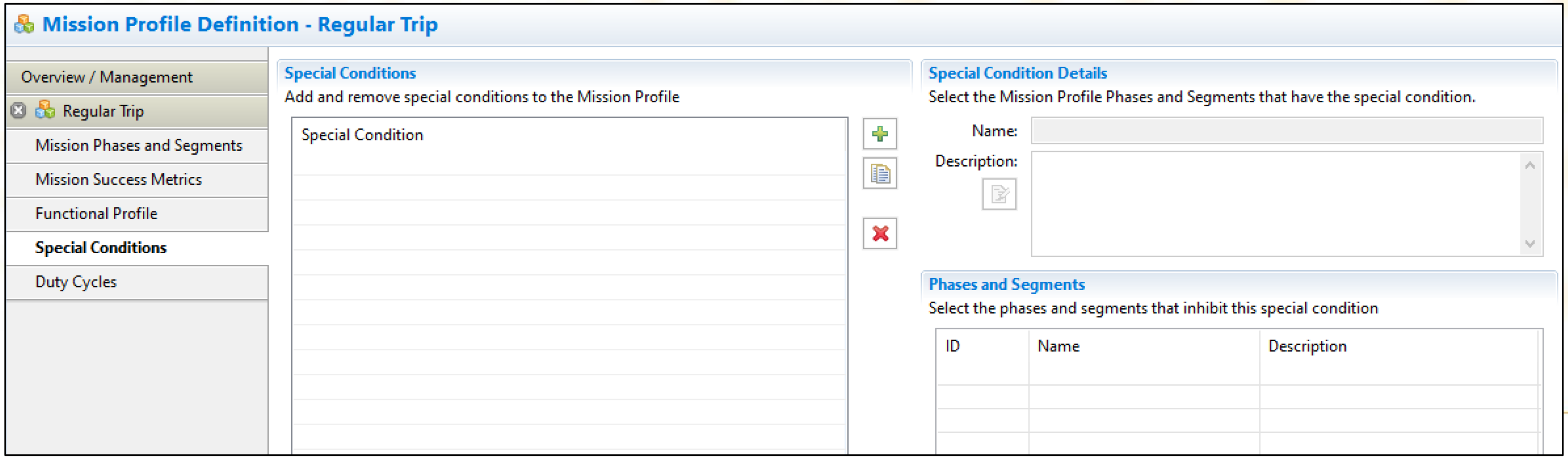
Assign an Importance Ranking to each Mission Success Metric associated with the output flows of each function. The Importance Ranking assigned to a function will automatically be applied to subsequent Mission Phases.

Name	1: Start-up	2: Acceleration	3: Cruise	4: Turning	5: Cruise 2	6: Deceleration	7: Shut-down
To Convert the Mechanical - rotational Angular velocity							
Acceptable upper limit (rad/s)	0.00	25.00	25.00		30.00		0.00
Acceptable lower limit (rad/s)	0.00	5.00	5.00		10.00		0.00
1: Transport Personnel - Importance to mission	**Low**	**Very High**	Very High	**Moderate**	**Very High**	Very High	**Low**
To Convert the Mechanical - rotational Angular velocity							
Acceptable upper limit (rad/s)	0.00	25.00	25.00		30.00		0.00
Acceptable lower limit (rad/s)	0.00	5.00	5.00		10.00		0.00
1: Transport Personnel - Importance to mission	**Low**	**Very High**	Very High	**Moderate**	**Very High**	Very High	**Low**

Session 2.3: Mission Profile & Groups

DISCUSSION 2.3.5 SPECIAL CONDITIONS

- Special Conditions are used to capture platform configurations resulting from emergency/abnormal conditions
  - E.g. Aircraft scenarios: Ditching, Engine Out, Loss of Communications, Depressurisation etc.
  - E.g. Vehicle scenarios: high traffic, low visibility, road surfaces etc.
- Special conditions are conditions a system must meet that do not fall under mission phases or environmental profile

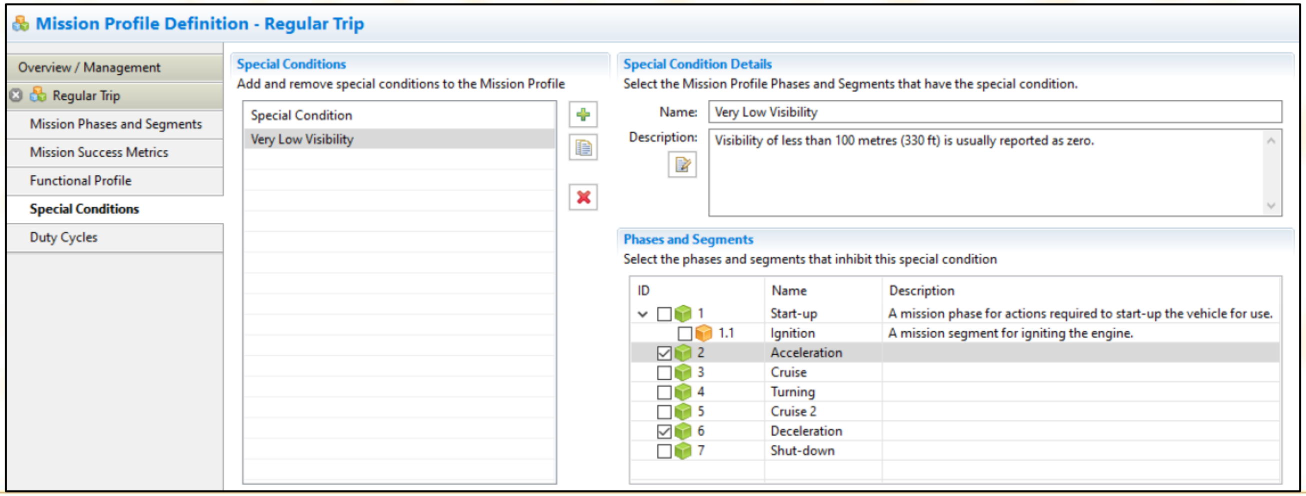


Session 2.3: Mission Profile & Groups

Exercise 2.3.5 Special Conditions

To add Special Conditions:

- Navigate to the **Special Conditions** tab
- Select [+] to add a **Special Condition**
- Rename special condition as: **Very Low Visibility**
- Enter Description: **Visibility of less than 100 metres (330 ft) is usually reported as zero.**
- Select Phase check boxes: **Acceleration** & **Deceleration**



Session 2.3: Mission Profile & Groups

Discussion 2.3.6 Duty Cycles

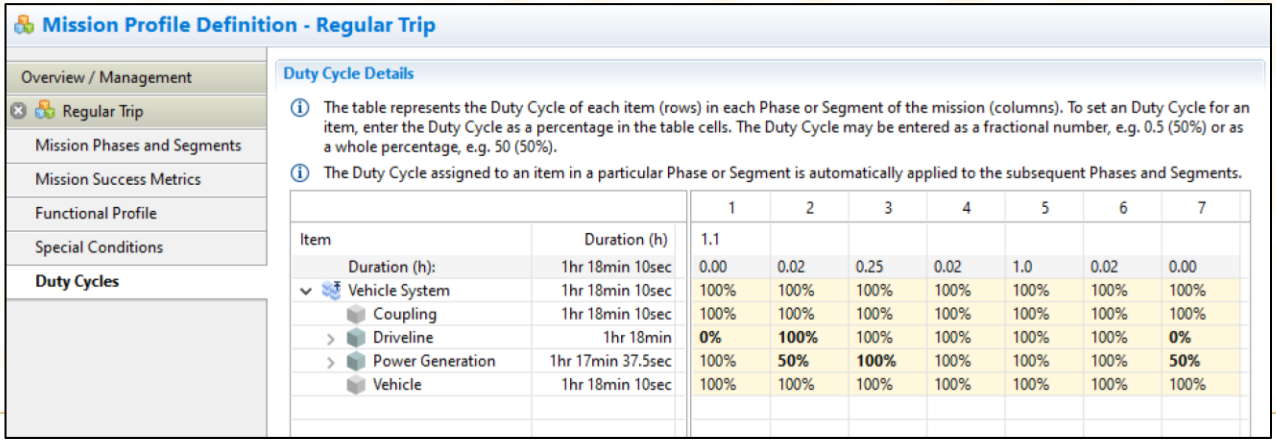
- This table defines the time duration each model item is operating for a mission profile
- Duty cycle is entered based on a percentage of each mission phase
- Duty cycles inheritance is top-down
    - E.g. A subsystem operates for 50% of a mission phase
    - One item within the subsystem operating with a 50% duty cycle = 25% of the mission phase duration
- Duty cycle % is translated into ‘duration of operation’ used for RAM analyses
- Duty cycles will lead into residual life estimation

Session 2.3: Mission Profile & Groups

EXERCISE 2.3.6 DUTY CYCLES

To set duty cycles:

- Select the **‘Driveline’** and in **Phase 1** and set it to: **0%**
- Select the **‘Driveline’** and in **Phase 2** and set it to: **100%**
- Select the **‘Driveline’** and in **Phase 7** and set it to: **0%**
- Set the **‘Power Generation’** and in **Phase 1** and set it to: **50%**
- Set the **‘Power Generation’** and in **Phase 2** and set it to: **100%**
- Set the **‘Power Generation’** and in **Phase 7** and set it to: **50%**



Item	Duration (h)	1	2	3	4	5	6	7
		1.1						
Duration (h):	1hr 18min 10sec	0.00	0.02	0.25	0.02	1.0	0.02	0.00
Vehicle System	1hr 18min 10sec	100%	100%	100%	100%	100%	100%	100%
Coupling	1hr 18min 10sec	100%	100%	100%	100%	100%	100%	100%
Driveline	1hr 18min	**0%**	**100%**	100%	100%	100%	100%	**0%**
Power Generation	1hr 17min 37.5sec	100%	**50%**	**100%**	100%	100%	100%	**50%**
Vehicle	1hr 18min 10sec	100%	100%	100%	100%	100%	100%	100%

Session 2.3: Mission Profile & Groups

Discussion 2.3.7 Mission Profile Groups

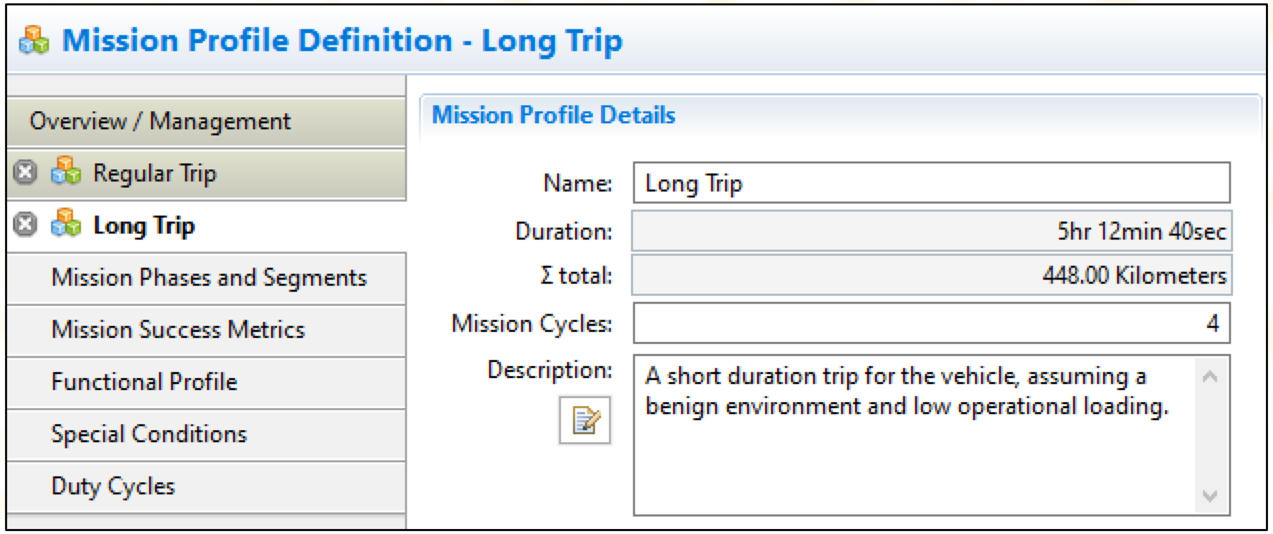
- Mission Profile Group allows aggregation of multiple mission profiles
- Groups are important for performing trade studies on reliability or maintenance costs for longer timespans
- Mission profiles can be stored and changed on demand to run new analyses later
- Mission Profile Groups are also used earlier in design for mission planning

Session 2.3: Mission Profile & Groups

Exercise 2.3.7 Mission Profile Groups

To create a new group:

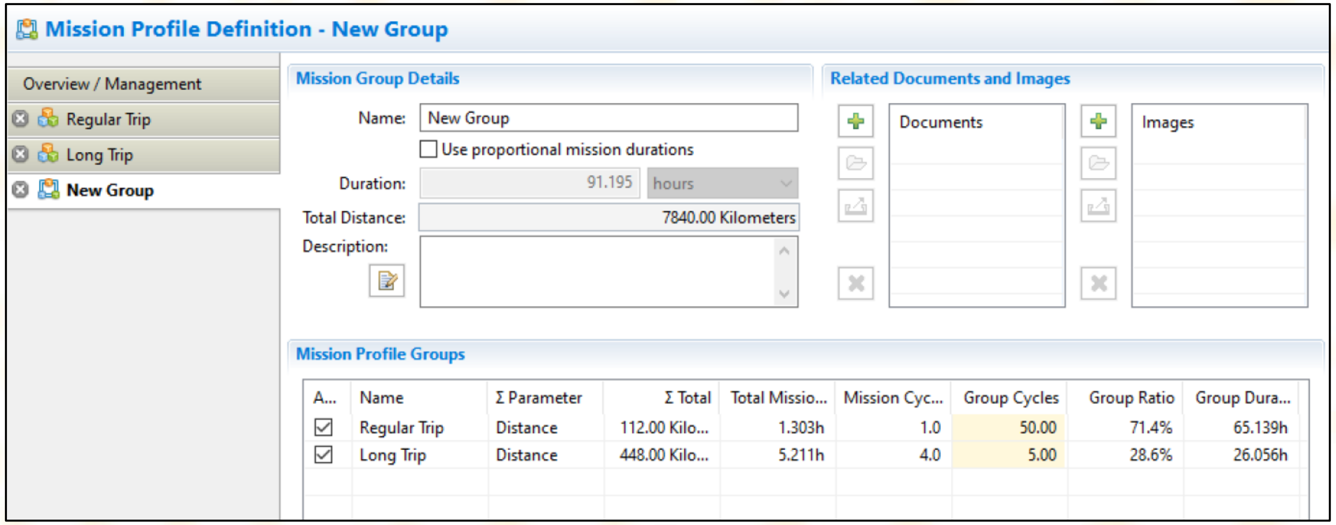
- Create a second mission profile using the following steps
  - Navigate to the **Overview/Management** tab
  - Copy the **Regular Trip** mission & rename the copy as **Long Trip**
  - Set **Mission Cycles** to **4**



Session 2.3: Mission Profile & Groups

EXERCISE 2.3.7 MISSION PROFILE GROUPS (CONTINUED)

- Select New Group in the **Overview/Management** page
- Select Open
- Select both **Regular Trip** and **Long Trip** missions in the Mission Profile Groups table
- Set **Group Cycles** of the **Regular Trip** to **50**
- Set **Group Cycles** of the **Long Trip** to **5**

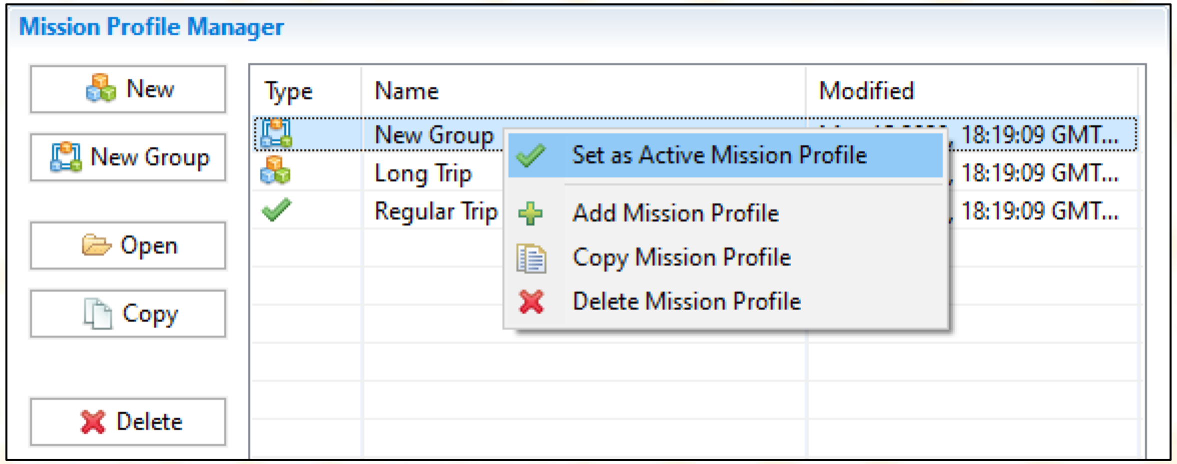


❖ Note: Selecting the **Use proportional mission durations** check box enables user to edit Group Ratio column

Session 2.3: Mission Profile & Groups

Exercise 2.3.7 Mission Profile Groups (continued)

- Set this New Group as the **Active Mission Profile** in the Overview/Management page
- Right-click on the new group and select **Set as Active Mission Profile**
- Verify item duration of operations now reflect currently assigned Mission Group
  - Open the **Advanced Properties** of any item in the model
  - View Operational section of **Advanced Properties** page



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Session 2.3: Mission Profile & Groups

DISCUSSION 2.3.8 MISSION PROFILE DEFINITION REPORTS

There are 2 mission reports & 2 environment reports to output Mission Profile/Group data:

1. **Mission Effective Functions List (MEFL)**

   This report details the critical components for a capability in a Mission Profile / Mission Group

2. **Mission Profile Report**

   This report presents general outcomes of a selected Mission Profile / Mission Group (mission details, operating scenarios, defined objectives and capabilities, operating modes, and environmental profile)

3. **Operating Environment Report**

   This report shows selected environments, environmental factors, ratings & system sensitivity details

4. **Operating Environment Comparison Report**

   This report provides a comparative analysis of two or more selected Operating environments which compares environmental factors

Session 2.3: Mission Profile & Groups

Session 2.3 Summary

- ✓ 2.3.1 Environment Profiles: System Baseline
- ✓ 2.3.2 Mission Phase/Segment-specific Environments
- ✓ 2.3.3 Mission Success Metrics: System Flow Properties
- ✓ 2.3.4 Functional Profile
- ✓ 2.3.5 Special Conditions
- ✓ 2.3.6 Duty Cycles
- ✓ 2.3.7 Mission Profile Groups
- ✓ 2.3.8 Mission Profile Definition Reports

Session 2.4: Failure Analysis

Session 2.4 Outline

2.4.1: Functional Failures

2.4.2: System & Subsystem Failure Diagrams

2.4.3: Component Failure Diagrams

2.4.4: Part Failure Diagrams

2.4.5: Response Paths

2.4.6: Propagation Table

Session 2.4: Failure Analysis

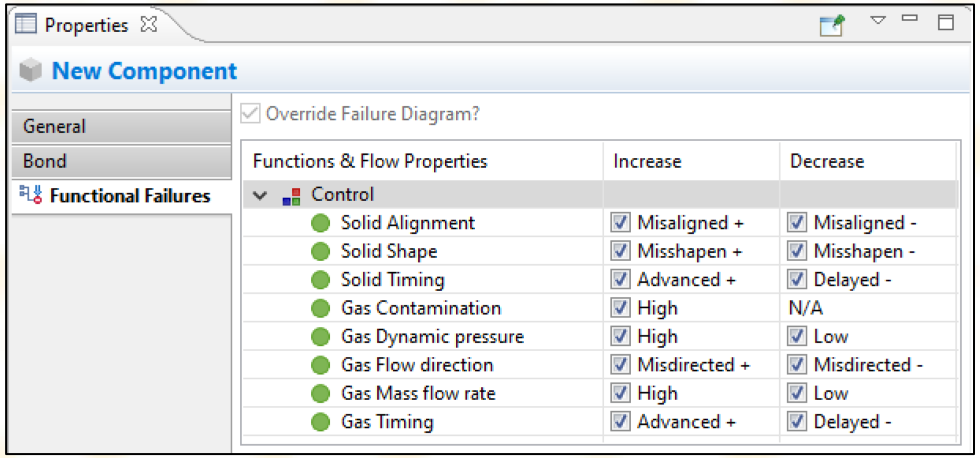
Discussion 2.4 Failure Analysis

- This session will cover all aspects of how failures are generated in MADe
- We will cover the difference between functional and physical failures
- We will use failure diagrams to define more detail of a failure
- We will generate response paths to look at all of the generated failures by the software
- We will look at the propagation table for responses generated by the software

Session 2.4: Failure Analysis

<u>DISCUSSION 2.4.1 FUNCTIONAL FAILURES</u>

- Failures are automatically derived from functions and flows
- Deviations from the nominal state are considered failures in MADe
  - We consider these Functional Failures
- Flow typically have two failure responses: **High** or **Low** deviation
- Different domains (flows) have different linguistic terms:
  - Flow rate & Contamination use **Increase** or **Decrease**
  - Flow direction uses **Misdirected +/-**
  - Timing uses **Advanced +/Delayed –**
  - Contamination only has **High** as a failure response
  - Also see: Alignment, Position, Shape, Timing



Functions & Flow Properties	Increase	Decrease
Control		
Solid Alignment	Misaligned +	Misaligned -
Solid Shape	Misshapen +	Misshapen -
Solid Timing	Advanced +	Delayed -
Gas Contamination	High	N/A
Gas Dynamic pressure	High	Low
Gas Flow direction	Misdirected +	Misdirected -
Gas Mass flow rate	High	Low
Gas Timing	Advanced +	Delayed -

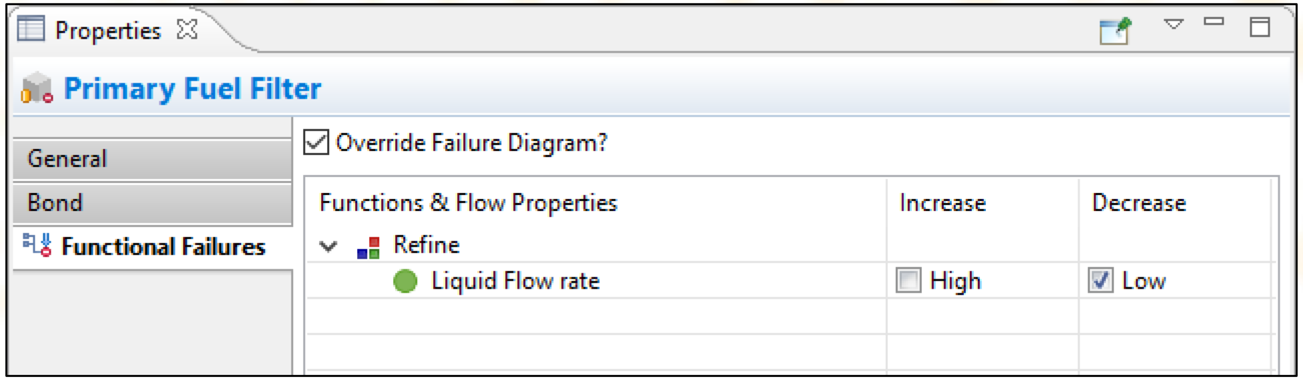
- These failure responses can be managed from the Properties viewer

Session 2.4: Failure Analysis

<u>EXERCISE 2.4.1 FUNCTIONAL FAILURE</u>

To edit a functional failure:

- Open the system model of the **'Diesel Engine'**
- Select the **'Primary Fuel Filter'**
- Navigate to the **Properties Viewer** and select **Functional Failures** tab
- Tick the **Override failure diagram** check box
- Disable the **High** Fuel Flow rate
- This overrides the failure analysis failure paths with the selected functional failure: **Low Flow Rate**



Session 2.4: Failure Analysis

Discussion 2.4.2 Failure Diagrams

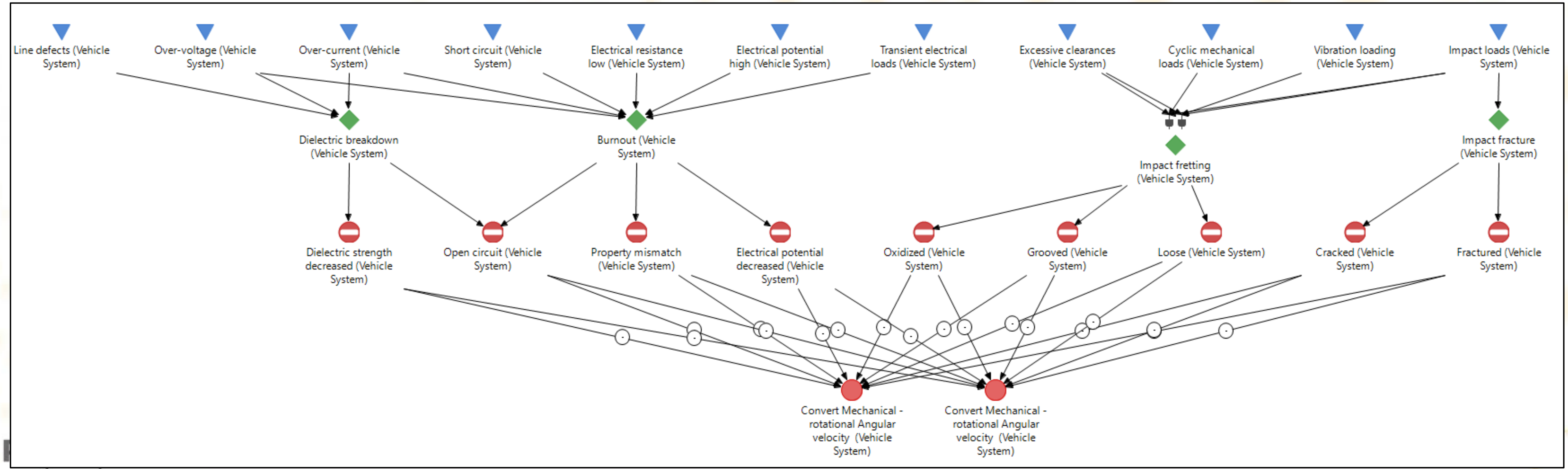
- Failure diagrams look at the causes & progression of failure
- Failure diagrams are focussed on physical aspect of failures
- Failure diagrams use a peer-reviewed taxonomy to assist in definition
- Taxonomy for failure concepts are shown below

Failure Concept	Symbol	Definition
Cause	▼	The abnormal state of input, loading or environment that leads to the degradation of an item.
Mechanism	◆	The chemical, electrical, mechanical or software processes which causes physical degradation of a system element and results in a fault.
Fault	⛔	The physically degraded state of a system element or a change in its behaviour which will result in a failure mode or the inability to carry out its function.
Symptom	⬢	The response of a failed system element or a loss generated by a failure process that can be used to detect a failure mode.
Failure Conditions	●	A Failure Condition describes the behaviour of a failure mode and its potential effects.
Failure Mode	●	The observable manner in which a system or system element fails to fulfil its function, expressed in terms of the deviation of its output flow from the specified or nominal limits.

Session 2.4: Failure Analysis

Discussion 2.4.2 System & Subsystem Failure Diagrams

- Systems and Subsystems can have failure diagrams assigned to them
- The System and Subsystem failure diagrams represent the system and subsystem's failures without knowing the root causes of failure

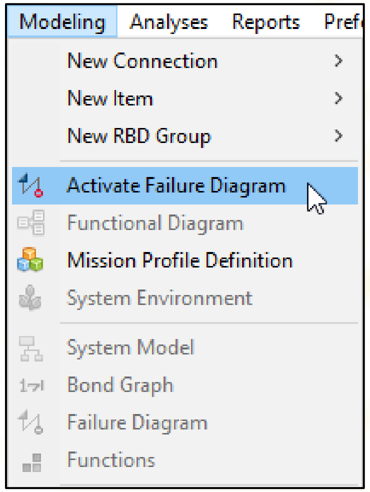


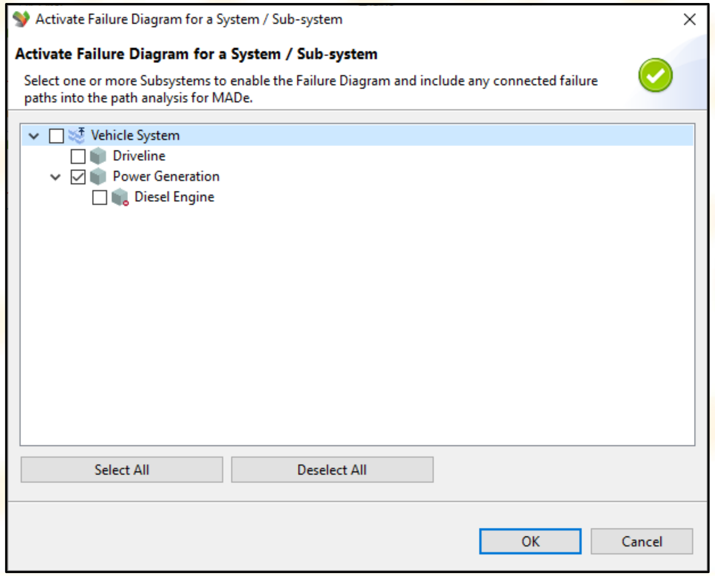
Session 2.4: Failure Analysis

Exercise 2.4.2 System & Subsystem Failure Diagrams

To activate a system or subsystem diagram:

- Select **Modeling → Activate Failure Diagram** from the main menu
- A pop-up dialog will appear listing the System and Subsystems in the model
- Select the '**Power Generation**' subsystem check box to activate the failure diagram
- Confirm selection by selecting OK



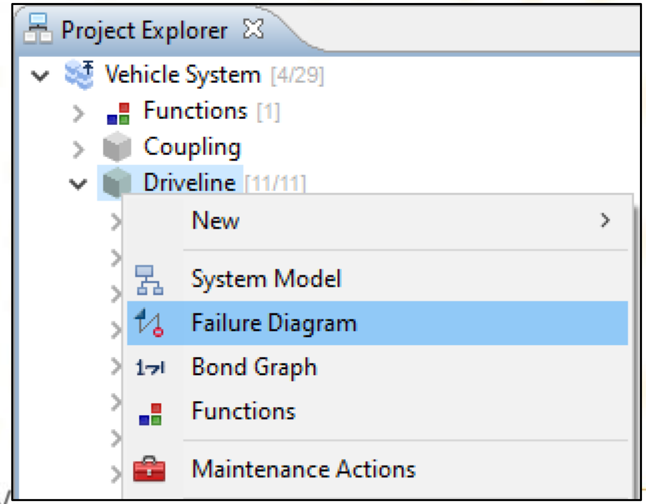


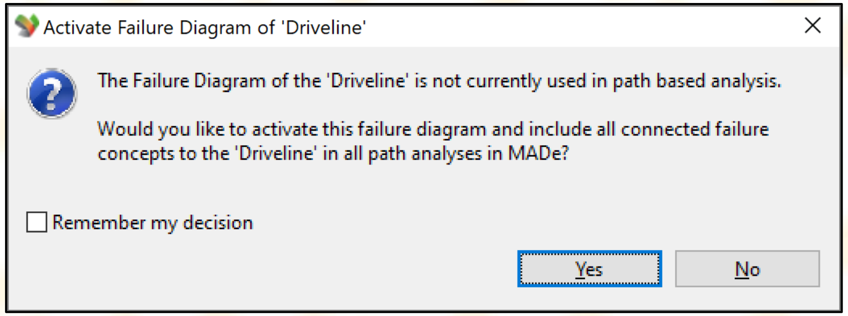
Session 2.4: Failure Analysis

EXERCISE 2.4.2 SYSTEM & SUBSYSTEM FAILURE DIAGRAMS

To construct a subsystem diagram:

- Right click on the **'Driveline'** subsystem from the Project Explorer
- Select **Failure Diagram**
- A prompt will appear asking to activate failure diagram
- Select Yes to activate Subsystem Failure Diagram

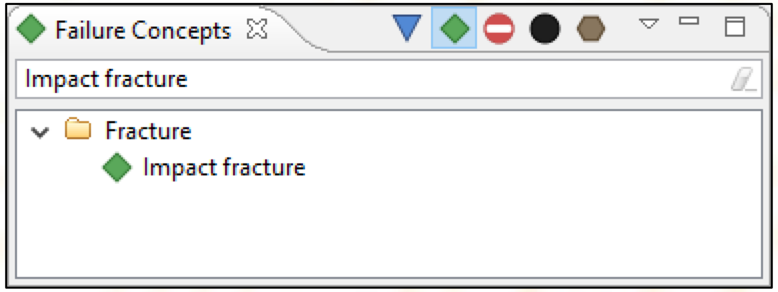


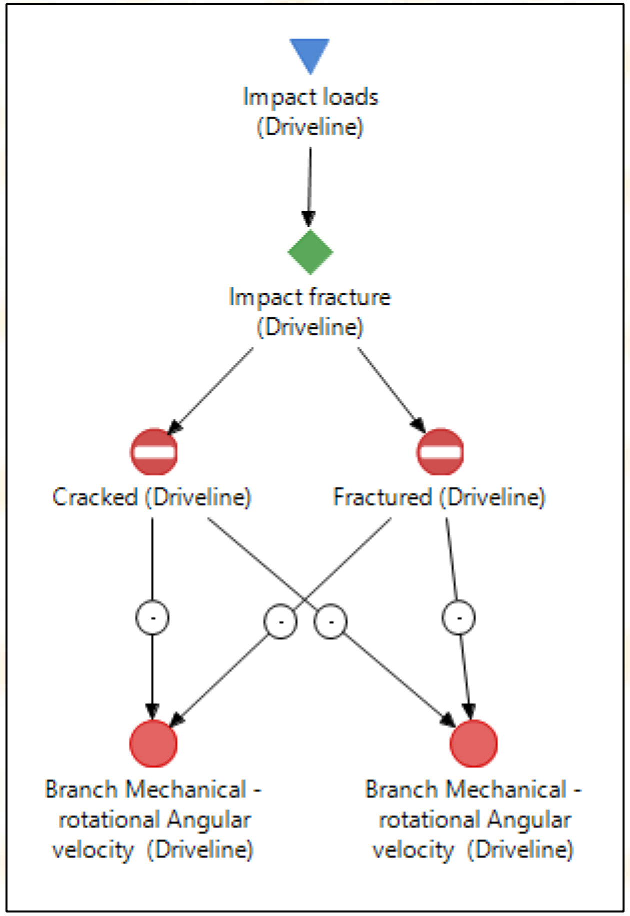


Session 2.4: Failure Analysis

EXERCISE 2.4.2 SYSTEM & SUBSYSTEM FAILURE DIAGRAMS (CONTINUED)

- Select **Mechanisms** in the Failure Concepts viewer
- Select the **Impact Fracture** mechanism from the Failure Concepts window
  - This can be located under the **Fracture** folder
  - Alternatively, use the Search bar and search for **Impact Fracture**
- Drag the failure concept onto the Failure Diagram canvas
- Connect the **Fractured** and **Cracked** faults to both failure modes



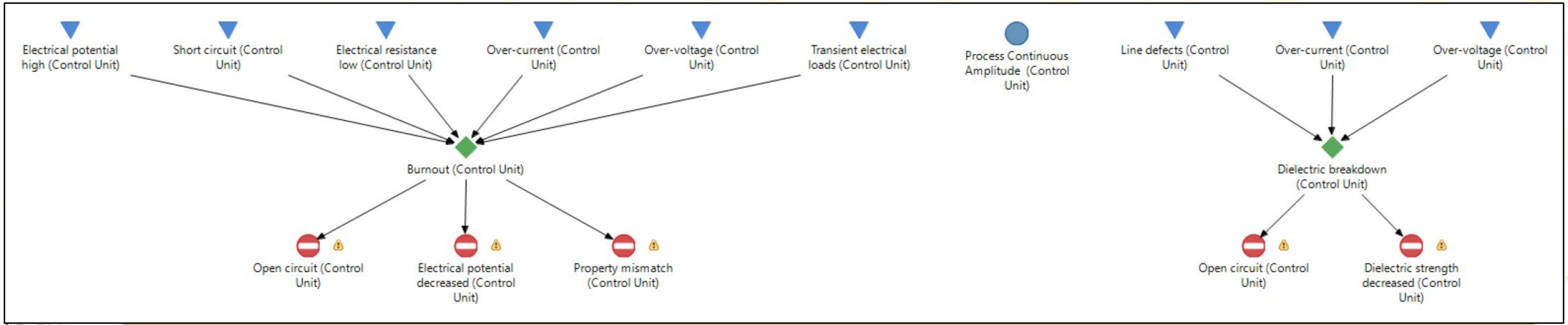


Session 2.4: Failure Analysis

Exercise 2.4.3 Component Failure Diagrams

To construct a component failure diagram:

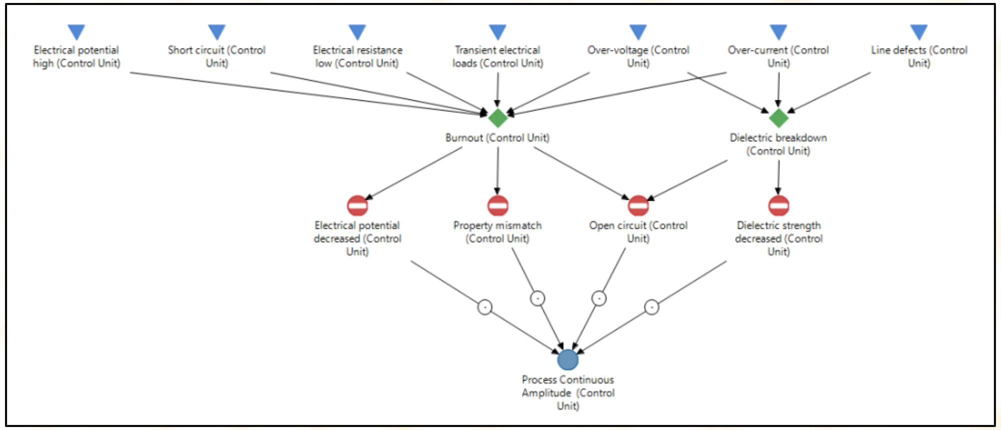
- Open the system model for the **'Power Generation'** subsystem
- Right-click the **'Control Unit'** component
- Select **Failure Diagram** from right-click menu
- Select **Mechanisms** in the Failure Concepts viewer
- Under **Electrical** category, click-and-drag **Burnout** & **Dielectric Breakdown** mechanisms onto the failure diagram editor



Session 2.4: Failure Analysis

Exercise 2.4.3 Component Failure Diagrams (Continued)

- You will find that there is a repeat of **Over-current** and **Over-Voltage** Causes and **Open circuit** fault
- We can simplify the failure diagram by deleting duplicates
  - Delete repeated failure concepts: **Over-voltage, Over-current and Open circuit**
- Connect all faults to the Functional failure mode



❖ Note: When selecting mechanisms, we can hold Ctrl and select. When multiple mechanisms are selected and placed onto the failure diagram canvas, it will be automatically simplified.

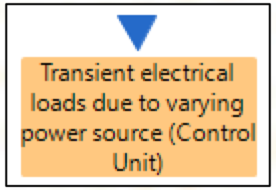
Session 2.4: Failure Analysis

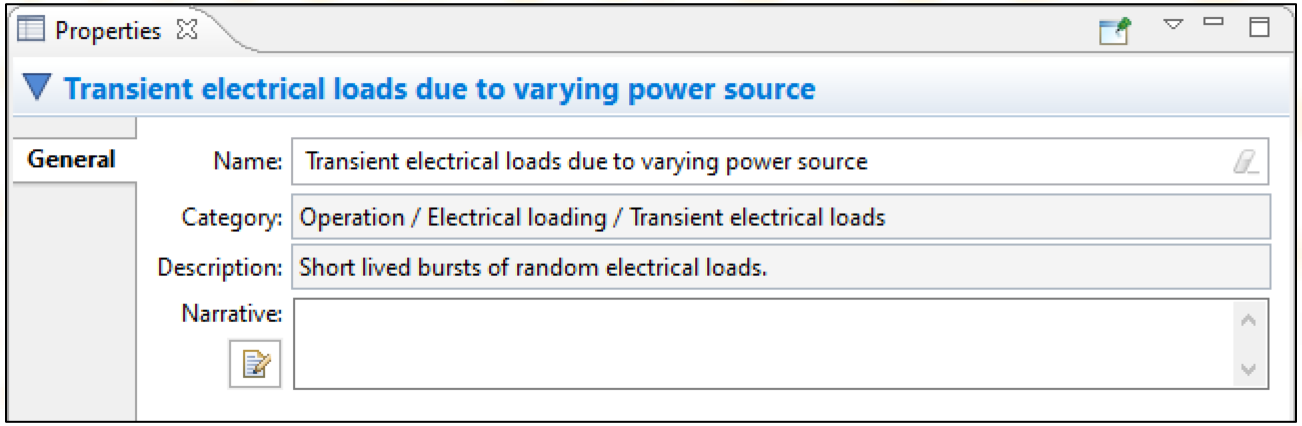
<u>Exercise 2.4.3 Component Failure Diagrams (continued)</u>

Failure diagrams have an underlying taxonomy, however, users may choose to edit the display name to better represent or provide additional information to the failure.

To change the display name of the Transient electrical loads:

- Select the **Transient electrical loads** cause
- Using the Properties viewer, edit the Name field to: **Transient electrical loads due to varying power source**

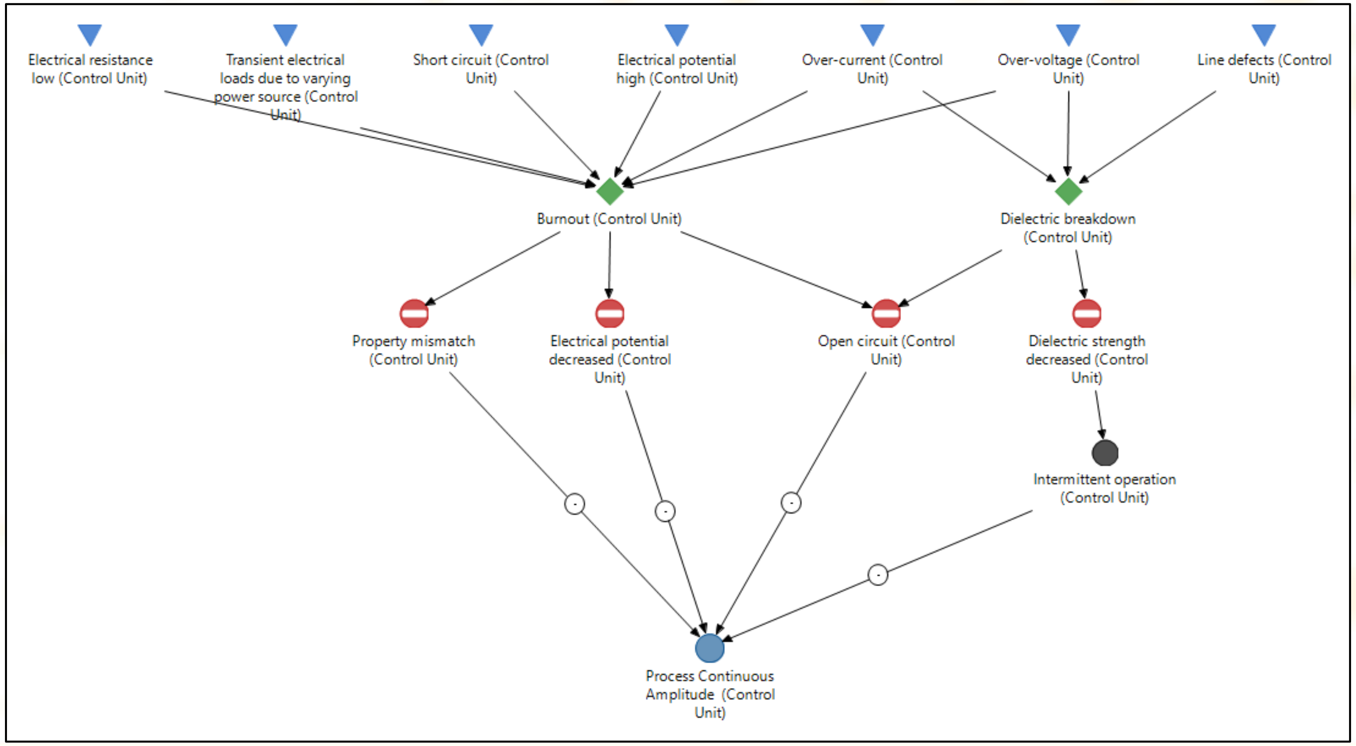




Session 2.4: Failure Analysis

Discussion 2.4.3 Component Failure Diagrams

- Failure condition describes the behaviour of the failure and is connected to the fault.
- It can be direct or consequential to the failure causing adverse operational conditions.

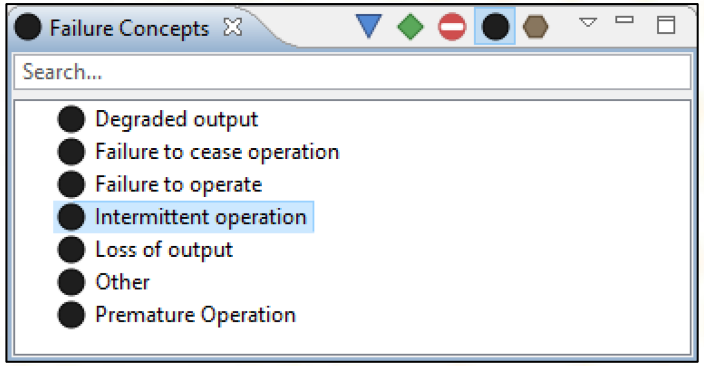


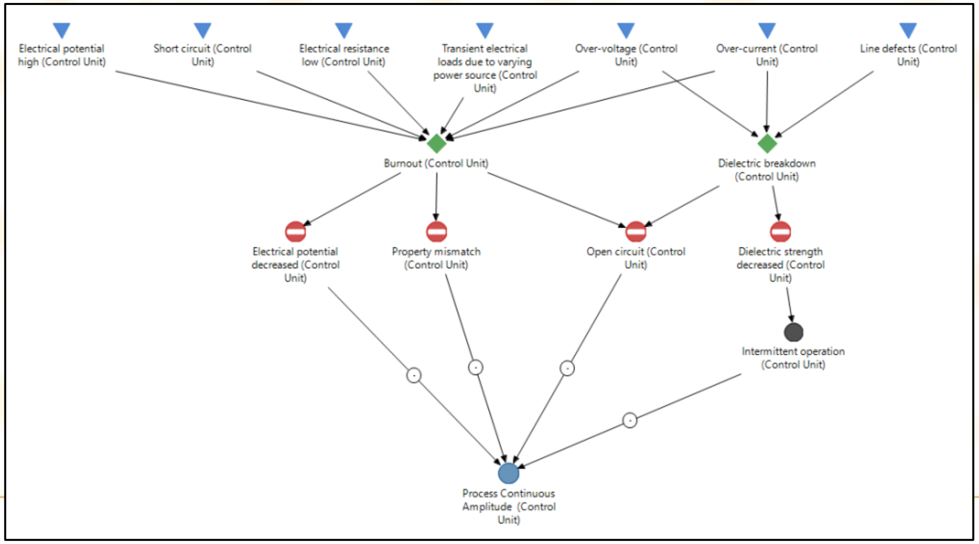
Session 2.4: Failure Analysis

EXERCISE 2.4.3 COMPONENT FAILURE DIAGRAMS

To add a failure condition to the Control Unit failure diagram:

- Select the failure condition icon in Failure concepts
- Select and drag the **Intermittent Operation** failure concept to the failure diagram
- Delete the connection between **Dielectric strength decreased** and the Functional failure mode
- Connect the **Dielectric strength decreased** fault to the failure condition
- Connect the failure condition to the failure mode





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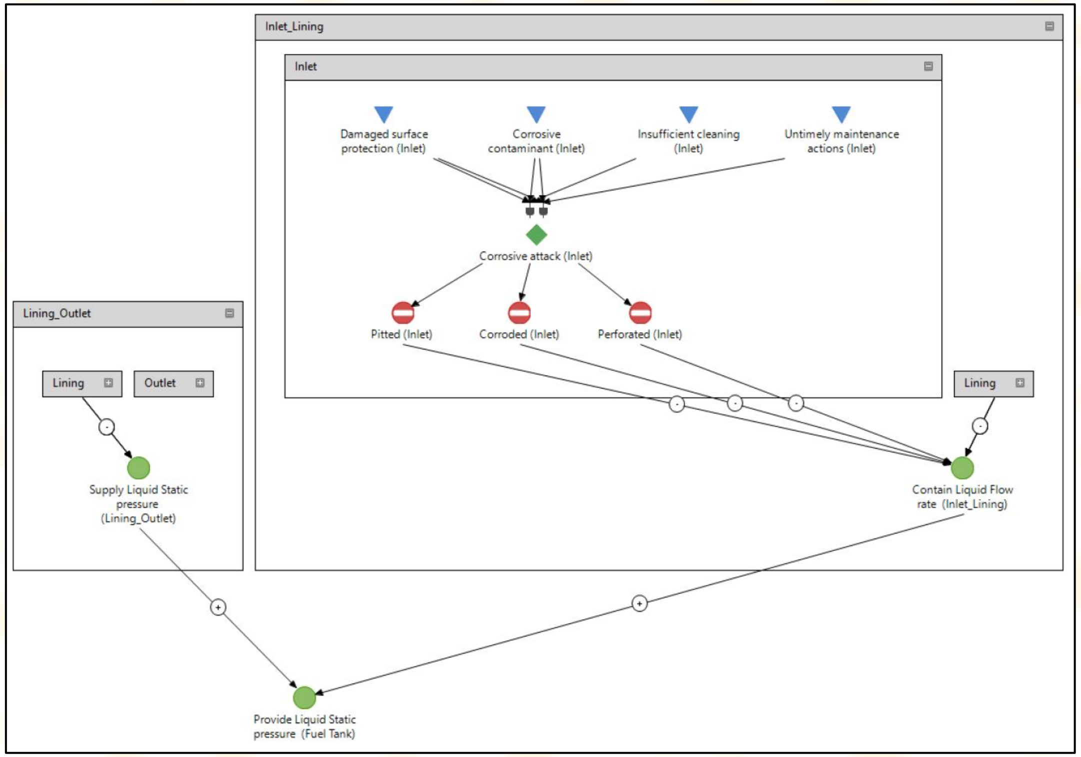
Session 2.4: Failure Analysis

DISCUSSION 2.4.4 PART FAILURE DIAGRAMS

- Part-level failure diagrams capture a more accurate location of failures
- Part-failure failure diagrams contain the most amount of detail on a failure
- Part-failure diagrams allow for better understanding of failures
    - Better informed root cause analysis & diagnosis of failures
    - Maintenance actions e.g. repair can be conducted more quickly and successfully as the root cause is identified
- Part failure diagrams describe how physical failures result in a component's loss of function/s

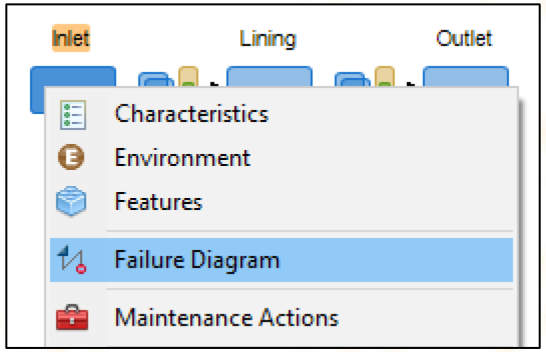


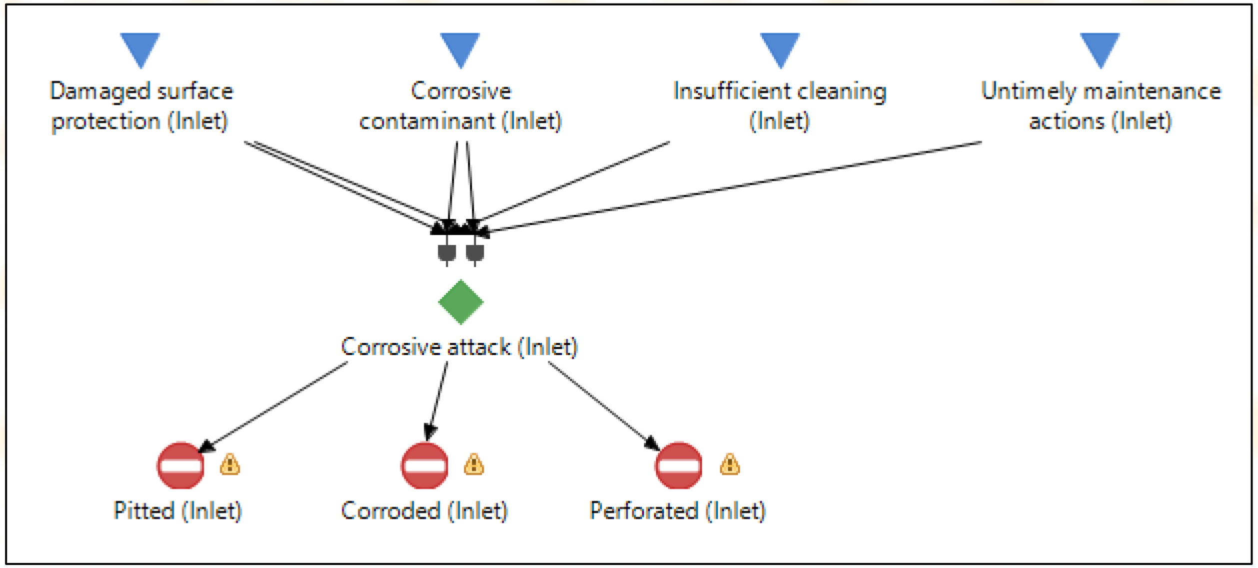
Session 2.4: Failure Analysis

Exercise 2.4.4 Part-level Failure Diagrams

To construct part-level failure diagrams:

- Open the system model for the **'Fuel Tank'**
- Right-click the **'Inlet'** part and select **Failure Diagram**
- From the Failure Concepts viewer select the **Corrosive attack** mechanism and add to the canvas

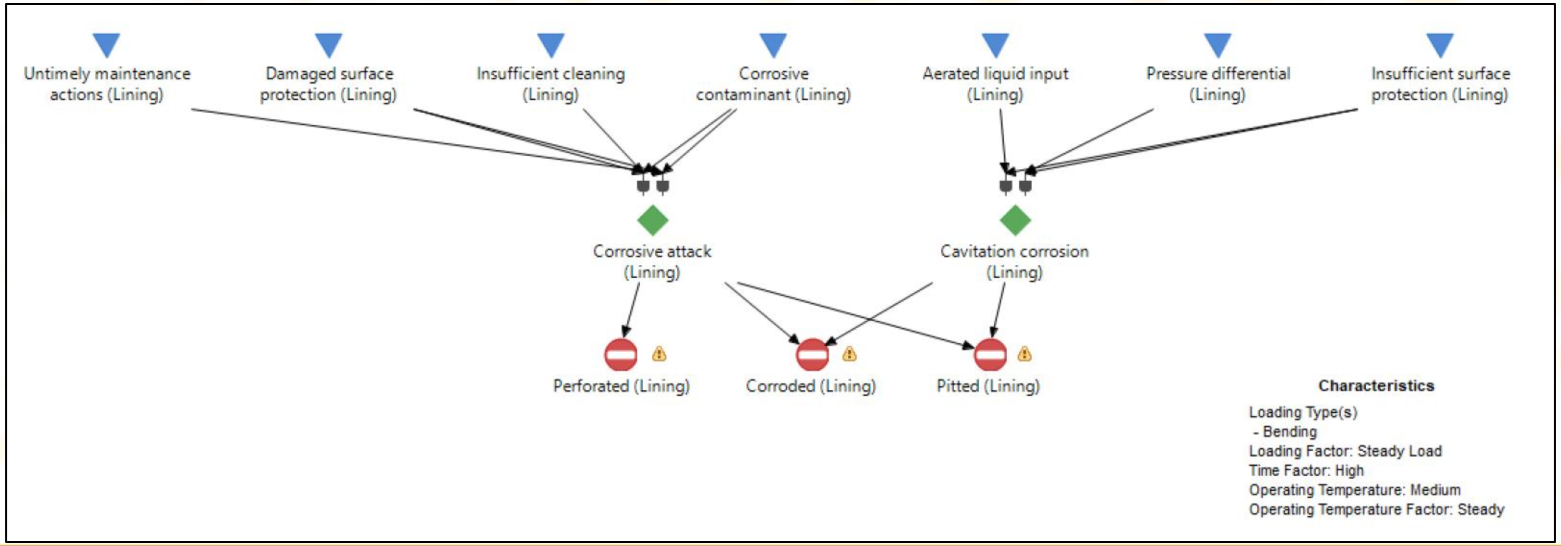




Session 2.4: Failure Analysis

Exercise 2.4.4 Part-level Failure Diagrams (Continued)

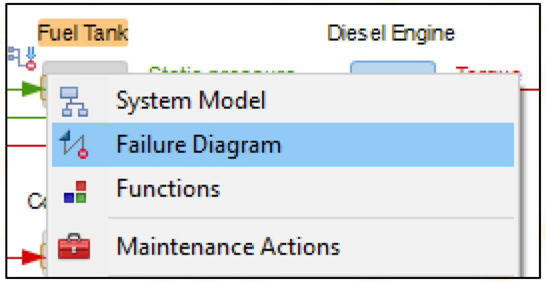
- Open the system model for the **'Fuel Tank'**
- Right-click the **'Lining'** part and select **Failure Diagram**
- For simplicity, we will modify the failure diagram and delete the mechanisms **Abrasive wear, Thermal Fatigue** and **Thermal degradation**
- To tidy up the failure diagram, delete the unconnected faults and causes

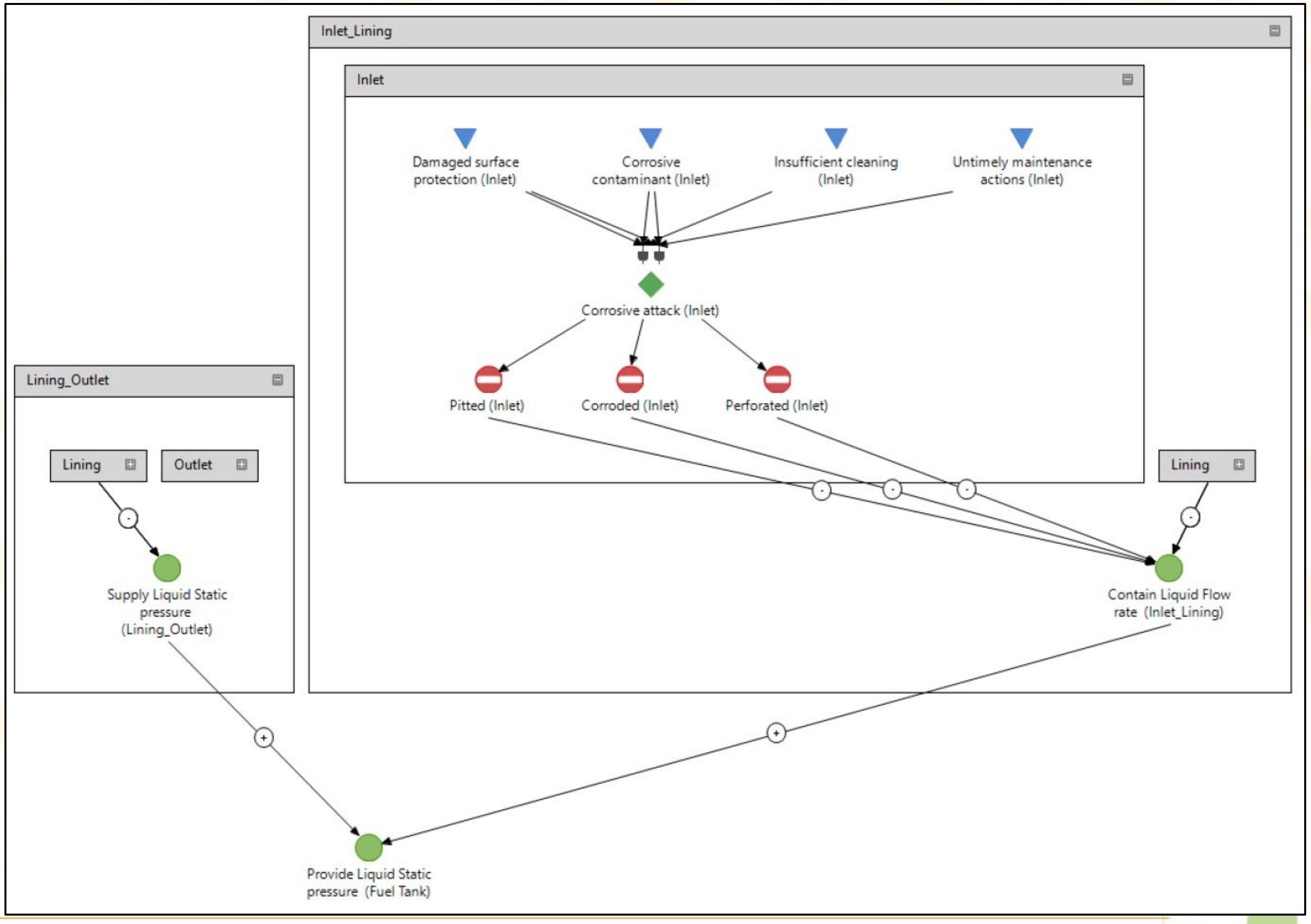


Session 2.4: Failure Analysis

Exercise 2.4.4 Part-level Failure Diagrams (continued)

- Open the system model for the **'Power Generation'**
- Right-click the **'Fuel Tank'** and select **Failure Diagram**
- Select ⊞ to expand the failure diagram of the **Inlet_Lining** and **Lining_Outlet** part-pairs
- Connect the faults in both the **'Lining'** and **'Inlet'** to the part-pair function
- Connect the part-pair function with the **'Fuel Tank'** component function





Session 2.4: Failure Analysis

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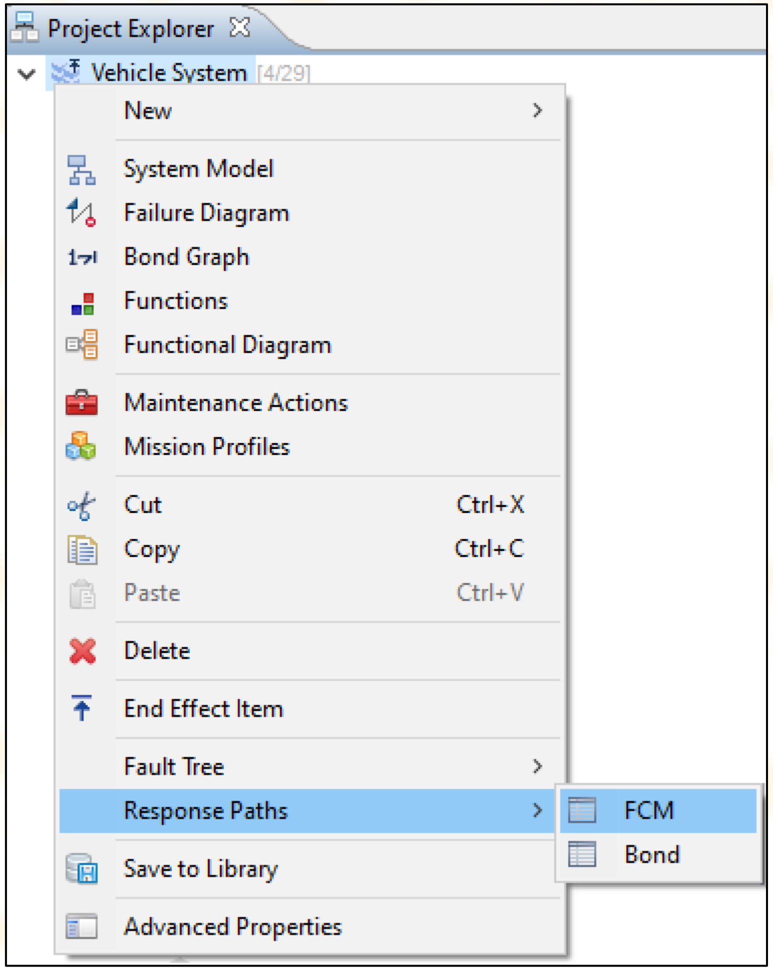
Discussion 2.4.5 Response Paths

- Since MADe is model-based, a list of all failures in the model are generated on-demand
- Failures are captured as discrete paths through the system to the End Effect Item
- Failure Diagrams split functional failure paths into multiple branches
- Failure Pathing can be checked at any time while modeling
- We use the **Response Paths** feature to accomplish this



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Session 2.4: Failure Analysis

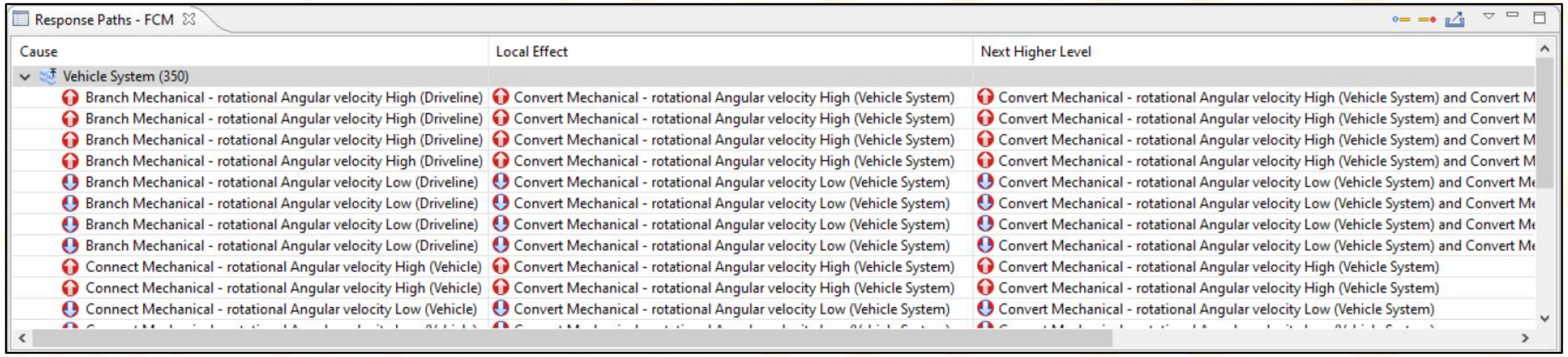
EXERCISE 2.4.5 RESPONSE PATHS

To generate response paths in the model:

➢ Right-click **'Power Generation'** in the Project Explorer

➢ Select: **Response Paths → FCM**

➢ In the Response Paths – FCM tab, expand item tree to view all of the model response paths


Response Paths - FCM

Cause	Local Effect	Next Higher Level
Vehicle System (350)		
Branch Mechanical - rotational Angular velocity High (Driveline)	Convert Mechanical - rotational Angular velocity High (Vehicle System)	Convert Mechanical - rotational Angular velocity High (Vehicle System) and Convert M
Branch Mechanical - rotational Angular velocity High (Driveline)	Convert Mechanical - rotational Angular velocity High (Vehicle System)	Convert Mechanical - rotational Angular velocity High (Vehicle System) and Convert M
Branch Mechanical - rotational Angular velocity High (Driveline)	Convert Mechanical - rotational Angular velocity High (Vehicle System)	Convert Mechanical - rotational Angular velocity High (Vehicle System) and Convert M
Branch Mechanical - rotational Angular velocity High (Driveline)	Convert Mechanical - rotational Angular velocity High (Vehicle System)	Convert Mechanical - rotational Angular velocity High (Vehicle System) and Convert M
Branch Mechanical - rotational Angular velocity Low (Driveline)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)	Convert Mechanical - rotational Angular velocity Low (Vehicle System) and Convert Me
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Branch Mechanical - rotational Angular velocity Low (Driveline)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)	Convert Mechanical - rotational Angular velocity Low (Vehicle System) and Convert Me
Connect Mechanical - rotational Angular velocity High (Vehicle)	Convert Mechanical - rotational Angular velocity High (Vehicle System)	Convert Mechanical - rotational Angular velocity High (Vehicle System)
Connect Mechanical - rotational Angular velocity High (Vehicle)	Convert Mechanical - rotational Angular velocity High (Vehicle System)	Convert Mechanical - rotational Angular velocity High (Vehicle System)
Connect Mechanical - rotational Angular velocity Low (Vehicle)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)

❖ Note 1: The cause shows the 'start' of each path that MADe calculates

❖ Note 2: Pathing is used for all FMEA/FMECA analyses

Session 2.4: Failure Analysis

DISCUSSION 2.4.6 PROPAGATION TABLE

- The Propagation Table shows the flow responses of items (columns) in the system that occur due to each individual functional failure (rows)
- Responses are shown in terms of High and Low responses
- Also shown: % of Detectable Failures, Threshold details

Propagation Table - FCM

Detectable Failures: 74% | Threshold Type: Trivalent Sigmoid | Criticality Threshold Type: N/A | Generated: 5:11:43 PM

LRU Group	Component	Flow Property	Failure	Air Filter (Gas - Ma...	Control Unit (Cont...	Coupling 1 (Mech...	Coupling (Mechan...	Diesel Engine (Me...	Differential (Mech...	Driveshaft (Mecha
	Air Filter (Diesel Engine)	Mass flow rate (Gas)	Low	Low		Low	Low	Low	Low	Low
	Control Unit (Power Generation)	Amplitude (Continuous)	Decrease		Low	Low	Low	Low	Low	Low
	Control Unit (Power Generation)	Amplitude (Continuous)	Intermittent ope...		Low	Low	Low	Low	Low	Low
	Coupling	Torque (Mechanical - rotational)	High				High		High	High
	Coupling	Torque (Mechanical - rotational)	Low				Low		Low	Low
	Coupling 1 (Diesel Engine)	Angular velocity (Mechanical - rotational)	Low			Low	Low	Low	Low	Low
	Diesel Engine (Power Generation)	Torque (Mechanical - rotational)	Low				Low	Low	Low	Low
	Differential (Driveline)	Angular velocity (Mechanical - rotational)	High						High	
	Differential (Driveline)	Angular velocity (Mechanical - rotational)	Low						Low	
	Driveshaft (Driveline)	Torque (Mechanical - rotational)	High						High	High
	Driveshaft (Driveline)	Torque (Mechanical - rotational)	Low						Low	Low
	Engine (Diesel Engine)	Torque (Mechanical - rotational)	Low			Low	Low	Low	Low	Low
	Fuel Tank (Power Generation)	Static pressure (Liquid)	Decrease			Low	Low	Low	Low	Low
	Governor (Diesel Engine)	Linear velocity (Mechanical - linear)	Low			Low	Low	Low	Low	Low
	Half Shaft Front (Driveline)	Torque (Mechanical - rotational)	High							
	Half Shaft Front (Driveline)	Torque (Mechanical - rotational)	Low							
	Half Shaft Rear (Driveline)	Torque (Mechanical - rotational)	High							
	Half Shaft Rear (Driveline)	Torque (Mechanical - rotational)	Low							

Session 2.4: Failure Analysis

EXERCISE 2.4.6 PROPAGATION TABLE

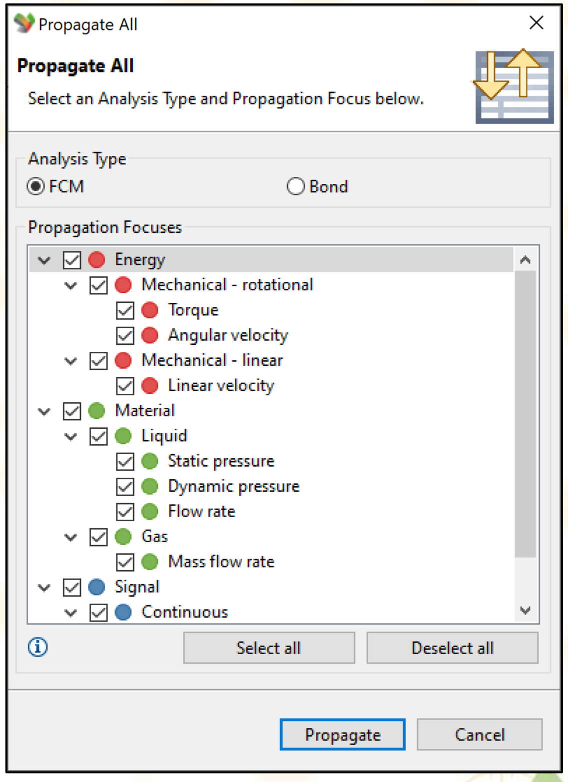
To generate the Propagation Table:

- Select the **Propagate All** icon from the icon toolbar
- Confirm Analysis Type: **FCM**
- Left-click Select all to select all flows in the Propagation Focuses
- Select Propagate to generate the Propagation Table

Propagation Table - FCM

Detectable Failures: 38% | Threshold Type: Trivalent Sigmoid | Generated: 11:04:49 AM

Diagnostic Group	Component	Flow Property	Failure	Air Filter (Gas - Ma...	Control Unit (Cont...	Coupling 1 (Mech...	Coupling (Mechan...	Diesel Engine (Me...
	Air Filter (Diesel Engine)	Mass flow rate (Gas)	Low	Low		Low	Low	Low
	Control Unit (Power Generation)	Amplitude (Continuous)	Decrease		Low	Low	Low	Low
	Control Unit (Power Generation)	Amplitude (Continuous)	Intermittent ope...		Low	Low	Low	Low
	Coupling 1 (Diesel Engine)	Angular velocity (Mechanical - rotational)	Low			Low	Low	Low
	Diesel Engine (Power Generation)	Torque (Mechanical - rotational)	Low				Low	Low
	Engine (Diesel Engine)	Torque (Mechanical - rotational)	Low			Low	Low	Low
	Fuel Tank (Power Generation)	Static pressure (Liquid)	Decrease			Low	Low	Low
	Governor (Diesel Engine)	Linear velocity (Mechanical - linear)	Low			Low	Low	Low
	Injector Pump (Diesel Engine)	Dynamic pressure (Liquid)	Low			Low	Low	Low
	Lift Pump (Diesel Engine)	Flow rate (Liquid)	Low			Low	Low	Low
	Power Generation	Torque (Mechanical - rotational)	Low				Low	
	Primary Fuel Filter (Diesel Engine)	Flow rate (Liquid)	Low			Low	Low	Low
	Secondary Fuel Filter (Diesel Engine)	Flow rate (Liquid)	Low			Low	Low	Low



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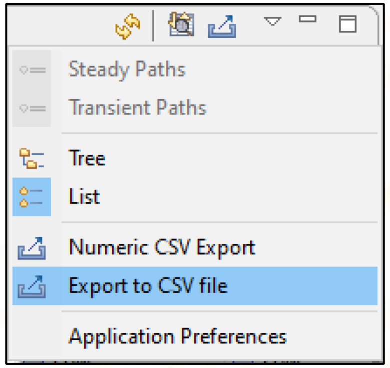
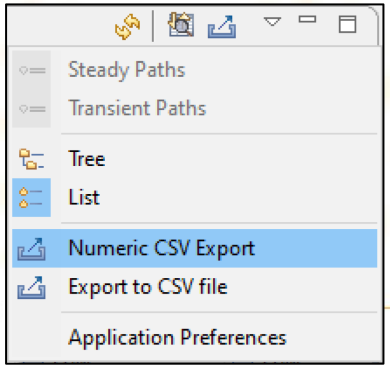
Session 2.4: Failure Analysis

EXERCISE 2.4.6: PROPAGATION TABLE (CONTINUED)

- The propagation table shows high and low failure responses for each item
  - Based on the nominal state of each item
- Propagation table can be exported with linguistic or numerical responses



Component	Flow Property	Failure	Air Filter (Gas - Mass flow rate)	Control Unit (Continuous - Amplitude)	Coupling 1 (Mechanical - rotational - Angular velocity)	Coupling (Mechanical - rotational - Torque)	Diesel Engine (Mechanical - rotational - Torque)	Differential (Mechanical - rotational - Angular velocity)	Driveshaft (Mechanical - rotational - Torque)	Engine (Mechanical - rotational - Torque)
Air Filter (Diesel Engine)	Mass flow rate (Gas)	Low	Low		Low	Low	Low	Low	Low	Low
Control Unit (Power Generation)	Amplitude (Continuous)	Decrease		Low	Low	Low	Low	Low	Low	Low
Control Unit (Power Generation)	Amplitude (Continuous)	Intermittent operation (Control Unit)		Low	Low	Low	Low	Low	Low	Low
Coupling 1 (Diesel Engine)	Angular velocity (Mechanical - rotational)	Low			Low	Low	Low	Low	Low	Low
Diesel Engine (Power Generation)	Torque (Mechanical - rotational)	Low				Low	Low	Low	Low	
Engine (Diesel Engine)	Torque (Mechanical - rotational)	Low			Low	Low	Low	Low	Low	Low
Fuel Tank (Power Generation)	Static pressure (Liquid)	Decrease			Low	Low	Low	Low	Low	Low
Governor (Diesel Engine)	Linear velocity (Mechanical - linear)	Low			Low	Low	Low	Low	Low	Low
Injector Pump (Diesel Engine)	Dynamic pressure (Liquid)	Low			Low	Low	Low	Low	Low	Low
Lift Pump (Diesel Engine)	Flow rate (Liquid)	Low			Low	Low	Low	Low	Low	Low
Power Generation	Torque (Mechanical - rotational)	Low				Low		Low	Low	
Primary Fuel Filter (Diesel Engine)	Flow rate (Liquid)	Low			Low	Low	Low	Low	Low	Low
Secondary Fuel Filter (Diesel Engine)	Flow rate (Liquid)	Low			Low	Low	Low	Low	Low	Low



Component	Flow Property	Failure	Air Filter (Gas - Mass flow rate)	Control Unit (Continuous - Amplitude)	Coupling 1 (Mechanical - rotational - Angular velocity)	Coupling (Mechanical - rotational - Torque)	Diesel Engine (Mechanical - rotational - Torque)	Differential (Mechanical - rotational - Angular velocity)	Driveshaft (Mechanical - rotational - Torque)	Engine (Mechanical - rotational - Torque)
Air Filter (Diesel Engine)	Mass flow rate (Gas)	Low	-1	0	-1	-1	-1	-1	-1	-1
Control Unit (Power Generation)	Amplitude (Continuous)	Decrease	0	-1	-1	-1	-1	-1	-1	-1
Control Unit (Power Generation)	Amplitude (Continuous)	Intermittent operation (Control Unit)	0	-1	-1	-1	-1	-1	-1	-1
Coupling 1 (Diesel Engine)	Angular velocity (Mechanical - rotational)	Low	0	0	-1	-1	-1	-1	-1	-1
Diesel Engine (Power Generation)	Torque (Mechanical - rotational)	Low	0	0	0	-1	-1	-1	-1	0
Engine (Diesel Engine)	Torque (Mechanical - rotational)	Low	0	0	-1	-1	-1	-1	-1	-1
Fuel Tank (Power Generation)	Static pressure (Liquid)	Decrease	0	0	-1	-1	-1	-1	-1	-1
Governor (Diesel Engine)	Linear velocity (Mechanical - linear)	Low	0	0	-1	-1	-1	-1	-1	-1
Injector Pump (Diesel Engine)	Dynamic pressure (Liquid)	Low	0	0	-1	-1	-1	-1	-1	-1
Lift Pump (Diesel Engine)	Flow rate (Liquid)	Low	0	0	-1	-1	-1	-1	-1	-1
Power Generation	Torque (Mechanical - rotational)	Low	0	0	0	-1	0	-1	-1	0
Primary Fuel Filter (Diesel Engine)	Flow rate (Liquid)	Low	0	0	-1	-1	-1	-1	-1	-1
Secondary Fuel Filter (Diesel Engine)	Flow rate (Liquid)	Low	0	0	-1	-1	-1	-1	-1	-1

Session 2.4: Failure Analysis

Session 2.4 Summary

✓ 2.4.1: Functional Failures

✓ 2.4.2: System & Subsystem Failure Diagram

✓ 2.4.3: Component Failure Diagrams

✓ 2.4.4: Part Failure Diagrams

✓ 2.4.5: Response Paths

✓ 2.4.6: Propagation Table

Session 2.5: Features & Characteristics

Session 2.5 Outline

2.5.1 Part Features

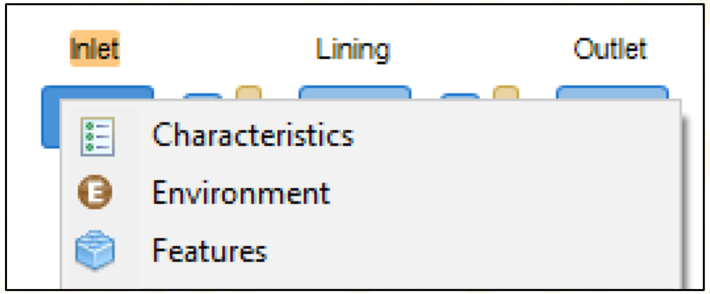
2.5.2 Part & Part-Pair Characteristics

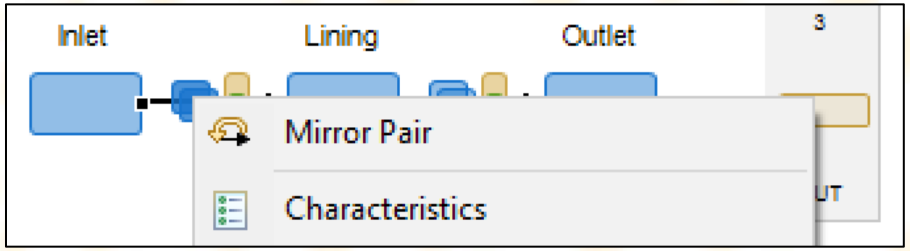
2.5.3 Part Internal Environment

Session 2.5: Features & Characteristics

Discussion 2.5 Features & Characteristics

- **Part & Pair Characteristics** provide additional information on the operation and usage of an item
- **Features** are used to define specific locations of a part where a failure mechanism acts on
- **Environmental Characteristics** allow the user to define the local conditions impacting a part
- All 3 modeling capabilities are accessible for parts (only pair characteristics for part-pairs)

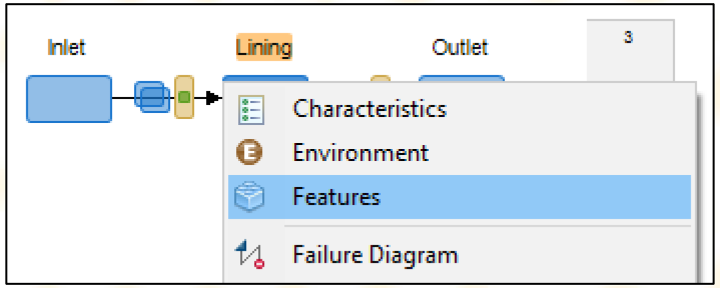




Session 2.5: Features & Characteristics

Discussion 2.5.1 Part Features

- Features are used to identify specific areas or aspects of a part
- Main purpose is to provide additional detail to a failure diagram
  - E.g. a crack occurred on the keyway of a shaft
- Provided with a features taxonomy to assist user
- New features can be added if no default features are applicable

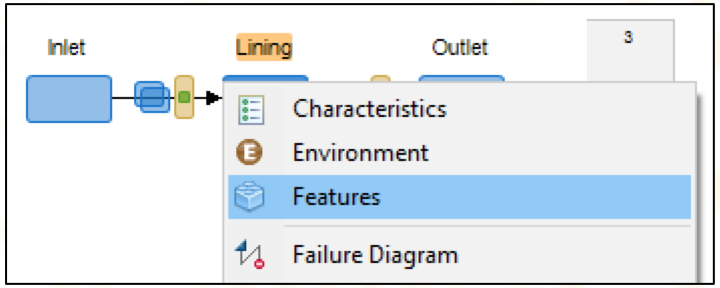


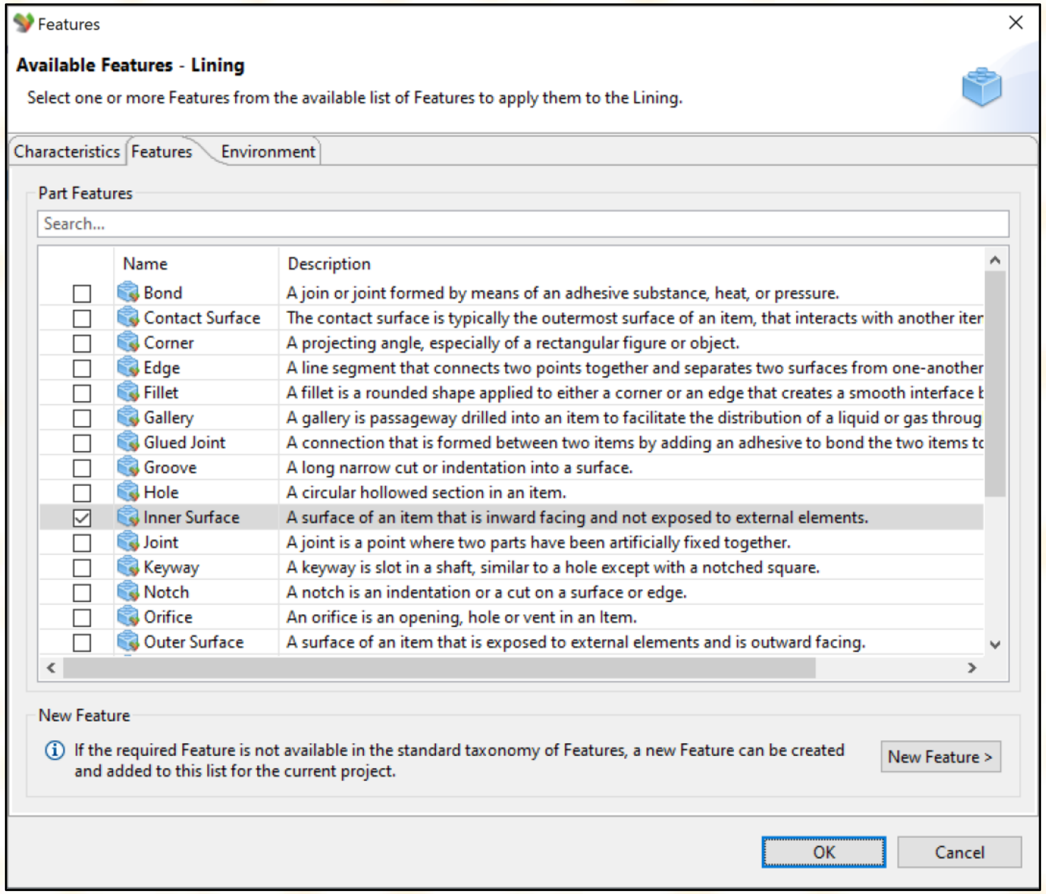
Session 2.5: Features & Characteristics

EXERCISE 2.5.1 PART FEATURES

To assign part features:

- Open the system model for the **'Fuel Tank'**
- Right-click the **'Lining'** and select **Features**
- Select the **Inner Surface** feature
- Select OK

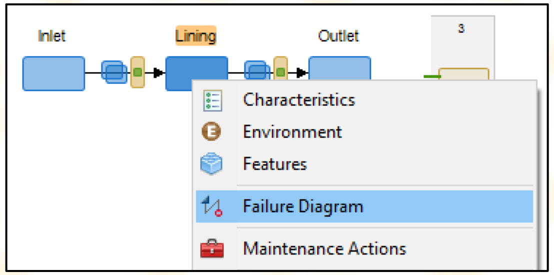


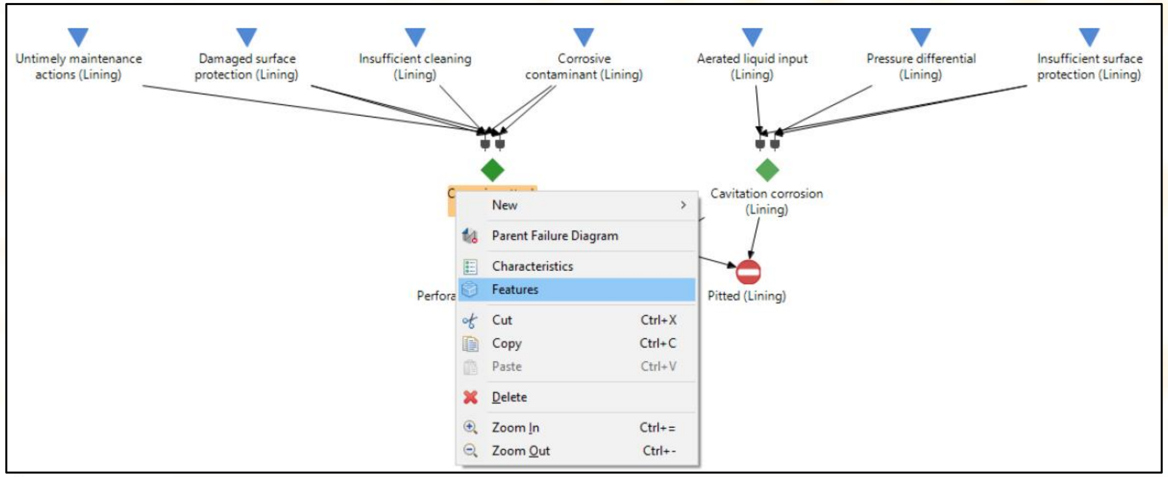


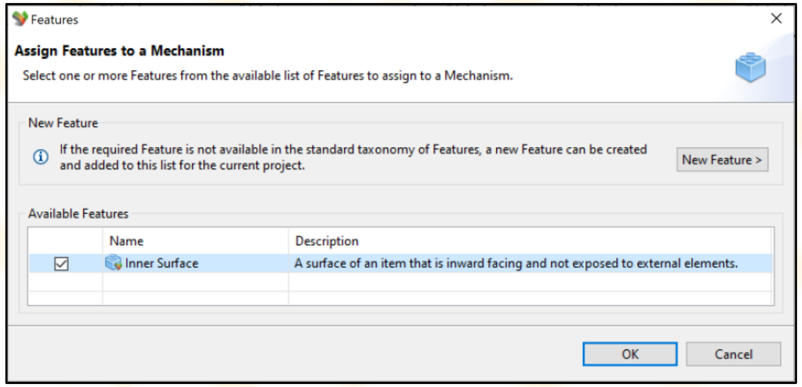
Session 2.5: Features & Characteristics

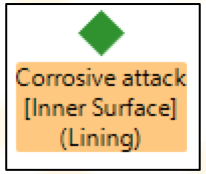
Exercise 2.5.1 Part Features (Continued)

- Open the **Failure Diagram** for the **'Lining'** part
- Right-click the **Corrosive attack** mechanism and select **Features**
- Verify Feature dialog opens
- Select **Inner Surface** and then select OK
  - The mechanism will now show it is occurring on the inner surface of the lining





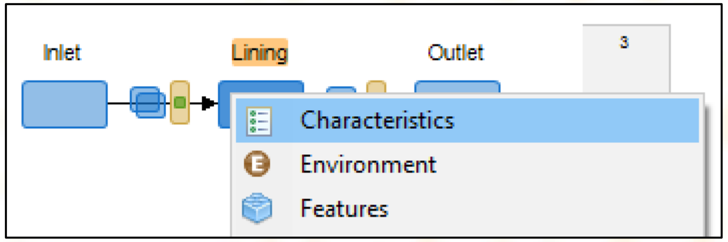


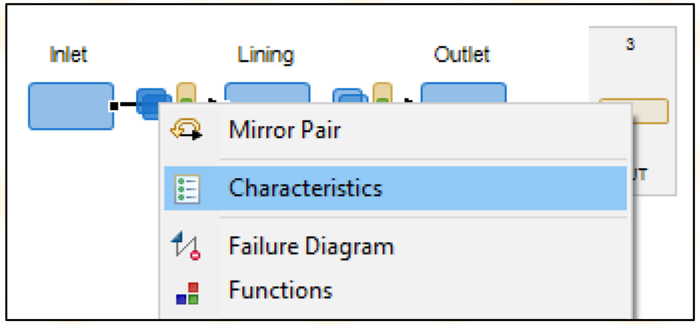


Session 2.5: Features & Characteristics

Discussion 2.5.2 Part & Part-Pair Characteristics

- Characteristics are used to identify the specific operation of a part or pair
- They can be used to identify the loading types and states
- The loading can advise potential methods of failure
  - E.g. a part in torsion, is likely to be susceptible to torsion or shearing mechanisms
- Future enhancements will look at automatically recommending failure concepts based on characteristics





Session 2.5: Features & Characteristics

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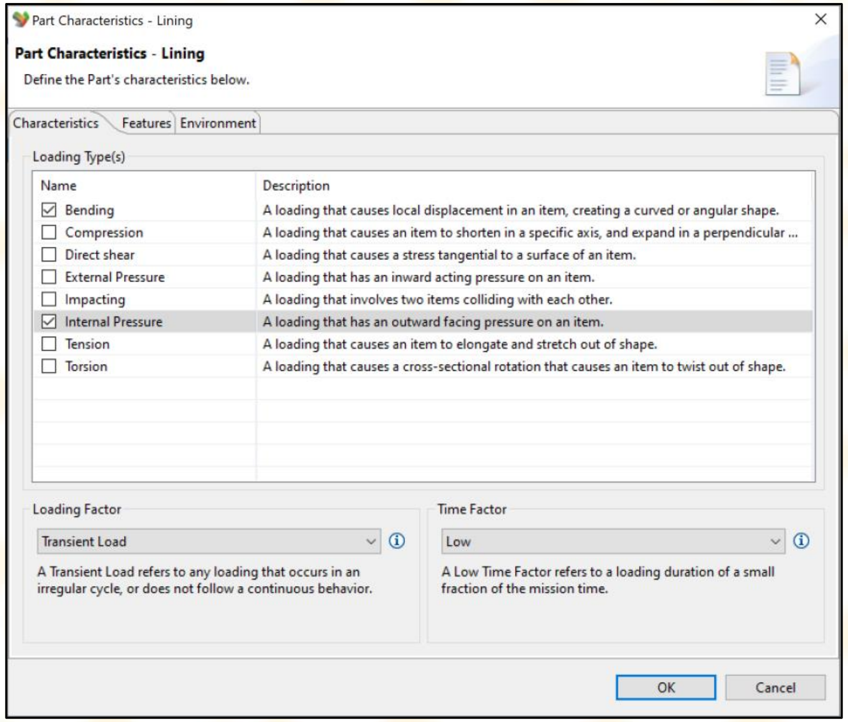
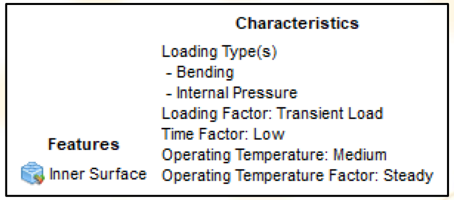
EXERCISE 2.5.2 PART & PART-PAIR CHARACTERISTICS

To specify part characteristics:

- ➢ Right-click the **'Lining'** part and select **Characteristics**
- ➢ Select **Internal Pressure** as the loading type
- ➢ Select **Transient Load** for the loading factor
- ➢ Select **Low** for the time factor
- ➢ Select OK
- ➢ Navigate to the **Failure Diagram** of the **'Lining'**
- ➢ Note the **Characteristics** in the bottom-right corner
  - ➢ The characteristics are used to inform the user of the appropriate failure concepts to build





Session 2.5: Features & Characteristics

Discussion 2.5.3 Part Internal Environment

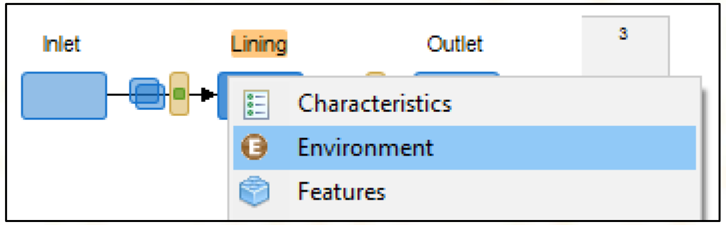
- Internal environment is used to identify the local operating temperature of the item
- The internal environment is supposed to define internal environment while the system environment defines the external environment
  - Bottom-up vs. top-down
- The environment can advise potential failures
  - E.g. high temperature may lead to temperature induced mechanisms
- Future enhancements will look at automatically recommending failure concepts based on internal environment

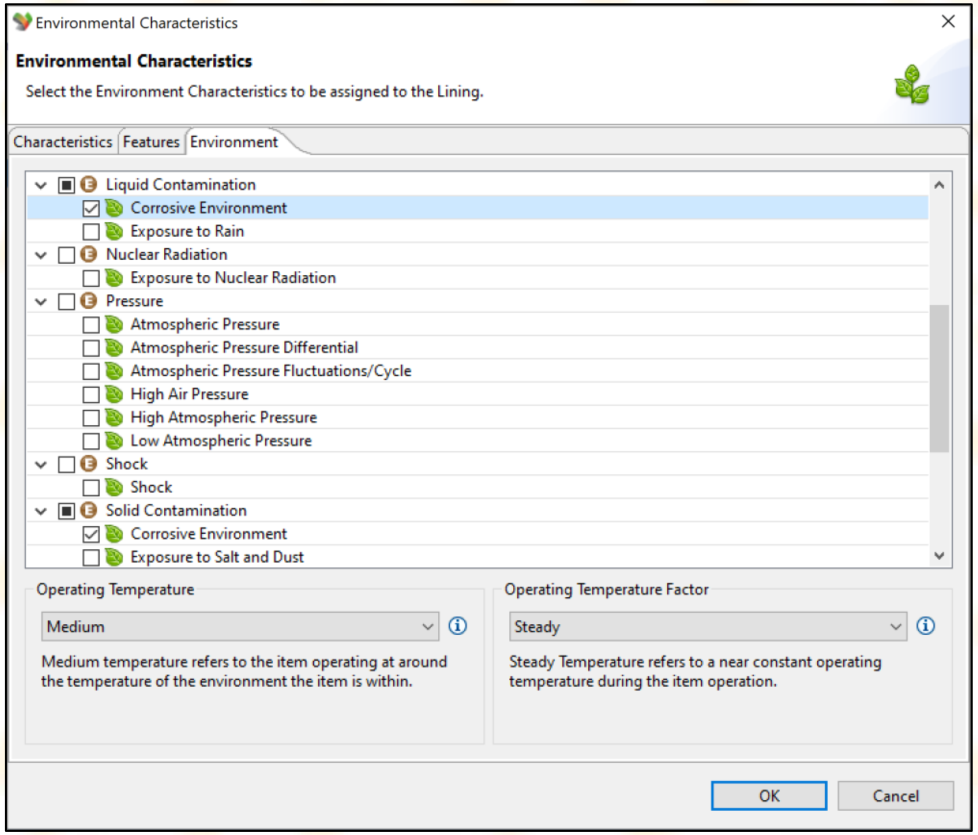
Session 2.5: Features & Characteristics

EXERCISE 2.5.3 PART INTERNAL ENVIRONMENT

To assign an internal environment:

- Right-click the **‘Lining’** and select **Environment**
- Select **Corrosive Environment** from **Liquid** and **Solid Contamination**
- Select the operating temperature as: **Medium**
- Select temperature time factor as: **Steady**
- Select OK

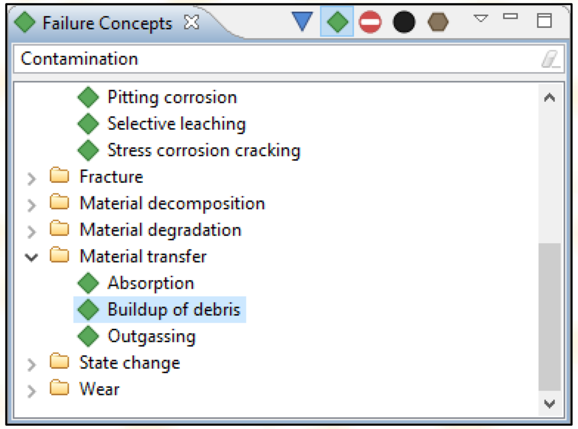


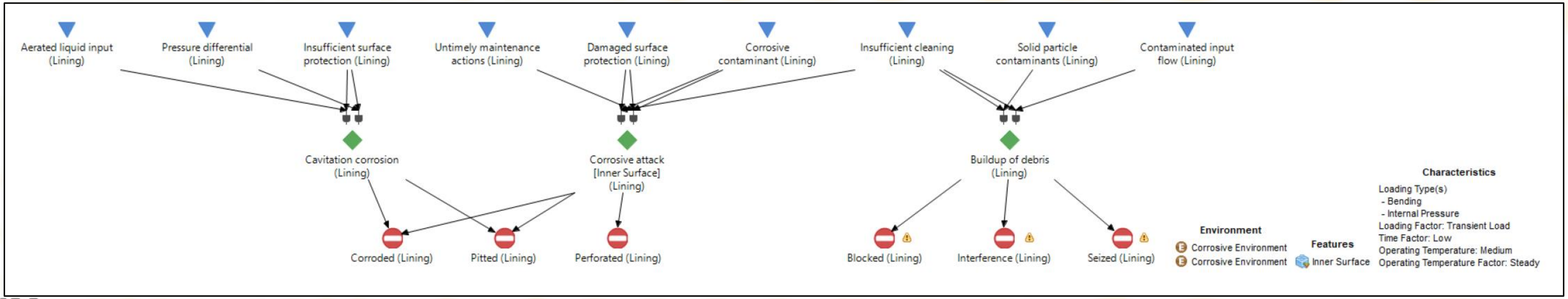


Session 2.5: Features & Characteristics

EXERCISE 2.5.3 PART INTERNAL ENVIRONMENT (CONTINUED)

- Navigate to the **Failure Diagram** of the **'Lining'** part
- Note the **Environment** in the bottom-right corner
- Search the **Mechanism** Failure Concepts for **Contamination**
- Drag **Buildup of debris** into the Failure Diagram editor
  - Note: This mechanism is located in the Material transfer folder
- Simplify the failure diagram (Insufficient Cleaning cause)





Session 2.5: Features & Characteristics

Session 2.5 Summary

- ✓ 2.5.1 Part Features
- ✓ 2.5.2 Part & Part-Pair Characteristics
- ✓ 2.5.3 Part Internal Environment

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Session 2: Failure Simulation

SESSION 2 SUMMARY

- ✓ 2.1: Annotations
- ✓ 2.2: Failure Simulation
- ✓ 2.3: Mission Profile (Solution-dependent) & Groups
- ✓ 2.4: Failure Analysis
- ✓ 2.5: Features & Characteristics

Session 3: Safety Analyses

Using a MADe Model to generate key analyses from Safety & Risk Management domains

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Session 3: Safety Analyses

Session 3 Outline

3.1: Failure Mode & Effects Analysis (FMEA)

3.2: Criticality Analysis

3.3: Revised FMECA

3.4: Critical Item Analysis

3.5: Failure Conditions (FHA)

3.6: Common Mode Analysis (CMA)

3.7: Functional Fault Tree Analysis (FTA)

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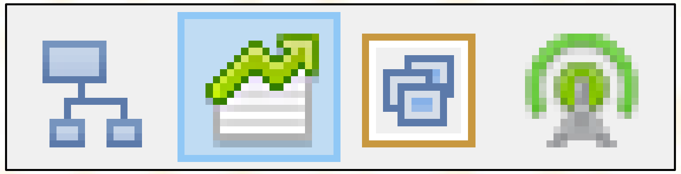
Session 3: Safety Analyses

SESSION 3 DISCUSSION

- Session 3 will take place in the SRA module.
- This session will focus on general safety assessments including:
  - FMEA
  - Criticality Analysis
  - FMECA
  - Failure conditions in FHA
  - Common Mode Analysis
  - Functional Fault Tree



Session 3.1: FMEA

Session 3.1 Outline

3.1.1: Failure Mode & Effects Analysis Definition

3.1.2: FMEA Analysis in MADe

3.1.3: Generating a FMEA Report

3.1.4: Override Failure Diagrams – Functional Failure Settings

Session 3.1: FMEA

Discussion 3.1.1 Failure Modes & Effects Analysis Definition

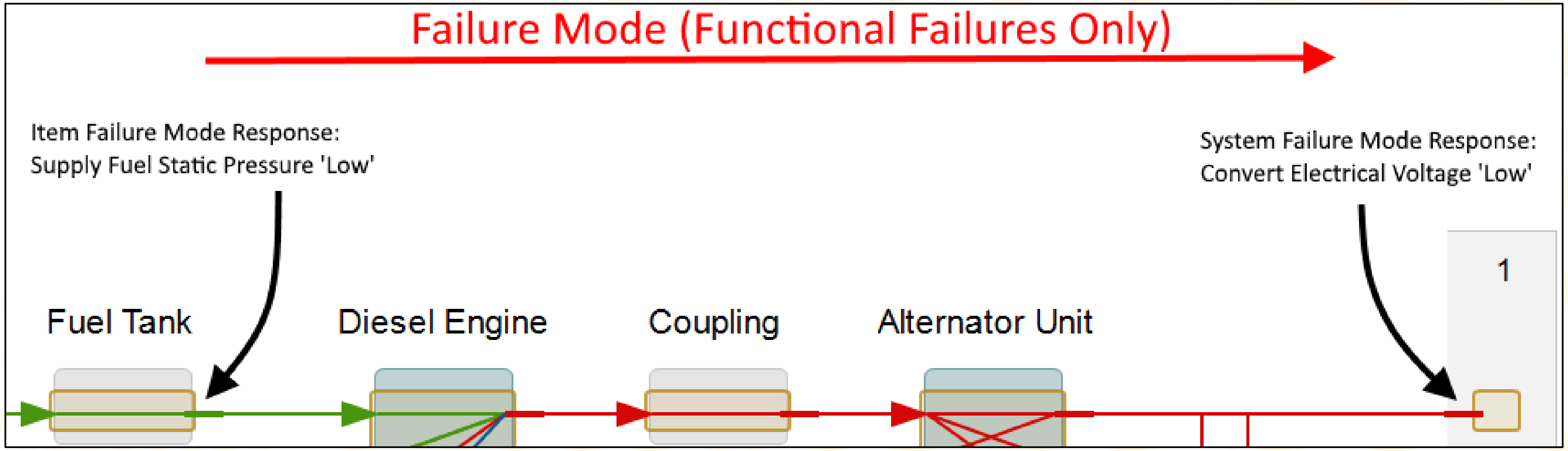
3.1.15 Failure mode and effects analysis (FMEA). A procedure by which each potential failure mode in a system is analyzed to determine the results or effects thereof on the system and to classify each potential failure mode according to its severity.

- MIL-STD-1629A
- Analyse each failure mode
- Determine their effects on the system
- Classify failure modes according to severity

Session 3.1: FMEA

Discussion 3.1.1 Failure Mode Definition

- MIL-STD-1629A Failure Mode = MADe Failure Mode (Functional Failures only)

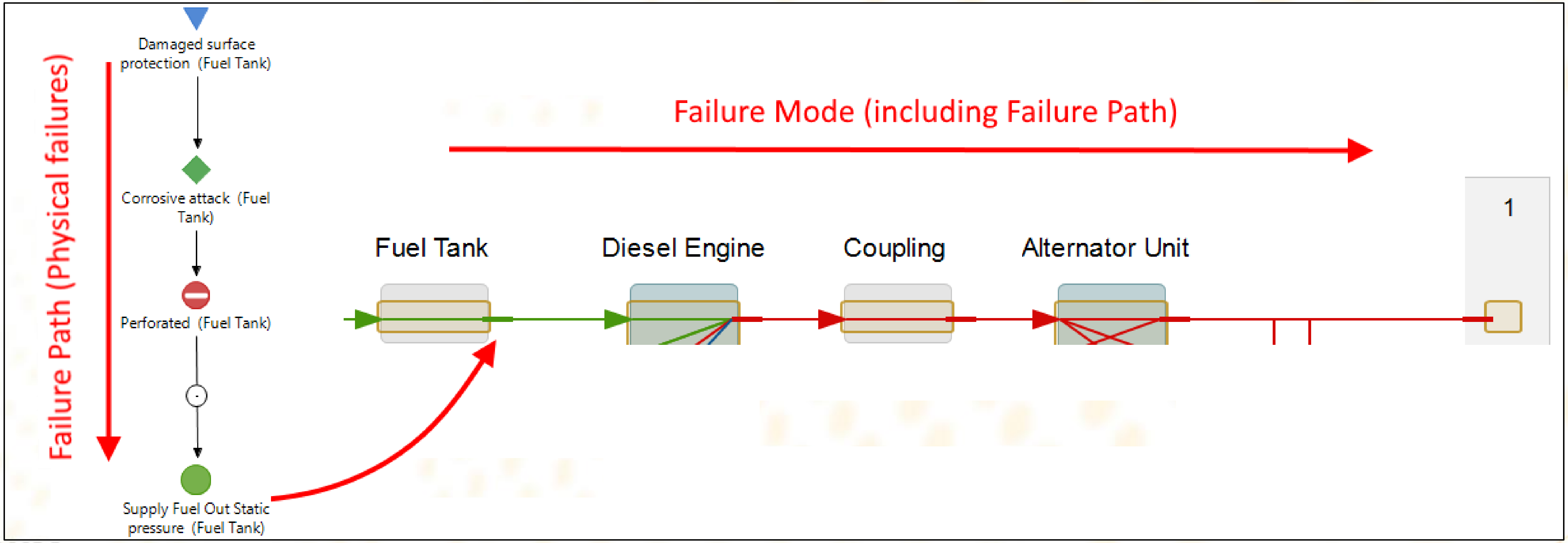


- How are physical failures captured in a MADe FMEA?

Session 3.1: FMEA

Discussion 3.1.1 Failure Mode Definition (Continued)

- A Failure Mode in a MADe model can have multiple **Failure Paths** (Physical Failures)



Session 3.1: FMEA

Discussion 3.1.2 FMEA Analysis in MADe

- MADe generates a FMEA report based on the MADe system model created
- Each row represents one failure path and failure mode (including local, next & end effects)
- Severity Classification of each row is calculated from the **Failure Mode Severity** of the **End effect Item**

Session 3.1: FMEA

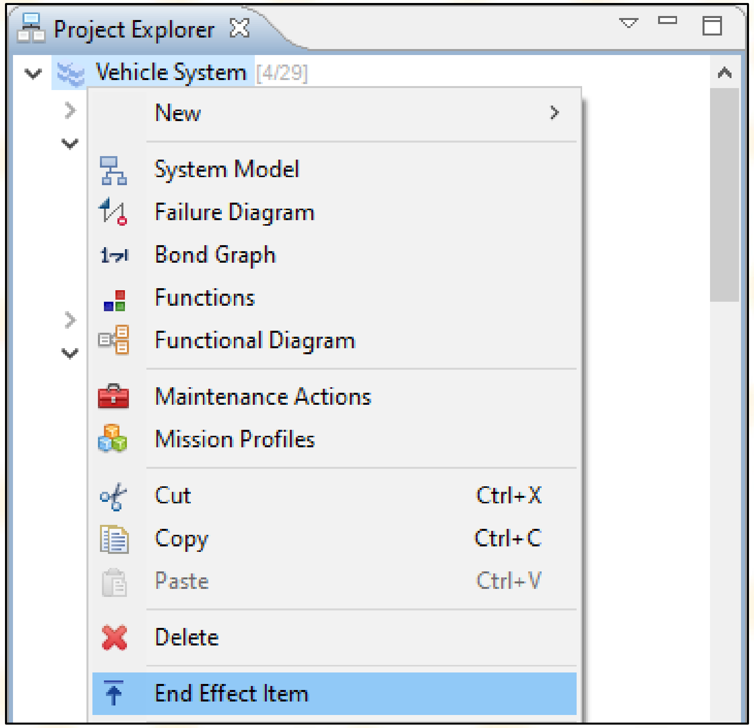
Exercise 3.1.2 Setting an End Effect in the System Model

Method 1:

- Right-click the **'Fuel Tank'** item in the Project Explorer
- Select **End Effect Item** from the menu
- Result: End effect is now the **'Fuel Tank'** item (upward-pointing arrow)

Method 2:

- Right-click the **'Power Generation'** system on the System canvas
- Select **End Effect Item** from the menu
- Result: End effect will be set to the **'Power Generation'** System



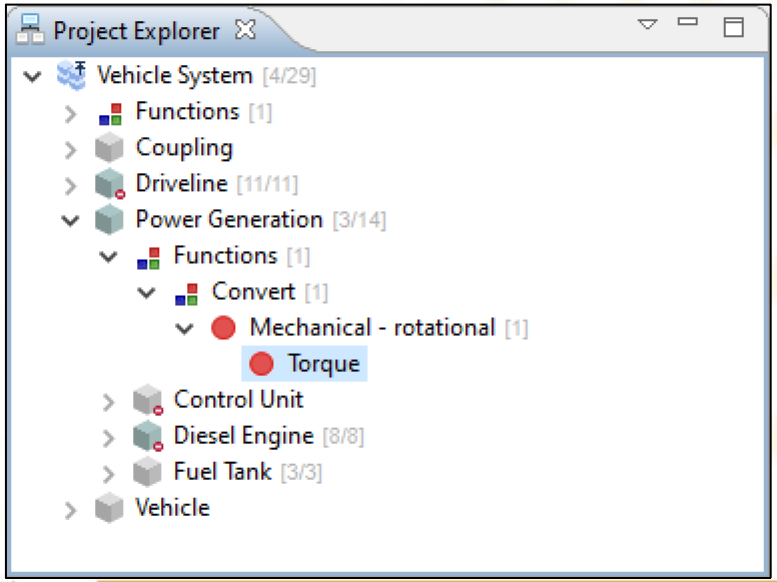
- Set the **'Vehicle System'** to the End Effect using either method

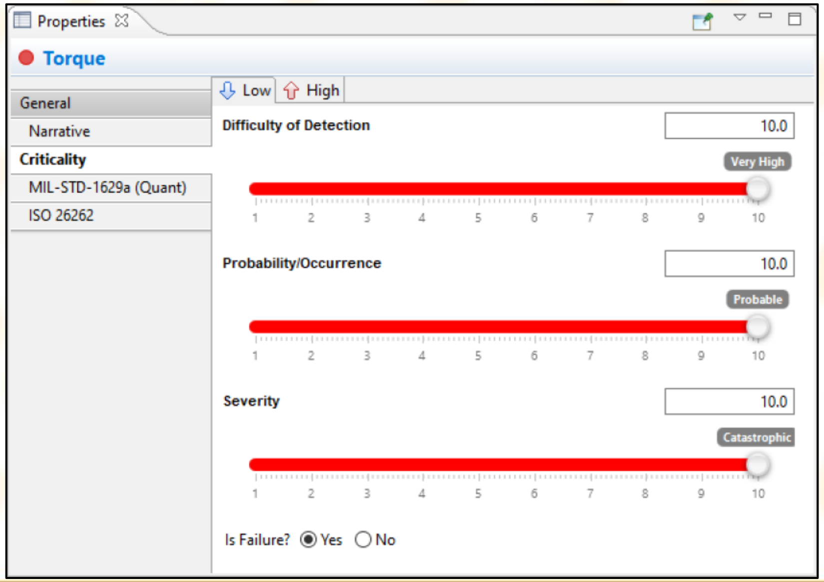
Session 3.1: FMEA

Exercise 3.1.2 Edit the End Effect Item Severity

To change the Severity factor:

- Locate the **‘Power Generation’** subsystem in the Project Explorer
- Expand the System Tree until Mechanical – rotational **Torque** is visible then select this item
- From the Properties viewer select the **Criticality** tab





Session 3.1: FMEA

Exercise 3.1.2 Edit the End Effect Item Severity (continued)

- Verify that the Failure Mode response (top tab) is set to: **Low**
- Change the **Severity** value to: **6.0**
- Change the Failure Mode response (top tab) to: **High**
- Change the **Severity** value to: **9.0**
- Save changes

Session 3.1: FMEA

Discussion 3.1.3 FMEA (MIL-STD-1629A) Report

There are 2 different FMEA reports available in MADe:

- Component/Subsystem FMEA
  - Component / Subsystem FMEA report is generated from any source and any selected end effect
  - This report is a condensed report that can be used to report only on select component / subsystem

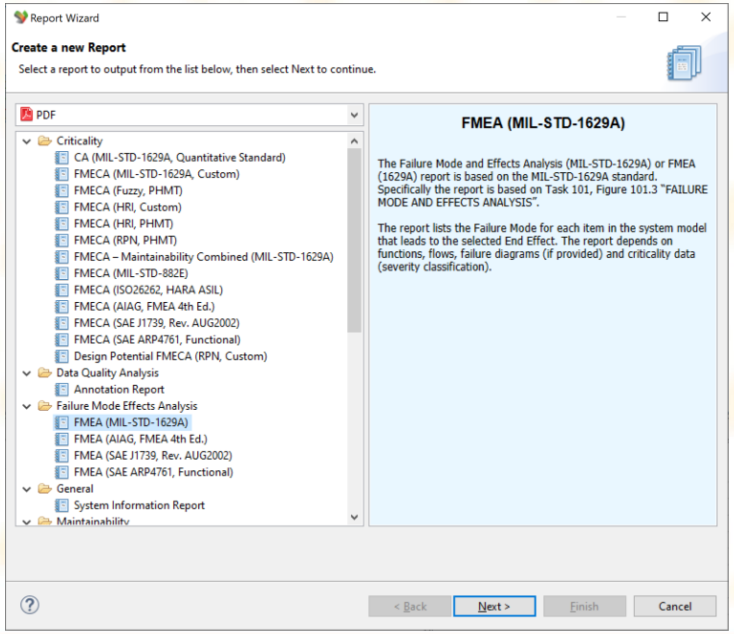
- System FMEA
  - The system FMEA report is generated on all components for the entirety of the system
  - This report is a full report which captures all component and subsystem effects on the end effect

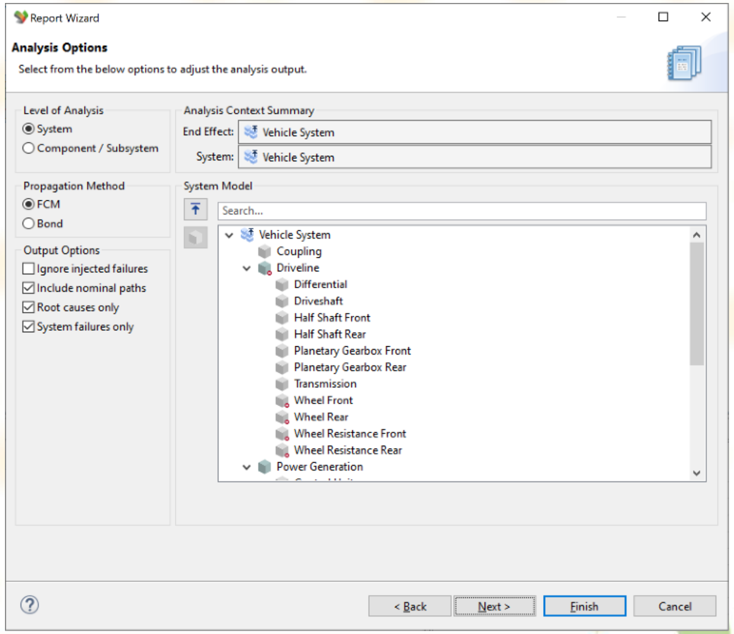
Session 3.1: FMEA

Exercise 3.1.3 Generate a FMEA (MIL-STD-1629A) Report

To generate a FMEA (MIL-STD-1629A) Report:

- Select **Reports → Report Wizard** from the main menu
- Under **Failure Mode Effects Analysis** select **FMEA (MIL-STD-1629A)**
- Select Next > to proceed to next page
- Set the Level of Analysis to **System**
- Ensure Propagation Method is set to **FCM**
- Select Finish to generate the report

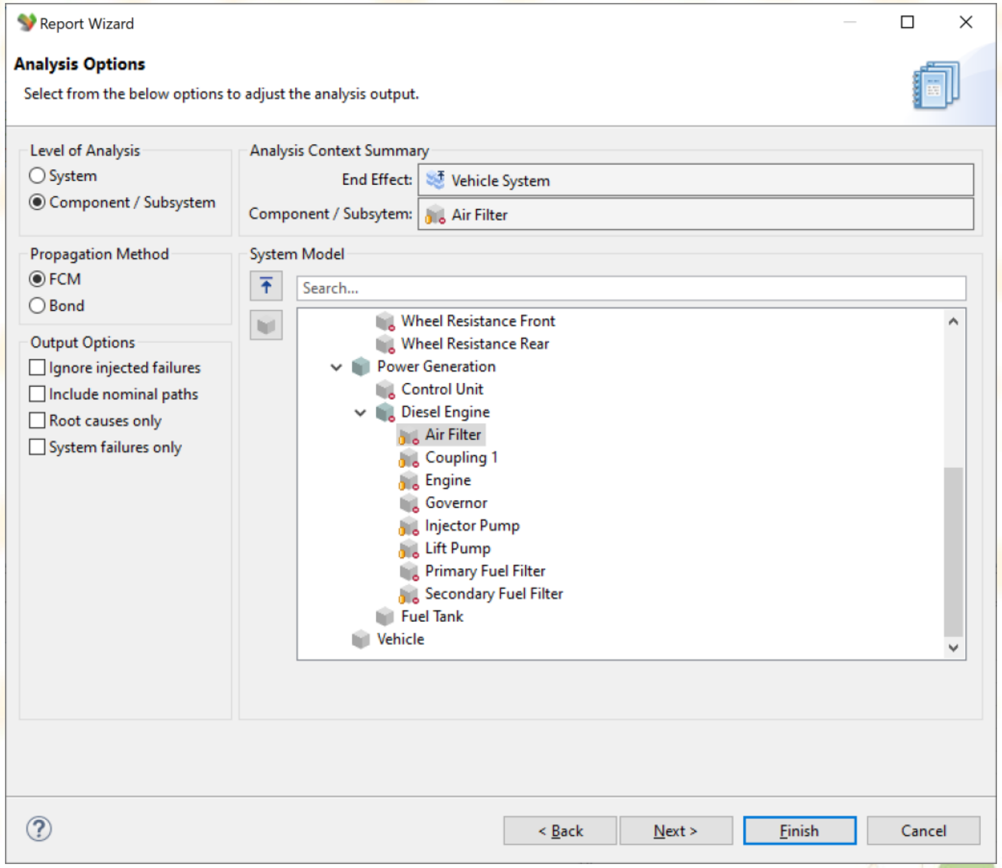




Session 3.1: FMEA

Exercise 3.1.3 Generate a FMEA (MIL-STD-1629A) Report (Continued)

- Select **Reports → Report Wizard** from the main menu
- Under **Failure Mode Effects Analysis** select **FMEA (MIL-STD-1629A)**
- Select Next > to proceed to next page
- Set the Level of Analysis to **Component/Subsystem**
- Select the **'Vehicle System'** item from the System Model list and select to set as end effect
- Select the **'Air Filter'** component from the **'Diesel Engine'** Subsystem and select
  - This will report on the **'Air Filter'** component
- Select Finish to generate the report



Session 3.1: FMEA

Exercise 3.1.3 Generate a FMEA (MIL-STD-1629A) Report

MADe Training — FMEA (MIL-STD-1629A) — 23/10/2019 10:19:28 AM

SYSTEM Vehicle System
INDENTURE LEVEL 1
REFERENCE DRAWING
MISSION Regular Trip

DATE 23/10/2019 10:19:28 AM
SHEET 3 **OF** 51
COMPILED BY Daniel Chan
APPROVED BY

IDENTIFICATION NUMBER	ITEM / FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES	MISSION PHASE / OPERATIONAL MODE	FAILURE EFFECTS			FAILURE DETECTION MEANS	COMPENSATING PROVISIONS	SEVERITY CLASS
					LOCAL EFFECTS	NEXT HIGHER LEVEL	END EFFECTS			
VS1	Vehicle System A land vehicle consisting of a driveline and power generation system.	Convert Mechanical - rotational Angular velocity	High Mechanical - rotational Angular velocity of the Vehicle System due to High Mechanical - rotational Angular velocity of the Vehicle	1: Start-up 100% 2: Acceleration 100% 3: Cruise 100% 4: Turning 100% 5: Cruise 2 100% 6: Deceleration 100% 7: Shut-down 100%	Convert Mechanical - rotational Angular velocity High		Convert Mechanical - rotational Angular velocity High			I
			Low Mechanical - rotational Angular velocity of the Vehicle System due to Low Mechanical - rotational Angular velocity of the Vehicle		Convert Mechanical - rotational Angular velocity Low		Convert Mechanical - rotational Angular velocity Low			I
			High Mechanical - rotational Angular velocity of the Vehicle System due to High Mechanical - rotational Angular velocity of the Vehicle		Convert Mechanical - rotational Angular velocity High		Convert Mechanical - rotational Angular velocity High			I

MADe Training — FMEA (MIL-STD-1629A) — 23/10/2019 10:29:37 AM

SYSTEM Vehicle System > Power Generation > Diesel Engine > Air Filter
INDENTURE LEVEL 4
REFERENCE DRAWING
MISSION Regular Trip

DATE 23/10/2019 10:29:37 AM
SHEET 6 **OF** 7
COMPILED BY Daniel Chan
APPROVED BY

IDENTIFICATION NUMBER	ITEM / FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES	MISSION PHASE / OPERATIONAL MODE	FAILURE EFFECTS			FAILURE DETECTION MEANS	COMPENSATING PROVISIONS	SEVERITY CLASS
					LOCAL EFFECTS	NEXT HIGHER LEVEL	END EFFECTS			
	Air Filter An air purifying device, removing particle contaminants from the air.	Refine Gas Mass flow rate Modelled as a resistive device, slightly restricting air flow and removing particles.	Low Gas Mass flow rate due to Contamination increasing of the Air Filter as a result of buildup of debris caused by insufficient cleaning and solid particle contaminants	1: Start-up 100% 2: Acceleration 100% 3: Cruise 100% 4: Turning 100% 5: Cruise 2 100% 6: Deceleration 100% 7: Shut-down 100%	Refine Gas Mass flow rate Low	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			I
			Low Gas Mass flow rate due to Contamination increasing of the Air Filter as a result of buildup of debris caused by contaminated input flow and insufficient cleaning		Refine Gas Mass flow rate Low	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			I
			Low Gas Mass flow rate due to Contamination increasing of the Air Filter as a result of buildup of debris caused by contaminated input flow and insufficient cleaning		Refine Gas Mass flow rate Low	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			I

Session 3.1: FMEA

EXERCISE 3.1.3 FMEA SEVERITY CLASSIFICATION

MADe Training | FMEA (MIL-STD-1629A) | 23/10/2019 10:29:37 AM

SYSTEM Vehicle System > Power Generation > Diesel Engine > Air Filter
INDENTURE LEVEL 4
REFERENCE DRAWING
MISSION Regular Trip

DATE 23/10/2019 10:29:37 AM
SHEET 6 **OF** 7
COMPILED BY Daniel Chan
APPROVED BY

IDENTIFICATION NUMBER	ITEM / FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES	MISSION PHASE / OPERATIONAL MODE	FAILURE EFFECTS: LOCAL EFFECTS	FAILURE EFFECTS: NEXT HIGHER LEVEL	FAILURE EFFECTS: END EFFECTS	FAILURE DETECTION MEANS	COMPENSATING PROVISIONS	SEVERITY CLASS
	Air Filter An air purifying device, removing particle contaminants from the air.	Refine Gas Mass flow rate Modelled as a resistive device, slightly restricting air flow and removing particles.	Low Gas Mass flow rate due to Contamination increasing of the Air Filter as a result of buildup of debris caused by insufficient cleaning and solid particle contaminants	1: Start-up 100% 2: Acceleration 100% 3: Cruise 100% 4: Turning 100% 5: Cruise 2 100% 6: Deceleration 100% 7: Shut-down 100%	Refine Gas Mass flow rate Low	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			I
			Low Gas Mass flow rate due to Contamination increasing of the Air Filter as a result of buildup of debris caused by contaminated input flow and insufficient cleaning		Refine Gas Mass flow rate Low	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			I
			Low Gas Mass flow rate due to Contamination increasing of the Air Filter as a result of buildup of debris caused by contaminated input flow and insufficient cleaning		Refine Gas Mass flow rate Low	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			I

SEVERITY CLASSIFICATION DEFINITION & TABLES

SEVERITY CATEGORY	RANGE	SEVERITY CLASSIFICATION
Cat IV - Minor	1.0 - 3.9	IV
Cat III - Marginal	4.0 - 6.9	III
Cat II - Critical	7.0 - 8.9	II
Cat I - Catastrophic	9.0 - 10.0	I

Session 3.1: FMEA

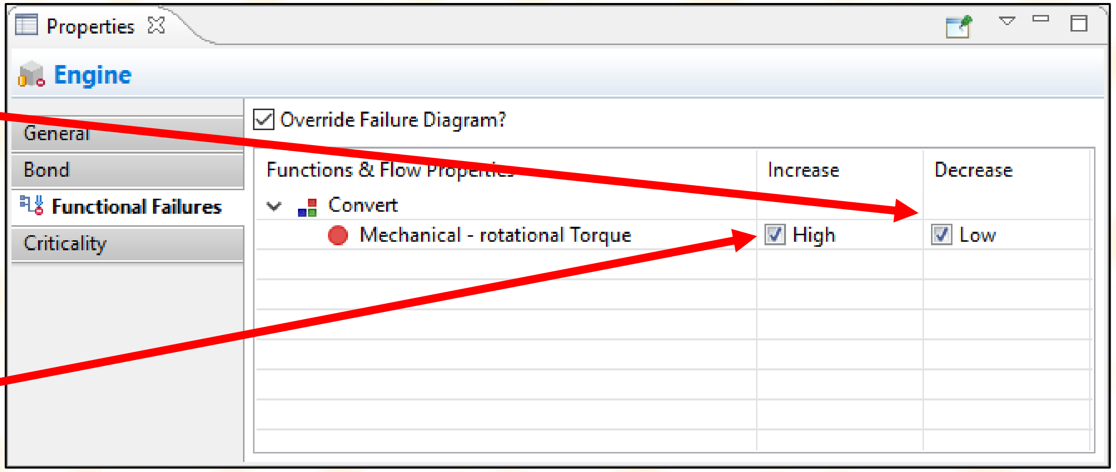
Discussion 3.1.4 Override Failure Diagrams – Functional Failure Settings

Override failure diagram option is available for items with Failure Diagrams

- Override is selected: FMEA/FMECA does not report Failure Paths, only Failure Mode responses
- Override is not selected: FMEA/FMECA reports Failure Paths AND Failure Mode responses (additional rows)

IDENTIFICATION NUMBER	ITEM / FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES
	Engine Internal combustion engine which burns diesel fuel to create rotational motion.	Convert Mechanical - rotational Torque Modelled as a transformer, converting chemical energy into rotational energy.	Low Mechanical - rotational Torque of the Engine
			Low Mechanical - rotational Torque of the Engine

IDENTIFICATION NUMBER	ITEM / FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES
	Engine Internal combustion engine which burns diesel fuel to create rotational motion.	Convert Mechanical - rotational Torque Modelled as a transformer, converting chemical energy into rotational energy.	High Mechanical - rotational Torque of the Engine
			High Mechanical - rotational Torque of the Engine



Session 3.1: FMEA

SESSION 3.1 SUMMARY

- ✓ 3.1.1: Failure Mode & Effects Definition
- ✓ 3.1.2: FMEA Analysis in MADe
- ✓ 3.1.3: Generating a FMEA Report
- ✓ 3.1.4: Override a Failure Diagram

Session 3.2: Criticality Analysis

Session 3.2 Outline

3.2.1: Criticality Analysis Definitions

3.2.2: Criticality Analysis – Risk Priority Number (RPN)

3.2.3: Assigning RPN Criticality Parameters in MADe

3.2.4: Generating a FMECA (RPN) report

3.2.5: Alternative Criticality Analyses in MADe

3.2.6: Criticality Profile Editor

Session 3.2: Criticality Analysis

DISCUSSION 3.2.1 CRITICALITY & CRITICALITY ANALYSIS DEFINITION (MIL-STD-1629A)

- **Criticality**: A relative measure of the consequences of a failure mode and probability of occurrence
- **Criticality Analysis (CA)**: A procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence

Types of Failure Mode, Effects & Criticality Analysis (FMECA) in MADe:

- Risk Priority Number (RPN)
- Fuzzy Risk Priority Number (Fuzzy RPN)
- Criticality Analysis (MIL-STD-1629)
- Hazard Risk Index (HRI)

Session 3.2: Criticality Analysis

Discussion 3.2.2 Criticality Analysis – Risk Priority Numbers (RPN)

- Risk Priority Number (RPN) is calculated using 3 criticality parameters:
    1) **Occurrence** (How often does it fail?)
    2) **Severity** (How bad are the failures?)
    3) **Difficulty of Detection** (How hard is it to detect these failures?)

Example:

Risk Priority Number = O × S × D = Failure Path Criticality No.

Occurrence (**8**)	×	Severity (**4**)	×	Difficulty of Detection (**9**) = **288**
[Local Failure Mode]		[End Effect Severity]		[Local Failure Mode]

Session 3.2: Criticality Analysis

Discussion 3.2.3 Assigning RPN Criticality Parameters in MADe

- Criticality factors are assigned to Faults & Failure Modes in the MADe model
- The table below shows where the Occurrence, Severity and Difficulty of detection parameters are editable for a RPN FMECA report

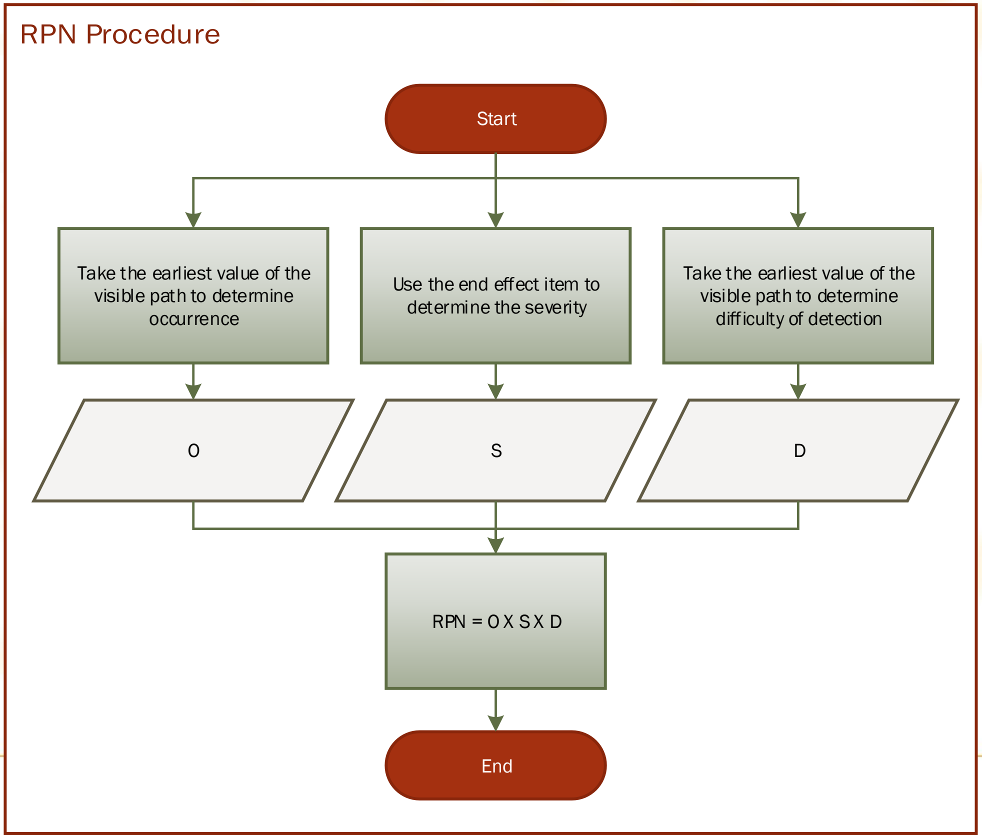
Failure Concepts	Occurrence	Severity	Difficulty of Detection
Fault (Local Item)	Yes	No	Yes
Failure Mode (Local Item)	Yes	Yes*	Yes
Failure Mode (End Effect Item)	Yes	Yes	Yes

*Local Failure Mode severity is overwritten by End Effect Item Failure Mode severity

Session 3.2: Criticality Analysis

Discussion 3.2.3 Assigning RPN Criticality Parameters in MADe

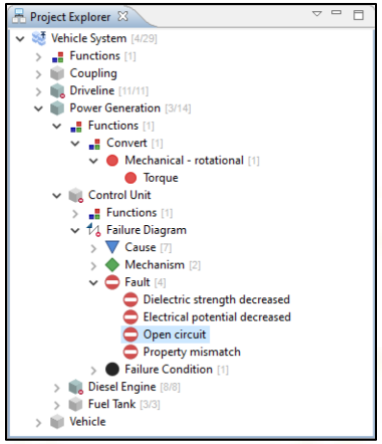
- Criticality factors are assigned to Faults & Failure Modes in the MADe model
- The criticality calculation for each failure mode follows the following procedure

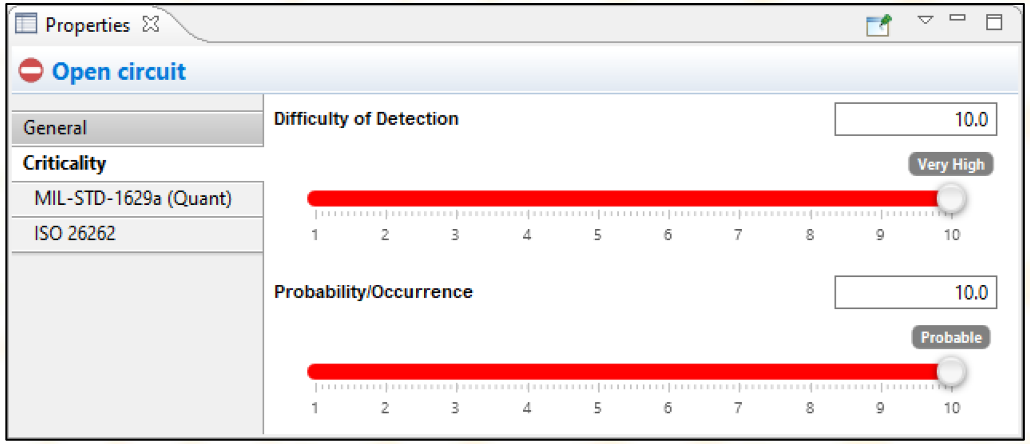


Session 3.2: Criticality Analysis

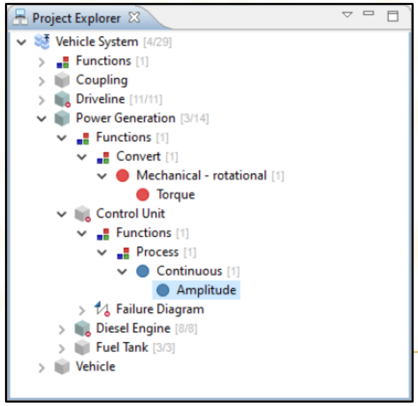
Discussion 3.2.3 Assigning Criticality Parameters for RPN (continued)

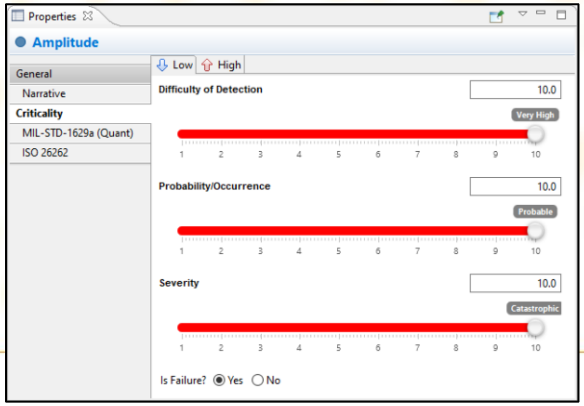
- Criticality Parameters for Faults & Failure conditions:





- Criticality Parameters for Failure Modes:



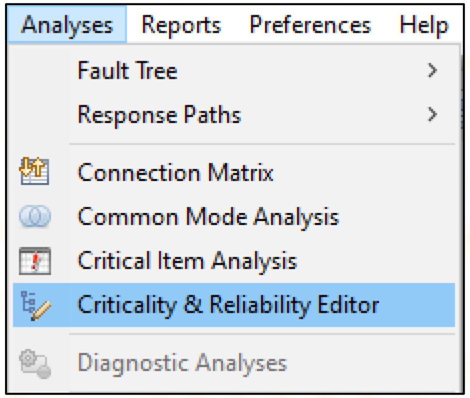


Session 3.2: Criticality Analysis

Exercise 3.2.3 Set Fuel Tank Criticality

To edit criticality values, open the Criticality editor by:

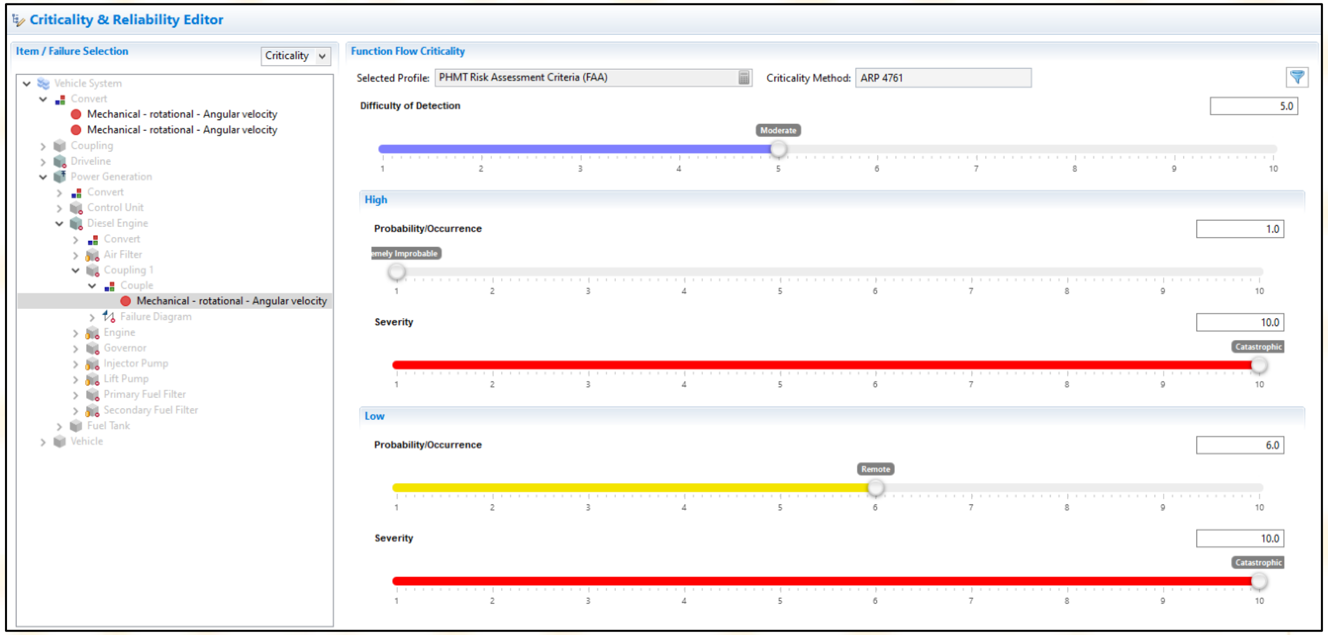
- Select **Analyses → Criticality & Reliability Editor** from the menu bar
- Expand the System Tree to show the **Corroded** fault for the **'Lining'** part in the **'Fuel Tank'** component
- Change their **Difficulty of Detection** value to **6.0** and **Occurrence** value to **9.0**



Session 3.2: Criticality Analysis

EXERCISE 3.2.3 SET COUPLING CRITICALITY

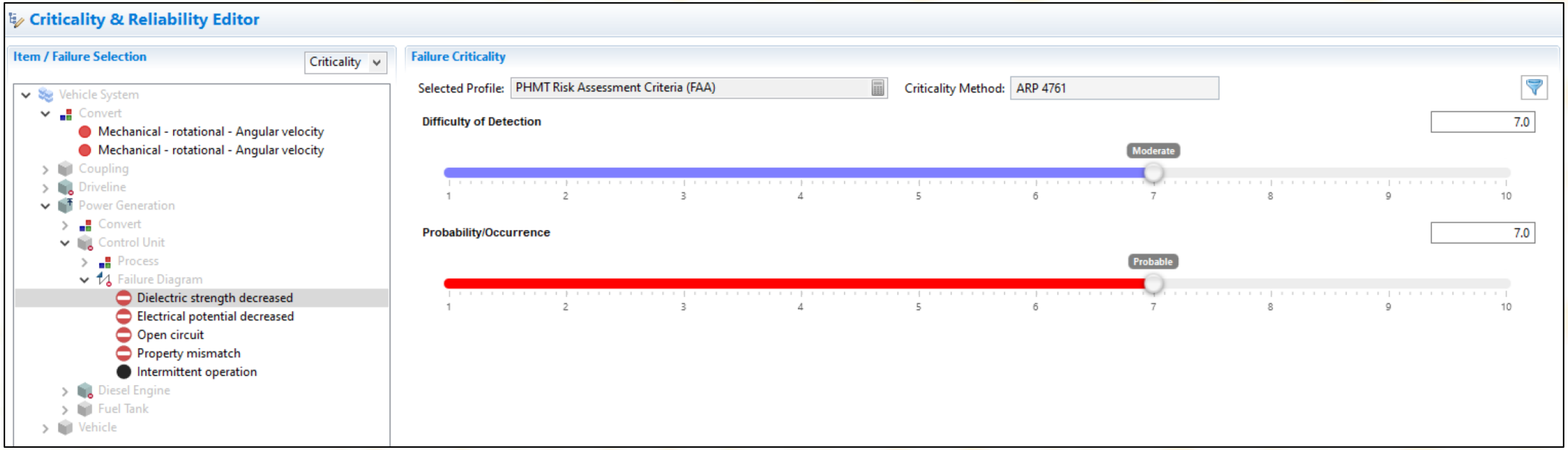
- Expand the System Tree and select: **Mechanical – rotational – Angular Velocity** failure mode of the **‘Coupling 1’** component in the **‘Diesel Engine’**
- Change **Difficulty of Detection** value to: **5.0**
- Under the **High** section set Occurrence to: **1.0**
- Under the **Low** section, set Occurrence to: **6.0**



Session 3.2: Criticality Analysis

EXERCISE 3.2.3 SET CONTROL UNIT CRITICALITY

- Expand the System Tree to show the **Dielectric strength decreased** faults in the **'Control Unit'** component
- Change Difficulty of Detection value to **7.0** and Occurrence value to **7.0**

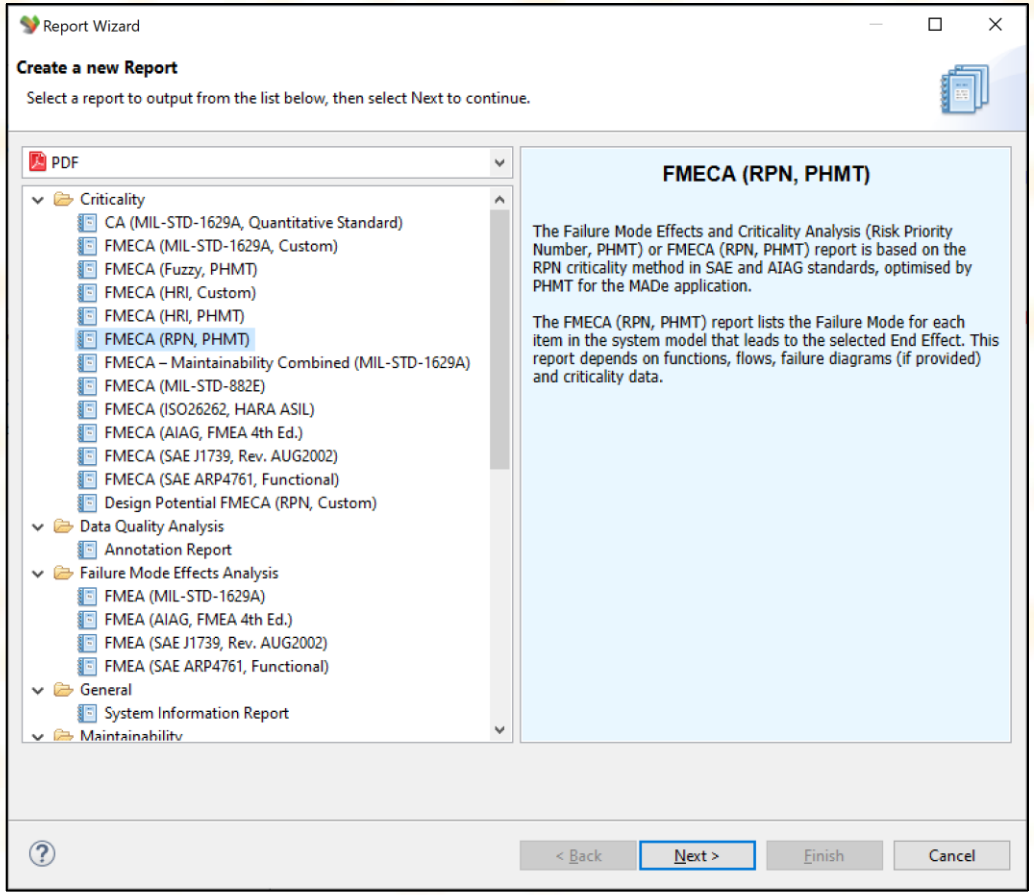


Session 3.2: Criticality Analysis

Exercise 3.2.4 Generate a FMECA (RPN) Report

To generate a FMECA (RPN) report:

- Select **Reports → Report Wizard** from the menu
- Under **Criticality** select FMECA (RPN, PHMT)
- Set Level of Analysis to **System**
- Set **'Power Generation'** as the End-Effect item
- Select Next > after each page
- Confirm Report Format customizations
- Confirm Company Details
- Select Finish to generate the report



Session 3.2: Criticality Analysis

Exercise 3.2.4 Generating a RPN FMECA Report (continued)

SYSTEM	Vehicle System > Power Generation > Control Unit	**DATE**	16/05/2020 12:49:06 PM
INDENTURE LEVEL	3	**SHEET**	5 **OF** 23
REFERENCE DRAWING		**COMPILED BY**	D CHAN
MISSION	New Group	**APPROVED BY**	

ITEM NO.	ITEM/PHYSICAL DESCRIPTION	FUNCTION/ FUNCTIONAL NARRATIVE	FAILURE MODE		CAUSES OF FAILURE		FAILURE EFFECTS		DETECTION METHODS	COMPENSATING PROVISIONS	CRITICALITY			
			FUNCTIONAL FAILURE	FAULT	MECHANISM	CAUSE	NEXT HIGHER LEVEL	END EFFECTS			O	S	D	RPN
	Control Unit	Process Continuous Amplitude	Process Continuous Amplitude Low (Control Unit)	Dielectric strength decreased (Control Unit)	Dielectric breakdown (Control Unit)	Line defects (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			7.0	6.0	7.0	294
			Intermittent operation			Over-current (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			7.0	6.0	7.0	294
						Over-voltage (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			7.0	6.0	7.0	294
			Process Continuous Amplitude Low (Control Unit)	Open circuit (Control Unit)	Burnout (Control Unit)	Electrical potential high (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			10.0	6.0	10.0	600
						Electrical resistance low (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			10.0	6.0	10.0	600
						Over-current (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			10.0	6.0	10.0	600
						Over-voltage (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			10.0	6.0	10.0	600
						Short circuit (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			10.0	6.0	10.0	600
						Transient electrical loads due to varying power source (Control Unit)	Convert Mechanical - rotational Torque Low (Power Generation)	Convert Mechanical - rotational Torque Low (Power Generation)			10.0	6.0	10.0	600

PHM Technology

Session 3.2: Criticality Analysis

Discussion 3.2.5 Alternative Criticality Analyses in MADe

- FMECA (MIL-STD-1629A) uses a different set of criticality parameters (see table below)
- In order to edit these values using the Reliability Editor you must be in the RAM module

Location	**Criticality Parameters**			
	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)
Fault (Local Item)	Yes	Yes[1]	No	No
Failure Mode (Local Item)	Yes[1]	Yes	No	No
Reliability Editor (Local Item)	No	No	Yes	Yes[2]
Mission Profile	No	No	No	Yes

[1]Criticality Parameter is overwritten when Failure Diagram is present

[2]Criticality Parameter is overwritten when Mission Profile is present

Session 3.2: Criticality Analysis

Exercise 3.2.5 Alternative Criticality Analyses in MADe

SYSTEM	Vehicle System > Power Generation > Diesel Engine > Air Filter	**DATE**	16/05/2020 12:52:55 PM
INDENTURE LEVEL	4	**SHEET**	7 **OF** 19
REFERENCE DRAWING		**COMPILED BY**	D Chan
MISSION	New Group	**APPROVED BY**	

IDENTIFICATION NUMBER	ITEM / FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES	MISSION PHASE / OPERATIONAL MODE	SEVERITY CLASS	FAILURE DATA SOURCE	FAILURE EFFECT PROBABILITY (β)	FAILURE MODE RATIO (α)	FAILURE RATE (λ_p)	OPERATING TIME (t)	FAILURE MODE CRIT # $C_m=\beta\alpha\lambda_p t$	ITEM CRIT # $C_r=\sum(C_m)$
	Air Filter An air purifying device, removing particle contaminants from the air.	Refine Gas Mass flow rate Modelled as a resistive device, slightly restricting air flow and removing particles.	Low Gas Mass flow rate due to perforating of the Air Filter as a result of abrasive wear caused by solid particle contaminants resulting in Low Mechanical - rotational Torque (Diesel Engine) and Low Mechanical - rotational Torque (Power Generation)	Regular Trip 1: Start-up 100% 2: Acceleration 100% 3: Cruise 100% 4: Turning 100% 5: Cruise 2 100% 6: Deceleration 100% 7: Shut-down 100% Long Trip 1: Start-up 100% 2: Acceleration 100% 3: Cruise 100% 4: Turning 100% 5: Cruise 2 100% 6: Deceleration 100% 7: Shut-down 100%	III	This item does not have a failure data source annotation	1.00	0.25	1.0E-6	71.2	1.779×10^{-5}	7.116×10^{-5}
			Low Gas Mass flow rate due to blocking of the Air Filter as a result of silting caused by contaminated input flow and input flow too slow resulting in Low Mechanical - rotational Torque (Diesel Engine) and Low Mechanical - rotational Torque (Power Generation)		III		1.00	0.25	1.0E-6	71.2	1.779×10^{-5}	
			Low Gas Mass flow rate due to contamination increasing of the Air Filter as a result of buildup of debris caused by contaminated input flow and insufficient cleaning resulting in Low Mechanical - rotational Torque (Diesel Engine) and Low Mechanical - rotational Torque (Power Generation)		III		1.00	0.25	1.0E-6	71.2	1.779×10^{-5}	
			Low Gas Mass flow rate due to contamination increasing of the Air Filter as a result of buildup of debris caused by insufficient cleaning and solid particle contaminants resulting in Low Mechanical - rotational Torque (Diesel Engine) and Low Mechanical - rotational Torque (Power Generation)		III							
			Low Gas Mass flow rate due to contamination increasing of the Air Filter as a result of silting caused by contaminated input flow and input flow too slow resulting in Low Mechanical - rotational Torque (Diesel Engine) and Low Mechanical - rotational Torque (Power Generation)		III							

Session 3.2: Criticality Analysis

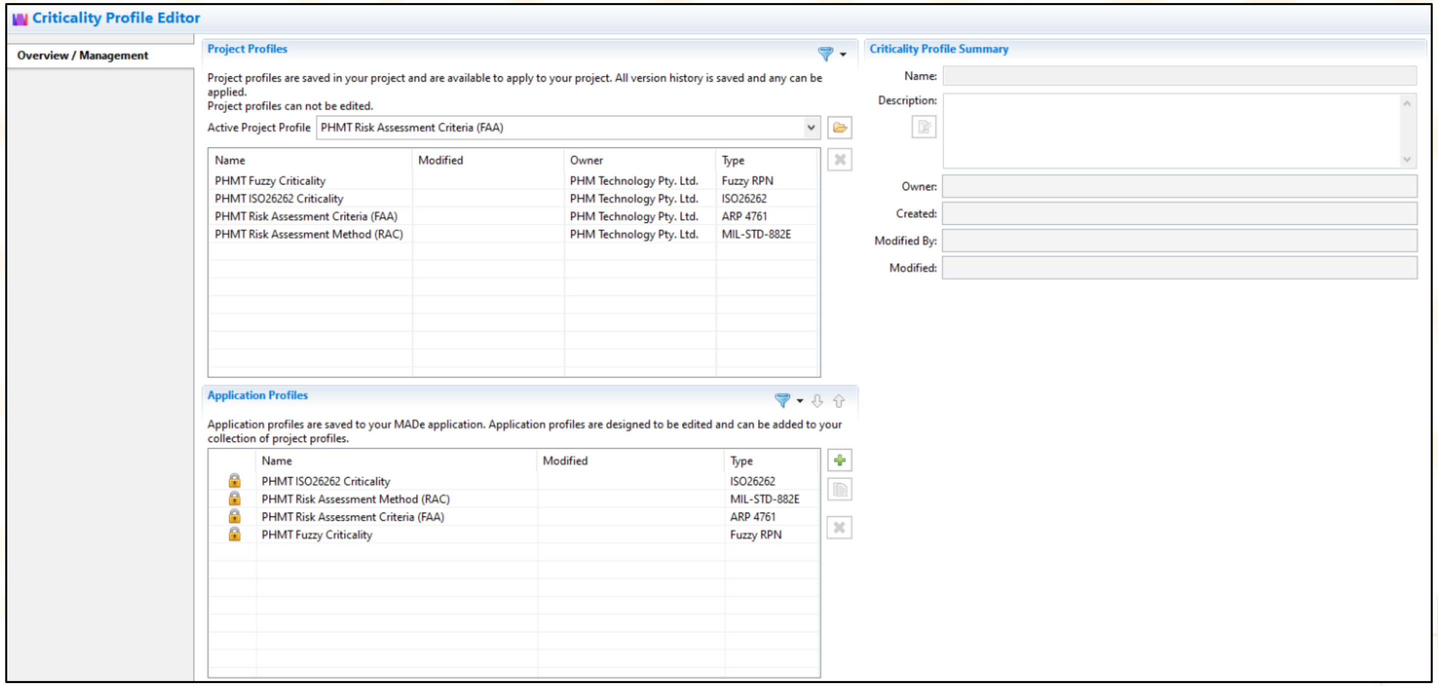
Discussion 3.2.6 Criticality Profile Editor

- Criticality Profile Editor is used to manage default and user-defined Criticality profiles.
- Criticality profiles can be application-based or project-based
  - Project-based = saved to a specific MADe project file
  - Application-based = saved to a user profile / local PC
- There are 4 default Criticality Profiles:
  - PHMT Fuzzy Criticality
  - PHMT ISO26262 Criticality
  - PHMT Risk Assessment Criteria (FAA)
  - PHMT Risk Assessment Method (RAC)
- User can create & edit an Application Profile then set it as a Project Criticality Profile

Session 3.2: Criticality Analysis

DISCUSSION 3.2.6 CRITICALITY PROFILE EDITOR (CONTINUED)

- Criticality Profile Editor is divided into:
  1. Overview/Management page – where Criticality Profiles are managed
  2. Criticality Profiles landing pages shows a summary of:
     - Criticality factors
     - Range charts
     - Fuzzy Membership Graphs
     - Severity terms
  3. Criticality Profile sub-pages
     - Setup for individual criticality factors
     - Setup for fuzzy rule base

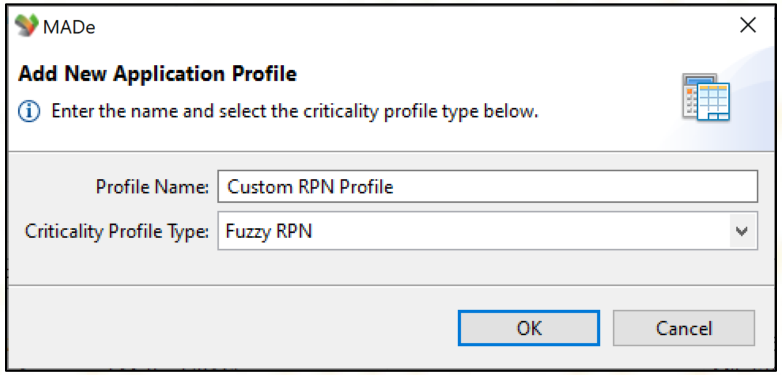


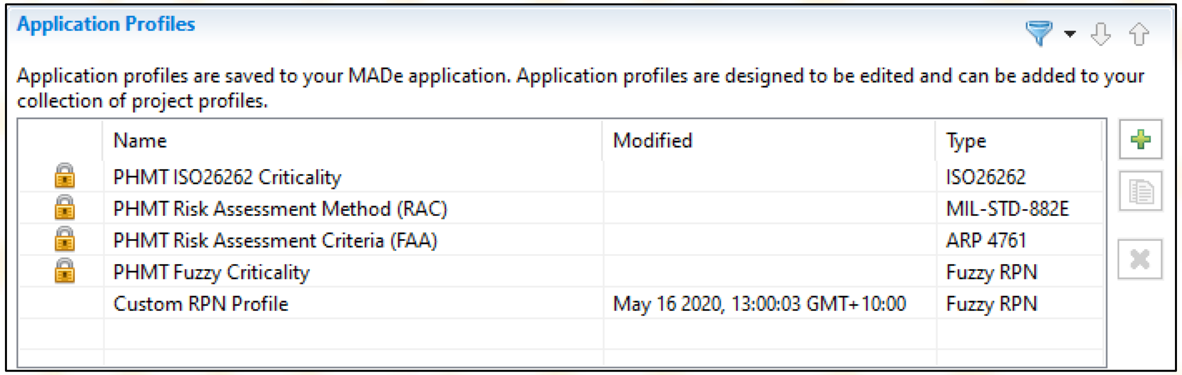
Session 3.2: Criticality Analysis

Exercise 3.2.6 Create a Criticality Profile – Fuzzy RPN

To create a Criticality Profile:

- Select **Preferences → Criticality Profile Editor**
- Under the **Application Profiles** section, create a new profile (Select)
  - From the dialog, enter Profile Name: **Custom RPN Profile**
  - Select Criticality Profile Type: **Fuzzy RPN**
  - Select OK





Session 3.2: Criticality Analysis

EXERCISE 3.2.6 CREATE A CRITICALITY PROFILE – FUZZY RPN (CONTINUED)

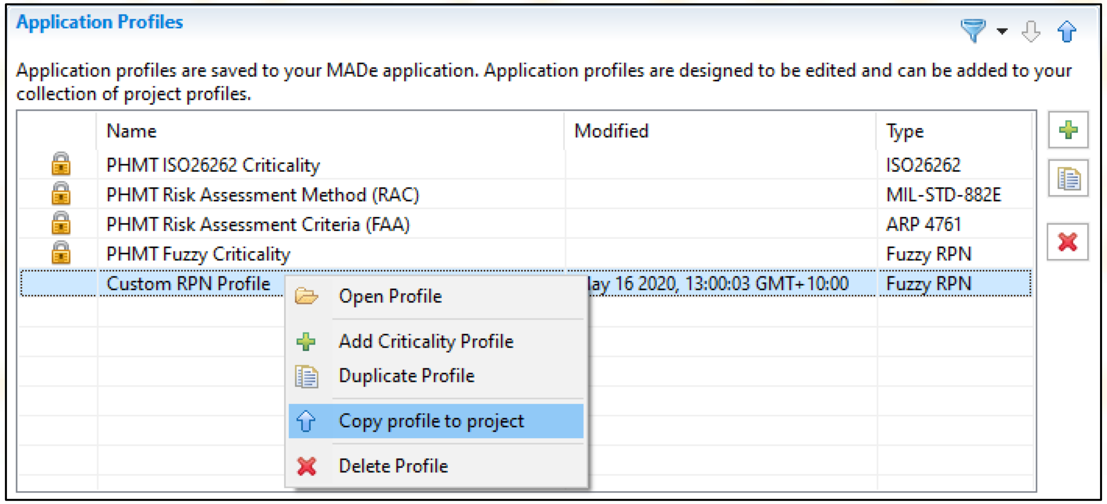
- Double-click Custom RPN Profile in table or right-click on the **Custom RPN Profile** and select **Open Profile**
- Select the unlock icon to allow editing of fuzzy memberships (→)

Session 3.2: Criticality Analysis

EXERCISE 3.2.6 CREATE A CRITICALITY PROFILE – FUZZY RPN (CONTINUED)

To apply the Custom RPN Profile to the project:

- On the Criticality Profile Editor **Overview/Management** page, right click the **Custom RPN Profile** under the Application Profiles section
- Select **Copy profile to project**
- Under **Project Profiles**, select **Custom RPN Profile** as the Active Project Profile



PHM Technology

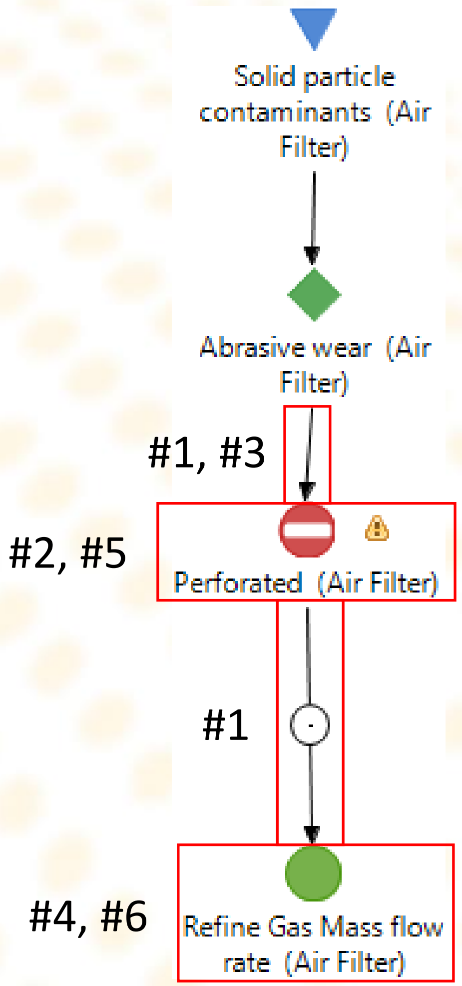
Session 3.2: Criticality Analysis

Discussion 3.2.6 Fuzzy RPN Criticality Factors

- Fuzzy RPN is calculated from 3 factors:
  - **Apparent Occurrence**, based on:
    1. Causal Probability
    2. Occurrence
  - **Apparent Severity**, based on:
    3. Progression Rate
    4. Severity
  - **Difficulty of Detection**, set from:
    5. Fault
    6. Item FFM

❖ Note 1: Difficulty of Detection is taken from Fault if present, otherwise FFM

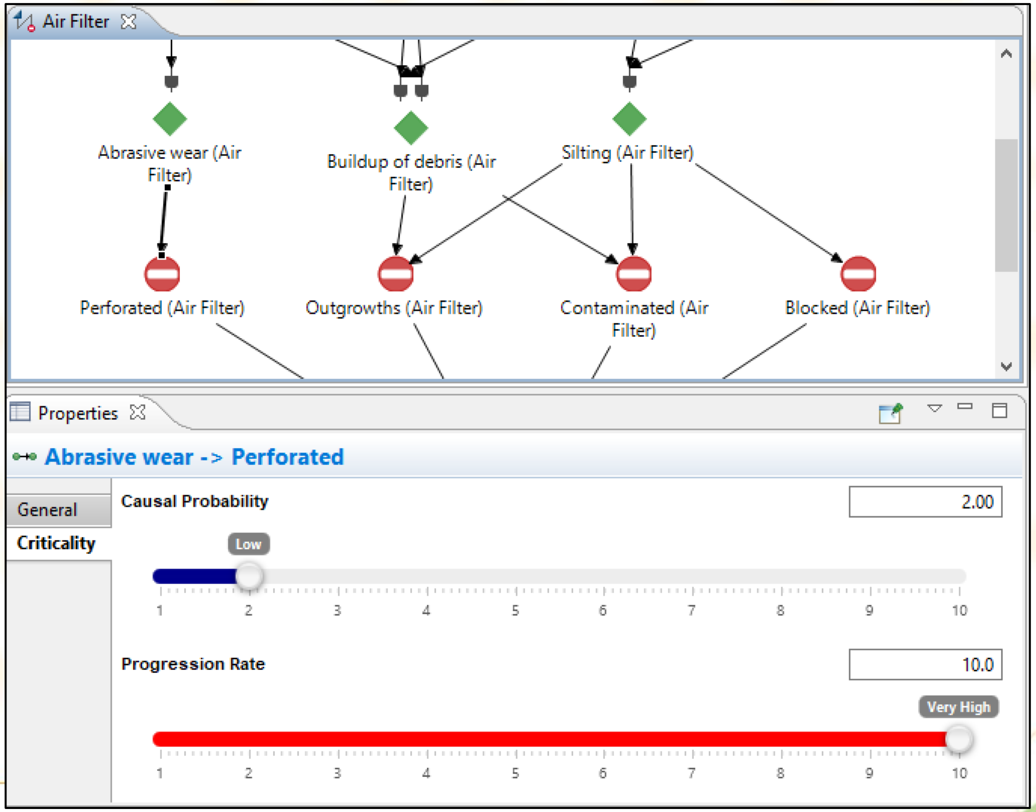
❖ Note 2: Causal Probability is taken from highest causal connection present in Failure Diagram



Session 3.2: Criticality Analysis

Discussion 3.2.6 Fuzzy RPN Criticality Factors (Continued)

- **Apparent Occurrence** is a compound factor based on **Causal Probability** & **Occurrence**
  - Causal Probability is set from 4 causal connections:
    1. Mechanism & Fault
    2. Mechanism & Failure condition
    3. Failure condition & Fault
    4. Fault & Functional Failure Mode
  - Occurrence is set from 3 failure concepts:
    1. Faults
    2. Failure conditions
    3. Item Functional failure modes (FFM)

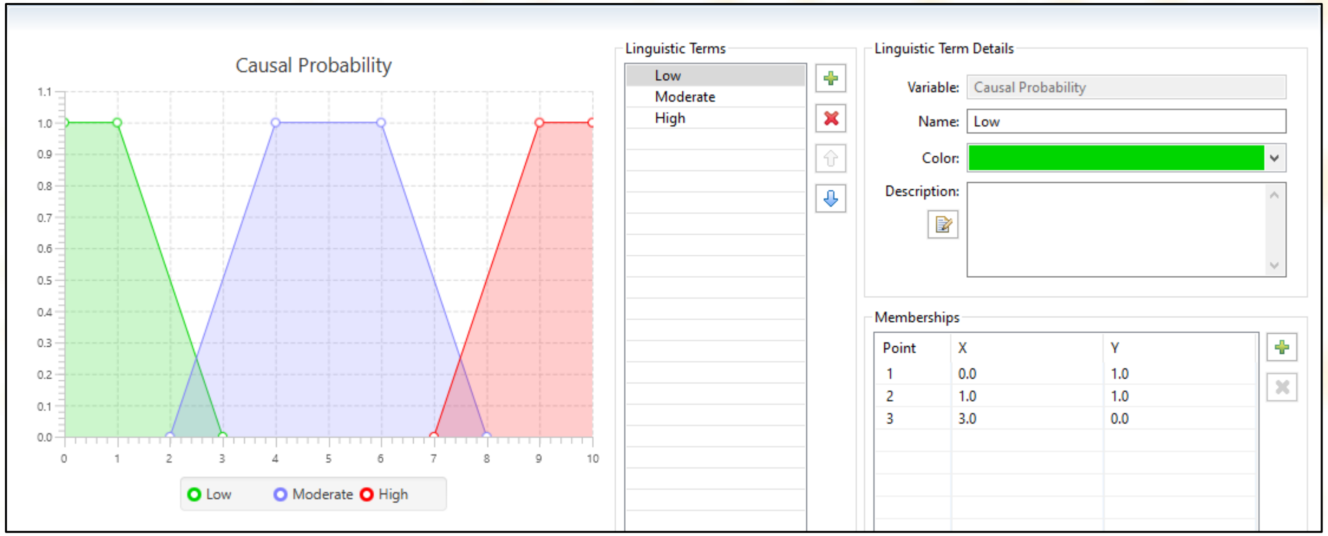


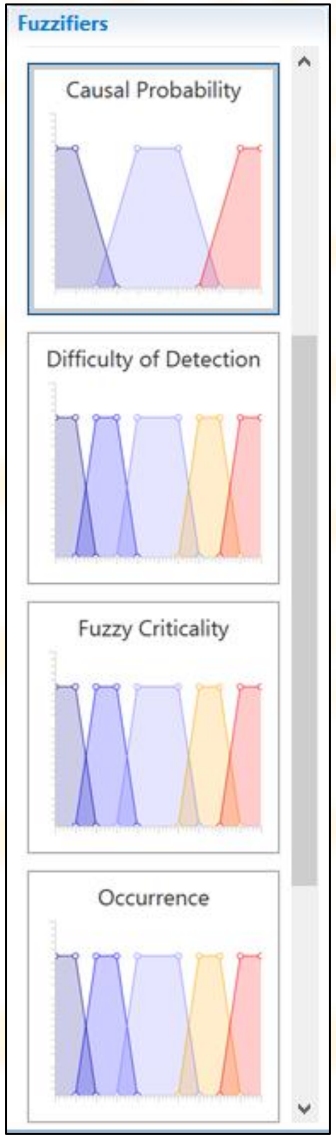
Session 3.2: Criticality Analysis

<u>Exercise 3.2.6 Set Causal Probability Memberships</u>

To set the causal probability memberships:

- Select the Causal Probability figure under the Fuzzifiers section
- There are 3 linguistic terms: Low, Moderate, High
- Change the **Low** linguistic term colour to green

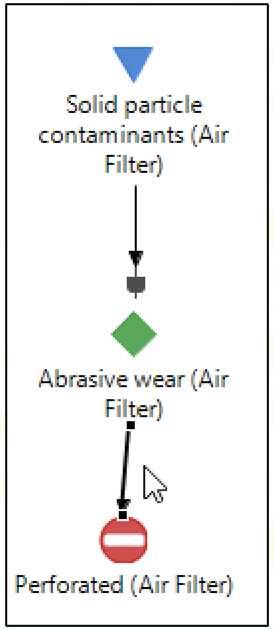


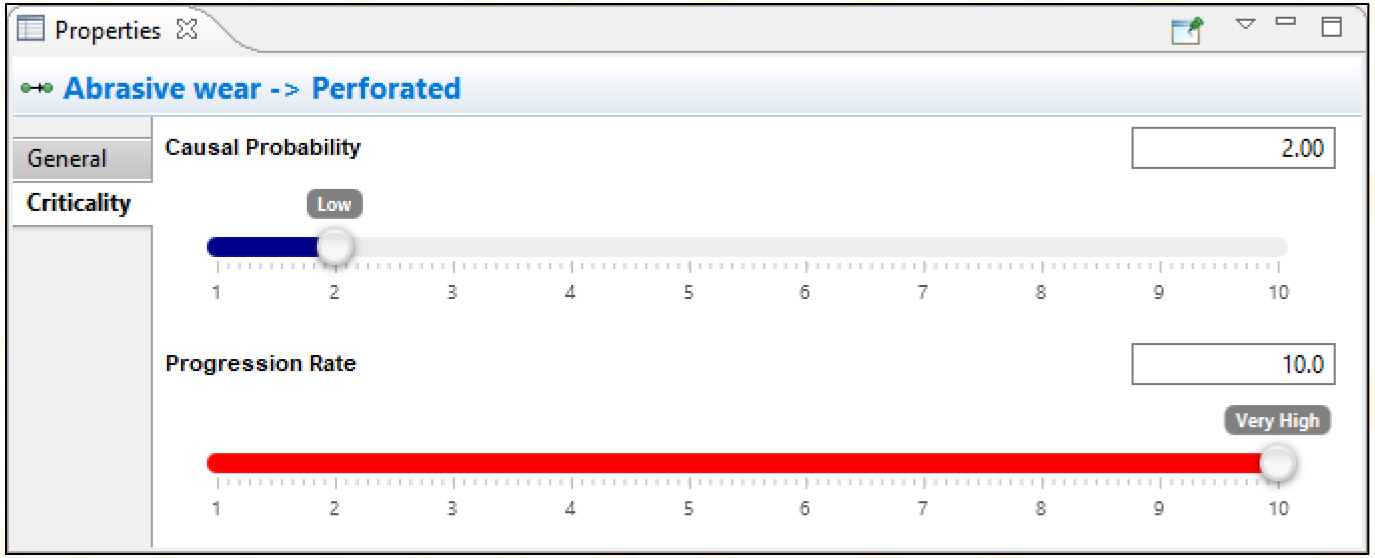


Session 3.2: Criticality Analysis

Exercise 3.2.6 Set Causal Probability Memberships (Continued)

- Open **'Air Filter'** Failure Diagram
- Select causal connection between the **Abrasive Wear** mechanism & **Perforated** fault
- Set Causal Probability slider to **2.00**



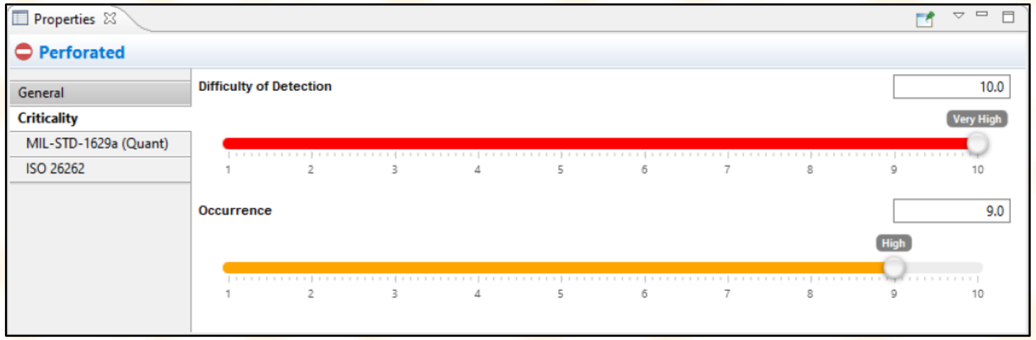


Session 3.2: Criticality Analysis

Exercise 3.2.6 Set Occurrence Memberships

To set Occurrence memberships:

- Select the **Occurrence** figure under the Fuzzifiers section
- Verify that there are 5 linguistic terms
- Open **'Air Filter'** Failure Diagram
- Select the **Perforated** fault
- Under **Criticality Tab** in the Properties Viewer, verify that the Causal Probability slider has:
  - The same colour schema
  - The same linguistic terms
- Set **Occurrence** slider to **9.0**

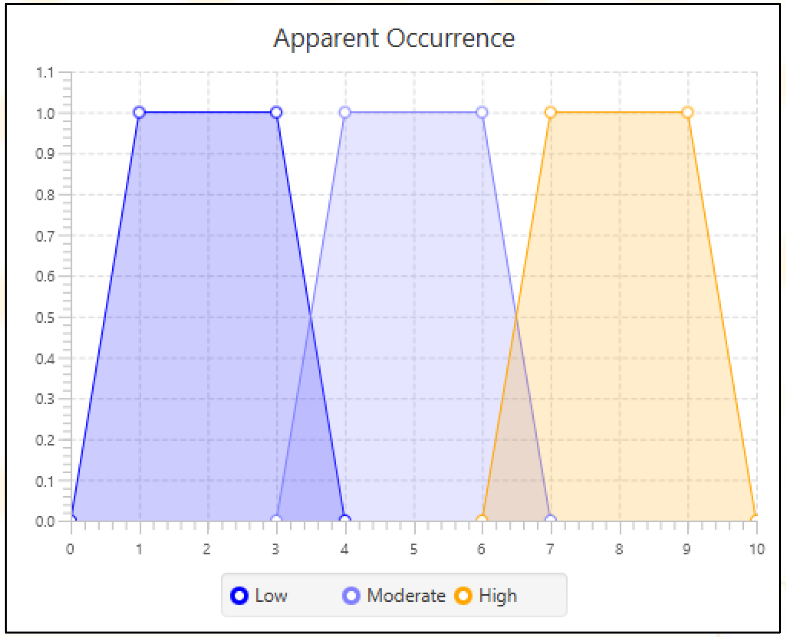


Session 3.2: Criticality Analysis

Exercise 3.2.6 Set Apparent Occurrence Memberships

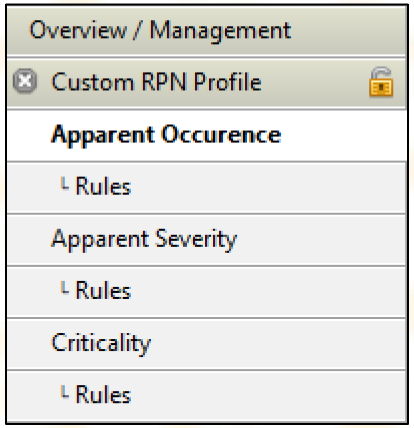
To set Apparent Occurrence membership:

- Select the **Apparent Occurrence** figure under the Fuzzifiers section
- Simplify the Linguistic terms by deleting **Very Low** & **Very High** using the button
- For the **Low** Linguistic Term:
  - Set Point 1 to X-Y Coordinates (0.0, 0.0) – select table cells for X or Y coordinates
  - Set Point 2 to X-Y Coordinates (1.0, 1.0)
- For the **High** Linguistic Term:
  - Set Point 3 to X-Y Coordinates (9.0, 1.0)
  - Set Point 4 to X-Y Coordinates (10.0, 0.0)



Session 3.2: Criticality Analysis

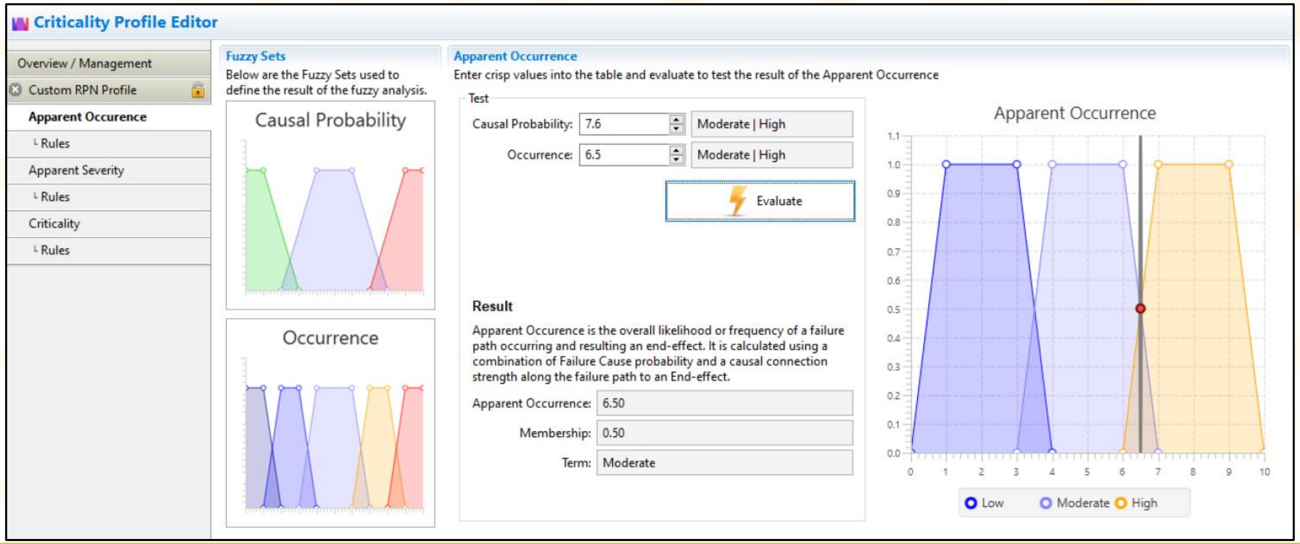
Exercise 3.2.6 Test Apparent Occurrence Memberships



To test the Apparent Occurrence memberships:

- Select the **Apparent Occurrence** tab
- To verify Apparent Occurrence is providing the required results:
  - Enter Causal Probability as **7.6**
  - Enter Occurrence as **6.5**
  - Select 

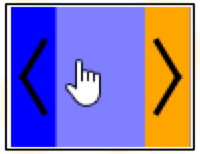
- Note the following:
  - Apparent Occurrence is **6.5**
  - Membership is **0.5**
  - Linguistic Term is **Moderate**



Session 3.2: Criticality Analysis

DISCUSSION 3.2.6 APPARENT OCCURRENCE RULES

- Rules page is used to associate Apparent Occurrence terms with:
  - Occurrence (Rows)
  - Causal Probability (Columns)
- Changes are made by hovering over each grid square:
  - The GUI shows an arrow indicating which shade (linguistic term) a grid square can be changed to
  - Example: Selecting the rectangle for Moderate Causal Probability & Moderate Occurrence will yield two arrows enabling the user to change it to either high or low

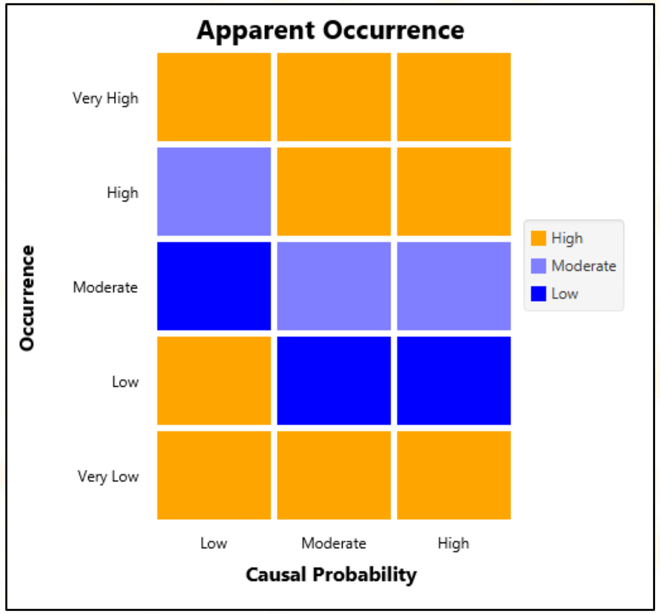


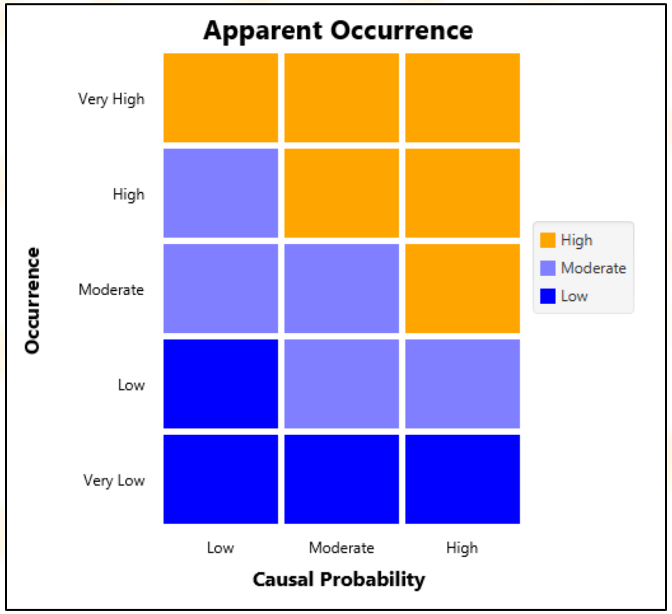
Session 3.2: Criticality Analysis

<u>Exercise 3.2.6 Set Apparent Occurrence Rules</u>

To set Apparent Occurrence rules:

- Select the **Rules** tab under **Apparent Occurrence**
- Change the grid squares from the default selection (left figure) to a new rule setup (right figure)



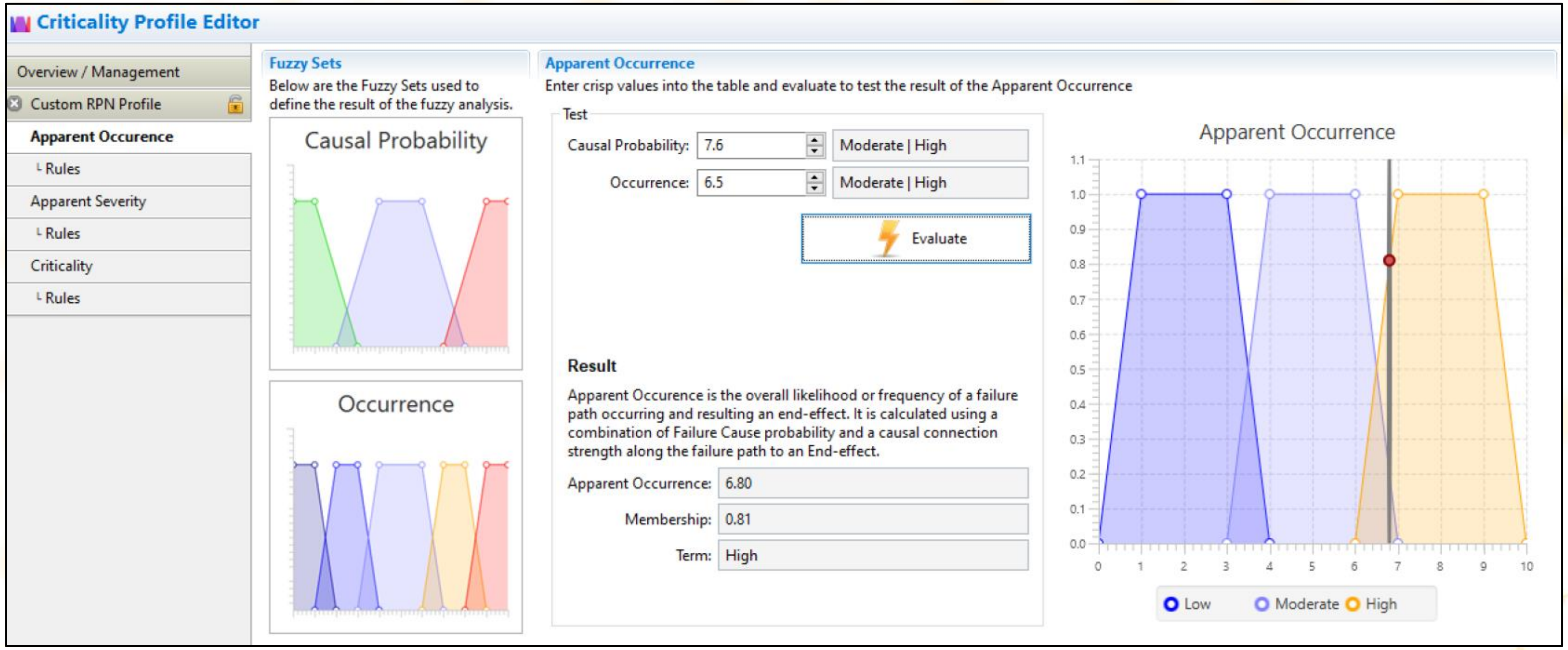


Session 3.2: Criticality Analysis

EXERCISE 3.2.6 TEST UPDATED APPARENT OCCURRENCE MEMBERSHIPS

To test the Apparent Occurrence Memberships:

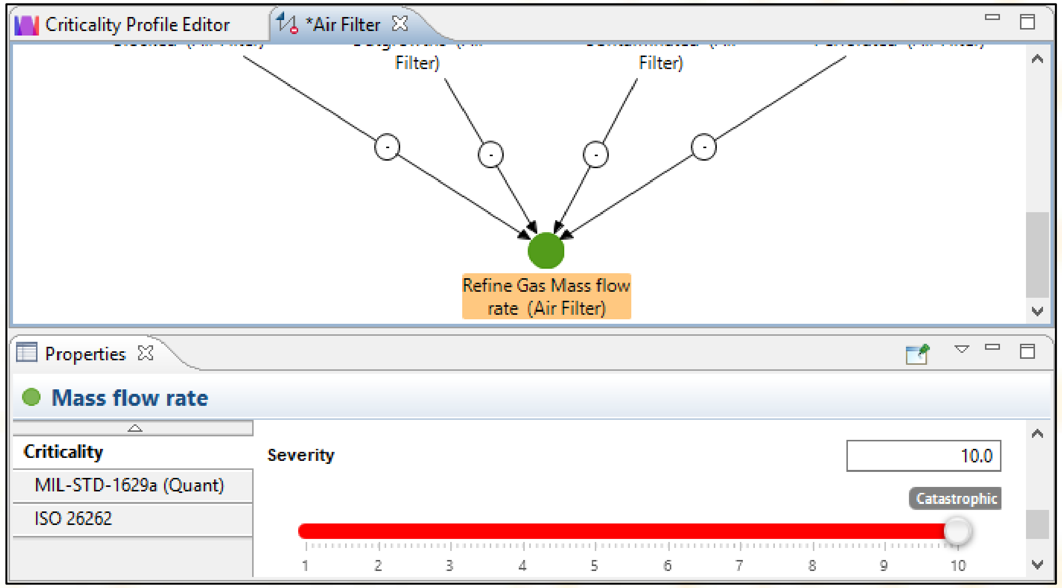
- Select the **Apparent Occurrence**
- To verify Apparent Occurrence rules have been updated:
  - Enter Causal Probability as **7.6**
  - Enter Occurrence as **6.5**
  - Select Evaluate
- Note the following:
  - Apparent Occurrence is **6.80**
  - Membership is **0.81**
  - Linguistic Term is **High**

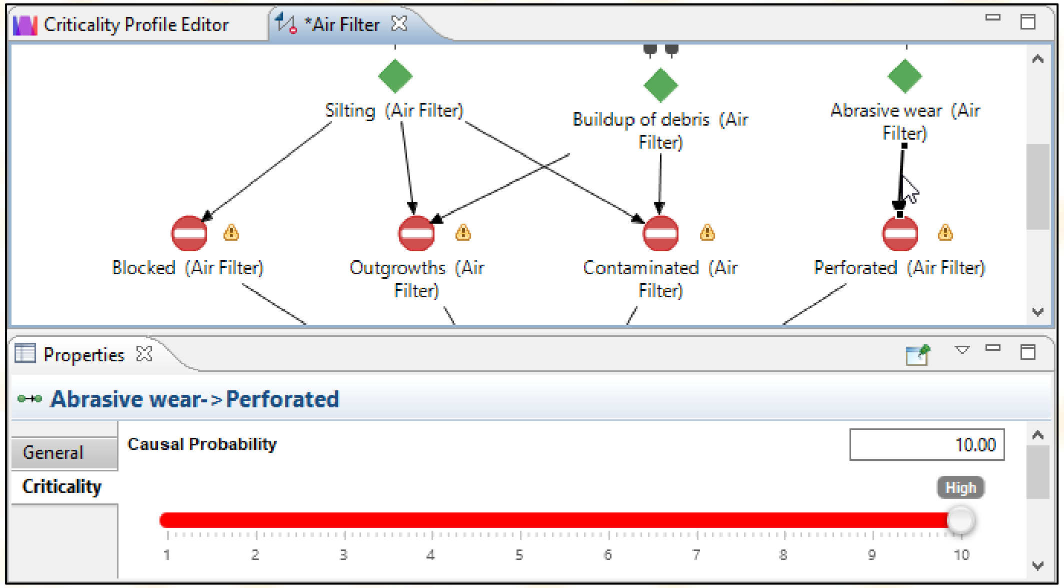


Session 3.2: Criticality Analysis

Discussion 3.2.6 Fuzzy RPN Criticality Factors

- **Apparent Severity** is a compound factor based on **Progression Rate** & **Severity**
  - Progression rate set from causal connection between a Mechanism & Fault
  - Severity is set from an item FFM



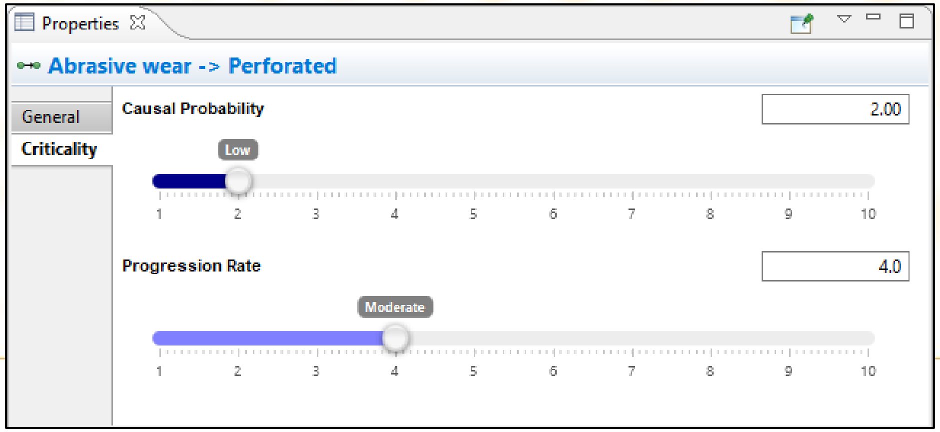


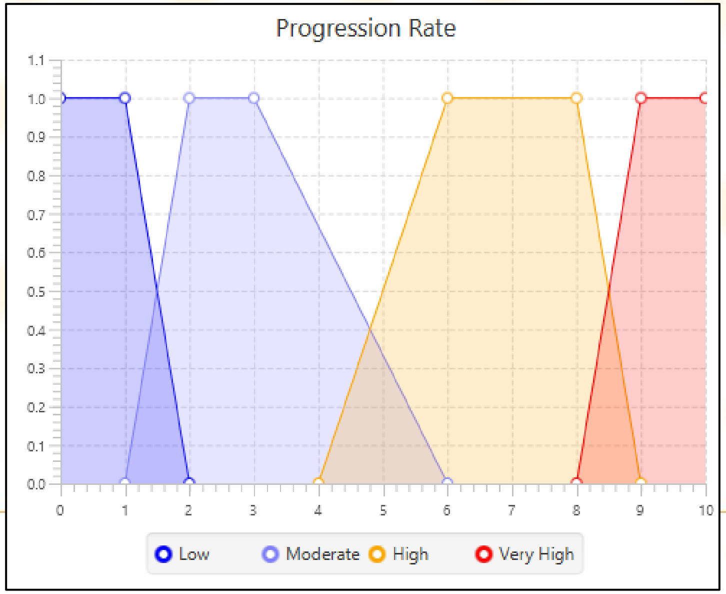
Session 3.2: Criticality Analysis

Exercise 3.2.6 Set Progression Rate Membership

To set the Progression Rate membership:

- Select the **Progression Rate** figure under the Fuzzifiers section
- Verify that there are 4 linguistic terms: Low, Moderate, High, Very High
- Open **'Air Filter'** Failure Diagram
- Select causal connection between the **Abrasive Wear** mechanism & **Perforated** fault
- Set **Progression rate** to **4.0 (Moderate)**



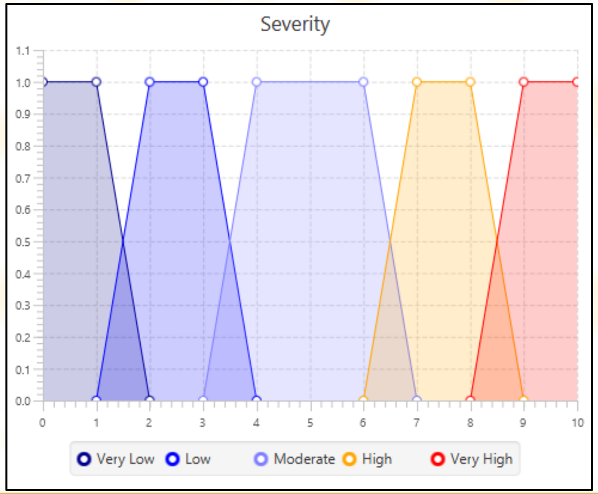


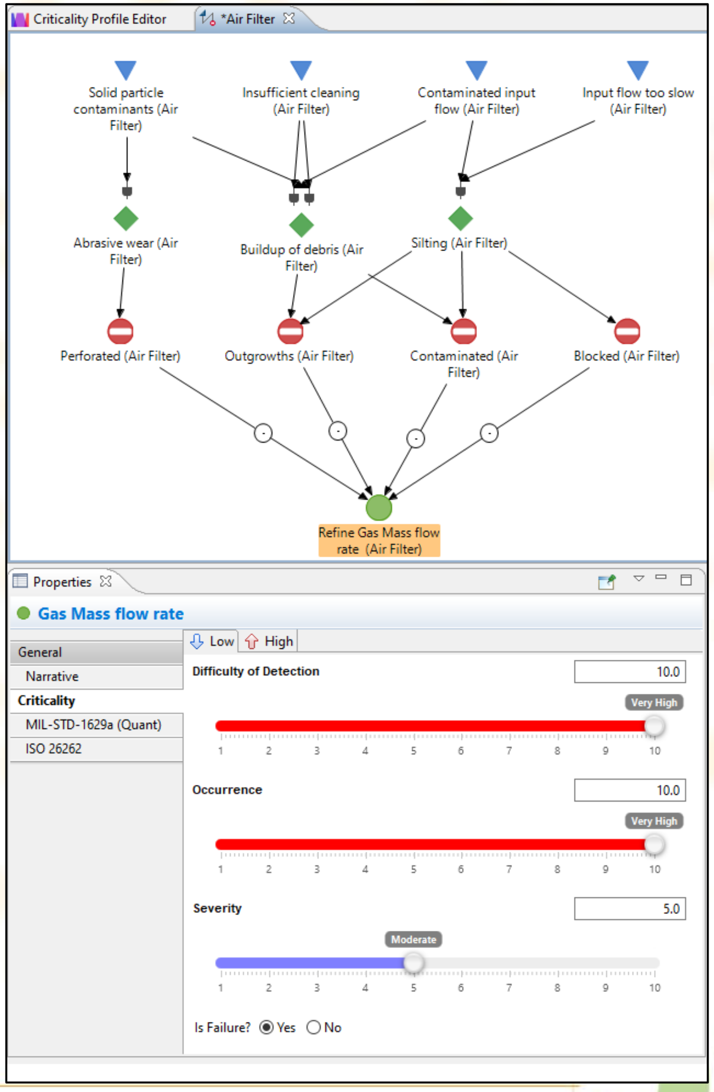
Session 3.2: Criticality Analysis

<u>Exercise 3.2.6 Set Severity Membership</u>

To set the Severity membership:

- Select the **Severity** figure under the Fuzzifiers section
- Verify that there are 5 linguistic terms
- Open **'Air Filter'** Failure Diagram
- Select **Refine Gas Mass Flow rate** FFM
- In the **Properties Viewer** select **Criticality**
- Select the **Low** tab
- Set Severity to **5.0**



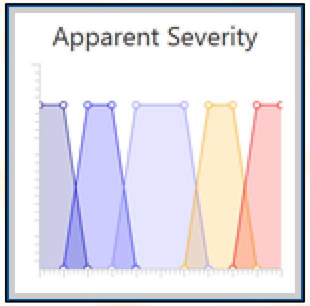


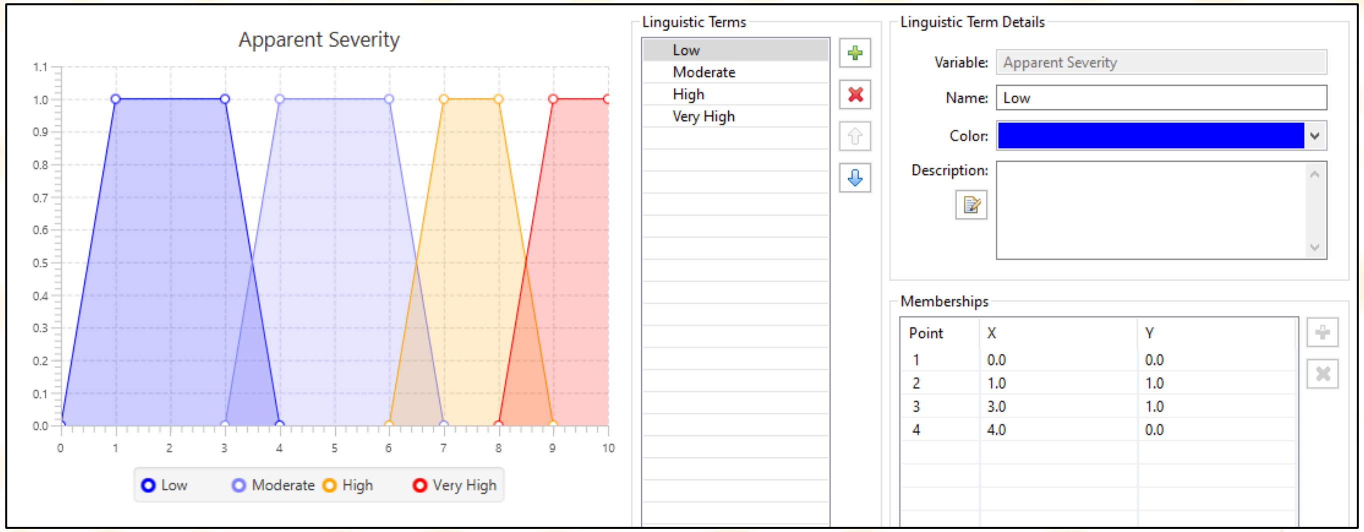
Session 3.2: Criticality Analysis

<u>EXERCISE 3.2.6 SET APPARENT SEVERITY MEMBERSHIP</u>

To set Apparent Severity membership:

- Select the **Apparent Severity** figure under the Fuzzifiers section
- Simplify the Linguistic terms by deleting **Very Low** using the button
- For the **Low** Linguistic Term:
  - Set **Point 1** to X-Y Coordinates **(0.0, 0.0)**
  - Set **Point 2** to X-Y Coordinates **(1.0, 1.0)**
  - Change **Low** colour to a green shade
- Verify new Apparent Severity Memberships

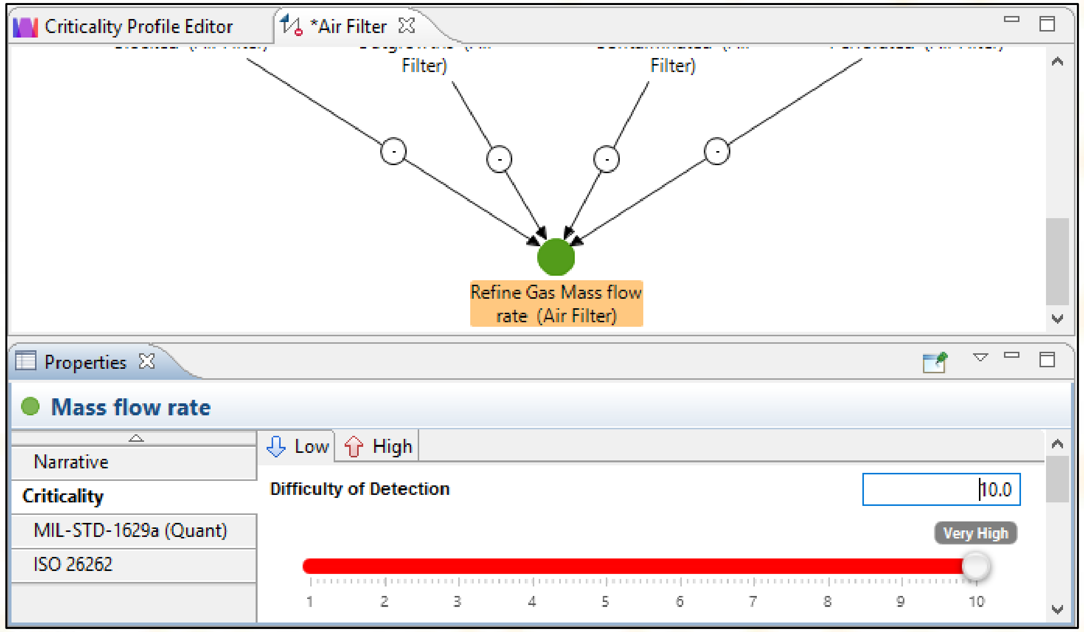


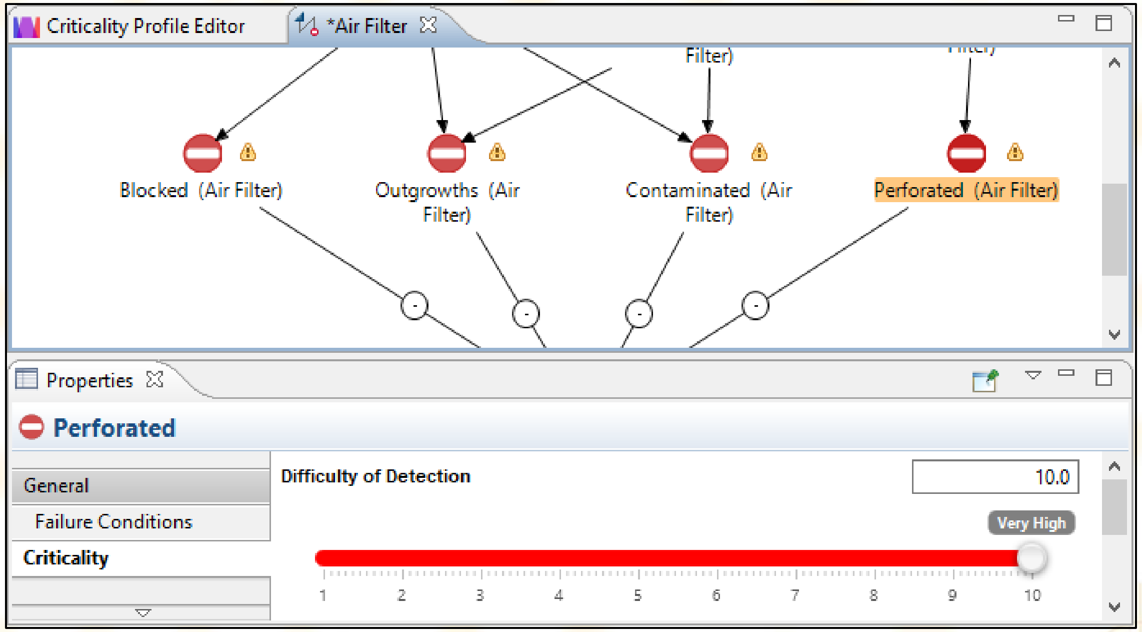


Session 3.2: Criticality Analysis

Discussion 3.2.6 Fuzzy Criticality Factors

- **Difficulty of Detection** is set from either:
  - Fault
  - Item FFM



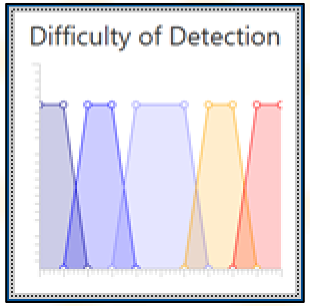


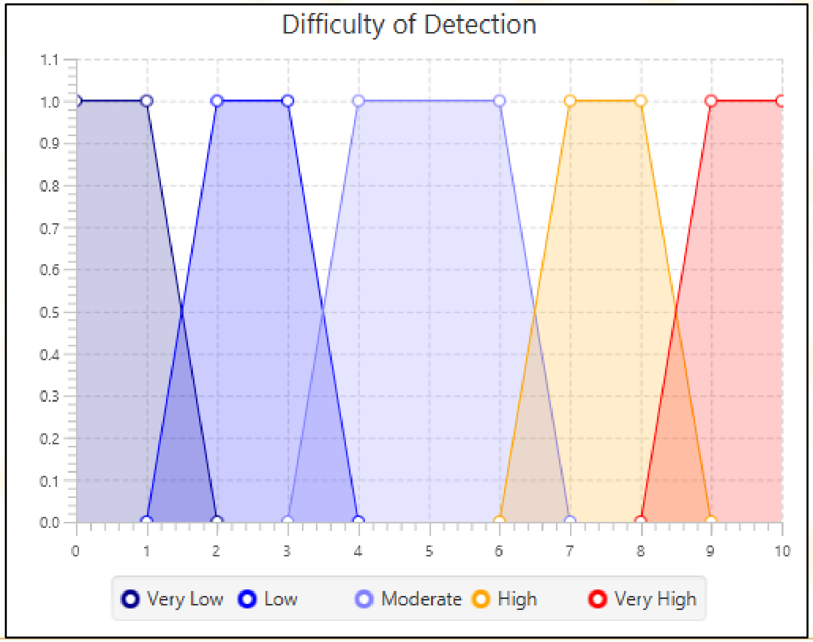
Session 3.2: Criticality Analysis

Exercise 3.2.6 Verify Difficulty of Detection Linguistic Terms

To verify the Difficulty of Detection linguistic terms:

- Select **Difficulty of Detection** figure under the Fuzzifiers section
- Verify that there are 5 linguistic terms: Very Low, Low, Moderate, High, Very High

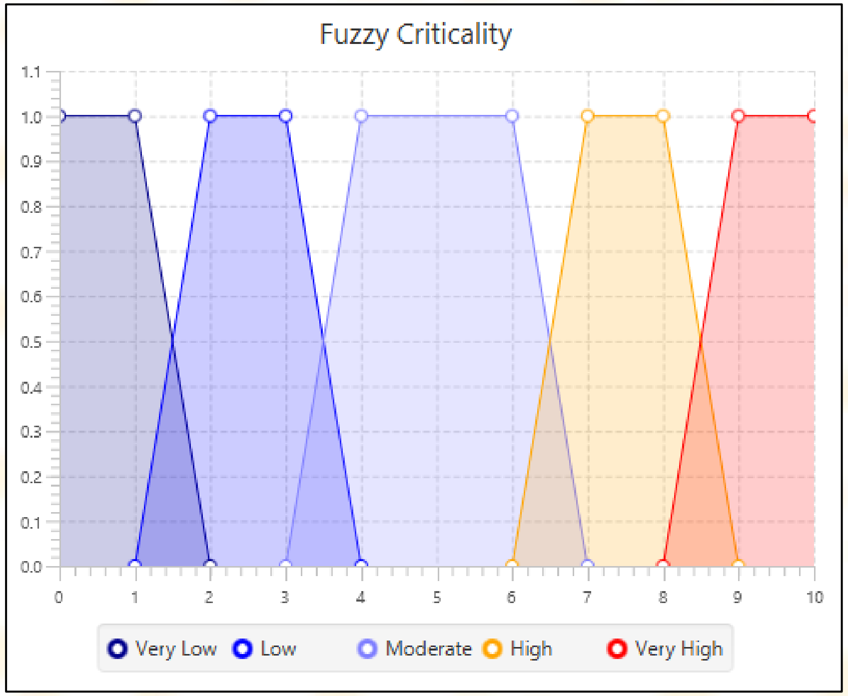




Session 3.2: Criticality Analysis

Discussion 3.2.6 Fuzzy Criticality Factors

- Fuzzy Criticality is based on 3 factors:
  - **Apparent Occurrence**
    - Causal Probability
    - Occurrence
  - **Apparent Severity**
    - Progression Rate
    - Severity
  - **Difficulty of Detection**
- Fuzzy Criticality has its own set of Memberships and Linguistic terms
- These memberships can be tested in the Criticality page
- Membership rules can be edited in the Rules page



Session 3.2: Criticality Analysis

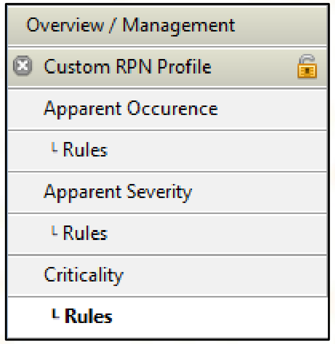
EXERCISE 3.2.6 VERIFY FUZZY CRITICALITY MEMBERSHIPS

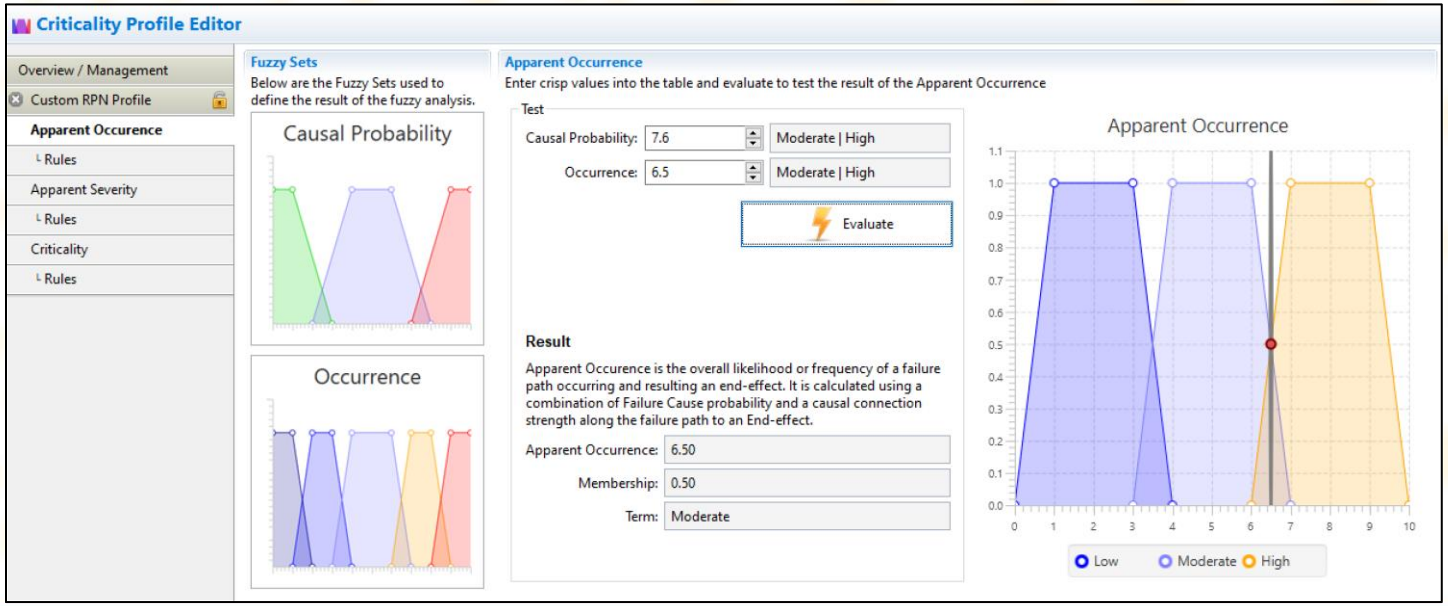
First, view Criticality Rules:

- Select the **Rules** tab under **Criticality**
- Verify the matrices for all 5 linguistic severity terms: Very Low, Low, Moderate, High, Very High

Next, test Criticality Rules:

- Select the **Criticality** tab





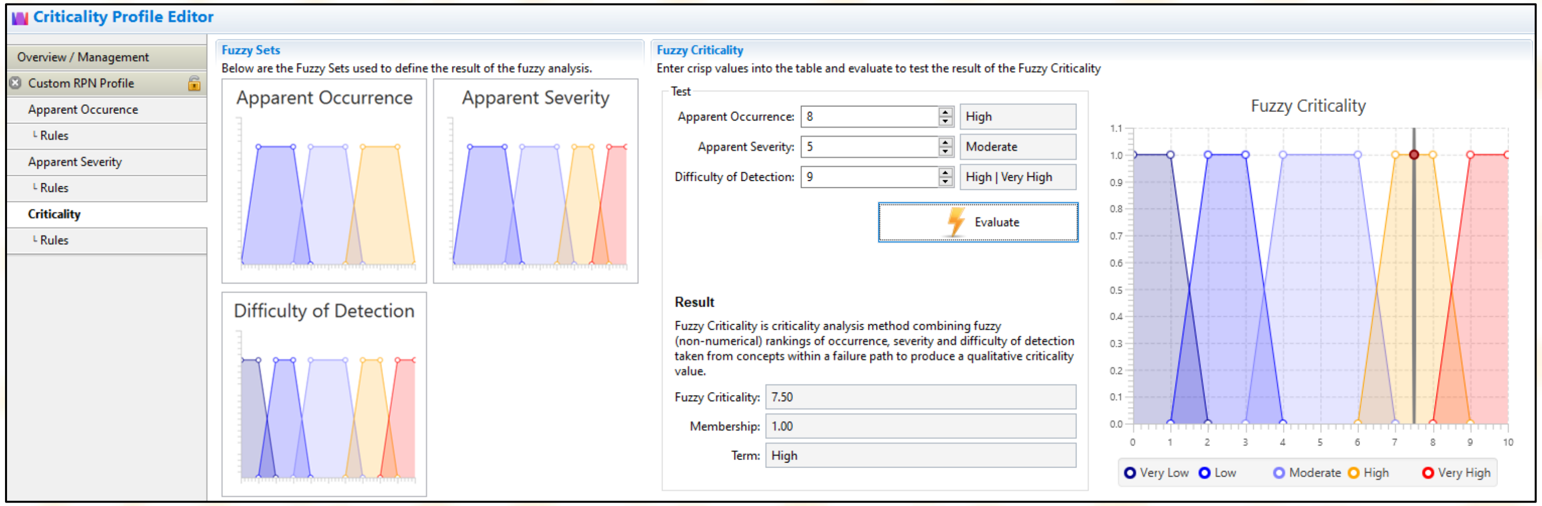
Session 3.2: Criticality Analysis

Exercise 3.2.6 Verify Fuzzy Criticality Memberships (Continued)

To verify Criticality rules:

- Enter Apparent Occurrence as **8.0**
- Enter Apparent Severity as **5.0**
- Enter Difficulty of Detection as **9.0**
- Select Evaluate

- Note Fuzzy Criticality is **7.50**
- Note Membership is **1.00**
- Note Linguistic Term is **High**

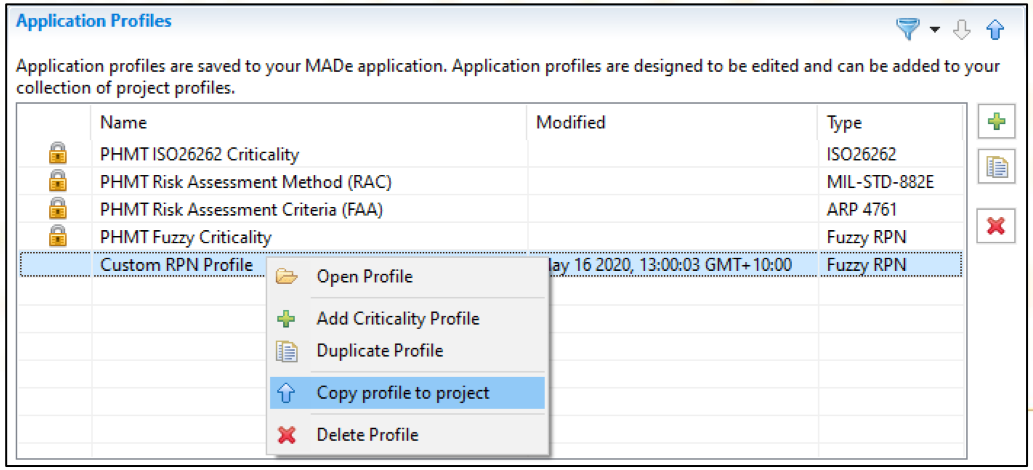


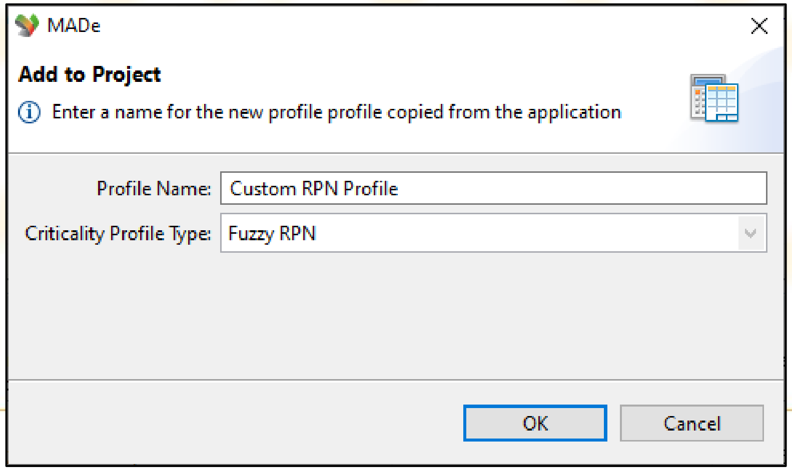
Session 3.2: Criticality Analysis

Exercise 3.2.7 Add Fuzzy Criticality Profile to Project

On the Criticality Profile Landing Page:

- Delete the **Custom RPN Profile** under the **Project Profiles** section
  - Note: We may need to change the active profile
- Right click the **Custom RPN Profile** under the **Application Profiles** section
- Select **Copy profile to project**
- Select OK to add **Custom RPN Profile** to Project



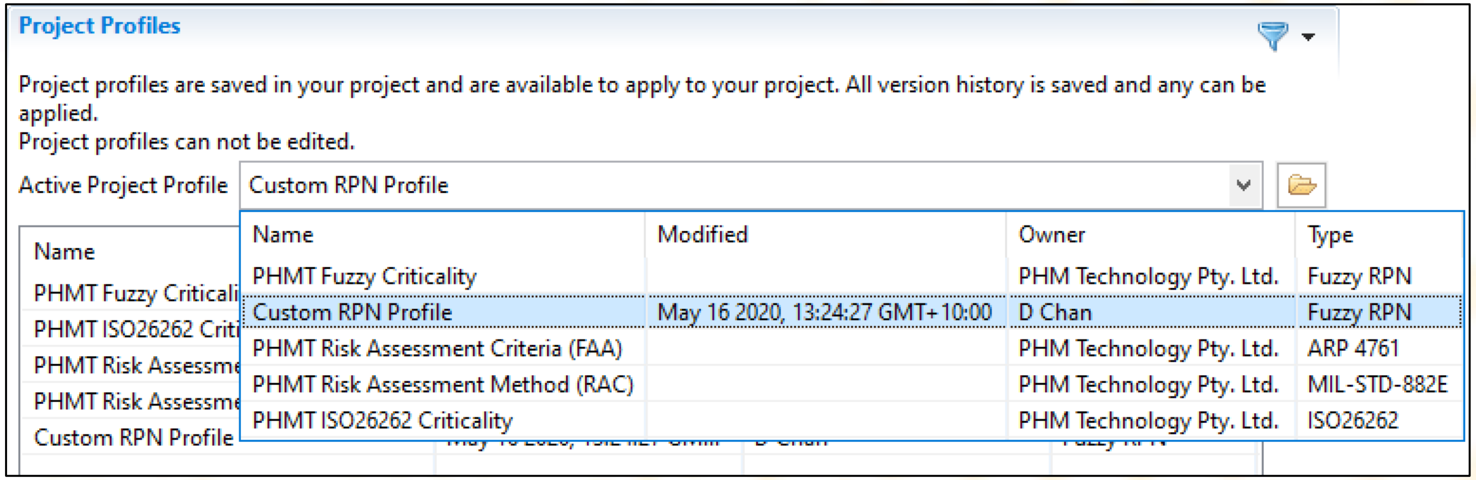


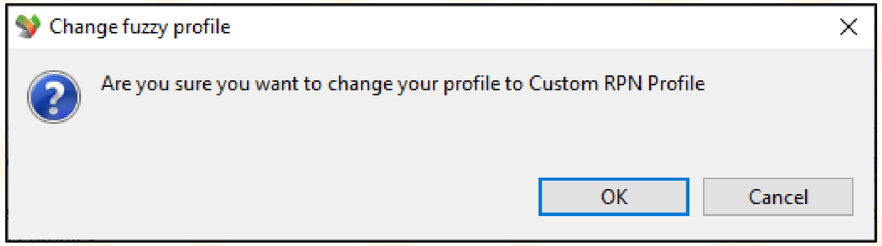
Session 3.2: Criticality Analysis

EXERCISE 3.2.7 ADD FUZZY CRITICALITY PROFILE TO PROJECT (CONTINUED)

Set the Custom RPN Profile as the active project profile

- Select the drop down arrow menu to Active Project Profile
- Select **Custom RPN Profile**
- Confirm change of profile by selecting OK





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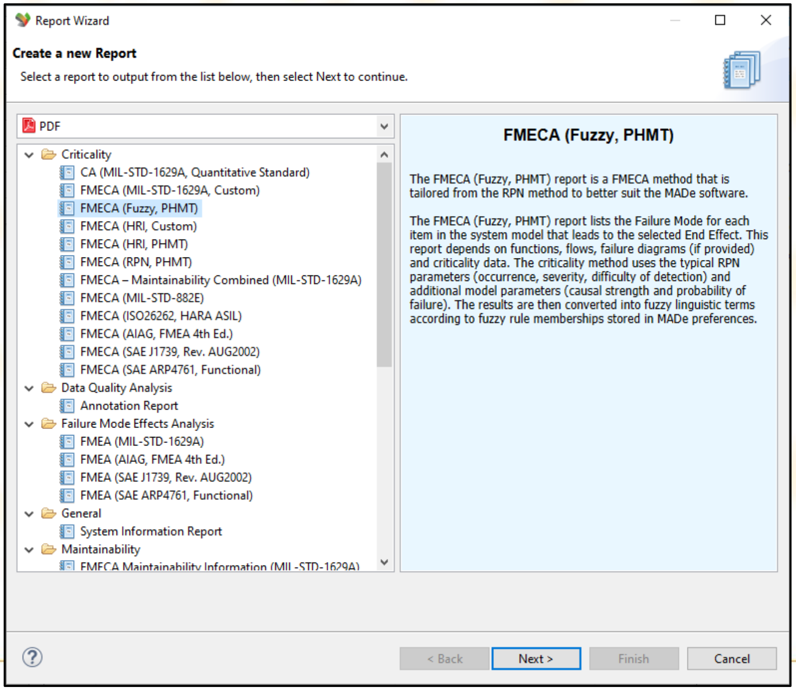
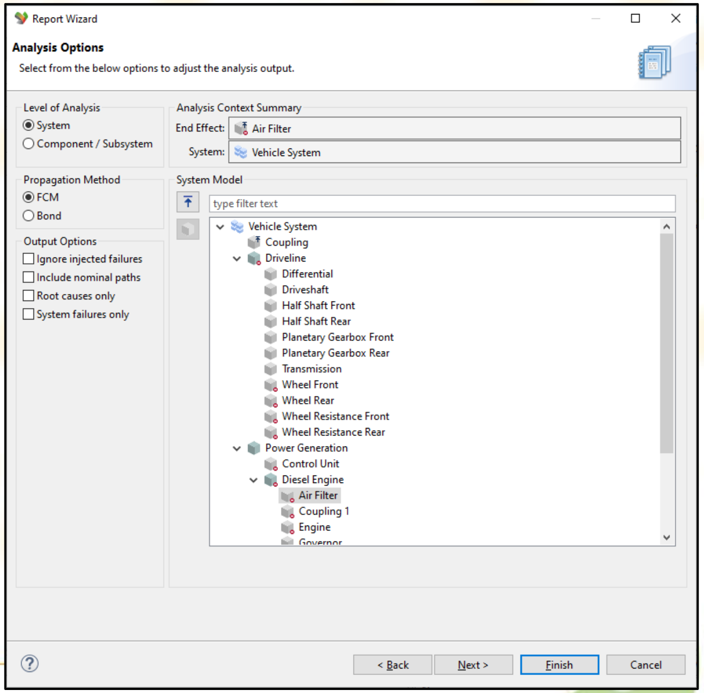
Session 3.2: Criticality Analysis

EXERCISE 3.2.6 GENERATE FUZZY RPN REPORT

We can verify the previous fuzzy criticality test by generating the FMECA report (Fuzzy, PHMT):

- Open the **Report Wizard**
- Select **FMECA (Fuzzy, PHMT)** then Next >
- Set Level of Analysis to **System**
- Set End Effect Item to **'Air Filter'**
- Select Finish





Session 3.2: Criticality Analysis

<u>EXERCISE 3.2.6 GENERATE FUZZY RPN REPORT (CONTINUED)</u>

- After FMECA report generates, navigate to the last page
- Locate last row with ‘**Perforated**’ fault
- Verify Criticality Factors:
  - Apparent Occurrence: High (8.0)
  - Apparent Severity: Moderate (5.0)
  - Difficulty of Detection: Very High (10.0)
  - Fuzzy RPN: High (7.5) → Matches Fuzzy Criticality Test Result

ITEM NO.	ITEM/PHYSICAL DESCRIPTION	FUNCTION/ FUNCTIONAL NARRATIVE	FAILURE MODE		CAUSES OF FAILURE		FAILURE EFFECTS		DETECTION METHODS	COMPENSATING PROVISIONS	CRITICALITY			
			FUNCTIONAL FAILURE	FAULT	MECHANISM	CAUSE	NEXT HIGHER LEVEL	END EFFECTS			APP. O	APP. S	D	FUZZY RPN
	Air Filter An air purifying device, removing particle contaminants from the air.	Refine Gas Mass flow rate Modelled as a resistive device, slightly restricting air flow and removing particles.	Refine Gas Mass flow rate Low	Contaminated	Silting	Contaminated input flow AND Input flow too slow	Convert Mechanical - rotational Torque Low (Diesel Engine)	Refine Gas Mass flow rate Low			High 8.0	High 7.5	Very High 10.0	Very High 9.2
					Buildup of debris	Insufficient cleaning AND Contaminated input flow	Convert Mechanical - rotational Torque Low (Diesel Engine)	Refine Gas Mass flow rate Low			High 8.0	High 7.5	Very High 10.0	Very High 9.2
						Insufficient cleaning AND Solid particle contaminants	Convert Mechanical - rotational Torque Low (Diesel Engine)	Refine Gas Mass flow rate Low			High 8.0	High 7.5	Very High 10.0	Very High 9.2
				Perforated	Abrasive wear	Solid particle contaminants	Convert Mechanical - rotational Torque Low (Diesel Engine)	Refine Gas Mass flow rate Low			High 8.0	Moderate 5.0	Very High 10.0	High 7.5
				Blocked	Silting	Contaminated input flow AND Input flow too slow	Convert Mechanical - rotational Torque Low (Diesel Engine)	Refine Gas Mass flow rate Low			High 8.0	High 7.5	Very High 10.0	Very High 9.2

Session 3.2: Criticality Analysis

SESSION 3.2 SUMMARY

- ✓ 3.2.1: Criticality Analysis Definitions
- ✓ 3.2.2: Criticality Analysis – Risk Priority Number (RPN)
- ✓ 3.2.3: Assigning RPN Criticality Parameters in MADe
- ✓ 3.2.4: Generating a FMECA (RPN) report
- ✓ 3.2.5: Alternative Criticality Analyses in MADe
- ✓ 3.2.6: Criticality Profile Editor

Session 3.3: Revised FMECA

Session 3.3 Outline

3.3.1: Adding Detection Methods

3.3.2: Adding Compensating Provisions

3.3.3: Adding Failure Conditions

3.3.4: Revised FMECA Reporting

Session 3.3: Revised FMECA

Discussion 3.3.1 Detection Method Definition

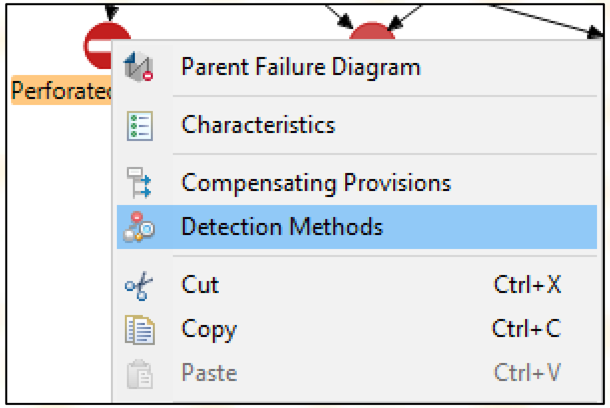
- **Detection Method**: The means by which the existence of a failure mode becomes known to relevant personnel
- In MADe, Detection Methods are assigned to either:
  - Failure Modes
  - Faults (if Failure Diagram is present)

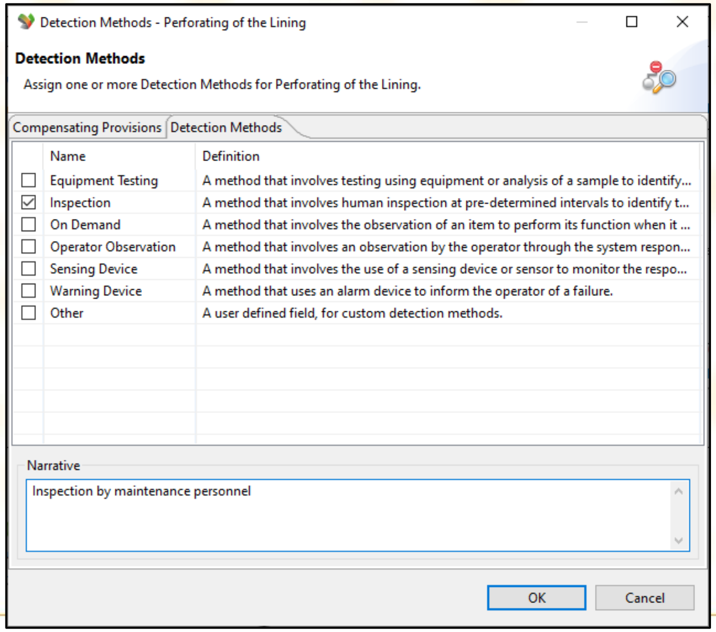
Session 3.3: Revised FMECA

EXERCISE 3.3.1 ASSIGNING DETECTION METHODS

To assign detection methods:

- Open the Failure Diagram editor of the **'Fuel Tank'** item
- Expand the boxes to **Inlet_Lining → Lining**
- Right-click the **Perforated** fault and select **Detection Methods**
- Select the check box for **Inspection**
- Enter the narrative: **Inspection by maintenance personnel**
- Select OK to close the dialog





Session 3.3: Revised FMECA

Discussion 3.3.2 Compensating Provision Definition

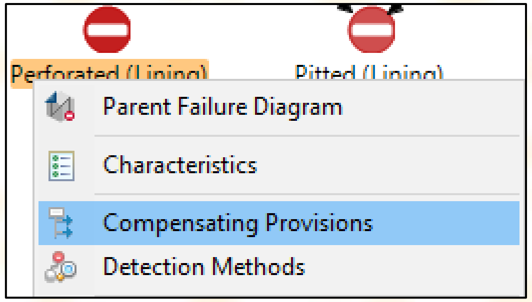
- **Compensating Provision**: Actions that can be taken to negate or mitigate the effect of a failure on a system
- In MADe, Compensating provisions are assigned to either:
  - Failure Modes
  - Faults (if a Failure Diagram Tree is present)

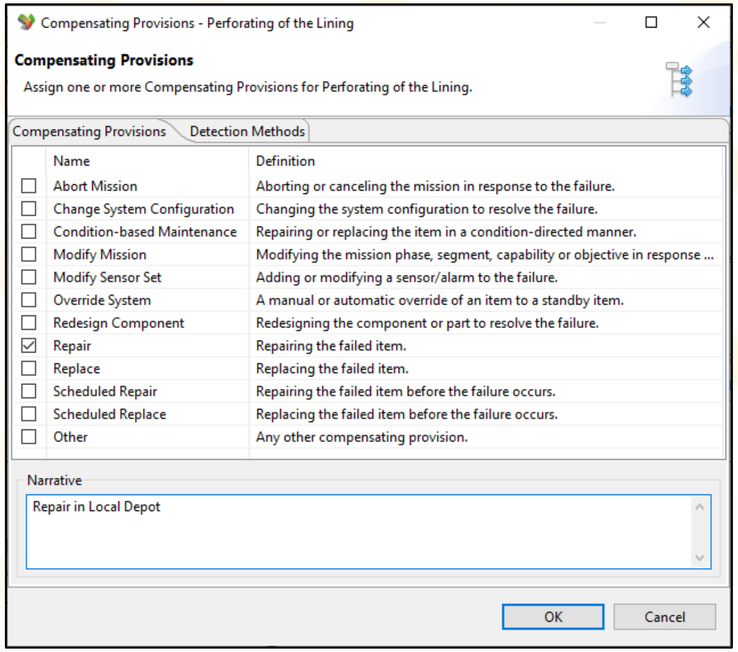
Session 3.3: Revised FMECA

EXERCISE 3.3.2 ASSIGNING COMPENSATING PROVISION

To assign a compensating provision:

- Open the Failure Diagram editor of the **‘Fuel Tank’** item
- Expand the boxes to **Inlet_Lining** and **‘Lining’**
- Right-click the **Perforated** fault and select **Compensating Provisions**
- Select the check box for **Repair**
- Enter the narrative : **Repair in Local Depot**
- Select OK to close the dialog



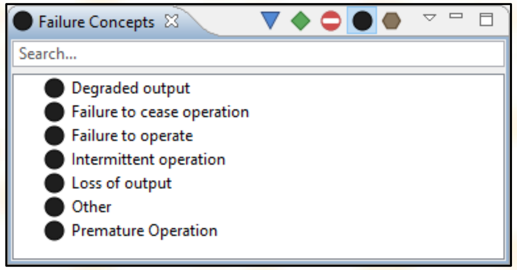


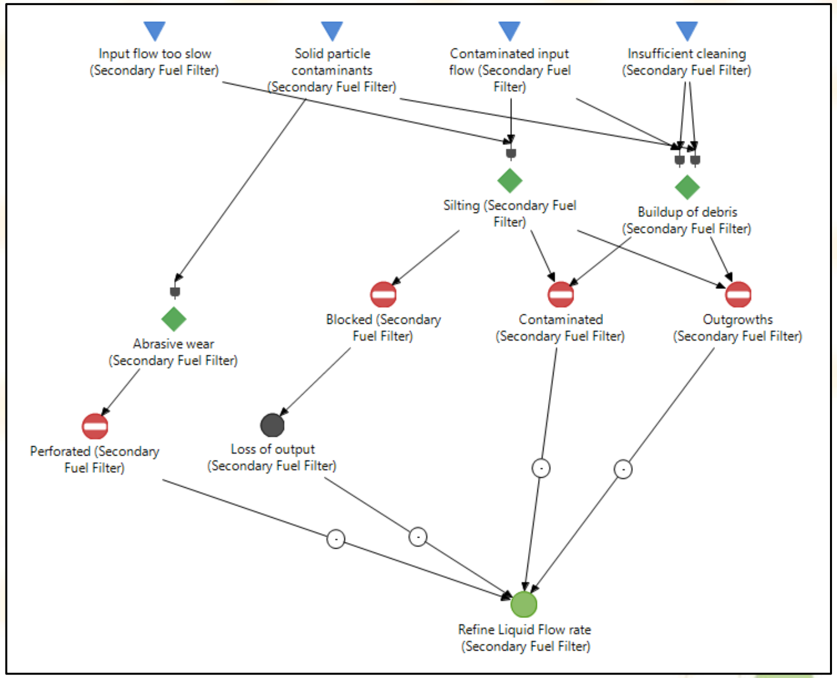
Session 3.3: Revised FMECA

EXERCISE 3.3.3 ASSIGNING FAILURE CONDITIONS

To assign failure conditions:

- Open the Failure Diagram editor of **'Secondary Fuel Filter'**
- Disconnect the path from **Blocked** to **Refine Liquid Flow rate**
- Select the failure condition icon in the Failure Concepts window
- Select and drag the **Loss of output** Failure condition onto the Failure Diagram
- Connect the **Blocked** Fault to **Loss of output**
- Complete the path by connecting the Loss of output failure condition to the Functional Failure Mode

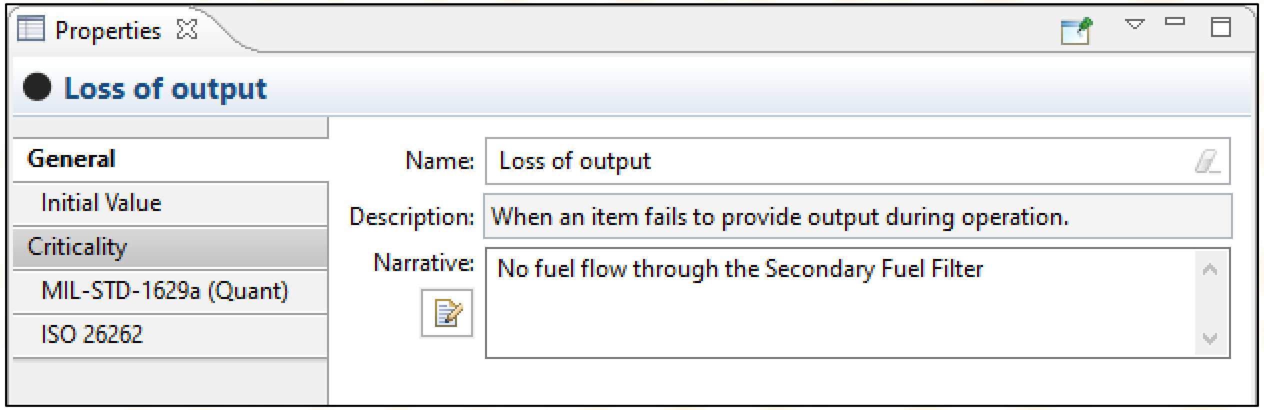




Session 3.3: Revised FMECA

Exercise 3.3.3 Assigning Failure Conditions (Continued)

- Select the Loss of output and in the Properties viewer and enter the following narrative: **No fuel flow through the Secondary Fuel Filter**



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Session 3.3: Revised FMECA

Discussion 3.3.4 Revised FMECA Report

- Failure Conditions, Detection Methods, and Compensating Provision information entered into the MADe model is captured in the FMECA report in their respective columns

MADe Training — FMECA (RPN, PHMT) — 19/11/2019 11:18:58 AM

SYSTEM	Vehicle System > Power Generation > Diesel Engine > Secondary Fuel Filter	**DATE**	19/11/2019 11:18:58 AM
INDENTURE LEVEL	4	**SHEET**	32 **OF** 34
REFERENCE DRAWING		**COMPILED BY**	Daniel Chan
MISSION	Regular Trip	**APPROVED BY**	

ITEM NO.	ITEM/PHYSICAL DESCRIPTION	FUNCTION/ FUNCTIONAL NARRATIVE	FAILURE MODE		CAUSES OF FAILURE		FAILURE EFFECTS		DETECTION METHODS	COMPENSATING PROVISIONS	CRITICALITY			
			FUNCTIONAL FAILURE	FAULT	MECHANISM	CAUSE	NEXT HIGHER LEVEL	END EFFECTS			O	S	D	RPN
	Secondary Fuel Filter A liquid purifying device, removing particle contaminants from the liquid flowing through it. The secondary filter filters out finer particles than the primary filter.	Refine Liquid Flow rate Modelled as a resistive device, slightly restricting fluid flow and removing particle contaminates.	Refine Liquid Flow rate Low Loss of output No fuel flow through the Secondary Fuel Filter	Blocked	Silting	Input flow too slow AND Contaminated input flow	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)	Sensing Device	Repair	10.0	10.0	10.0	1000
							Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)	Sensing Device	Repair	10.0	10.0	10.0	1000
			Refine Liquid Flow rate Low	Contaminated	Buildup of debris	Insufficient cleaning AND Contaminated input flow	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			10.0	10.0	10.0	1000

Session 3.3: Revised FMECA

Exercise 3.3.4 Revised FMECA Report

- Generate a FMECA (RPN, PHMT) Report
  - Set the Level of analysis to **System**
  - Propagation Focus: **FCM**
  - End Effect: **Vehicle System**

MADe Training FMECA (RPN, PHMT) 19/11/2019 11:18:58 AM

SYSTEM Vehicle System > Power Generation > Diesel Engine > Secondary Fuel Filter
INDENTURE LEVEL 4
REFERENCE DRAWING
MISSION Regular Trip

DATE 19/11/2019 11:18:58 AM
SHEET 32 **OF** 34
COMPILED BY Daniel Chan
APPROVED BY

ITEM NO.	ITEM/PHYSICAL DESCRIPTION	FUNCTION/ FUNCTIONAL NARRATIVE	FAILURE MODE		CAUSES OF FAILURE		FAILURE EFFECTS		DETECTION METHODS	COMPENSATING PROVISIONS	CRITICALITY			
			FUNCTIONAL FAILURE	FAULT	MECHANISM	CAUSE	NEXT HIGHER LEVEL	END EFFECTS			O	S	D	RPN
	Secondary Fuel Filter A liquid purifying device, removing particle contaminants from the liquid flowing through it. The secondary filter filters out finer particles than the primary filter.	Refine Liquid Flow rate Modelled as a resistive device, slightly restricting fluid flow and removing particle contaminates.	Refine Liquid Flow rate Low Loss of output No fuel flow through the Secondary Fuel Filter	Blocked	Silting	Input flow too slow AND Contaminated input flow	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)	Sensing Device	Repair	10.0	10.0	10.0	1000
							Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)	Sensing Device	Repair	10.0	10.0	10.0	1000
			Refine Liquid Flow rate Low	Contaminated	Buildup of debris	Insufficient cleaning AND Contaminated input flow	Convert Mechanical - rotational Torque Low (Diesel Engine)	Convert Mechanical - rotational Angular velocity Low (Vehicle System)			10.0	10.0	10.0	1000

❖ Note: Detection methods and narratives entered should be displayed on the FMECA report

Session 3.3: Revised FMECA

Session 3.3 Summary

- ✓ 3.3.1: Adding Detection Methods
- ✓ 3.3.2: Adding Compensating Provisions
- ✓ 3.3.3: Adding Failure Conditions
- ✓ 3.3.4: Revised FMECA Reporting

Session 3.4: Critical Item Analysis

Session 3.4 Outline

3.4.1: Critical Item Analysis

3.4.2: Find & Replace: Criticality

3.4.3: Critical Item List

Session 3.4: Critical Item Analysis

Discussion 3.4.1 Critical Item Analysis

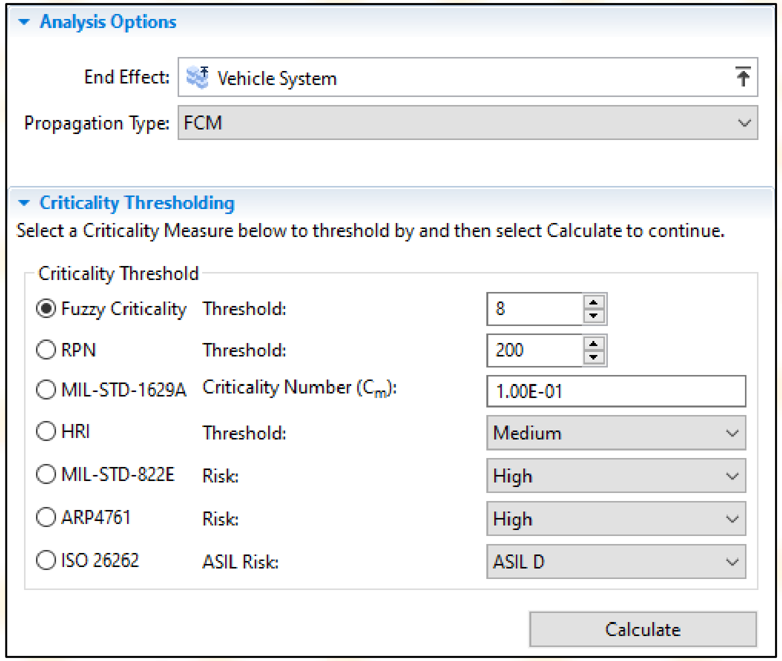
- Identifies critical items based on a criticality threshold
  - Fuzzy Criticality
  - RPN
  - MIL-STD-1629A
  - HRI
  - MIL-STD-882E
  - ARP4761
  - ISO 262626
- Bar chart will display the number of items in that category
- Apply ‘critical’ designation to items in system model

Session 3.4: Critical Item Analysis

EXERCISE 3.4.1 PERFORMING CRITICAL ITEM ANALYSIS

To perform a critical item analysis on the model:

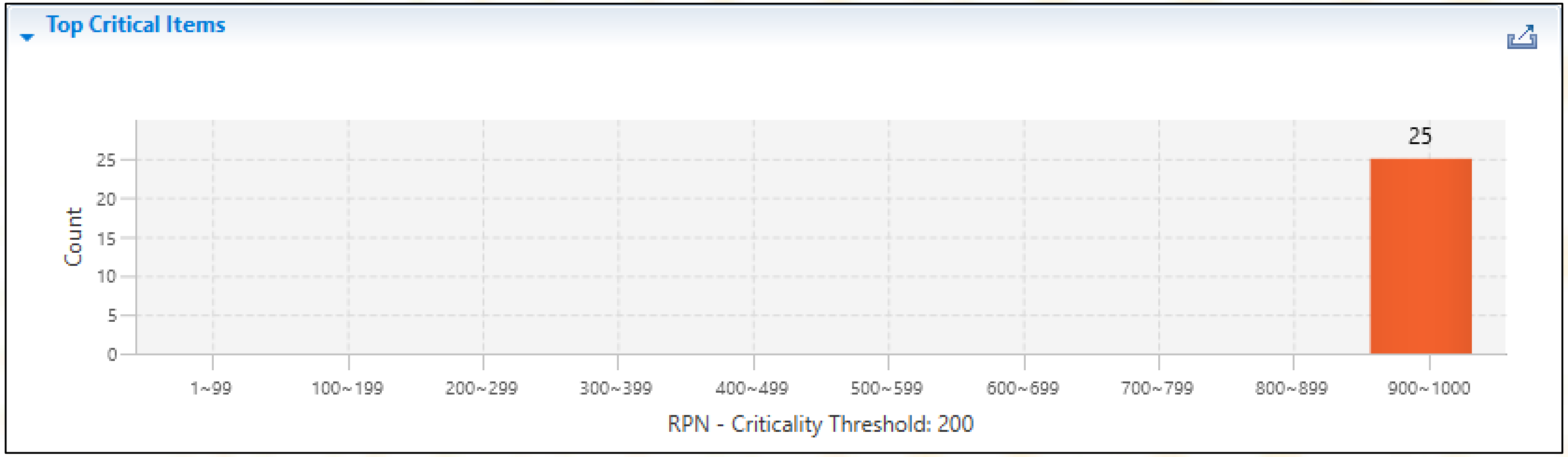
- Select **Analyses → Critical Item Analysis** to open the editor
- Select to change **End effect** to **'Power Generation'**
- Set the **Propagation Type** as **FCM**
- Select **RPN** as the Criticality Measure
- Change the threshold value to **200**
- Select the Calculate button to display top critical items in the chart



Session 3.4: Critical Item Analysis

DISCUSSION 3.4.2 FIND & REPLACE (CRITICALITY)

- Default criticality setting is set to 10 for OSD (critical until otherwise specified)
- Critical Item Analysis needs a complete analysis to work
- Find & Replace can be used to bulk edit information in the model (e.g. occurrence)

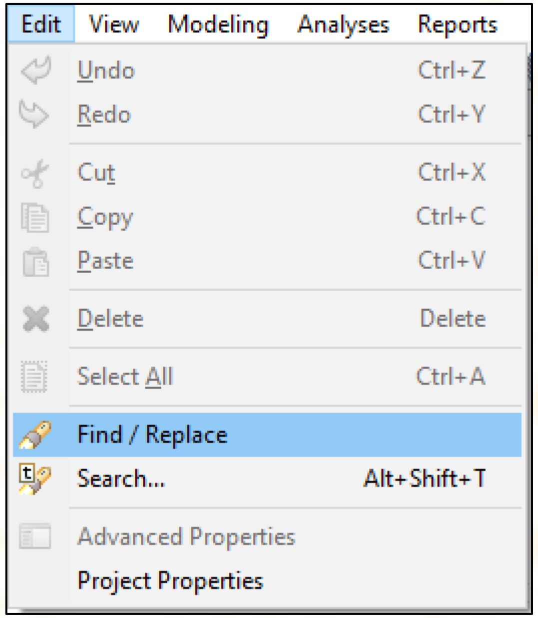


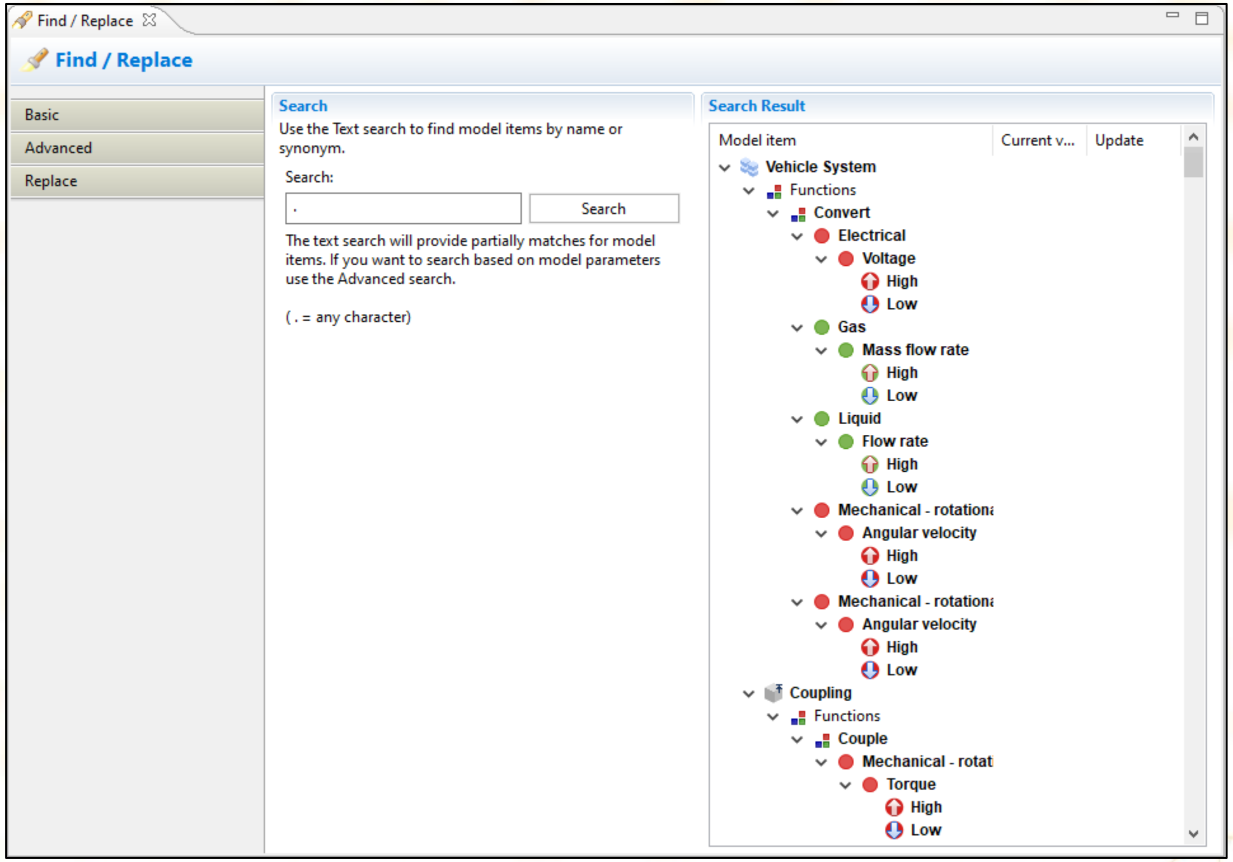
Session 3.4: Critical Item Analysis

Exercise 3.4.2 Replace occurrence using Find & Replace

To search and replace item parameters:

- Select **Edit → Find/Replace** from the main menu
- Type **“.”** into the search box and select Search

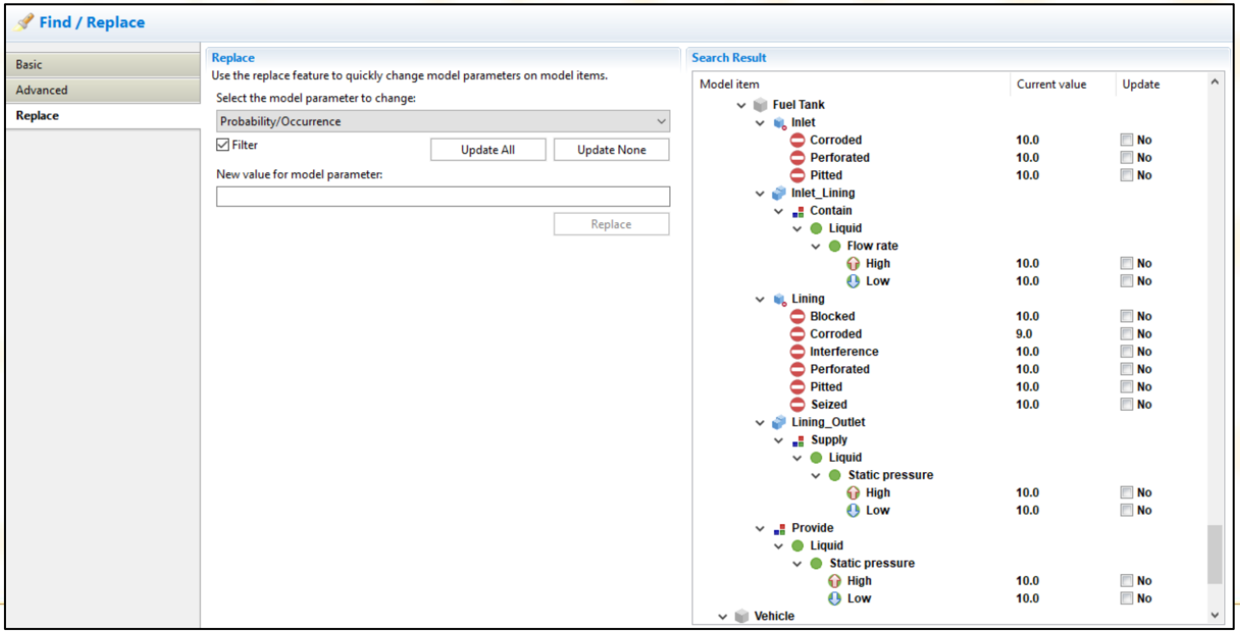




Session 3.4: Critical Item Analysis

EXERCISE 3.4.2 REPLACE OCCURRENCE USING FIND & REPLACE (CONTINUED)

- Select the **Replace** tab
- Select the **Probability/Occurrence** value from the parameter drop down list
- Select the **Filter** checkbox and Update All
- Deselect failure modes, failure conditions & faults for: ‘**Coupling 1**’, ‘**Control Unit’** and **‘Fuel Tank’** (including parts)



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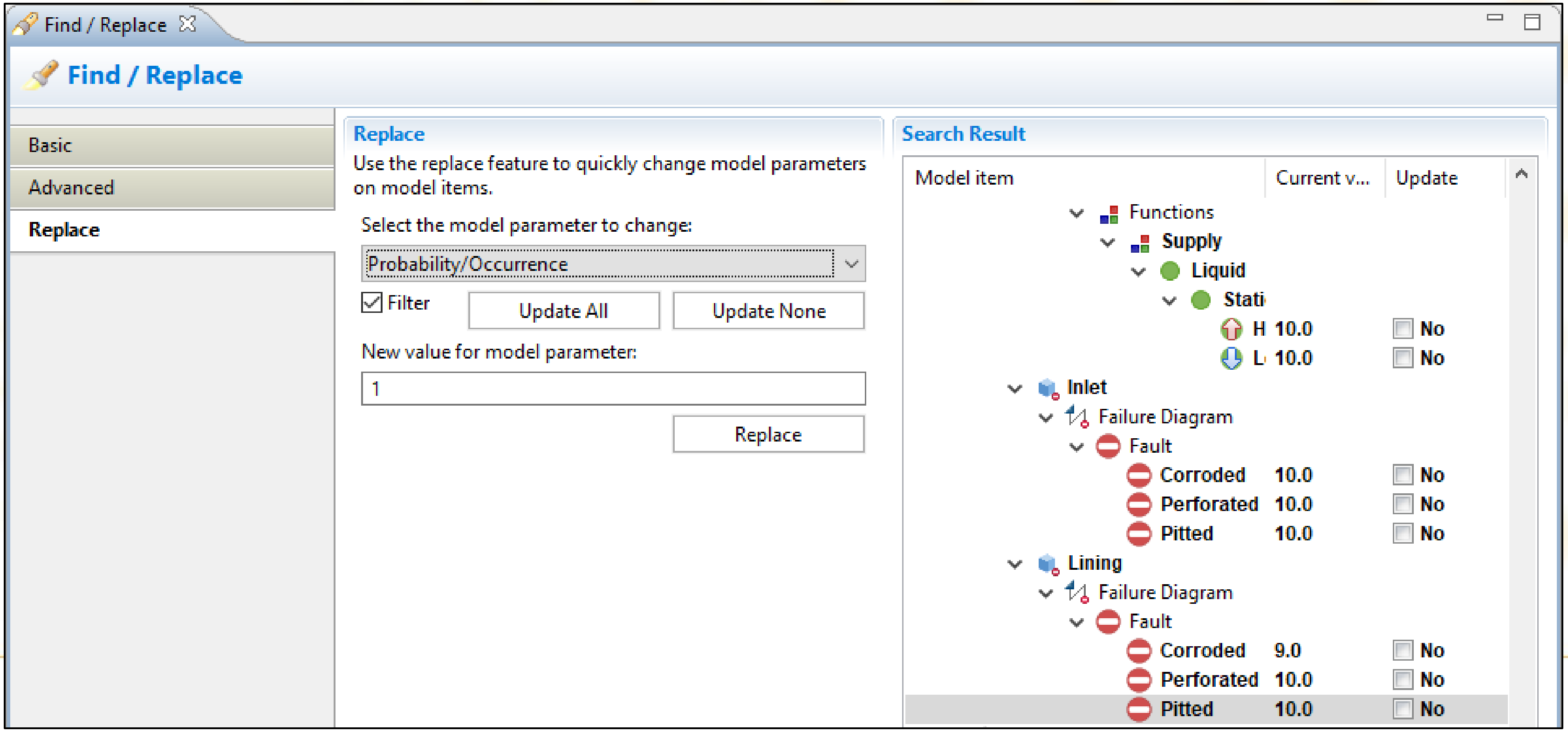
Session 3.4: Critical Item Analysis

Exercise 3.4.2 replace occurrence using Find & Replace (continued)

- Set the new value for model parameter to: **1**
- Select Replace



Session 3.4: Critical Item Analysis

Discussion 3.4.3 Critical Item List

- Items with failures above a certain threshold can be marked as Critical
- Critical Items are flagged in the model with a red symbol
- A Critical Item List (viewer) can be used to track Critical Items

▾ Critical Items

Apply to Model

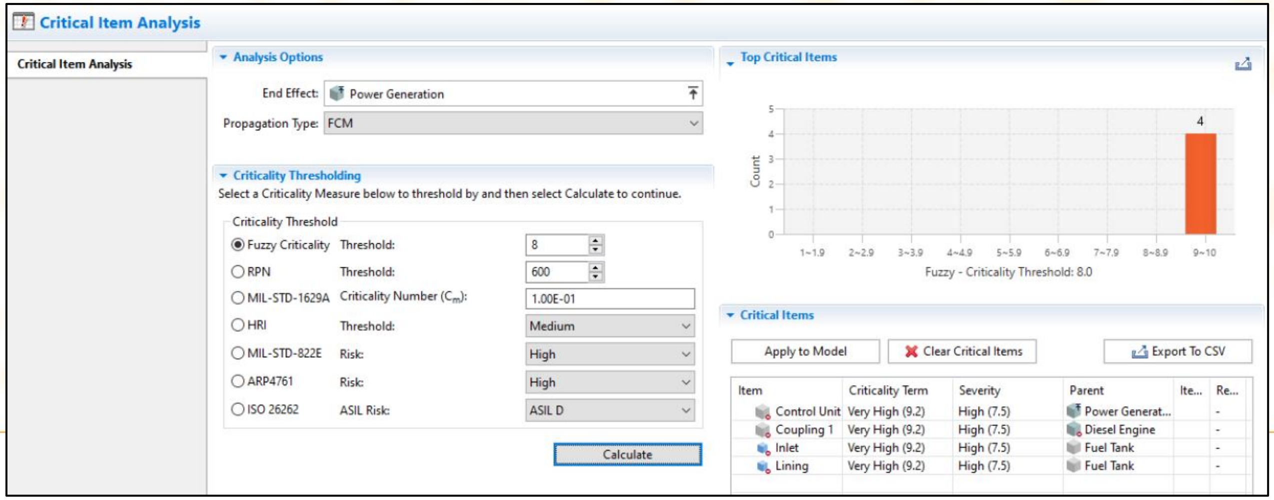
Item	Parent	Item No.	Replaceable
Control Unit	Power Generation		-
Inlet	Fuel Tank		-
Lining	Fuel Tank		-

Session 3.4: Critical Item Analysis

EXERCISE 3.4.3 APPLY CRITICAL ITEMS TO MODEL

To apply critical items to the model:

- Select **Analyses → Critical Item Analysis**
- Set the RPN Threshold to: **600**
- Select [Calculate]
- Review Critical Items in the table
- Select [Apply to Model] to mark items in the system model with the critical icon



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Session 3.4: Critical Item Analysis

Session 3.4 Summary

✓ 3.4.1: Critical Item Analysis

✓ 3.4.2: Find & Replace (criticality)

✓ 3.4.3: Critical Item List

Session 3.5: Failure Conditions (FHA)

Session 3.5 Outline

3.5.1: Failure Modes & Failure Conditions

3.5.2: Mission Profile Section

3.5.3: Environment Section

3.5.3: Criticality Section

3.5.4: Verification Methods Section

3.5.5: FHA Report

Session 3.5: Failure Conditions (FHA)

Discussion 3.5.1 Failure Conditions

Failure Conditions page in the Functional Model editor is used to:

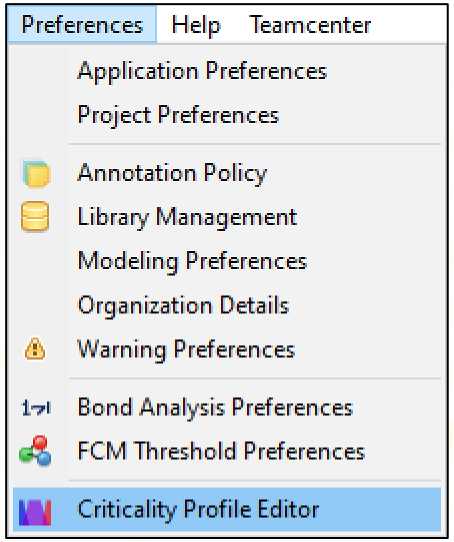
- Associate Failure conditions to individual Functional Failures
- Define the Failure Condition Type
- Associate a Failure Condition with Mission Profile Phases/Segments
- Associate a Failure Condition with special conditions & environmental characteristics
- Associate a Failure Condition with a Criticality Profile, severity classifications, probabilities etc.
- Associate a Failure Condition with Verification Methods

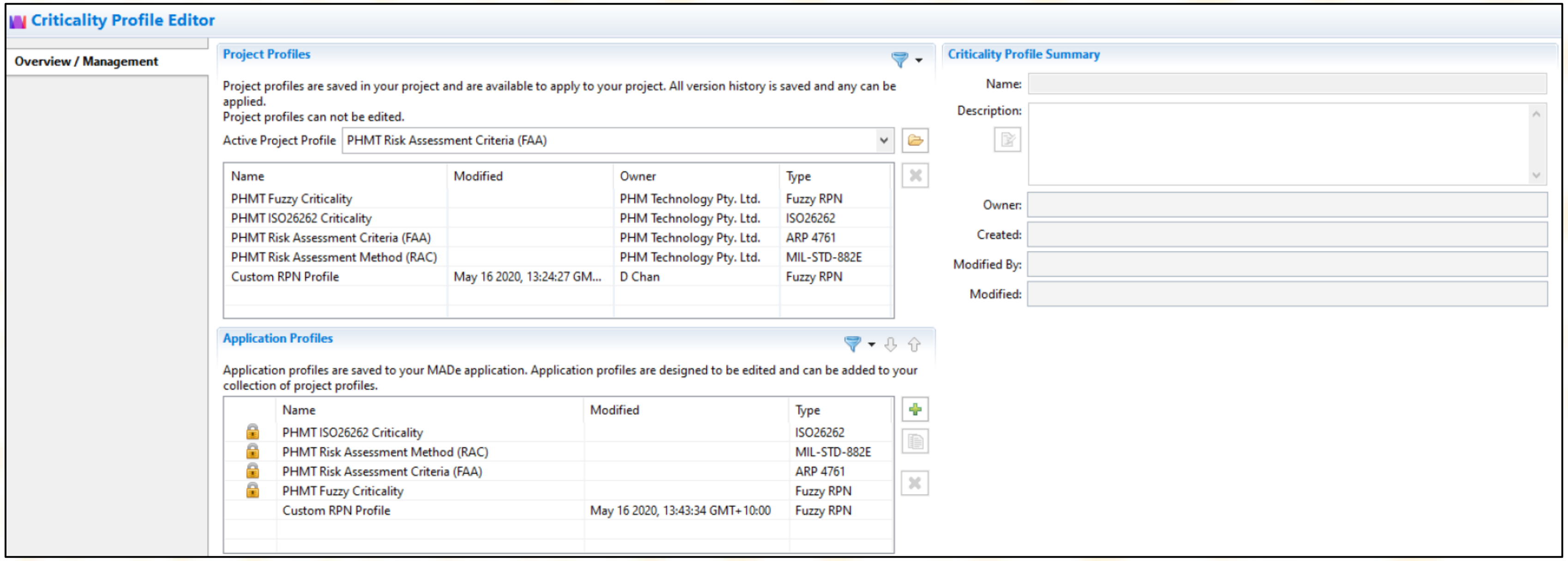
Session 3.5: Failure Conditions (FHA)

Exercise 3.5.1 Pre-requisite

For this section we will need to change the criticality profile to **PHMT Risk Assessment Criteria (FAA).**

- Select **Preferences → Criticality Profile Editor** from the menu bar
- Select **PHMT Risk Assessment Criteria (FAA)** as the Active Project Profile



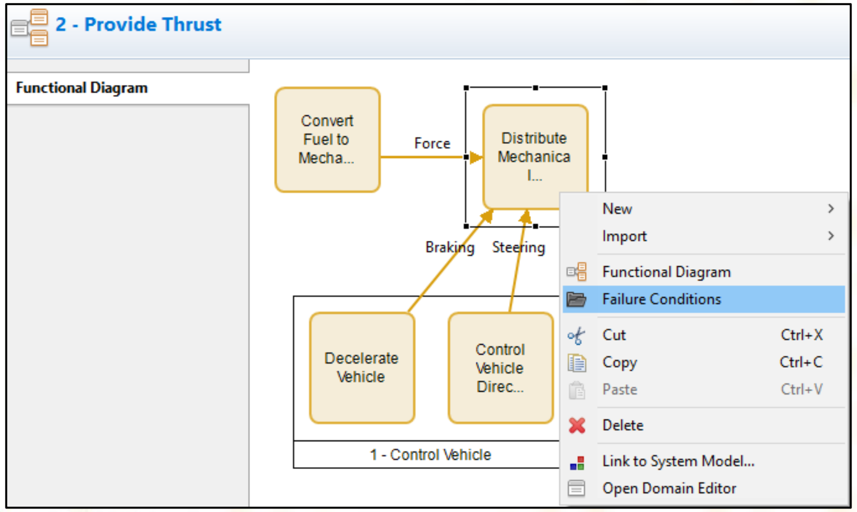


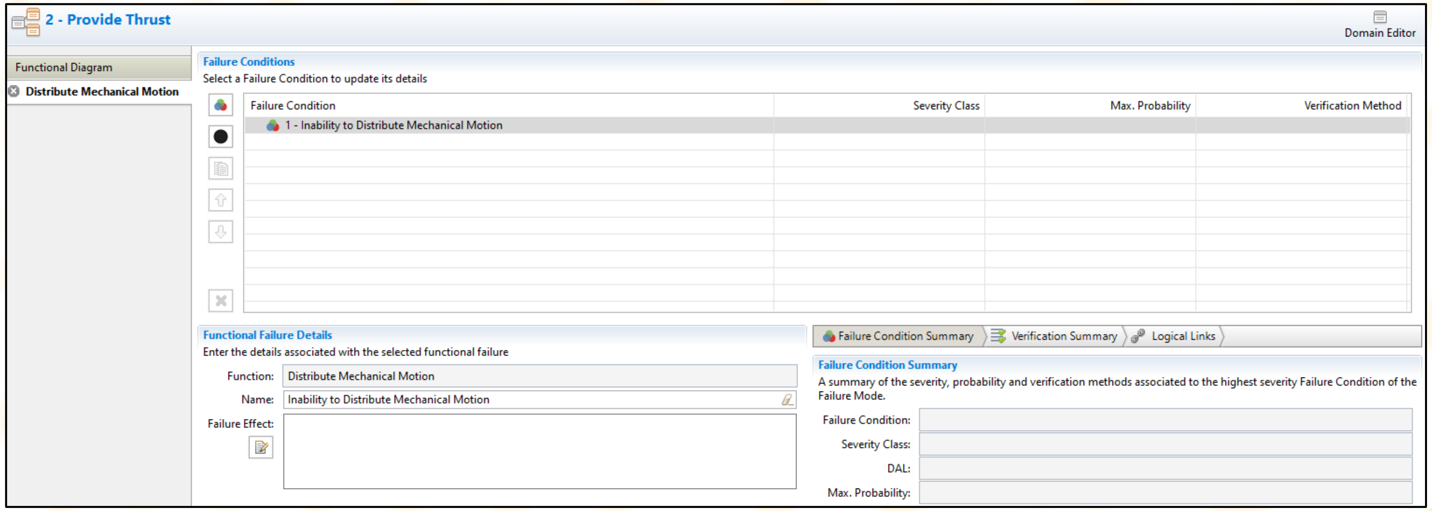
Session 3.5: Failure Conditions (FHA)

EXERCISE 3.5.1 ACCESS FAILURE CONDITIONS PAGE

To open the Functional Diagram editor:

- ➢ Select the System in Project Explorer, **Modeling → Functional Diagram**
- ➢ Open Functional Diagram of the **Provide Thrust** function
- ➢ Open Failure Condition page for **Distribute Mechanical Motion**
  - ➢ Right-click Distribute Mechanical Motion then select **Failure Condition** from menu





Session 3.5: Failure Conditions (FHA)

DISCUSSION 3.5.1 FAILURE CONDITIONS PAGE

- The Failure Condition page enables user to create:
  - 1 or more Failure Modes per Function
  - 1 or more Failure Conditions per Failure Mode
- This page summarises the following information:
  - Severity Classification
  - Maximum probability of Failure Condition
  - Verification methods

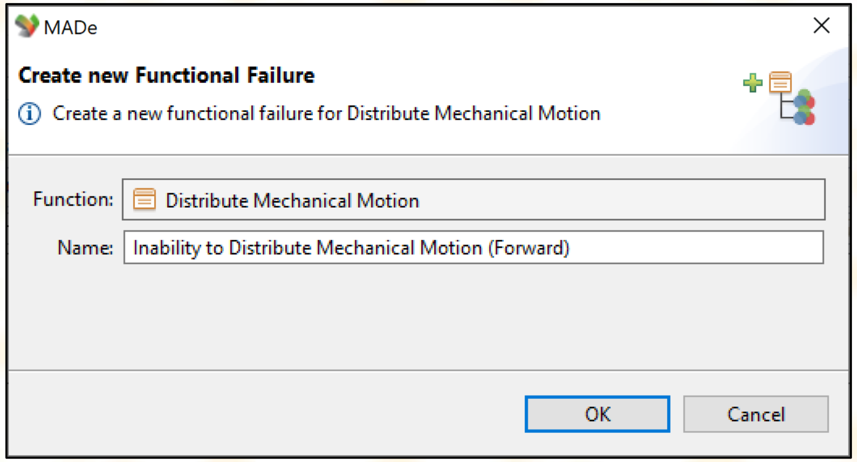
Session 3.5: Failure Conditions (FHA)

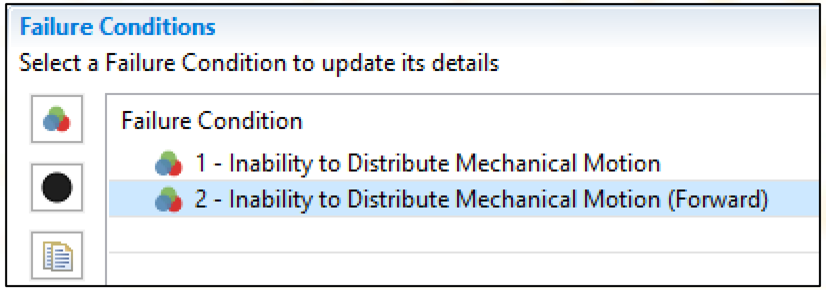
EXERCISE 3.5.1 CREATE A NEW FAILURE MODE & FAILURE CONDITION

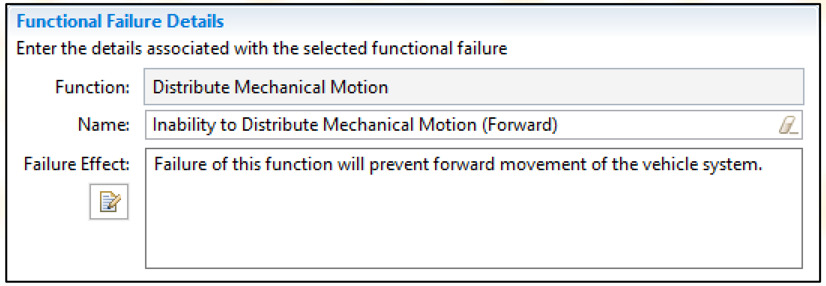
To create a new Failure Mode:

- In the **Distribute Mechanical Motion** Failure Conditions page:
  - Select to add a new Failure Mode
- From the Create new Failure Mode dialog:
  - Enter name: **Inability to Distribute Mechanical Motion (Forward)**
- Select the newly created Failure Mode
- In the **Functional Failure Details** section, enter Failure Effect Narrative:

Failure of this function will prevent forward movement of the vehicle system.







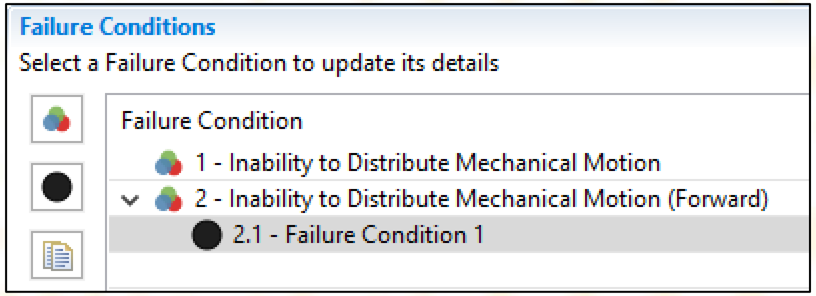
Session 3.5: Failure Conditions (FHA)

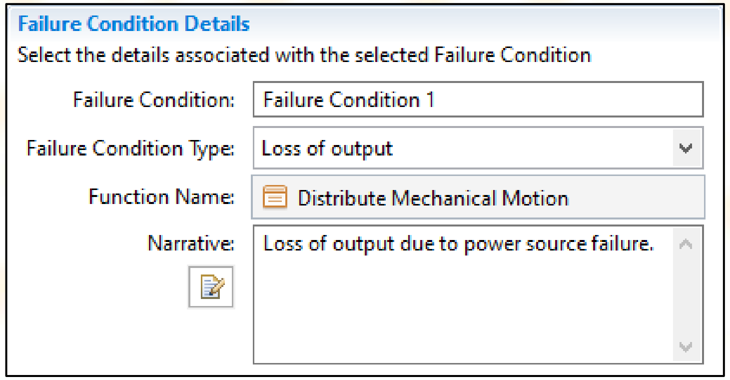
Exercise 3.5.1 Create a New Failure Mode & Failure Condition (Continued)

- Select the newly created Failure Mode
- Select the **Add new Failure Condition** icon ●
- Select the newly added Failure Condition

Update Failure Condition Details section:

- Rename Failure Condition: **Failure Condition 1**
- Select Failure Condition Type: **Loss of Output**
- Enter Failure Condition Narrative: **Loss of output due to power source failure.**

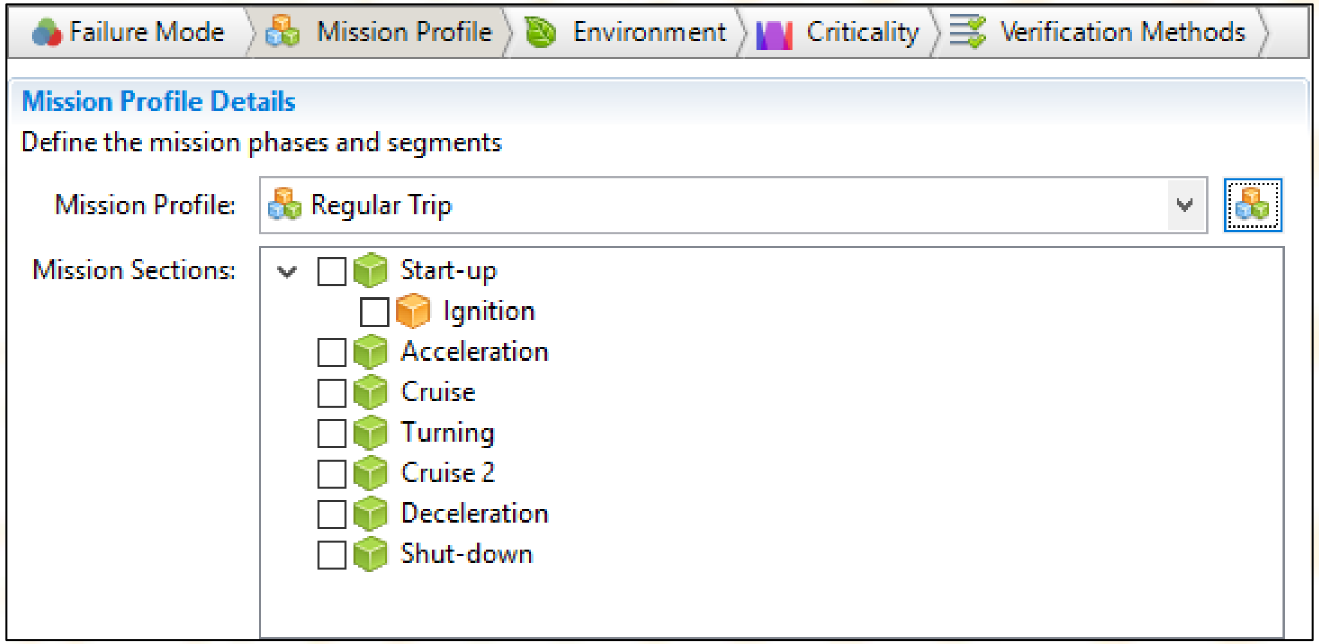




Session 3.5: Failure Conditions (FHA)

Discussion 3.5.2 Mission Profile Section

- This section allows the user to select applicable mission profiles to a selected failure condition
- User selects applicable mission phases/segments where the failure condition occurs

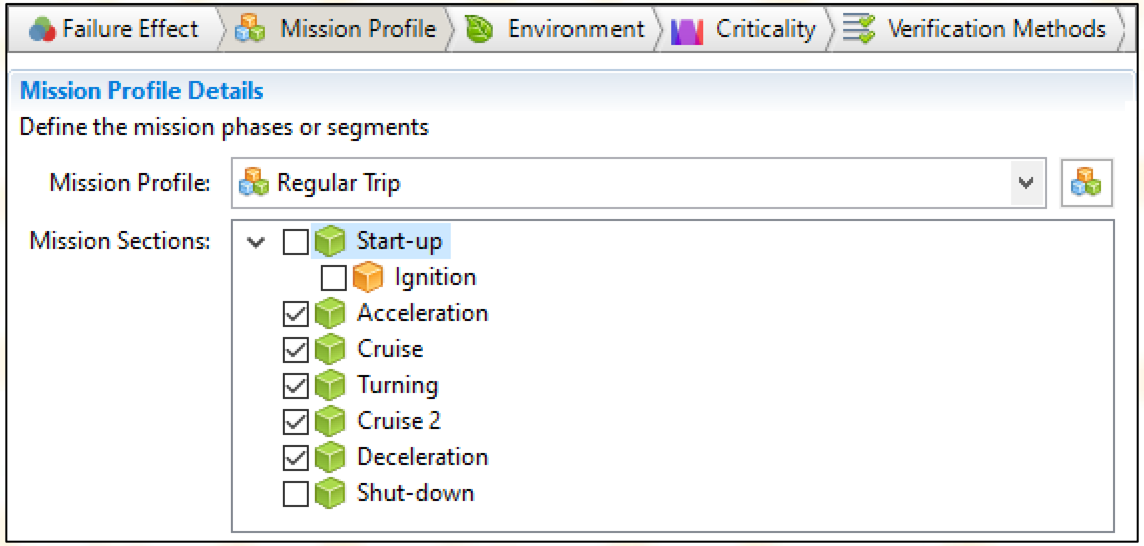


Session 3.5: Failure Conditions (FHA)

Exercise 3.5.2 Select Mission Profile Details

To edit the Mission Profile details for the Failure Condition:

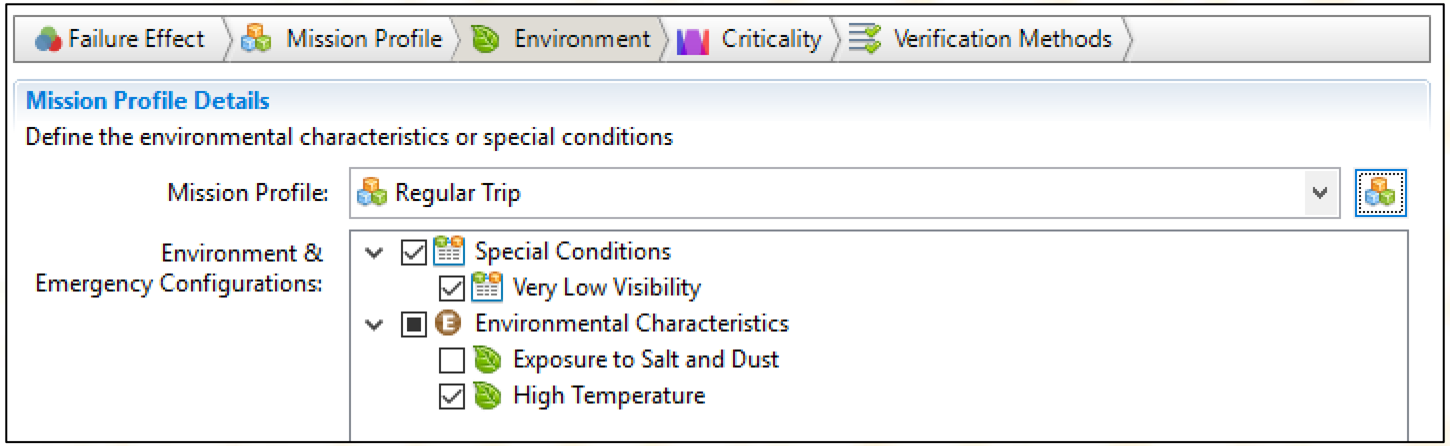
- Select **Failure Condition 1**
- Select the **Mission Profile** tab
- From the drop down menu and select **Regular Trip**
- Select the following Mission Phases:
    - Acceleration
    - Cruise
    - Turning
    - Cruise 2
    - Deceleration



Session 3.5: Failure Conditions (FHA)

Discussion 3.5.3 Environmental Section

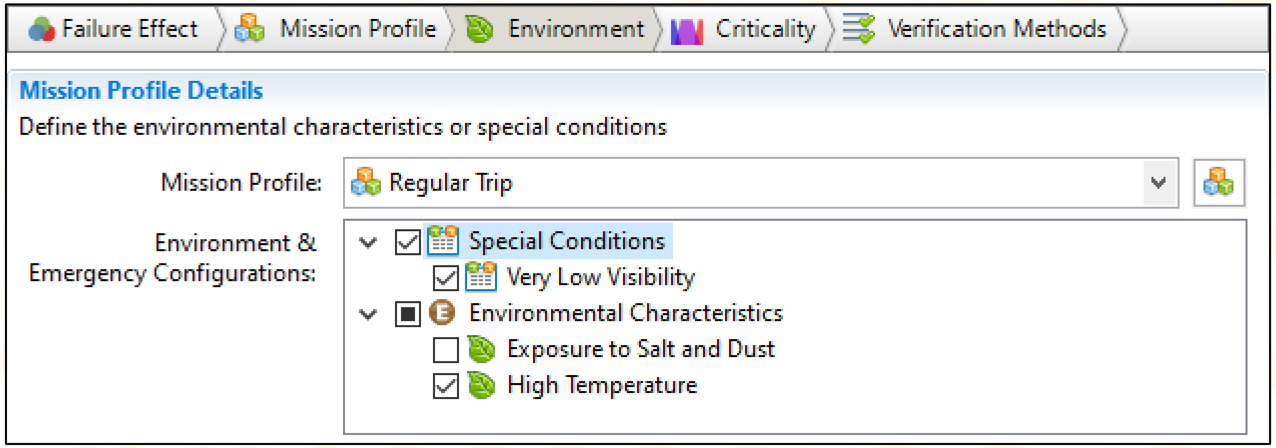
- This section allows the user to select applicable Special Conditions & Environmental Characteristics relating to the selected Failure Condition



Session 3.5: Failure Conditions (FHA)

EXERCISE 3.5.3 SELECTING SPECIAL CONDITIONS AND ENVIRONMENTAL CHARACTERISTICS

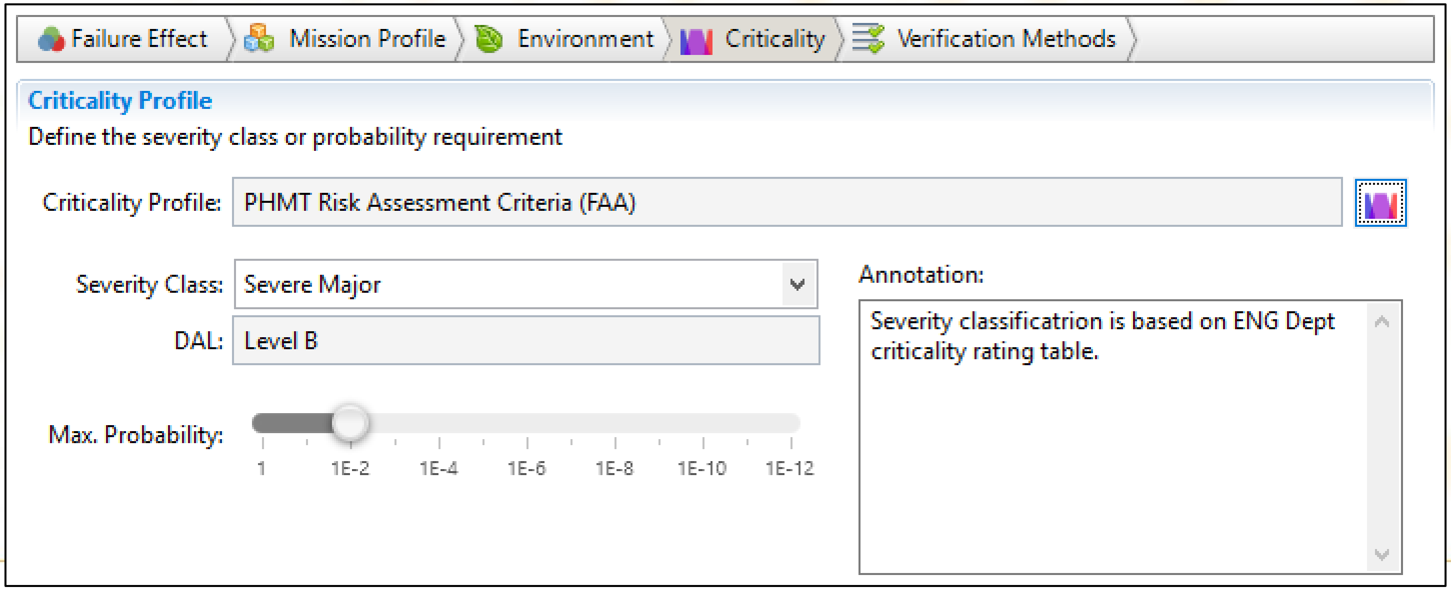
- Select the **Environment** tab
- Select Special Condition: **Very Low Visibility**
- Select Environmental Characteristic: **High Temperature**



Session 3.5: Failure Conditions (FHA)

Discussion 3.5.4 Criticality Section

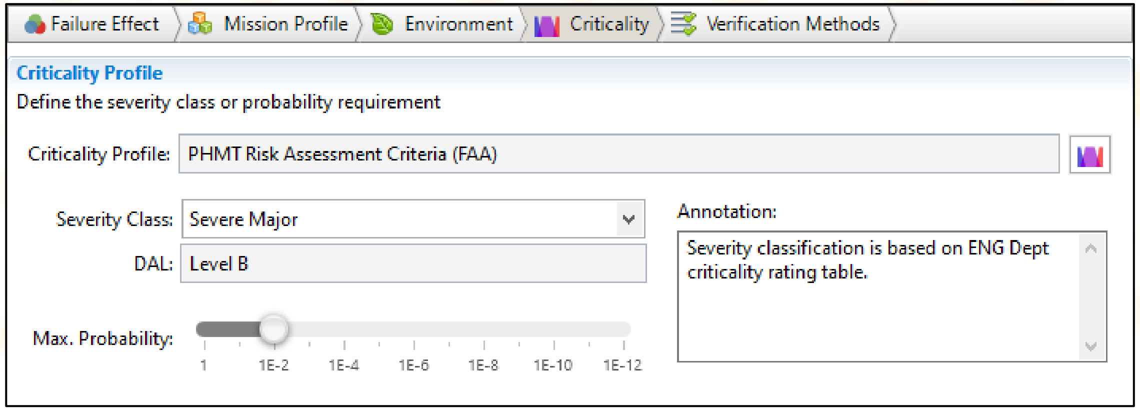
- This section allows the user to set:
  - An applicable criticality profile
  - Assign a severity class to the selected failure condition & view corresponding Design Assurance Level (DAL)
  - Assign a maximum probability for the failure condition
  - Enter an annotation regarding the criticality entry



Session 3.5: Failure Conditions (FHA)

Exercise 3.5.4 Select Criticality Details

- Select the **Criticality** tab
- Verify Criticality Profile is set to **PHMT Risk Assessment Criteria (FAA),** if not, set it in the **Criticality Profile Editor**
  - Select the **Criticality Profile** icon
  - Set the Active Project Profile as **PHMT Risk Assessment Criteria (FAA)**
- Set Severity Class as **Severe Major**
- Enter Annotation: **Severity classification is based on ENG Dept criticality rating table.**
- Verify DAL: **Level B**
- Set Max. Probability: **1E-2**



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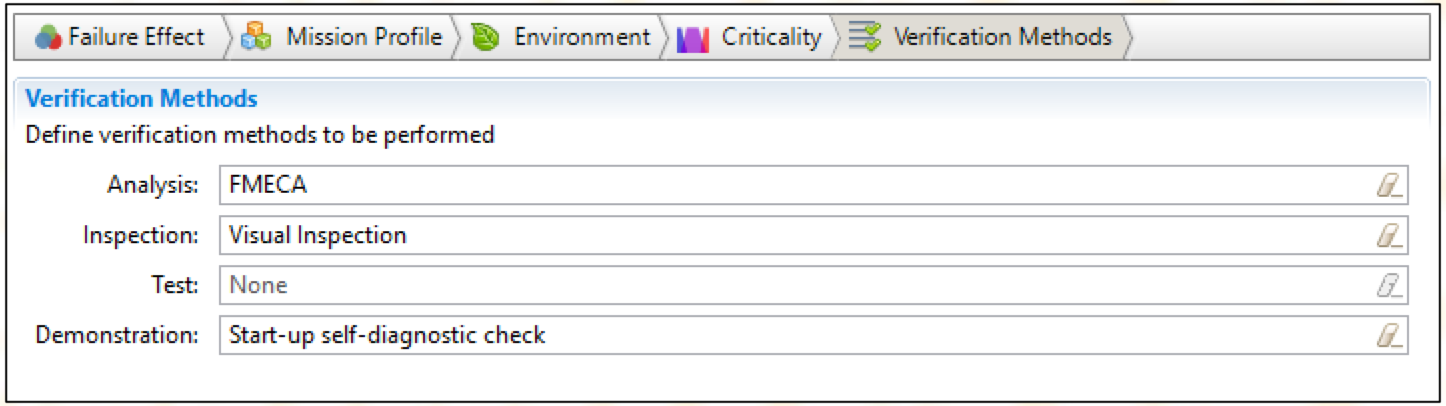
Session 3.5: Failure Conditions (FHA)

Discussion 3.5.4 Verification Methods Section

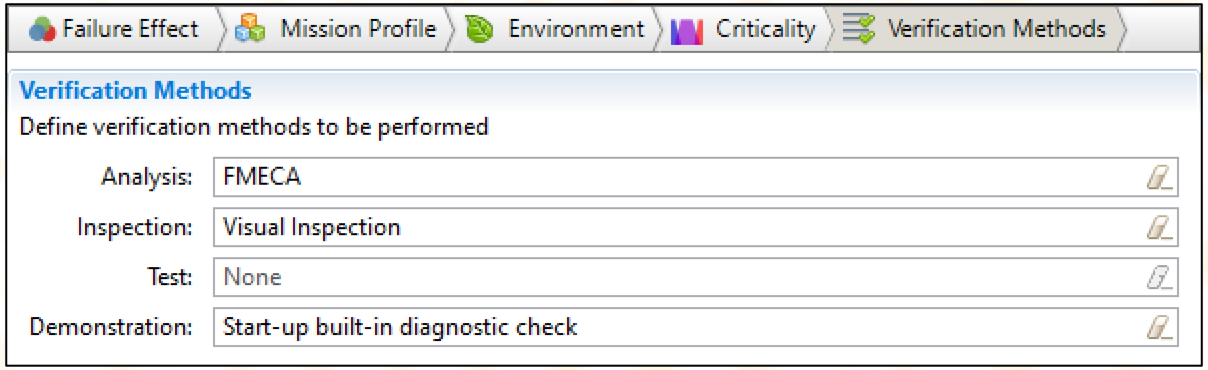
- This section allows the user to enter verification methods used to check for a failure condition
- Verification Methods are divided into four categories:
  - Analysis
  - Inspection
  - Test
  - Demonstration



Session 3.5: Failure Conditions (FHA)

EXERCISE 3.5.4 SELECT VERIFICATION METHODS DETAILS

- Select the **Verification Methods** tab
- Enter the following:
  - Analysis: **FMECA**
  - Inspection enter: **Visual Inspection**
  - Test: **None**
  - Demonstration: **Start-up built-in diagnostic check**



Session 3.5: Failure Conditions (FHA)

Discussion 3.5.5 FHA Report

- This Report Summarises the Function List & Failure Condition pages for all Functions in the Functional Model
- Report is divided into sections:
  - Function List
  - Environment & Emergency Configuration List
  - Derived Safety Requirements List
  - Functional Hazard Assessment

Training Session 6 Functional Hazard Assessment (ARP4761) 20/09/2018 5:58:16 PM

PLATFORM	Vehicle System	MISSION PROFILE	Regular Trip	DATE	20/09/2018 5:58:16 PM
PLATFORM ID	VS1	CRITICALITY PROFILE	PHMT Risk Assessment Criteria (FAA)	SHEET	6 OF 6
AUTHOR	Josh	REVIEWER		FILE	Training Session 6

FUNCTIONAL HAZARD ASSESSMENT

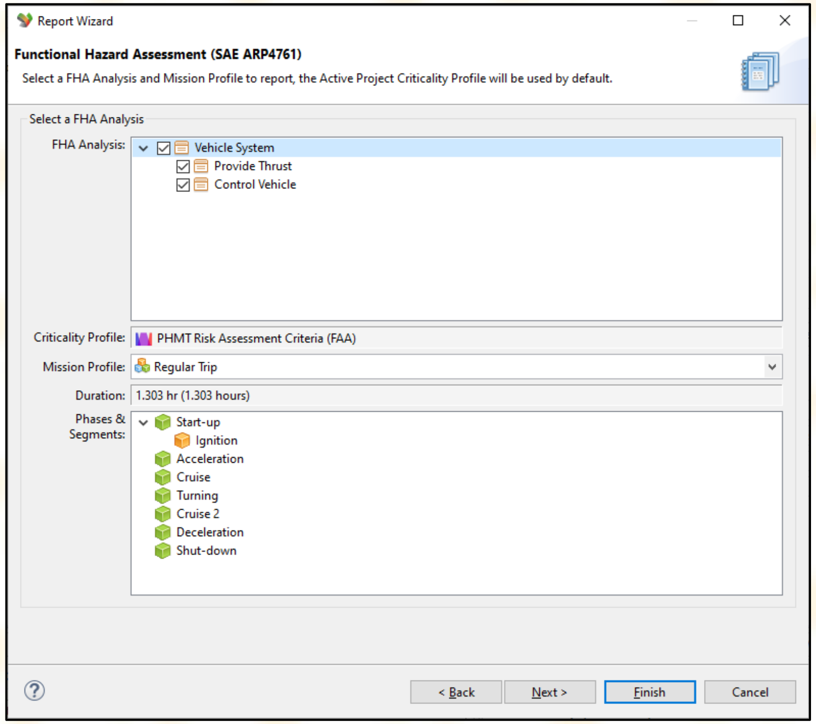
FUNCTION ID	FUNCTION	FAILURE MODE	FC ID	FAILURE CONDITION (HAZARD DESCRIPTION)	PHASE / SEGMENT	EFFECT	SEVERITY CLASSIFICATION	SUPPORTING MATERIAL	VERIFICATION METHODS
1	Control Vehicle								
1.2	Control Vehicle Direction	Inability to Control Vehicle Direction (Forward)	3.1	Failure Condition 1			TBD		
			3.2	Failure Condition 2			TBD		
			3.3	Failure Condition 3			TBD		
1.3	Decelerate Vehicle								
2	Provide Thrust								
2.1	Convert Fuel to Mechanical Motion								
2.2	Distribute Mechanical Motion	Inability to Distribute Mechanical Motion (Forward) Failure of this function will prevent forward movement of the vehicle system.	2.1	Failure Condition 1 Loss of output due to power source failure.	2: Acceleration 3: Cruise 4: Turning 5: Cruise 2 6: Deceleration	Failure of this function will prevent forward movement of the vehicle system.	Severe Major	Severity classification is based on ENG Dept criticality rating table.	Analysis: FMECA Inspection: Visual Inspection Demonstration: Start-up built-in diagnostic check
3	Air/Ground Determinations								
4	Crew Alerting								

Session 3.5: Failure Conditions (FHA)

EXERCISE 3.5.5 GENERATE FHA REPORT

To generate a FHA report:

- Select from the icon toolbar
- Select **Functional Hazard Assessment (SAE ARP4761)**
- Select Next >
- Verify FHA Analysis: **Vehicle System**
- Select Mission Profile: **Regular Trip**
- Select Finish



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Session 3.5: Failure Conditions (FHA)

Session 3.5 Summary

- ✓ 3.5.1: Failure Modes & Failure Conditions
- ✓ 3.5.2: Mission Profile Section
- ✓ 3.5.3: Environment Section
- ✓ 3.5.3: Criticality Section
- ✓ 3.5.4: Verification Methods Section
- ✓ 3.5.5: FHA Report

Session 3.6: Common Mode Analysis (CMA)

<u>Session 3.6 Outline</u>

3.6.1: CMA in ARP4761 Context

3.6.2: CMA Editor Layout

3.6.3: Common Mode Item Search

3.6.4: Common Mode Events

3.6.5: CMA Worksheet

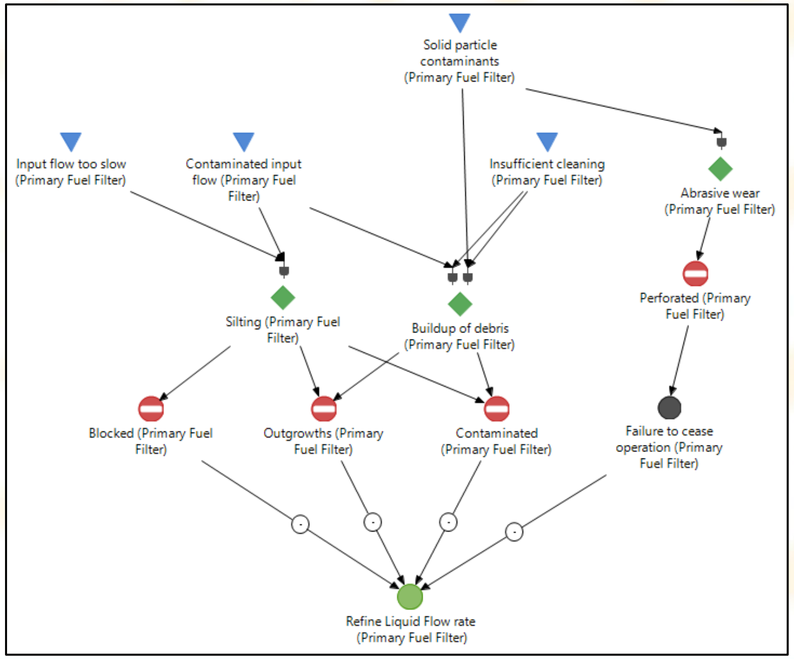
3.6.6: CMA Report

Session 3.6: Common Mode Analysis (CMA)

Discussion 3.6 Common Mode Analysis Pre-requisite

Pre-requisite: Add the Failure Condition **Failure to Cease Operation** to **Perforated** Fault in **'Primary Fuel Filter'** component failure diagram

This piece of information will be used in the analysis.



Session 3.6: Common Mode Analysis (CMA)

Discussion 3.6.1 CMA in ARP4761 Context

- ARP4761 Standard: Guidelines & methods of performing safety assessment for certification of civilian aircraft
- CMA Definition: Verify that ANDed events in FTA, Dependence Diagrams (DD) & Markov Analysis (MA) are independent in the actual implementation
  - Analyse effects of Design, Manufacturing, Maintenance errors & Failures of components which defeat their independence
  - Consider independence of functions & their respective monitors
    - E.g. Items with identical hardware/software could be susceptible to the same faults
- Performed during Concept and Preliminary Design Stages
- CMA is performed at 2 levels: Platform (e.g. Aircraft) Level & System Level
- Pre-requisites: BOM/FBD Model, Failure Diagrams, RBD Groups

Session 3.6: Common Mode Analysis (CMA)

Discussion 3.6.2 Common Mode Editor Layout

The default layout of the CMA editor consists of:

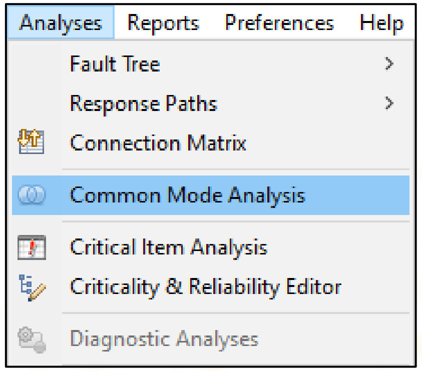
- Vertical Tabs (Left): Overview, CMA Events & Common Mode Event Worksheet pages
- Overview Page: Displays a list of CMAs including CMA details & a pie chart
- Analysis Page: Displays search options & results, and Common Mode Events
- Worksheet Page: Displays Common Mode Failures & details

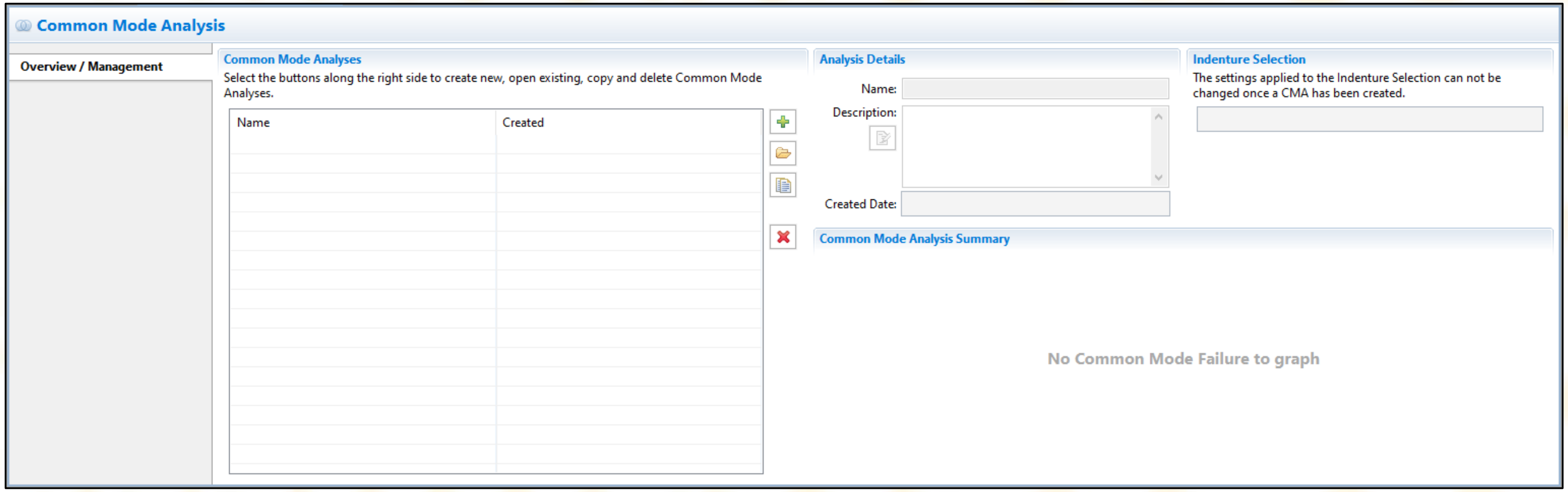
Session 3.6: Common Mode Analysis (CMA)

Exercise 3.6.2 Create a Common Mode Analysis

To create a new CMA:

- Select **Analyses → Common Mode Analyses** from the main menu



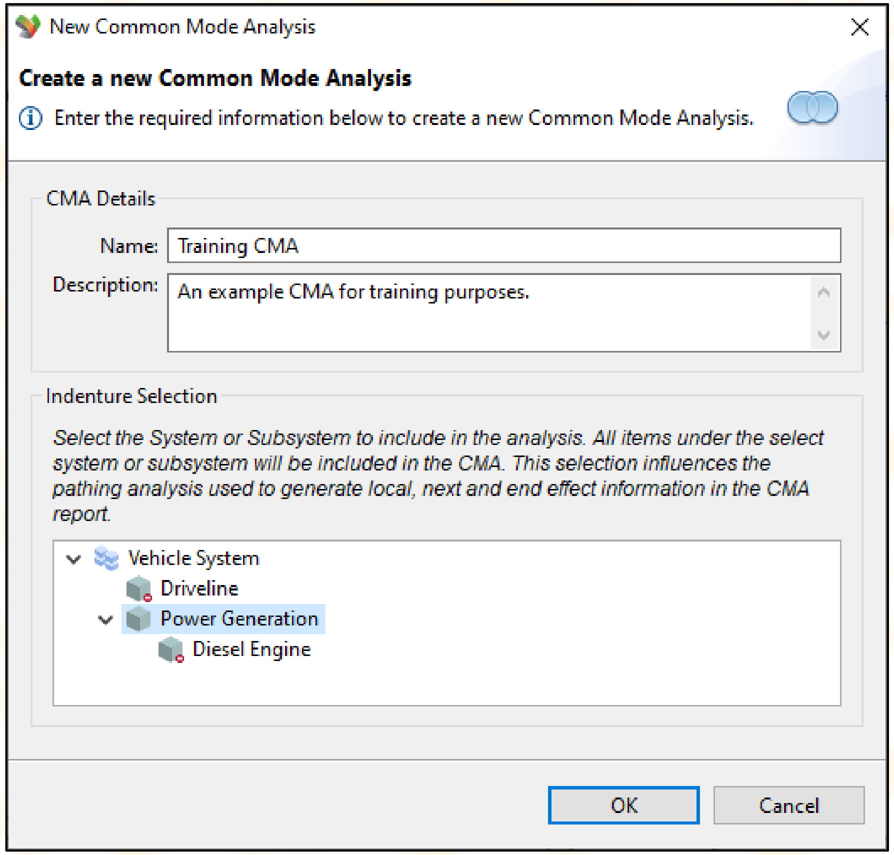


Session 3.6: Common Mode Analysis (CMA)

Exercise 3.6.2 Create a New CMA

From the Overview page:

- Select ➕ to create a new Common Mode Analysis
- From the dialog:
  - Enter Name: **Training CMA**
  - Enter Description: **An example CMA for training purposes.**
  - Select Indenture: **'Power Generation'**
  - Select OK



Session 3.6: Common Mode Analysis (CMA)

Discussion 3.6.3 Common Mode Item Search

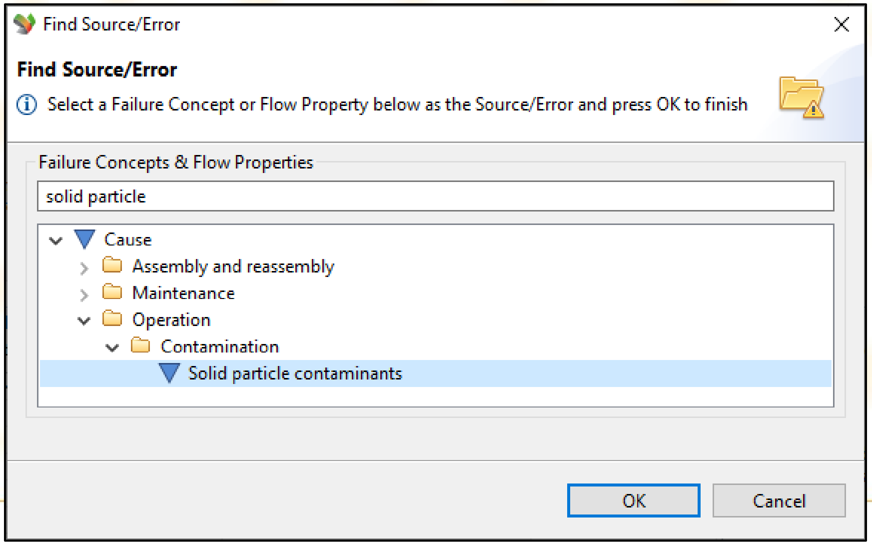
- The Analysis page is used to conduct an initial search of items based on 3 criteria:
  - Items arranged in a Parallel RBD group (covered in Session 4.3)
  - Items with common failure concepts
  - Searching for items by display name
- Candidate items are grouped into a Common Mode Event for further evaluation in the Worksheet page
- Common Mode Events are also used to capture:
  - Description of common mode items
  - Relevant requirements if applicable (see ARP4761 examples)

Session 3.6: Common Mode Analysis (CMA)

Exercise 3.6.3 Common Mode Item Search

In the **Search Options** section:

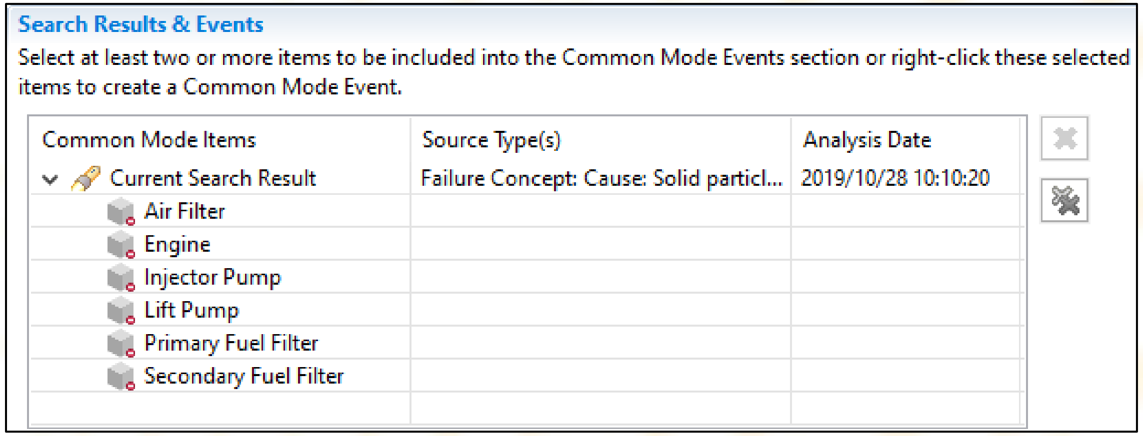
- Select the Failure Concept check box
- Select the Failure Concept Icon to browse for a relevant failure concept
  - From the dialog search for **Solid Particle Contaminants**
  - Select the Cause Failure Concept under **Cause → Operation → Contamination**
  - Select OK to close dialog
- Select Search button

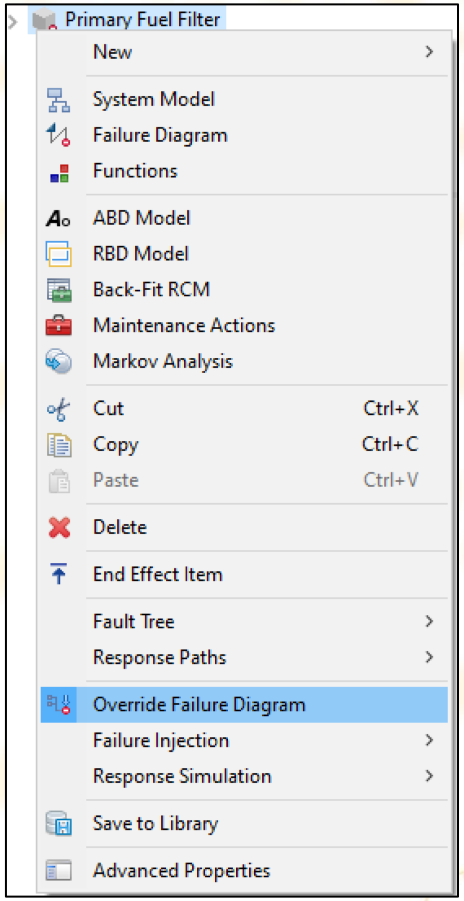


Session 3.6: Common Mode Analysis (CMA)

EXERCISE 3.6.3 COMMON MODE ITEM SEARCH (CONTINUED)

➢ Verify that the Search Results & Events table displays a current search result below





❖ Note: **'Primary Fuel Filter'** will not appear due to the failure diagram override. To deactivate failure diagram override, right click the **'Primary Fuel Filter'** component from the Project Explorer and select **Override Failure Diagram**.

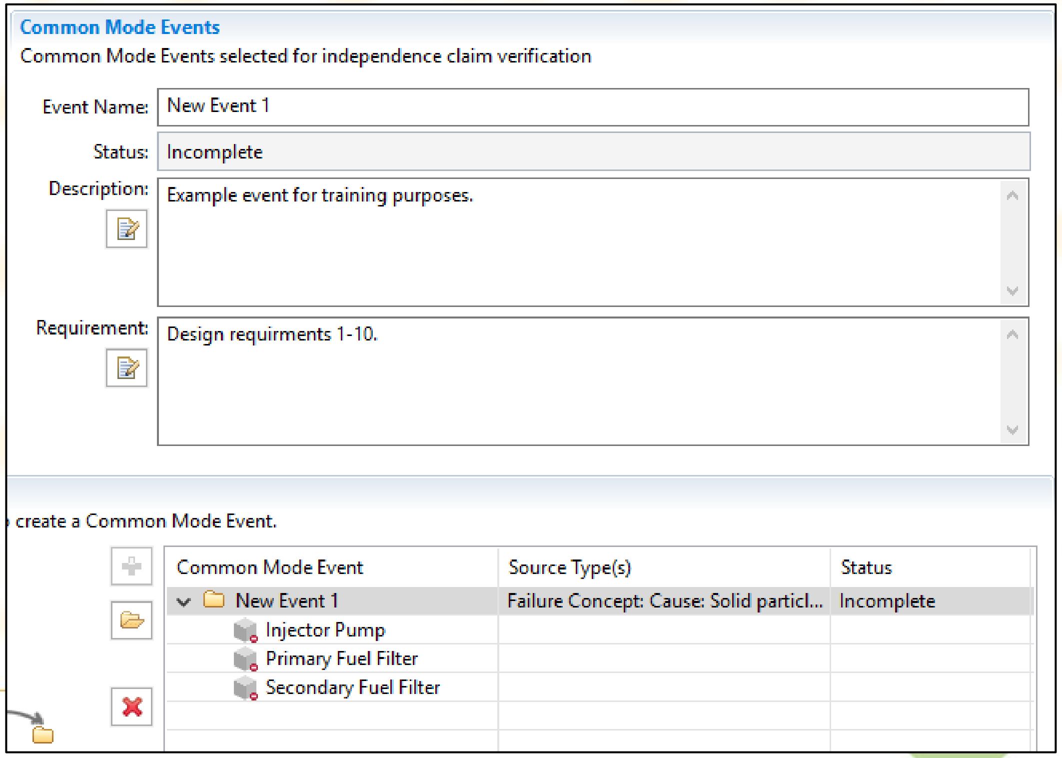
➢ Once this has been done, select Search to re-run the search results

➢ Verify that **'Primary Fuel Filter'** is displayed in the search results

Session 3.6: Common Mode Analysis (CMA)

Discussion 3.6.4 Common Mode Events

- Common Mode Events are used to aggregate selected items for further analyses
- Each CMA can have multiple Common Mode Events
- Each Common Mode Event stores the following information:
  - Event Name
  - Event Description
  - Event Requirements
  - List of items
  - CMA Worksheet data

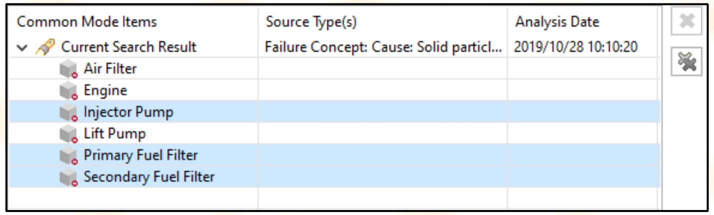


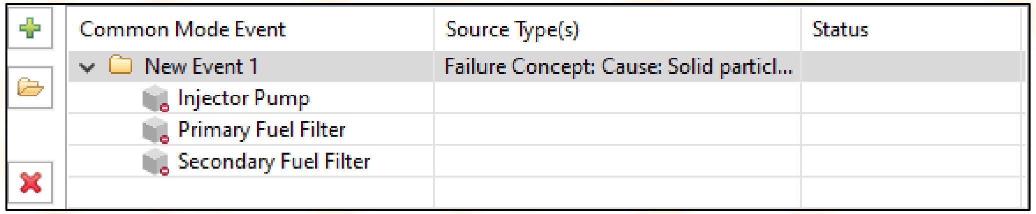
Session 3.6: Common Mode Analysis (CMA)

Exercise 3.6.4 Create a Common Mode Event

In the **Search Results & Events** section:

- Highlight 3 components: **‘Injector Pump’**, **‘Primary Fuel Filter’** & **‘Secondary Fuel Filter’**
  - Ctrl + Left Select
- There are 3 methods to create a Common Mode Event:
  - Method 1: Drag-and-drop selected items to the Common Mode Event table
  - Method 2: Right-click and select **Create New Event**
  - Method 3: Select and from New Common Mode Event dialog:
    - Enter an Event Name
    - Enter a Event Description
    - Select Item check boxes to include into CMA
    - Select OK
- Open Common Mode Event: Select or Double-click Event

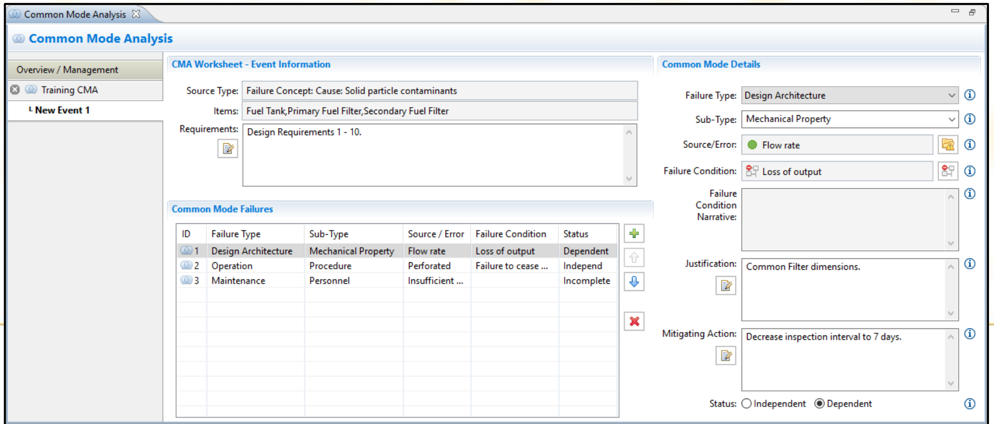




Session 3.6: Common Mode Analysis (CMA)

Discussion 3.6.5 CMA Worksheet

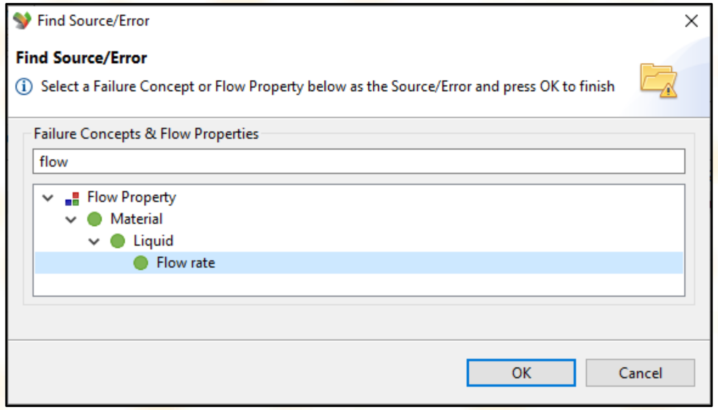
- This page captures common mode failures for items included in the Common Mode Event
- Common Mode Failure details include:
  - Failure Type/Sub-type (As per ARP4761 & CMA Literature)
  - Failure Source/Error: Common Failure Concepts
  - Failure Conditions & Narratives
  - Failure Justification: Explain how this common mode failure occurs for all items
  - Mitigating Action: What must be done to prevent this common mode failure from happening
  - Status: whether a common mode failure is dependent/independent

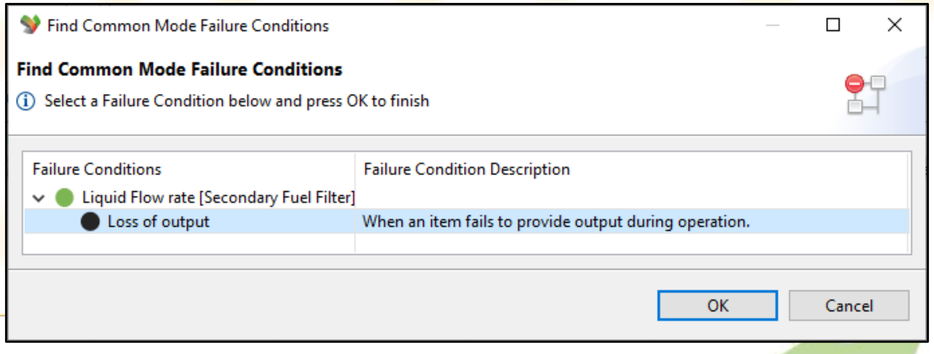


Session 3.6: Common Mode Analysis (CMA)

Exercise 3.6.5 Create Common Mode Failures

- Create a new Common Mode Failure by selecting
  - Verify common mode failure in first row of table with ID of **1** & Status: **Incomplete**
- For Requirements, input the narrative: **Design requirements 1-10.**
- Select Failure Type & Sub-Type: **Design Architecture, Mechanical Property**
- Select Source/Error icon to open dialog:
  - Search for **Flow Rate** (Flow Property → Material → Liquid) then select OK
- Select Failure Condition: **Loss of output**
- Enter Justification: **Common Filter dimensions**
- Enter Mitigating Action: **Decrease inspection interval to 7 days.**
- Select Status: **Dependent**





Session 3.6: Common Mode Analysis (CMA)

made
decisions better MADe...

Exercise 3.6.5 Create Common Mode Failures (Continued)

CMA Worksheet - Event Information

Source Type: Failure Concept: Cause: Solid particle contaminants

Items: Injector Pump,Primary Fuel Filter,Secondary Fuel Filter

Requirements: Design requirements 1-10.

Common Mode Failures

ID	Failure Type	Sub-Type	Source / Error	Failure Condition	Status
1	Design Architecture	Mechanical Property	Flow rate	Loss of output	Dependent

Common Mode Details

Failure Type: Design Architecture

Sub-Type: Mechanical Property

Source/Error: Flow rate

Failure Condition: Loss of output

Failure Condition Narrative: No fuel flow through the Secondary Fuel Filter

Justification: Common filter dimensions

Mitigating Action: Decrease inspection interval to 7 days

Status: ○ Independent ◉ Dependent

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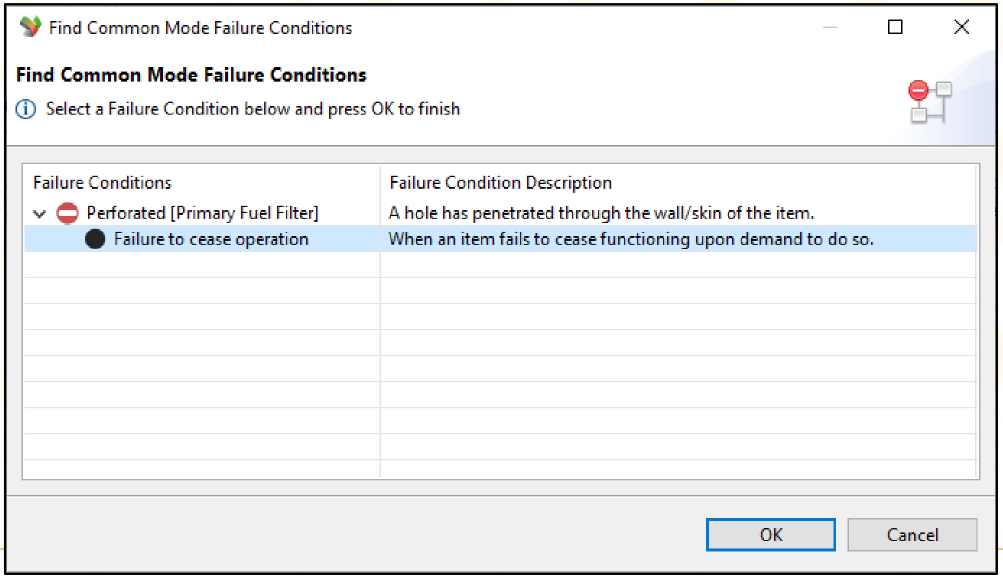
Session 3.6: Common Mode Analysis (CMA)

Exercise 3.6.5 Create Common Mode Failures (Continued)

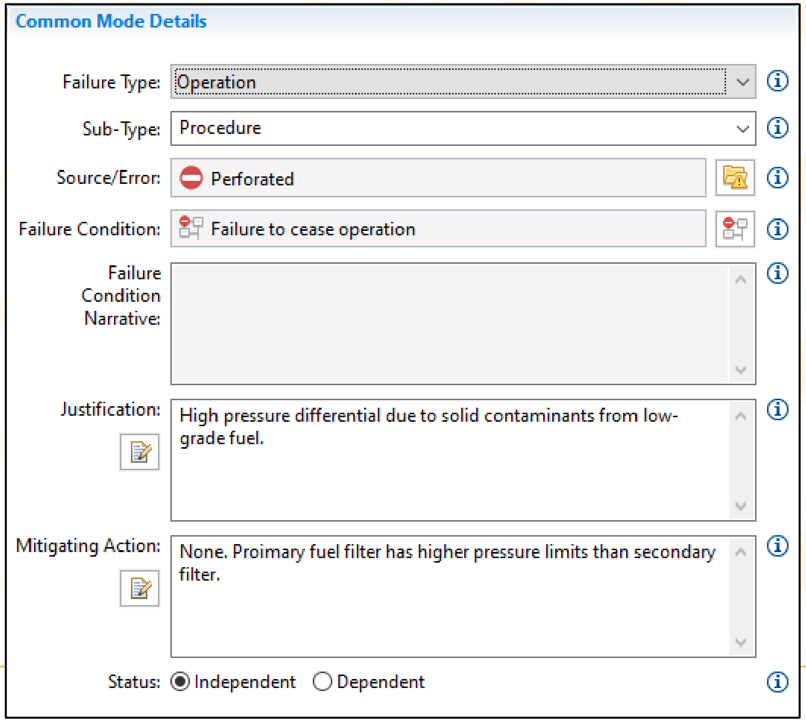
- Create a second Common Mode Failure by selecting
  - Verify common mode failure in first row of table with ID of **2** & Status: **Incomplete**
- Select Failure Type & Sub-Type: **Operation, Procedure**
- Select Source/Error icon to open dialog:
  - Search for **Perforated** (Fault → Perforated) then select OK



Session 3.6: Common Mode Analysis (CMA)

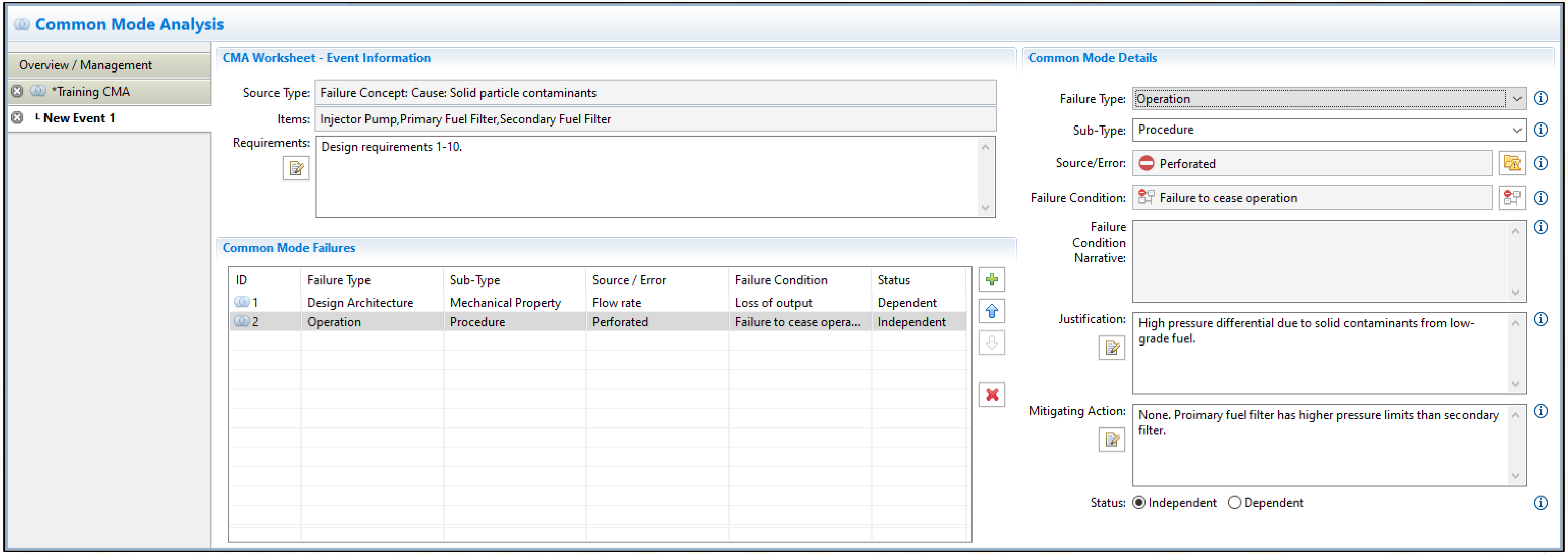
EXERCISE 3.6.5 CREATE COMMON MODE FAILURE (CONTINUED)

- Select Failure Condition: **Failure to cease operation**
- Enter Justification: **High pressure differential due to solid contaminants from low-grade fuel.**
- Enter Mitigating Action: **None. Primary fuel filter has higher pressure limits than secondary filter.**
- Select Status: **Independent**



Session 3.6: Common Mode Analysis (CMA)

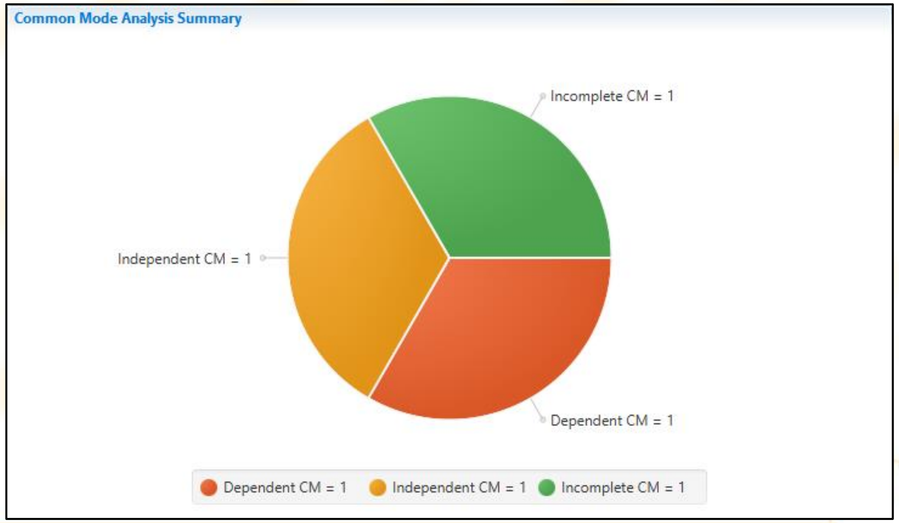
EXERCISE 3.6.5 CREATE COMMON MODE FAILURES (CONTINUED)



Session 3.6: Common Mode Analysis (CMA)

<u>Exercise 3.6.5 Create Common Mode Failures (Continued)</u>

- Create a third Common Mode Failure by selecting ✚
  - Verify common mode failure in first row of table with ID of 3 & Status Incomplete
- Select Failure Type & Sub-Type: **Maintenance, Personnel**
- Select Source / Error icon to open dialog:
  - Search for **Insufficient cleaning** (Maintenance → Procedure) then select OK
- Leave all other fields blank
- Verify Status for current Common Mode Failure as **Incomplete**
- Return to **Overview/Management** tab
  - Verify Common Mode Analysis Summary Graph



Session 3.6: Common Mode Analysis (CMA)

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EXERCISE 3.6.5 CREATE COMMON MODE FAILURES (CONTINUED)

Common Mode Analysis

Overview / Management

Training CMA

└ **New Event 1**

CMA Worksheet - Event Information

Source Type: Failure Concept: Cause: Solid particle contaminants

Items: Injector Pump,Primary Fuel Filter,Secondary Fuel Filter

Requirements: Design requirements 1-10.

Common Mode Failures

ID	Failure Type	Sub-Type	Source / Error	Failure Condition	Status
1	Design Architecture	Mechanical Property	Flow rate	Loss of output	Dependent
2	Operation	Procedure	Perforated	Failure to cease opera...	Independent
3	Maintenance	Personnel	Insufficient cleaning		Incomplete

Common Mode Details

Failure Type: Maintenance

Sub-Type: Personnel

Source/Error: Insufficient cleaning

Failure Condition:

Failure Condition Narrative:

Justification:

Mitigating Action:

Status: Independent Dependent

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Session 3.6: Common Mode Analysis (CMA)

Discussion 3.6.6 CMA Report

- This report summarises each CMA, including Common Mode Events & Items
- The CMA Report is divided into sections:
  - CMA Report Summary
  - Common Mode Events
  - Reference Documents, Drawings & Support Material

CMA REPORT SUMMARY

NAME	Training CMA	CREATED DATE	2019/10/28 10:08:20
DESCRIPTION	An example CMA for training purposes.		

COMMON MODE EVENT SUMMARY

	EVENT TYPE	COUNT
1	Total Dependent Events	0
2	Total Independent Events	0
3	Total Incomplete Events	1
	Total Common Mode Events	1

COMMON MODE ITEM SUMMARY

	ITEM TYPE	COUNT
1	Total Dependent Items	1
2	Total Independent Items	1
3	Total Incomplete Items	1
	Total Common Mode Items	3

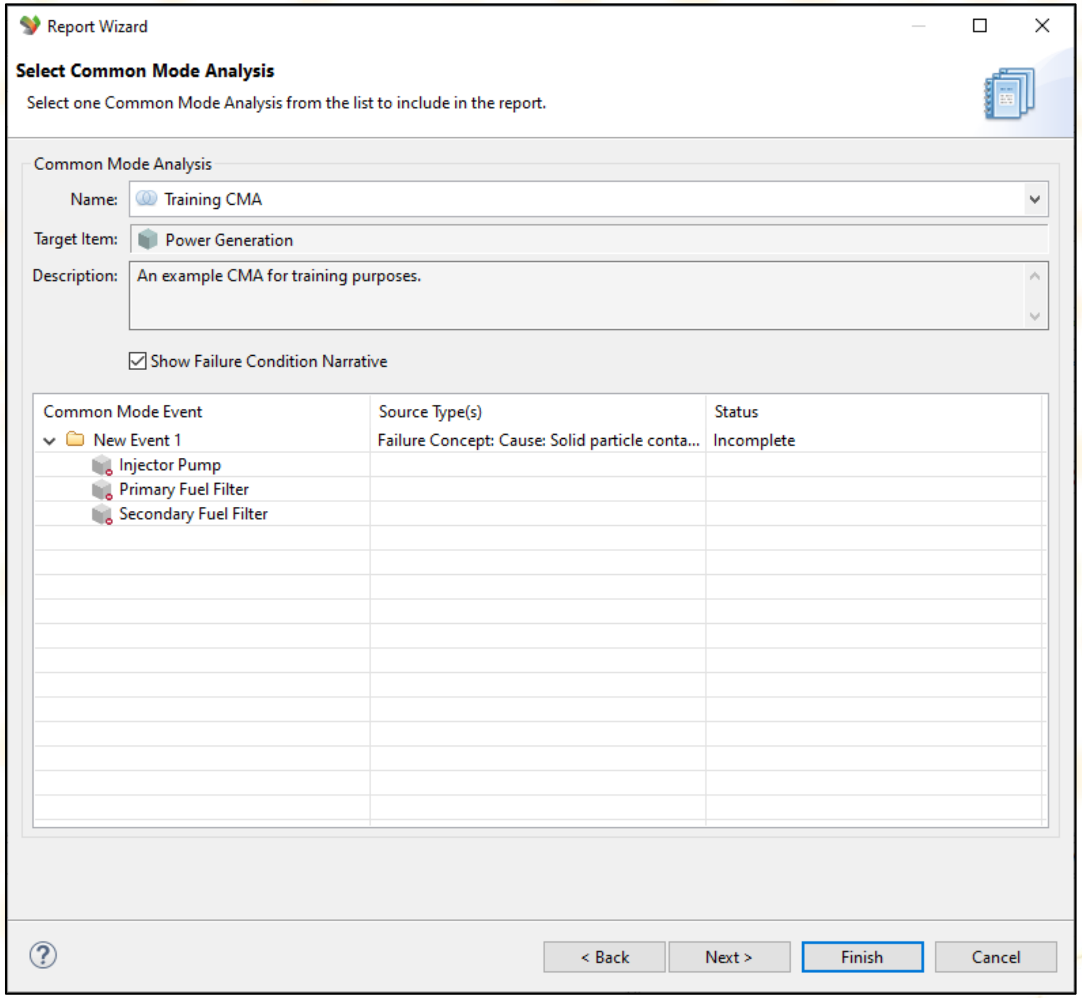
TARGET ITEM	PHYSICAL DESCRIPTION	FUNCTION	FUNCTION NARRATIVE
Power Generation		Convert Mechanical - rotational Torque (Power Generation)	

Session 3.6: Common Mode Analysis (CMA)

EXERCISE 3.6.6 GENERATE CMA REPORT

To generate a CMA Report:

- From the menu bar, select **Report → Report Wizard**
- Select **Common Mode Analysis** then select Next >
- Verify CMA Analysis: **Training CMA**
- Verify Common Mode Event: **New Event 1**
- Select Finish



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Session 3.6: Common Mode Analysis (CMA)

Session 3.6 Summary

- ✓ 3.6.1: CMA in ARP4761 Context
- ✓ 3.6.2: CMA Editor Layout
- ✓ 3.6.3: Common Mode Item Search
- ✓ 3.6.4: Common Mode Events
- ✓ 3.6.5: CMA Worksheet
- ✓ 3.6.6: CMA Report

Session 3.7: Functional Fault Tree Analysis (FTA)

<u>Session 3.7 Outline</u>

3.7.1: Fault Tree Builder

3.7.2: Fault Tree Analysis (Model-based)

3.7.3: Custom Fault Tree

3.7.3: Custom Fault Tree Properties

3.7.4: Custom Fault Tree Analysis

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7 Fault Tree Builder

- The Fault Tree Builder identifies all Faults that lead to an End Effect
- Three different fault tree options are presented:
  - **User Defined** allows customization of the Functional Fault Tree
  - **Model-based Analysis** automatically generated the Functional Fault Tree according to the model
  - **Hardware Fault Tree** generated the Fault Tree based on the RBD

❖ Note: Hardware Fault Tree will be covered in Session 4.6.

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7 Fault Tree Builder (Continued)

- The Functional Fault Tree Builder allows customization of the Fault Tree
- Various gates can be implemented to represent a specific configuration / use case
    - AND
    - OR
    - K of N
    - Transfer
- Various Events can be assigned to the root cause
    - Basic Event
    - House Event
    - Undeveloped Event

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7 Fault Tree Builder (Continued)

- Event Types and Probability of Failure can be specified using the **Properties** viewer
- Types of Gates:
  - AND gates represents the output flow occurring if all inputs occur
  - OR gates represent the output flow occurring if any one of the input flows occur
  - K of N gates represent the output flow occurring only if ‘K’ of the input flows occur
  - Transfer gates breaks up the fault tree into separate diagrams whilst maintaining connectivity. This is particularly useful when the fault tree gets large in size and become hard to follow. It will assist in presenting the fault tree in a readable manner, allowing sections of the fault trees to be separated. There is no mathematical calculations involved with the Transfer gate.

Session 3.7: Functional Fault Tree Analysis (FTA)

<u>DISCUSSION 3.7 FAULT TREE BUILDER (CONTINUED)</u>

- Types of Events:

Basic Event is an event which does not develop any further

House Event is an event which is normally expected to occur

Undeveloped Event is an event which is not further developed either because it is of insufficient consequence or because information is unavailable

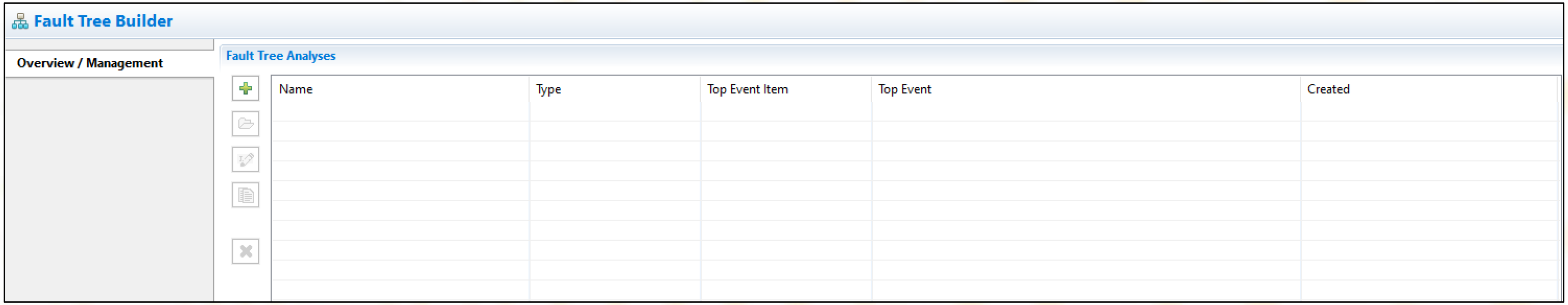
- Event Properties:
  - Event ID: Pre-assigned ID for the Fault Tree branch
  - Event Code: Custom event code to display on the Fault Tree, this field can be used to capture repeat events
  - Narrative: Text field to add additional details of the event

Session 3.7: Functional Fault Tree Analysis (FTA)

<u>Exercise 3.7.1 Fault Tree Builder (Model-based)</u>

To create a Model-based Functional Fault Tree:

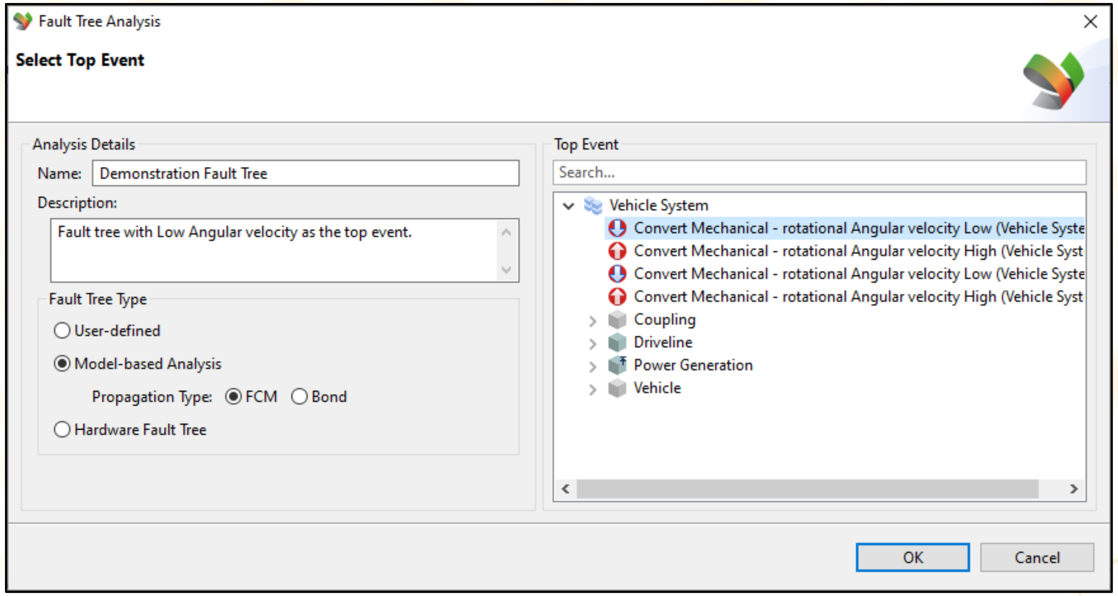
- Right-click the **'Power Generation'** in the Project Explorer
- Select **Fault Tree → Fault Tree Builder**
  - This will be the landing page for the Fault Tree Builder where all Fault Tree analyses will be listed



Session 3.7: Functional Fault Tree Analysis (FTA)

EXERCISE 3.7.1 FAULT TREE BUILDER (MODEL-BASED) (CONTINUED)

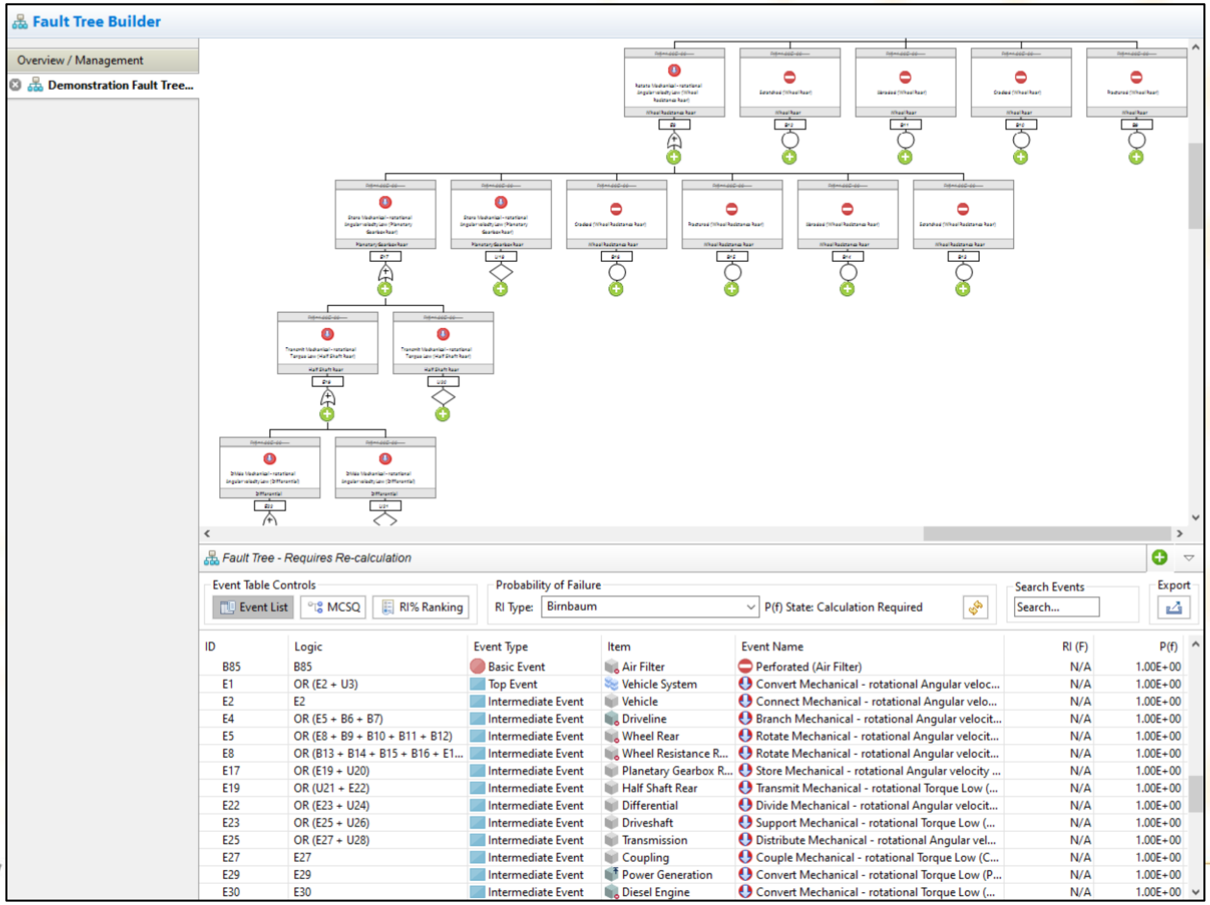
- Set the first **Convert Mechanical – rotational Angular velocity Low (Vehicle System)** as the Top Event
- Enter the following details:
  - Name: **Demonstration Fault Tree Analysis**
  - Description: **Fault tree with Low Angular velocity as the top event**
  - Set Fault Tree Type to **Model-based Analysis**
  - Set Propagation Type to **FCM**
- Select OK to generate the fault tree

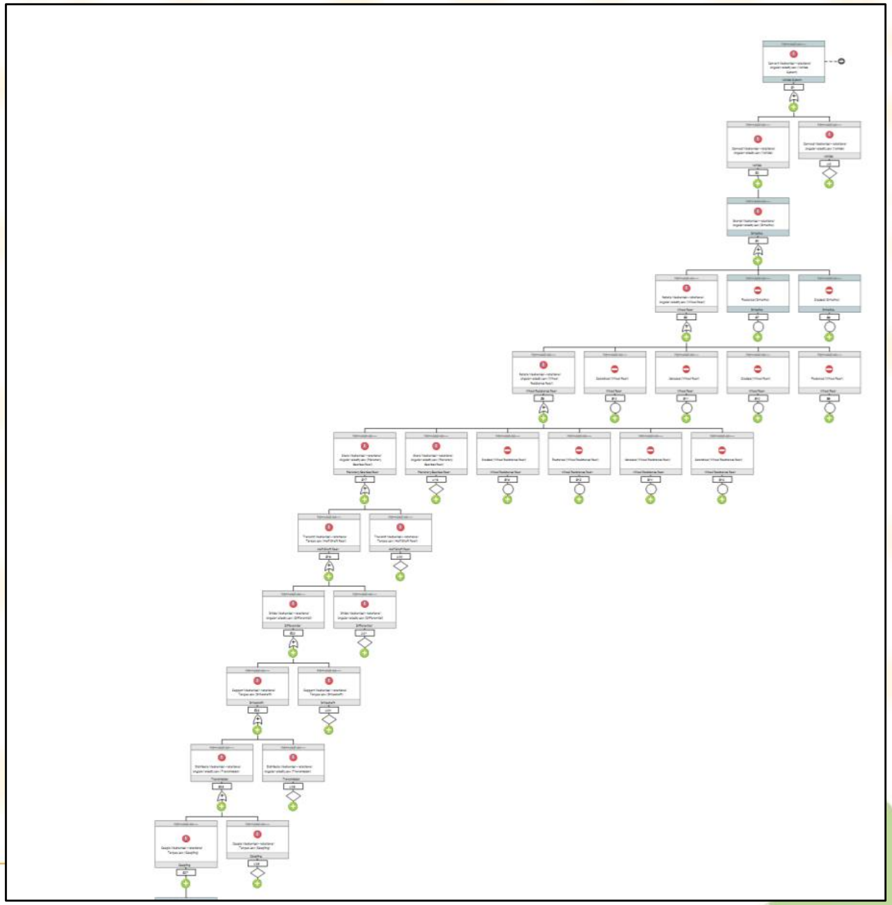


Session 3.7: Functional Fault Tree Analysis (FTA)

<u>EXERCISE 3.7.1 FAULT TREE BUILDER (MODEL-BASED) (CONTINUED)</u>

- Fault tree is generated from the model

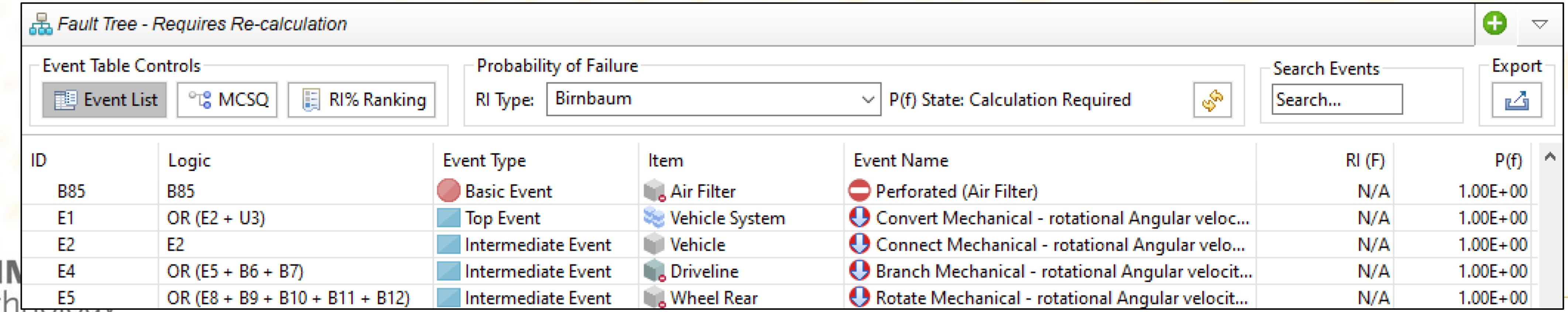




Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.2 Fault Tree Analysis (Model-based)

- The Fault Tree analysis page displays the Fault tree as well as Analysis controls in the window below
- Edit Mode allow change to be made to the Fault Tree
- Event Table Controls:
  - Event List displays all the elements within the fault tree with the respective analysis data
  - MCSQ displays the minimum cut-set sequences of the fault tree
  - RI % Ranking displays the relative importance
- Calculations on the fault tree are derived from Minimum Cut-set Sequence methodology which considers repeat events

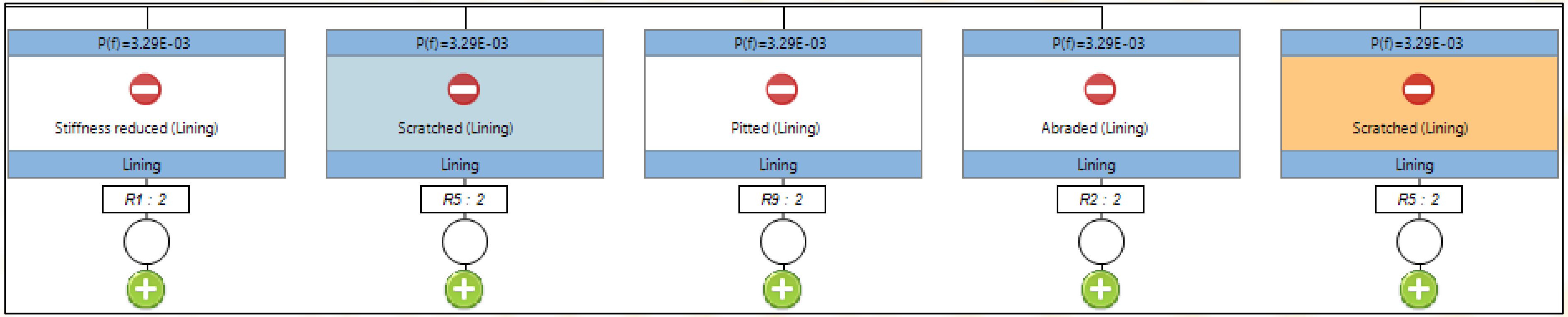


ID	Logic	Event Type	Item	Event Name	RI (F)	P(f)
B85	B85	Basic Event	Air Filter	Perforated (Air Filter)	N/A	1.00E+00
E1	OR (E2 + U3)	Top Event	Vehicle System	Convert Mechanical - rotational Angular veloc...	N/A	1.00E+00
E2	E2	Intermediate Event	Vehicle	Connect Mechanical - rotational Angular velo...	N/A	1.00E+00
E4	OR (E5 + B6 + B7)	Intermediate Event	Driveline	Branch Mechanical - rotational Angular velocit...	N/A	1.00E+00
E5	OR (E8 + B9 + B10 + B11 + B12)	Intermediate Event	Wheel Rear	Rotate Mechanical - rotational Angular velocit...	N/A	1.00E+00

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.2 Fault Tree Analysis (Model-based) (continued)

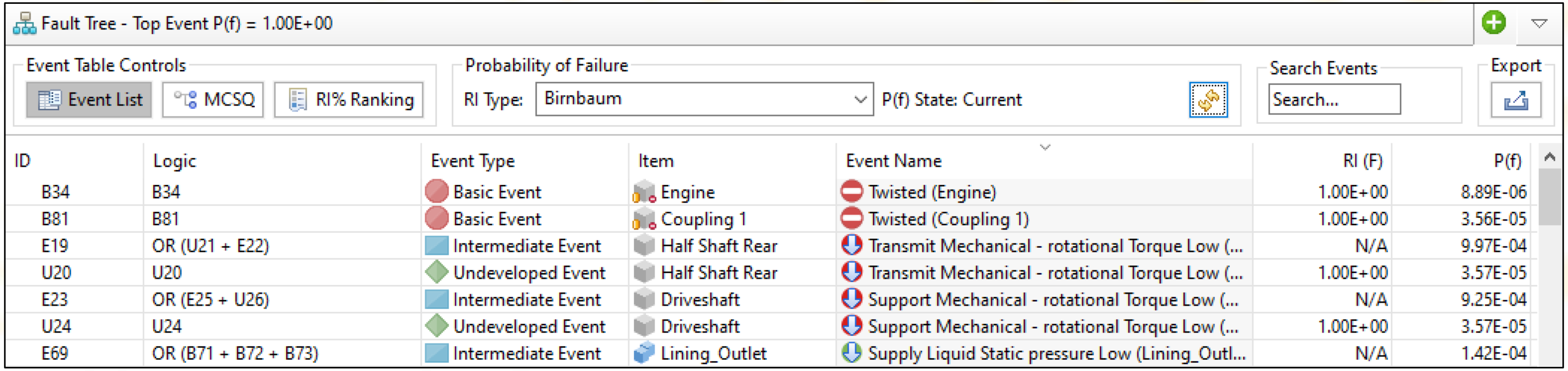
- Repeat events can be modelled in the fault tree and are denoted by the same Event code
- The notation for repeat event codes in MADe is **Event Code : Number of repeats**
- Once a repeat event is selected, the repeat events are also highlighted



Session 3.7: Functional Fault Tree Analysis (FTA)

<u>DISCUSSION 3.7.2 FAULT TREE ANALYSIS (MODEL-BASED) (CONTINUED)</u>

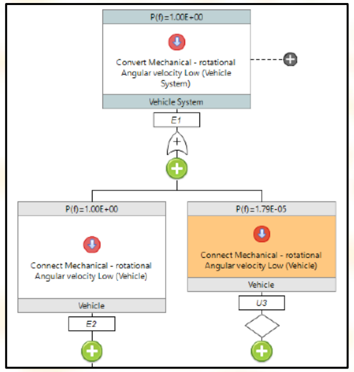
- Probability of Failure Relative Importance type:
  - Birnabaum: A value assigned to each basic event indicating its relative increase to risk of failure
  - Fussel-Vesely: A value assigned to each basic event indicating its contribution to the top level event failure
- Refresh and Calculate the P(f) values by selecting
- Select to export the table to a .csv



ID	Logic	Event Type	Item	Event Name	RI (F)	P(f)
B34	B34	Basic Event	Engine	Twisted (Engine)	1.00E+00	8.89E-06
B81	B81	Basic Event	Coupling 1	Twisted (Coupling 1)	1.00E+00	3.56E-05
E19	OR (U21 + E22)	Intermediate Event	Half Shaft Rear	Transmit Mechanical - rotational Torque Low (...	N/A	9.97E-04
U20	U20	Undeveloped Event	Half Shaft Rear	Transmit Mechanical - rotational Torque Low (...	1.00E+00	3.57E-05
E23	OR (E25 + U26)	Intermediate Event	Driveshaft	Support Mechanical - rotational Torque Low (...	N/A	9.25E-04
U24	U24	Undeveloped Event	Driveshaft	Support Mechanical - rotational Torque Low (...	1.00E+00	3.57E-05
E69	OR (B71 + B72 + B73)	Intermediate Event	Lining_Outlet	Supply Liquid Static pressure Low (Lining_Outl...	N/A	1.42E-04

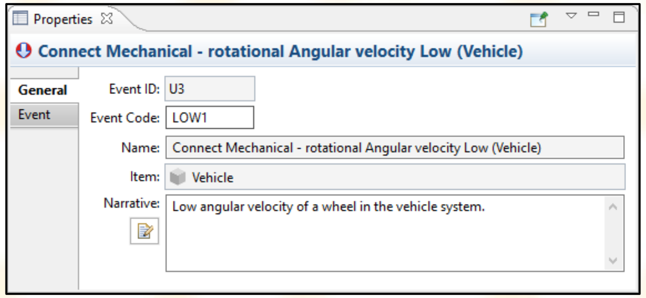
Session 3.7: Functional Fault Tree Analysis (FTA)

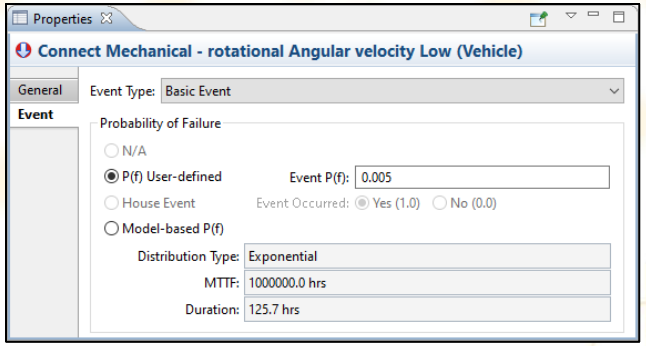
EXERCISE 3.7.2 FAULT TREE ANALYSIS (MODEL-BASED)



To modify the Event Type and P(f) of a fault:

- Select the **Convert Mechanical – rotational Angular velocity Low (Vehicle)** Undeveloped event
- Navigate to the **Properties viewer** and input the following
    - General Tab:
        - Event Code: **LOW1**
        - Narrative: **Low angular velocity of a wheel in the vehicle system.**
    - Event Tab:
        - Event Type: **Basic Event**
        - Probability of Failure: P(f) User-defined, Event P(f): **0.005**





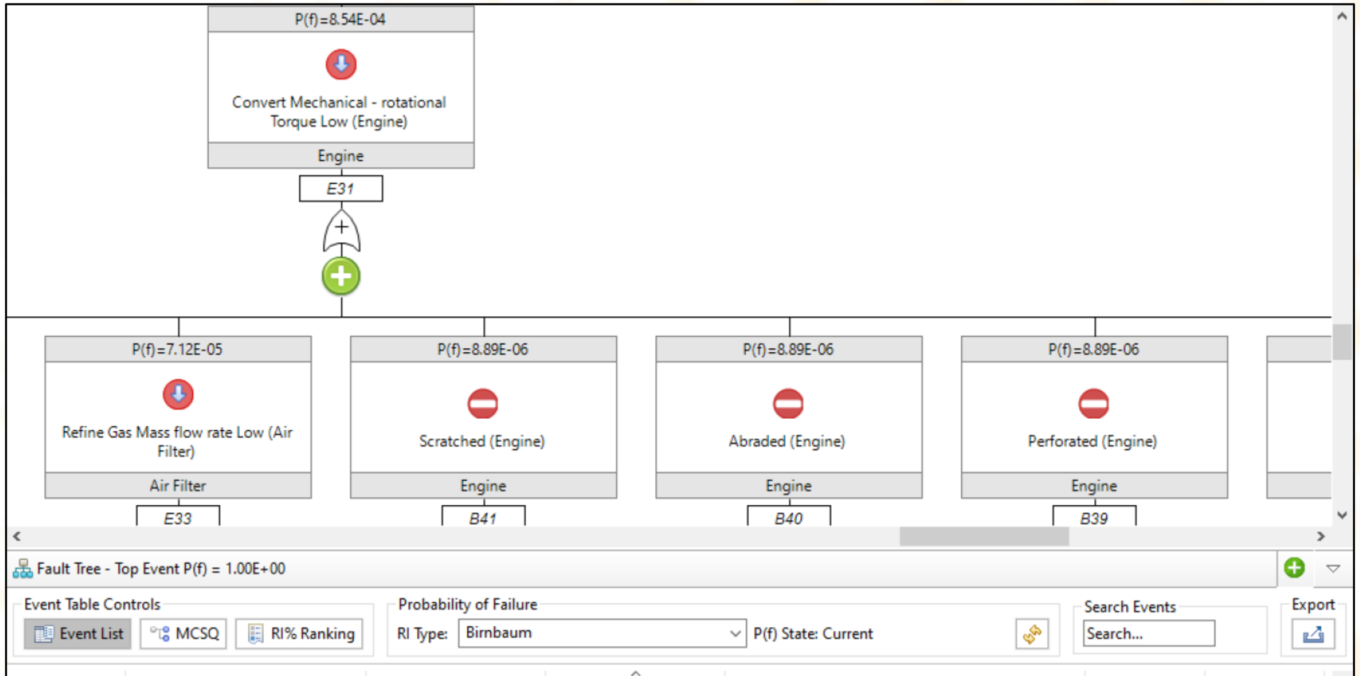
❖ Note: Intermediate Events cannot be changed

❖ Note: Although we have specified Model-based for the analysis, there is the option to manually adjust P(f) as required.

Session 3.7: Functional Fault Tree Analysis (FTA)

EXERCISE 3.7.2 FAULT TREE ANALYSIS (MODEL-BASED) (CONTINUED)

- Calculate the P(f) of the Fault tree by selecting



ID	Logic	Event Type	Item	Event Name	RI (F)	P(f)
B59	B59	Basic Event	Secondary Fuel Filter	Outgrowths (Secondary Fuel Filter)	1.00E+00	1.78E-05
E43	OR (B56 + B57 + B58 + B59 + E6...	Intermediate Event	Secondary Fuel Filter	Refine Liquid Flow rate Low (Secondary Fuel Fil...	N/A	4.98E-04
E25	OR (E27 + U28)	Intermediate Event	Transmission	Distribute Mechanical - rotational Angular velo...	N/A	8.90E-04
U26	U26	Undeveloped Event	Transmission	Distribute Mechanical - rotational Angular velo...	1.00E+00	3.57E-05
LOW1	LOW1	Basic Event	Vehicle	Connect Mechanical - rotational Angular veloci...	1.00E+00	5.00E-03

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.3 Custom Fault Tree

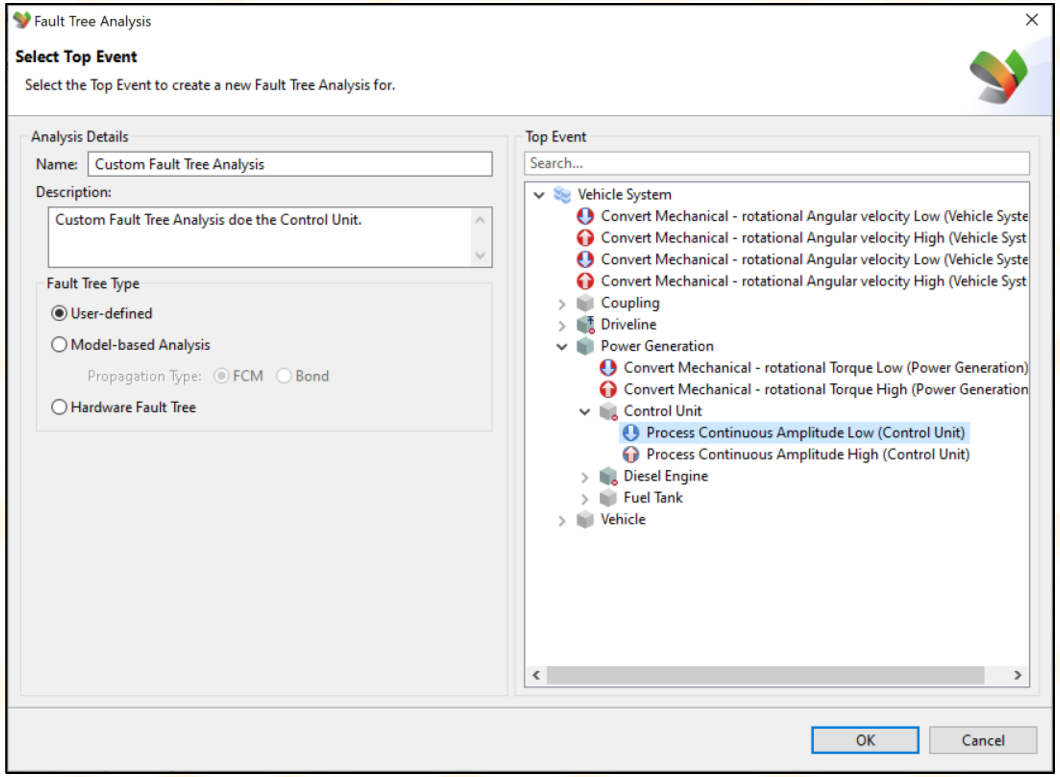
- User-defined fault trees can be created to represent specific scenarios to calculate the probability of failure
- The custom fault tree capability allows events to be added in the order the user specifies as well as allowing the Probability of failure to be manually entered
- Failure conditions can be associated with the top event to provide context of the top event failure

Session 3.7: Functional Fault Tree Analysis (FTA)

Exercise 3.7.3 Custom Fault Tree

To create a Custom Function Fault Tree Analysis:

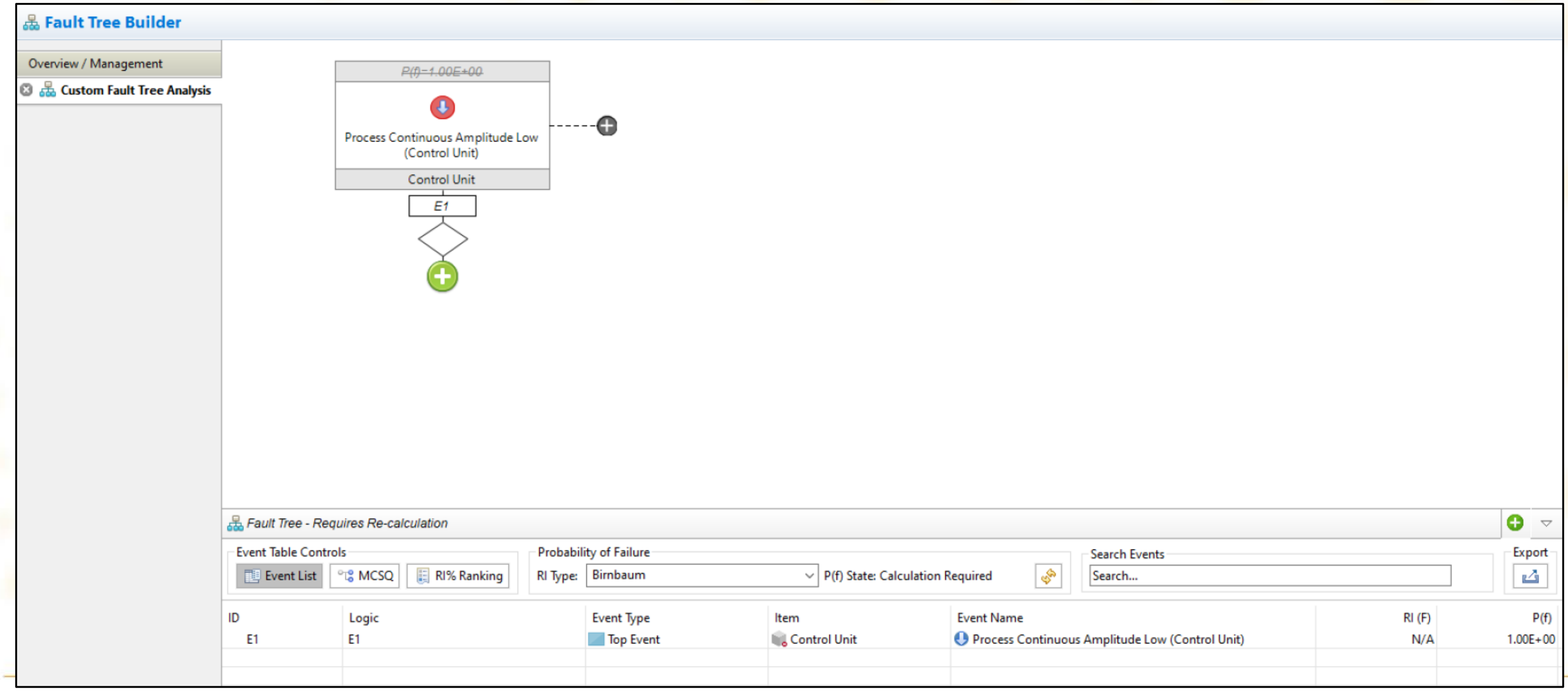
- On the **Fault Tree Builder landing page**, select
- In the dialogue, enter the following:
  - Name: **Custom Fault Tree Analysis**
  - Description: **Custom Fault Tree Analysis doe the Control Unit.**
  - Select **Process Continuous Amplitude Low (Control Unit)** as the top event



Session 3.7: Functional Fault Tree Analysis (FTA)

EXERCISE 3.7.3 CUSTOM FAULT TREE (CONTINUED)

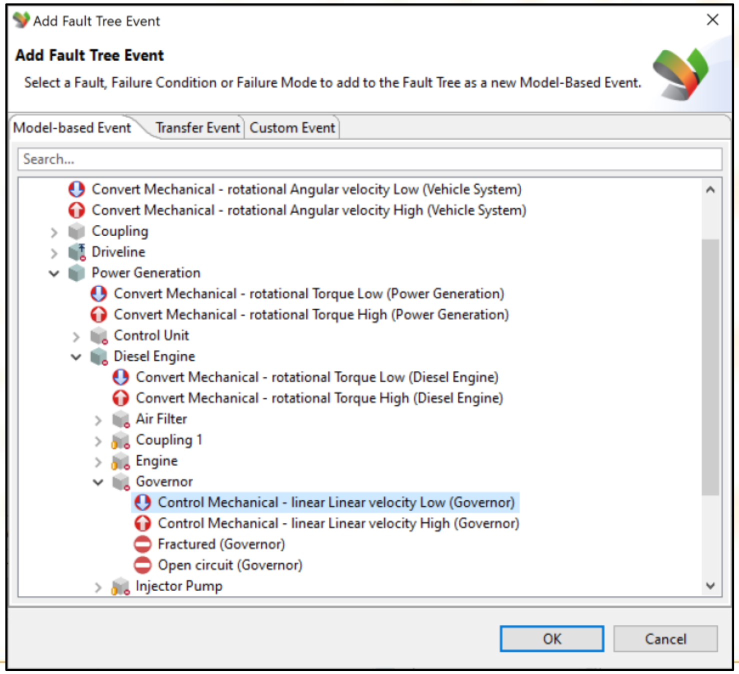
- The Fault Tree Builder will place the Top Event on the Fault Tree Builder canvas
  - By default it is set to the 'Modeling mode'. This can be toggled selecting
  - Fault Tree – Event list can be viewed or hidden by selecting

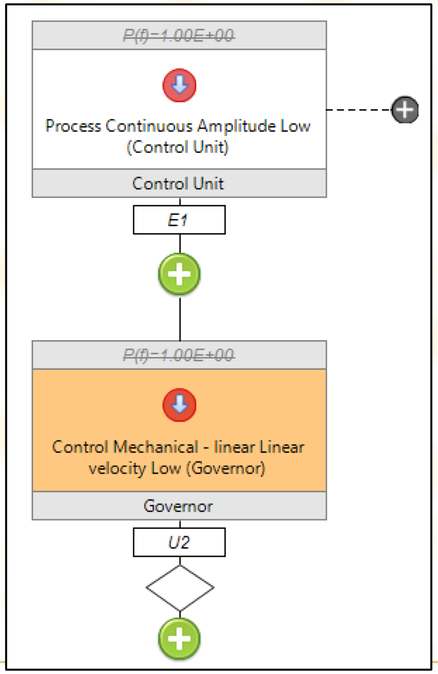


Session 3.7: Functional Fault Tree Analysis (FTA)

EXERCISE 3.7.2 CUSTOM FAULT TREE (CONTINUED)

- Select ⊕ under the top event to build the fault tree in sequential order
- In the **Add Fault Tree Event** dialog select the **Model Event** tab
- Select **Process Continuous Amplitude Low Govenor)** to add event to the Custom Fault Tree



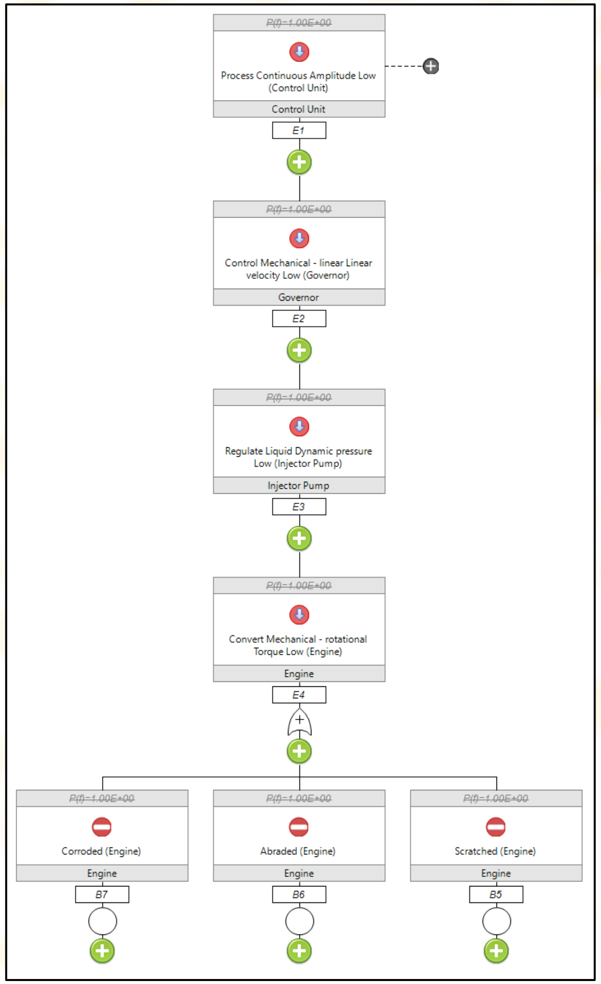


Session 3.7: Functional Fault Tree Analysis (FTA)

EXERCISE 3.7.2 CUSTOM FAULT TREE (CONTINUED)

Proceed to build the fault tree using the information below

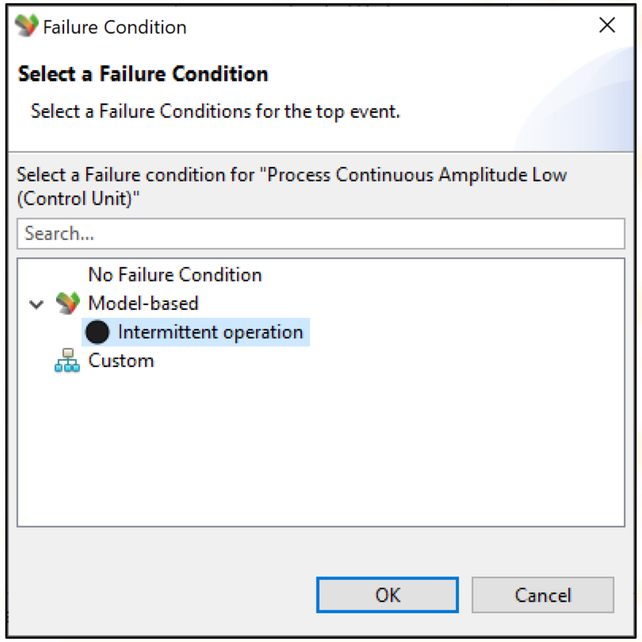
- Top event: **Process Continuous Amplitude Low (Control Unit)**
- Next Intermediate Event: **Convert Mechanical – rotational linear Linear Velocity Low (Governor)**
- Next Intermediate Event: **Regulate Liquid Dynamic pressure Low (Injector Pump)**
- Next Intermediate Event: **Convert Mechanical – rotational Torque Low (Engine)**
- Basic Events: **Corroded (Engine), Abraded (Engine), Scratched (Engine)**

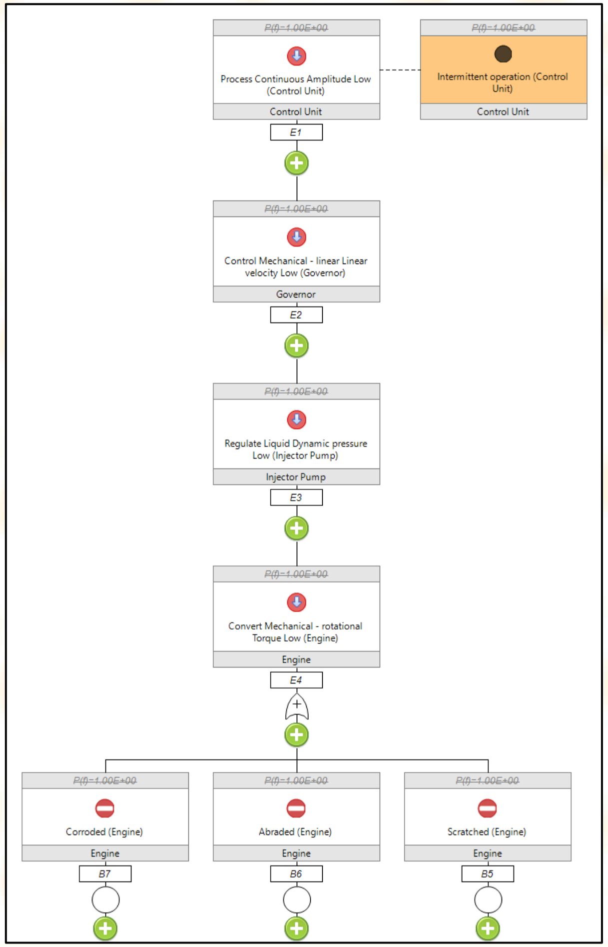


Session 3.7: Functional Fault Tree Analysis (FTA)

Exercise 3.7.2 Custom Fault Tree (Continued)

- Select the ⊕ icon to add a Failure Condition to the top event
- Expand the Model-based tree and select **Intermittent operation**
- Select OK to add the Failure Condition to the tree



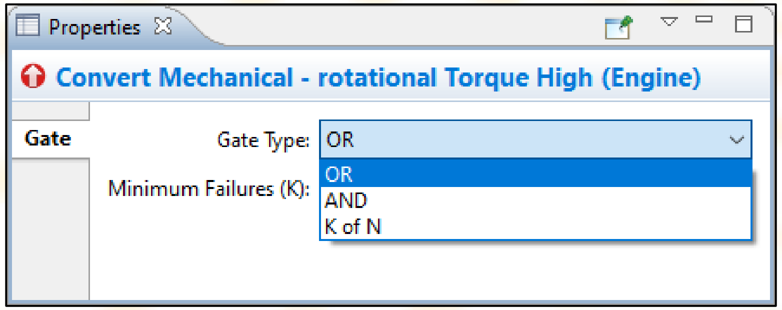


Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.3 Custom Fault Tree Properties

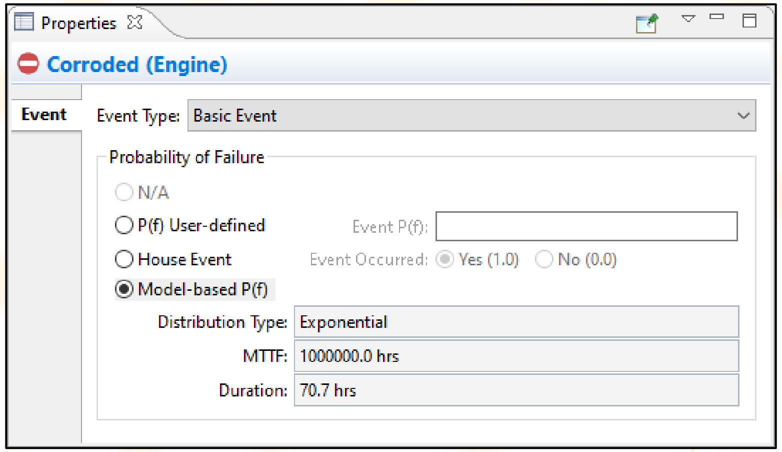
The default gate type in the Fault Tree is an OR gate.
To change a Gate Type:

- Select the Gate
- In the Properties viewer, use the drop down menu to select the Gate Type
- Alternatively, use the icon toolbar and select the appropriate gate



To change an Event Type:

- Select the Event
- In the Property window, use the drop down menu to select the Event Type
- Alternatively, use the icon toolbar and select the appropriate event type



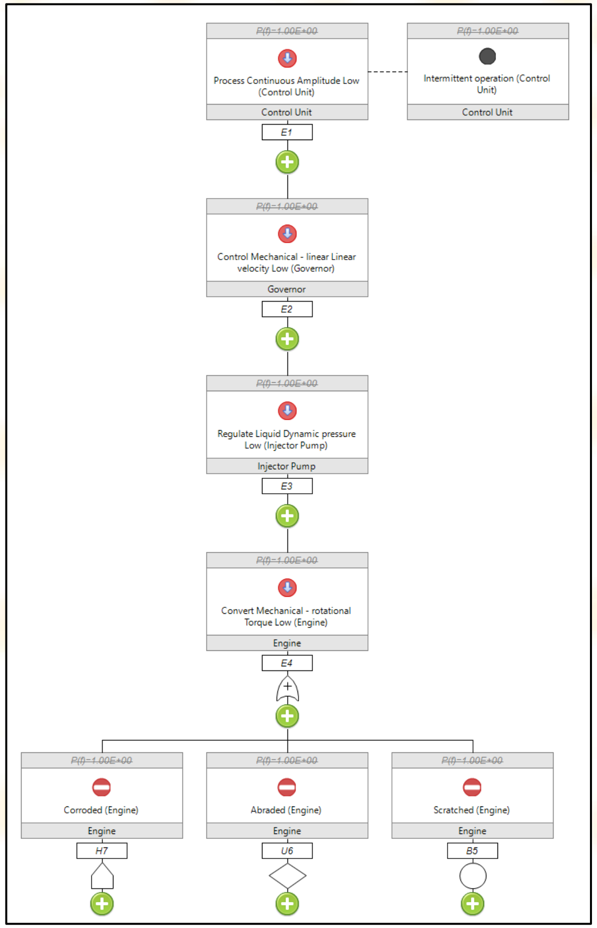
Session 3.7: Functional Fault Tree Analysis (FTA)

Exercise 3.7.3 Custom Fault Tree Properties (continued)

Verify that the gate connecting Convert Mechanical – rotational Torque High (Engine) to the faults is an OR gate.

Change the following events:

- Corroded (Engine): House event
    - Event Occurred: No (0.0)
- Abraded (Engine): Undeveloped Event



Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.4 Custom Fault Tree Analysis

- In the Fault Tree – Event List view there are three different tables which can be viewed:
  - Event List
  - MCSQ
  - RI% Ranking

Fault Tree - Requires Re-calculation

Event Table Controls: Event List | MCSQ | RI% Ranking

Probability of Failure: RI Type: Birnbaum — P(f) State: Stale

Search Events: Search...

Export

ID	Logic	Event Type	Item	Event Name	RI (F)	P(f)
B5	B5	Basic Event	Engine	Scratched (Engine)	N/A	1.00E+00
E1	E1	Top Event	Control Unit	Process Continuous Amplitude Low (Control Unit)	N/A	1.00E+00
E2	E2	Intermediate Event	Governor	Control Mechanical - linear Linear velocity Low (Governor)	N/A	1.00E+00
E3	E3	Intermediate Event	Injector Pump	Regulate Liquid Dynamic pressure Low (Injector Pump)	N/A	1.00E+00
E4	OR (B5 + U6 + H7)	Intermediate Event	Engine	Convert Mechanical - rotational Torque Low (Engine)	N/A	1.00E+00
H7	H7	House Event	Engine	Corroded (Engine)	N/A	1.00E+00
U6	U6	Undeveloped Event	Engine	Abraded (Engine)	N/A	1.00E+00

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.4 Custom Fault Tree Analysis (Continued)

- Event List
  - The event list shows the fault tree content in a list form.
  - The Relative Importance column is calculated using one of two methods:
    - Birnbaum
    - Fussell-Vesely

Fault Tree - Requires Re-calculation

Event Table Controls: Event List | MCSQ | RI% Ranking

Probability of Failure: RI Type: Birnbaum | P(f) State: Stale

Search Events: Search...

Export

ID	Logic	Event Type	Item	Event Name	RI (F)	P(f)
B5	B5	Basic Event	Engine	Scratched (Engine)	N/A	1.00E+00
E1	E1	Top Event	Control Unit	Process Continuous Amplitude Low (Control Unit)	N/A	1.00E+00
E2	E2	Intermediate Event	Governor	Control Mechanical - linear Linear velocity Low (Governor)	N/A	1.00E+00
E3	E3	Intermediate Event	Injector Pump	Regulate Liquid Dynamic pressure Low (Injector Pump)	N/A	1.00E+00
E4	OR (B5 + U6 + H7)	Intermediate Event	Engine	Convert Mechanical - rotational Torque Low (Engine)	N/A	1.00E+00
H7	H7	House Event	Engine	Corroded (Engine)	N/A	1.00E+00
U6	U6	Undeveloped Event	Engine	Abraded (Engine)	N/A	1.00E+00

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.4 Custom Fault Tree Analysis (Continued)

- MCSQ (Minimum Cut-set Sequence)
  - Displays the minimum cut set with the relevant information.

Fault Tree - Top Event P(f) = 1.78E-05

Event Table Controls: Event List | MCSQ | RI% Ranking

Probability of Failure: RI Type: Ith | P(f) State: Current

Search Events: Search...

Export

ID	Cut Set	Logic	RI% (F)	P(f)
C1	Min. Cut Set 1	U6	50%	8.89E-06
U6	Abraded (Engine)		N/A	8.89E-06
C2	Min. Cut Set 2	B5	50%	8.89E-06
B5	Scratched (Engine)		N/A	8.89E-06
C3	Min. Cut Set 3	H7	< 0.01%	0.00E+00
H7	Corroded (Engine)		N/A	0.00E+00

Session 3.7: Functional Fault Tree Analysis (FTA)

Discussion 3.7.4 Custom Fault Tree Analysis (Continued)

- RI% Ranking
  - Displays the list of root causes and the calculated relative importance

Fault Tree - Top Event P(f) = 1.78E-05

Event Table Controls: Event List | MCSQ | RI% Ranking

Probability of Failure: RI Type: Birnbaum | P(f) State: Current

Search Events: Search...

Export

ID	Event Type	Item	Event Name	BIM	FV	P(f)
B5	Basic Event	Engine	Scratched (Engine)	1.00E+00	5.00E-01	8.89E-06
H7	House Event	Engine	Corroded (Engine)	1.00E+00	0.00E+00	0.00E+00
U6	Undeveloped Event	Engine	Abraded (Engine)	1.00E+00	5.00E-01	8.89E-06

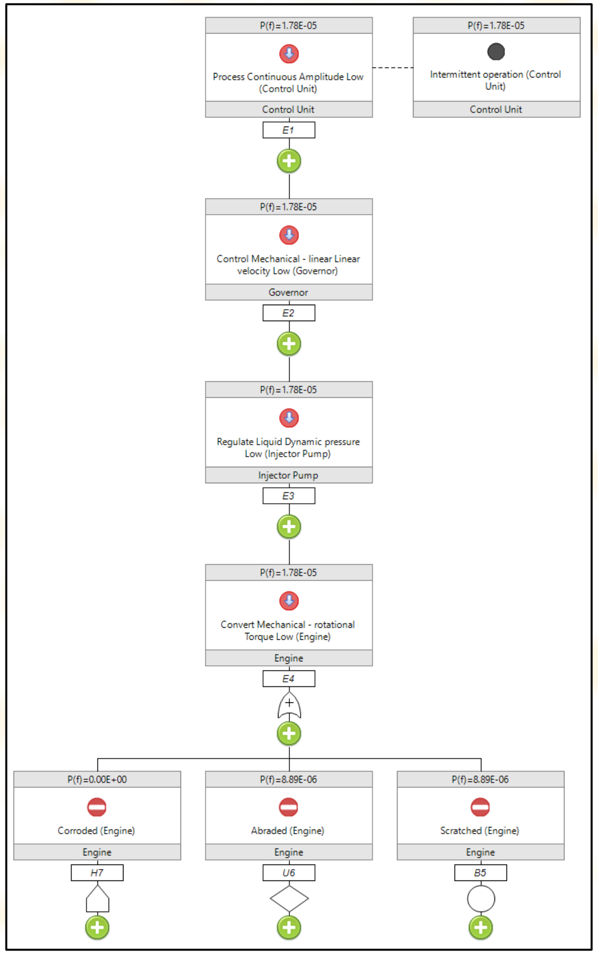
Session 3.7: Functional Fault Tree Analysis (FTA)

EXERCISE 3.7.4 CUSTOM FAULT TREE ANALYSIS

To refresh / calculate the Custom Fault Tree P(f):

- Select 
- Verify the P(f) of the Fault Tree Analysis with the table below

Event	P(f)
Intermittent operation (Control Unit)	1.78 E-05
Process Continuous Amplitude Low (Control Unit)	1.78 E-05
Control Mechanical – linear Linear velocity Low (Governor)	1.78 E-05
Regulate Liquid Dynamic pressure Low (Injector Pump)	1.78 E-05
Convert Mechanical – rotational Torque Low (Engine)	1.78 E-05
Corroded (Engine)	0.00 E+00
Abraded (Engine)	8.89 E-06
Engine (Engine)	8.89 E-06



Session 3.7: Functional Fault Tree Analysis (FTA)

Session 3.7 Summary

- ✓ 3.7.1: Fault Tree Builder
- ✓ 3.7.2: Fault Tree Analysis (Model-based)
- ✓ 3.7.3: Custom Fault Tree
- ✓ 3.7.3: Custom Fault Tree Properties
- ✓ 3.7.4: Custom Fault Tree Analysis

Session 3: Safety Analyses

Session 3 Summary

- ✓ 3.1: Failure Mode & Effects Analysis (FMEA)
- ✓ 3.2: Criticality Analysis
- ✓ 3.3: Revised FMECA
- ✓ 3.4: Critical Item Analysis
- ✓ 3.5: Failure Conditions (FHA)
- ✓ 3.6: Common Mode Analysis
- ✓ 3.7: Functional Fault Tree Analysis

Session 4: Reliability Analyses

Using the MADe Model to generate key analyses from the Reliability and Availability domains

Session 4: Reliability Analyses

Session 4 Outline

4.1: Reliability Block Diagram

4.2: Reliability Allocation

4.3: Reliability Editing

4.4: Failure Rate Prediction

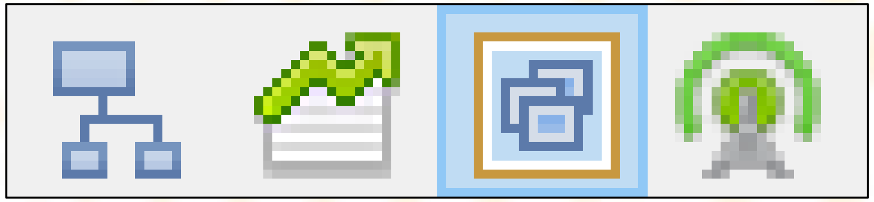
4.5: Markov Analysis

4.6: Hardware Fault Tree Analysis (HFTA)

Session 4: Reliability Analyses

Session 4 Discussion

- Session 4 will take place in the RAM module
- This session will focus on setting up and generating reliability analyses from the MADe model including:
  - RBD
  - Reliability Allocation
  - Failure Rate Prediction (MIL-HBK-217F)
  - Markov Analysis
  - Hardware Fault Tree



Session 4.1: Reliability Block Diagram

Session 4.1 Outline

4.1.1: Reliability & Availability Block Diagrams

4.1.2: Create RBD groups

4.1.3: Create ABD groups

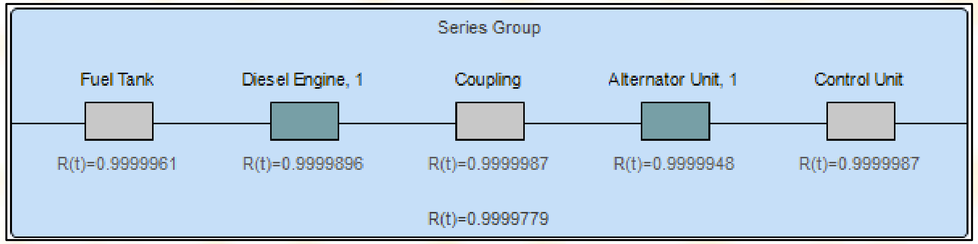
4.1.4: Generate RBD Analysis

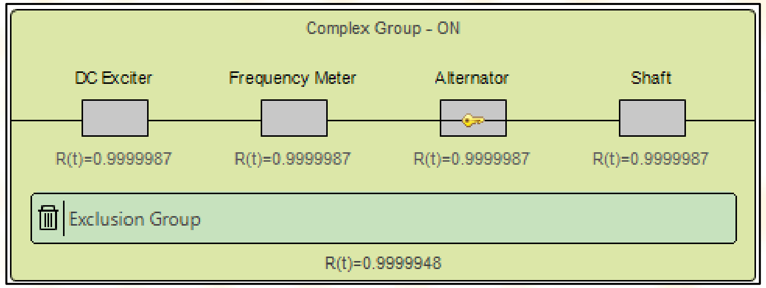
4.1.5: Generate ABD/RBD Report

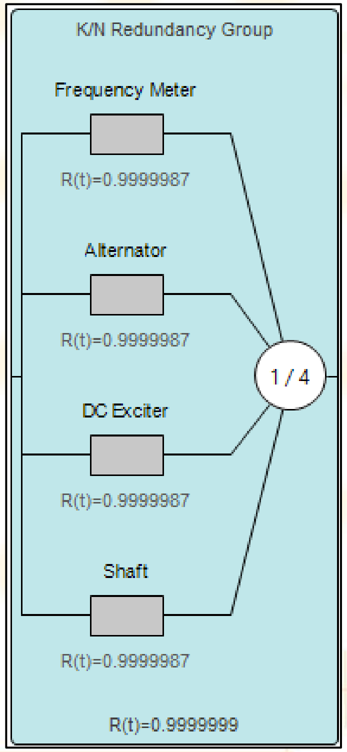
Session 4.1: Reliability Block Diagram

DISCUSSION 4.1.1 RELIABILITY & AVAILABILITY BLOCK DIAGRAMS

- Availability/Reliability Block Diagrams are models showing reliability dependencies between items
- The blocks (subsystems, components, parts) are derived from system model items
- Both Availability and Reliability Block Diagrams share the same model structure
- Types of ABD/RBD groupings in MADe:
  - Series Grouping
  - Parallel Grouping
  - Complex Group (Decomposition)
  - Complex Group (Event Space)
  - Standby Redundancy Grouping
  - K/N Redundancy Grouping
  - Exclusion Grouping





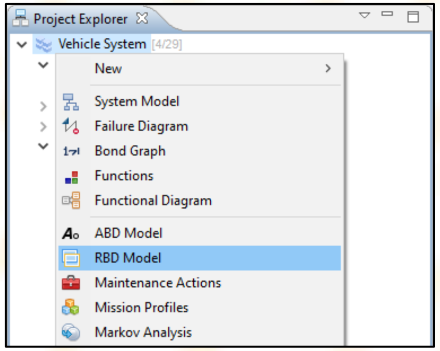


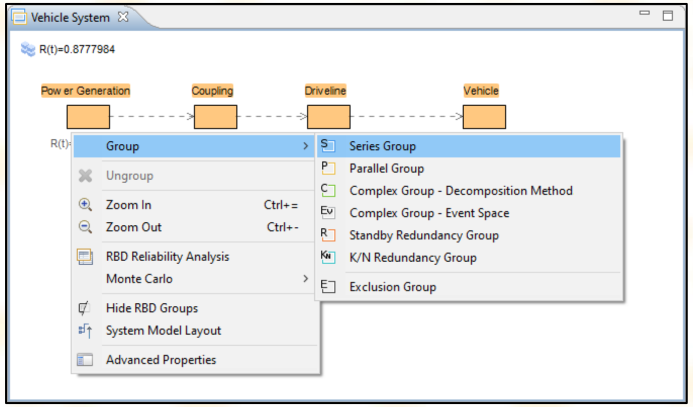
Session 4.1: Reliability Block Diagram

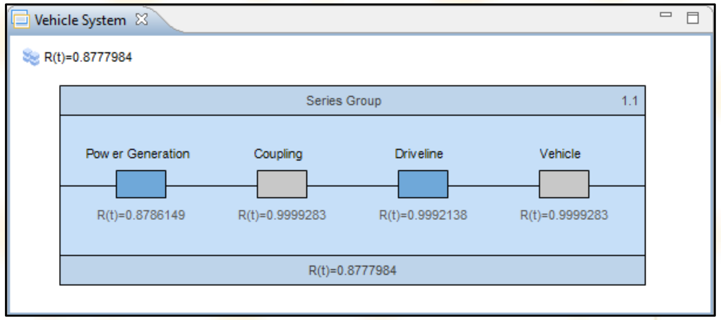
Exercise 4.1.2 Create RBD Groups

To apply a **Series** RBD grouping:

- Right-click **'Vehicle System'** in Project Explorer viewer
- Select **RBD Model**
- Select all items in the RBD Model editor
  - Method 1: Shift + Select
  - Method 2: Select and drag
- Select from icon menu or **Group** → **Series Group** from the right-click menu
- Review reliability of series group and individual subsystems







❖ Note: Within the RBD group, components and subsystems can be rearranged by clicking and dragging

Session 4.1: Reliability Block Diagram

made
decisions better MADe...

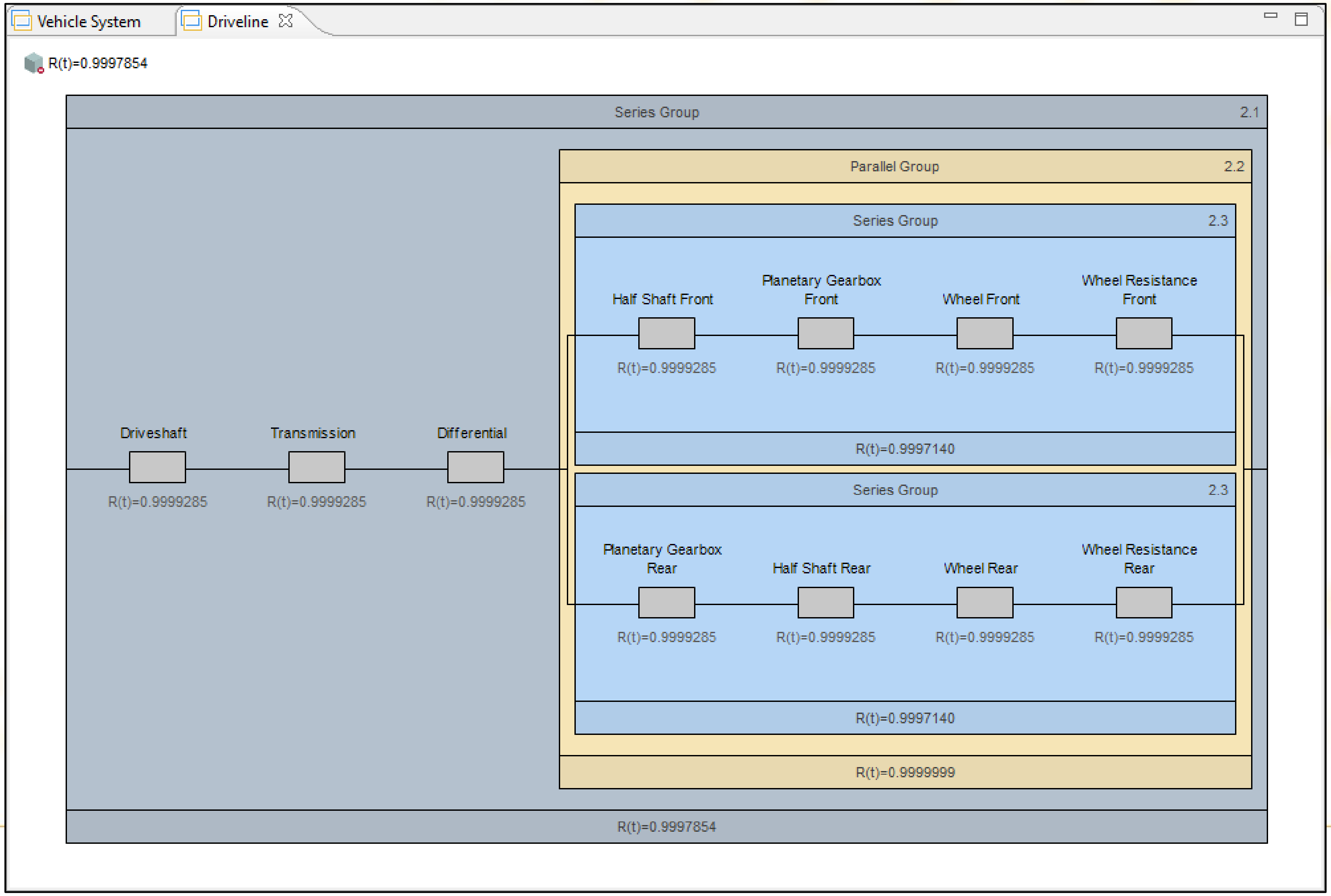
EXERCISE 4.1.2 CREATE RBD GROUPS (CONTINUED)

Continue to apply RBD groupings to items in the Driveline Subsystem:

- Right-click **'Driveline'** Subsystem in Project Explorer & select **RBD Model**
- Create **Series Group #1** and include:
  - **'Half Shaft Rear'**, **'Planetary Gearbox Rear'**, **'Wheel Resistance Rear'** & **'Wheel Rear'**
- Create **Series Group #2** and include:
  - **'Half Shaft Front'**, **'Planetary Gearbox Front'**, **'Wheel Resistance Front'** & **'Wheel Front'**
- Create **Parallel group** for **Series Groups 1 & 2**
- Create **Series group** for remaining items and include **Parallel group**
- Review reliability of top series group and individual sub-groups

Session 4.1: Reliability Block Diagram

EXERCISE 4.1.2 CREATE RBD GROUPS (CONTINUED)

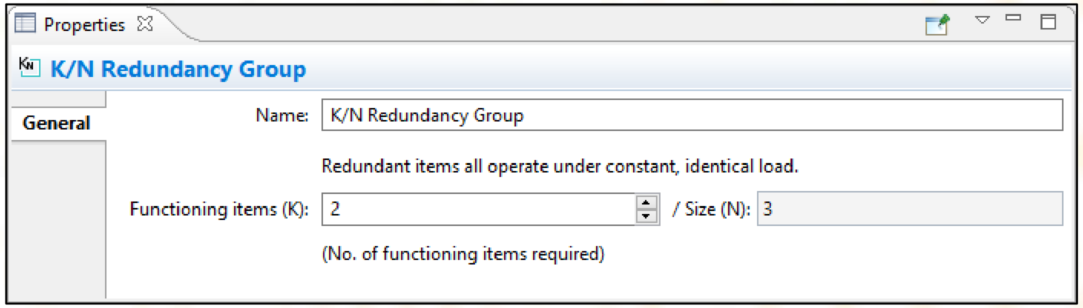


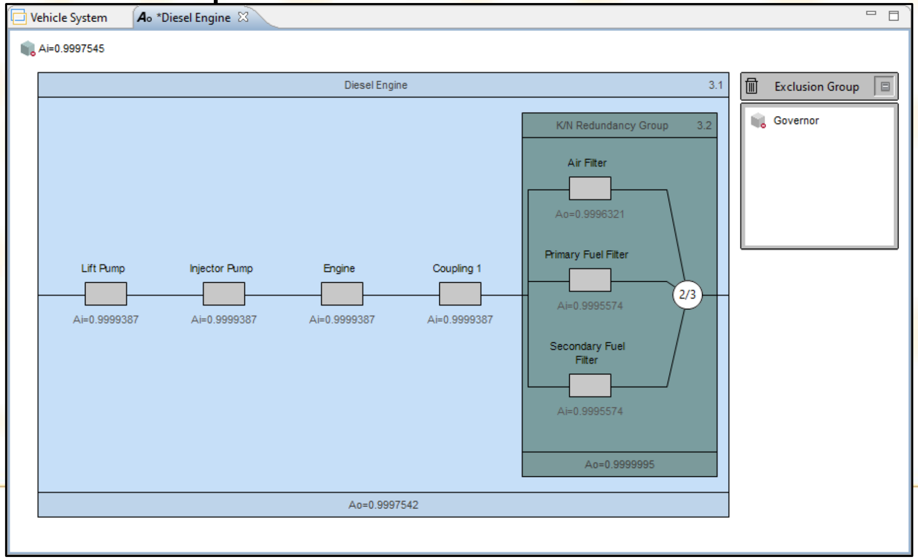
Session 4.1: Reliability Block Diagram

Exercise 4.1.3 Create ABD groups

Create the following ABD groupings to the **'Diesel Engine'** subsystem:

- Right-click on the **'Diesel Engine'** subsystem in Project Explorer and select **ABD Model**
- Create a **K/N Redundancy Group** and include:
  - Air Filter, Primary Fuel Filter & Secondary Fuel Filter
  - Set Functioning items / No. of Redundant Items (Properties viewer): **2/3**
- Create an **Exclusion Group** and place the **'Governor'** in the Exclusion Group

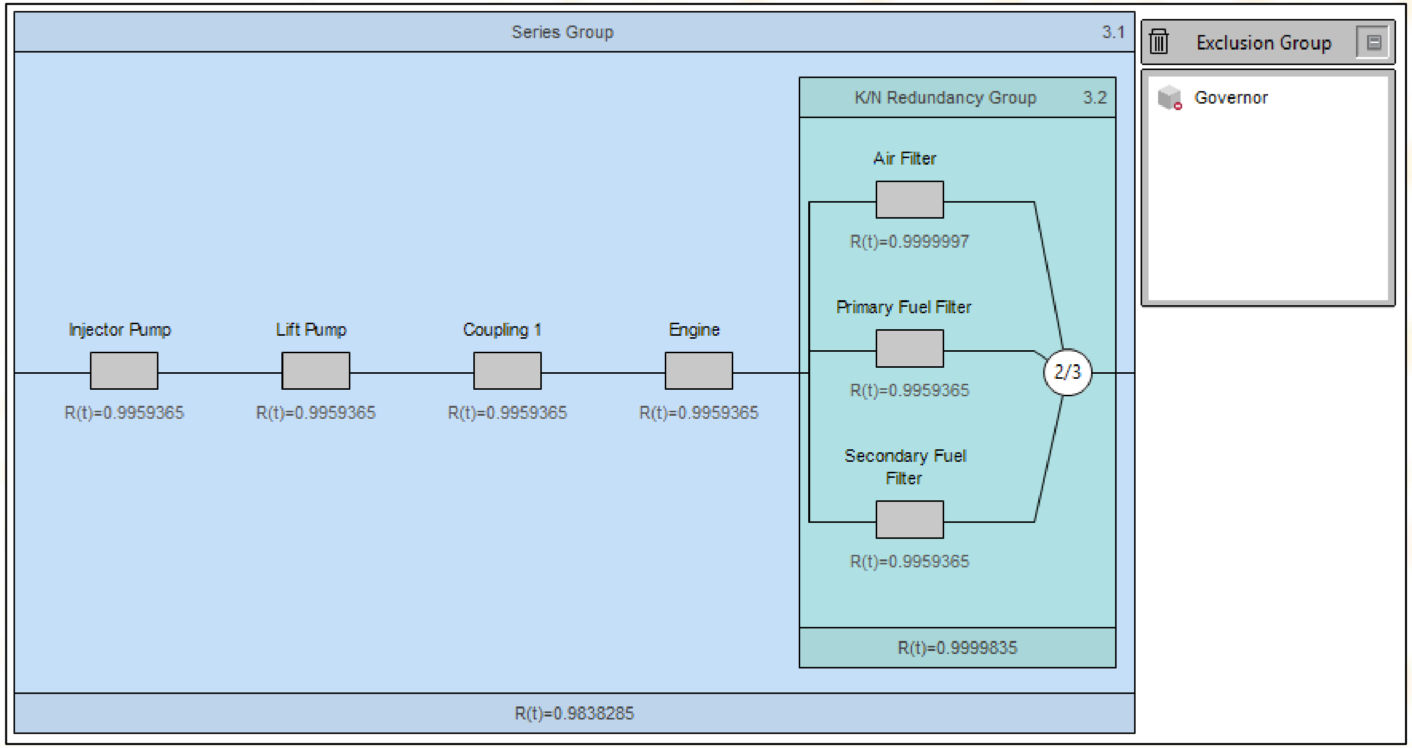




Session 4.1: Reliability Block Diagram

EXERCISE 4.1.3 CREATE ABD GROUPS (CONTINUED)

- Right-click on the **'Diesel Engine'** subsystem in Project Explorer and select **RBD Model**
- Note that the structure matches the ABD Model



Session 4.1: Reliability Block Diagram

Discussion 4.1.4 Generate RBD Analysis

- RBD Analysis uses reliability information (Session 4.3) & RBD Groups (Session 4.4)
- Outputs include:
  - Reliability – Calculated based on the distribution type e.g. $R_i = e^{-\Sigma\lambda_i t}$ for Exponential
  - MTTF – Calculated based on Part Failure Rate
  - Inherent Availability – Based solely on reactive maintenance: $A_I = \frac{MTTF}{MTTF+MTTR}$
  - Operational Availability – Based on preventative maintenance & logistic delay:
    - $A_O = \frac{MTTF}{MTTF+MTTR+DT+\left[\frac{\left(\left(\frac{TT}{MTTF}\right)^S \times TT\right)}{(k+1)!}\right]}$
  - General Reliability & Distribution Type parameters
- Dynamically updates based on changes to the system & reliability parameters

Session 4.1: Reliability Block Diagram

Discussion 4.1.4 Generate RBD Analyses

ABD / RBD

Item	Reliability	MTTF (hrs)	Inherent Availability	Operational Availability	MTTR (hrs)	Replaceable	Duration of Operation (hrs)	Failure Rate (fpmh)	Characteristic Life (hrs)	Slope
Vehicle System	0.9400088	1141.51	0.9988752	0.9985009	1.36	No	70.7			
Series Group	0.9400088	1141.51	0.9988752	0.9985009	1.36		70.7			
Coupling	0.9999293	999999.90	0.9999990	0.9999990	1.00	No	70.7	1.00		
Driveline	0.9997882	194805.18	0.9999970	0.9999970	1.00	No	70.6			
Series Group	0.9997882	194805.18	0.9999970	0.9999970	1.00		70.6			
Parallel Group	0.9999999	374999.98	0.9999999	0.9999999	1.00		70.6			
Series Group	0.9997177	249999.98	0.9999960	0.9999960	1.00		70.6			
Half Shaft Rear	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Planetary Gearbox Rear	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Wheel Rear	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Wheel Resistance Rear	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Series Group	0.9997177	249999.98	0.9999960	0.9999960	1.00		70.6			
Half Shaft Front	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Planetary Gearbox Front	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Wheel Front	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Wheel Resistance Front	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Differential	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Driveshaft	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Transmission	0.9999294	999999.90	0.9999990	0.9999990	1.00	No	70.6	1.00		
Power Generation	0.9403410	1148.10	0.9988802	0.9985059	1.36	No	70.7			
Control Unit	0.9912064	8000.00	0.9996251	0.9992506	3.00	No	70.7	125.00		
Diesel Engine	0.9825932	3885.90	0.9997515	0.9997515	1.26	No	70.7			
Series Group	0.9825932	3885.90	0.9997515	0.9997515	1.26		70.7			
K/N Redundancy Group	0.9999999	24916.48	0.9999999	0.9999999	2.90		70.7			
Air Filter	0.9999996	8929.80	0.9994404	0.9988814	5.00	No	70.7		10000	3.00
Primary Fuel Filter	0.9956196	16095.53	0.9999379	0.9999379	1.00	No	70.7	62.1291		
Secondary Fuel Filter	0.9956196	16095.53	0.9999379	0.9999379	1.00	No	70.7	62.1291		
Coupling 1	0.9956196	16095.53	0.9999379	0.9999379	1.00	No	70.7	62.1291		
Engine	0.9956196	16095.53	0.9999379	0.9999379	1.00	No	70.7	62.1291		
Injector Pump	0.9956196	16095.53	0.9999379	0.9999379	1.00	No	70.7	62.1291		
Lift Pump	0.9956196	16095.53	0.9999379	0.9999379	1.00	No	70.7	62.1291		
Fuel Tank	0.9654894	2011.94	0.9995031	0.9995031	1.00	No	70.7	497.0324		
Inlet	0.9883615	6035.82	0.9998343	0.9998343	1.00	No	70.7	165.6775		

Session 4.1: Reliability Block Diagram

EXERCISE 4.1.4 GENERATE RBD ANALYSIS

To determine the reliability of the Control Unit component:

- From the menu bar, select **Analyses → RBD Analysis**
- Expand the tree and select the **'Control Unit'**
- Verify that Control Unit reliability is **0.9998750**

Analyses | Reports | Preferences | Help

- Fault Tree
- Response Paths
- Connection Matrix
- Common Mode Analysis
- Critical Item Analysis
- Criticality & Reliability Editor
- Diagnostic Analyses
- Failure Rate Prediction
- Markov Analysis
- RBD Analysis
- Reliability Allocation Editor

Properties | Problems | ABD / RBD

Item	Reliability	MTTF (hrs)	Inherent Availability	Operational Availability	MTTR (hrs)	Replaceable	Duration of Operation (hrs)	Failure Rate (fpmh)	Characteristic Life (hrs)	Slope
Vehicle System	0.9389819	955.47	0.9991341	0.9987592	1.00	No	71.7			
Series Group	0.9389819	955.47	0.9991341	0.9987592	1.00		71.7			
Coupling	0.9999283	999999.90	0.9999990	0.9999990	1.00	No	71.7	1.00		
Driveline	0.9997854	194805.18	0.9999970	0.9999970	1.00	No	71.5			
Power Generation	0.9393181	958.65	0.9991391	0.9987641	1.00	No	71.6			
Control Unit	0.9910929	8000.00	0.9998750	0.9995002	1.00	No	71.6	125.00		
Diesel Engine	0.9816368	1982.69	0.9997544	0.9997539	1.00	No	71.6			
Diesel Engine	0.9816368	1982.69	0.9997544	0.9997539	1.00		71.6			
K/N Redundancy Group	0.9990266	3189.86	0.9999997	0.9999992	1.00		71.6			
Coupling 1	0.9956196	16304.34	0.9999387	0.9999387	1.00	No	71.6	61.3334		
Engine	0.9956196	16304.34	0.9999387	0.9999387	1.00	No	71.6	61.3334		
Injector Pump	0.9956196	16304.34	0.9999387	0.9999387	1.00	No	71.6	61.3334		
Lift Pump	0.9956196	16304.34	0.9999387	0.9999387	1.00	No	71.6	61.3334		
Fuel Tank	0.9654894	2038.04	0.9995095	0.9995095	1.00	No	71.6	490.667		
Vehicle	0.9999283	999999.90	0.9999990	0.9999990	1.00	No	71.7	1.00		

Session 4.1: Reliability Block Diagram

DISCUSSION 4.1.5 GENERATE RBD REPORT

- This Report Summarises the RBD & ABD Models, including Failure Rates, Groups, MTTR, and other reliability/availability information
- Report is divided into sections:
  - Cover Page & Glossary
  - Poor Performers
  - Reliability & Availability
  - Item Properties
  - ABD/RBD Diagrams

ITEM PROPERTIES

SYSTEM HIERACHY		Vehicle System									
ITEM NAME		Vehicle System					ITEM ID	VS1			
PHYSICAL DESCRIPTION		A land vehicle consisting of a driveline and power generation system.									
RELIABILITY		0.9996415	INHERENT AVAILABILITY		0.9999950		MTTF (HRS)		9,088.44	INDENTURE LEVEL	1
GROUP	ITEM ID & NAME	MTTF (HRS)	DURATION OF OPERATION (HRS)	DELAY TIME (HRS)	TURN AROUND TIME (HRS)	SPARES	MTTR (HRS)	LRU	EXPONENTIAL λ	WEIBULL CHAR. LIFE	WEIBULL SLOPE
1.1 Series Group (Series)	Power Generation	9,451.97	70.66	0	0	0	1.36	No	1119.06	N/A	N/A
	Vehicle	999,999.9	70.74	0	0	0	1	No	1.00	N/A	N/A
	Coupling	999,999.9	70.74	0	0	0	1	No	1.00	N/A	N/A
	Driveline	194,805.18	70.58	0	0	0	1	No	11.00	N/A	N/A

SYSTEM HIERACHY		Vehicle System > Series Group > Power Generation									
ITEM NAME		Power Generation					ITEM ID				
PHYSICAL DESCRIPTION											
RELIABILITY		0.9999947	INHERENT AVAILABILITY		0.9999999		MTTF (HRS)		9,451.97	INDENTURE LEVEL	2.0
GROUP	ITEM ID & NAME	MTTF (HRS)	DURATION OF OPERATION (HRS)	DELAY TIME (HRS)	TURN AROUND TIME (HRS)	SPARES	MTTR (HRS)	LRU	EXPONENTIAL λ	WEIBULL CHAR. LIFE	WEIBULL SLOPE
2.1 Parallel Group (Parallel)	Control Unit	8,000	70.66	3	5	2	3	No	125.00	N/A	N/A
	Diesel Engine	3,885.9	70.66	0	0	0	1.26	No	497.03	N/A	N/A
	Fuel Tank	2,011.94	70.66	0	0	0	1	No	497.03	N/A	N/A

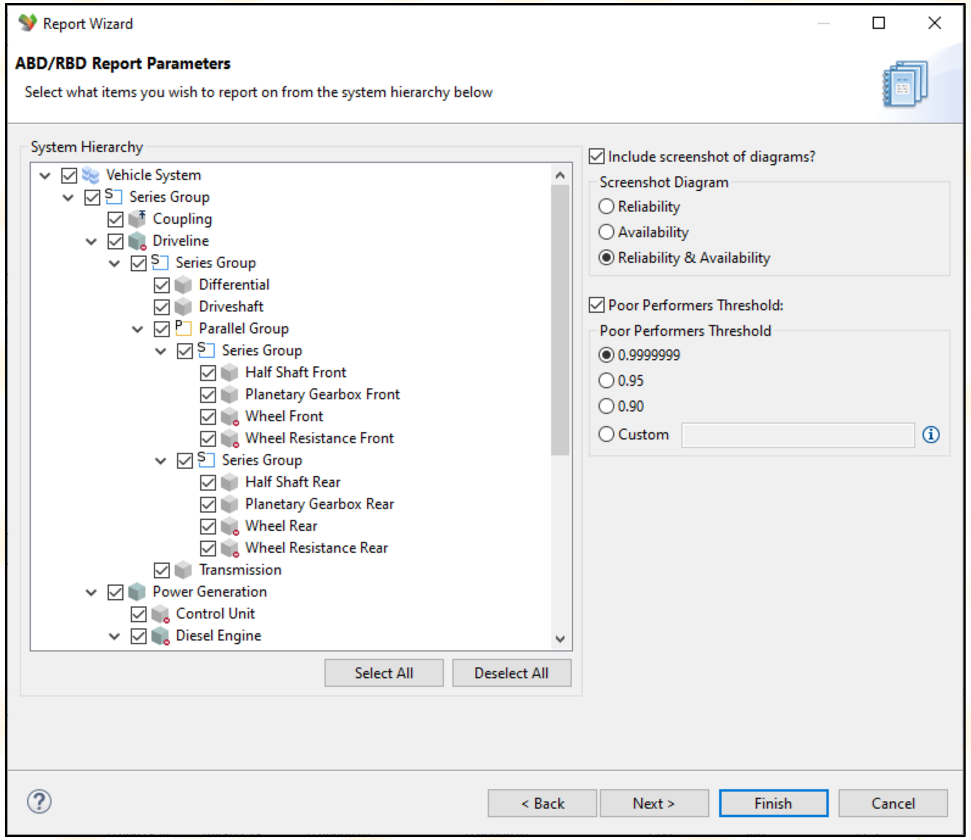
PHM Technology

Session 4.1: Reliability Block Diagram

EXERCISE 4.1.5 GENERATE RBD REPORT

To generate the RBD report:

- Select **Reports → Report Wizard** from the main menu
- Select **Reliability Block Diagram** Report then select Next >
- Select **'Vehicle System'** check box in the System Hierarchy section (or select Select All)
- Select the **Include screenshot of diagrams** check box
- Select **Reliability & Availability** radio-button
- Select **Poor Performers Threshold** of **0.9999999**
- Select Finish



Session 4.1: Reliability Block Diagram

Exercise 4.1.5 Generate RBD Report (Continued)

MADe Training | Reliability Block Diagram Report | 31/10/2019 3:21:39 PM

RELIABILITY & AVAILABILITY

SYSTEM HIERACHY	Vehicle System				**INDENTURE LEVEL**	1
ITEM NAME	Vehicle System				**ITEM ID**	VS1
PHYSICAL DESCRIPTION	A land vehicle consisting of a driveline and power generation system.					
RELIABILITY	0.9389819	**INHERENT AVAILABILITY**	0.9991341	**MTTF (HRS)** 955.47	**MTTR (HRS)**	1
GROUP	**ITEM ID & NAME**	**RELIABILITY**	**MTTF (HRS)**	**INHERENT AVAILABILITY**	**OPERATIONAL AVAILABILITY**	**MTTR (HRS)**
1.1 Series Group (Series)	Coupling	0.9999283	999,999.9	0.9999990	0.9999990	1
	Vehicle	0.9999283	999,999.9	0.9999990	0.9999990	1
	Driveline	0.9997854	194,805.18	0.9999970	0.9999970	1
	Power Generation	0.9393181	958.65	0.9991391	0.9987641	1

SYSTEM HIERACHY	Vehicle System > Series Group > Driveline				**INDENTURE LEVEL**	2.0
ITEM NAME	Driveline				**ITEM ID**	
PHYSICAL DESCRIPTION						
RELIABILITY	0.9997854	**INHERENT AVAILABILITY**	0.9999970	**MTTF (HRS)** 194,805.18	**MTTR (HRS)**	1
GROUP	**ITEM ID & NAME**	**RELIABILITY**	**MTTF (HRS)**	**INHERENT AVAILABILITY**	**OPERATIONAL AVAILABILITY**	**MTTR (HRS)**
2.1 Series Group (Series)	Differential	0.9999285	999,999.9	0.9999990	0.9999990	1
	Driveshaft	0.9999285	999,999.9	0.9999990	0.9999990	1
	Transmission	0.9999285	999,999.9	0.9999990	0.9999990	1
2.3 Series Group (Series)	Half Shaft Front	0.9999285	999,999.9	0.9999990	0.9999990	1
	Half Shaft Rear	0.9999285	999,999.9	0.9999990	0.9999990	1
	Planetary Gearbox Front	0.9999285	999,999.9	0.9999990	0.9999990	1
	Planetary Gearbox Rear	0.9999285	999,999.9	0.9999990	0.9999990	1
	Wheel Front	0.9999285	999,999.9	0.9999990	0.9999990	1
	Wheel Rear	0.9999285	999,999.9	0.9999990	0.9999990	1
	Wheel Resistance Front	0.9999285	999,999.9	0.9999990	0.9999990	1
	Wheel Resistance Rear	0.9999285	999,999.9	0.9999990	0.9999990	1

Session 4.1: Reliability Block Diagram

made
decisions better MADe...

Session 4.1 Summary

- ✓ 4.1.1: Reliability & Availability Block Diagrams
- ✓ 4.1.2: Create RBD Groups
- ✓ 4.1.3: Create ABD Groups
- ✓ 4.1.4: Generate RBD Analysis
- ✓ 4.1.5: Generate ABD/RBD Report

Session 4.2: Reliability Allocation

Session 4.2 Outline

4.2.1: Types of Reliability Allocation in MADe

4.2.2: Create an Equal Reliability Allocation Analysis

4.2.3: Create a Weighted Reliability Allocation Analysis

4.2.4: Generate a Reliability Allocation Report

Session 4.2: Reliability Allocation

Discussion 4.2.1 Types of Reliability Allocation in MADe

There are two approaches for Reliability Allocation in MADe:

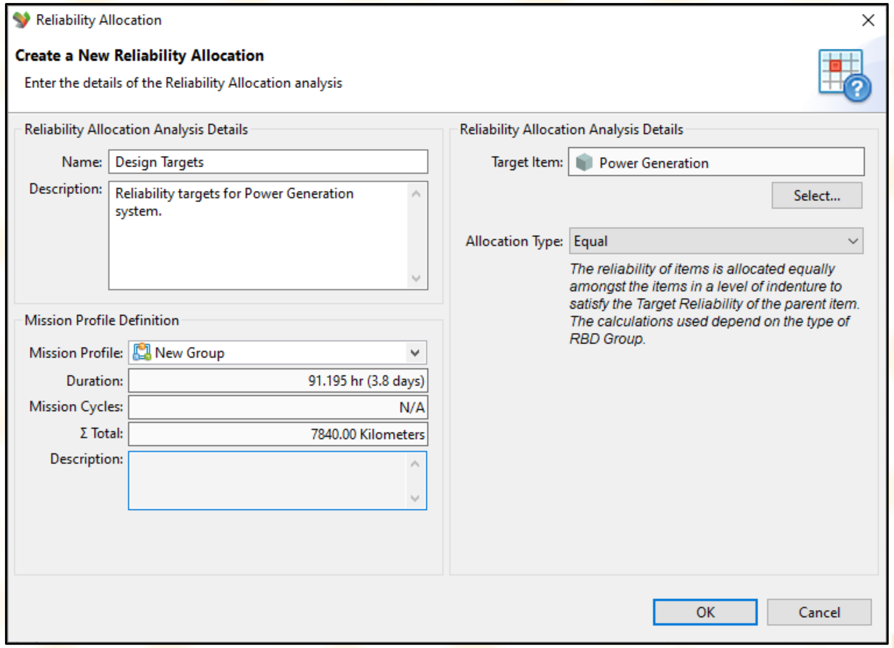
1. Equal Target Allocation
   - Based on Advisory Group on the Reliability of Electronic Equipment (AGREE) method
   - Uses an evenly distributed reliability approach for all items
2. Weighted Target Allocation
   - Based on four different methods of weighting:
     - State of the Art
     - Hardware Complexity
     - Functional Complexity
     - Historical Reliability Data

Session 4.2: Reliability Allocation

EXERCISE 4.2.2 CREATE AN EQUAL RELIABILITY ALLOCATION ANALYSIS

Create a new reliability allocation analysis:

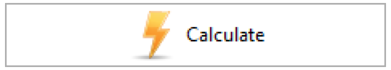
- From the menu bar, select from the **Analyses → Reliability Allocation Editor**
- Select to create a new Reliability Allocation
- Select Select... to set **'Power Generation'** as the Target Item
- Set the Analysis Type to: **Equal**
- Fill in the RA Analysis Name: **Design Targets**
- Fill in the RA Analysis Description: **Reliability targets for Power Generation system.**
- Select the **New group** (Mission Group) from the drop down list
- Select OK to create the new RA analysis



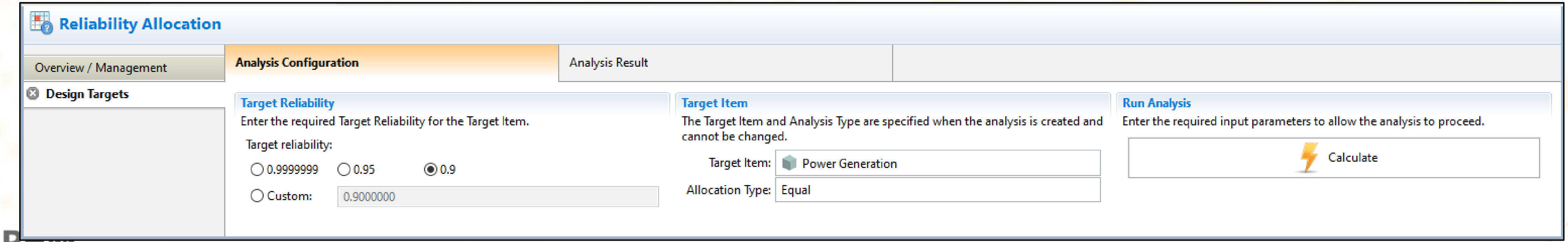
Session 4.2: Reliability Allocation

Exercise 4.2.2 Create an Equal Reliability Allocation Analysis (continued)

From the Analysis Configuration page:

- Set the Reliability Target as **0.90**
- Verify Target item is the **'Power Generation'** subsystem
- Select 

to calculate the reliability
- Verify that the **Analysis Result** page will be displayed once the calculations are complete

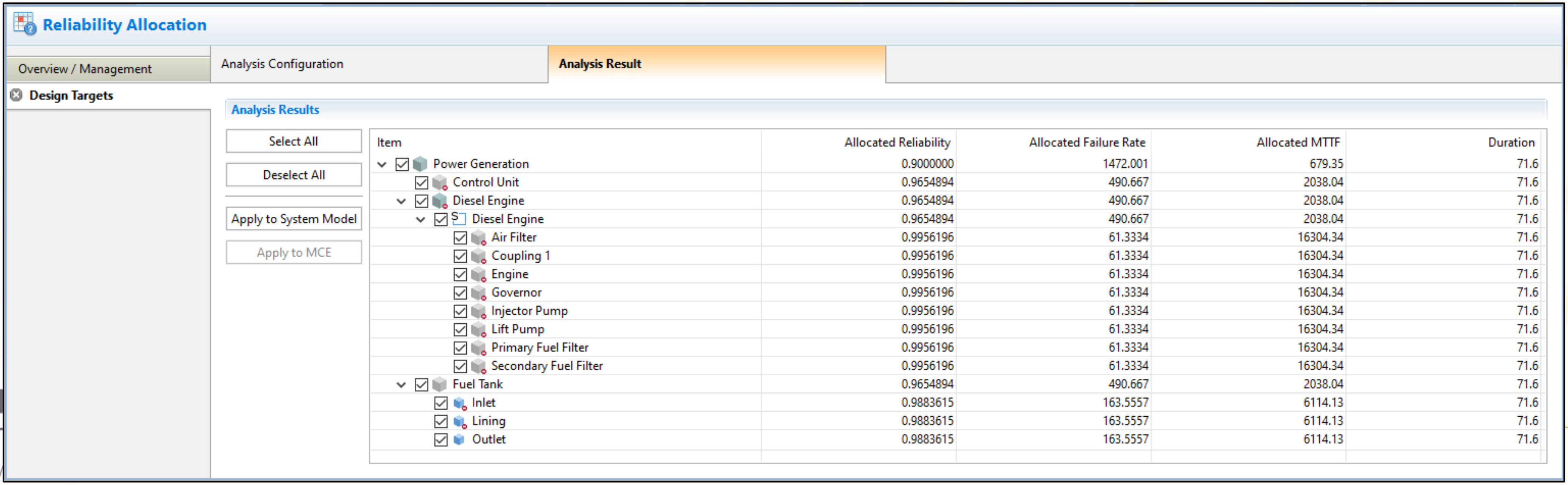


Session 4.2: Reliability Allocation

<u>EXERCISE 4.2.2 CREATE AN EQUAL RELIABILITY ALLOCATION ANALYSIS (CONTINUED)</u>

Apply Reliability Allocation analysis results:

- Evaluate all the results shown in the analysis results table
- Select the Select All to select all items in the table
- Select Apply to System Model to open the **Confirm Allocation** dialog

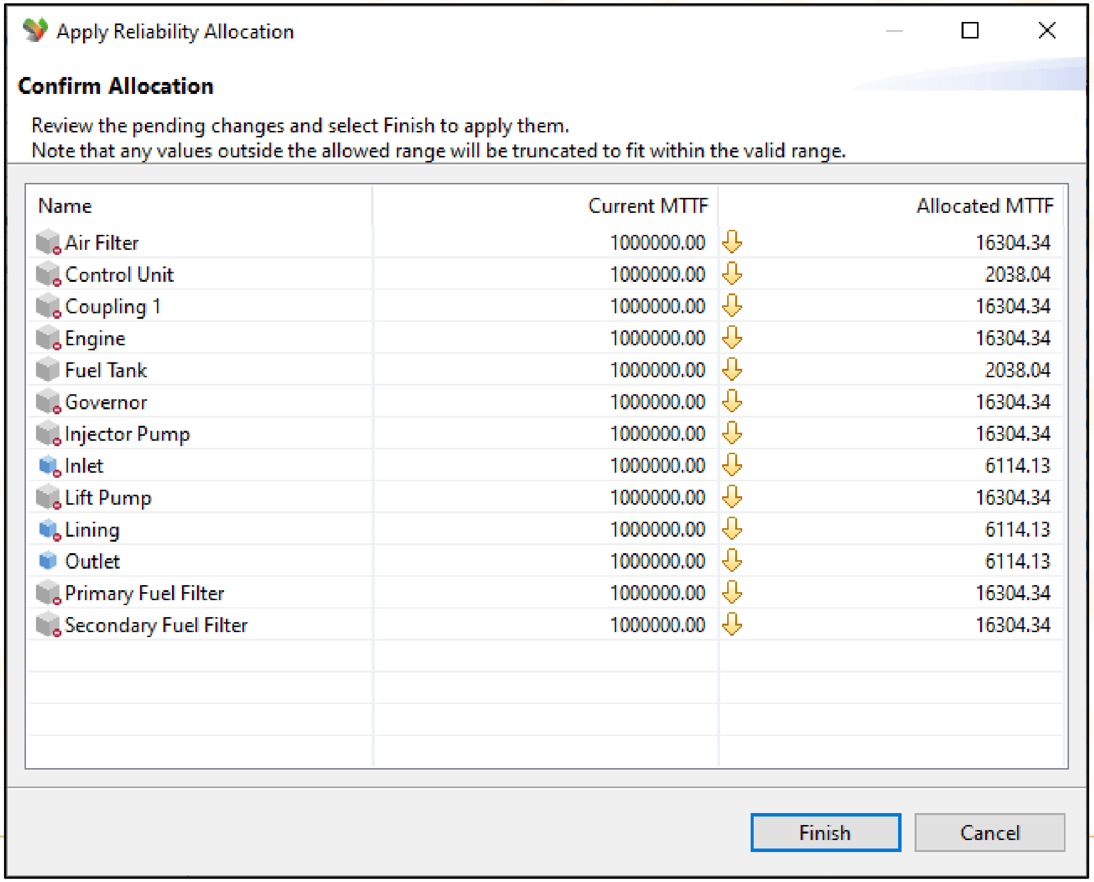


Item	Allocated Reliability	Allocated Failure Rate	Allocated MTTF	Duration
Power Generation	0.9000000	1472.001	679.35	71.6
Control Unit	0.9654894	490.667	2038.04	71.6
Diesel Engine	0.9654894	490.667	2038.04	71.6
Diesel Engine	0.9654894	490.667	2038.04	71.6
Air Filter	0.9956196	61.3334	16304.34	71.6
Coupling 1	0.9956196	61.3334	16304.34	71.6
Engine	0.9956196	61.3334	16304.34	71.6
Governor	0.9956196	61.3334	16304.34	71.6
Injector Pump	0.9956196	61.3334	16304.34	71.6
Lift Pump	0.9956196	61.3334	16304.34	71.6
Primary Fuel Filter	0.9956196	61.3334	16304.34	71.6
Secondary Fuel Filter	0.9956196	61.3334	16304.34	71.6
Fuel Tank	0.9654894	490.667	2038.04	71.6
Inlet	0.9883615	163.5557	6114.13	71.6
Lining	0.9883615	163.5557	6114.13	71.6
Outlet	0.9883615	163.5557	6114.13	71.6

Session 4.2: Reliability Allocation

EXERCISE 4.2.2 CREATE AN EQUAL RELIABILITY ALLOCATION ANALYSIS (CONTINUED)

➢ Review the changes in MTTF for each item then select Finish apply the new MTTF values

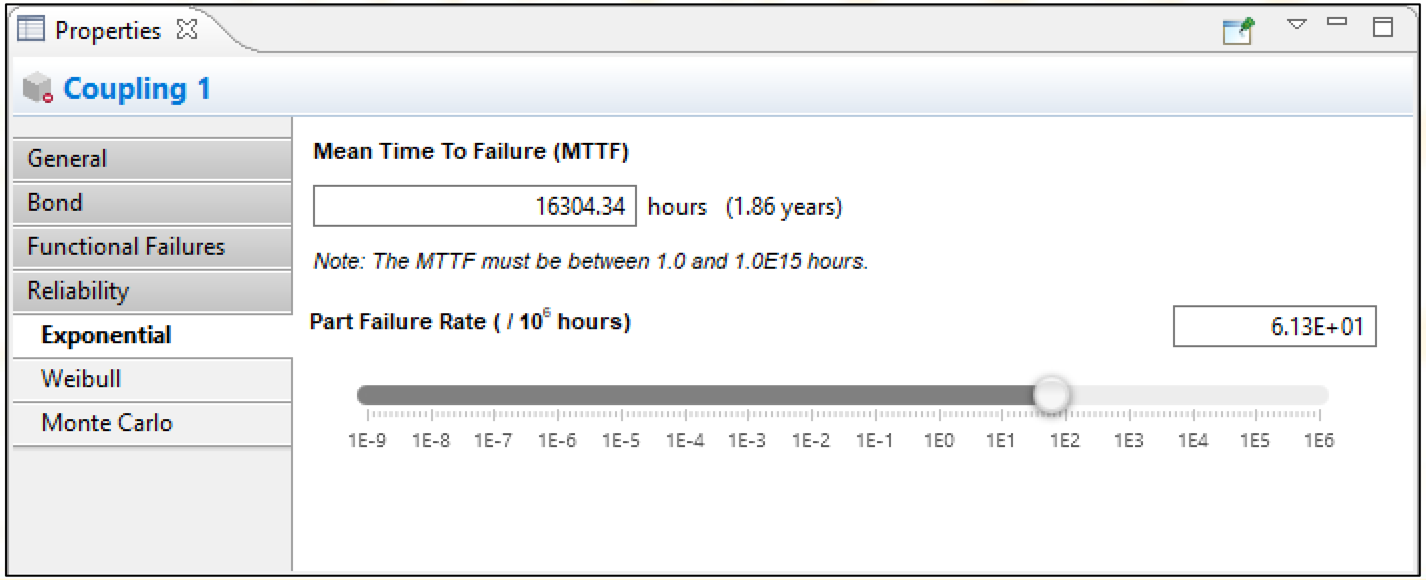


Session 4.2: Reliability Allocation

EXERCISE 4.2.2 CREATE AN EQUAL RELIABILITY ALLOCATION ANALYSIS (CONTINUED)

Verify Reliability Allocation analysis results:

- Open the **'Diesel Engine'** System Model and select the **'Coupling 1'** component
- From the **Properties** viewer select the **Exponential** tab
- Verify that the allocated **Part Failure Rate** matches up with the allocated value below



Session 4.2: Reliability Allocation

Discussion 4.2.3 Create a Weighted Reliability Allocation Analysis

Weighted RA is based on four different methods of weighting described below:

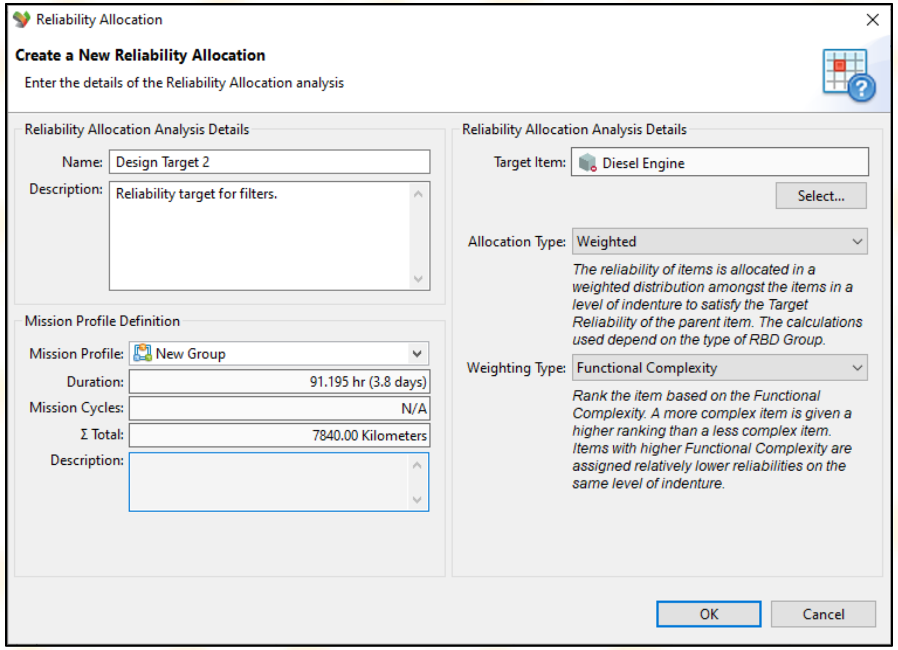
- **State of the Art**
  - A more highly developed item is given a higher ranking than a less developed item
  - Items with higher State of the Art are assigned relatively lower reliabilities than other items on the same level of indenture
- **Hardware Complexity**
  - A more complex item is given a higher ranking than a less complex item
  - Items with higher Hardware Complexity are assigned relatively lower reliabilities on the same level of indenture
- **Functional Complexity**
  - A more complex item is given a higher ranking than a less complex item
  - Items with higher Functional Complexity are assigned relatively lower reliabilities on the same level of indenture
- **Historical Reliability Data**
  - Weighting is automatically calculated based on the relative current reliability values in the system model

Session 4.2: Reliability Allocation

EXERCISE 4.2.3 CREATE A WEIGHTED RELIABILITY ALLOCATION ANALYSIS

Create a new reliability allocation analysis:

- From the menu bar, select **Analyses → Reliability Allocation Editor**
- Select to create a new Reliability Allocation
- Select Select... to select **'Diesel Engine'** as the Target Item
- Set Analysis Type to **Weighted**
- Set Weighting Type to **Functional Complexity**
- Fill in the RA Analysis Details as follows:
  - Name: **Design Target 2**
  - Description: **Reliability targets for filters.**
- Select the **New group** (Mission Group) from the drop down list
- Select OK to create the new RA analysis

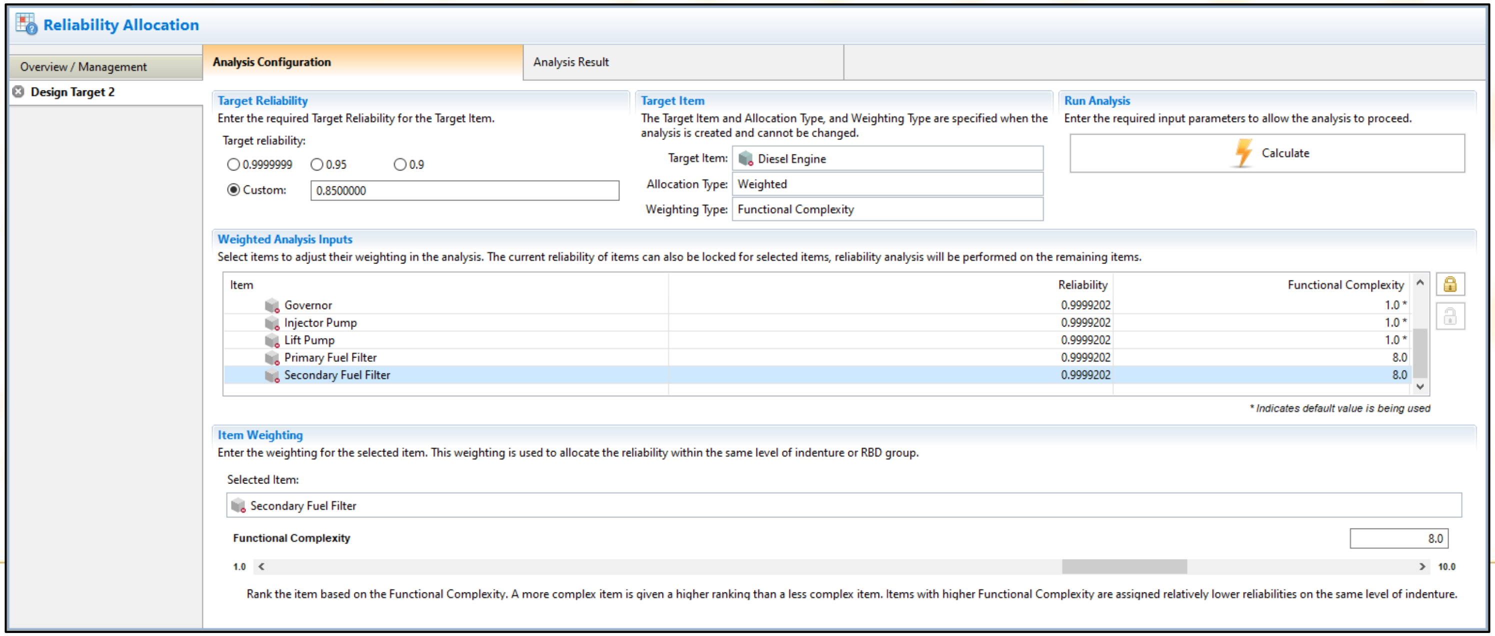


Session 4.2: Reliability Allocation

EXERCISE 4.2.3 CREATE A WEIGHTED RELIABILITY ALLOCATION ANALYSIS (CONTINUED)

From the Analysis Configuration page:

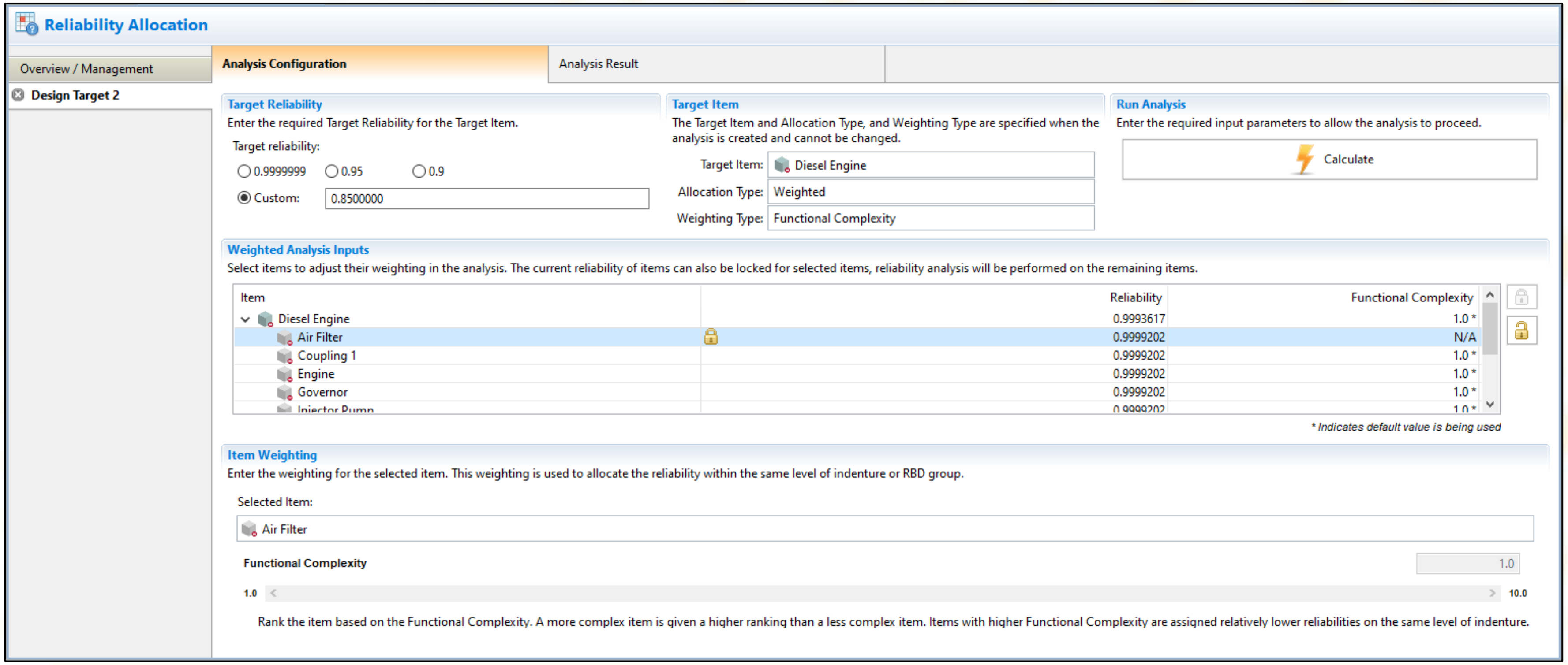
- Set the Reliability Target to **Custom** and enter **0.85**
- Select the **'Primary Fuel Filter'** & **'Secondary Fuel Filter'** components in the Weighted Analysis Inputs table
- Set Functional Complexity Item Weighting for both components to **8.0** from the slider



Session 4.2: Reliability Allocation

Exercise 4.2.3 Create a Weighted Reliability Allocation Analysis (continued)

- Lock the Reliability of the Air Filter component using the icon
  - Locking the reliability of the Air Filter forces the reliability to not change when the allocation analysis is conducted.



Session 4.2: Reliability Allocation

EXERCISE 4.2.3 CREATE A WEIGHTED RELIABILITY ALLOCATION ANALYSIS (CONTINUED)

- Run the analysis by selecting Calculate
- Verify that the **Analysis Result** page will be displayed once the calculations are complete

Reliability Allocation

Overview / Management | Analysis Configuration | **Analysis Result**

Design Target 2

Analysis Results

Select All

Deselect All

Apply to System Model

Apply to MCE

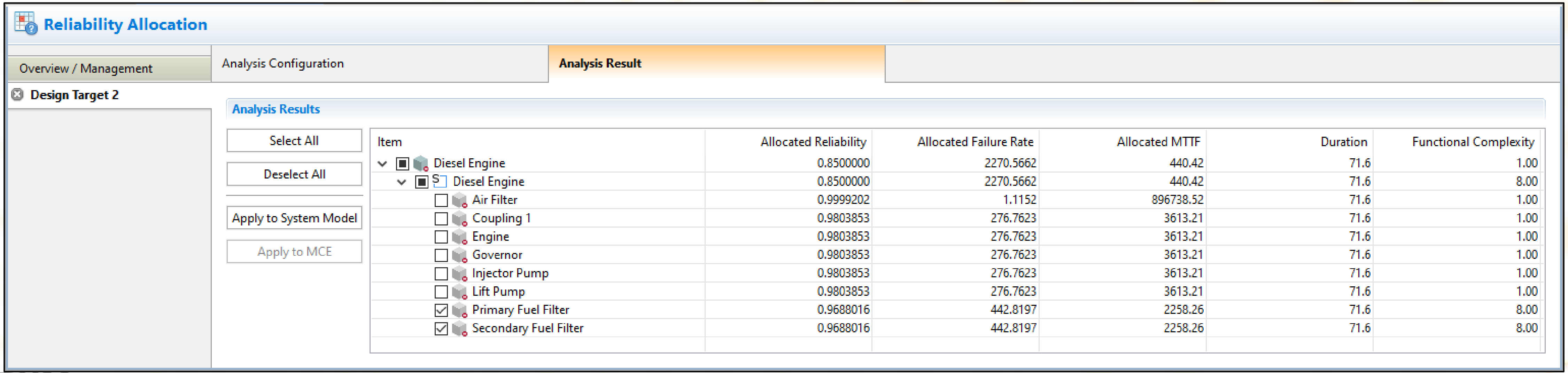
Item	Allocated Reliability	Allocated Failure Rate	Allocated MTTF	Duration	Functional Complexity
Diesel Engine	0.8500000	2270.5662	440.42	71.6	1.00
Diesel Engine	0.8500000	2270.5662	440.42	71.6	8.00
Air Filter	0.9999202	1.1152	896738.52	71.6	N/A
Coupling 1	0.9803853	276.7623	3613.21	71.6	1.00
Engine	0.9803853	276.7623	3613.21	71.6	1.00
Governor	0.9803853	276.7623	3613.21	71.6	1.00
Injector Pump	0.9803853	276.7623	3613.21	71.6	1.00
Lift Pump	0.9803853	276.7623	3613.21	71.6	1.00
Primary Fuel Filter	0.9688016	442.8197	2258.26	71.6	8.00
Secondary Fuel Filter	0.9688016	442.8197	2258.26	71.6	8.00

Session 4.2: Reliability Allocation

EXERCISE 4.2.3 CREATE A WEIGHTED RELIABILITY ALLOCATION ANALYSIS (CONTINUED)

Apply Reliability Allocation analysis results:

- Evaluate all the results shown in the analysis results table
- Select the **'Primary Fuel Filter'** & **'Secondary Fuel Filter'** check boxes in the table
- Select Apply to System Model to open the **Confirm Allocation** dialog

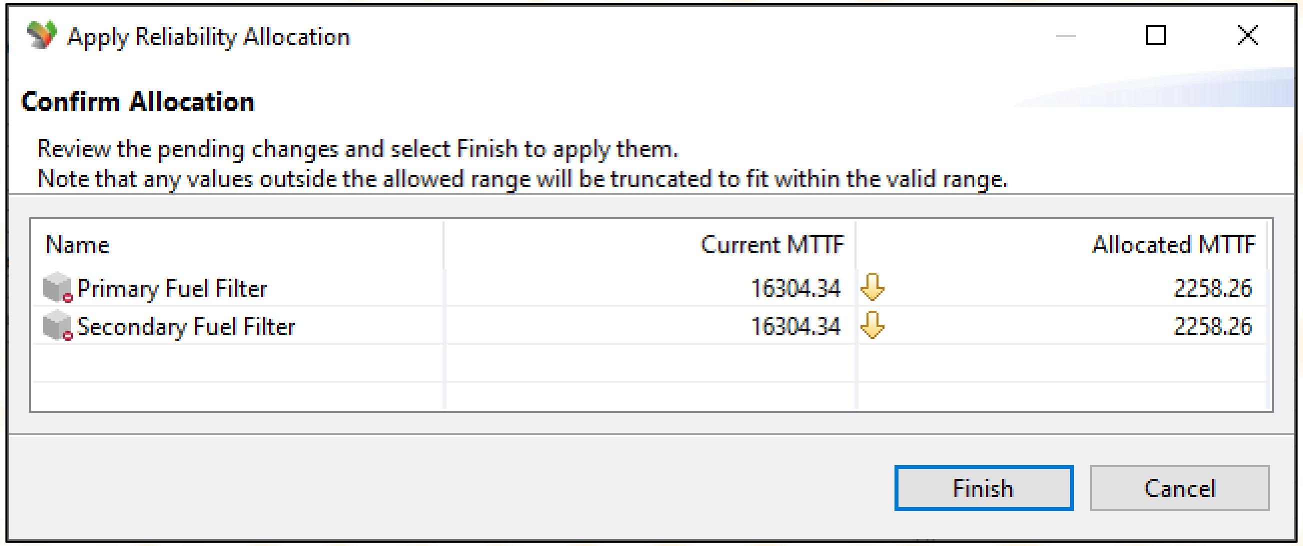


Item	Allocated Reliability	Allocated Failure Rate	Allocated MTTF	Duration	Functional Complexity
Diesel Engine	0.8500000	2270.5662	440.42	71.6	1.00
Diesel Engine	0.8500000	2270.5662	440.42	71.6	8.00
Air Filter	0.9999202	1.1152	896738.52	71.6	1.00
Coupling 1	0.9803853	276.7623	3613.21	71.6	1.00
Engine	0.9803853	276.7623	3613.21	71.6	1.00
Governor	0.9803853	276.7623	3613.21	71.6	1.00
Injector Pump	0.9803853	276.7623	3613.21	71.6	1.00
Lift Pump	0.9803853	276.7623	3613.21	71.6	1.00
Primary Fuel Filter	0.9688016	442.8197	2258.26	71.6	8.00
Secondary Fuel Filter	0.9688016	442.8197	2258.26	71.6	8.00

Session 4.2: Reliability Allocation

EXERCISE 4.2.3 CREATE A WEIGHTED RELIABILITY ALLOCATION ANALYSIS (CONTINUED)

- Review the changes in MTTF for each item then select Finish to apply the new MTTF values

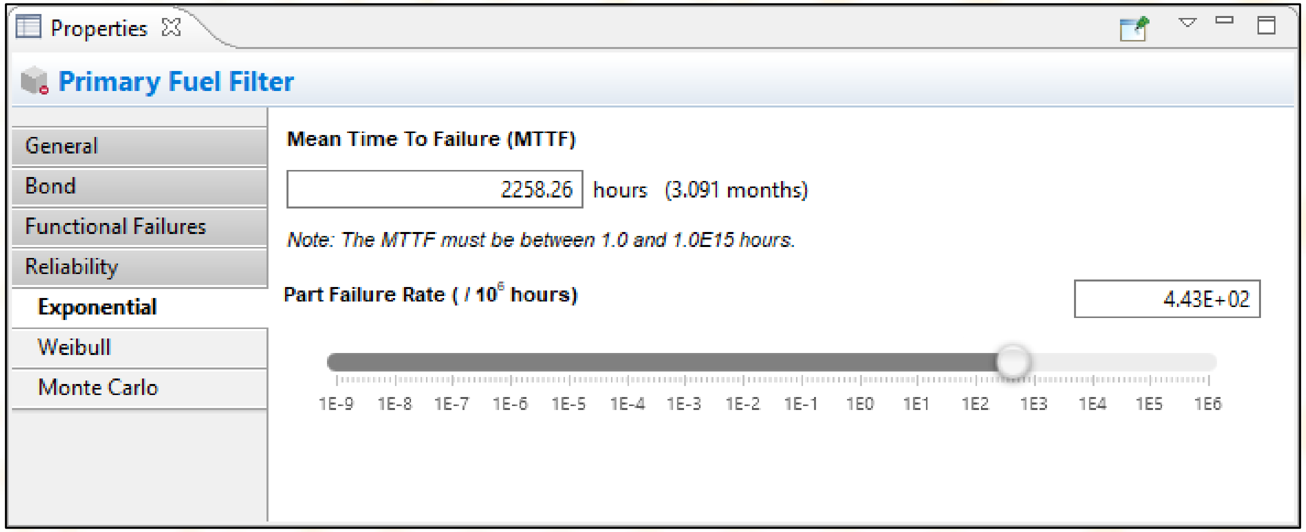


Session 4.2: Reliability Allocation

Exercise 4.2.3 Create a Weighted Reliability Allocation Analysis (continued)

Verify Reliability Allocation analysis results:

- Open the **'Diesel Engine'** System Model and select the **'Primary Fuel Filter'**
- From the Properties viewer select the **Exponential** tab
- Verify that the allocated **Part Failure Rate** matches up with the allocated value



Session 4.2: Reliability Allocation

<u>Discussion 4.2.4 Generate a Reliability Allocation Report</u>

- This report summarises each RA analysis
- The RA Report is divided into 3 sections:
  - Cover Page
  - Glossary of Terms
  - Reliability Allocation Analysis – includes Duration of Operation, Item Reliability, Failure Rate, MTTF, Weighting,

RELIABILITY ALLOCATION ANALYSIS

NAME	Design Targets			MISSION PROFILE DEFINITION			
ALLOCATION TYPE	Equal	WEIGHTING TYPE	N/A	NAME	New Group	CYCLES	1.00
TARGET ITEM	Power Generation	TARGET RELIABILITY	0.9000000	DURATION OF OPERATION	91.195 hr (3.8 days)	Σ TOTAL	7840.00 Kilometers
DESCRIPTION	Reliability targets for Power Generation system.			DESCRIPTION			

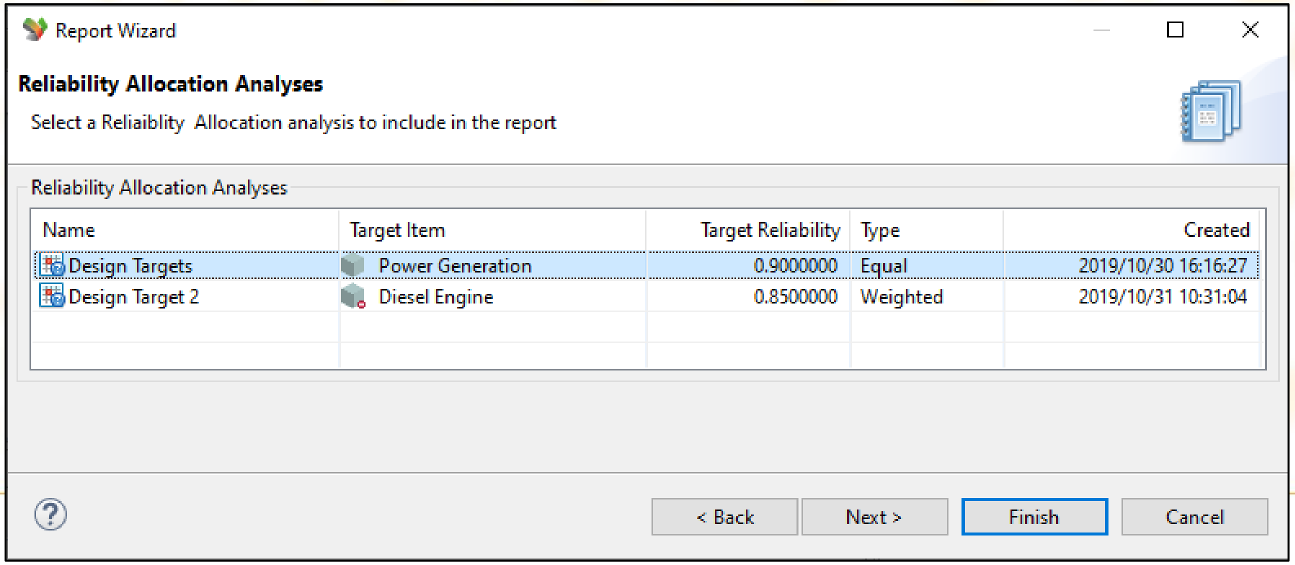
ITEM	FAILURE PROBABILITY DISTRIBUTION	DURATION OF OPERATION	ALLOCATED RELIABILITY	MAXIMUM ALLOWABLE FAILURE RATE	MINIMUM ALLOWABLE MTTF	WEIGHTING FACTOR	CHARACTERISTIC RELIABILITY	CHARACTERISTIC FAILURE RATE	CHARACTERISTIC MTTF
Power Generation	Exponential	71.58	0.9000000	1472.001	679.35	N/A	0.6602351	8805.5402	120.92
Control Unit	Exponential	71.58	0.9654894	490.667	2,038.04	N/A	0.9654894	490.667	2,038.04
Diesel Engine	Exponential	71.58	0.9654894	490.667	2,038.04	N/A	0.7082778	7824.2063	132.95
Diesel Engine	Exponential	71.58	0.9654894	490.667	2,038.04	N/A	0.7082778	0.00	132.95
Coupling 1	Exponential	71.58	0.9930006	98.1334	10,190.21	N/A	0.9930030	98.10	10,193.68
Engine	Exponential	71.58	0.9930006	98.1334	10,190.21	N/A	0.9930006	98.1334	10,190.21
Injector Pump	Exponential	71.58	0.9930006	98.1334	10,190.21	N/A	0.9930006	98.1334	10,190.21
K/N Redundancy Group	Exponential	71.58	0.9930006	98.1334	10,190.21	N/A	0.7284581	0.00	138.39
Air Filter	Weibull	71.58	0.9508867	703.5895	1,421.28	N/A	0.9999996	703.5895	8,929.8
Primary Fuel Filter	Markov	71.58	0.9508867	703.5895	1,421.28	N/A	0.4789033	3346.5904	94.38
Secondary Fuel Filter	Markov	71.58	0.9508867	703.5895	1,421.28	N/A	0.4789033	3346.5904	94.38
Lift Pump	Exponential	71.58	0.9930006	98.1334	10,190.21	N/A	0.9930006	98.1334	10,190.21

Session 4.2: Reliability Allocation

Exercise 4.2.4 Generate a Reliability Allocation Report

To generate a Reliability Allocation report:

- Select **Reports → Report Wizard** from the main menu
- Select **Reliability Allocation Report** then select Next >
- Select the **Design Targets** analysis
- Select Finish



Session 4.2: Reliability Allocation

EXERCISE 4.2.4 GENERATE A RELIABILITY ALLOCATION REPORT

MADe Training | Reliability Allocation Report | 31/10/2019 12:40:50 PM

RELIABILITY ALLOCATION ANALYSIS

NAME	Design Targets			MISSION PROFILE DEFINITION			
ALLOCATION TYPE	Equal	WEIGHTING TYPE	N/A	NAME	New Group	CYCLES	1.00
TARGET ITEM	Power Generation	TARGET RELIABILITY	0.9000000	DURATION OF OPERATION	91.195 hr (3.8 days)	Σ TOTAL	7840.00 Kilometers
DESCRIPTION	Reliability targets for Power Generation system.			DESCRIPTION			

ITEM	FAILURE PROBABILITY DISTRIBUTION	DURATION OF OPERATION	ALLOCATED RELIABILITY	MAXIMUM ALLOWABLE FAILURE RATE	MINIMUM ALLOWABLE MTTF	WEIGHTING FACTOR	CHARACTERISTIC RELIABILITY	CHARACTERISTIC FAILURE RATE	CHARACTERISTIC MTTF
Power Generation	Exponential	1.3	0.9000000	1472.001	679.35	N/A	0.9970957	2234.9737	447.43
Control Unit	Exponential	1.3	0.9654894	490.667	2,038.04	N/A	0.9993617	490.667	2,038.04
Diesel Engine	Exponential	1.3	0.9654894	490.667	2,038.04	N/A	0.9983699	1253.6397	797.68
Diesel Engine	Exponential	1.3	0.9654894	490.667	2,038.04	N/A	0.9983699	0.00	797.68
Air Filter	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9999202	61.3334	16,304.34
Coupling 1	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9999202	61.3334	16,304.34
Engine	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9999202	61.3334	16,304.34
Governor	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9999202	61.3334	16,304.34
Injector Pump	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9999202	61.3334	16,304.34
Lift Pump	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9999202	61.3334	16,304.34
Primary Fuel Filter	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9994239	442.8197	2,258.26
Secondary Fuel Filter	Exponential	1.3	0.9956196	61.3334	16,304.34	N/A	0.9994239	442.8197	2,258.26
Fuel Tank	Exponential	1.3	0.9654894	490.667	2,038.04	N/A	0.9993617	490.667	2,038.04
Inlet	Exponential	1.3	0.9883615	163.5557	6,114.13	N/A	0.9997872	163.5557	6,114.13
Lining	Exponential	1.3	0.9883615	163.5557	6,114.13	N/A	0.9997872	163.5557	6,114.13
Outlet	Exponential	1.3	0.9883615	163.5557	6,114.13	N/A	0.9997872	163.5557	6,114.13

Session 4.2: Reliability Allocation

<u>Session 4.2 Summary</u>

✓ 4.2.1: Types of Reliability Allocation in MADe

✓ 4.2.2: Create an Equal Reliability Allocation

✓ 4.2.3: Create a Weighted Reliability Allocation

✓ 4.2.4: Generate Reliability Allocation Report

Session 4.3: Reliability Editing

Session 4.3 Outline

4.3.1: Introduction to Item Reliability

4.3.2: Access Reliability Editor

4.3.3: Edit Item Reliability – Exponential Distribution

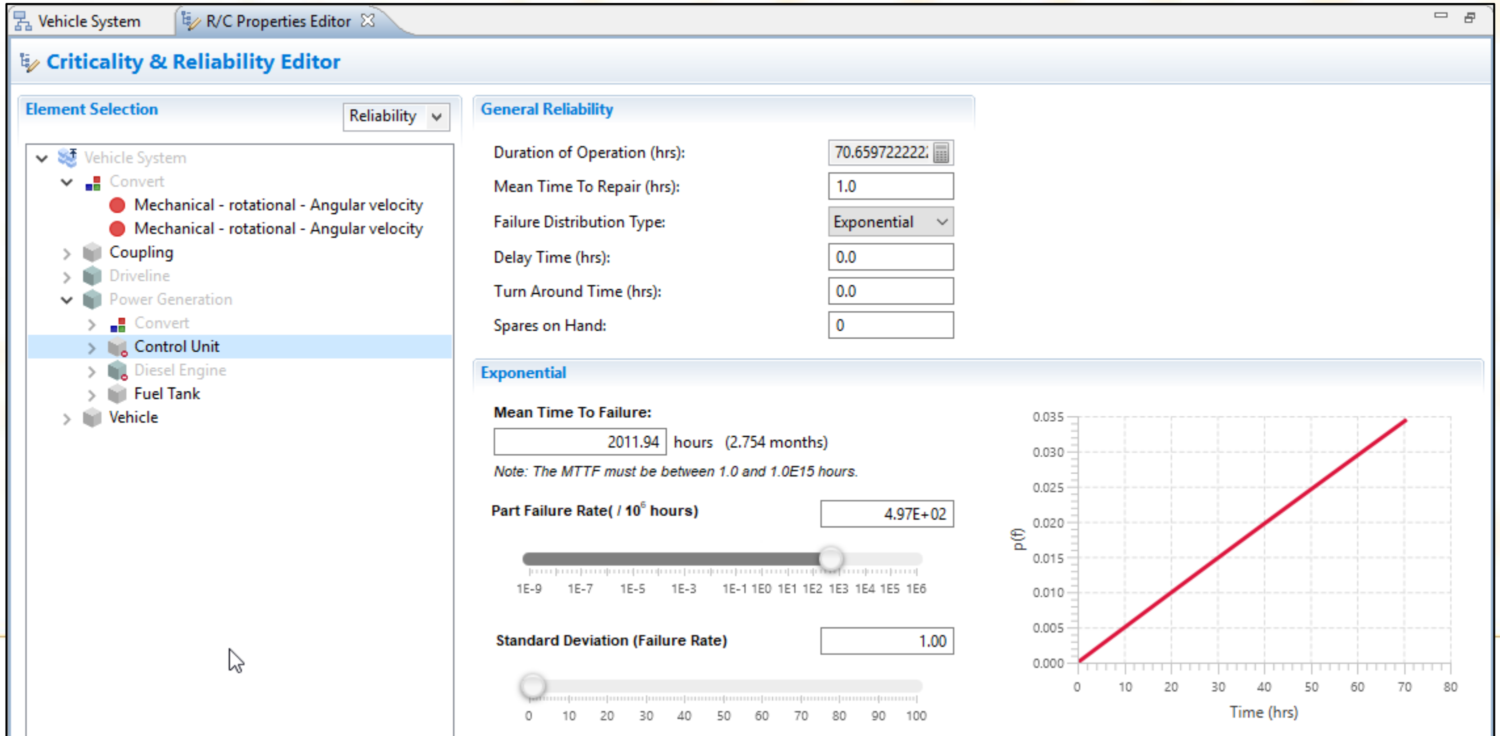
4.3.4: Edit Item Reliability – Weibull Distribution

4.3.5: Edit Failure Mode Ratios

Session 4.3: Reliability Editing

DISCUSSION 4.3.1 INTRODUCTION TO ITEM RELIABILITY

- Entering Reliability Data into components & parts determines their **Probability of Failure, P(f)**
- Item reliability is taken into account in the RBD model to calculate subsystem & system reliability
- Aggregation of P(f) determines Reliability of RBD Groups

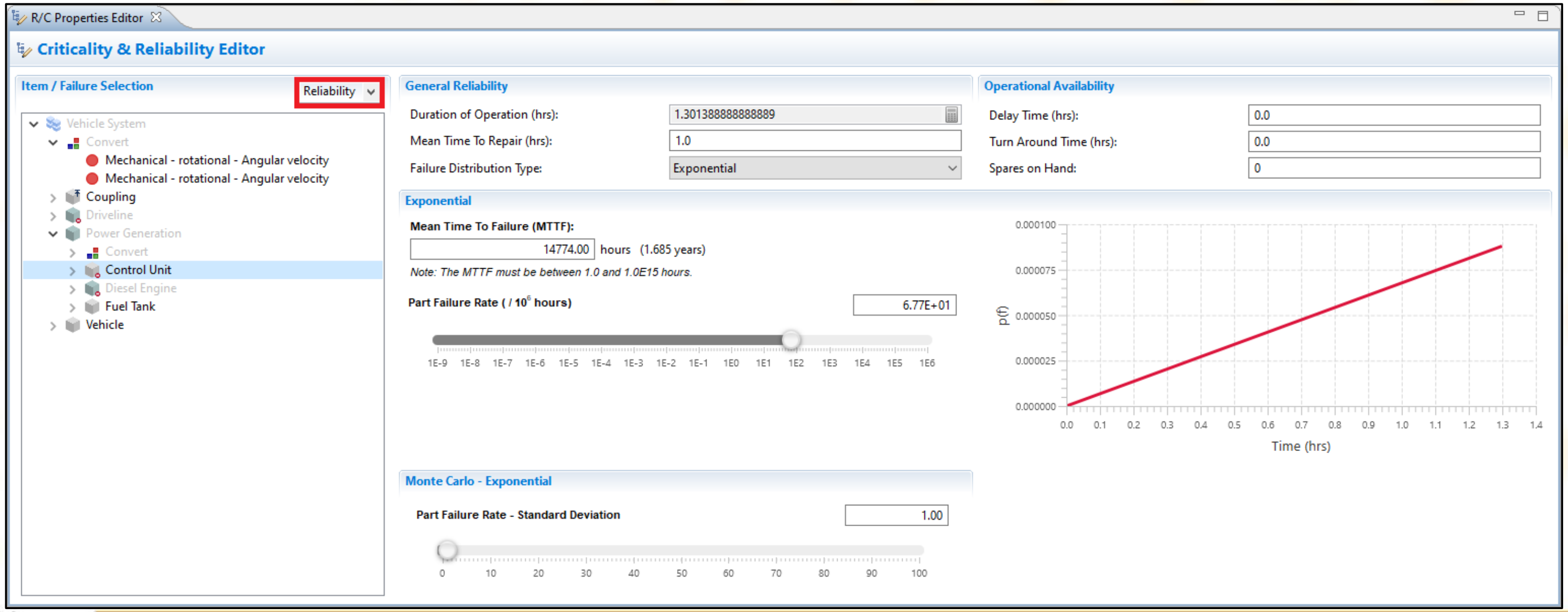


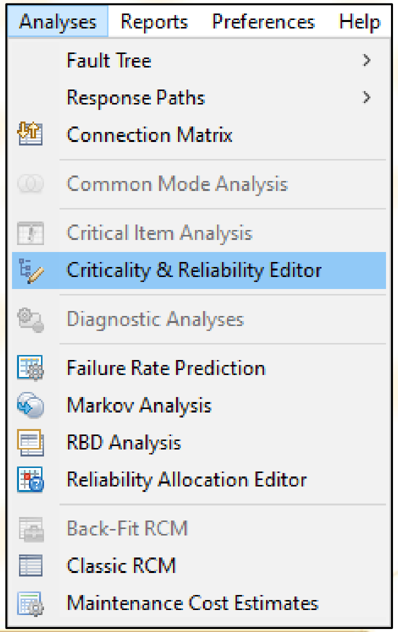
Session 4.3: Reliability Editing

EXERCISE 4.3.2 ACCESSING RELIABILITY EDITOR

To access the Reliability Editor:

- Select **Analyses → Criticality & Reliability Editor** from the main menu
- In the **Item/Failure Selection** section select **Reliability** from the drop down menu and select the **'Control Unit'** component from the tree





Session 4.3: Reliability Editing

DISCUSSION 4.3.3 EDIT ITEM RELIABILITY – EXPONENTIAL DISTRIBUTION

General Reliability section contains reliability fields used to capture:

- Duration of Operation
- Mean Time to Repair (MTTR)
- Failure Distribution Type: Exponential or Weibull
- Delay Time
- Turn Around Time
- Spares on Hand

General Reliability	
Duration of Operation (hrs):	125.65972222222223
Mean Time To Repair (hrs):	3.0
Failure Distribution Type:	Exponential

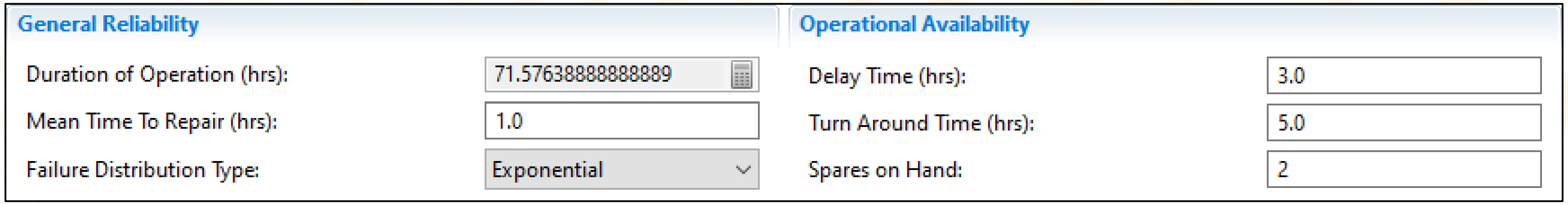
Operational Availability	
Delay Time (hrs):	3.0
Turn Around Time (hrs):	5.0
Spares on Hand:	2

Session 4.3: Reliability Editing

EXERCISE 4.3.3 EDIT ITEM RELIABILITY – EXPONENTIAL DISTRIBUTION

To edit reliability values from the Reliability editor:

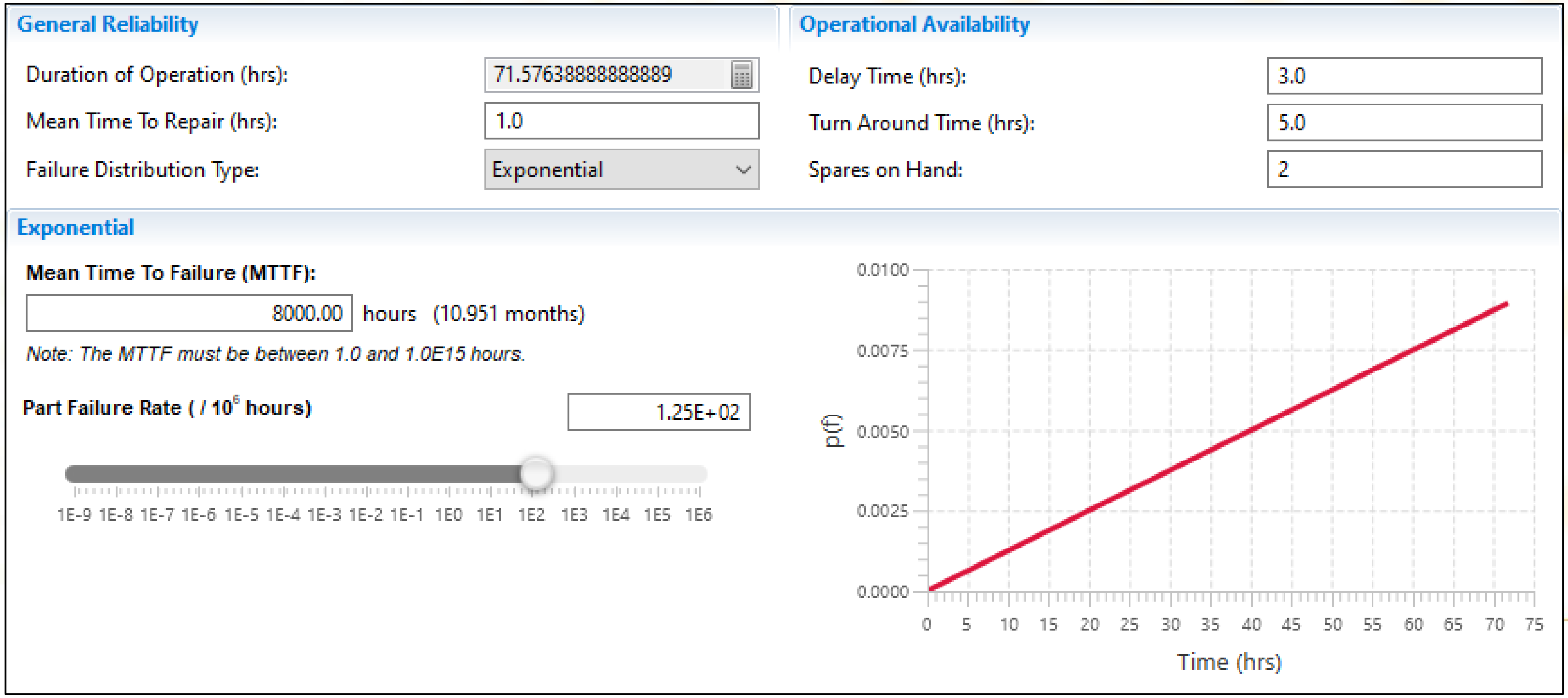
- Select the **‘Control Unit’** component from the **Item/Failure Selection** tree
- For the **General Reliability** section, edit/confirm the following reliability information:
  - Duration of Operation: ~**71.58 Hours** (from Mission Group)
  - Mean Time To Repair: **3 Hours**
  - Failure Distribution Type: **Exponential**
  - Delay Time: **3 Hours**
  - Turnaround Time: **5 Hours**
  - Spares on Hand: **2**



Session 4.3: Reliability Editing

EXERCISE 4.3.3 EDIT ITEM RELIABILITY – EXPONENTIAL DISTRIBUTION (CONTINUED)

- For the **Exponential** Section enter or verify the following reliability information:
  - Mean Time To Failure: **8,000 Hours**
  - Part Failure Rate: **125.00 (1.25E+02)**



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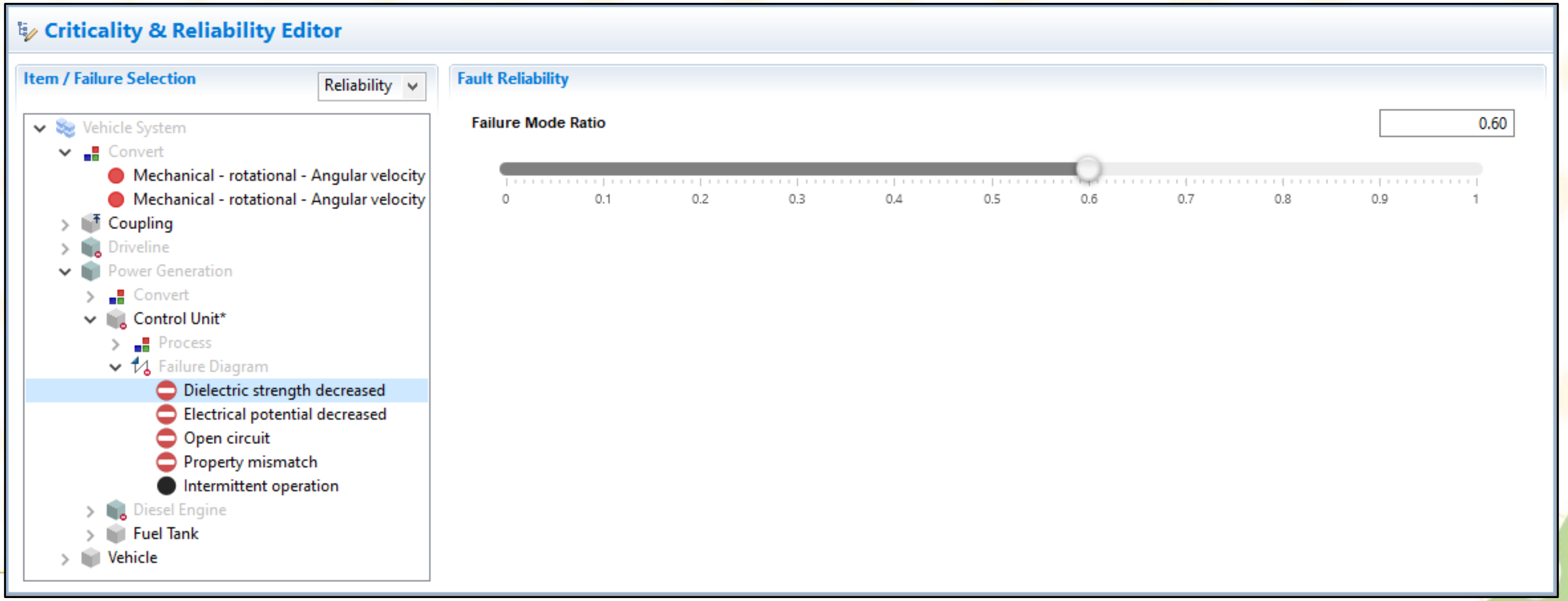
Session 4.3: Reliability Editing

EXERCISE 4.3.3 EDIT ITEM RELIABILITY – EXPONENTIAL DISTRIBUTION (CONTINUED)

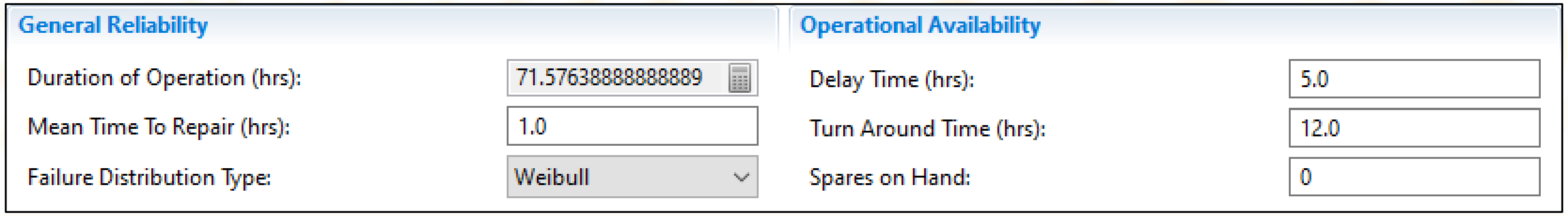
- Expand the **‘Control Unit’** component & Failure Diagram in the Item/Failure Selection Tree
- Select the **Faults** below to set their individual Failure Mode Ratio (FMR):
  - Dielectric strength decreased: **0.60**
  - Electrical potential decreased: **0.10**
  - Open circuit: **0.15**
  - Property mismatch: **0.15**



Session 4.3: Reliability Editing

Exercise 4.3.4 Edit Item Reliability – Weibull Distribution

- Select the **‘Air Filter’** component from the Item / Failure Selection Tree
- For the **General Reliability** section, edit/confirm the following reliability information:
  - Duration of Operation: ~**71.58 Hours** (taken from Mission Profile)
  - Mean Time To Repair: **5 Hours**
  - Failure Distribution Type: **Weibull**
  - Delay Time: **5 hours**
  - Turn Around Time: **12 Hours**
  - Spares on Hand: **0**



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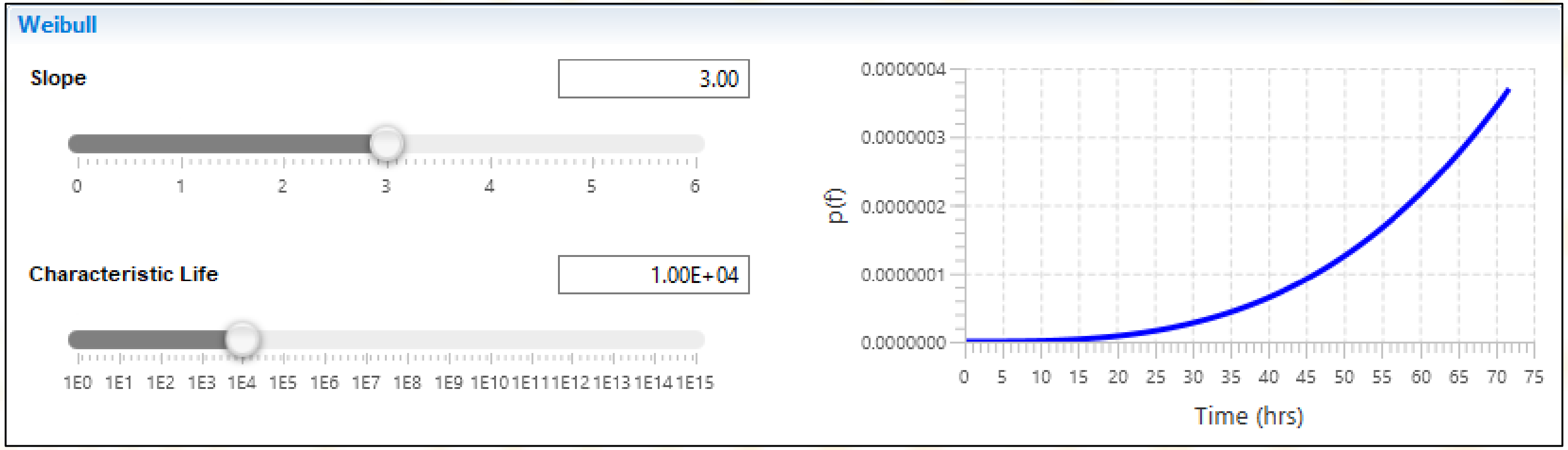
Session 4.3: Reliability Editing

Exercise 4.3.4 Edit Item Reliability – Weibull Distribution (Continued)

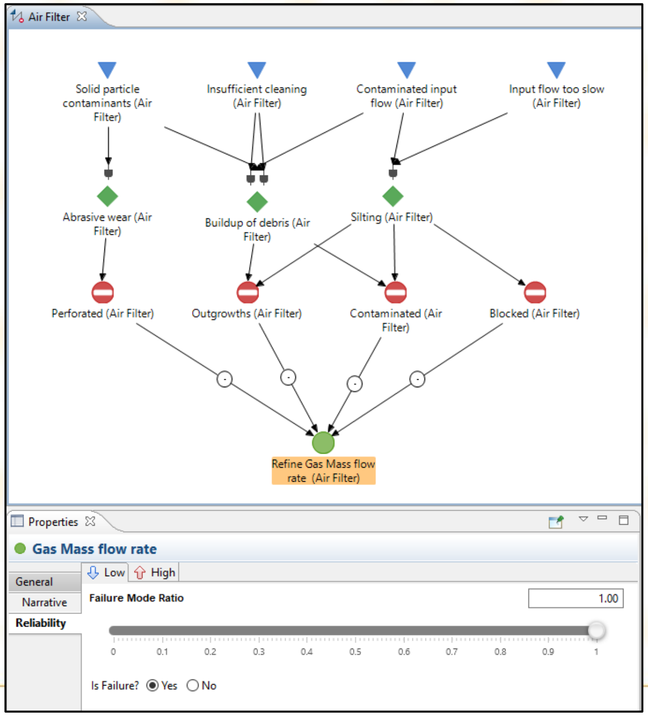
- For the **Weibull** section, enter or verify the following reliability information:
  - Slope: **3**
  - Characteristic Life: **10000 Hours**

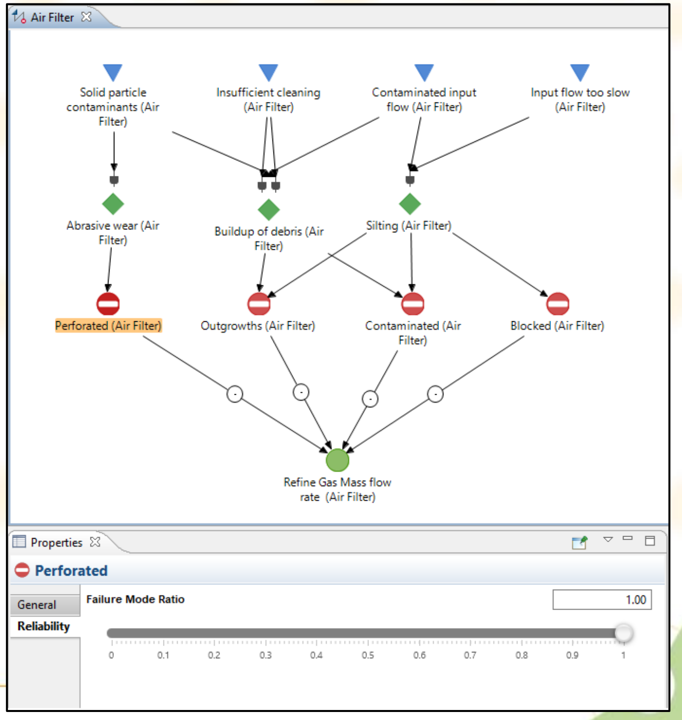


Session 4.3: Reliability Editing

Discussion 4.3.5 Edit Failure Mode Ratios

- MIL-STD-1629A: Failure Mode Ratios represent probabilities that an item will fail in the identified failure mode with respect to other failures.
- Failure Mode Ratio is applied in MADe in two areas:
  - Failure Mode Responses (e.g. High/Low)
  - Faults





Session 4.3: Reliability Editing

DISCUSSION 4.3.5 EDIT FAILURE MODE RATIOS

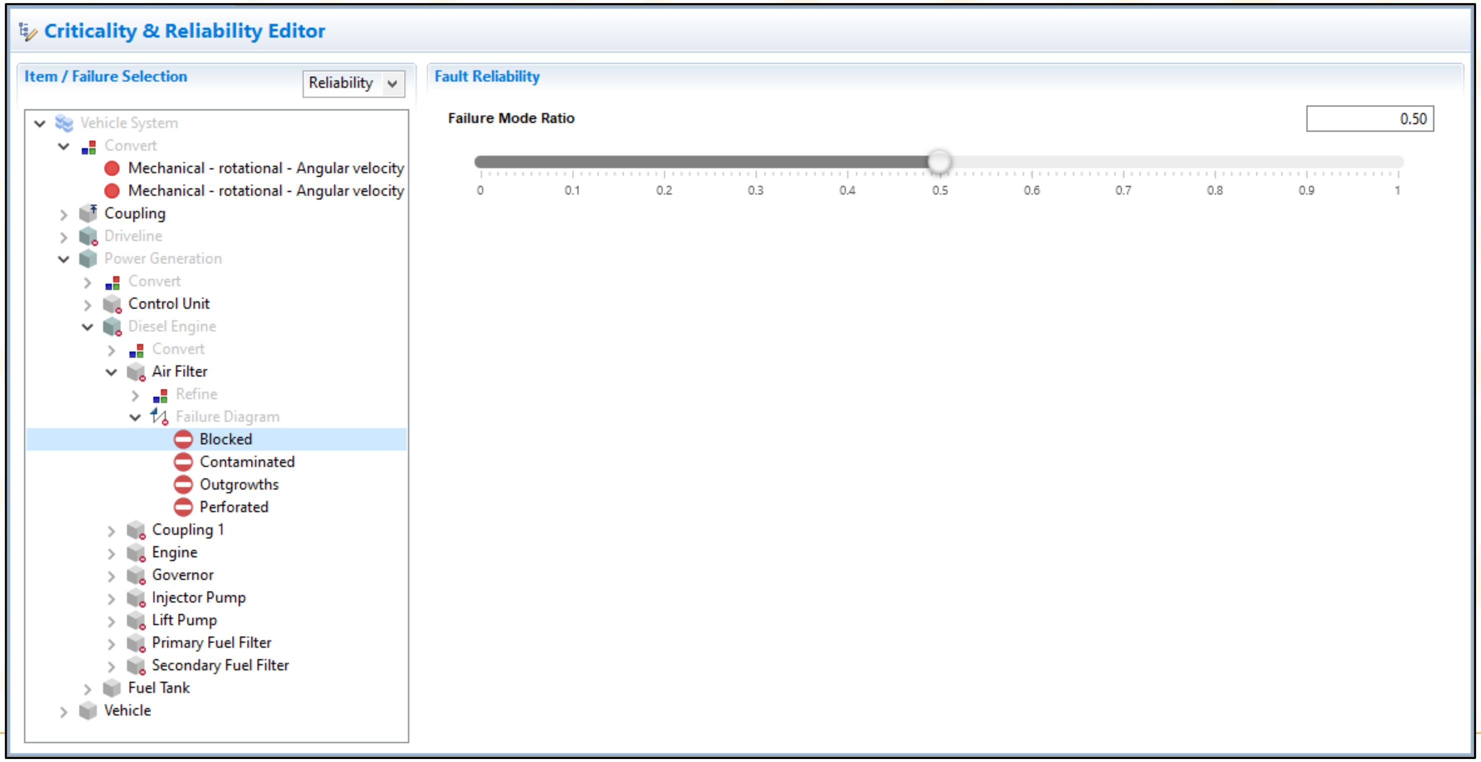
Which Failure Mode Ratios should be used?

- Use Failure Mode Response FMR when:
  - Physics of Failure is not known
  - There are no failure concepts in the Failure Diagram (except for Failure Mode)
  - Failure Diagram Override is applied
- Use Fault FMR when:
  - Physics of Failure is understood (i.e. Fault-level information)
  - Failure Trees are present: Cause → Mechanism → Fault → Failure Mode
- FMR is used in the following analysis outputs:
  - Criticality Analysis FMECA
  - Relative Probability of Failure Causes (Classic RCM)

Session 4.3: Reliability Editing

EXERCISE 4.3.5 EDIT FAILURE MODE RATIOS

- Expand the **'Air Filter'** component & Failure Diagram in the **Item/Failure Selection** tree
- Select the **Faults** below to set their individual Failure Mode Ratio (FMR):
  - Blocked: **0.50**
  - Contaminated: **0.2** (FMR)
  - Outgrowths: **0.1** (FMR)
  - Perforated: **0.2** (FMR)



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Session 4.3: Reliability Editing

<u>SESSION 4.3 SUMMARY</u>

- ✓ 4.3.1: Introduction to Item Reliability
- ✓ 4.3.2: Access Reliability Editor
- ✓ 4.3.3: Edit Item Reliability – Exponential Distribution
- ✓ 4.3.4: Edit Item Reliability – Weibull Distribution
- ✓ 4.3.5: Edit Failure Mode Ratios

Session 4.4: Failure Rate Prediction

Session 4.4 Outline

4.4.1: Failure Rate Prediction in Standards Context

4.4.2: Create a Failure Rate Prediction Analysis

4.4.3: Enter Part Detail Parameters

4.4.4: Apply Predicted MTTF to Item(s)

Session 4.4: Failure Rate Prediction

DISCUSSION 4.4.1 FAILURE RATE PREDICTION IN STANDARDS CONTEXT

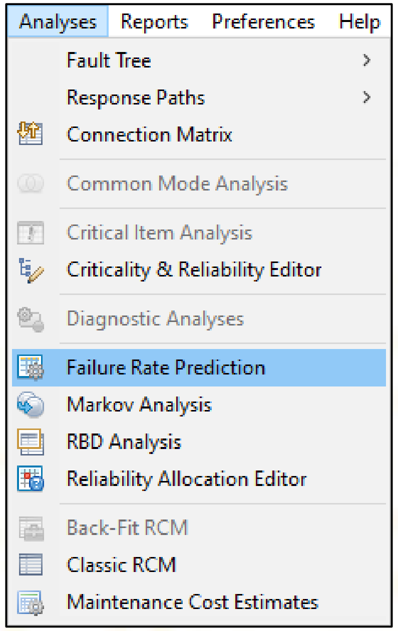
- MIL-STD-217F: Handbook for calculating reliability predictions using 'Part Stress Analysis' method
- Failure Rate Prediction purpose:
    - Establish & maintain consistent and uniform methods for estimating inherent reliability
    - Provide common basis of reliability prediction during acquisition stage
    - Standard applies to electronic equipment & systems
- Performed during Detailed Design Stages
- Applied to Component & Part-level Items

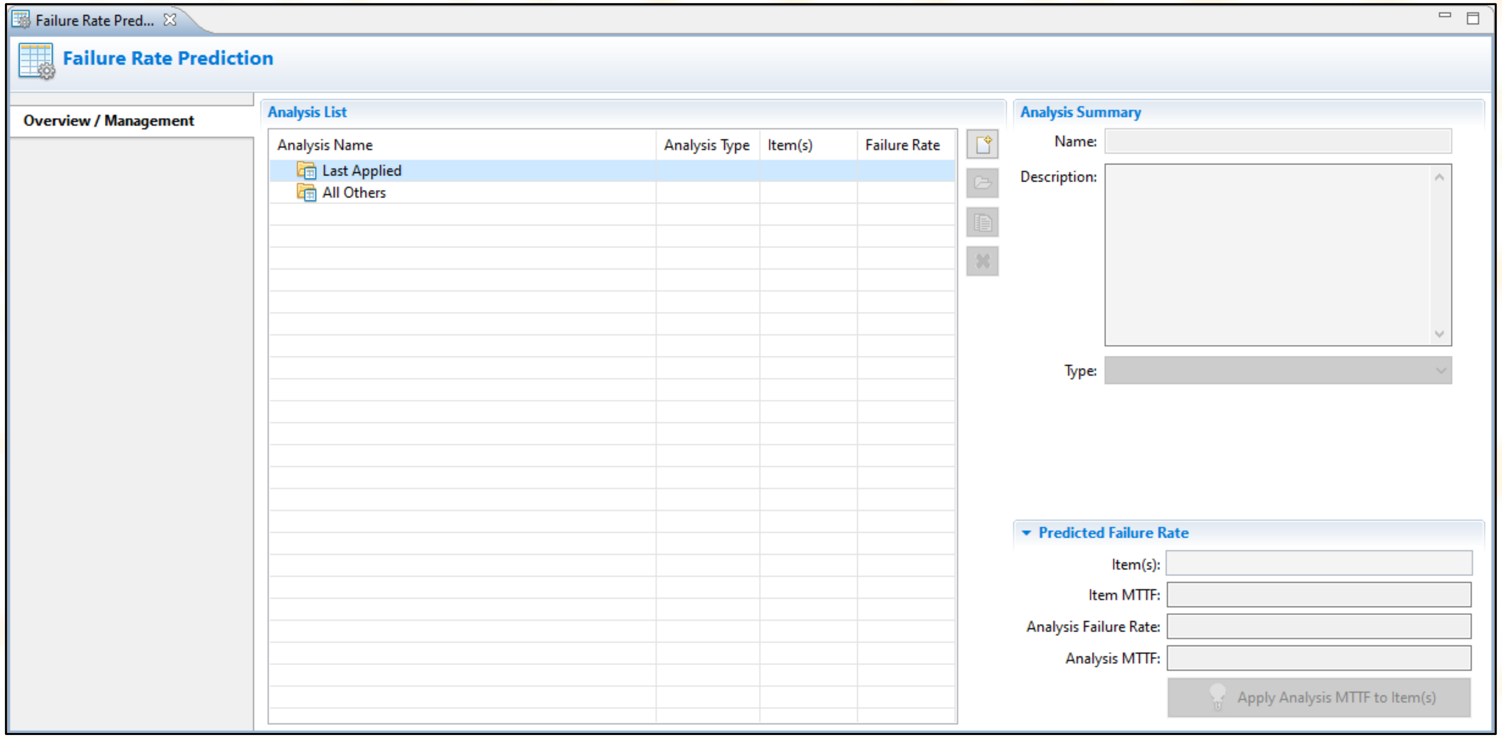
Session 4.4: Failure Rate Prediction

Exercise 4.4.2 Create a Failure Rate Prediction Analysis

To create a Failure Rate Prediction analysis:

- Select **Analyses → Failure Rate Prediction** from the menu bar

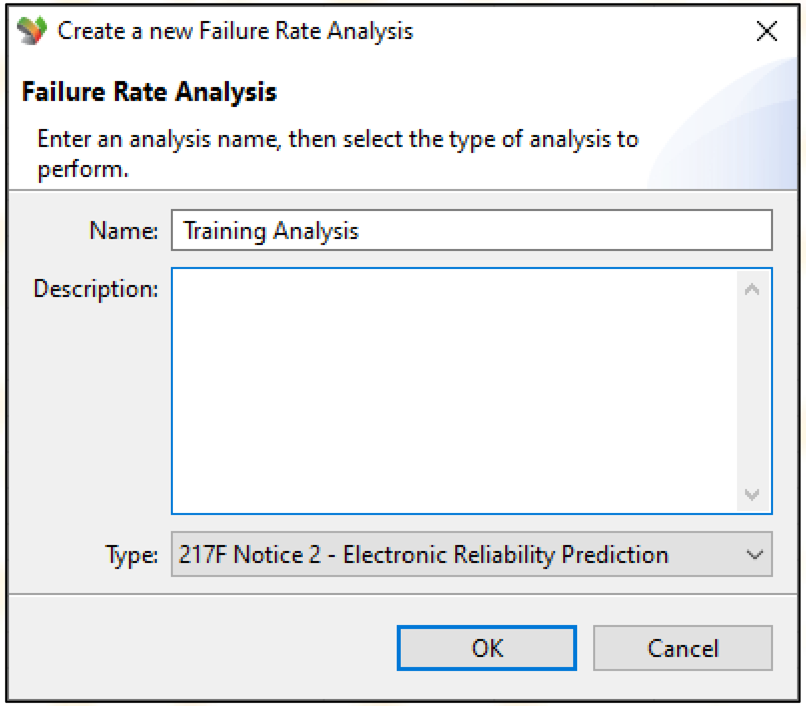




Session 4.4: Failure Rate Prediction

EXERCISE 4.4.2 CREATE A FAILURE RATE PREDICTION ANALYSIS (CONTINUED)

- Select to create a new Failure Rate Analysis
- Enter the following details:
  - Name: **Training Analysis**
  - Description: **Example Failure Rate Prediction analysis for Control Unit.**
  - Verify Failure Rate Standard type is ‘**217F Notice 2…**’
  - Select OK



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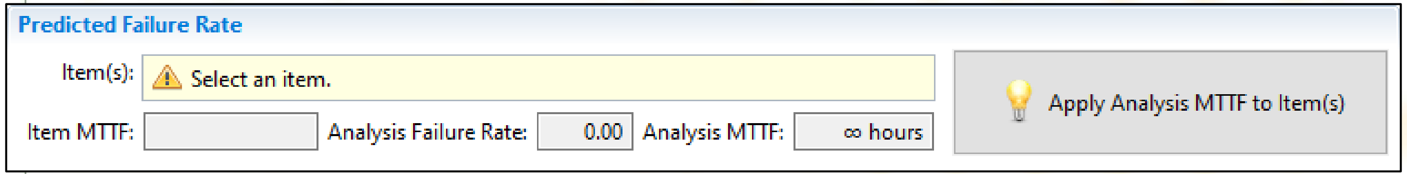
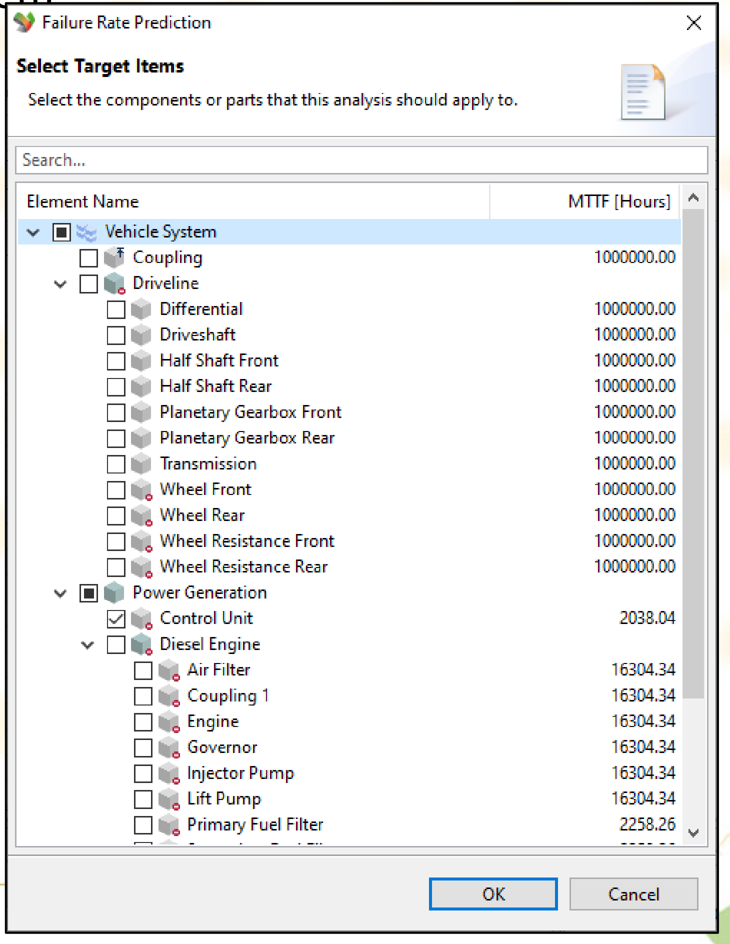
Session 4.2: Failure Rate Prediction

EXERCISE 4.4.2 CREATE A FAILURE RATE PREDICTION ANALYSIS (CONTINUED)

- In the Predicted Failure Rate section, select Select an item. to choose a model item
- Select **'Control Unit'** as the item for analysis
- Select OK

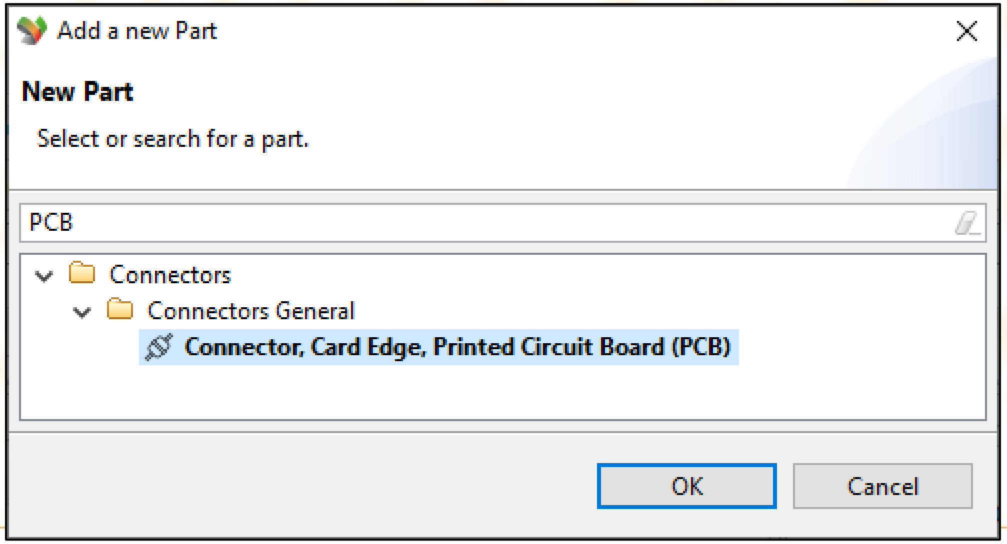




Session 4.4: Failure Rate Prediction

Exercise 4.4.2 Create a Failure Rate Prediction Analysis (continued)

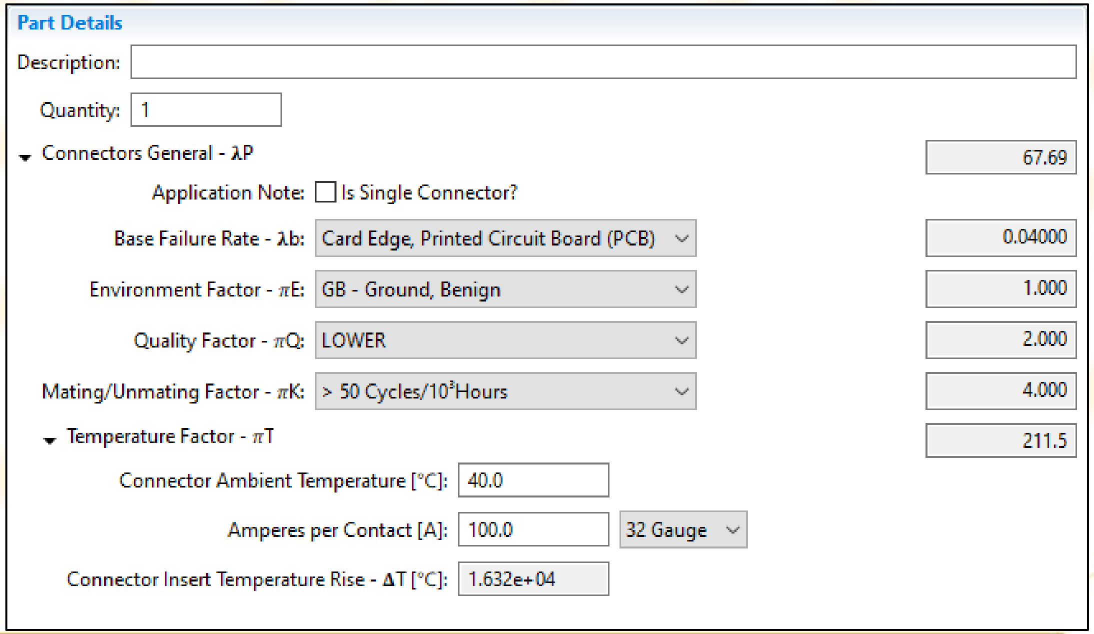
- Select to add New Parts to the analysis
- In the New Part dialog, search for **PCB**
- Select **Connectors, Card Edge, Printed Circuit Board (PCB)** from the list
- Select OK



Session 4.4: Failure Rate Prediction

EXERCISE 4.4.3 ENTER PART DETAIL PARAMETERS

- Verify the following parameters:
  - Part Quantity is **1**
  - Base Failure Rate: **Card Edge, Printed Circuit Board (PCB)**
  - Environment Factor: **GB – Ground, Benign**
  - Quality Factor: **LOWER**
- Change the following parameters:
  - Mating/Unmating Factor: **> 50 Cycles/10^3 Hours**
  - Connected Ambient Temperature: **40**
  - Amperes per Contact: **100, 32 Gauge**



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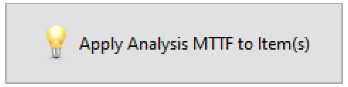
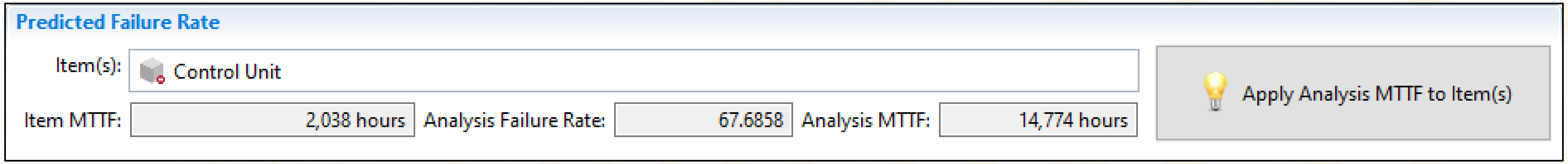
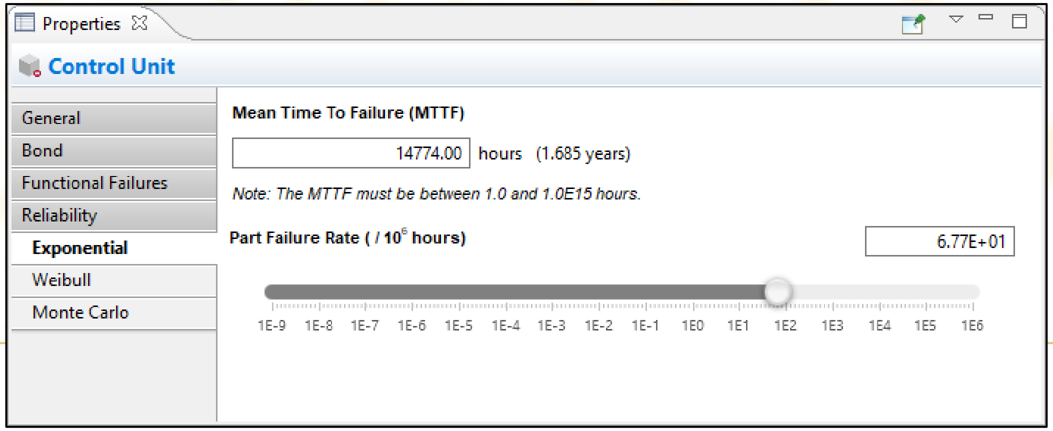
Session 4.4: Failure Rate Prediction

Exercise 4.4.4 Apply Predicted to Items

- Verify Predicted Failure Rate: **67.6858**
- Select 

- Verify updated MTTF for **‘Control Unit’** from the **Properties** viewer





Session 4.4: Failure Rate Prediction

Session 4.4 Summary

- ✓ 4.4.1: Failure Rate Prediction in Standards Context
- ✓ 4.4.2: Create a Failure Rate Prediction Analysis
- ✓ 4.4.3: Enter Part Detail Parameters
- ✓ 4.4.4: Apply Predicted MTTF to Item(s)

Session 4.5: Markov Analysis

Session 4.5 Outline

4.5.1: Markov Analysis in ARP4761 Context

4.5.2: Accessing Markov Analysis Editor

4.5.3: Markov Analysis Canvas Overview

4.5.4: Markov Analysis States

4.5.5: Markov Analysis Transitions

4.5.6: Markov Analysis Results

Session 4.5: Markov Analysis

Discussion 4.5.1 Markov Analysis in ARP4761 Context

- ARP4761 Standard: Guidelines & methods of performing safety assessment for certification of civilian aircraft
- Markov Analysis (MA) Definition: A Markov Model (chain) represents various system states & the relationships among them.
  - States: Operational, Degraded, Non-Operational (Failed)
  - Transition rate between states is a function of failure/repair rate
  - State probabilities derived from differential equations derived from Markov chain

Session 4.5: Markov Analysis

Discussion 4.5.1 Markov Analysis in ARP4761 Context (Continued)

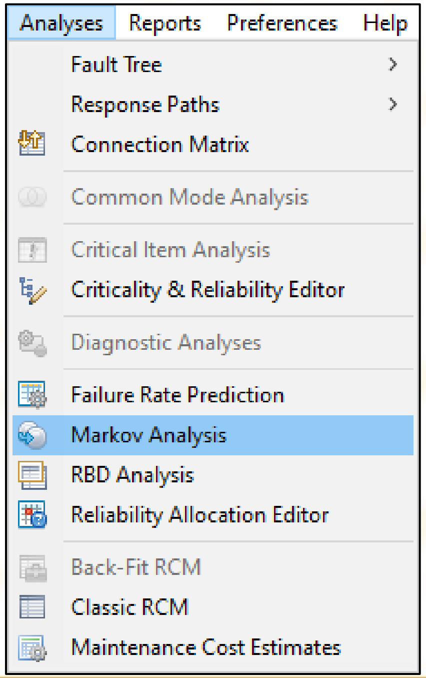
- Used to model complex, fault-tolerant systems with condition monitoring & reconfiguration
- Performed during Concept and Preliminary Design Stages
- Unlike Fault Trees, MA cover complex system behaviours of repairable systems or systems where failure/repair rate are state dependent
- Disadvantage: Markov model size grows exponentially with number of components
    - In MADe, MA is conducted on each individual item for simplicity

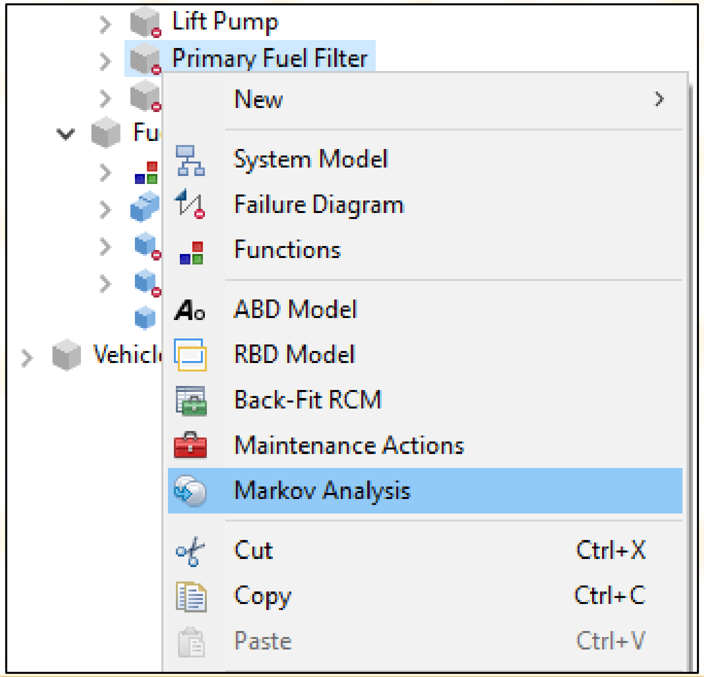
Session 4.5: Markov Analysis

Exercise 4.5.2 Accessing Markov Analysis Model Editor

To create a Markov Analysis:

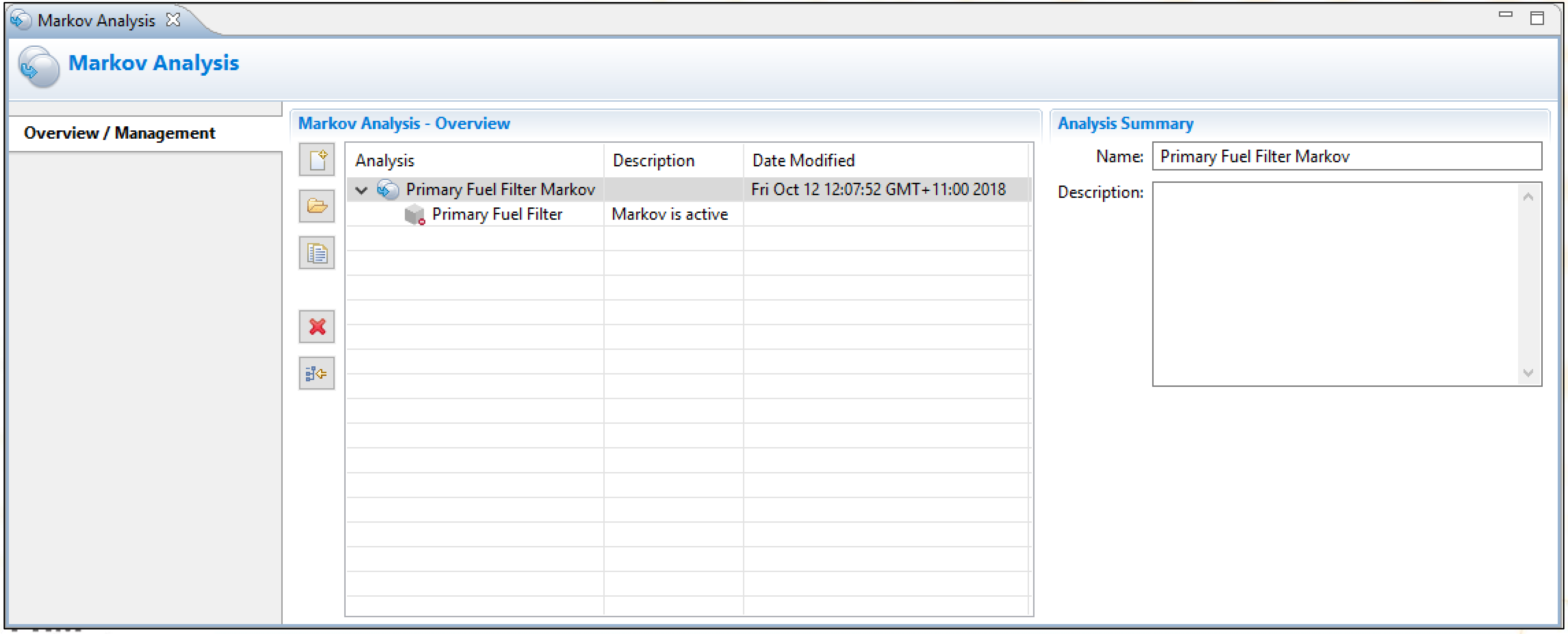
- Select **Analyses → Markov Analysis** from the main menu
- Alternatively, right-click an item in the Project Explorer/System Model then select **Markov Analysis**





Session 4.5: Markov Analysis

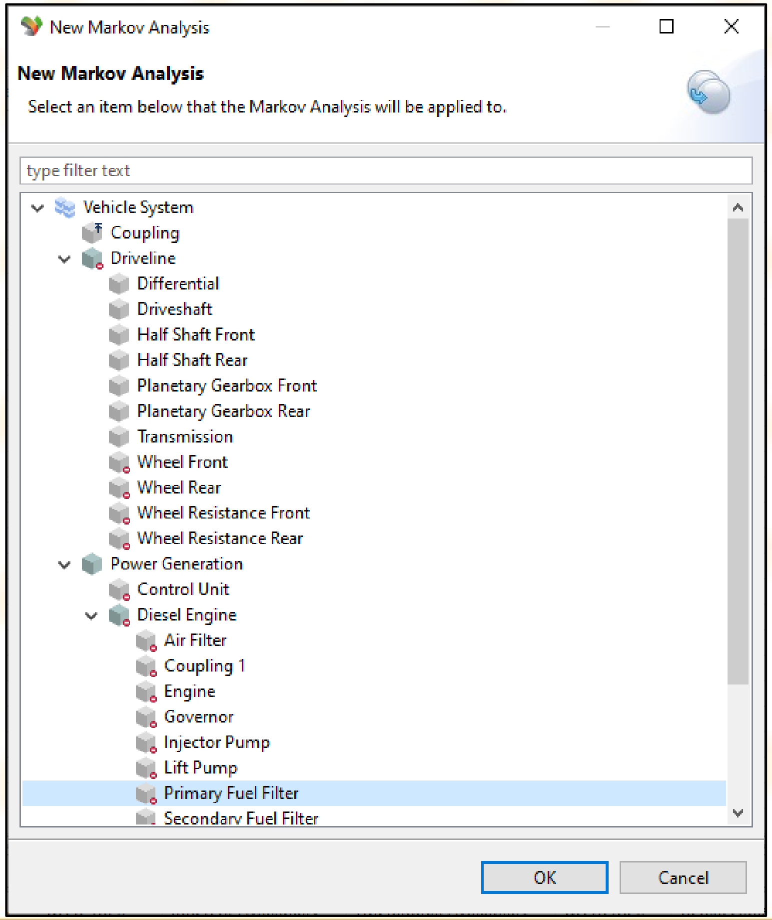
Exercise 4.5.2 Accessing Markov Analysis Model editor (continued)



Session 4.5: Markov Analysis

EXERCISE 4.5.2 ACCESSING MARKOV ANALYSIS MODEL EDITOR (CONTINUED)

- Select the new Markov Analysis icon
- From the dialog, select **‘Primary Fuel Filter’**
- Select OK



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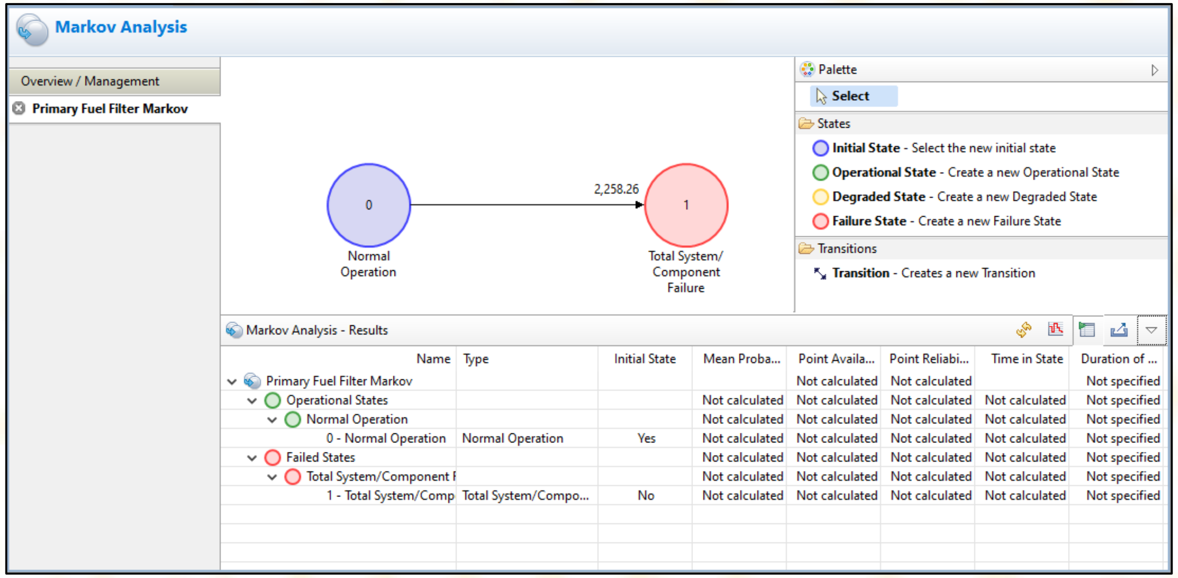
Session 4.5: Markov Analysis

Discussion 4.5.3 Markov Analysis Canvas Overview

- **Canvas**: Displays states, transitions and transition durations in hours
- **Palette**: Contains a selection tool, list of state categories and transition connection
- **Markov Analysis Results**: Shows states & corresponding availability, reliability & duration of operation



❖ Note: Properties Viewer edits canvas details: transitions, durations, state details.

Session 4.5: Markov Analysis

DISCUSSION 4.5.4 MARKOV ANALYSIS STATES

There are 4 types of states use in the Markov Analysis:

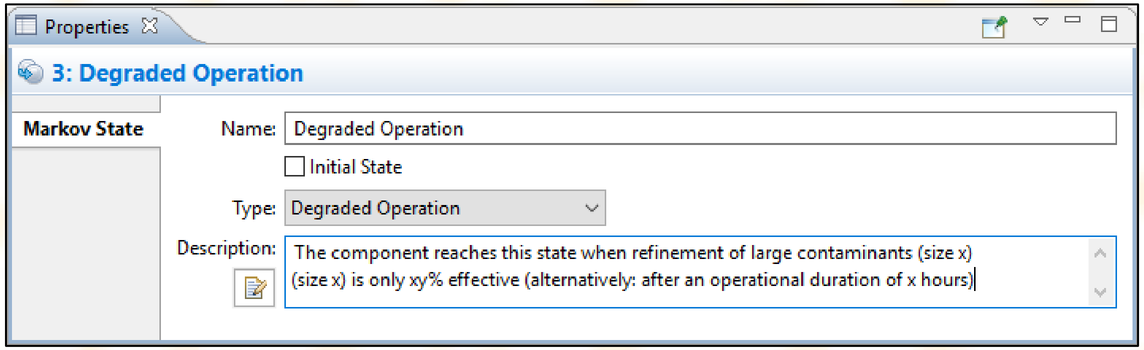
1. **Initial State**: Item state at time $t = 0$
   - Indicated by a blue circle
   - Default numerical label (indicating state) is ‘0’ but can be a larger value
2. **Operational State**: Item state in which the item is capable of performing the required function
   - Indicated by a green circle
   - Default numerical label is $n \geq 0$
3. **Degraded State**: Item state in which the item is capable of partially performing the required function
   - Indicated by a yellow circle
   - Default numerical label is $n \geq 0$
4. **Failure State**: Item state in which the item is not capable of performing the required function
   - Indicated by a red circle
   - Default numerical label is $n \geq 0$

Session 4.5: Markov Analysis

DISCUSSION 4.5.4 MARKOV ANALYSIS STATES

The user can modify Markov states from the Properties viewer:

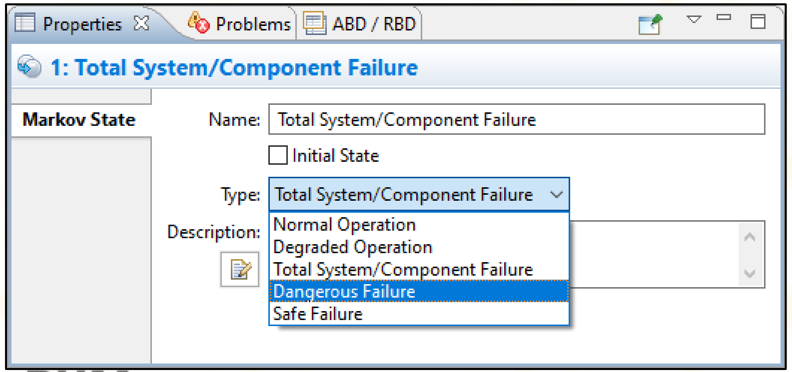
- **State Name**: Updates individual state names in the canvas
- **Initial State** (check box)
- **(State) Type**:
  - **Normal Operation**
  - **Degraded Operation**
  - **Total System/Component Failure**
  - **Dangerous Failure**: Failure which has the potential to put the safety related system into a hazardous state or fail-to-function state
  - **Safe Failure**: Failure that does not have the potential to put the system into a hazardous state or fail-to-function state
- **Description Field**: Used to describe the condition of the item during a specific Markov state

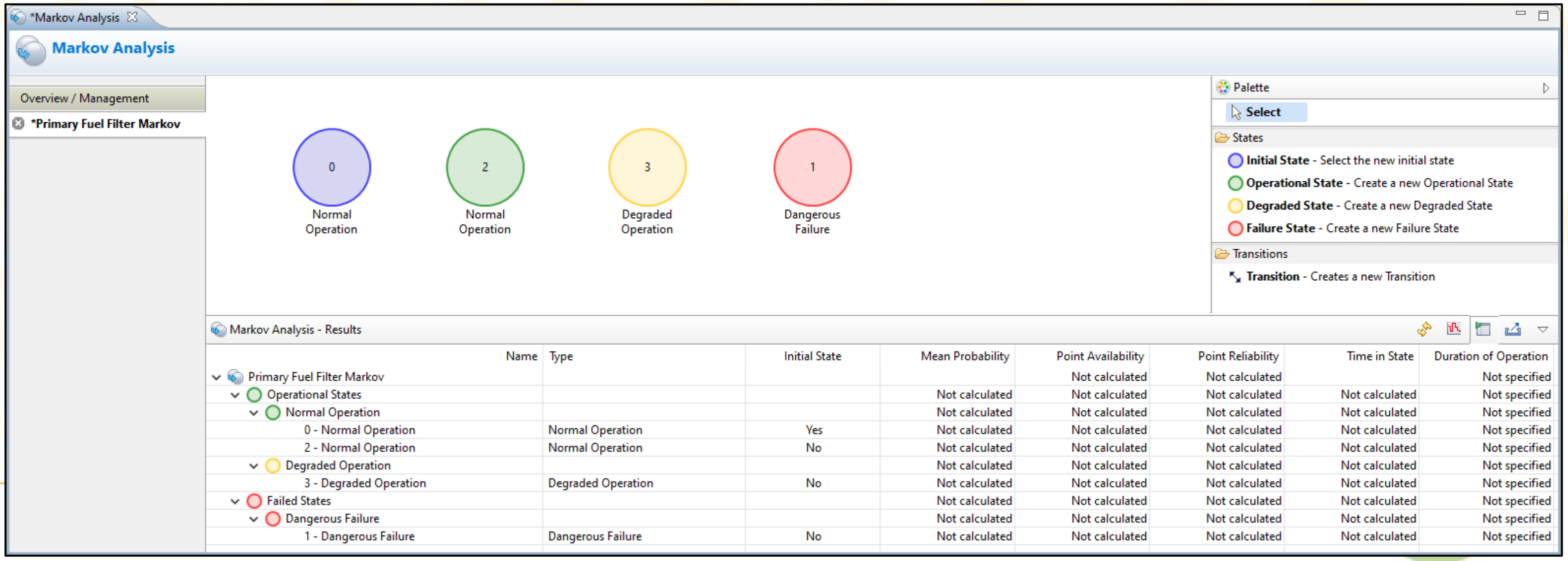


Session 4.5: Markov Analysis

Exercise 4.5.4 Markov Analysis States

- Create the following states: **Operational State**, **Degraded State**
  - Step 1: Select states in Markov Analysis palette
  - Step 2: Select canvas to create state
- Change Total System/Component failure type to **‘Dangerous Failure’**
- Delete the existing connection between Normal Operation and Dangerous Failure

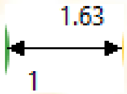




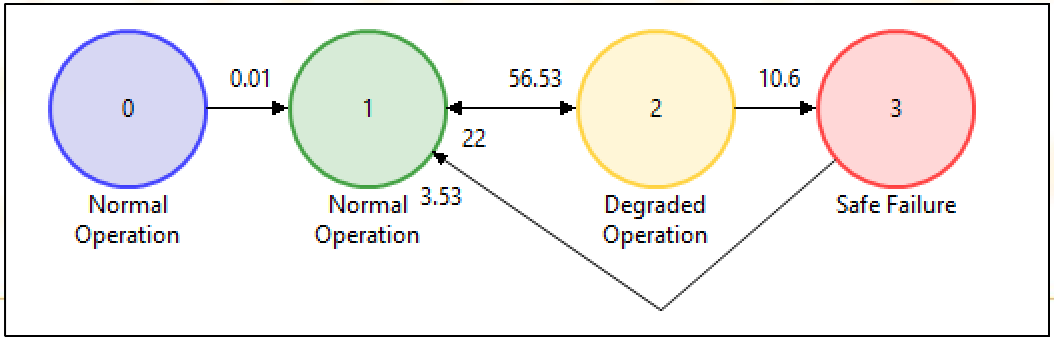
Session 4.5: Markov Analysis

Discussion 4.5.5 Markov Analysis Transitions

- Markov Analysis Transitions represent the change from one state to another
- Indicated by a single or double-sided arrow connected two states in the canvas
  - Single arrow indicates transition in only one direction/only one state
  - Double-headed arrow indicates transition is possible between both states
- Transition connection displays time in hours to transition between states
  - Double-headed arrows show 2 transition times



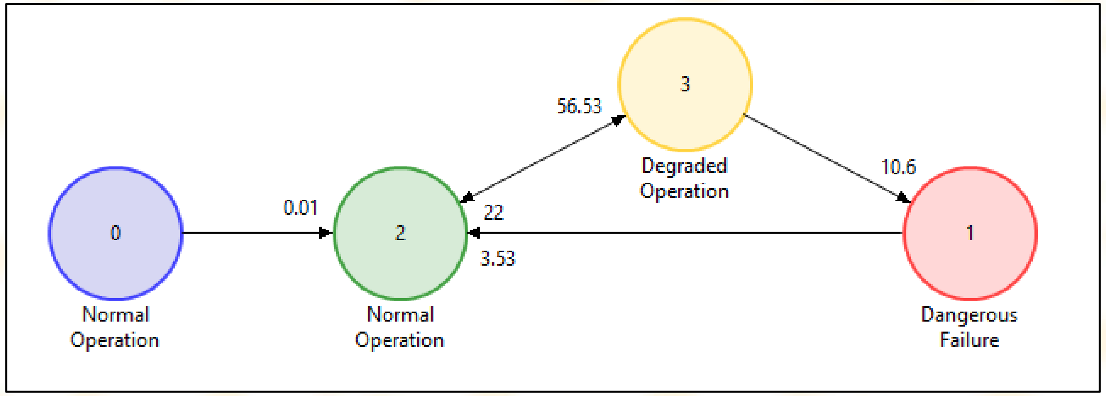
  - Set from the Properties viewer
- Transition placement is manipulated by selecting the square on the line



Session 4.5: Markov Analysis

Exercise 4.5.5 Markov Analysis States

- Create the following transitions:
  - **State 0 to 2:** Initial State to Operational State
    - Set transition hours (0→1) to **0.01**
  - **State 2 to 3:** Operational State to Degraded State
    - Set transition hours (2→3) to **56.53**
    - Set transition hours (3→2) to **22**
  - **State 3 to 1:** Degraded State to Failure State
    - Deselect check box: **Allow transition from state 1 to state 3**
    - Set transition hours (3→1) to **10.6**
  - **State 1 to 2**: Failure State to Normal Operation State
    - Deselect check box: **Allow transition from state 1 to state 3**
    - Set transition hours (3→1) to **3.53**



❖ Note: the numbering may be different due to the order each state was created.

Session 4.5: Markov Analysis

DISCUSSION 4.5.6 MARKOV ANALYSIS RESULTS

- Markov Analysis – Results collapsible canvas is refreshed to generate updated results
- Results are displayed in table or line chart format
- Export of table in .csv format available

Markov Analysis - Results

Name	Type	Initial State	Mean Probability	Point Availability	Point Reliability	Time in State	Duration of Operation
Primary Fuel Filter Markov				0.9639423	0.4839453		70.66
Operational States			0.9688068	0.9639423	0.4839453	68.46	70.66
Normal Operation			0.8697296	0.8556660	0.4253365	61.45	70.66
0 - Normal Operation	Normal Operation	Yes	0.0001415	0.0	0.0	0.01	70.66
1 - Normal Operation	Normal Operation	No	0.8695881	0.8556660	0.4253365	61.44	70.66
Degraded Operation			0.0990772	0.1082763	0.0586087	7.00	70.66
2 - Degraded Operation	Degraded Operation	No	0.0990772	0.1082763	0.0586087	7.00	70.66
Failed States			0.0311932	0.0360577	0.5160547	2.20	70.66
Safe Failure			0.0311932	0.0360577	0.5160547	2.20	70.66
3 - Safe Failure	Safe Failure	No	0.0311932	0.0360577	0.5160547	2.20	70.66

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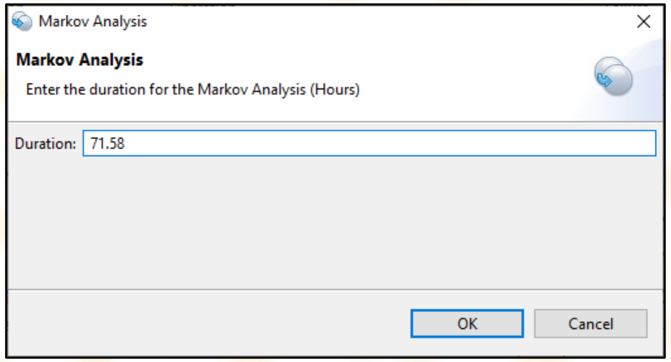
Session 4.5: Markov Analysis

Exercise 4.5.6 Markov Analysis Results

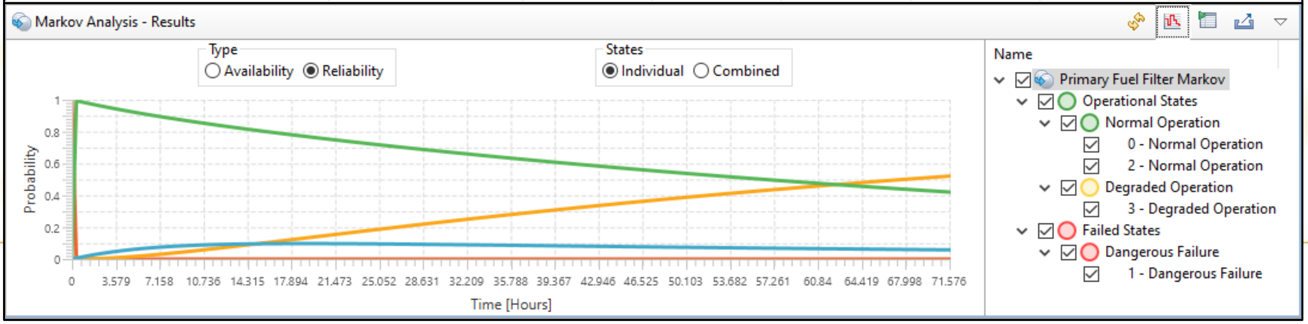
To generate results for all Markov states:

- Select to recalculate the Markov Reliability graph
- Select OK to confirm duration of operation of 71.58
- Toggle Analysis Data/Line Charts icons to view results



Markov Analysis - Results

Name	Type	Initial State	Mean Probability	Point Availability	Point Reliability	Time in State	Duration of Ope...
Primary Fuel Filter Markov				0.9639422	0.4789033		71.58
Operational States			0.9687445	0.9639422	0.4789033	69.34	71.58
Normal Operation			0.8695495	0.8556658	0.4209048	62.24	71.58
0 - Normal Operation	Normal Operation	Yes	0.0001397	0.0	0.0	0.01	71.58
2 - Normal Operation	Normal Operation	No	0.8694098	0.8556658	0.4209048	62.23	71.58
Degraded Operation			0.0991950	0.1082764	0.0579986	7.10	71.58
3 - Degraded Operation	Degraded Operation	No	0.0991950	0.1082764	0.0579986	7.10	71.58
Failed States			0.0312555	0.0360578	0.5210967	2.24	71.58
Dangerous Failure			0.0312555	0.0360578	0.5210967	2.24	71.58
1 - Dangerous Failure	Dangerous Failure	No	0.0312555	0.0360578	0.5210967	2.24	71.58

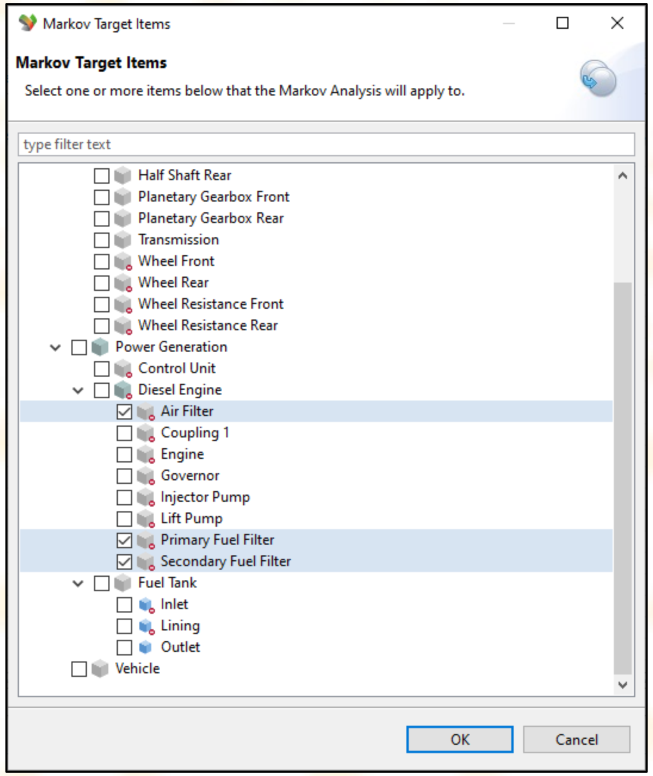


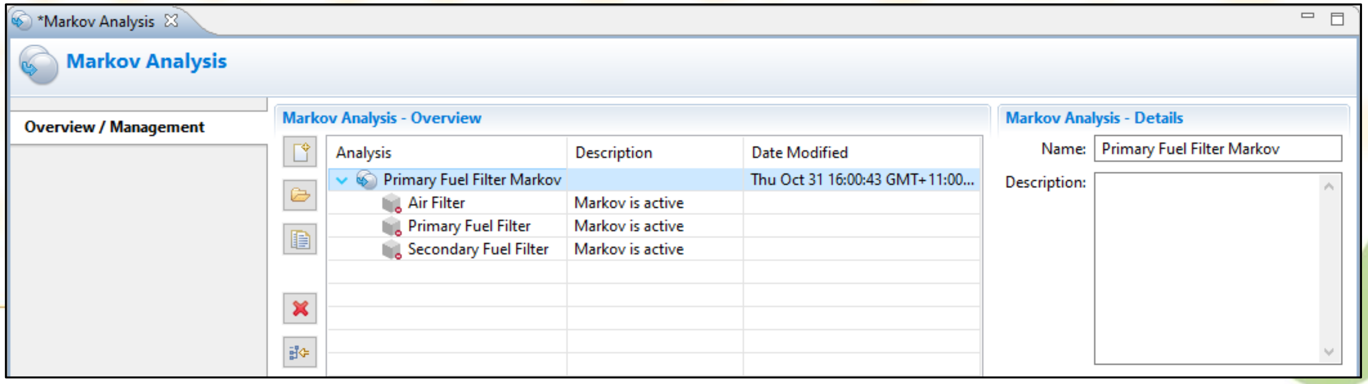
Session 4.5: Markov Analysis

EXERCISE 4.5.6 MARKOV ANALYSIS RESULTS (CONTINUED)

To apply the current Markov Analysis to multiple items in the system:

- Navigate to **Overview/Management** page
- Select the Markov Analysis
- Select to open the Target Items dialog
- From the target item dialog select item check boxes that apply
  - Apply to **'Primary Fuel Filter'** (default), **'Secondary Fuel Filter'** & **'Air Filter'**
- Select OK
- Verify Markov Analysis application in table





Session 4.5: Markov Analysis

made
decisions better MADe...

Session 4.5 Outline

- ✓ 4.5.1: Markov Analysis in ARP4761 Context
- ✓ 4.5.2: Accessing Markov Analysis Editor
- ✓ 4.5.3: Markov Analysis Canvas Overview
- ✓ 4.5.4: Markov Analysis States
- ✓ 4.5.5: Markov Analysis Transitions
- ✓ 4.5.6: Markov Analysis Results

Session 4.6: Hardware Fault Tree Analysis (HFTA)

<u>Session 4.6 Outline</u>

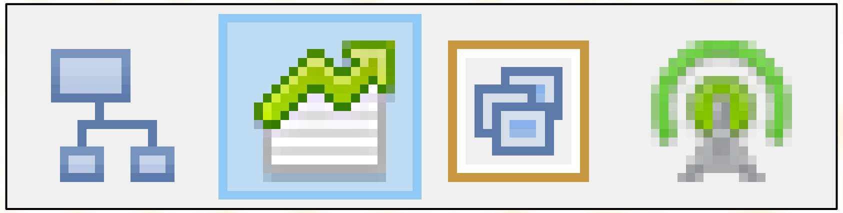
4.6.1: Generate a Hardware Fault Tree Analysis (HFTA)

4.6.2: Export Hardware FTA Results

Session 4.6: Hardware Fault Tree Analysis (HFTA)

DISCUSSION 4.6.1 HARDWARE FAULT TREE ANALYSIS

- The hardware fault tree traces progression of failures based on the System RBD structure
- Instead of functional failure modes it displays parts, components and systems
- For this session, we will need to be in the SRA Module



Session 4.6: Hardware Fault Tree Analysis (HFTA)

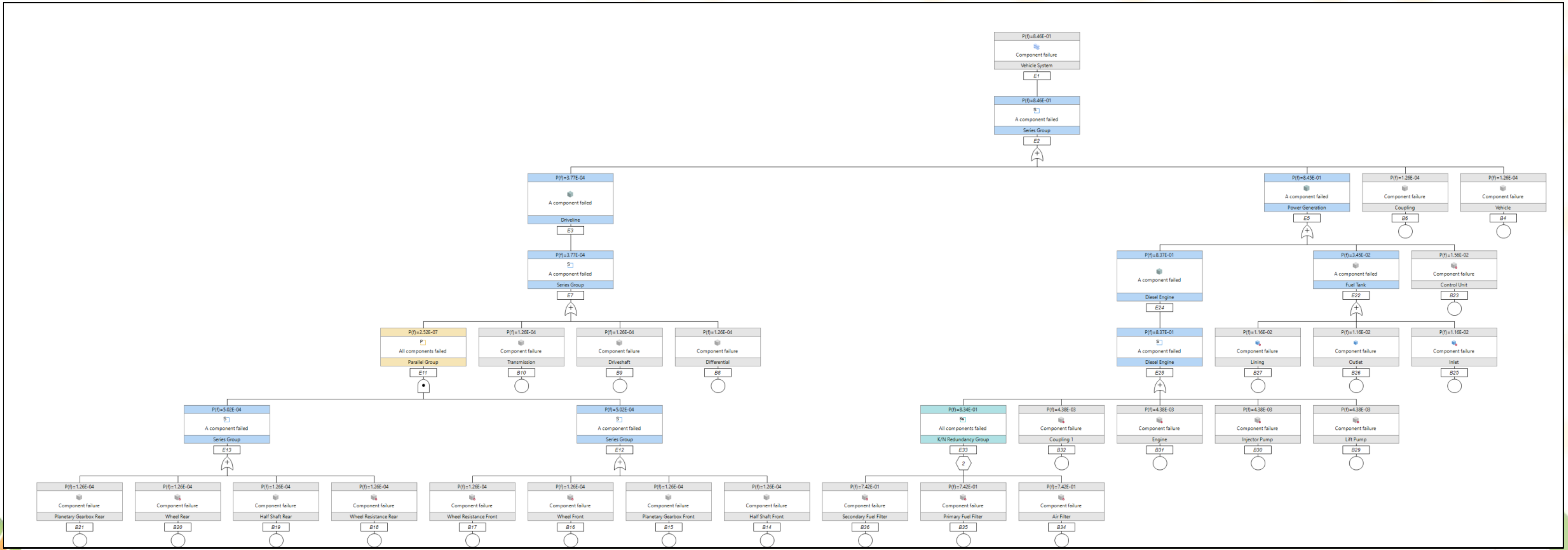
Exercise 4.6.1 Hardware Fault Tree Analysis

To generate a hardware fault tree analysis:

- Access the Fault Tree Builder and select ➕
- Enter the following details:
  - Name: **Hardware Fault Tree**
  - Description: **Hardware Fault Tree for Vehicle System**
  - Fault Tree Type: **Hardware Fault Tree**
  - Set **'Vehicle System'** as the Top Event

Session 4.6: Hardware Fault Tree Analysis (FTA)

EXERCISE 4.6.1 HARDWARE FAULT TREE ANALYSIS



Technology

Session 4.6: Hardware Fault Tree Analysis (HFTA)

<u>Exercise 4.6.2 Exporting Hardware Fault Tree Results</u>

To export the Hardware Fault Tree as an image:

- Select to capture the entire Hardware Fault Tree
- Select a directory and enter a file name for the PNG image
- Select Save to save the image of the current Fault Tree

To export the Hardware Fault Tree analysis results:

- Select in the Hardware Fault Tree tab
- Select a directory and enter a file name for the .csv export
- Select Save to save the analysis results of the Hardware Fault Tree

Session 4.6: Hardware Fault Tree Analysis (HFTA)

Session 4.6 Summary

✓ 4.6.1: Generate a Hardware Fault Tree Analysis (FTA)

✓ 4.6.2: Export Hardware FTA Results

Session 4: Reliability Analyses Summary

SESSION 4 SUMMARY

✓ 4.1: Reliability Block Diagram

✓ 4.2: Reliability Allocation

✓ 4.3: Reliability Editing

✓ 4.4: Failure Rate Prediction

✓ 4.5: Markov Analysis

✓ 4.6: Hardware Fault Tree Analysis (HFTA)

Session 5: Maintainability Analyses

Using the MADe Model to generate key analyses from Maintenance and ILS domains

Session 5: Maintainability Analyses

Session 5 Outline

5.1: Maintenance Cost Estimates

5.2: Maintenance Actions

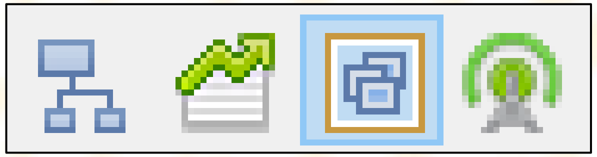
5.3: Reliability Centered Maintenance (Classic)

5.4: Reliability Centered Maintenance (Back-Fit RCM)

Session 5: Maintainability Analysis

Session 5 Discussion

- Session 5 will take place in the RAM module.
- This session will focus on Maintenance. This includes:
  - Maintenance Cost Estimate
  - Maintenance Actions
  - Reliability Centred Maintenance (Classic)
  - Reliability Centred Maintenance (Back-Fit)



Session 5.1: Maintenance Cost Estimates

SESSION 5.1 OUTLINE

5.1.1: MCE Management

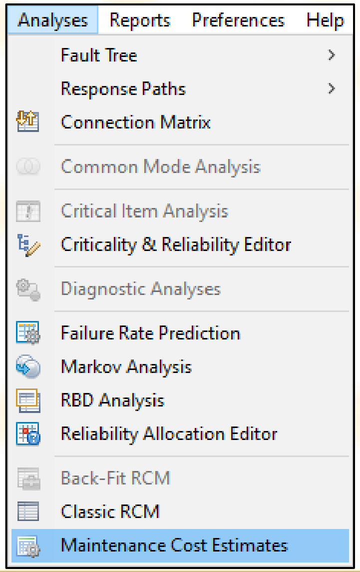
5.1.2: MCE Summary & Details

5.1.3: Charting & MCE Report

Session 5.1: Maintenance Cost Estimates

DISCUSSION 5.1 MAINTENANCE COST ESTIMATES

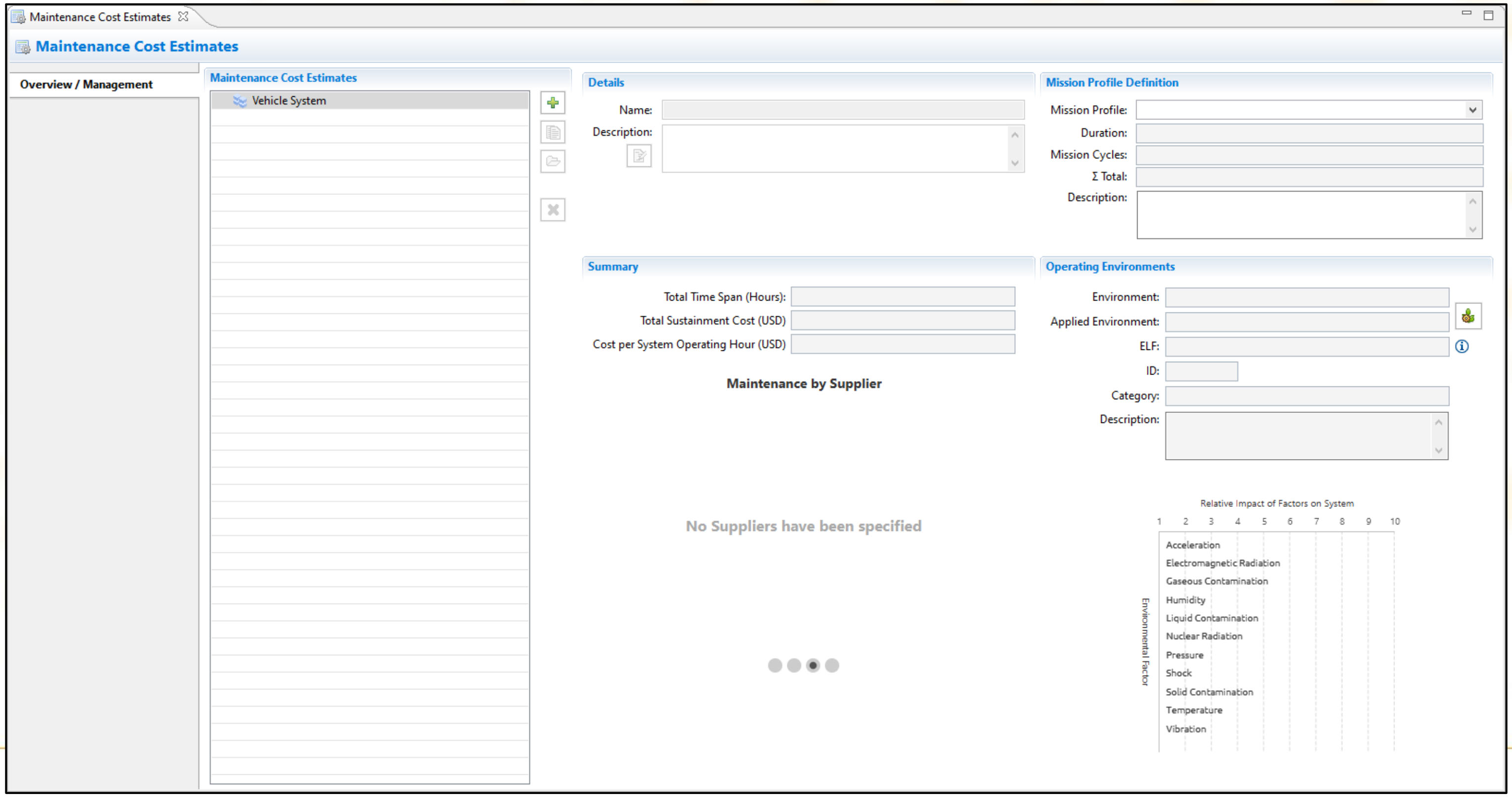
- MCE generates and compares costs of maintenance procedures over the operational timespan of an item
- Typically used in early stages of the design lifecycle to estimate and predict the total maintenance costs
- Can be used to detail the maintenance and support aspect of lifecycle costs



Session 5.1: Maintenance Cost Estimates

DISCUSSION 5.1.1 MCE MANAGEMENT

- This page is used to create, store and edit MCE analyses
- The page also provides an overview for a specific analysis

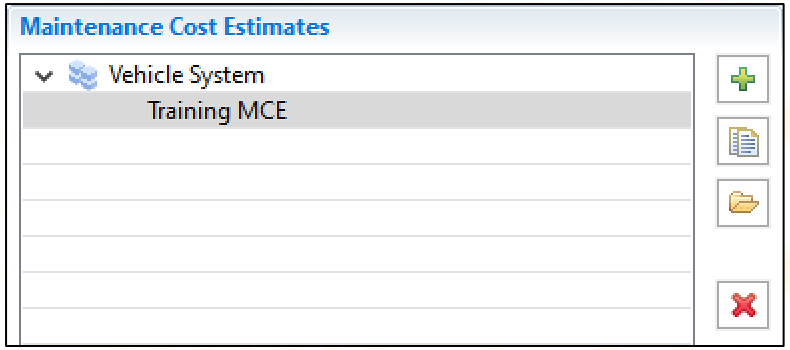


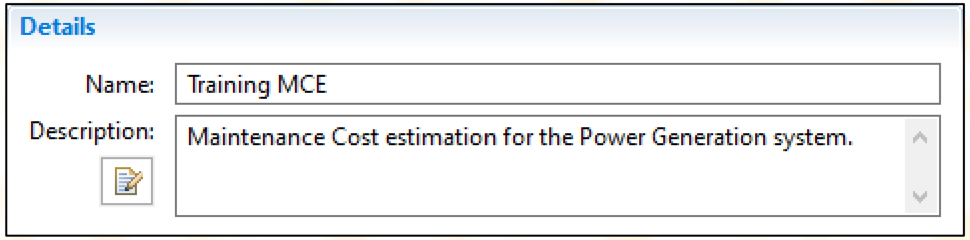
Session 5.1: Maintenance Cost Estimates

Exercise 5.1.1 Create a new MCE analysis

To create a MCE analysis:

- Select to create a new MCE analysis
- Enter the MCE Name: **Training MCE**
- Enter the MCE Description: **Maintenance Cost estimation for the Power Generation system.**

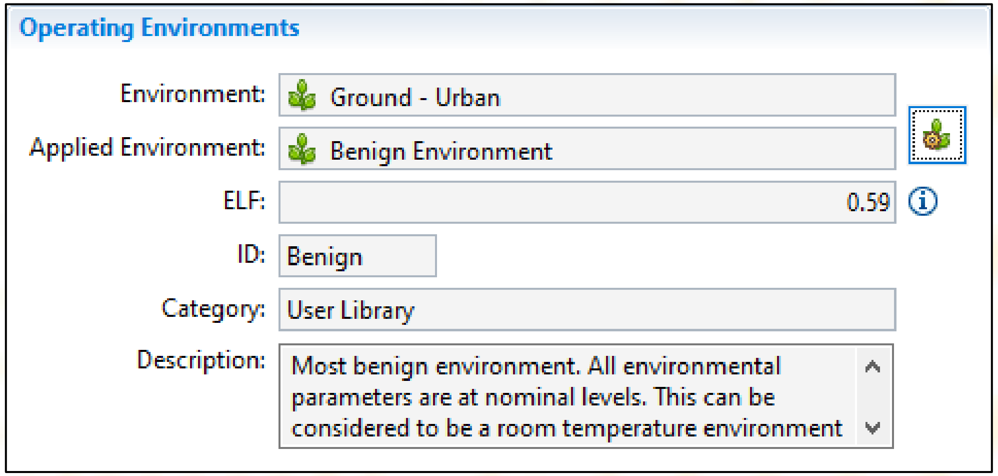


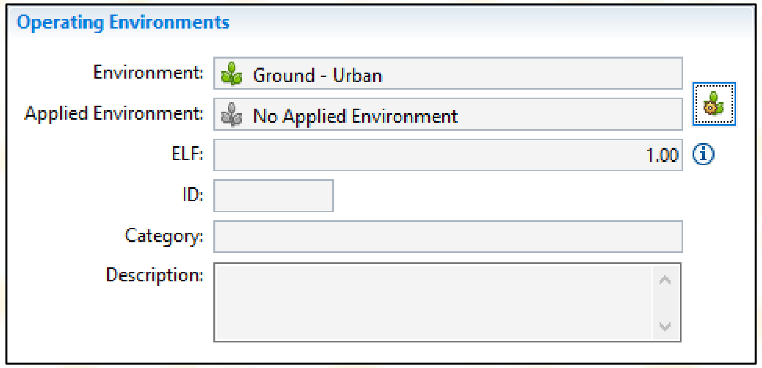


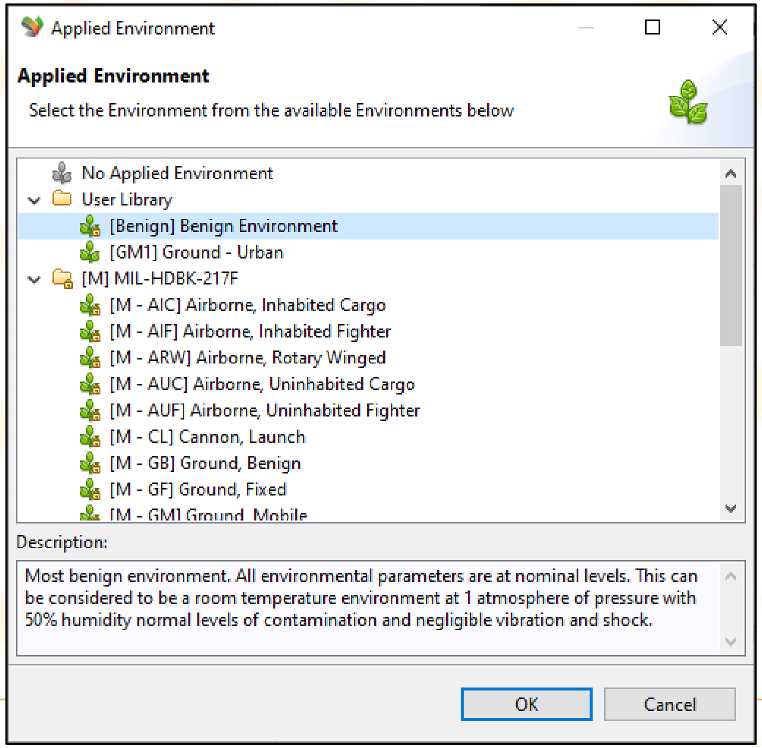
Session 5.1: Maintenance Cost Estimates

Exercise 5.1.1 Edit Applied Environment

- Select to choose an applied environment
- Under **User Library** select **Benign Environment**
- Select OK to close dialog and select applied environment
- Verify that **Environmental Loading Factor (ELF)** is: **0.59**





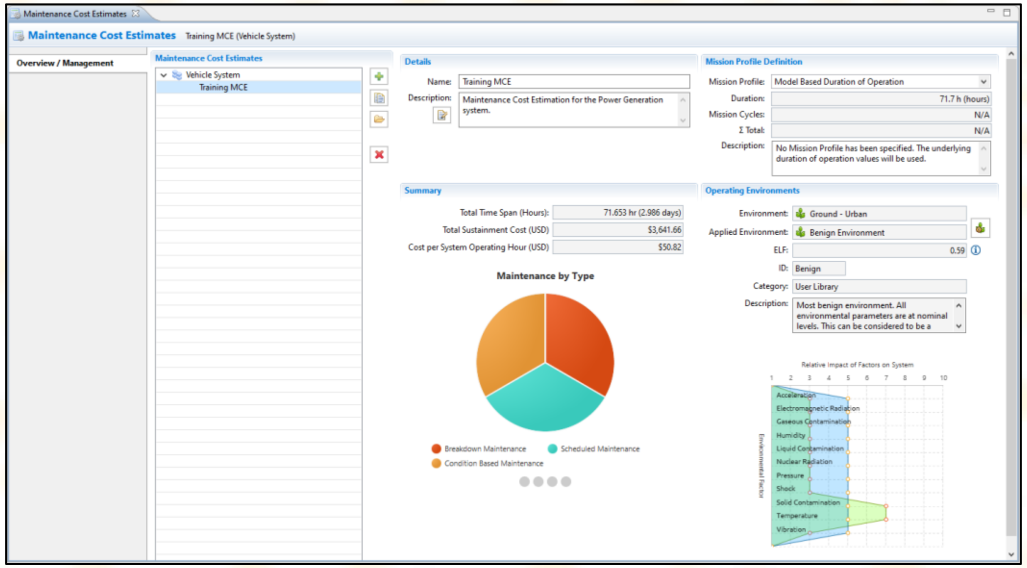


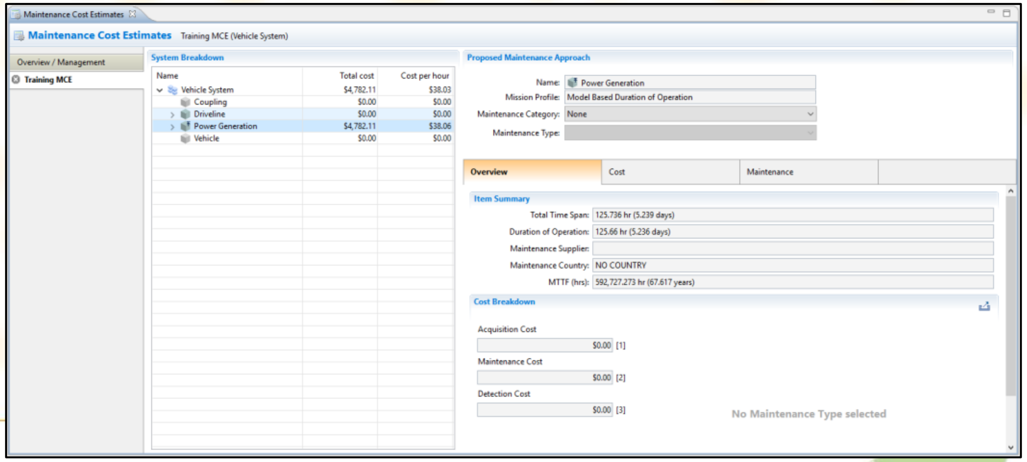
❖ Note: The ELF is calculated based on the selected environment

Session 5.1: Maintenance Cost Estimates

DISCUSSION 5.1.2 MCE PAGE

- After a new MCE analysis has been created, maintenance and item costs must be estimated
  - MCE is a bottom-up approach
- This is accessed by selecting the new analysis and clicking 🗁 to open the analysis
- This page defines the estimated cost of sustainment for the system based on the component maintenance actions
- If item maintenance estimates are unknown, costs can be estimated at the subsystem level
  - Less detailed (estimates are more rough)
  - Lower-level component estimates can be updated later



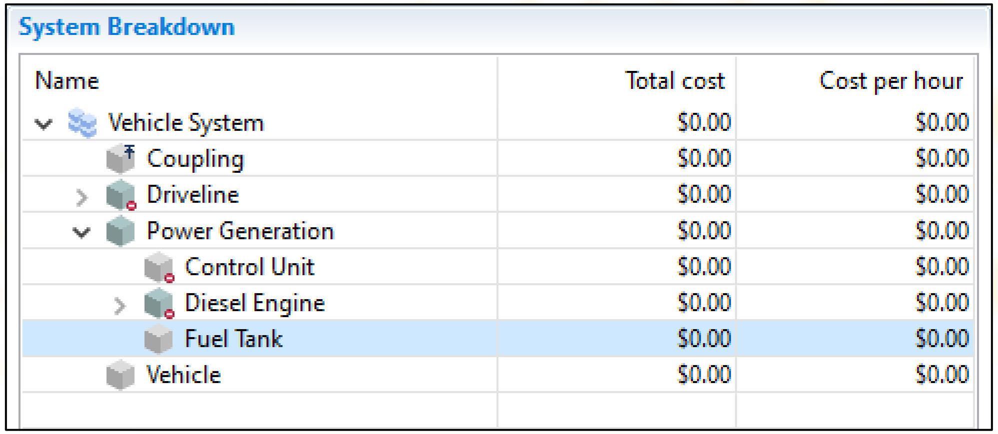


Session 5.1: Maintenance Cost Estimates

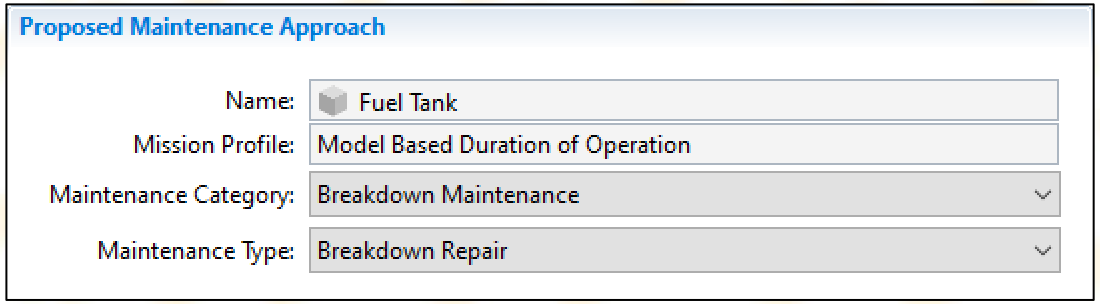
Exercise 5.1.2 Add Breakdown Repair for Fuel Tank component

To edit details for the MCE:

- Select **Training MCE** then select
- Expand the system tree and select **Fuel Tank**
- Under Proposed Maintenance Approach section:
  - Select Maintenance Category: **Breakdown Maintenance**
  - Select Maintenance Type: **Breakdown Repair**


System Breakdown

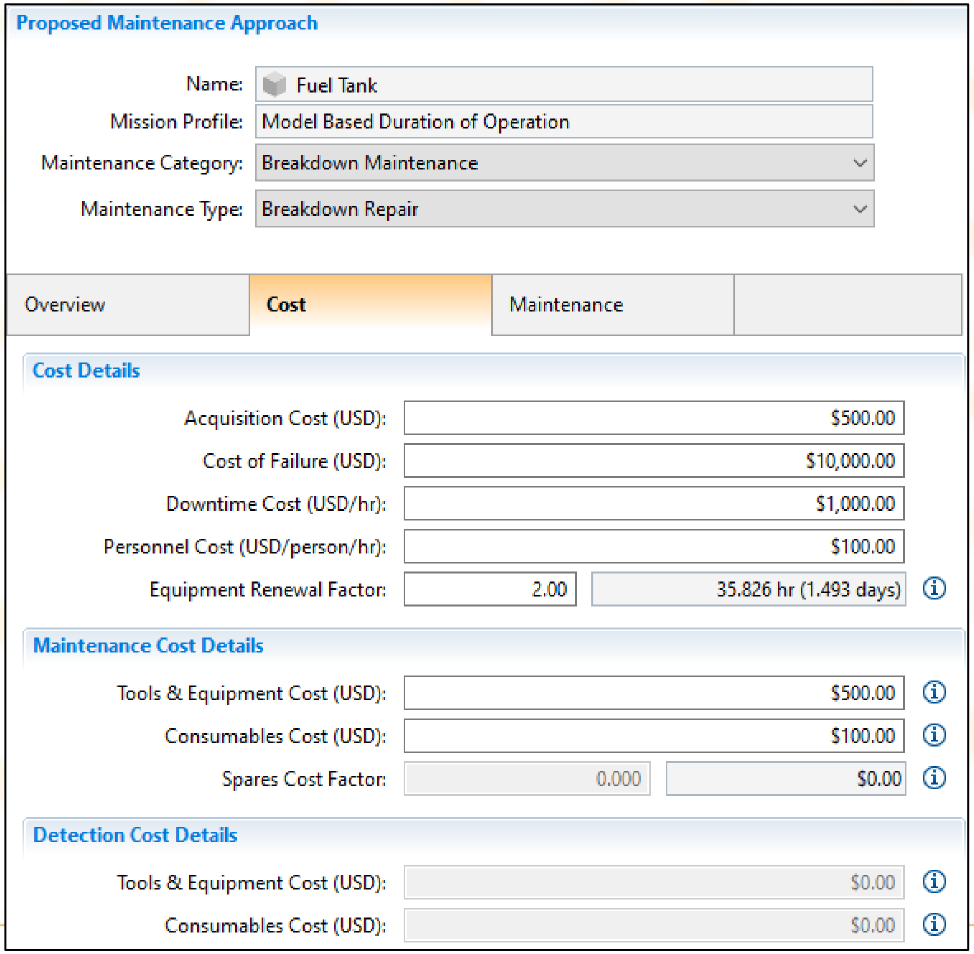
Name	Total cost	Cost per hour
Vehicle System	$0.00	$0.00
Coupling	$0.00	$0.00
Driveline	$0.00	$0.00
Power Generation	$0.00	$0.00
Control Unit	$0.00	$0.00
Diesel Engine	$0.00	$0.00
Fuel Tank	$0.00	$0.00
Vehicle	$0.00	$0.00



Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.2 ADD BREAKDOWN REPAIR FOR FUEL TANK COMPONENT (CONTINUED)

- Select the **Cost** tab and enter:
  - Acquisition cost: **$500**
  - Cost of Failure: **$10,000**
  - Downtime cost: **$1,000**
  - Personnel cost: **$100** (per person per hour)
  - Equipment Renewal Factor: **2.00**
  - Tools & Equipment Cost: **$500**
  - Consumables Cost: **$100**



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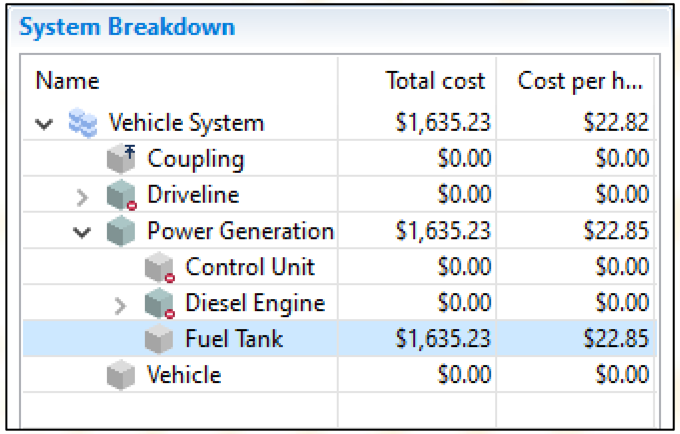
Session 5.1: Maintenance Cost Estimates

Exercise 5.1.2 Add Breakdown Repair for Fuel Tank component (continued)

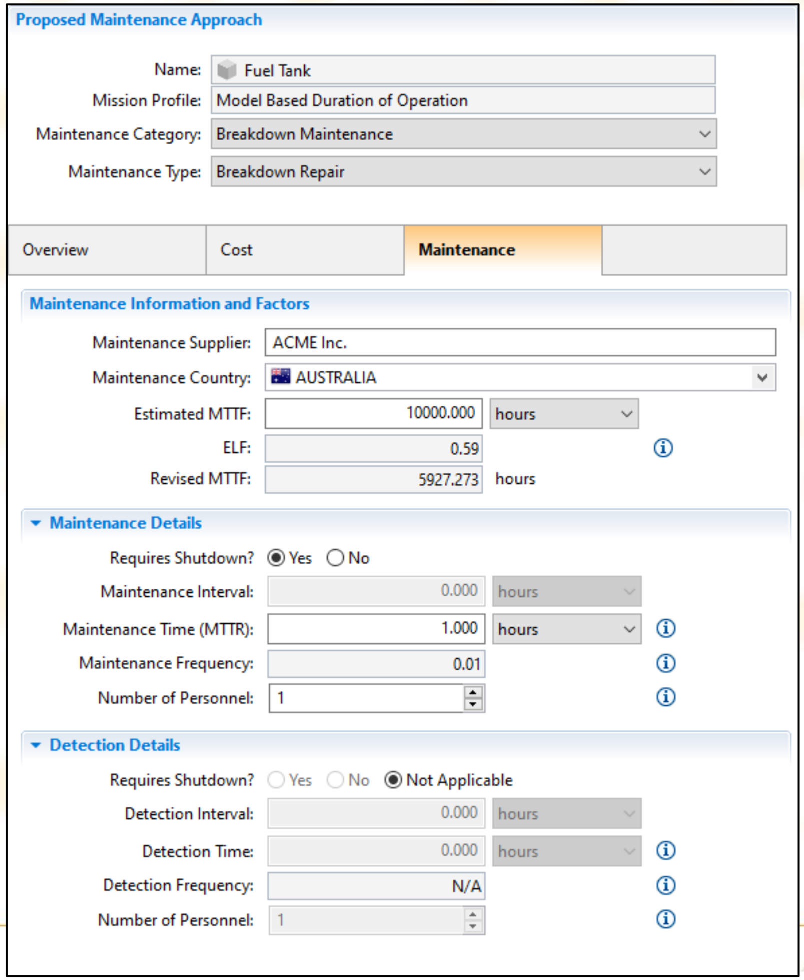
- Select the **Maintenance** tab and enter:
  - Maintenance Supplier: **ACME Inc.**
  - Maintenance Country: **Australia**
  - Estimated MTTF: **10,000 Hours**
  - Maintenance Time: **1 Hour**
  - No. of Personnel: **1**



System Breakdown

Name	Total cost	Cost per h...
Vehicle System	$1,635.23	$22.82
Coupling	$0.00	$0.00
Driveline	$0.00	$0.00
Power Generation	$1,635.23	$22.85
Control Unit	$0.00	$0.00
Diesel Engine	$0.00	$0.00
Fuel Tank	$1,635.23	$22.85
Vehicle	$0.00	$0.00

- Verify Total Cost: **$1635.23**
- Verify Cost per Hour: **$22.85**



Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.2 ADD BREAKDOWN REPAIR FOR FUEL TANK COMPONENT (CONTINUED)

- Breakdown of Total Cost: $1635.23
  1. MTBM = (MTTF × ELF) + MTTR = (10,000 × 0.5927273) + 1 = 5928.273 hours
  2. Maintenance Frequency = Duration of Operation / MTBM = 71.576 / 5928.273 = 0.012074
  3. Total Cost = Maintenance Frequency × Action Costs =

$(MF \times Cost_{Failure}) + (MF \times Cost_{Downtime}) + (MF \times Cost_{Personnel}) + (MF \times Cost_{Consumables}) +$
$([\text{Equipment Renewal Factor} \times Cost_{Tools/Equipment}] + Cost_{Tools/Equipment}) =$

(0.012074 × 10,000) + (0. 012074 × 1,000) + (0. 012074 × 100) + (0.012074 × 100) + (2 x 500 + 500) =

120.74 + 12.074 + 1.2074 + 1.2074 + 1500 = $1635.23

Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.3 ADD SCHEDULED SERVICE FOR CONTROL UNIT COMPONENT

To add expected maintenance for an item:

- Select **'Control Unit'** from the System Breakdown tree
- Under Proposed Maintenance Approach section:
  - Set Maintenance Category to **Scheduled Maintenance**
  - Set Maintenance Type to **Scheduled Service**

System Breakdown

Name	Total cost	Cost per h...
Vehicle System	$1,635.23	$22.82
Coupling	$0.00	$0.00
Driveline	$0.00	$0.00
Power Generation	$1,635.23	$22.85
Control Unit	$0.00	$0.00
Diesel Engine	$0.00	$0.00
Fuel Tank	$1,635.23	$22.85
Vehicle	$0.00	$0.00

Proposed Maintenance Approach

Name: Control Unit

Mission Profile: Model Based Duration of Operation

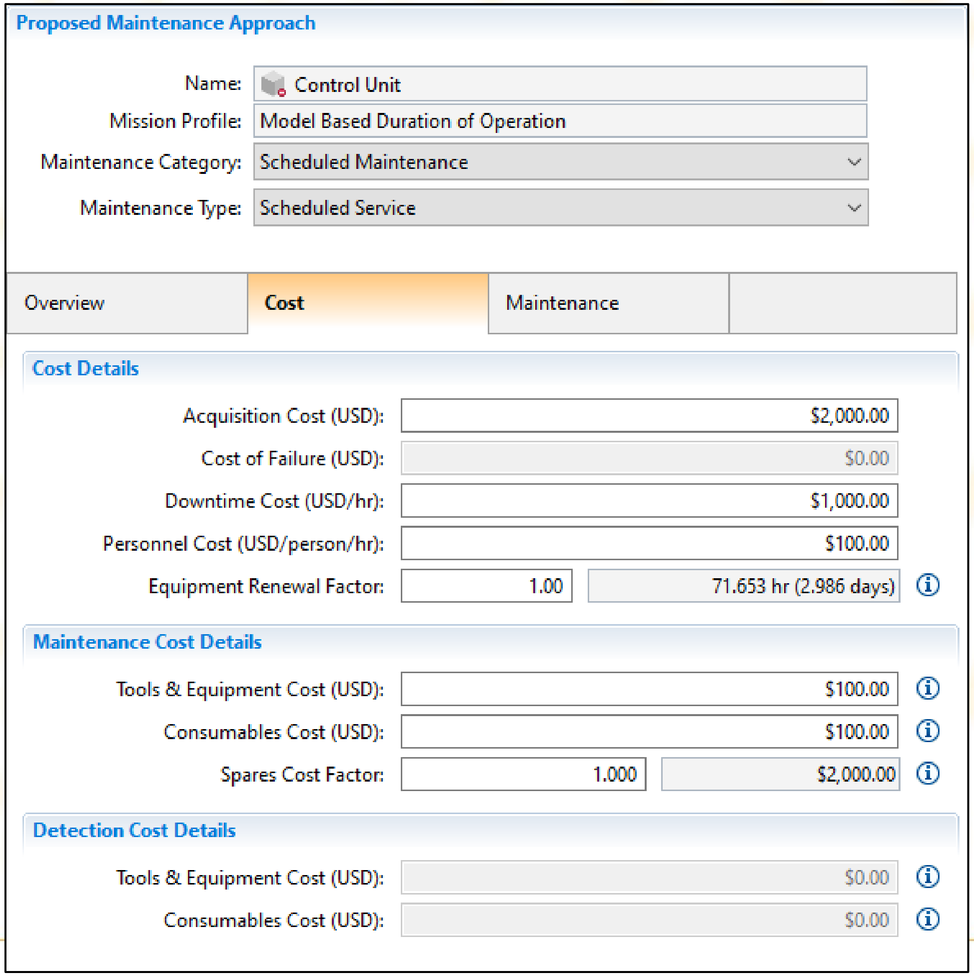
Maintenance Category: Scheduled Maintenance

Maintenance Type: Scheduled Service

Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.3 ADD SCHEDULED SERVICE FOR CONTROL UNIT COMPONENT (CONTINUED)

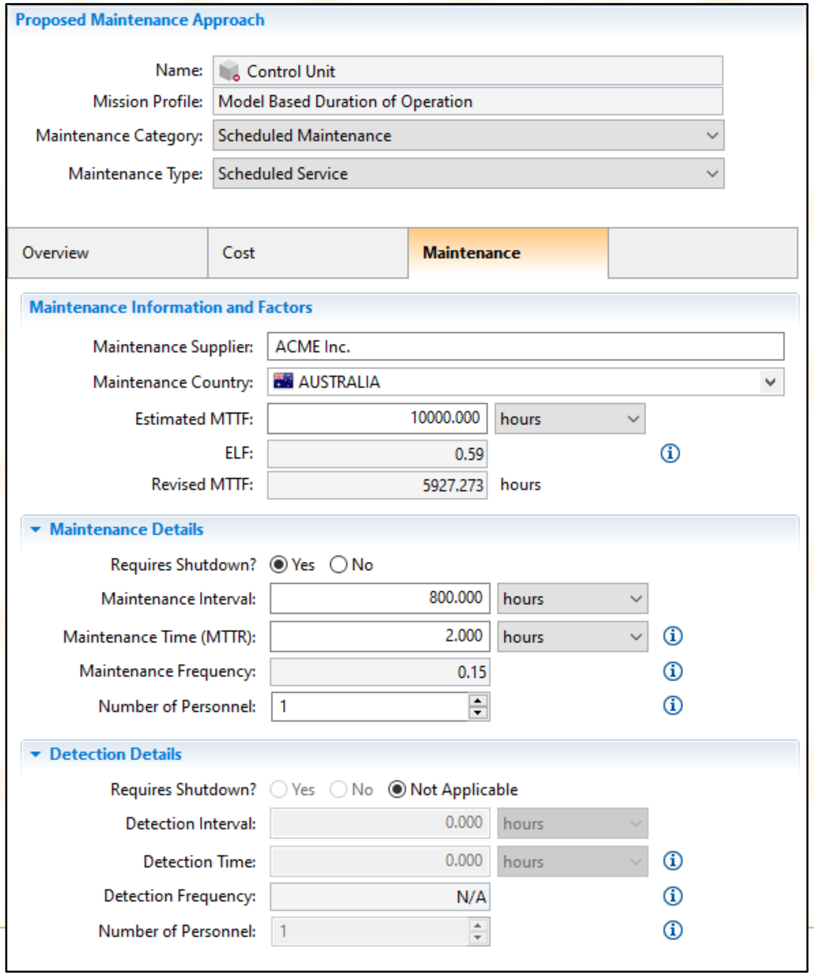
- Select the **Cost** tab and enter:
  - Acquisition cost: **$2000**
  - Downtime cost: **$1,000**
  - Personnel cost: **$100** (person per hour)
  - Equipment Renewal Factor: **1.00**
  - Tools & Equipment Cost: **$100**
  - Consumables Cost: **$100**
  - Spares Cost Factor: **1**



Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.3 ADD SCHEDULED SERVICE FOR CONTROL UNIT COMPONENT (CONTINUED)

- Select the **Maintenance** tab and enter:
  - Maintenance Supplier: **ACME Inc.**
  - Maintenance Country: **Australia**
  - Estimated MTTF: **10,000 Hours**
  - Maintenance Interval: **800 Hours**
  - MTTR: **2 Hours**
  - No. of Personnel: **1**



- Verify Total Cost: **$846.35**
- Verify Cost per Hour: **$11.82**

Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.4 ADD CONDITION BASED REPLACE FOR COUPLING COMPONENT

- Select the **Coupling 1** from the system tree
- Under Proposed Maintenance Approach section:
  - Select Maintenance Category: **Condition Based Maintenance**
  - Select Maintenance Type: **Condition Based Replace – Continuous Monitoring**

System Breakdown

Name	Total cost	Cost per hour
Vehicle System	$2,481.57	$34.63
Coupling	$0.00	$0.00
Driveline	$0.00	$0.00
Power Generation	$2,481.57	$34.67
Control Unit	$846.35	$11.82
Diesel Engine	$0.00	$0.00
Air Filter	$0.00	$0.00
Coupling 1	$0.00	$0.00
Engine	$0.00	$0.00
Governor	$0.00	$0.00
Injector Pump	$0.00	$0.00
Lift Pump	$0.00	$0.00
Primary Fuel Filter	$0.00	$0.00
Secondary Fuel Filter	$0.00	$0.00
Fuel Tank	$1,635.23	$22.85
Vehicle	$0.00	$0.00

Proposed Maintenance Approach

Name: Coupling 1

Mission Profile: Model Based Duration of Operation

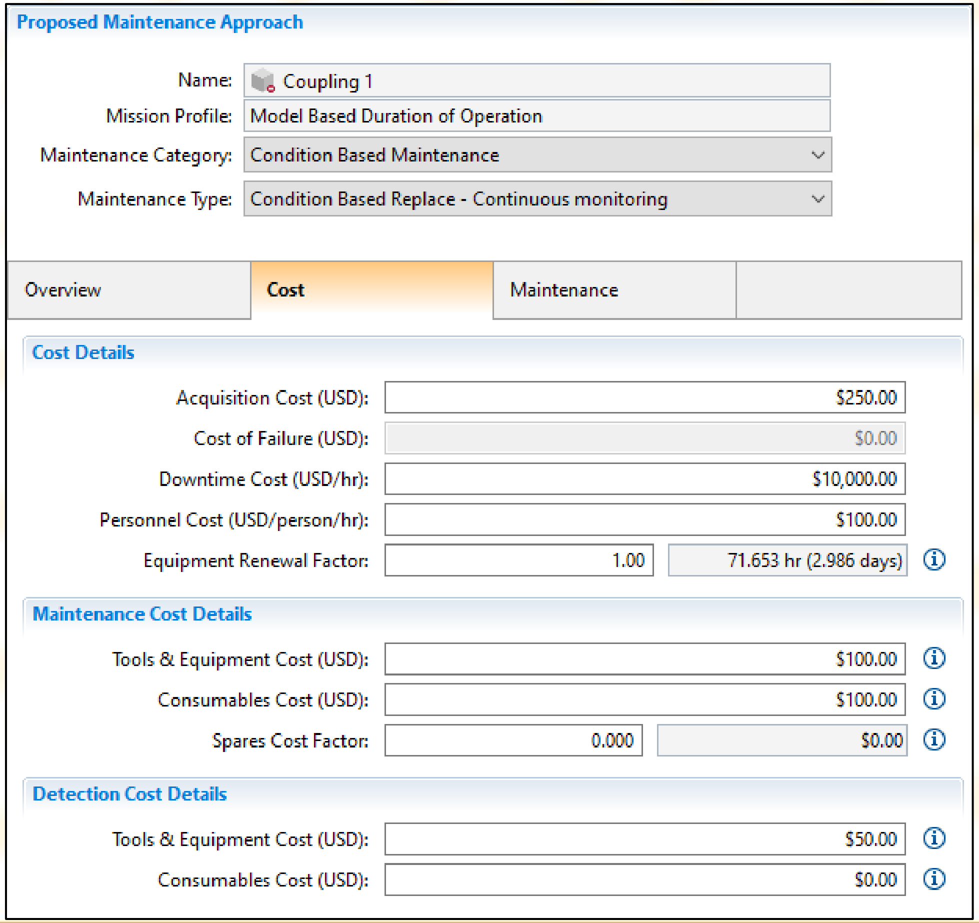
Maintenance Category: Condition Based Maintenance

Maintenance Type: Condition Based Replace - Continuous monitoring

Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.4 ADD CONDITION BASED REPLACE FOR COUPLING COMPONENT (CONTINUED)

- Select the **Cost** tab and enter:
  - Acquisition cost: **$250**
  - Downtime cost: **$10,000**
  - Personnel cost: **$100** (person per hour)
  - Equipment Renewal Factor: **1.00**
  - Maintenance Tools & Equipment Cost: **$100**
  - Maintenance Consumables Cost: **$100**
  - Maintenance Spares cost factor: **0**
  - Detection Tools & Equipment Cost: **$50**
  - Detection Consumables Cost: **$0**



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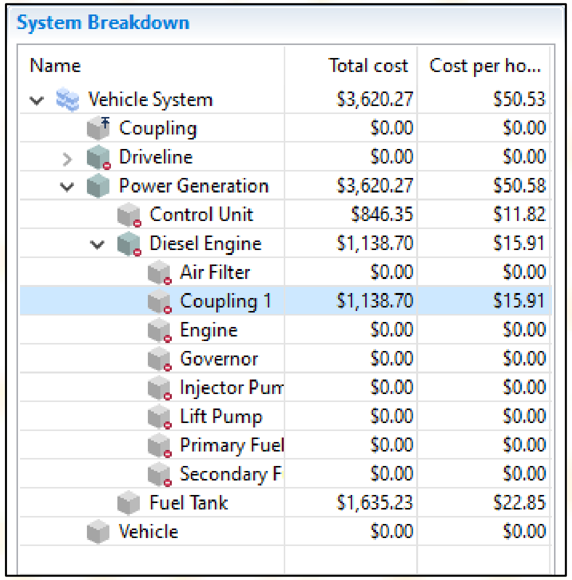
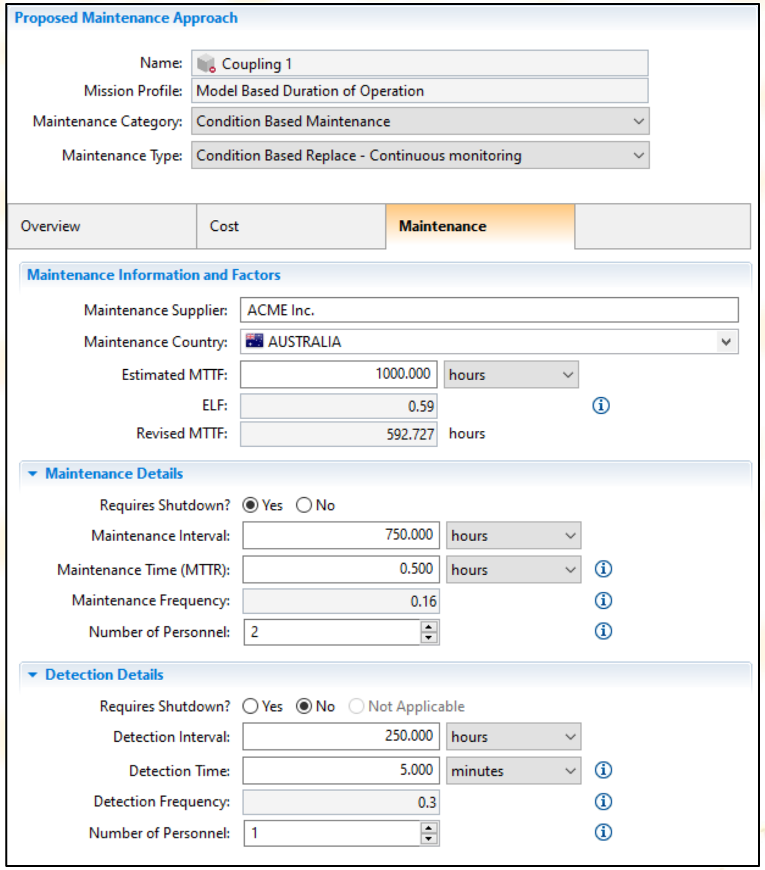
Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.4 ADD CONDITION BASED REPLACE FOR COUPLING COMPONENT (CONTINUED)

- Select the **Maintenance** tab and enter:
  - Maintenance Supplier: **ACME Inc.**
  - Maintenance Country: **Australia**
  - Estimated MTTF: **1,000 Hours**
  - Requires shutdown (Maintenance): **Yes**
  - Maintenance Interval: **750 Hours**
  - MTTR: **0.5 Hours**
  - No. of Personnel: **2**
  - Requires shutdown (Maintenance): **No**
  - Detection Interval: **250 hours**
  - Detection Time: **5 minutes**
  - No. of Personnel: **1**
- Verify Total Cost: **$1,138.70**
- Verify Cost per Hour: **$15.91**


System Breakdown

Name	Total cost	Cost per ho...
Vehicle System	$3,620.27	$50.53
Coupling	$0.00	$0.00
Driveline	$0.00	$0.00
Power Generation	$3,620.27	$50.58
Control Unit	$846.35	$11.82
Diesel Engine	$1,138.70	$15.91
Air Filter	$0.00	$0.00
Coupling 1	$1,138.70	$15.91
Engine	$0.00	$0.00
Governor	$0.00	$0.00
Injector Pum	$0.00	$0.00
Lift Pump	$0.00	$0.00
Primary Fuel	$0.00	$0.00
Secondary F	$0.00	$0.00
Fuel Tank	$1,635.23	$22.85
Vehicle	$0.00	$0.00

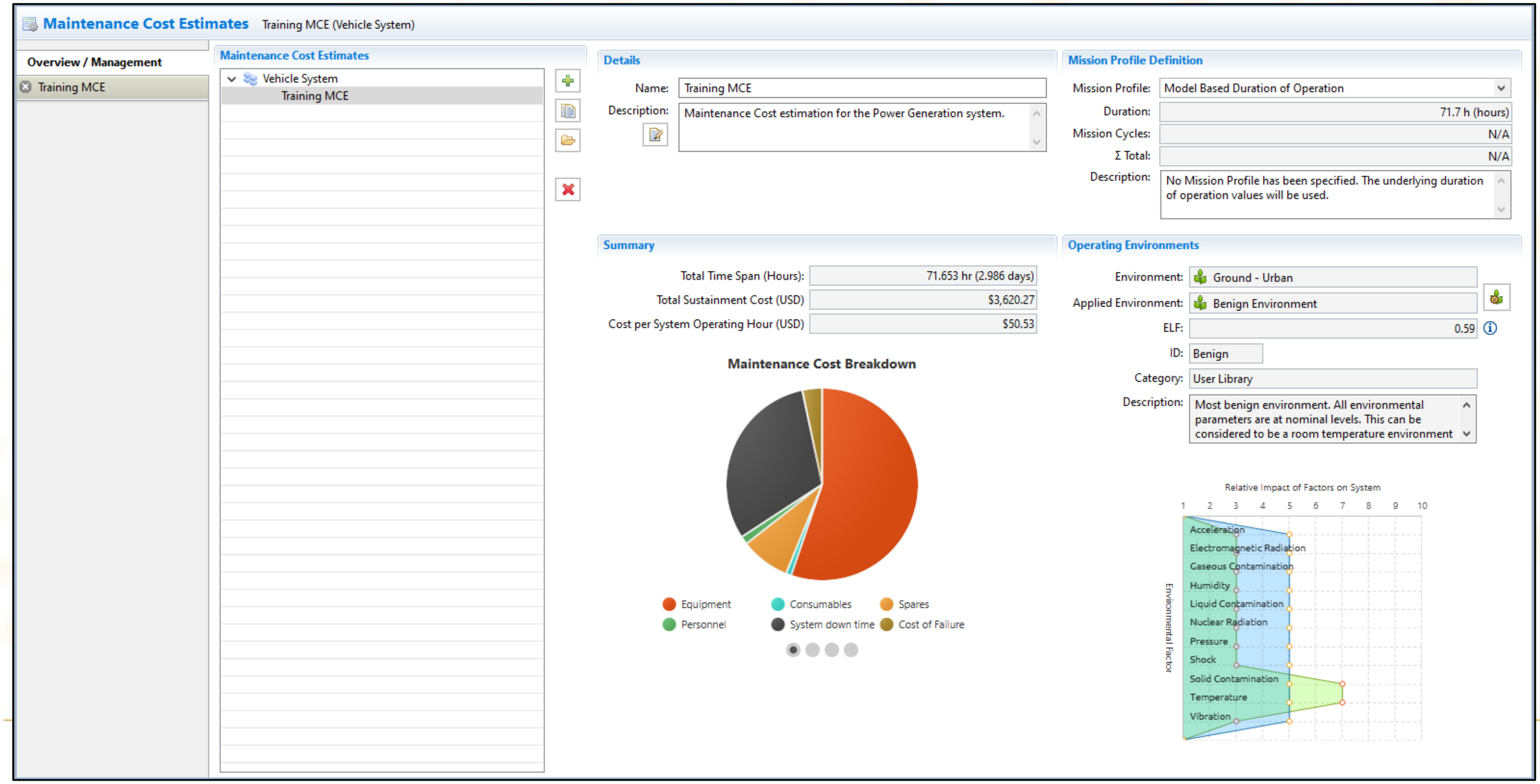


Technology

Session 5.1: Maintenance Cost Estimates

DISCUSSION 5.1.5 CHARTING & MCE REPORT

- Once all relevant analysis information has been provided, the user can view the breakdown of the MCE analysis in the Overview/Management page.

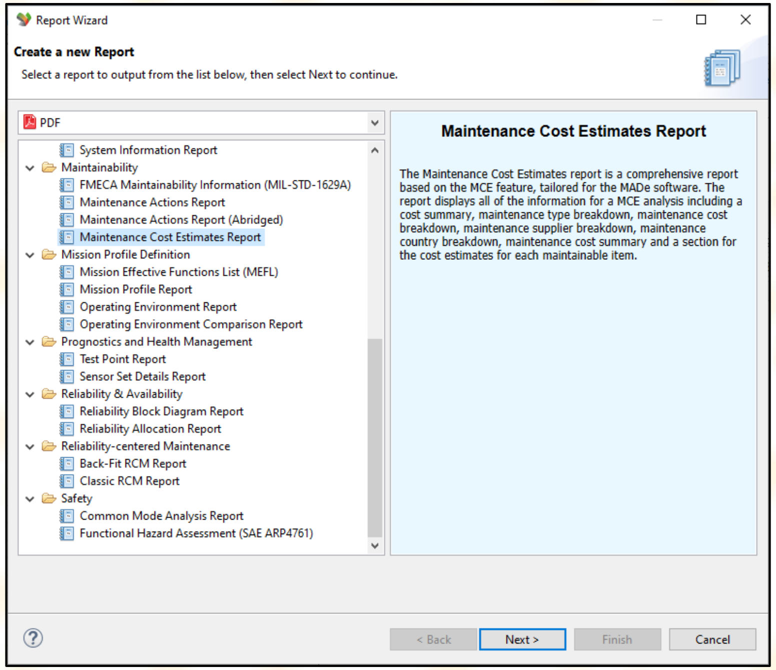


Session 5.1: Maintenance Cost Estimates

EXERCISE 5.1.5 GENERATE A MCE REPORT

To generate a MCE report:

- Select **Reports → Report Wizard**
- Select **Maintenance Cost Estimates Report**
- Select Next >
- Select **Training MCE** and select Next >
- Set formatting or select Finish to generate the report



Session 5.1: Maintenance Cost Estimates

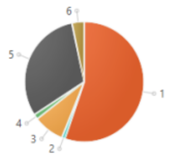
Exercise 5.1.5 Generate a MCE Report

MAINTENANCE COST ESTIMATE SUMMARY

TRAINING MCE

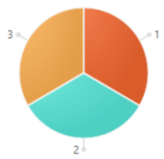
ITEM ID	VS1
ITEM NAME	Vehicle System
MISSION PROFILE	Model Based Duration of Operation
TOTAL TIME SPAN	71.653 hr (2.986 days)
BASELINE ENVIRONMENT	Ground - Urban
APPLIED ENVIRONMENT	Benign Environment

TOTAL SUSTAINMENT COST	$3,620.27
COST PER SYSTEM OPERATING HOUR	$50.53



COST BREAKDOWN

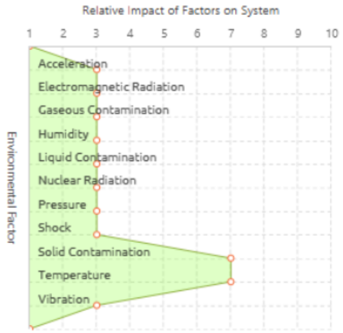
1	EQUIPMENT	$2,000.00
2	CONSUMABLES	$32.32
3	SPARES	$300.63
4	PERSONNEL	$49.74
5	SYSTEM DOWNTIME	$1,116.85
6	COST OF FAILURE	$120.74



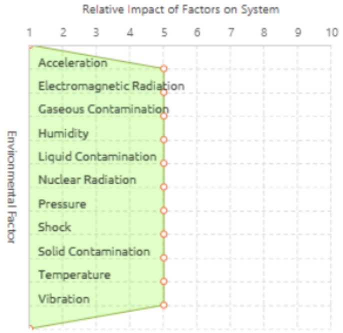
MAINTENANCE BY TYPE

1	BREAKDOWN MAINTENANCE	1
2	SCHEDULED MAINTENANCE	1
3	CONDITION BASED MAINTENANCE	1

BASELINE ENVIRONMENT



APPLIED ENVIRONMENT



Session 5.1: Maintenance Cost Estimates

Session 5.1 Summary

- ✓ 5.1: MCE Analysis for Fuel Tank, Control Unit & Coupling components
  - ✓ Determine Total MCE per item/cost per operating hour
  - ✓ Generate MCE Report

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Session 5.2: Maintenance Actions

Session 5.2 Outline

5.2.1: Maintenance Actions Page

5.2.2: Enter Maintenance Actions

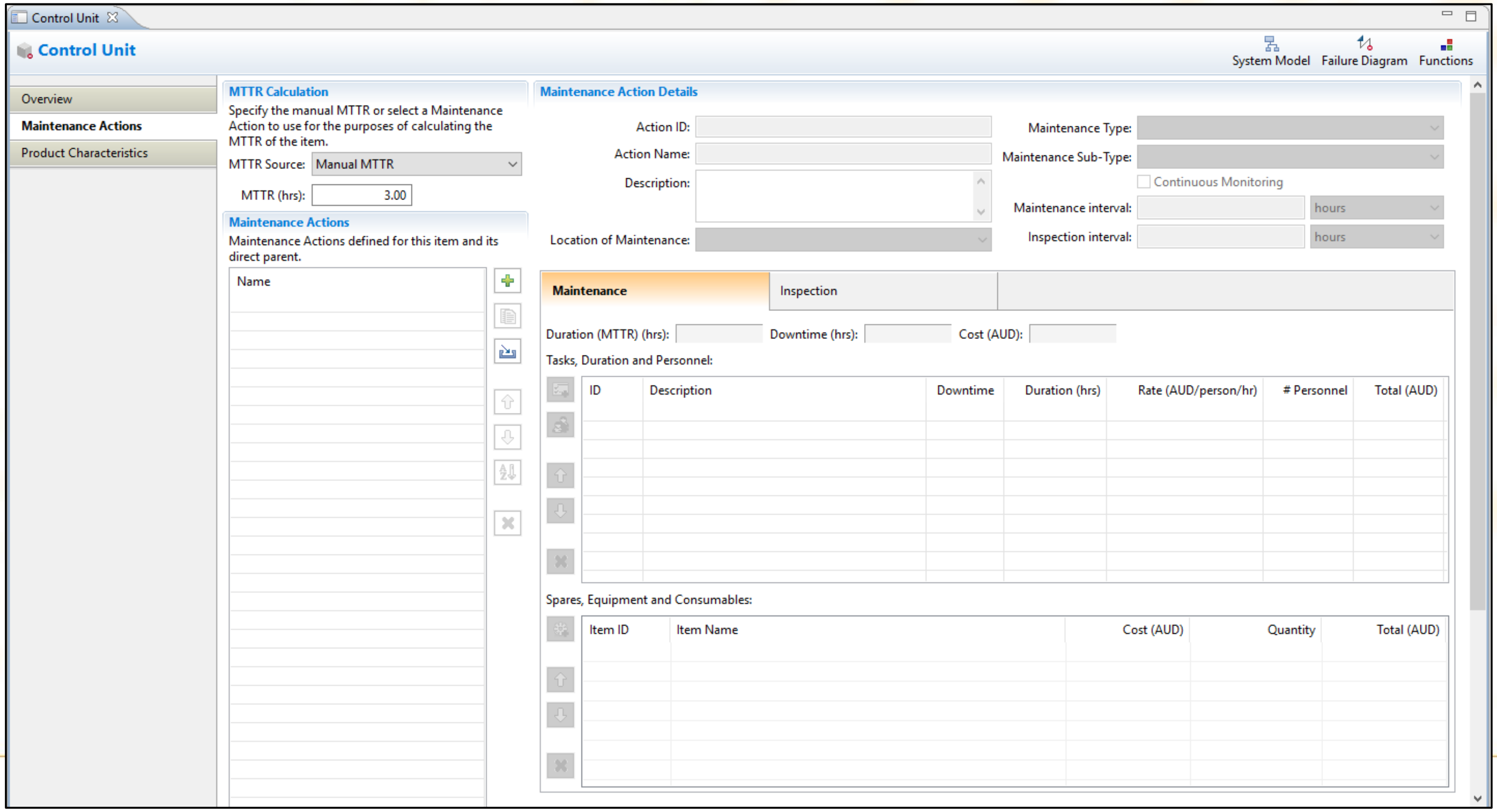
5.2.3: Import Maintenance Actions

5.2.4: Generate a Maintenance Actions Report

Session 5.2: Maintenance Actions

Discussion 5.2.1 Maintenance Properties

- MADe captures the maintenance actions of the system and model elements (subsystems, components or parts) in the Maintenance Actions page under advanced properties

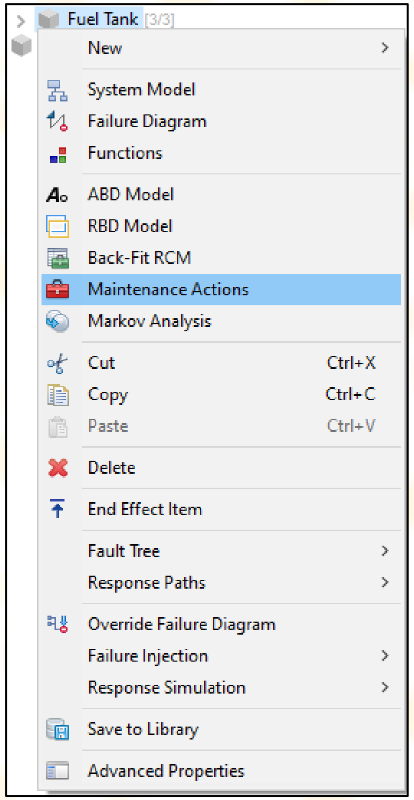


Session 5.2: Maintenance Actions

Exercise 5.2.2 Create a Maintenance Action for the Fuel Tank

To create a Maintenance Action:

- Select the **'Fuel Tank'** component in the Project Explorer
- From the drop down menu, select the **Maintenance Actions** option

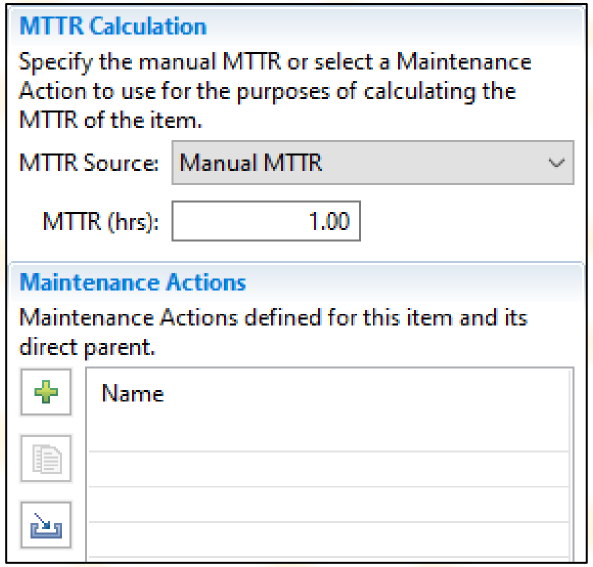


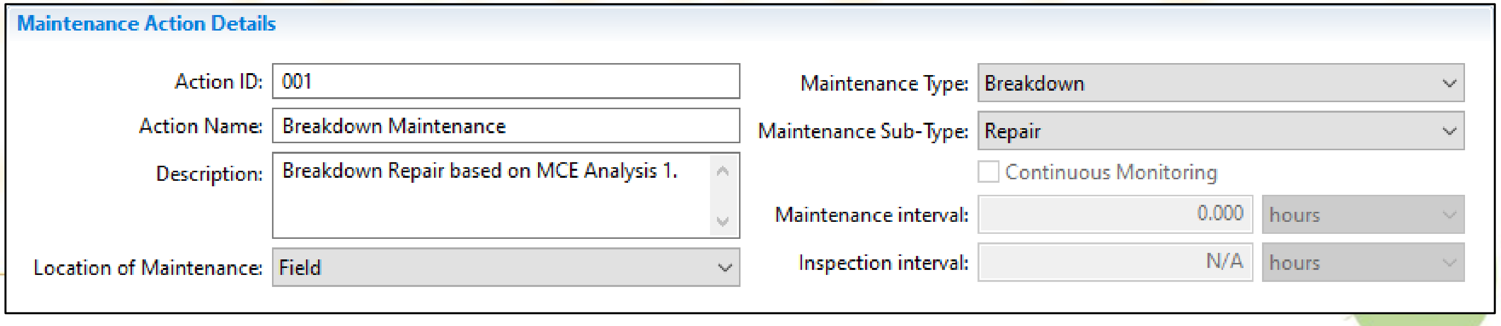
Session 5.2: Maintenance Actions

EXERCISE 5.2.2 CREATE A MAINTENANCE ACTION FOR THE FUEL TANK (CONTINUED)

To create a maintenance actions:

- Select to add a new maintenance action
- Select the check box to set the new Maintenance Action as default
- In the Maintenance Action Details section, populate the following information:
  - Action ID: **001**
  - Action Name: **Breakdown Maintenance**
  - Description: **Breakdown Repair based on MCE Analysis 1.**
  - Location of Maintenance: **Field**
  - Maintenance Type: **Breakdown**
  - Maintenance Sub-Type: **Repair**

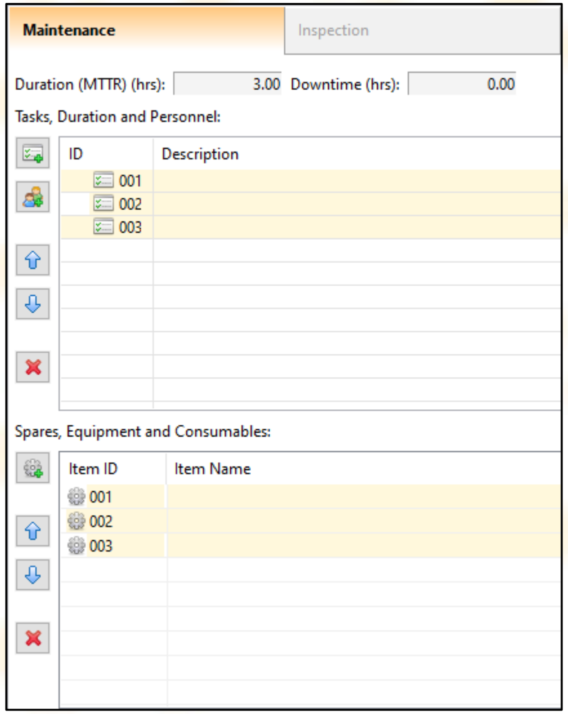




Session 5.2: Maintenance Actions

EXERCISE 5.2.2 CREATE A MAINTENANCE ACTION FOR THE FUEL TANK (CONTINUED)

- Select to create a New Maintenance Task
- Select to create a New Personnel Record – this assign a new personnel to a task
- Select to rearrange tasks/personnel/items
- Select to create New Maintenance Items
- Select to delete selected tasks/personnel/items



Session 5.2: Maintenance Actions

Exercise 5.2.2 Create a Maintenance Action for the Fuel Tank (continued)

➢ Enter the following tasks (ID/Description), personnel (ID/Description/#), Rates & Equipment ($, QTY):

Maintenance | Inspection

Duration (MTTR) (hrs): 6.00 Downtime (hrs): 5.50 Cost (USD): $2,600.00

Tasks, Duration and Personnel:

ID	Description	Downtime	Duration (hrs)	Rate (USD/person/hr)	# Personnel	Total (USD)
001	Detection / Diagnosis	☑	0.50	$100.00	1	$50.00
001	New Personnel			$100.00	1	$50.00
002	Removal	☑	1.00	$100.00	1	$100.00
001	New Personnel			$100.00	1	$100.00
003	Technician	☑	3.00	$100.00	1	$300.00
001	New Personnel			$100.00	1	$300.00
004	Reinstallation	☑	1.00	$100.00	1	$100.00
001	New Personnel			$100.00	1	$100.00
005	Testing / Administration	☐	0.50	$100.00	1	$50.00
001	New Personnel			$100.00	1	$50.00

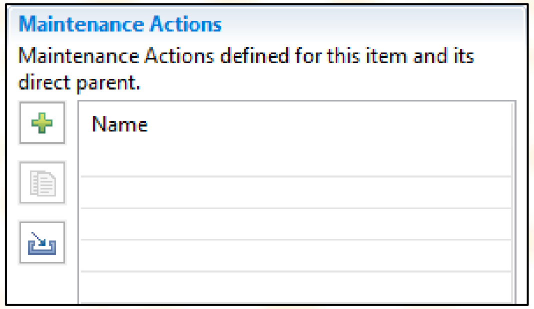
Spares, Equipment and Consumables:

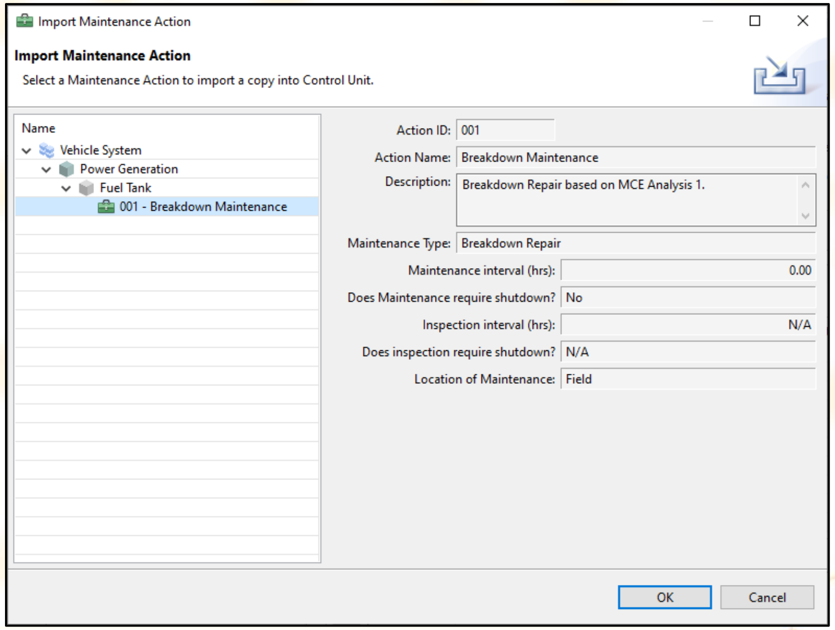
Item ID	Item Name	Cost (USD)	Quantity	Total (USD)
001	Spare Component	$1,000.00	2.00	$2,000.00

Session 5.2: Maintenance Properties

EXERCISE 5.2.3 IMPORT A MAINTENANCE ACTION FOR THE CONTROL UNIT

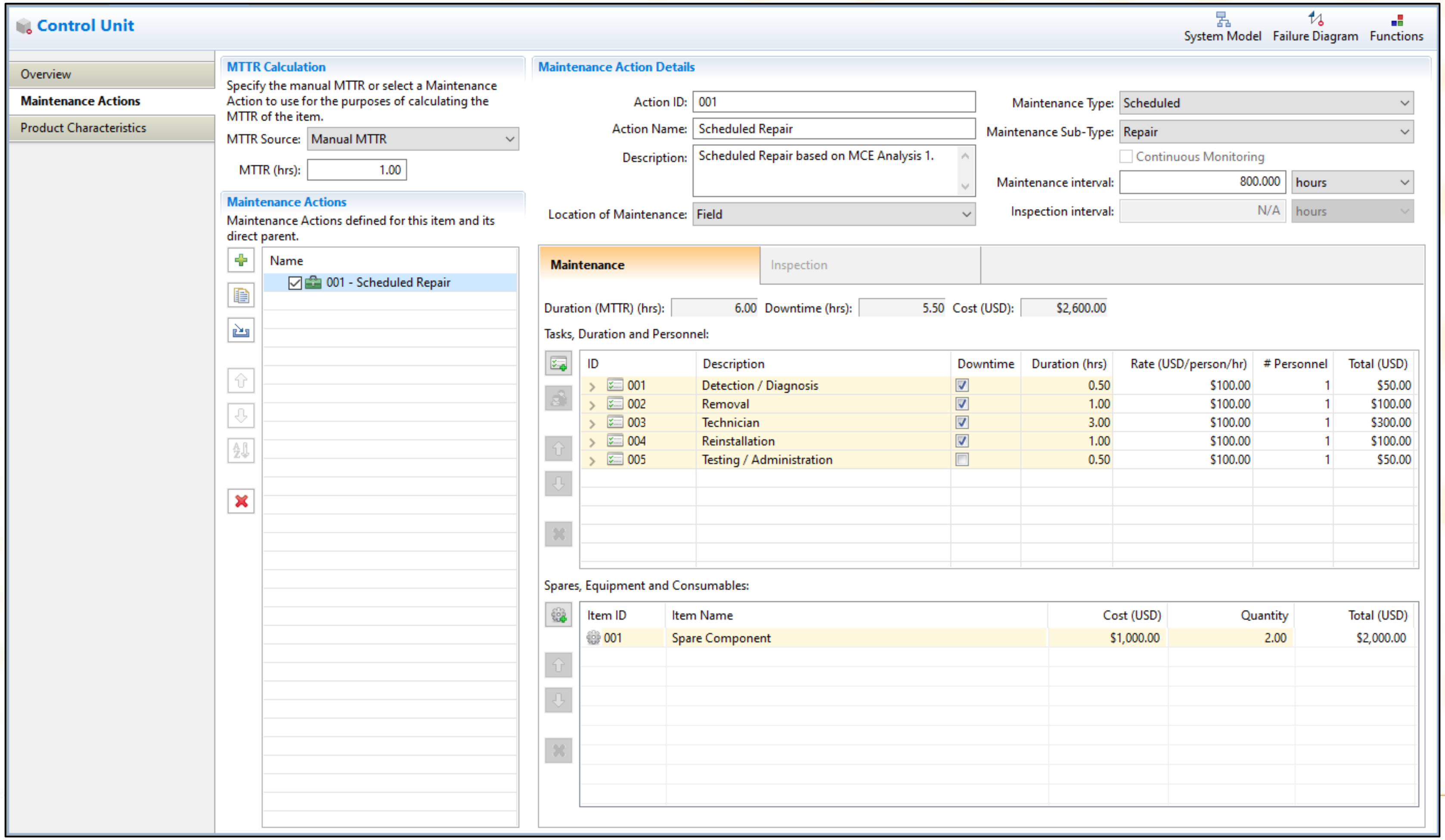
- Select the **'Control Unit'** component in the system model
- Select **Maintenance Actions**
- Select to import
- Select **001 – Breakdown Maintenance** from **'Fuel Tank'** then select OK
- Change the imported maintenance action Name and Type to **Scheduled Repair**
    - Maintenance Interval: **800 hour interval**
    - Action Name: **Scheduled Repair**
    - Description: **Scheduled Repair based on MCE Analysis 1.**





Session 5.2: Maintenance Actions

Exercise 5.2.3 Import a Maintenance Action for the Control Unit (Continued)

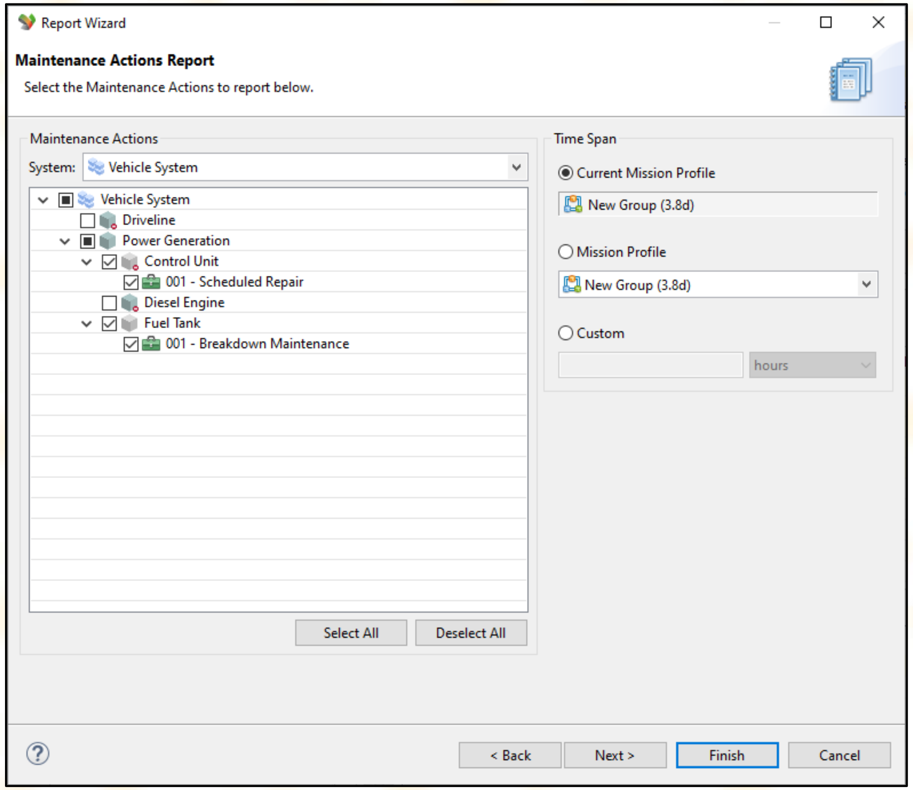


Session 5.2: Maintenance Actions

EXERCISE 5.2.4 CREATE A MAINTENANCE ACTION REPORT

To generate a Maintenance Actions Report:

- Select **Reports → Report Wizard** from the main menu
- Select **Maintenance Actions Report**
- Select Next >
- Select **Breakdown Maintenance** for the **'Fuel Tank'** component
  Confirm the Time Span is the current mission profile: **New Group**
- Set formatting or select Finish to generate the report



Session 5.2: Maintenance Actions

<u>Exercise 5.2.4 Create a Maintenance Action Report</u>

The report consists of several sections:

- Maintenance Actions Summary – Aggregates costs & time spans across all items
- Maintenance Actions Dashboard – Pie charts visualise maintenance breakdown
- Maintenance Actions Summary – Aggregates costs & time spans across all item MAs
- Maintenance Actions Breakdown – Records all fields from Maintenance Actions page per item

Session 5.2: Maintenance Actions

Session 5.2 Summary

- ✓ 5.2.1: Access the Maintenance Actions editor
- ✓ 5.2.2: Generate a Maintenance Action
- ✓ 5.2.3: Import Maintenance Actions
- ✓ 5.2.4: Generate a Maintenance Action Report

Session 5.3: Reliability Centered Maintenance (Classic)

Session 5.3 Outline

5.3.1: Background to RCM

5.3.2: RCM Overview and Management (Step 0)

5.3.3: Functions & Functional failures (Step 1 & 2)

5.3.4: Failure Causes (Step 3)

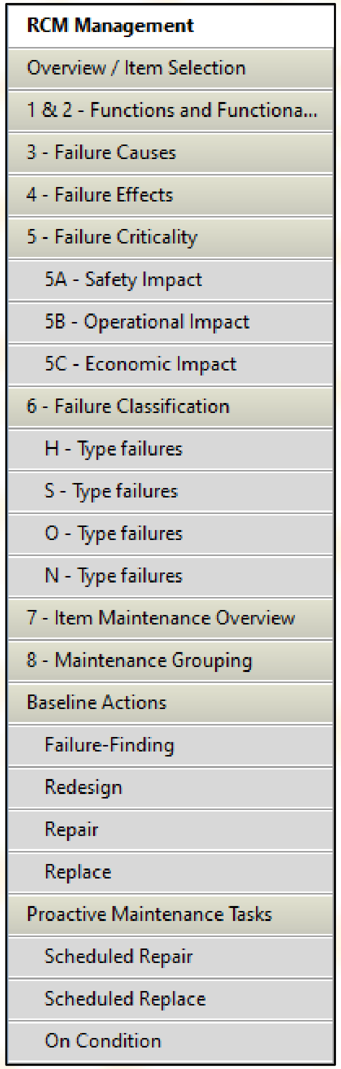
5.3.5: Failure Effects (Step 4)

5.3.6: Failure Criticality (Step 5A/5B/5C; Repair & Replace worksheets)

5.3.7: Failure Classification (Step 6H/6S/6O/6N; Failure Finding, Redesign, Scheduled Repair, Scheduled Replace & On Condition worksheets)

5.3.8: Item Maintenance Overview (Step 7)

5.3.9: Classic RCM Report



Session 5.3: Reliability Centered Maintenance

Discussion 5.3 Background to RCM

What is the difference between Back-Fit & Classic RCM? When are they used?

Classic RCM: A process that develops, analyses and documents requirements to develop a maintenance program

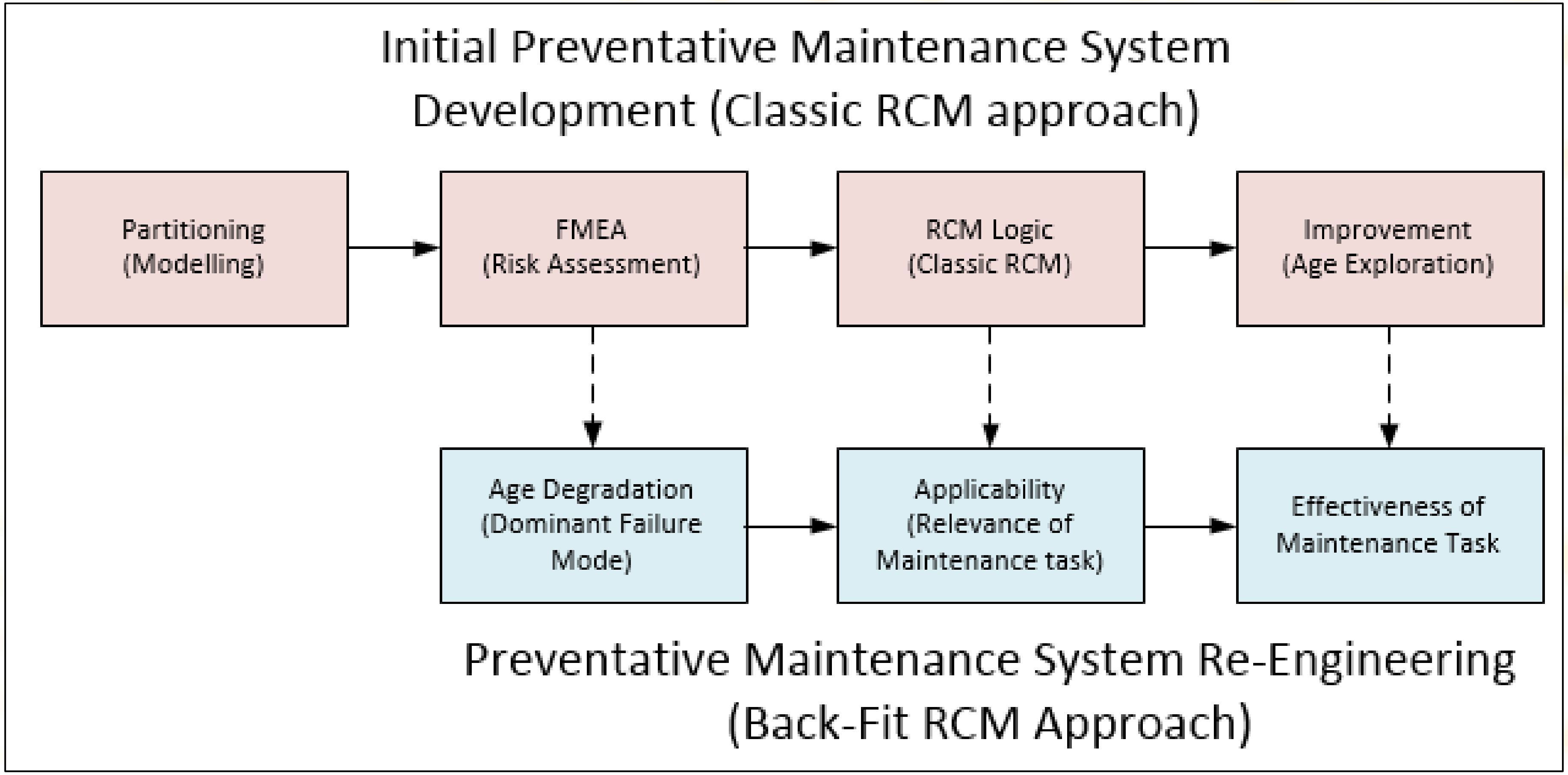
- Environment of uncertainty
- Limited operating data

Back-Fit RCM: A process that confirms assumptions when the original maintenance program was developed once sufficient operating data exists

- Validates existing maintenance requirements
- Recommends changes where appropriate

Session 5.3: Reliability Centered Maintenance

Discussion 5.3 Background to RCM (continued)



Session 5.3: Classic RCM

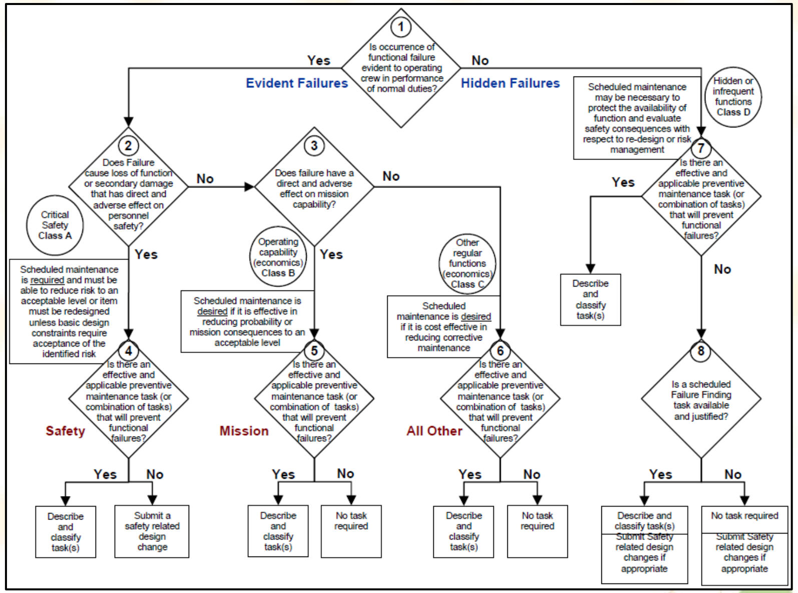
Discussion 5.3 Classic RCM

The MADe Classic Reliability Centered Maintenance (RCM) analysis is based on a process referenced from J. Moubray[1] and USN SSC Handbook S9081-AB-GIB-010.

Two types of RCM in MADe: **Classic RCM** & **Back-Fit RCM**

RCM retrieves reliability and maintenance information in the system model:

- Overview/Item Selection
- Functions & Functional Failures
- Failure Causes
- Failure Effects
- Failure Criticality
- Failure Classification
- Item Maintenance Overview
- Reporting Outputs



RCM Logic Tree (Source: MIL-STD-3034)

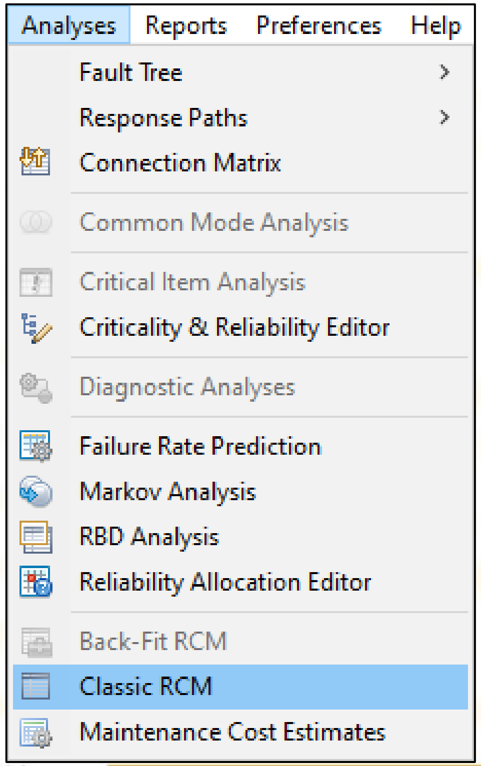
[1]Moubray, John, *Reliability Centered Maintenance; RCM II;* Second Edition, Industrial Press, 1997, ISBN 0-8311-3078-4

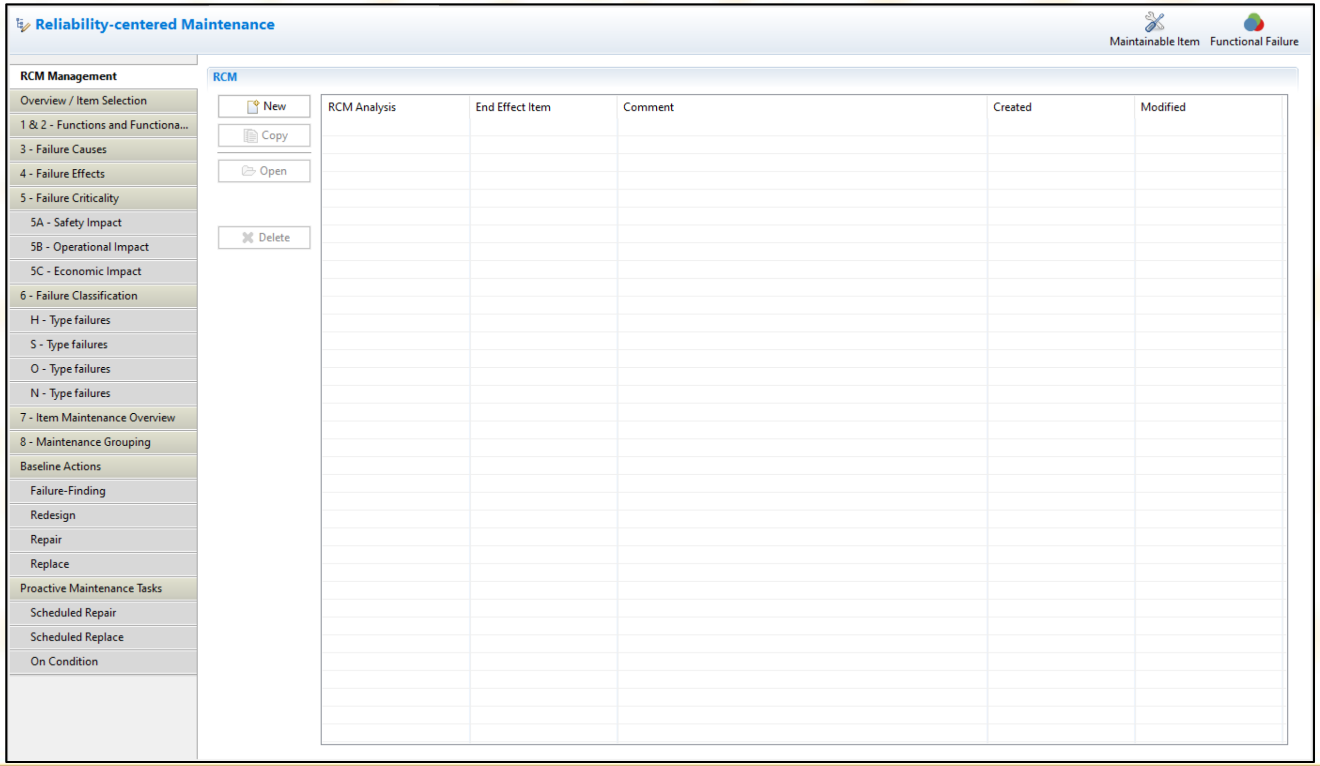
Session 5.3: Classic RCM

EXERCISE 5.3.1 OPEN CLASSIC RCM EDITOR

To access the Classic RCM editor:

➢ Select **Analyses → Classic RCM** from the main menu

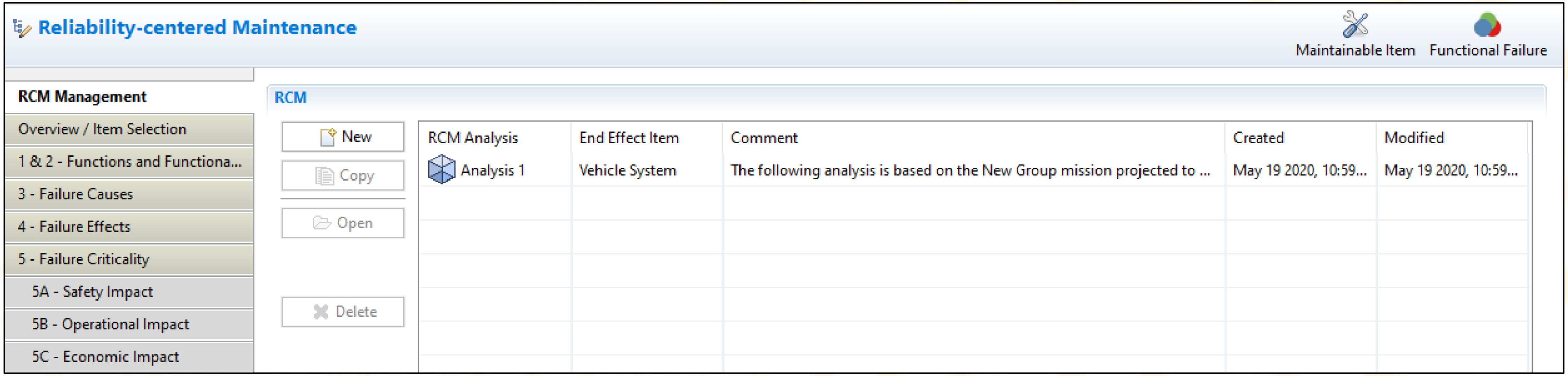




Session 5.3: Classic RCM

Discussion 5.3.1 RCM Management

- Lists all RCM Analyses conducted on the modelled system
- Define or allocate the Maintainable Items for the RCM analysis
- Provides System Reliability & System Functions information

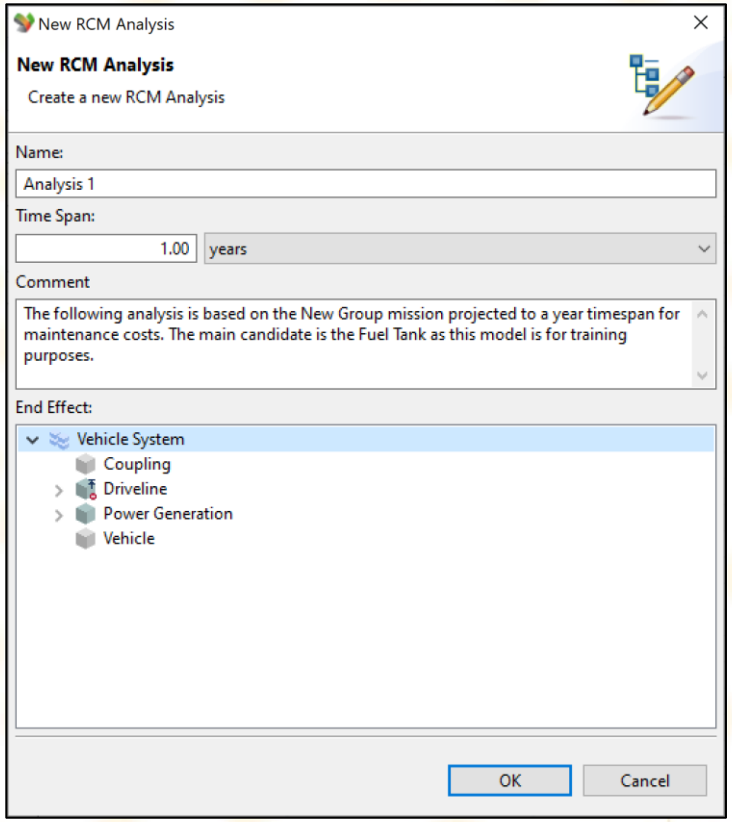


Session 5.3: Classic RCM

EXERCISE 5.3.1 RCM MANAGEMENT

To create a RCM Analysis, in the RCM Management page:

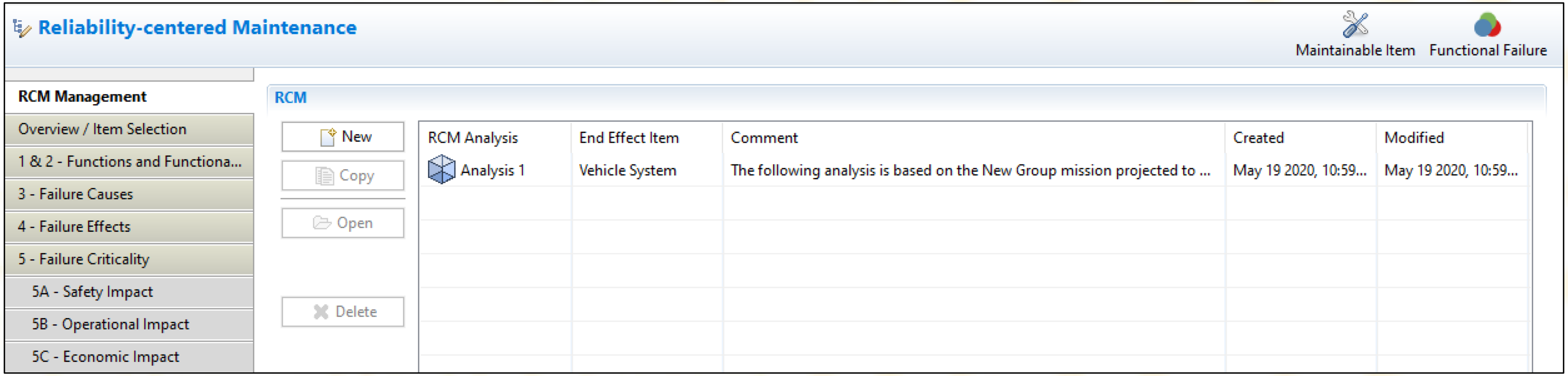
- Select New to open the New RCM Analysis dialog
- Enter the analysis name: **Analysis 1**
- Enter the time span: **1.00 years**
- Enter the following comment: **The following analysis is based on the New Group mission projected to a year timespan for maintenance costs. The main candidate is the Fuel Tank as this model is for training purposes.**
- Select **'Vehicle System'** as the End Effect
- Select OK to create RCM analysis



Session 5.3: Classic RCM

EXERCISE 5.3.1 RCM MANAGEMENT (CONTINUED)

- Select **Analysis 1** in the table
- Select Open to open the RCM analysis
- The RCM analysis will automatically redirect to the **Overview/Item Selection** page



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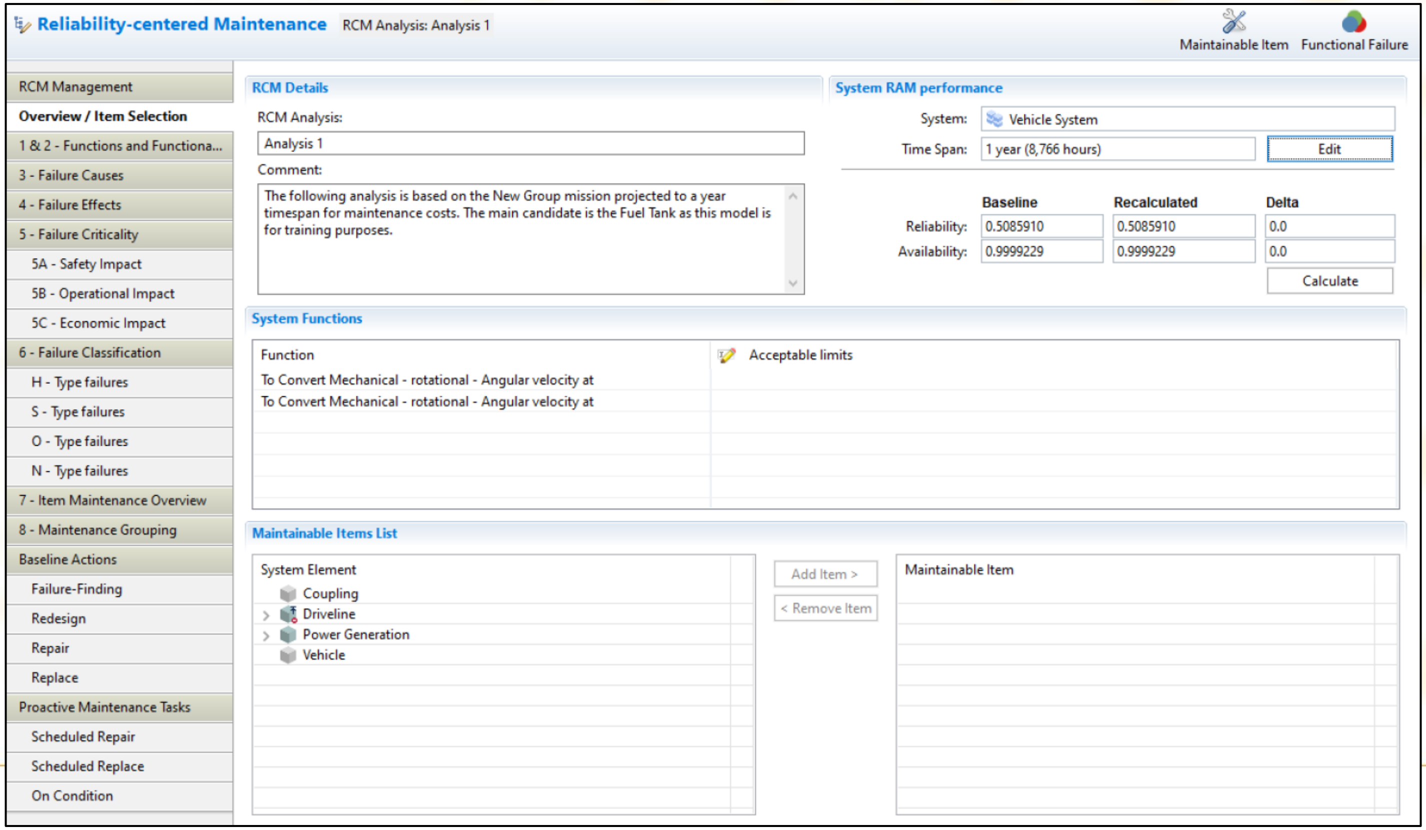
Session 5.3: Classic RCM

Discussion 5.3.2 Overview/Item Selection

- Provides System Reliability & System Functions information
- User can define or allocate the Maintainable Items for the RCM analysis

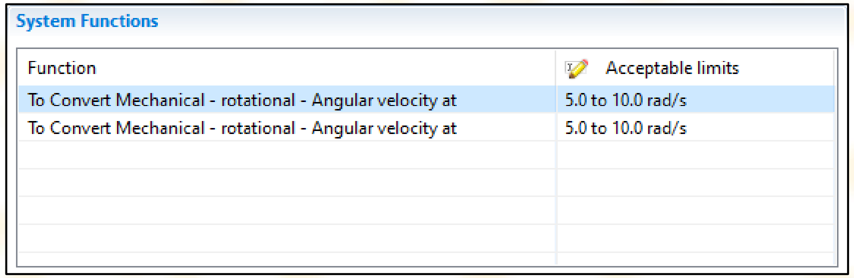


Session 5.3: Classic RCM

EXERCISE 5.3.2 OVERVIEW/ITEM SELECTION

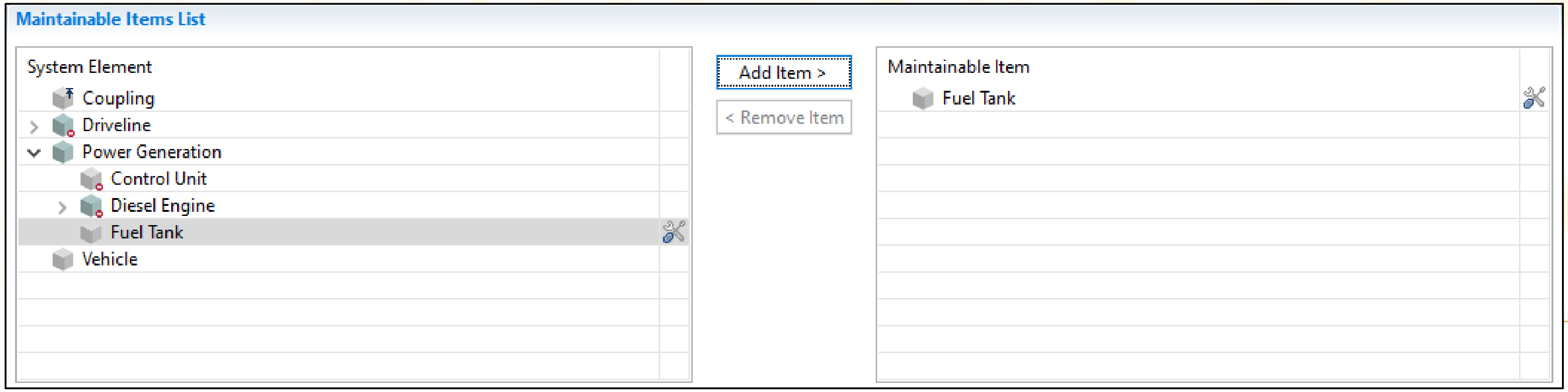
Edit the following information in the Overview/Item Selection page:

- For System Functions, enter the following Acceptable Limits: **5.0 – 10.0 rad/s**



To fill in the Maintainable Item List section:

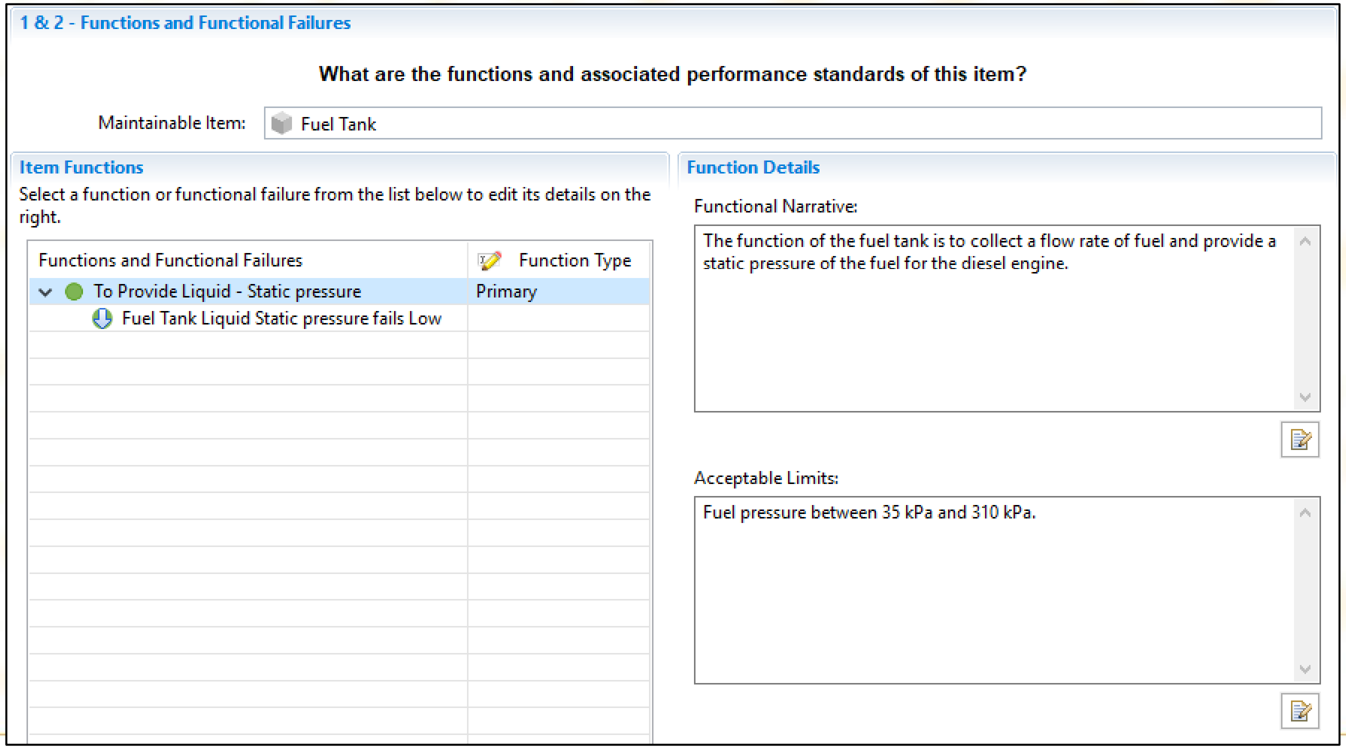
- Select the **'Fuel Tank'** component
- Select Add Item > to add **'Fuel tank'** to the **Maintainable Item** table



Session 5.3: Classic RCM

Discussion 5.3.3 Functions & Functional Failures

- The Functions and Functional Failures are displayed for the selected Maintainable Item
- This page allow the user to verify and confirm the functions of the component and to add descriptions
- Sections include:
  - Item Functions
  - Function Details
  - Functional Failure Details

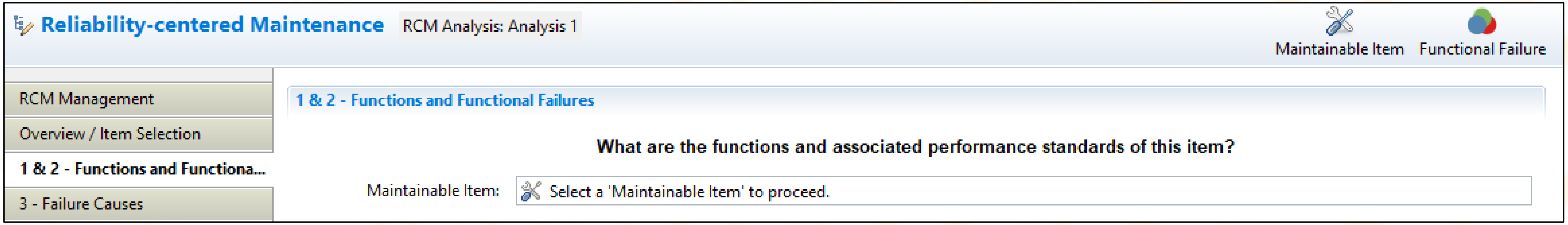


Session 5.3: Classic RCM

EXERCISE 5.3.3 FUNCTIONS & FUNCTIONAL FAILURES

To add Function details in the Function & Functional Failures page:

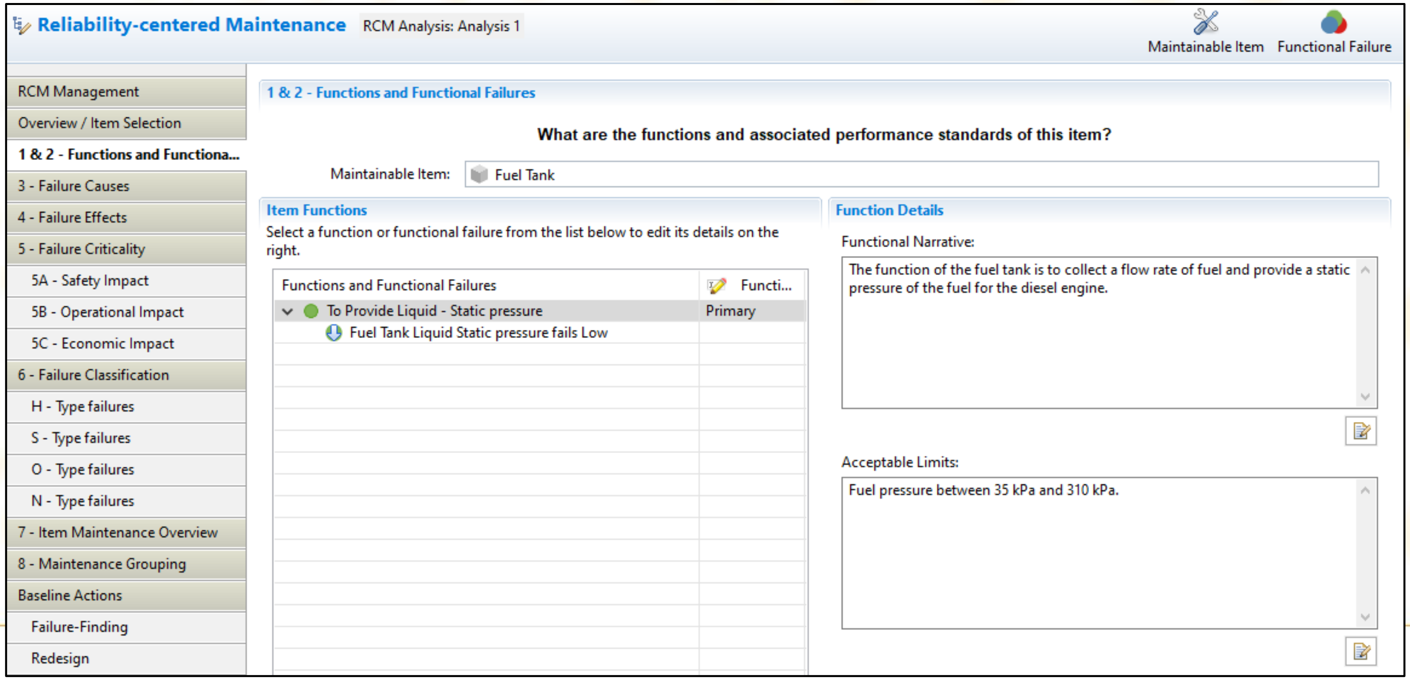
- Select the Maintainable Item by selecting the Maintainable Item Field Maintainable Item: Select a 'Maintainable Item' to proceed.
- From the **Maintainable Item** dialog table select: **'Fuel Tank'**
- Select OK



Session 5.3: Classic RCM

Exercise 5.3.3 Functions & Functional Failures (Continued)

- Under the Item Functions section select: **To Provide Liquid – Static Pressure**
- Under Functional Narrative enter: **The function of the fuel tank is to collect a flow rate of fuel and provide a static pressure of the fuel for the diesel engine.**
- Under Acceptable Limits enter: **Fuel pressure between 35 kPa and 310 kPa.**



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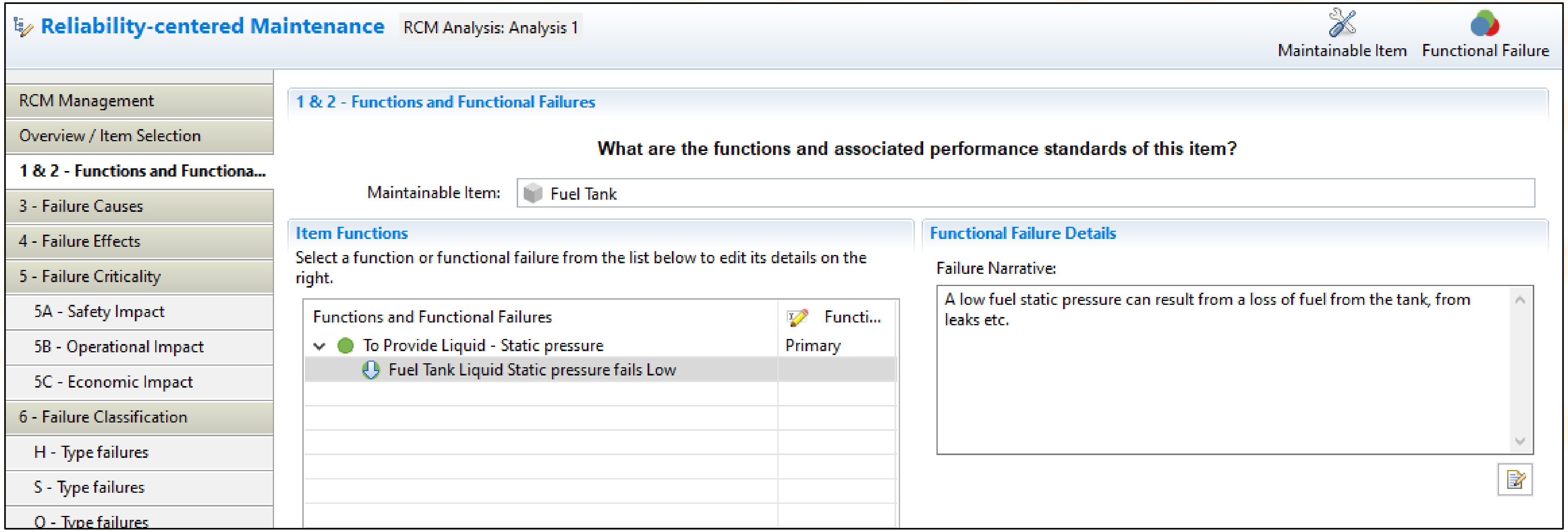
Session 5.3: Classic RCM

EXERCISE 5.3.3 FUNCTIONS & FUNCTIONAL FAILURES (CONTINUED)

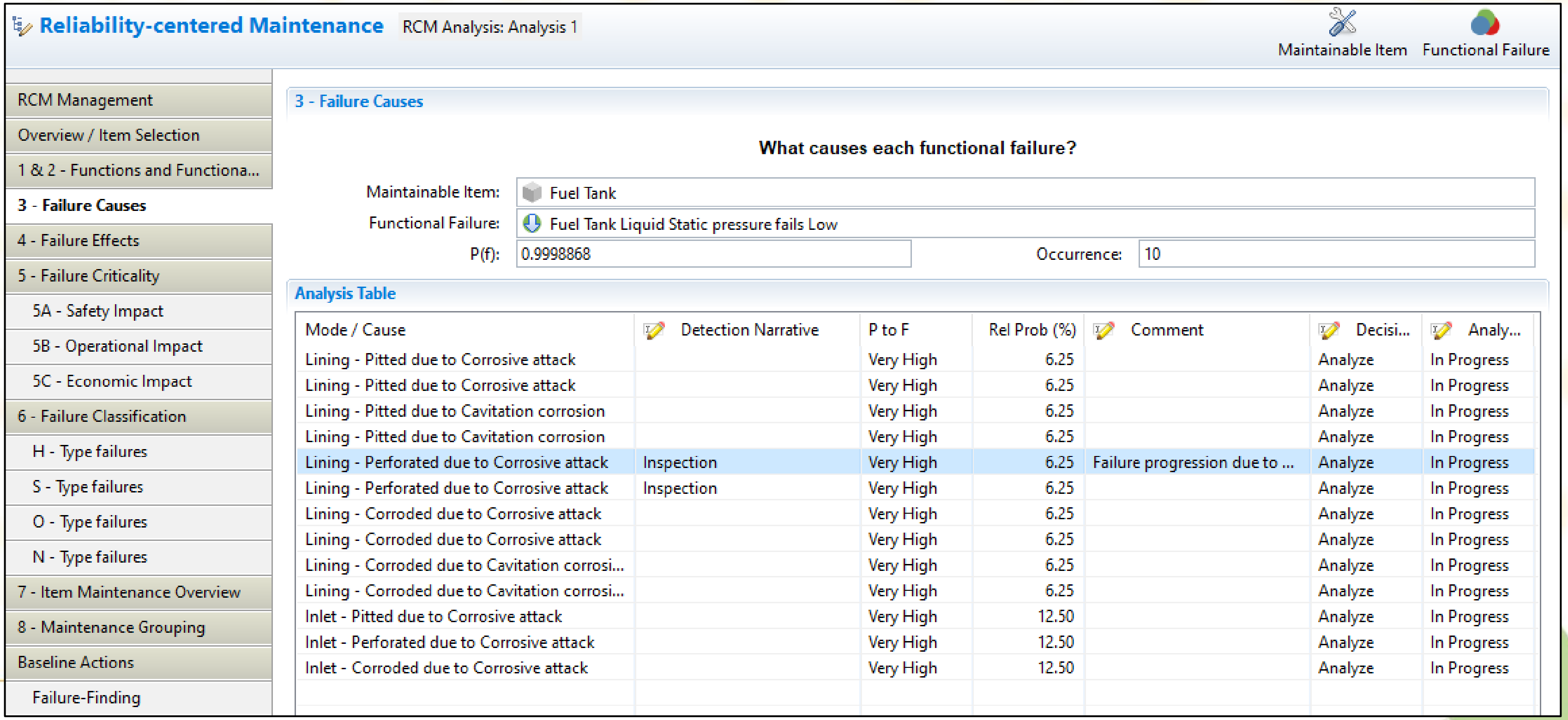
- Select the Functional Failure: **Fuel Tank Liquid Static pressure fails Low**
- Under Functional Failure Details, Failure Narrative enter the following: **A low fuel static pressure can result from a loss of fuel from the tank, from leaks etc.**



Session 5.3: Classic RCM

Discussion 5.3.4 Failure Causes

- User identifying and assessing the causes of the failures of the Maintainable Item
- This section provides additional information e.g. relative importance, Mode / Cause of each path that leads to the failure
- Table columns include:
  - Mode / Cause
  - Detection Narrative
  - Progression to Failure
  - Relative Probability
  - Comment
  - Decision
  - Analysis Status



Mode / Cause	Detection Narrative	P to F	Rel Prob (%)	Comment	Decisi...	Analy...
Lining - Pitted due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Pitted due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Pitted due to Cavitation corrosion		Very High	6.25		Analyze	In Progress
Lining - Pitted due to Cavitation corrosion		Very High	6.25		Analyze	In Progress
Lining - Perforated due to Corrosive attack	Inspection	Very High	6.25	Failure progression due to ...	Analyze	In Progress
Lining - Perforated due to Corrosive attack	Inspection	Very High	6.25		Analyze	In Progress
Lining - Corroded due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Corroded due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Corroded due to Cavitation corrosi...		Very High	6.25		Analyze	In Progress
Lining - Corroded due to Cavitation corrosi...		Very High	6.25		Analyze	In Progress
Inlet - Pitted due to Corrosive attack		Very High	12.50		Analyze	In Progress
Inlet - Perforated due to Corrosive attack		Very High	12.50		Analyze	In Progress
Inlet - Corroded due to Corrosive attack		Very High	12.50		Analyze	In Progress

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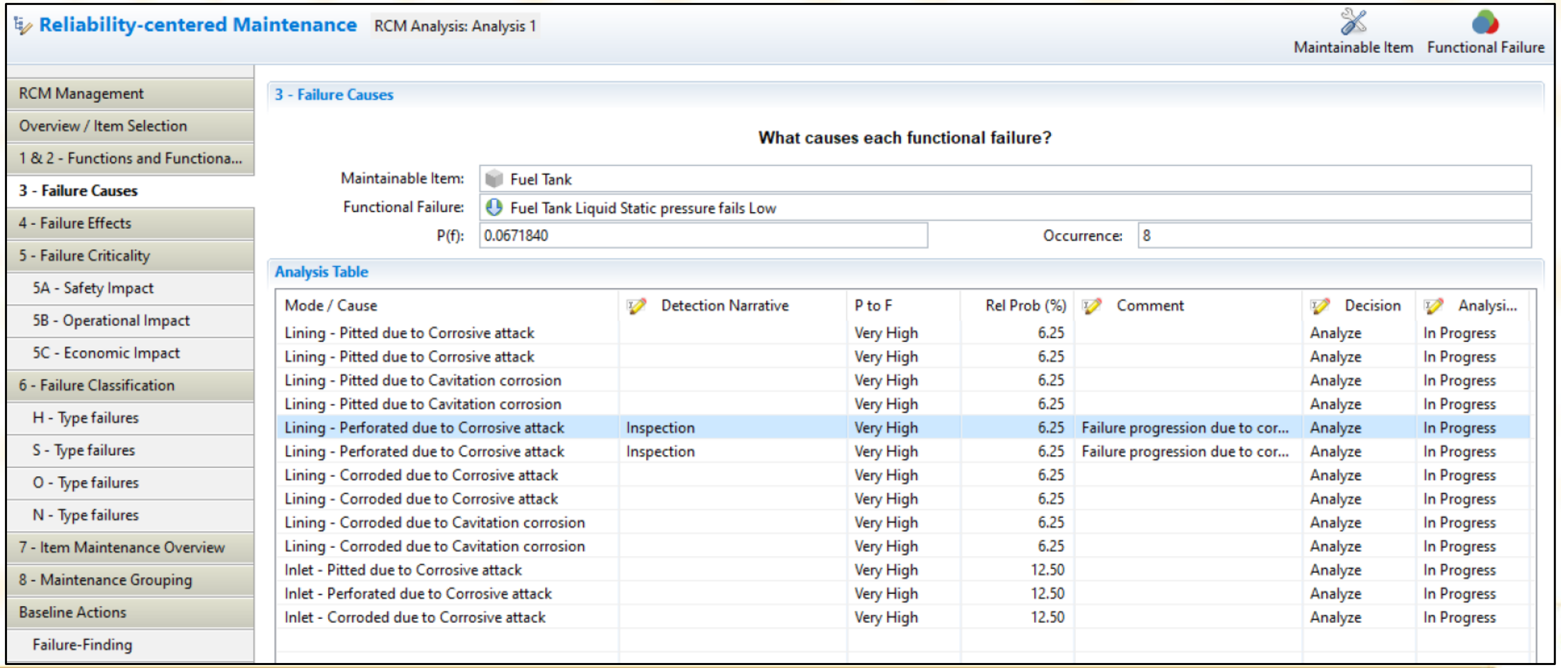
Session 5.3: Classic RCM

EXERCISE 5.3.4 FAILURE CAUSES

Enter the following information for the Failure Causes page:

- Enter/Verify detection Narrative for **Perforated due to corrosive attack**: **Inspection**
- Comment: **Failure progression due to corrosive attack**
- Decision: **Analyse**
- Analysis Status: **In Progress**



Mode / Cause	Detection Narrative	P to F	Rel Prob (%)	Comment	Decision	Analysi...
Lining - Pitted due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Pitted due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Pitted due to Cavitation corrosion		Very High	6.25		Analyze	In Progress
Lining - Pitted due to Cavitation corrosion		Very High	6.25		Analyze	In Progress
Lining - Perforated due to Corrosive attack	Inspection	Very High	6.25	Failure progression due to cor...	Analyze	In Progress
Lining - Perforated due to Corrosive attack	Inspection	Very High	6.25	Failure progression due to cor...	Analyze	In Progress
Lining - Corroded due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Corroded due to Corrosive attack		Very High	6.25		Analyze	In Progress
Lining - Corroded due to Cavitation corrosion		Very High	6.25		Analyze	In Progress
Lining - Corroded due to Cavitation corrosion		Very High	6.25		Analyze	In Progress
Inlet - Pitted due to Corrosive attack		Very High	12.50		Analyze	In Progress
Inlet - Perforated due to Corrosive attack		Very High	12.50		Analyze	In Progress
Inlet - Corroded due to Corrosive attack		Very High	12.50		Analyze	In Progress

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Session 5.3: Classic RCM

Discussion 5.3.5 Failure Effects

- Failure Effects (RCM Step 4) involves reviewing the effects of the Functional Failure of the elected component (in this case, Fuel Tank) and commenting on its effect on the Vehicle System.
- Main table columns:
  - Functions & Functional Failures
  - System Level Response
  - Response Narrative

4 - Failure Effects

What happens when each failure occurs?

Maintainable Item: Fuel Tank

Functions and Failures

Functions and Functional Failures	Steady-State system level response	Response Narrative
To Provide Liquid - Static pressure at		
Fuel Tank Liquid Static pressure fails Low	Vehicle System Convert Mechanical - rotational Angular ...	A loss of static pressure in the fuel tank will propagate through the diesel engine and r...

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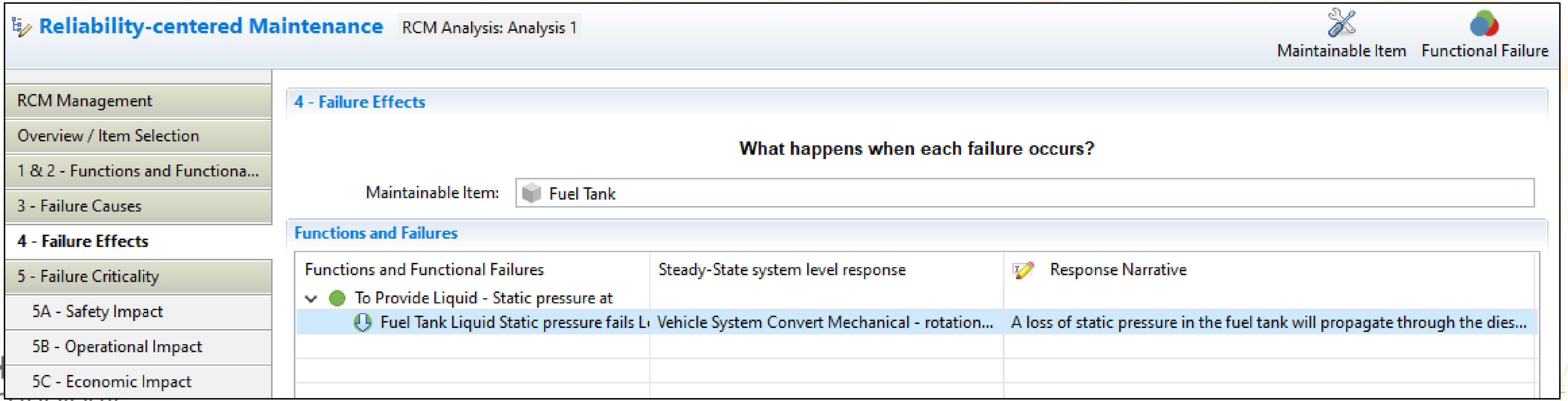
Session 5.3: Classic RCM

Exercise 5.3.5 Failure Effects

Enter the following response narrative for the Generator system response:

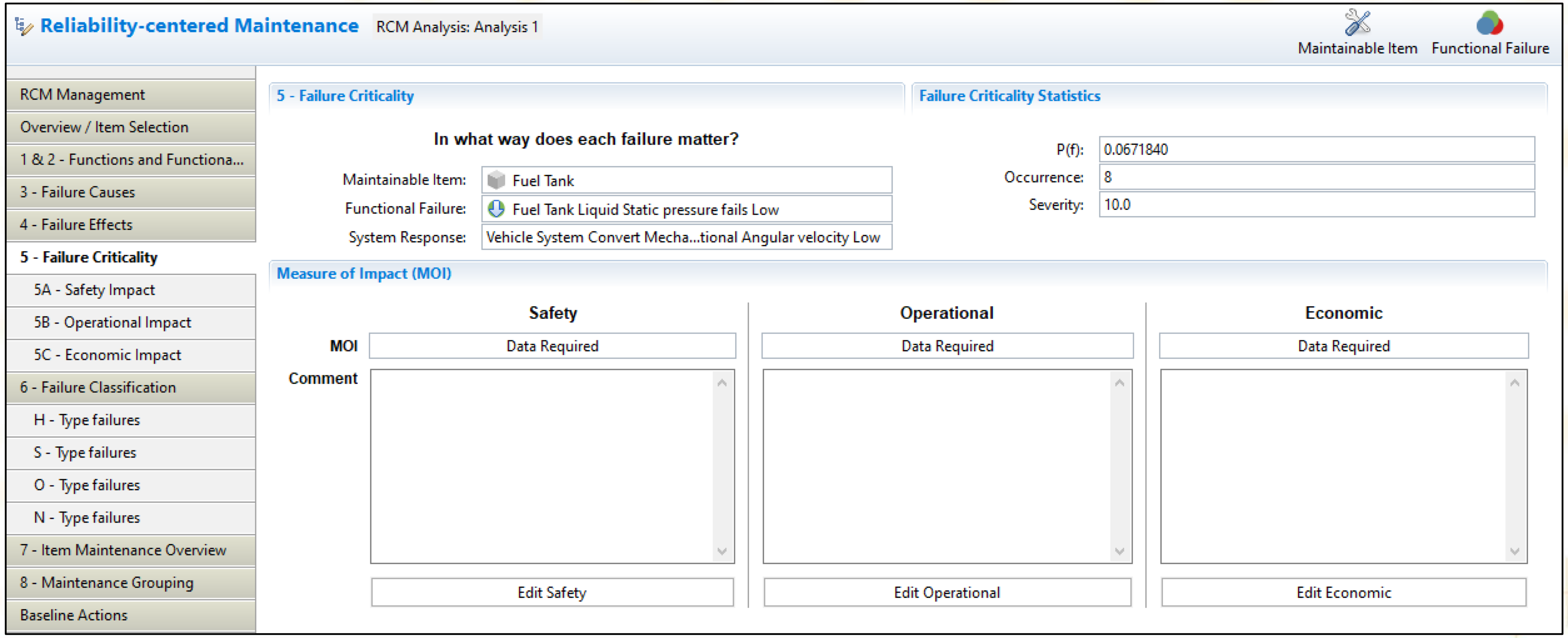
- Select the **Response Narrative** table cell
- Select ... to open the Response Narrative text editor
- Enter the Response Narrative: **A loss of static pressure in the fuel tank will propagate through the diesel engine and result in a reduction of force at the end of the vehicle system.**



Session 5.3: Classic RCM

Discussion 5.3.6 Failure Criticality

- Involves assessing the criticality of the effects of the failure through 'Measures of Impacts' (MOIs)
- It is important in understanding the impact that a failure can have in terms of the following MOIs:
  - Safety Impact
  - Operational Impact
  - Economic Impact



Session 5.3: Classic RCM

Discussion 5.3.6 Failure Criticality (Safety Impact)

- Safety Measure of Impact is measured from both human and environmental impact rankings

5A - Safety Impact

Safety Impact of Failure

Maintainable Item:	Fuel Tank
Functional Failure:	Fuel Tank Liquid Static pressure fails Low
System Response:	Vehicle System Convert Mechanical - rotational Angular velocity Low

Safety Impact Statistics

Safety MOI:	Very High
P(f):	0.9998868
Occurrence:	10

Human - Safety Impact of System Level Effect

The safety measure of impact combines your estimation of risk to human life with your estimation of risk to the local and broader environment. When you have ranked the severity of both of these impacts, an overall safety MOI is calculated.

Safety Impact Ranking: Moderate (5-6) - Significantly reduces operator performance

Impact Narrative: A loss of fuel is likely to only result in a break-down in an isolated area, this will significantly impact the ability for the vehicle to complete its mission but will not have any directly dangerous hazards.

Environmental - Safety Impact of System Level Effect

Safety Impact Ranking: Low (3-4) - Minor repair/cleaning required

Impact Narrative: Leaking of the fuel tank or loss of torque is only likely to cause minor short-term damage or minor clean-up, examples would be a fuel leak.

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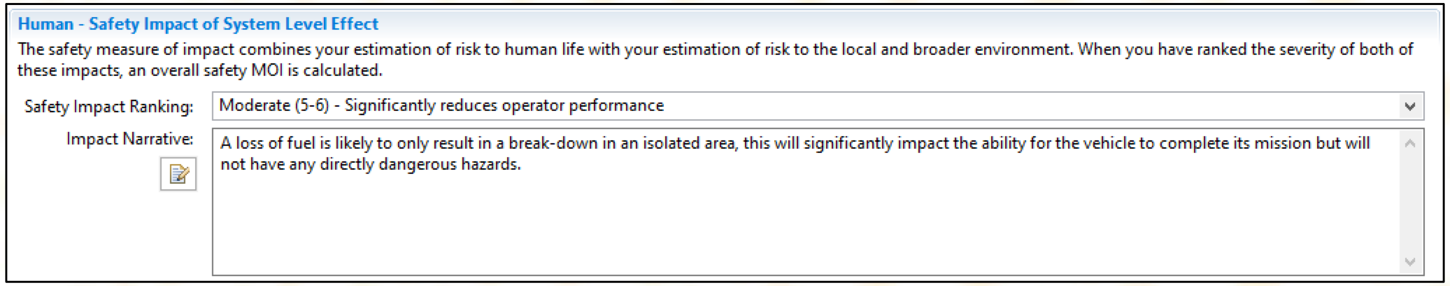
Exercise 5.3.6 Failure Criticality (Safety Impact)

Overall Safety Measure of Impact is measured from a combination of human and environmental impact.
To assess the Safety Impacts:

- Select page: **5A – Safety Impact**
- Select Human Safety Impact Rating: **Moderate (5-6) – Significantly reduces operator performance**
- Enter Impact Narrative: **A loss of fuel is likely to only result in a break-down in an isolated area, this will significantly impact the ability for the vehicle to complete its mission but will not have any directly dangerous hazards**.


Human - Safety Impact of System Level Effect

The safety measure of impact combines your estimation of risk to human life with your estimation of risk to the local and broader environment. When you have ranked the severity of both of these impacts, an overall safety MOI is calculated.

Safety Impact Ranking: Moderate (5-6) - Significantly reduces operator performance

Impact Narrative: A loss of fuel is likely to only result in a break-down in an isolated area, this will significantly impact the ability for the vehicle to complete its mission but will not have any directly dangerous hazards.

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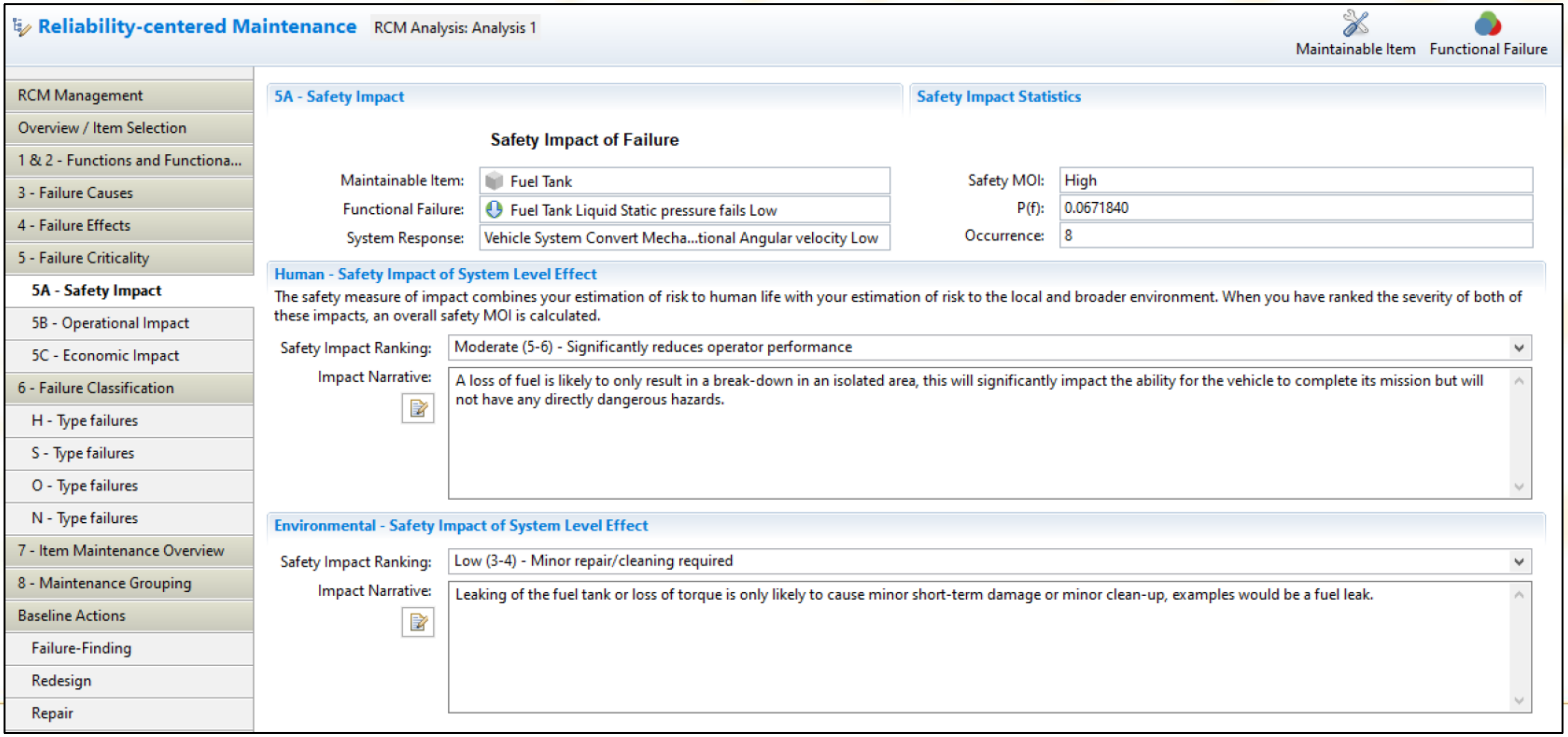
EXERCISE 5.3.6 FAILURE CRITICALITY (SAFETY IMPACT) (CONTINUED)

- Environmental Safety Impact Rating: **Low (3-4) – Minor repair/cleaning required**
- Enter Impact Narrative: **Leaking of the fuel tank or loss of torque is only likely to cause minor short-term damage or minor clean-up, examples would be a fuel leak.**



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Discussion 5.3.6 Failure Criticality (Operational Impact)

- Operational Measure of Impact is derived from functional importance affected by the functional failure, and whether it will cause a shutdown/mission abort of the system

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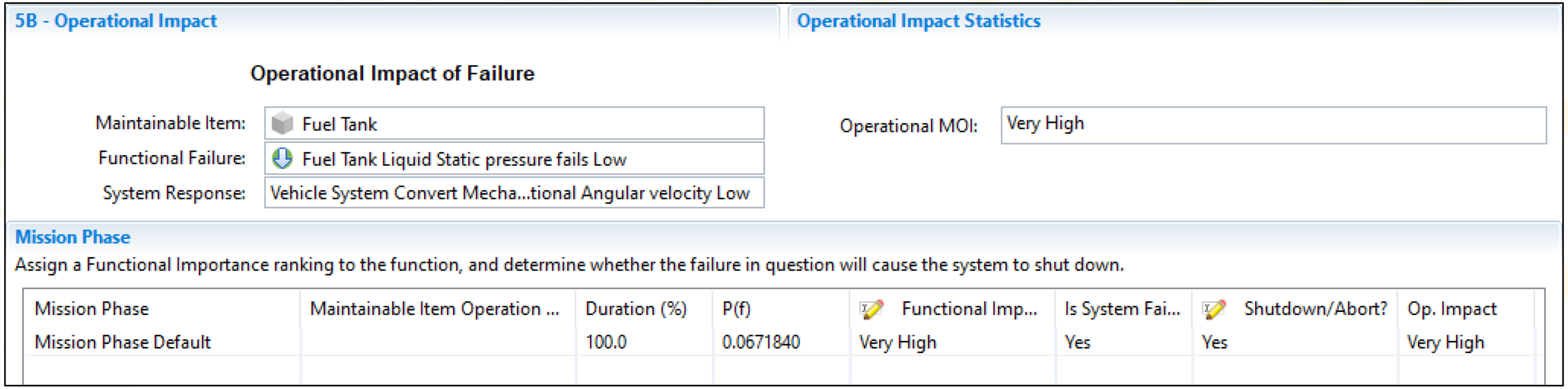
<u>Exercise 5.3.6 Failure Criticality (Operational Impact)</u>

To assess the Operational Impacts:

- Select the Operational Impact page (5B – Operational Impact):
- Confirm the cell under the **Functional Importance** column is set to: **Very High**
- Confirm the cell under the **Shutdown/Abort?** column is set to: **Yes**
- Confirm the **Operational Impact** is set to: **Very High**



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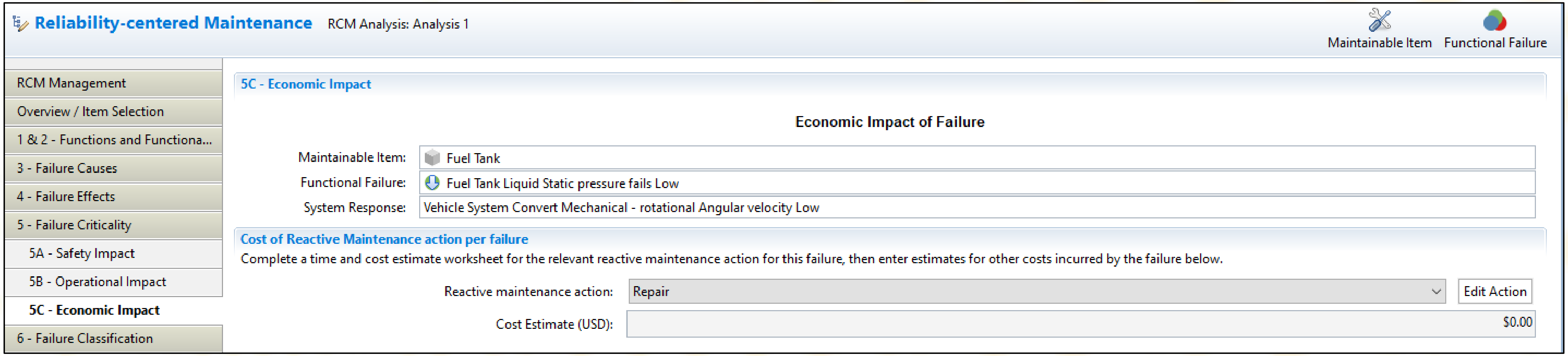
Discussion 5.3.6 Failure Criticality (Economic Impact)

- Economic Measure of Impact is determined by defining baseline maintenance actions, which consist of:
  - Repair Worksheet
  - Replace Worksheet
  - Cost of System Failure Effects per Failure



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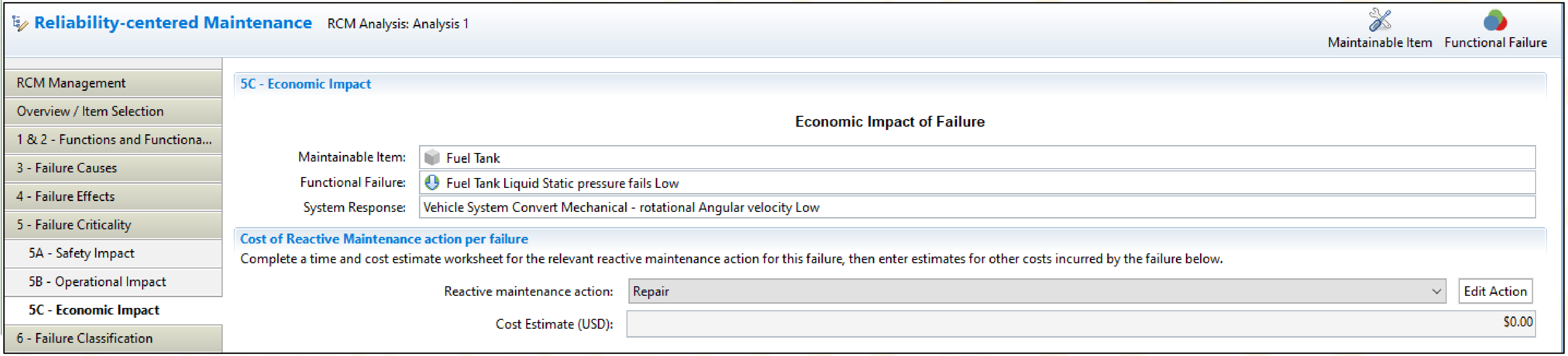
EXERCISE 5.3.6 FAILURE CRITICALITY (ECONOMIC IMPACT)

Select the following information in the Economic Impact page (5C – Economic Impact):

- Select Reactive Maintenance Action as: **Repair**
- Select Edit Action to edit the Repair worksheet



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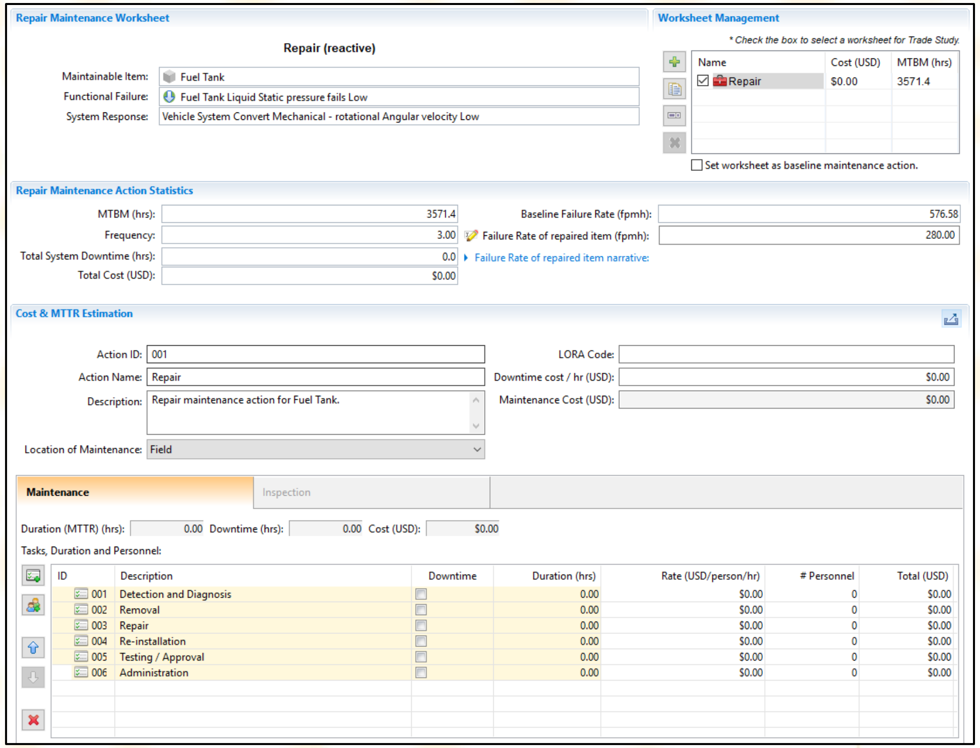
Discussion 5.3.6 Failure Criticality (Economic Impact): Repair/Replace worksheets

- The repair & replace worksheets consist of the following sections:
    - **Repair/Replace Maintenance Worksheet**:
      Lists the maintainable item, functional failure & system response
    - **Worksheet management**:
      Allows the user to select/deselect, rename, copy and delete tasks
    - **Repair Maintenance Action Statistics**:
      Summary of durations, costs and failure rates
    - **Cost & MTTR Estimation**:
      Fields and Tables for the proposed Maintenance Action



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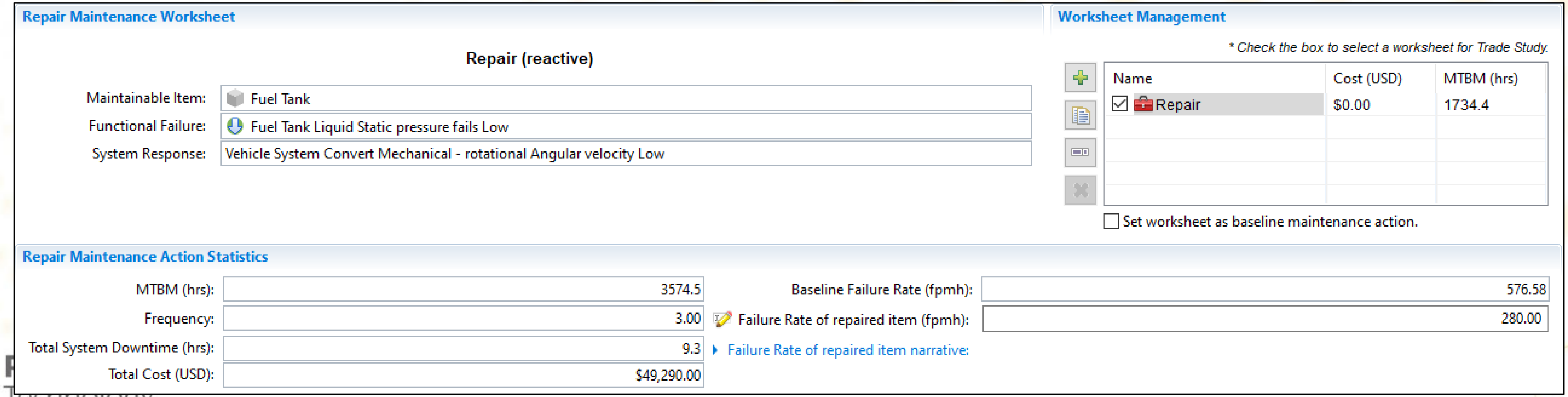
EXERCISE 5.3.6 FAILURE CRITICALITY (ECONOMIC IMPACT)

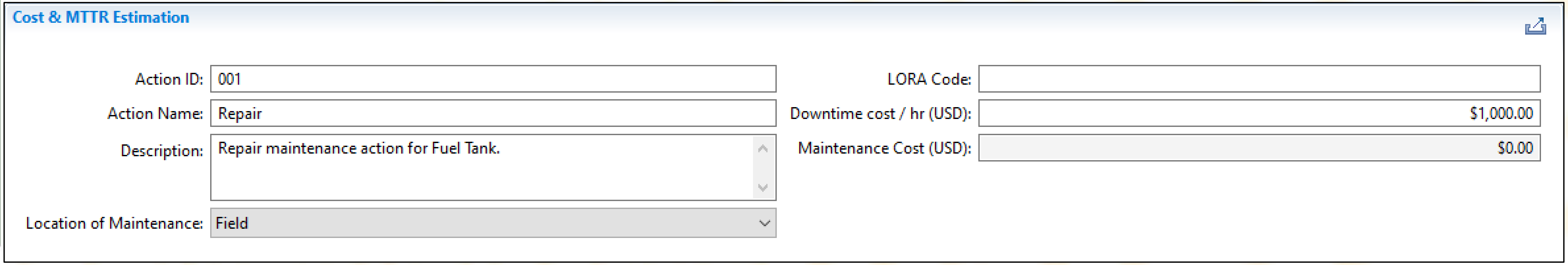
Select/Enter the following information in the Repair worksheet:

- In the Worksheet management section select: **Repair** check box (worksheet is included for Step 7)
- In the Repair Maintenance Action Statistics section:
  - Enter Failure Rate of Repaired Item: **280** (Failure per million hours)
  - Enter Failure Rate narrative: **Failure Rate based on Reliability Allocation analysis.**



EXERCISE 5.3.6 FAILURE CRITICALITY (ECONOMIC IMPACT) (CONTINUED)

- In the Cost & MTTR Estimation section:
  - Enter Action ID: **001**
  - Verify Action Name: **Repair**
  - Enter Description: **Repair maintenance action for Fuel Tank.**
  - Select Location of Maintenance: **Field**
  - Enter Downtime cost/hr: **$1000**



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EXERCISE 5.3.6 FAILURE CRITICALITY (ECONOMIC IMPACT) (CONTINUED)

- Enter information for the Cost & MTTR Estimation section tables as shown below:

Maintenance | Inspection

Duration (MTTR) (hrs): 4.60 Downtime (hrs): 3.10 Cost (USD): $100.00

Tasks, Duration and Personnel:

ID	Description	Downtime	Duration (hrs)	Rate (USD/person/hr)	# Personnel	Total (USD)
001	Detection and Diagnosis	☑	0.10	$50.00	1	$5.00
001	Technician			$50.00	1	$5.00
002	Removal	☑	0.50	$50.00	1	$25.00
001	Technician			$50.00	1	$25.00
003	Repair	☑	2.00	$50.00	1	$100.00
001	Technician			$50.00	1	$100.00
004	Re-installation	☑	0.50	$50.00	1	$25.00
001	Technician			$50.00	1	$25.00
005	Testing / Approval	☐	0.50	$50.00	1	$25.00
001	Technician			$50.00	1	$25.00
006	Administration	☐	1.00	$50.00	1	$50.00
001	Technician			$50.00	1	$50.00

Spares, Equipment and Consumables:

Item ID	Item Name	Cost (USD)	Quantity	Total (USD)
001	Repair Toolkiut	$100.00	1.00	$100.00

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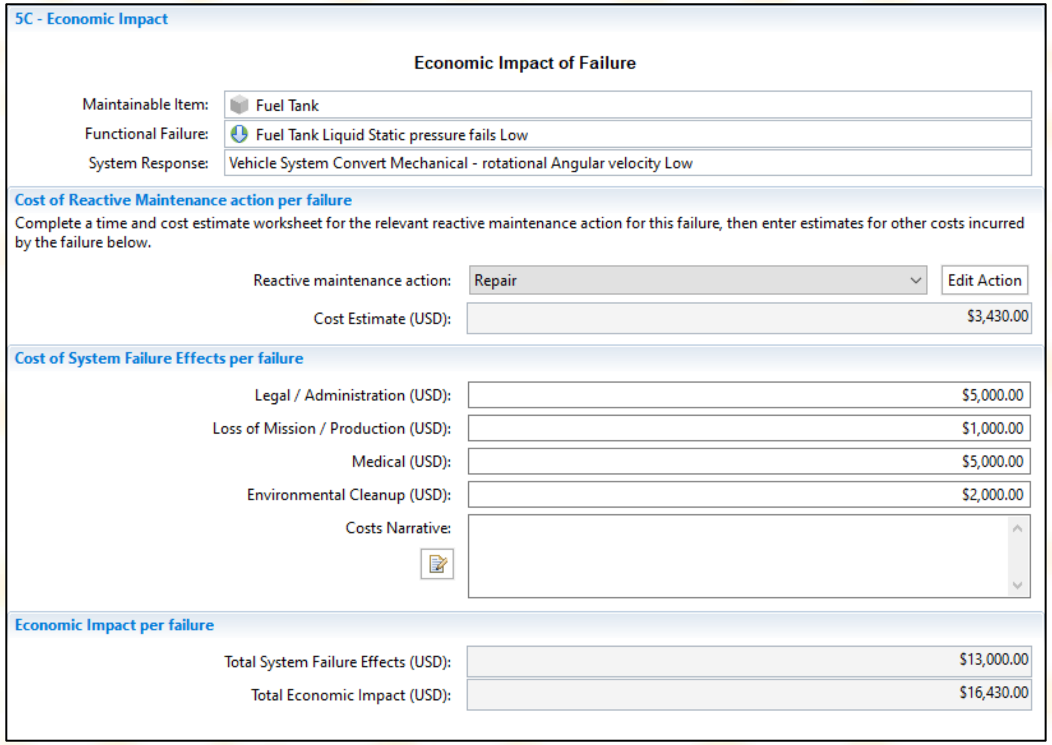
EXERCISE 5.3.6 FAILURE CRITICALITY (ECONOMIC IMPACT) (CONTINUED)

- Return to **Page 5C – Economic Impact**
- Enter the following costs for Cost of System Failure Effects per failure section:
  - Legal/Administration cost: **$5,000**
  - Loss of Mission/Production cost: **$1,000**
  - Medical cost: **$5,000**
  - Environmental Cleanup cost: **$2,000**
- Enter the following cost narrative: **Cost based on FY17 estimates.**
- Verify that the Total System Failure Effects cost: **$13,000**
- Verify Total Economic Impact: **$16,430**



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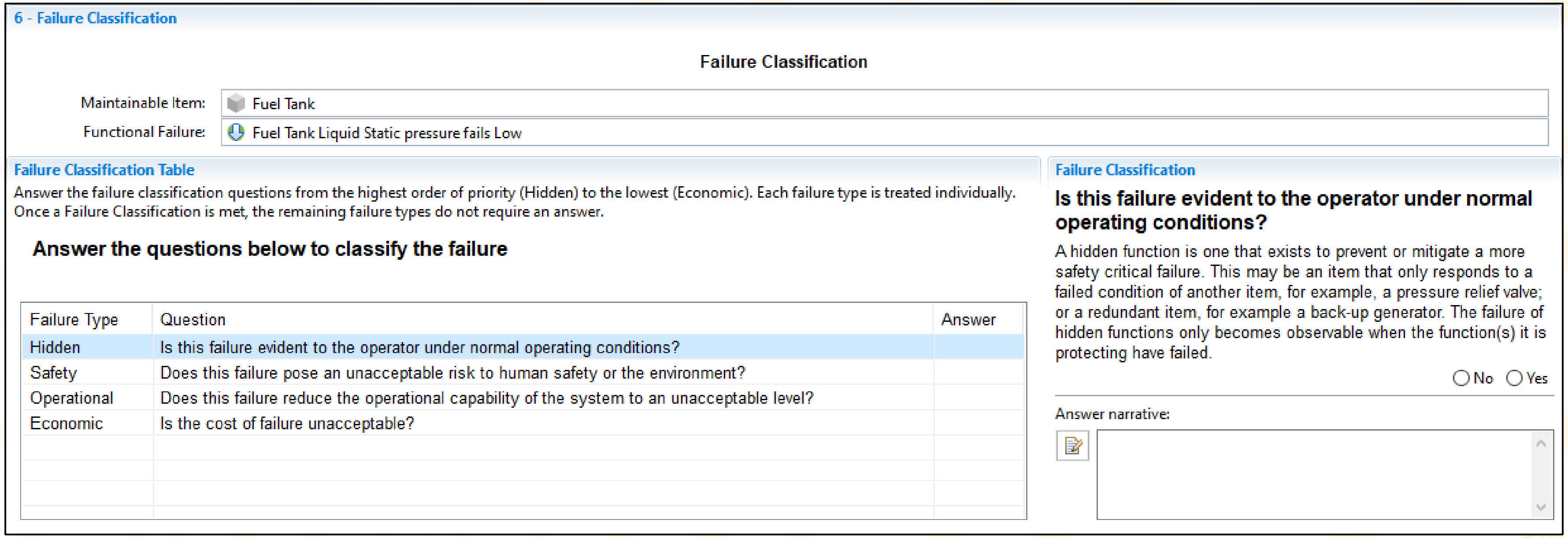
DISCUSSION 5.3.7 FAILURE CLASSIFICATION

- RCM Step 6 involves classifying the Failure based on the classic RCM II approach, identifying then alleviating it by taking the appropriate maintenance action
- Failure classifications types are divided into:
  - **Hidden Failures**
  - **Safety Failures**
  - **Operational Failures**
  - **Economic Failures**



6 - Failure Classification

Failure Classification

Maintainable Item: Fuel Tank

Functional Failure: Fuel Tank Liquid Static pressure fails Low

Failure Classification Table

Answer the failure classification questions from the highest order of priority (Hidden) to the lowest (Economic). Each failure type is treated individually. Once a Failure Classification is met, the remaining failure types do not require an answer.

Answer the questions below to classify the failure

Failure Type	Question	Answer
Hidden	Is this failure evident to the operator under normal operating conditions?	
Safety	Does this failure pose an unacceptable risk to human safety or the environment?	
Operational	Does this failure reduce the operational capability of the system to an unacceptable level?	
Economic	Is the cost of failure unacceptable?	

Failure Classification

Is this failure evident to the operator under normal operating conditions?

A hidden function is one that exists to prevent or mitigate a more safety critical failure. This may be an item that only responds to a failed condition of another item, for example, a pressure relief valve; or a redundant item, for example a back-up generator. The failure of hidden functions only becomes observable when the function(s) it is protecting have failed.

No Yes

Answer narrative:

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Exercise 5.3.7 Select Failure Classification

- In Failure Classification table select: **Hidden** failure type
  - Read question and select response: **Yes**
  - Enter narrative: **Functional Failure is not hidden.**

6 - Failure Classification

Failure Classification

Maintainable Item: Fuel Tank

Functional Failure: Fuel Tank Liquid Static pressure fails Low

Failure Classification Table

Answer the failure classification questions from the highest order of priority (Hidden) to the lowest (Economic). Each failure type is treated individually. Once a Failure Classification is met, the remaining failure types do not require an answer.

Answer the questions below to classify the failure

Failure Type	Question	Answer
Hidden	Is this failure evident to the operator under normal operating conditions?	Yes
Safety	Does this failure pose an unacceptable risk to human safety or the environment?	
Operational	Does this failure reduce the operational capability of the system to an unacceptable level?	
Economic	Is the cost of failure unacceptable?	

Failure Classification

Is this failure evident to the operator under normal operating conditions?

A hidden function is one that exists to prevent or mitigate a more safety critical failure. This may be an item that only responds to a failed condition of another item, for example, a pressure relief valve; or a redundant item, for example a back-up generator. The failure of hidden functions only becomes observable when the function(s) it is protecting have failed.

No / Yes (selected)

Answer narrative:

Functional Failure is not hidden.

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EXERCISE 5.3.7 SELECT FAILURE CLASSIFICATION

- In Failure Classification table select: **Safety** failure type
  - Read question and select response: **No**
  - Enter narrative: **Moderate (Human) & Low (Environment) rankings are acceptable.**

6 - Failure Classification

Failure Classification

Maintainable Item: Fuel Tank

Functional Failure: Fuel Tank Liquid Static pressure fails Low

Failure Classification Table

Answer the failure classification questions from the highest order of priority (Hidden) to the lowest (Economic). Each failure type is treated individually. Once a Failure Classification is met, the remaining failure types do not require an answer.

Answer the questions below to classify the failure

Failure Type	Question	Answer
Hidden	Is this failure evident to the operator under normal operating conditions?	Yes
Safety	Does this failure pose an unacceptable risk to human safety or the environment?	No
Operational	Does this failure reduce the operational capability of the system to an unacceptable level?	
Economic	Is the cost of failure unacceptable?	

Failure Classification

Does this failure pose an unacceptable risk to human safety or the environment?

The Safety Impact Ranking of this failure is Very High. This is based on:

- Human Safety Impact Ranking of Moderate (5-6) - Significantly reduces operator performance
- Environmental Safety Impact Ranking of Low (3-4) - Minor repair/cleaning required.

○ Yes ◉ No

Answer narrative:

Moderate (Human) & Low (Environment) rankings are acceptable.

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Exercise 5.3.7 Select Failure Classification

- In Failure Classification table select: **Operational failure**
  - Read question and select response: **Yes**
  - Enter narrative: **Failure of Fuel Tank significantly decreases output of Vehicle system.**
- Select link: Proceed to Step 6-O: Operational failure maintenance analysis decision sheet

6 - Failure Classification

Failure Classification

Maintainable Item: Fuel Tank

Functional Failure: Fuel Tank Liquid Static pressure fails Low

Failure Classification Table

Answer the failure classification questions from the highest order of priority (Hidden) to the lowest (Economic). Each failure type is treated individually. Once a Failure Classification is met, the remaining failure types do not require an answer.

The failure may be classified as an Operational failure

Proceed to Step 6-O: Operational failure maintenance analysis decision sheet

Failure Type	Question	Answer
Hidden	Is this failure evident to the operator under normal operating conditions?	Yes
Safety	Does this failure pose an unacceptable risk to human safety or the environment?	No
Operational	Does this failure reduce the operational capability of the system to an unacceptable level?	Yes
Economic	Is the cost of failure unacceptable?	

Failure Classification

Does this failure reduce the operational capability of the system to an unacceptable level?

The Operational Impact Ranking of this failure is Unknown.

(•) Yes ( ) No

Answer narrative:

Failure of Fuel Tank significantly decreases output of Vehicle system.

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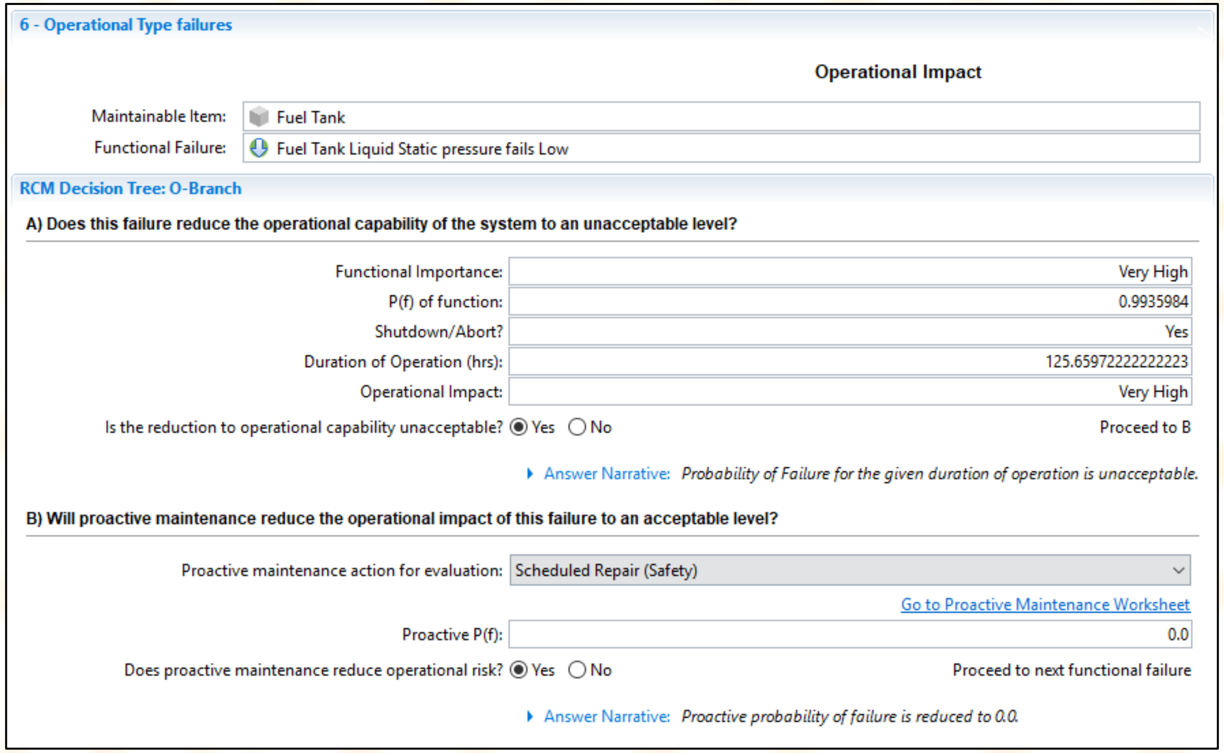
Discussion 5.3.7 Failure Classification (O-Type)

- The Operational (O-Type) decision tree investigates the decision making process for Operational Failures
- Three questions requiring a justifiable decision for the best course of action to address failure
- The main steps to decide:
  1. Whether failure is acceptable
  2. Whether Proactive maintenance can resolve the failure
  3. Whether Redesign is required to fix the failure



6 - Operational Type failures

Operational Impact

Maintainable Item: Fuel Tank
Functional Failure: Fuel Tank Liquid Static pressure fails Low

RCM Decision Tree: O-Branch

A) Does this failure reduce the operational capability of the system to an unacceptable level?

Functional Importance: Very High
P(f) of function: 0.9935984
Shutdown/Abort? Yes
Duration of Operation (hrs): 125.65972222222223
Operational Impact: Very High
Is the reduction to operational capability unacceptable? Yes No Proceed to B

Answer Narrative: *Probability of Failure for the given duration of operation is unacceptable.*

B) Will proactive maintenance reduce the operational impact of this failure to an acceptable level?

Proactive maintenance action for evaluation: Scheduled Repair (Safety)
Go to Proactive Maintenance Worksheet
Proactive P(f): 0.0
Does proactive maintenance reduce operational risk? Yes No Proceed to next functional failure

Answer Narrative: *Proactive probability of failure is reduced to 0.0.*

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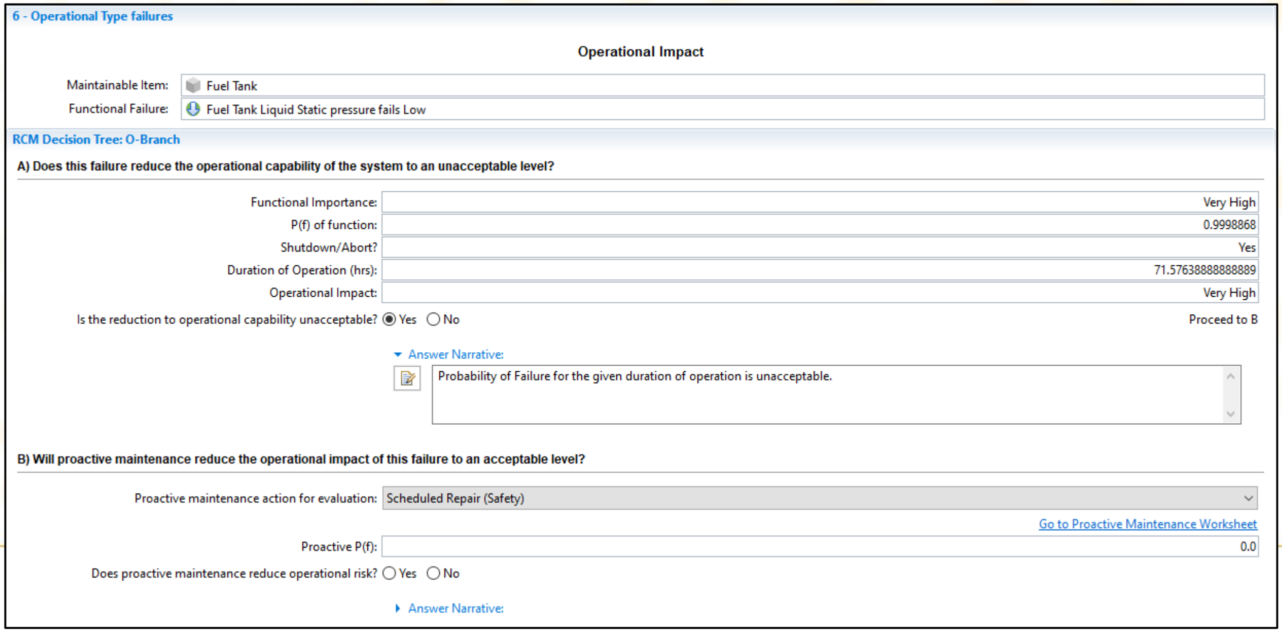
EXERCISE 5.3.7 COMPLETE O-TYPE FAILURE CLASSIFICATION PAGE

- Read Question A and select response: **Yes** (unacceptable reduction to operational capability)
- Enter narrative: **Probability of Failure for the given duration of operation is unacceptable.**
- Read Question B and select proactive maintenance: **Scheduled Repair (Safety)**
- Select link: Go to Proactive Maintenance Worksheet



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made
decisions better MADe...

DISCUSSION 5.3.7 FAILURE CLASSIFICATION (SCHEDULED MAINTENANCE)

- Proactive maintenance aims to fix failures before they occur – for scheduled repair the fuel tank is repaired at set intervals to avoid the failure from occurring
- Scheduled Repair and Replace Worksheets consist of the following sections:
  - **Scheduled Repair/Replace Maintenance Worksheet**: Lists the maintainable item, functional failure & system response
  - **Worksheet management**: allows the user to select/deselect, rename, copy and delete worksheets
  - **Statistics**: Baseline failure rate
  - **Technical Feasibility**: Fields for age-related failures, useful life and cause/mode narratives
  - **Cost & MTTR Estimation**: Fields and Tables for the proposed Maintenance Action
  - **Economic Feasibility**: Yes/No Questions that define failures and maintenance
  - **Summary:** Table showing comparison between scheduled repair and repair in terms of timespans and costs

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Exercise 5.3.7 Complete Scheduled Repair Worksheet

Select/Enter the following information in the Scheduled Repair worksheet:

- In the Worksheet management section:
  - Select: **Scheduled Repair** check box (worksheet is included for Step 7)
  - Select: **Set worksheet as baseline maintenance action** check box
- In the Technical feasibility section enter the following age-related & useful life values:

Cause/Mode	Age-related?	Useful Life (hr)	Narrative
Lining – Corroded due to Cavitation corrosion	Yes	2000	OEM data source
Lining – Perforated due to Corrosive attack	Yes	5000	OEM data source
Lining – Pitted due to Cavitation corrosion	No	-	OEM data source
Lining – Corroded due to Corrosive attack	Yes	5000	OEM data source
Lining – Pitted due to Corrosive attack	Yes	5000	OEM data source

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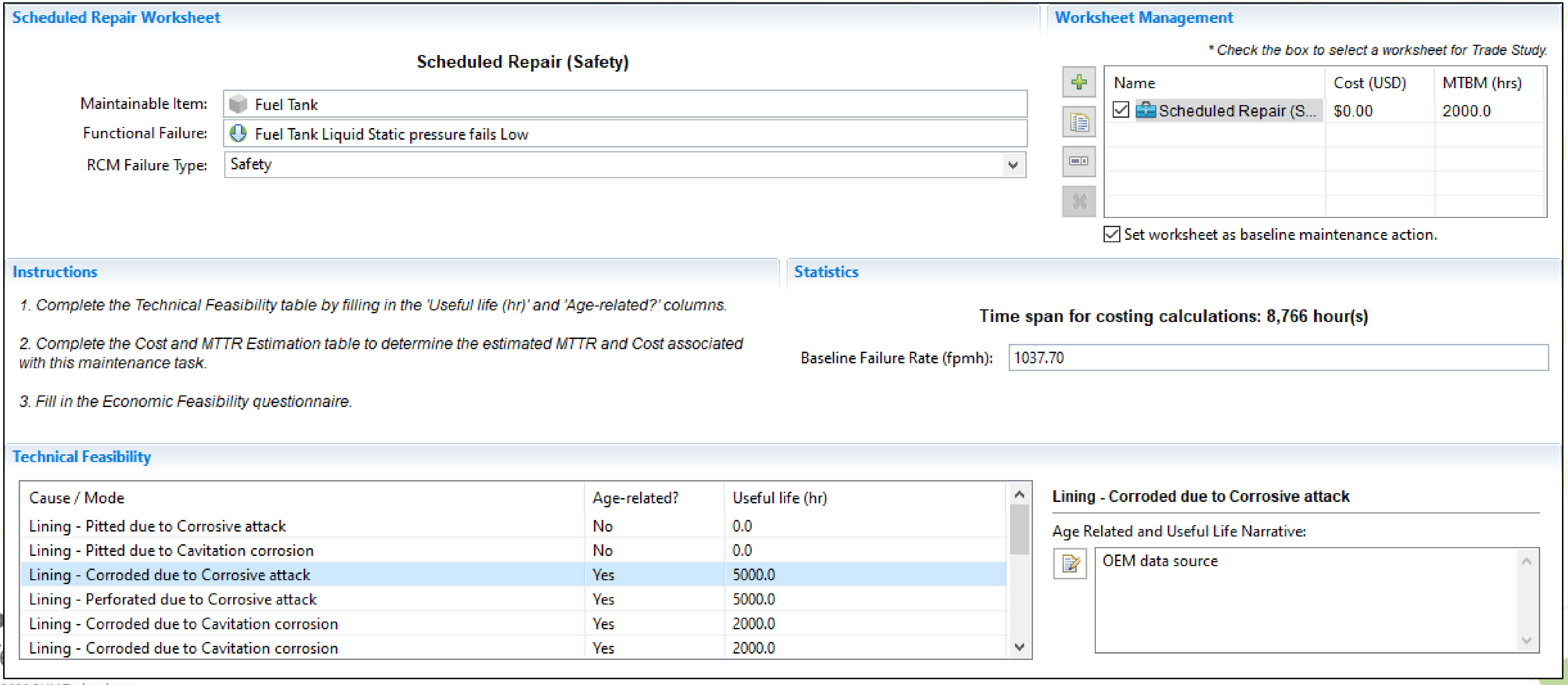
Exercise 5.3.7 Complete Scheduled Repair Worksheet (Continued)



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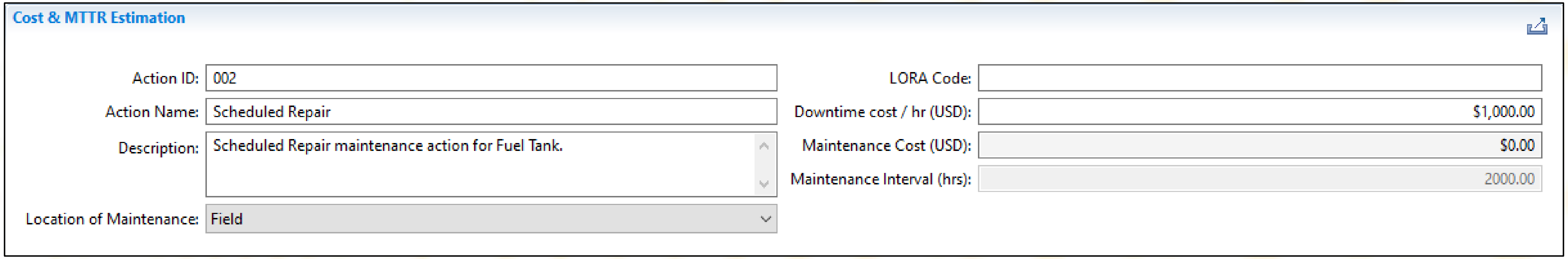
<u>EXERCISE 5.3.7 COMPLETE SCHEDULED REPAIR WORKSHEET (CONTINUED)</u>

- In the Cost & MTTR Estimation section:
  - Enter Action ID: **002**
  - Verify Action Name: **Scheduled Repair**
  - Enter Description: **Scheduled Repair maintenance action for Fuel Tank.**
  - Select Location of Maintenance: **Local Depot**
  - Enter Downtime cost/hr: **$1000**



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Exercise 5.3.7 Complete Scheduled Repair Worksheet (Continued)

- Enter information for the Cost & MTTR Estimation section tables as shown below:

Maintenance | Inspection

Duration (MTTR) (hrs): 3.00 Downtime (hrs): 0.00 Cost (USD): $310.00

Tasks, Duration and Personnel:

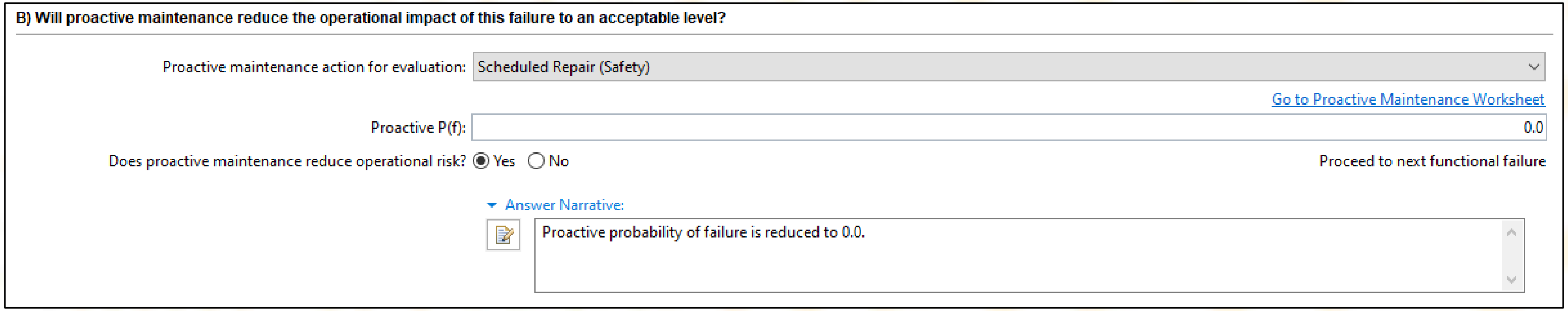
ID	Description	Downtime	Duration (hrs)	Rate (USD/person/hr)	# Personnel	Total (USD)
001	Removal	☐	0.50	$70.00	1	$35.00
001	Technician			$70.00	1	$35.00
002	Repair	☐	1.00	$70.00	1	$70.00
001	Technician			$70.00	1	$70.00
003	Reinstallation	☐	0.50	$70.00	1	$35.00
001	Technician			$70.00	1	$35.00
004	Testing Approval	☐	0.50	$70.00	1	$35.00
001	Technician			$70.00	1	$35.00
005	Administration	☐	0.50	$70.00	1	$35.00
001	Technician			$70.00	1	$35.00

Spares, Equipment and Consumables:

Item ID	Item Name	Cost (USD)	Quantity	Total (USD)
001	Repair toolkit	$100.00	1.00	$100.00

EXERCISE 5.3.7 COMPLETE SCHEDULED REPAIR WORKSHEET (CONTINUED)

- Return to **Page 6O – Type Failures**
- Read Question B and answer: **Yes**
- Enter Narrative: **Proactive probability of failure is reduced to 0.0.**



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Discussion 5.3.7 Failure Classification (Condition Based Maintenance)

- On Condition Maintenance (or Condition Based Maintenance) investigates the feasibility of performing maintenance as indicated by the health of a component
- Proactive Maintenance allows the monitoring of the health of a failure by monitoring, analysis and maintenance tasks
- Key Areas of the On Condition Worksheet:
  - Symptoms of Incipient Failure
  - Summary of CBM Activities
  - Maintenance Activities
  - Monitoring Tasks
  - Analysis Tasks
  - Maintenance Tasks

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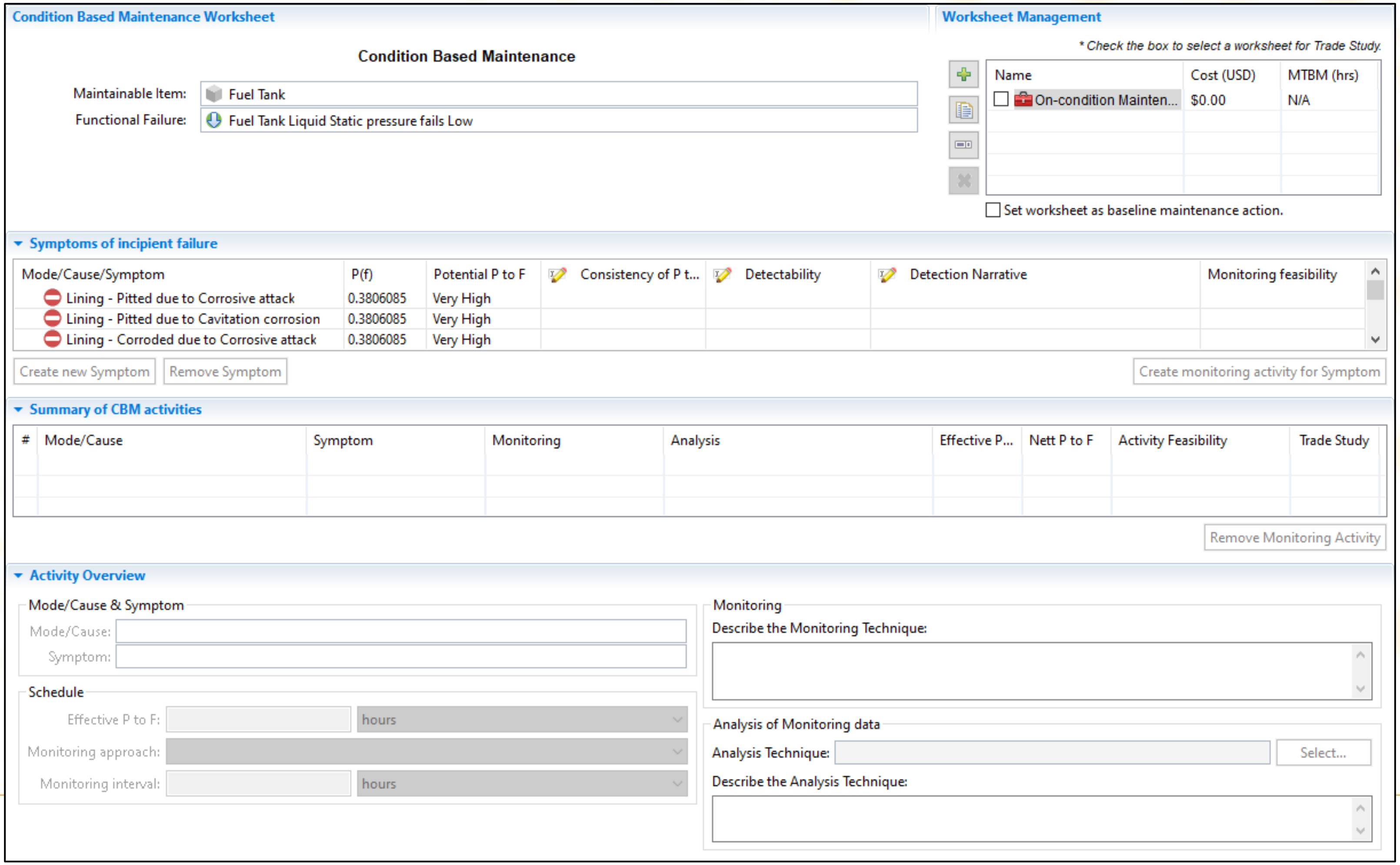
DISCUSSION 5.3.7 FAILURE CLASSIFICATION (CONDITION BASED MAINTENANCE) (CONTINUED)



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Discussion 5.3.7 Failure Classification (Redesign)

- Redesign is intended as a last resort for unacceptable failures that cannot be fixed by Reactive/Proactive Maintenance Tasks
- The scope of the Redesign in MADe is to provide the feasibility and general tasks involved with redesign to determine whether it would be more appropriate than other actions
- Key sections of the Redesign Worksheet:
    - Item Reliability Status
    - Redesign Approach
    - Mitigation of Operational Impact
    - Redesign Effect
    - Redesign cost & Project delay time estimation
    - Feasibility of Redesign

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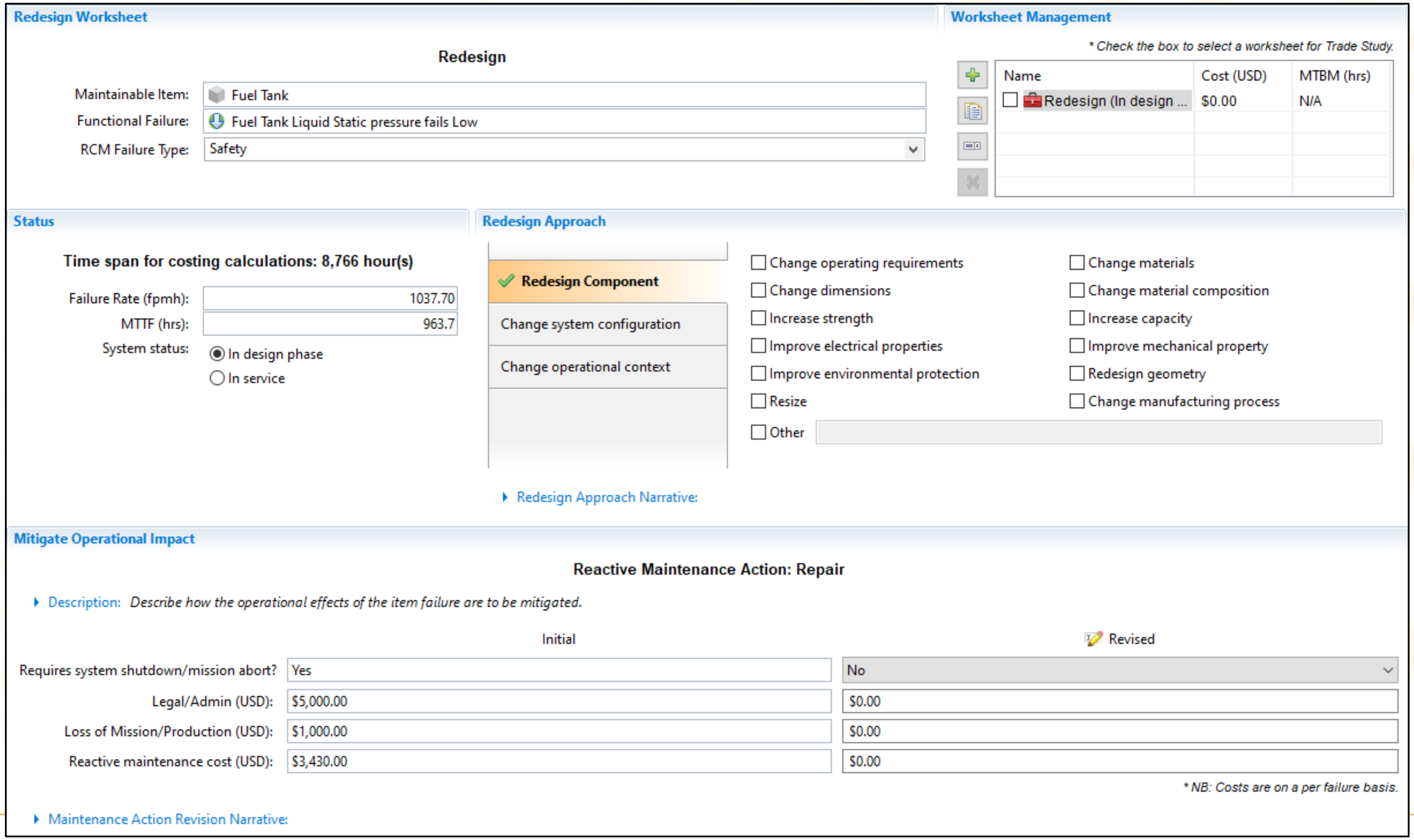
Discussion 5.3.7 Failure Classification (Redesign)



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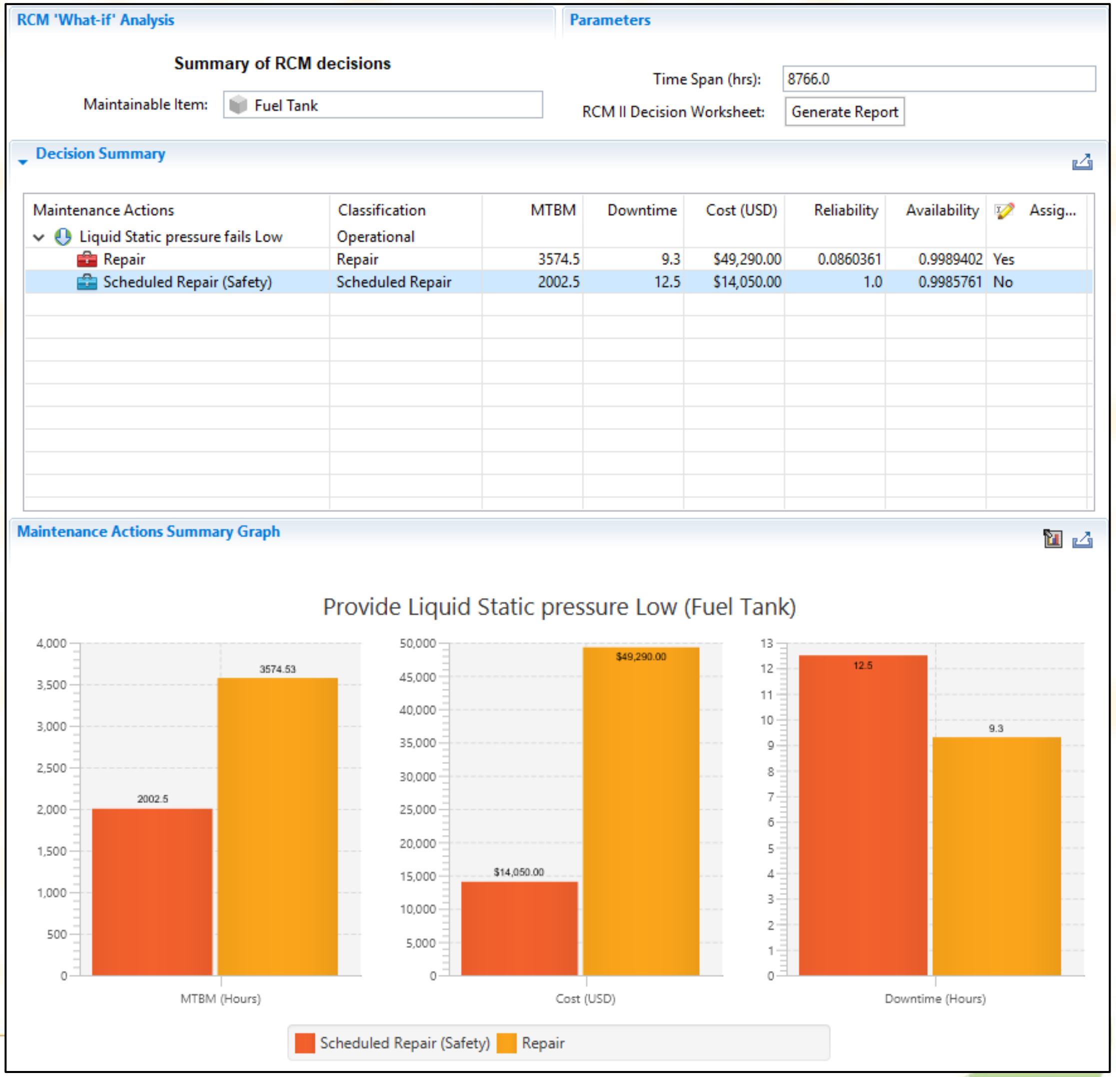
DISCUSSION 5.3.8 ITEM MAINTENANCE OVERVIEW

- Item Maintenance Overview page allows the comparison of important characteristics for all completed worksheets. The overview allows to compare costs, downtimes and MTBM for each task and to also report out on the RCM process
- Worksheet Factors compared in the Overview page:
    - Maintenance Classification
    - MTBM
    - Downtime
    - Cost
    - Reliability
    - Availability
    - Summary Graphs



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DISCUSSION 5.3.9 REPORTING OUTPUTS

- RCM Reports can be automatically generated from the Item Maintenance Overview page.
  - Reports are generated in both PDF and XLS formats
  - Allows multiple component RCM analyses to be incorporated

- The main types of RCM reports include:
  - Classic RCM Report (Long Form)
  - Classic RCM Report (Abbreviated)
  - Classic RCM Report (Expanded)

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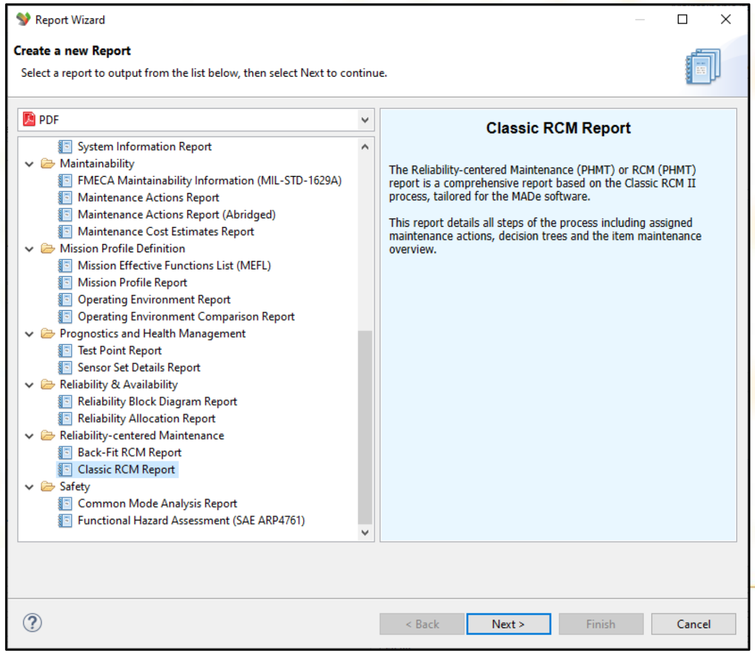
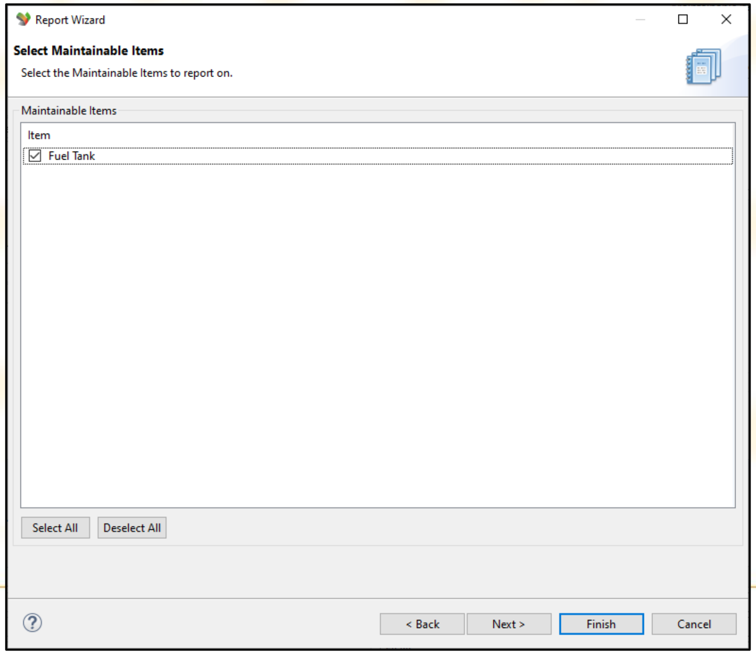
EXAMPLE 5.3.9 GENERATE A CLASSIC RCM REPORT

To generate a Classic RCM report:

- Select **Reports → Report Wizard** from the main menu
- Select the Maintainable Item as **‘Fuel Tank’**
- Select Finish to generate the report





Session 5.3: Classic RCM

Session 5.3 Summary

- ✓ 5.3.1: Background to RCM
- ✓ 5.3.2: Classic RCM Overview and Management
- ✓ 5.3.3: Functions & Functional failures
- ✓ 5.3.4: Failure Causes
- ✓ 5.3.5: Failure Effects
- ✓ 5.3.6: Failure Criticality
- ✓ 5.3.7: Failure Classification
- ✓ 5.3.8: Item Maintenance Overview
- ✓ 5.3.9: Classic RCM Report

Session 5.4: Reliability Centered Maintenance (Back-Fit)

SESSION 5.4 OUTLINE

5.4.1: Back-Fit RCM Background

5.4.2: Back-Fit RCM Editor

5.4.3: NAVSEA Road MAP: Identify Failure Modes

5.4.3: Failure Assessment

5.4.4: Maintenance Classification

5.4.5: Maintenance Applicability

5.4.6: Failure Consequences

5.4.7: Maintenance Effectiveness

5.4.8: Improve Task

5.4.9: Proposed Maintenance

5.4.10: Maintenance Association

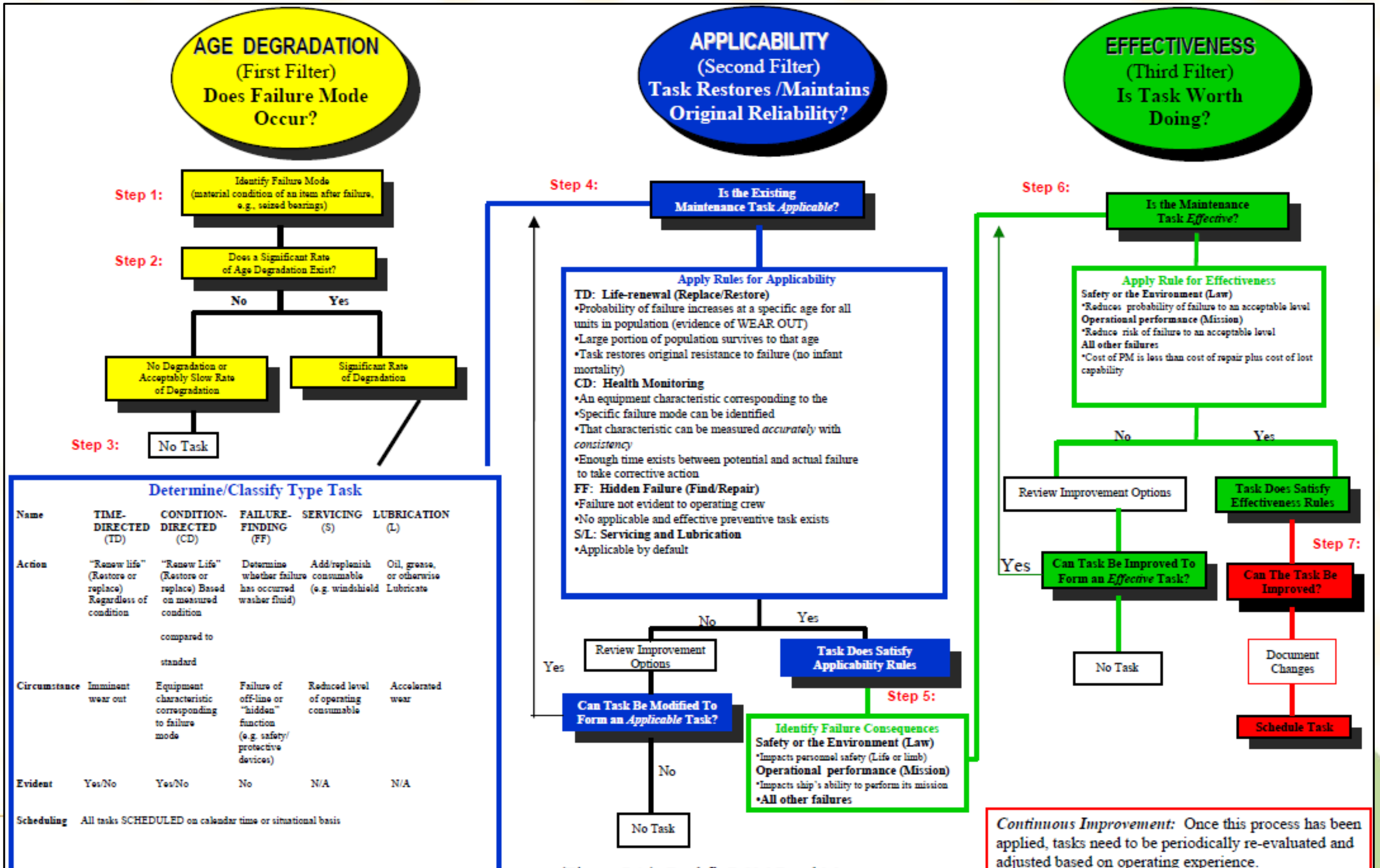
5.4.11: Back-Fit RCM Report

PHM Technology

Session 5.4: Back-Fit RCM

Discussion 5.4.1 Back-Fit RCM Background

- Back-Fit RCM is based on a process described in USN SSC Handbook **S9081-AB-GIB-010**
- Back-Fit RCM processes involve:
    - Identifying Failure Mode / Faults
    - Failure Assessment
    - Maintenance Classification
    - Maintenance Applicability
    - Failure Consequences
    - Maintenance Effectiveness
    - Maintenance Task Improvement
    - Review Proposed Maintenance

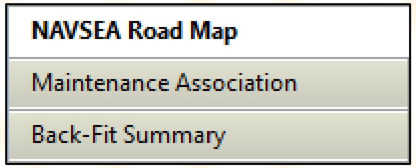


(Figure 7.1.) Backfit RCM Road Map

Session 5.4: Back-Fit RCM

DISCUSSION 5.4.2 BACK-FIT RCM EDITOR

- The Back-Fit RCM Analysis editor consists of 3 main pages:
  1. **Back-Fit Summary:** For defining RCM time-span
  2. **NAVSEA Road Map:** Contains Back-Fit RCM analysis steps
  3. **Maintenance Association:**
     - Summarises current & proposed maintenance actions
     - Displays maintenance durations, downtimes, cost divergence

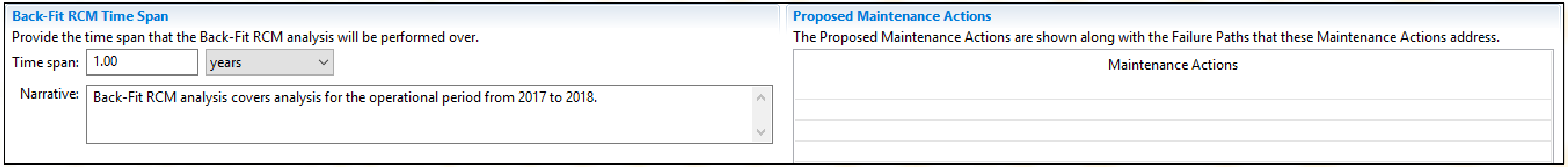


Session 5.4: Back-Fit RCM

Discussion 5.4.2 Back-Fit Summary Page

- The Back-Fit Summary page contains 2 sections

1. **Back-Fit RCM Time Span**
    - Enter duration (time span) Back-Fit RCM analysis is performed over
2. **Proposed Maintenance Actions**
    - Lists maintenance actions which address Failure Modes or Faults

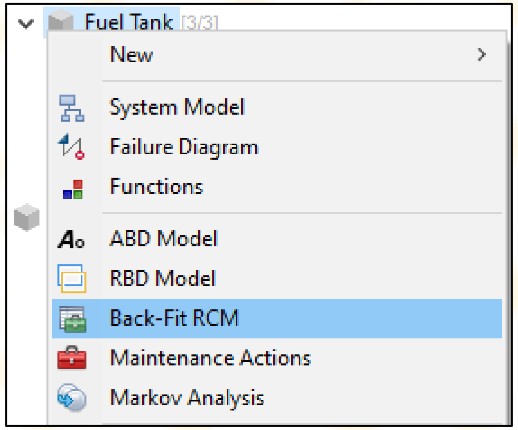


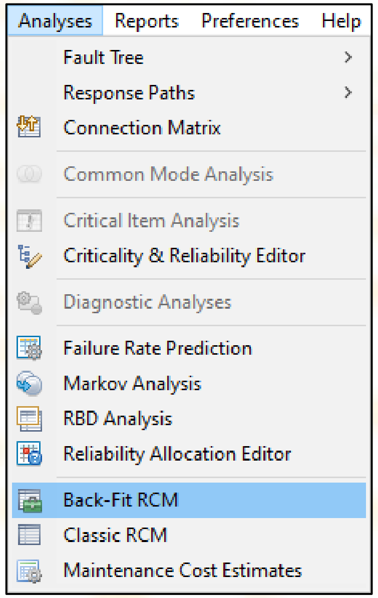
Session 5.4: Back-Fit RCM

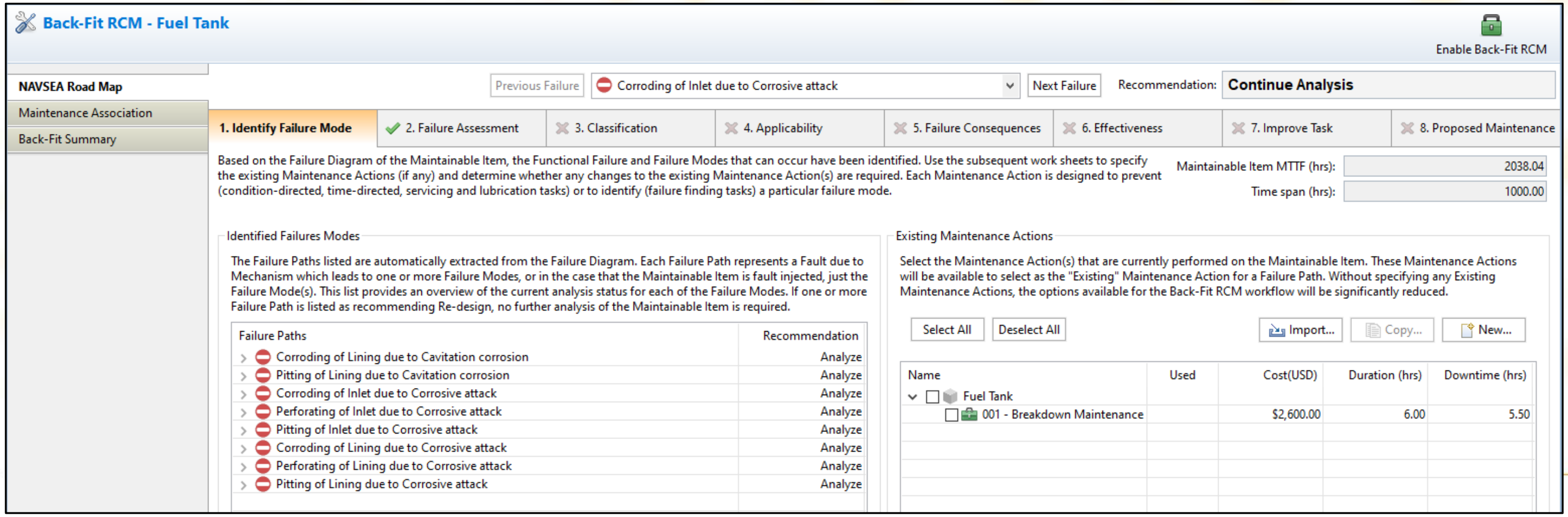
EXERCISE 5.4.2 BACK-FIT RCM EDITOR

To create a Back-Fit RCM Analysis:

- Right-click the **'Fuel Tank'** in the System Model/Project Explorer
- Select **Back-Fit RCM**
- Alternatively, select the **'Fuel Tank'** item
- From the menu bar, select **Analyses → Back-Fit RCM**





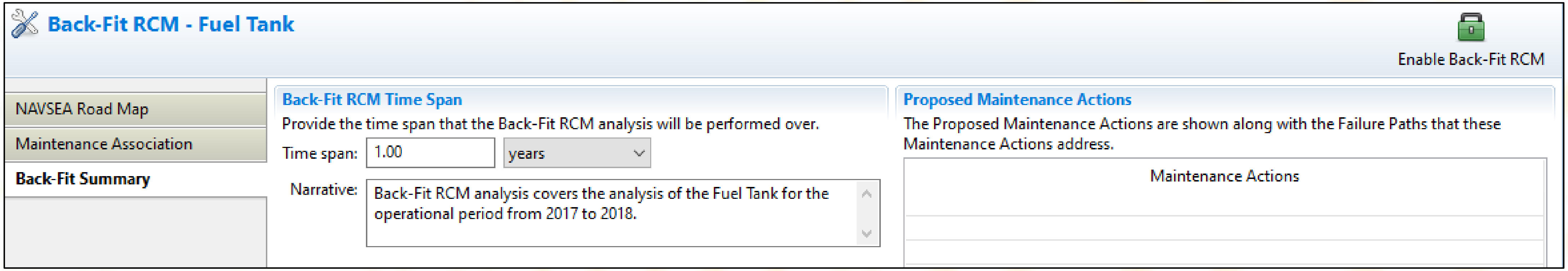


Session 5.4: Back-Fit RCM

<u>Exercise 5.4.2 Back-Fit Summary Page</u>

Enter the following Timespan and narrative:

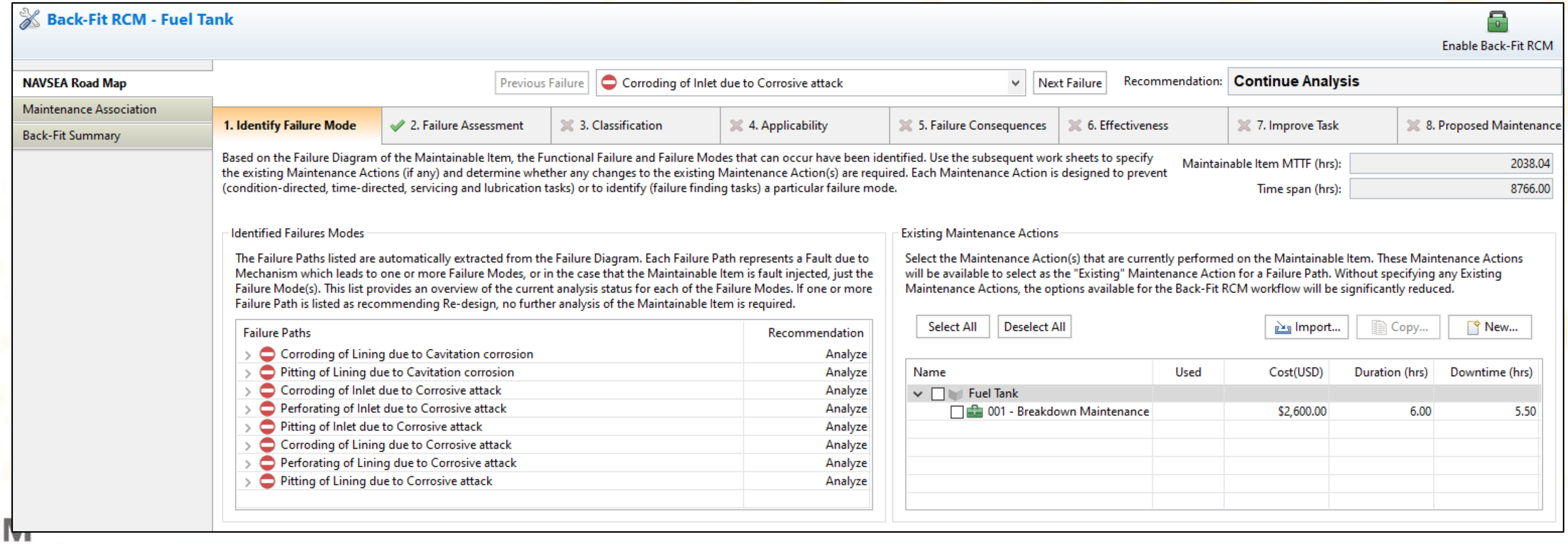
- Time Span: **1 Year**
- Narrative: **Back-Fit RCM analysis covers the analysis of the Fuel Tank for the operational period from 2017 to 2018.**



Session 5.4: Back-Fit RCM

Discussion 5.4.3 NAVSEA Road Map: Identify Failure Modes

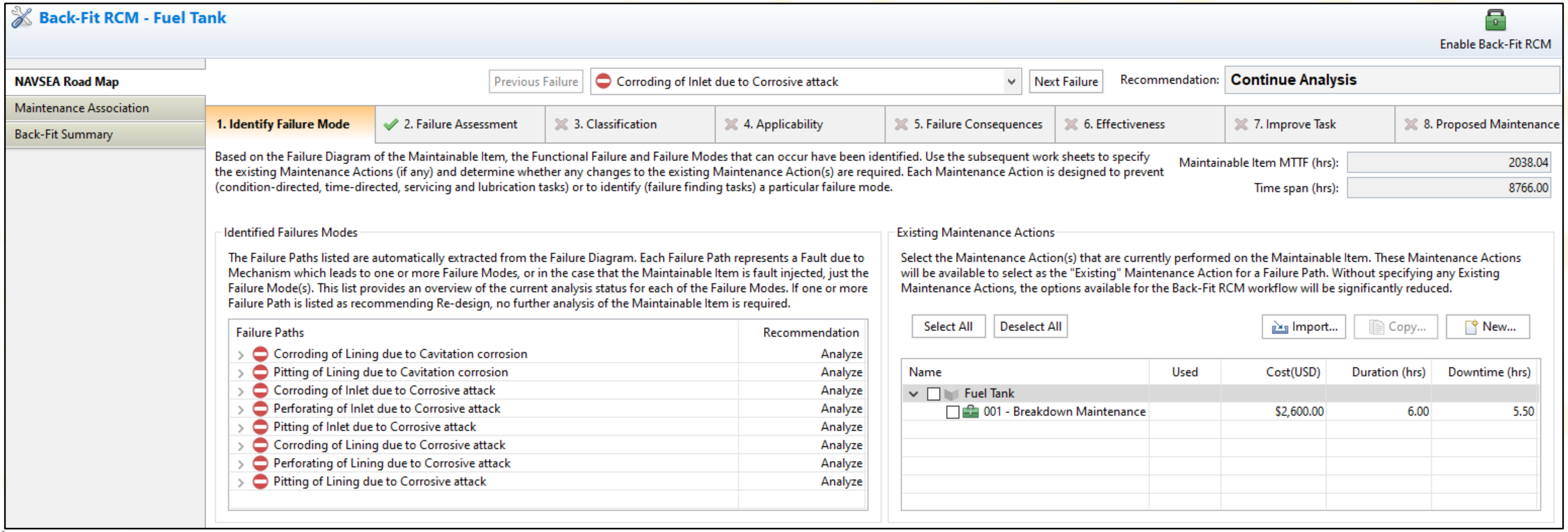
- NAVSEA Road Map starts by identifying **failure modes or faults of a component**
- Existing **maintenance actions** (if available) are listed



Session 5.4: Back-Fit RCM

EXERCISE 5.4.3 NAVSEA ROAD MAP: IDENTIFY FAILURE MODES

- Select Enable Back-Fit RCM to enable Back-Fit RCM
- Select from the drop down menu: **Corroding of Lining due to Cavitation corrosion**
- Under Existing Maintenance Actions select: **001 – Breakdown Maintenance**



Session 5.4: Back-Fit RCM

Discussion 5.4.3 Failure Assessment

- Failure Assessment contains questions to determine:
  - Whether existing maintenance exists for the failure mode
  - Whether the Failure Mode occurs during the service life
  - Whether a maintenance action can be created to address the failure path

- Displays existing maintenance actions associated to the component
- Recommended action with a link displayed at the bottom of page after the questions are answered
  - E.g. “Yes” to existing maintenance actions and existence of age degradation will cause Back-Fit RCM to recommend continuing to classify the type of maintenance task

Session 5.4: Back-Fit RCM

Exercise 5.4.3 Failure Assessment

To conduct Back-Fit RCM failure assessment, on the Back-Fit RCM page:

- Select the **Failure Assessment** tab
- Read Question 1 (Is there an existing Maintenance Action?) and select response: **Yes**
- Select existing maintenance action from drop down menu: **001 – Breakdown Maintenance**
- Read Question 2 (Does Failure Mode occur…) and select response: **Yes**
- Enter comment: **Item Failure diagram – sourced from maintenance data**.
- Review Recommended Action: **Continue Analysis**
- Select Go to step 3: Classification

Session 5.4: Back-Fit RCM

EXERCISE 5.4.3 FAILURE ASSESSMENT (CONTINUED)

Back-Fit RCM - Fuel Tank

Enable Back-Fit RCM

NAVSEA Road Map

Maintenance Association

Back-Fit Summary

Previous Failure | Corroding of Inlet due to Corrosive attack | Next Failure | Recommendation: **Continue Analysis**

1. Identify Failure Mode | **2. Failure Assessment** | 3. Classification | 4. Applicability | 5. Failure Consequences | 6. Effectiveness | 7. Improve Task | 8. Proposed Maintenance

Using 3-M (Maintenance and Material Management) data and other operational information, determine whether or not the failure mode actually occurs. If this failure has ever been observed in the system outside the time span of analysis or in similar systems then it is recommended that the failure is treated as if it is possible to occur during service life of this system.

Maintainable Item MTTF (hrs): 2038.04

Time span (hrs): 8766.00

Identify Failure Mode

Is there an existing Maintenance Action?

(•) YES — A Maintenance Action is performed for this failure. Specify the Maintenance Action below.

( ) NO — No Maintenance Action is currently performed. Continue the questionnaire below to determine if a maintenance action is required.

Existing Maintenance Action: Breakdown Maintenance

New... Copy...

Does the Failure Mode actually occur in the service life or a significant rate of age degradation exist?

Based on your operational and professional experience, does this Failure Mode actually occur within the service life of the equipment?

(•) YES — If the Failure Mode does occur or if the analyst is unsure, select "YES" and move to the next step.

( ) NO — If the item does not degrade meaningfully with age or if the degradation is sufficiently slow as to be of no practical concern, then there is no need for the task, and it can be removed. The analysis is then complete.

Comment:

Item Failure diagram – sourced from maintenance data.

Existing Maintenance Action

Maintenance Action: Breakdown Maintenance

Description: Breakdown Repair based on MCE Analysis 1.

Maintenance Type: Breakdown Repair

Maintenance interval (hrs): 0.00

Inspection interval (hrs): N/A

Location of Maintenance: Field

Maintenance | Inspection

Duration (MTTR) (hrs): 6.00 Downtime (hrs): 5.50 Cost (USD): $2,600.00

Tasks, Duration and Personnel:

ID	Description	Down...	Duration...	Rate (USD/pers...	# Perso...	Total (...
	Detection / Diagnosis	☑	0.50	$100.00	1	$50.00
	Removal	☑	1.00	$100.00	1	$100.00
	Technician	☑	3.00	$100.00	1	$300.00
	Reinstallation	☑	1.00	$100.00	1	$100.00
	Testing / Administration	☐	0.50	$100.00	1	$50.00

Session 5.4: Back-Fit RCM

Discussion 5.4.4 Maintenance Classification

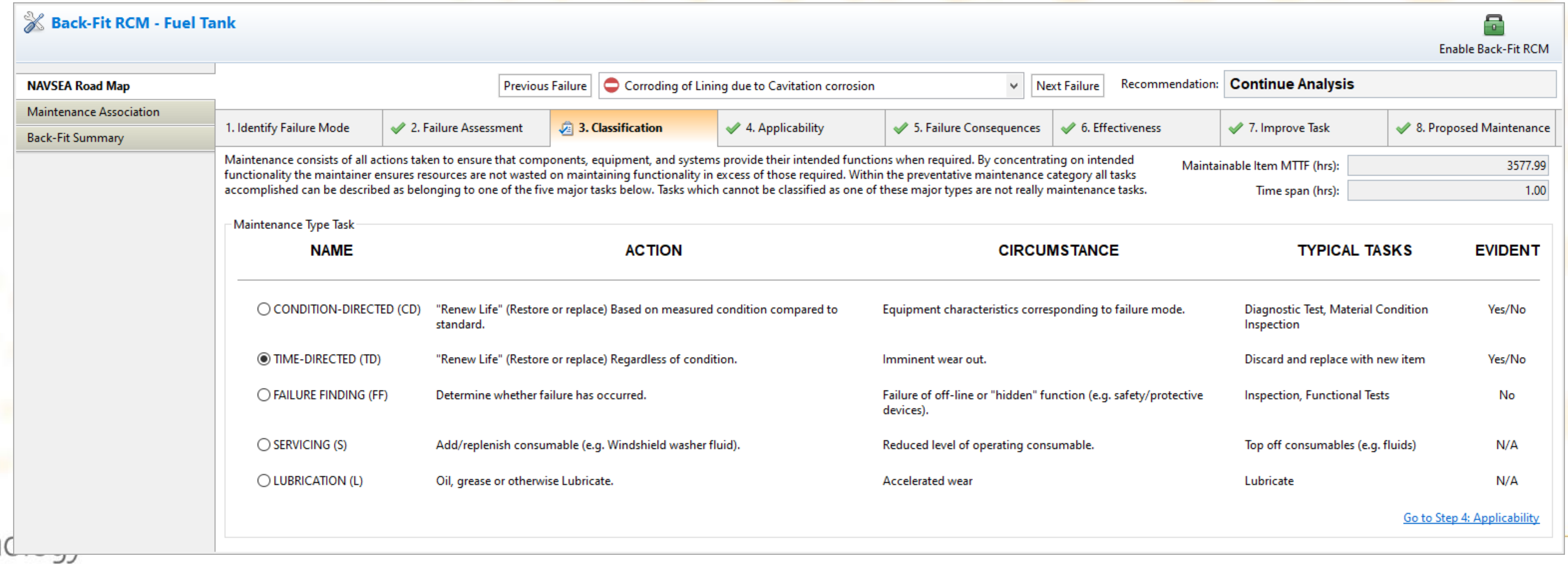
This page is used to determine which major category the maintenance action falls under

- Main categories include:
  - Condition-Directed (CD)
  - Time-Directed (TD)
  - Failure Finding (FF)
  - Servicing (S)
  - Lubrication (L)
- Selecting a maintenance type category will generate a link at the bottom of the page
  - E.g. Selecting **Time-Directed** maintenance will prompt the user to continue to **Step 4: Applicability**

Session 5.4: Back-Fit RCM

EXERCISE 5.4.4 MAINTENANCE CLASSIFICATION

- Select **Time-Directed** for Maintenance Type Task
  - Note: Recall 001 – Scheduled Maintenance is regular, periodic maintenance
- Select link: Go to Step 4: Applicability



Session 5.4: Back-Fit RCM

DISCUSSION 5.4.5 MAINTENANCE APPLICABILITY

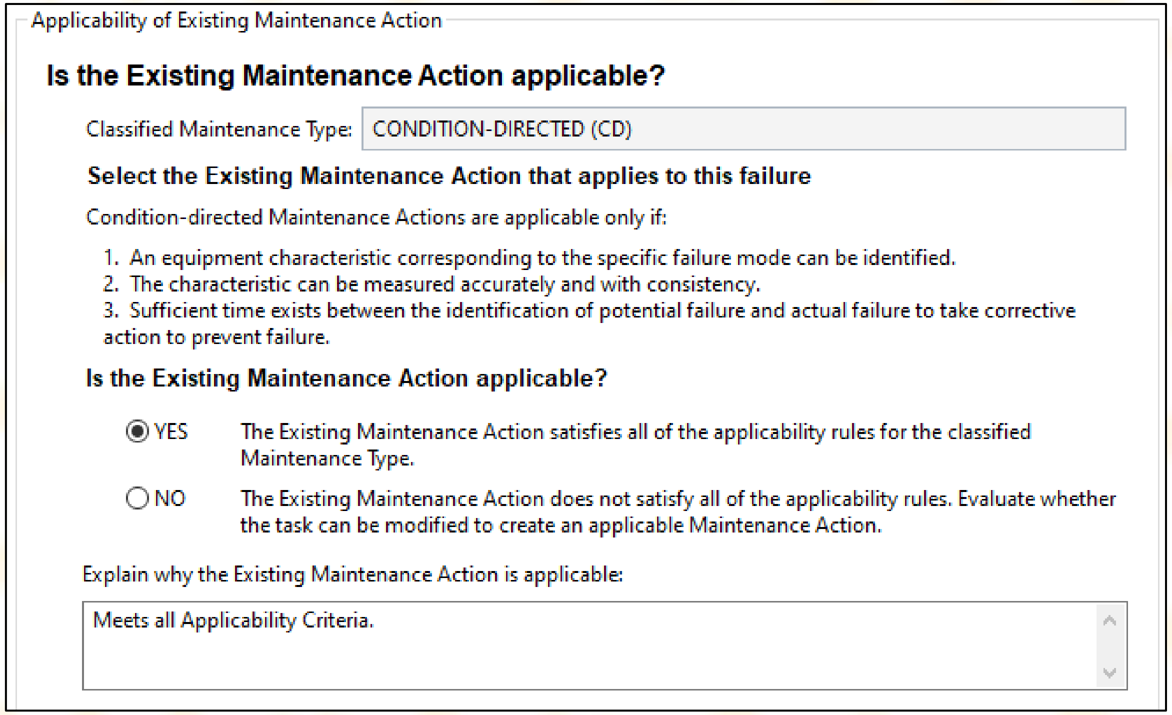
- The Maintenance Applicability page contains questions to determine:
  - Whether the existing maintenance action is applicable
  - Whether the existing maintenance action can be modified in order to meet applicability requirements

- The page displays existing maintenance actions associated to the component
  - Recommended action with a link is displayed at the bottom of page after the questions are answered
    - E.g. **Yes** to the applicability of existing maintenance actions will cause Back-Fit RCM to recommend continuing to describe the consequences of the failure mode occurring

Session 5.4: Back-Fit RCM

EXERCISE 5.4.5 MAINTENANCE APPLICABILITY

- Review applicability criteria
- Select: **Yes** (Existing Maintenance is applicable)
- Enter Narrative: **Meets Applicability Criteria.**
- Select link: Go to step 5: Failure Consequences


Applicability of Existing Maintenance Action

Is the Existing Maintenance Action applicable?

Classified Maintenance Type: CONDITION-DIRECTED (CD)

Select the Existing Maintenance Action that applies to this failure

Condition-directed Maintenance Actions are applicable only if:

1. An equipment characteristic corresponding to the specific failure mode can be identified.
2. The characteristic can be measured accurately and with consistency.
3. Sufficient time exists between the identification of potential failure and actual failure to take corrective action to prevent failure.

Is the Existing Maintenance Action applicable?

(●) YES — The Existing Maintenance Action satisfies all of the applicability rules for the classified Maintenance Type.

( ) NO — The Existing Maintenance Action does not satisfy all of the applicability rules. Evaluate whether the task can be modified to create an applicable Maintenance Action.

Explain why the Existing Maintenance Action is applicable:

Meets all Applicability Criteria.

Session 5.4: Back-Fit RCM

Discussion 5.4.6 Failure Consequences

- The Failure Consequences page aims to classify the nature of the selected failure mode into the following categories:
  - Safety/Environmental
  - Operational Performance
  - Others

- A recommended action with a link is displayed at the bottom of the page after a failure consequence type is selected
  - E.g. Selecting Operational Performance as a failure consequence of blockage of the primary fuel filter due to silting will cause Back-Fit RCM to recommend continuing to describe the effectiveness of the existing maintenance

Session 5.4: Back-Fit RCM

Exercise 5.4.6 Failure Consequences

- Select: **Operational Performance**
- Narrative: **Cavitation corrosion in Fuel Tank will prevent fuel flow.**
- Select link: Go to step 6: Effectiveness

Determine whether the consequence of the failure being evaluated has a detrimental impact on safety of personnel, violates federal or state laws, or impacts the ability of the ship to perform its mission.

Maintainable Item MTTF (hrs): 2038.04

Time span (hrs): 8766.00

Failure Consequences

NAME	CONSEQUENCE
○ SAFETY / ENVIRONMENTAL (LAW)	The consequences of the failure has a detrimental impact on safety of personnel or violates federal or state laws.
◉ OPERATIONAL PERFORMANCE	The consequences of the failure has a detrimental impact on the performance of the mission or mission objectives.
○ ALL OTHERS	The failure has consequences which are neither Safety/Environment(Law) or Operational in nature.

Failure Consequence Narrative:

Cavitation corrosion in Fuel Tank will prevent fuel flow.

Go to step 6: Effectiveness

PHM Technology

Session 5.4: Back-Fit RCM

Discussion 5.4.7 Maintenance Effectiveness

- The page displays existing maintenance actions associated to the component
  - A recommended action with a link is displayed at the bottom of the page after the questions have been answered
  - E.g. If the risk of failure is not reduced to an acceptable level (**No**), leads to the next question activating. A **Yes** Response to whether the existing maintenance action can be improved will show a link to the final page

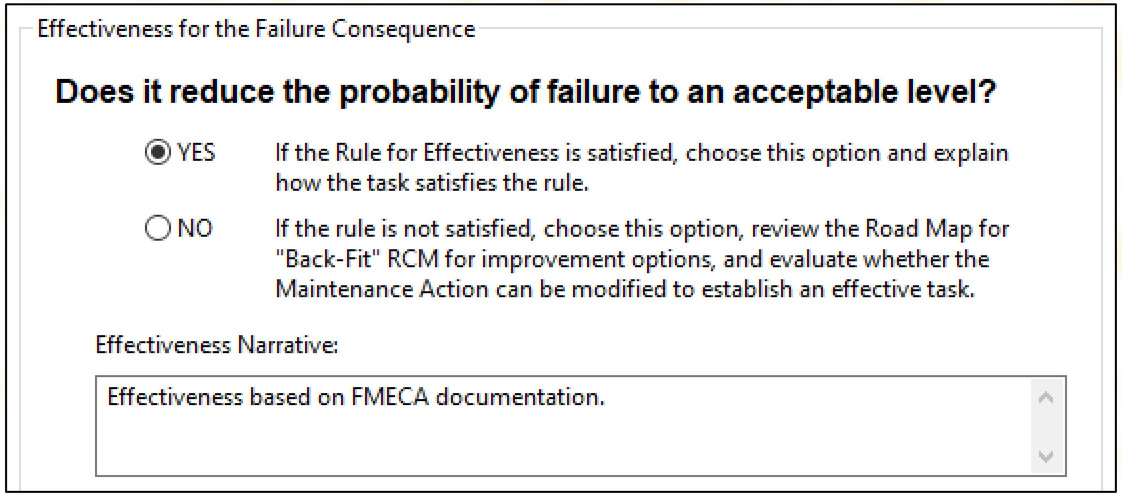
- The Maintenance Effectiveness page contains questions to determine:
  - Whether the existing maintenance reduce the risk of failure to an acceptable level (Probability of Failure × Severity of Failure)
  - Whether the existing maintenance action can be improved to demonstrate its effectiveness

Session 5.4: Back-Fit RCM

EXERCISE 5.4.7 MAINTENANCE EFFECTIVENESS

To assess the maintenance effectiveness:

- Review Effectiveness criteria – Does it reduce the probability of failure to an acceptable level?
- Select: **Yes** (Existing Maintenance is Effective)
- Enter Narrative: **Effectiveness based on FMECA documentation.**
- Select [Go to step 7: Improve Task]



PHM Technology

Session 5.4: Back-Fit RCM

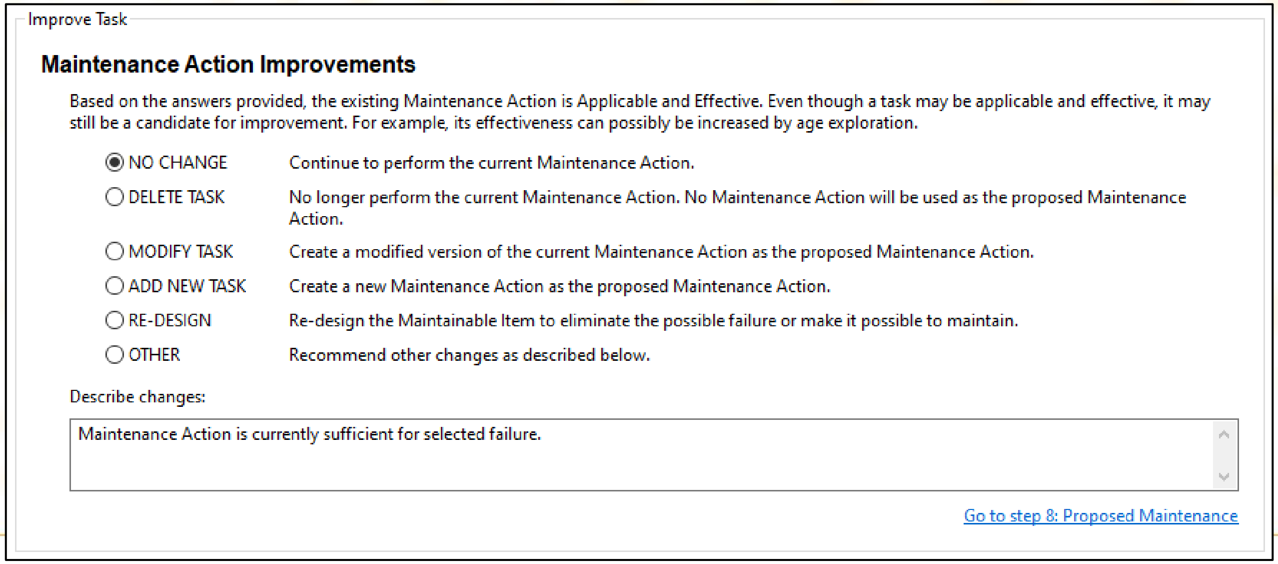
<u>DISCUSSION 5.4.8 IMPROVE TASK</u>

- The Improve Task page allows the user to decide whether the current maintenance task can be improved or to override the recommendations put forward e.g. modify the existing maintenance task
    - A narrative box is provided to enable the user to explain the motive behind the decision
    - A link is displayed at the bottom of the page after a decision has been selected

Exercise 5.4.8 Improve Task

To select the Maintenance Action improvement:

- Review list of Maintenance Action Improvements
- Select: **No Change** (Existing Maintenance is Effective)
- Enter Narrative: **Maintenance Action is currently sufficient for selected failure.**
- Select Go to step 8: Proposed Maintenance



Session 5.4: Back-Fit RCM

Discussion 5.4.9 Proposed Maintenance

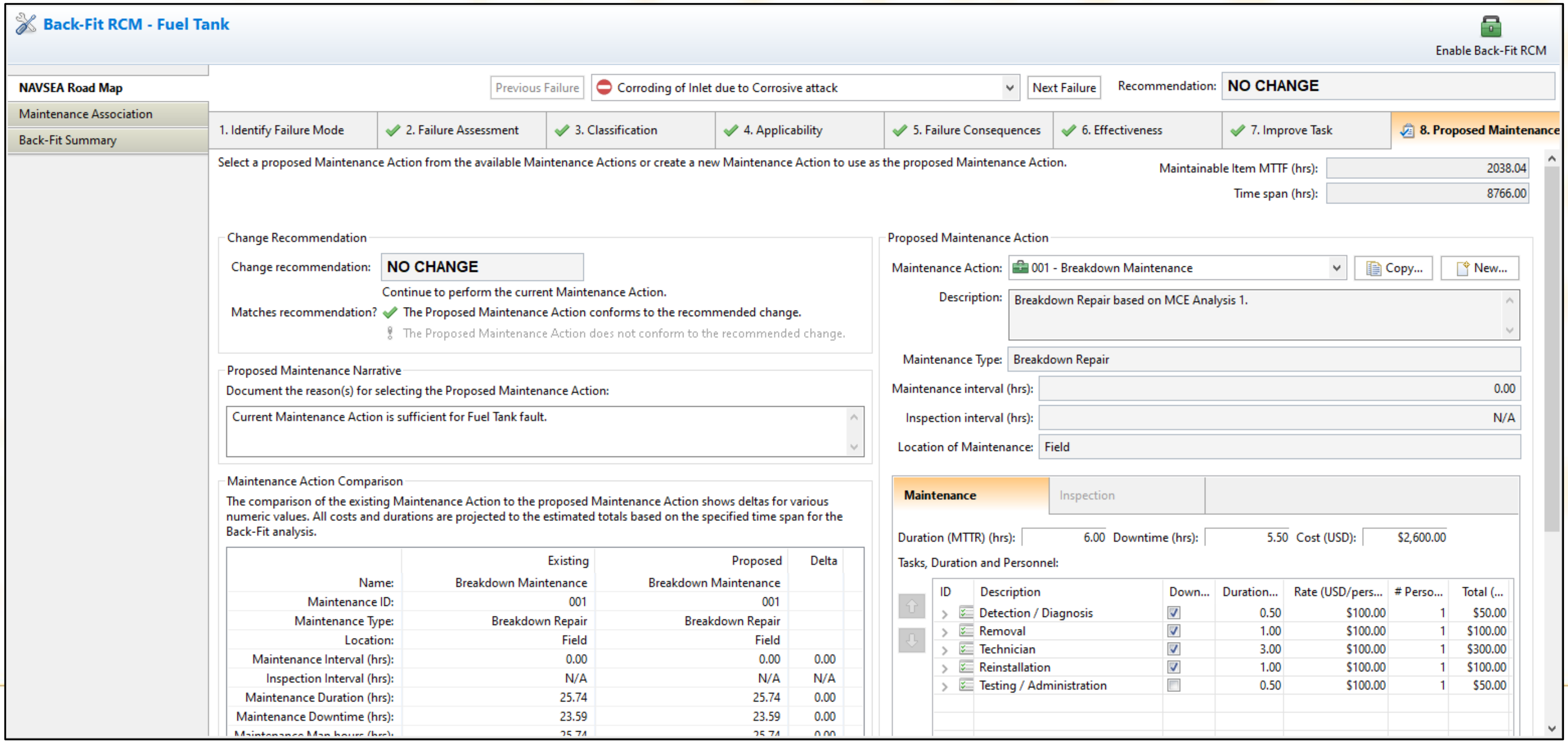
- The page displays a section to create a proposed maintenance action
- The Maintenance comparison table shows the differences between **current maintenance** and **proposed maintenance** if differences are present
- The Proposed Maintenance page shows the recommended action based on the answers selected in previous pages which can include the following:
    - No Change
    - Modify task
    - Delete task
    - Add New task
    - Re-design

Session 5.4: Back-Fit RCM

<u>EXERCISE 5.4.9 PROPOSED MAINTENANCE</u>

To justify the proposed maintenance task:

➢ Enter Proposed Maintenance Narrative: **Current Maintenance Action is sufficient for Fuel Tank fault.**



Session 5.4: Back-Fit RCM

DISCUSSION 5.4.10 MAINTENANCE ASSOCIATION

- The Maintenance Association page summarises:
  - Faults or failure modes that have been analysed
  - Current and proposed maintenance actions
  - Comparison between the two maintenance actions if applicable

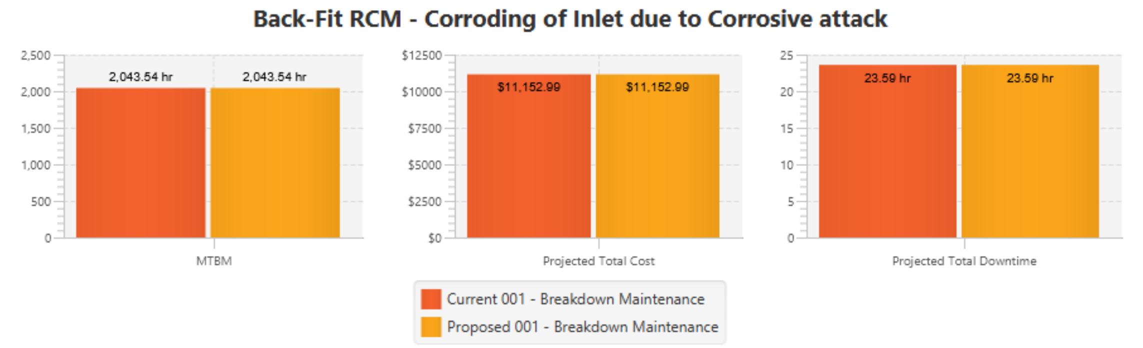
- The page also displays in a graph format:
  - Meantime between Maintenance (MTBM)
  - Cost
  - Downtime deltas

Maintenance Action Association

Assign the current and proposed Maintenance Actions to the Failure Paths. Multiple Failure Paths can be assigned the same Maintenance Action using the context menu options.

Failure Path	Current Action	Proposed Action	Duration delta	Downtime delta	Cost delta (USD)
Corroding of Inlet due to Corrosive attack	001 - Breakdown Maintenance	No change proposed	0.00	0.00	$0.00
Provide Liquid Static pressure					
Corroding of Lining due to Cavitation corrosion	No Maintenance Action	No Maintenance Action	0.00	0.00	$0.00
Corroding of Lining due to Corrosive attack	No Maintenance Action	No Maintenance Action	0.00	0.00	$0.00
Perforating of Inlet due to Corrosive attack	No Maintenance Action	No Maintenance Action	0.00	0.00	$0.00
Perforating of Lining due to Corrosive attack	No Maintenance Action	No Maintenance Action	0.00	0.00	$0.00
Pitting of Inlet due to Corrosive attack	No Maintenance Action	No Maintenance Action	0.00	0.00	$0.00
Pitting of Lining due to Cavitation corrosion	No Maintenance Action	No Maintenance Action	0.00	0.00	$0.00
Pitting of Lining due to Corrosive attack	No Maintenance Action	No Maintenance Action	0.00	0.00	$0.00

Maintenance Action Assessment Summary



Session 5.4: Back-Fit RCM

Discussion 5.4.11 Back-Fit RCM Report

The Back-Fit RCM Report summarises the Back-Fit RCM analysis into the following sections:

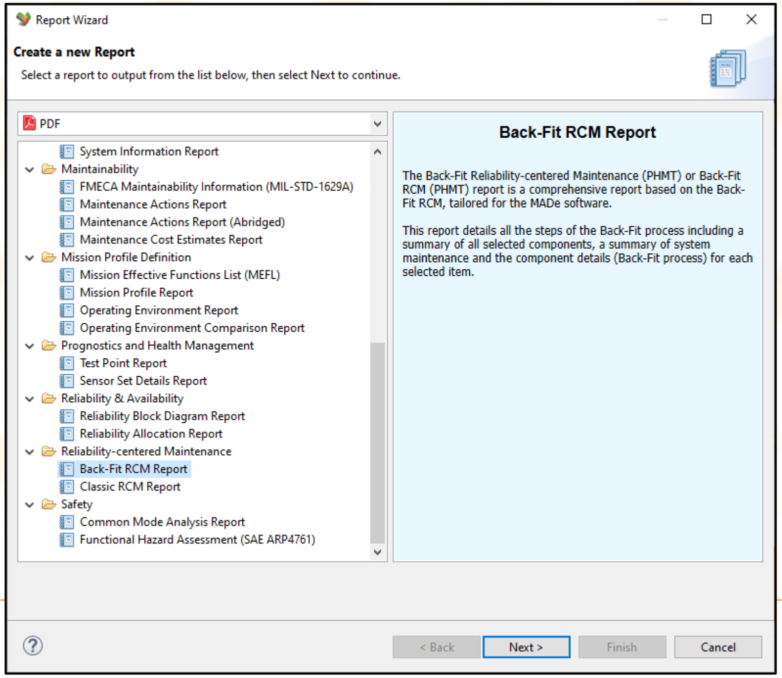
- **Component Summary**: Shows a summary of changes in MTTF, durations and costs.
- **Maintenance Action Summary**: Compares existing maintenance to proposed maintenance and the duration and cost differences between the two.
- **Component Details**:
  - Specific breakdown of each failure path in terms of frequency, durations and costs.
  - A summary of responses to all NAVSEA questions answered
  - Displays the maintenance action comparison table
  - Displays the current and proposed maintenance action details e.g. tasks, personnel, costs, durations etc.

Session 5.4: Back-Fit RCM

EXERCISE 5.4.11 BACK-FIT RCM REPORT

To generate a Back-Fit RCM Report:

- Select **Reports → Report Wizard** from the main menu
- Select **Back-Fit RCM Report**
- Select Next > then select the check box for maintainable items to include in the report
- Select Finish to generate the Back-Fit RCM report



Session 5.4: Back-Fit RCM

Session 5.4 Summary

- ✓ 5.4.1: Back-Fit RCM Background
- ✓ 5.4.2: Back-Fit RCM Editor
- ✓ 5.4.2: NAVSEA Road MAP: Identify Failure Modes
- ✓ 5.4.3: Failure Assessment
- ✓ 5.4.4: Maintenance Classification
- ✓ 5.4.5: Maintenance Applicability
- ✓ 5.4.6: Failure Consequences
- ✓ 5.4.7: Maintenance Effectiveness
- ✓ 5.4.8: Improve Task
- ✓ 5.4.9: Proposed Maintenance
- ✓ 5.4.10: Maintenance Association
- ✓ 5.4.11: Back-Fit RCM Report

Session 5: Maintainability Analyses

Session 5 Summary

- ✓ 5.1: Maintenance Cost Estimates analysis
- ✓ 5.2: Maintenance Actions
- ✓ 5.3: Reliability Centered Maintenance (Classic)
- ✓ 5.4: Reliability Centered Maintenance (Back-Fit RCM)

Session 6: Prognostics & Health Management Analyses

Using the MADe Model to generate sensor analyses for Health-monitoring domains

PHM Technology

Session 6: PHM Analyses

Session 6 Outline

6.1: Sensor Library

6.2: Test Points

6.3: Automated Diagnostic Analysis

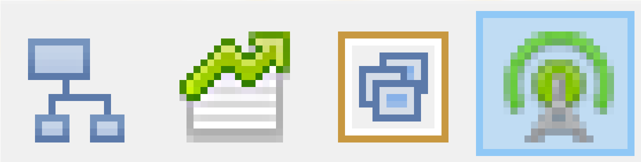
6.4: User-defined Diagnostic Analysis

6.5: Modeling for PHM and Additional Features

Session 6: PHM Analyses

Session 6 Discussion

- Session 6 will take place in the PHM Module
- Prognostics & Health Monitoring (PHM) Module is used for several purposes:
  - Understand coverage of functional flows in a system by sensors
  - Understand how built-In sensors on legacy systems monitor functional flows
  - Use algorithms to generate sensor sets to provide optimal coverage



Session 6.1: Sensor Library

SESSION 6.1 OUTLINE

6.1.1: Sensor Library

6.1.2: Access Sensor Library

6.1.3: Sensor Library Editor

6.1.4: Create a Sensor Library

6.1.5: Sensor Library Categories

6.1.6: Sensor Detail Sections

6.1.7: Creating Sensors

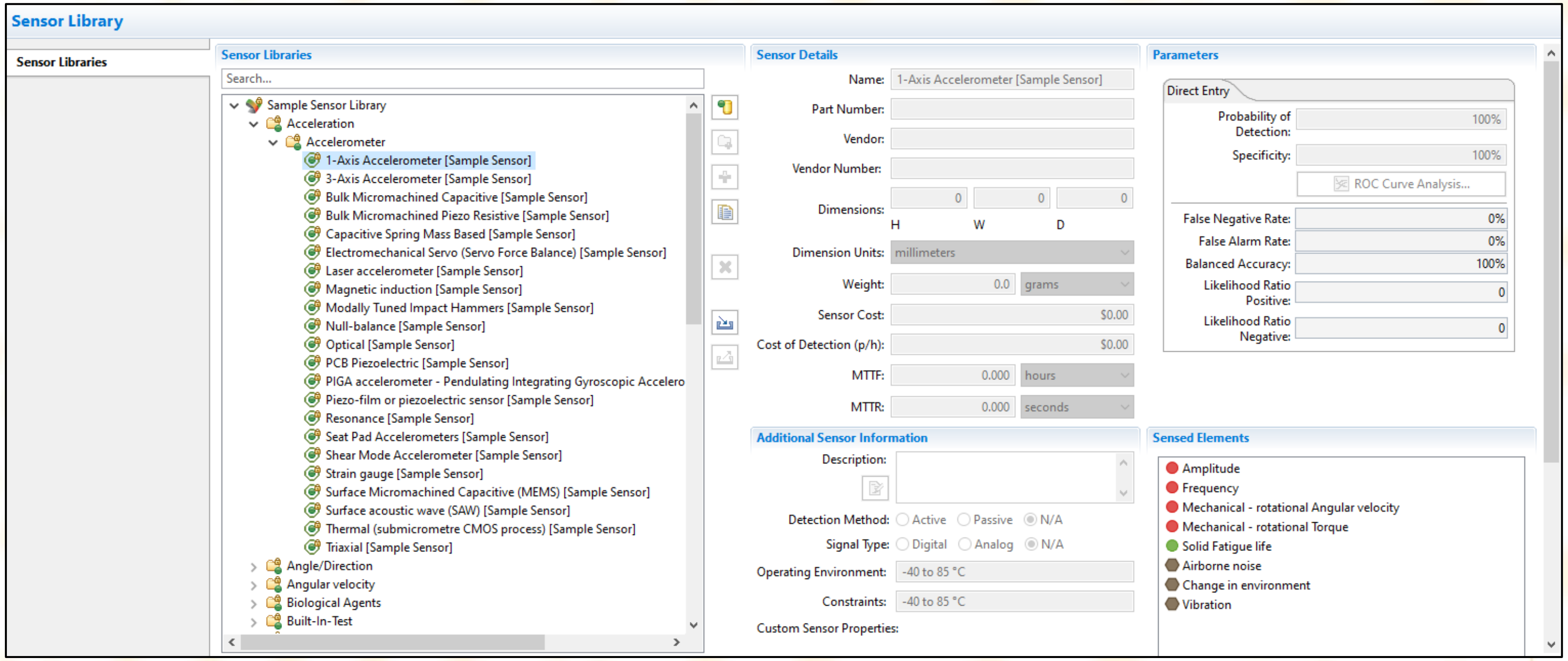
6.1.8: ROC Curves

6.1.9: Sensor Selection Optimizer

Session 6.1: Sensor Library

Discussion 6.1.1 Sensor Library

- Contains both sample sensors & user-defined sensors in multiple categories
- Sensors can be defined based on:
  - Physical attributes
  - Performance parameters
  - Operating environment
  - Flows types sensed
  - Any other custom properties

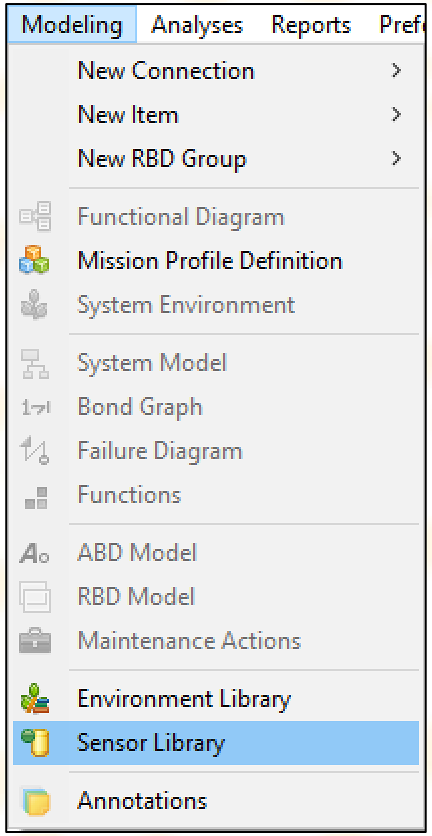


Session 6.1: Sensor Library

Exercise 6.1.2 Access Sensor Library

To access the Sensor Library:

- Select **Modeling → Sensor Library** from the main menu
- Alternatively, select the Sensor Library icon from the icon toolbar

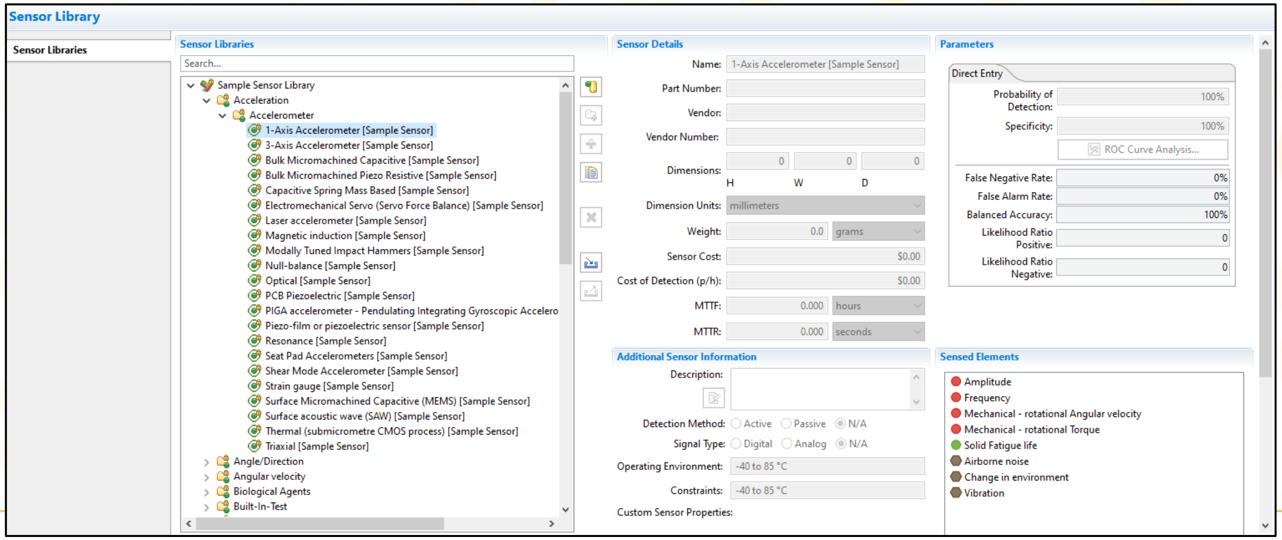


Session 6.1: Sensor Library

Discussion 6.1.3 Sensor Library Editor

Editor is divided into 5 sections:

- **Sensor Libraries table** shows a list of libraries, categories and sensors
- **Sensors Details** shows information on sensor ID, dimensions, costs, and reliability data
- **Sensed Elements** show the applicable flows for a sensor or sensor category
- **Parameters** show detailed sensor performance details such as POD, specificity, true/false rates, likelihood ratios etc.
- **Additional Sensor Information** shows additional sensor information such as environmental constraints and custom properties

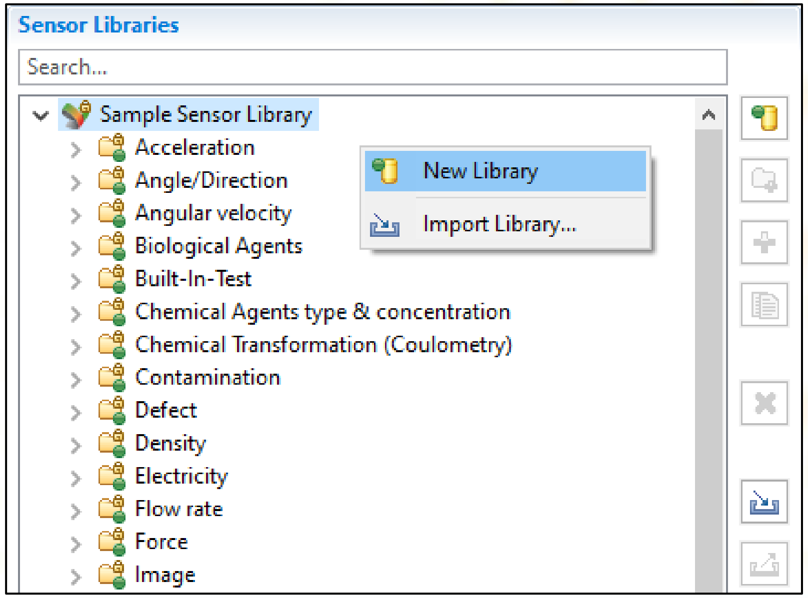


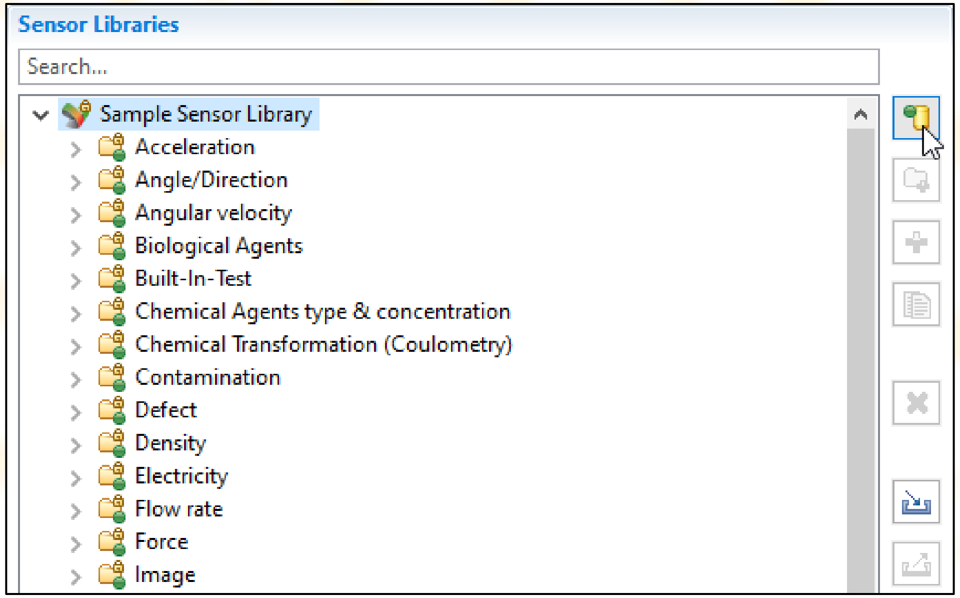
Session 6.1: Sensor Library

Exercise 6.1.4 Create a Sensor Library

To create a Sensor Library:

- Right-click on the open space within the **Sensor Libraries** table
- Select **New Library**
- Alternatively, select next to the Sensor Libraries section



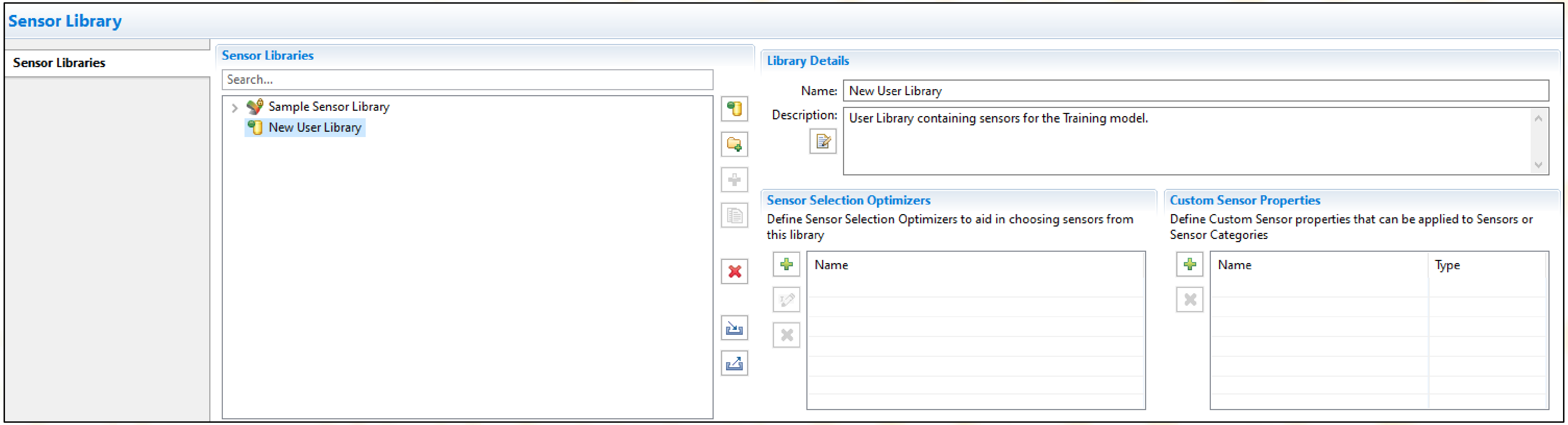


PHM Technology

Session 6.1: Sensor Library

EXERCISE 6.1.4 CREATE A SENSOR LIBRARY (CONTINUED)

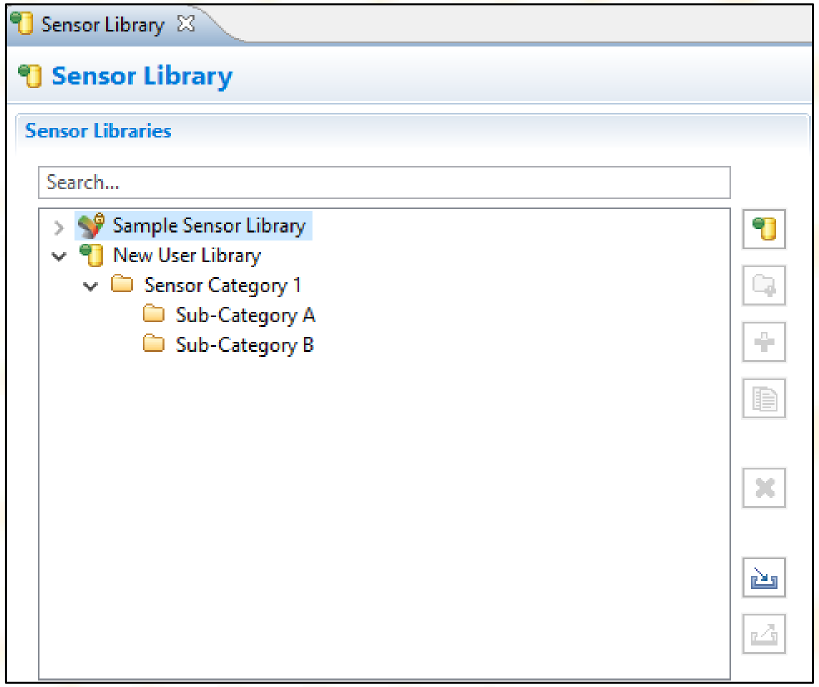
- Complete the Library Details with the following information:
  - Name: **New User Library**
  - Description: **User Library containing sensors for the Training model.**



Session 6.1: Sensor Library

DISCUSSION 6.1.5 SENSOR LIBRARY CATEGORIES

- User can create multiple levels of sensor categories for a user library
- Each library can contain specific sensed elements (flows, flow properties, symptoms)

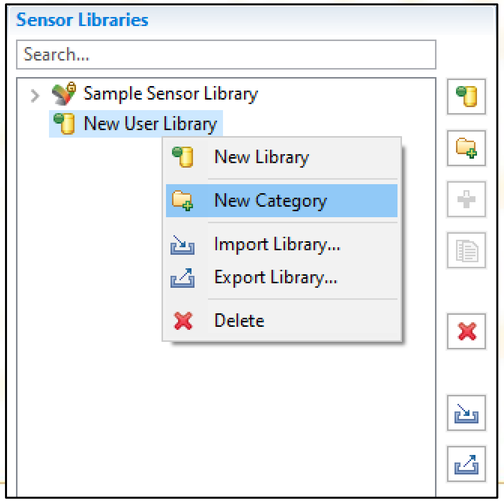


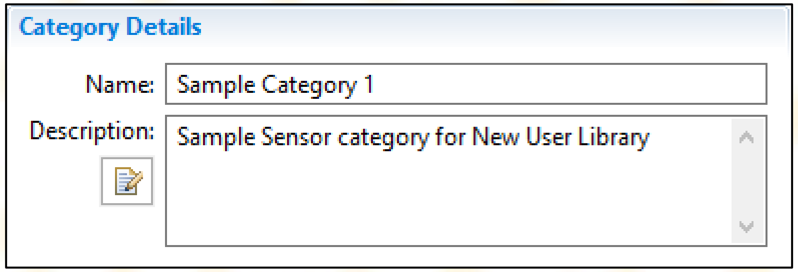
Session 6.1: Sensor Library

Exercise 6.1.5 Sensor Library Categories

To create new Sensor Library categories:

- Select **New User Library** from the sensor libraries list
- Select or right click on **New User Library** and select **New Category** from the menu
- Enter the following details for the Sensor category:
  - Name: **Sample Category 1**
  - Description: **Sample Sensor category for New User Library**





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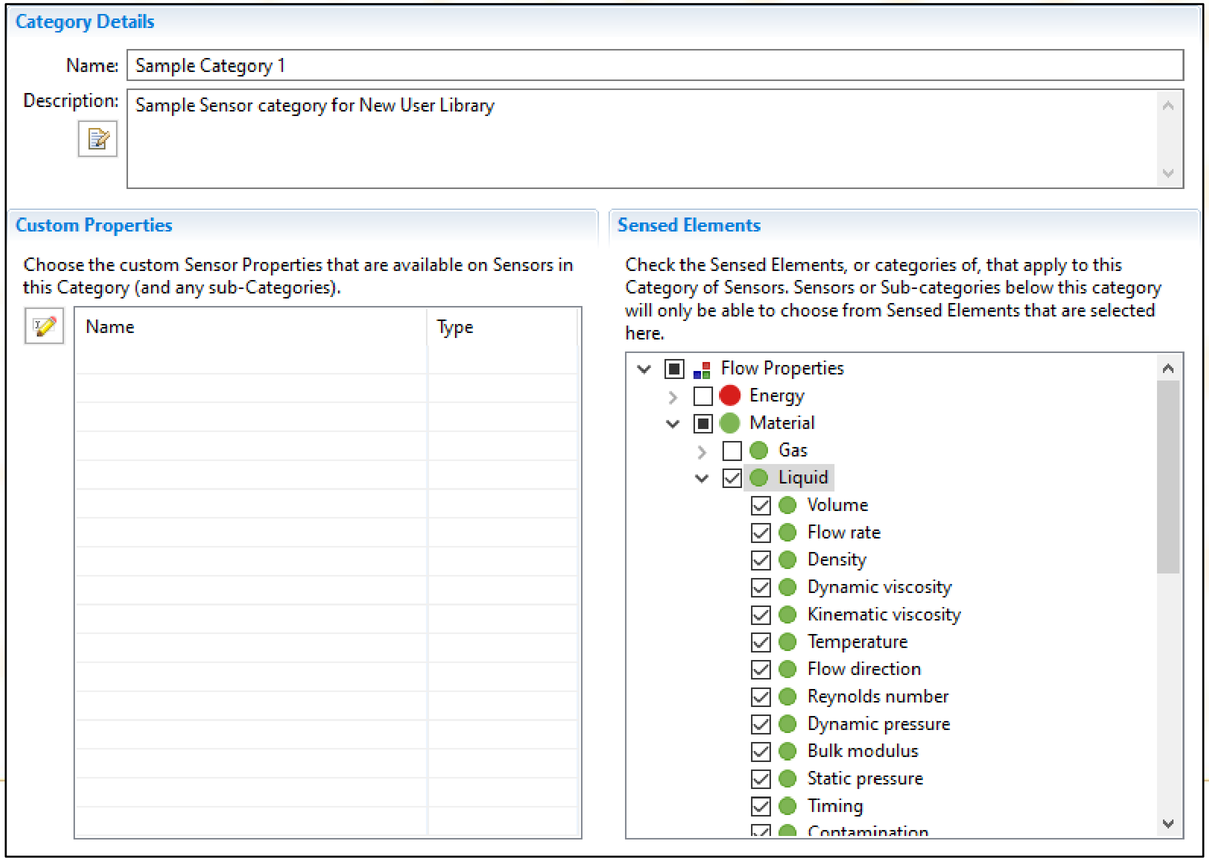
Session 6.1: Sensor Library

Exercise 6.1.5 Sensor Library Categories (Continued)

- Select Flow Properties to be considered for this category by selecting the check boxes
  - For this category we will select **Material – Liquid**



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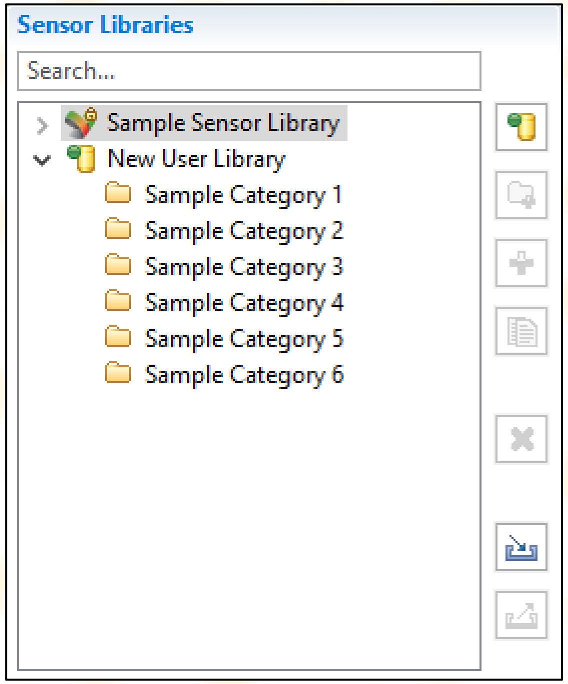
Session 6.1: Sensor Library

EXERCISE 6.1.5 SENSOR LIBRARY CATEGORIES (CONTINUED)

- Create 5 additional Sensor categories using the information from the table below

Name	Description	Sensed Flow
Sample Category 2	Category for rotational energy flow	Energy, Mechanical – rotational
Sample Category 3	Category for linear energy flow	Energy, Mechanical – linear
Sample Category 4	Category for gas flow	Material, Gas
Sample Category 5	Category for liquid flow	Material, Liquid
Sample Category 6	Category for continuous signal flow	Signal, Continuous



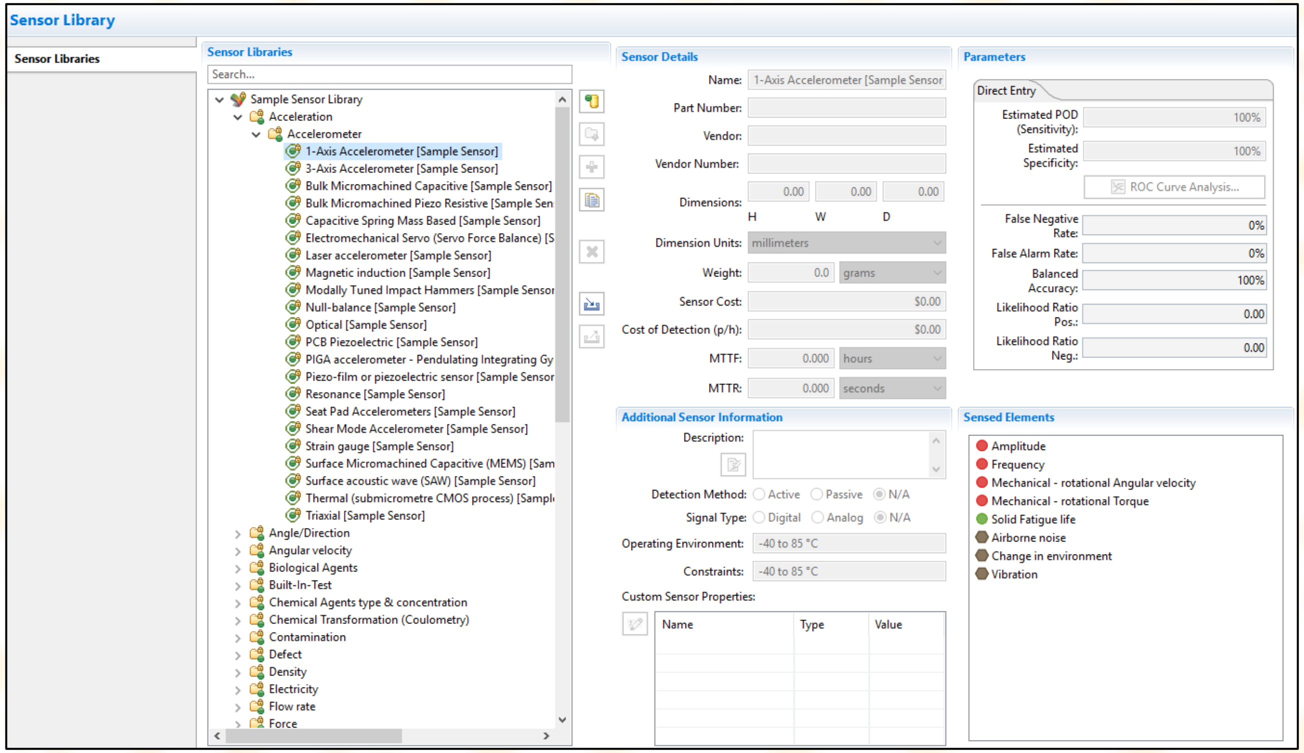
- Note: Sensors created in the categories will only be able to sense the selected sensed flows

Session 6.1: Sensor Library

Discussion 6.1.6 Sensor Detail Sections

For a created sensor there are 5 sections:

- **Sensor Libraries table** shows a list of libraries, categories and sensors
- **Sensors Details** shows information on sensor ID, dimensions, costs, and reliability data
- **Sensed Elements** show the applicable flows for a sensor or sensor category
- **Parameters** show detailed sensor performance details such as POD, specificity, true/false rates, likelihood ratios etc.
- **Other** shows additional sensor information such as environmental constraints

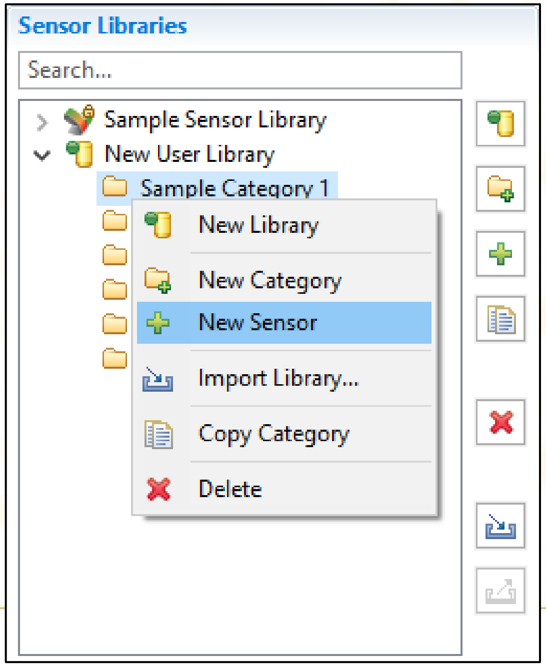


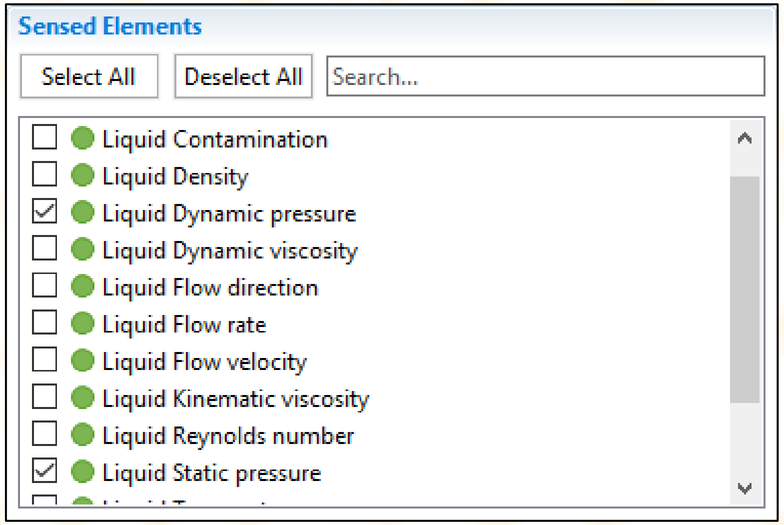
Session 6.1: Sensor Library

Exercise 6.1.7 Create a New Sensor

To create a new sensor in a category:

- Select **Sample Sensor Category 1**
- Select the sensor icon or right-click and select **New Sensor** from the menu
- Uncheck all Sensed Elements and select only **Liquid Dynamic pressure** and **Liquid Static pressure**

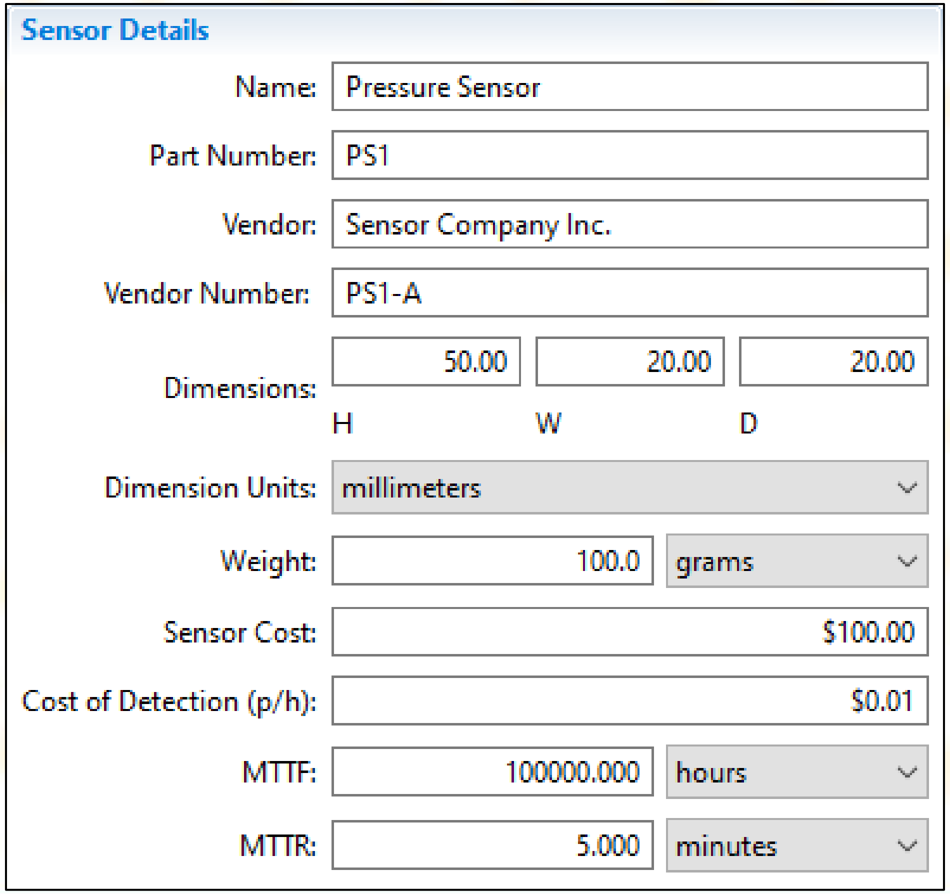




Session 6.1: Sensor Library

EXERCISE 6.1.7 CREATE A NEW SENSOR (CONTINUED)

- Enter the following sensor details:
  - Name: **Pressure Sensor**
  - Part Number: **PS1**
  - Vendor: **Sensor Company Inc.**
  - Vendor Number: **PS1-A**
  - Dimensions: **50.0 (H), 20.0 (W), 20.0 (D)**
  - Dimension Units: **Millimetres**
  - Weight: **100.0 grams**
  - Sensor Cost: **$100**
  - Cost of Detection: **$0.01 (per hour)**
  - MTTF: **100,000 hours**
  - Replacement time: **5 minutes**



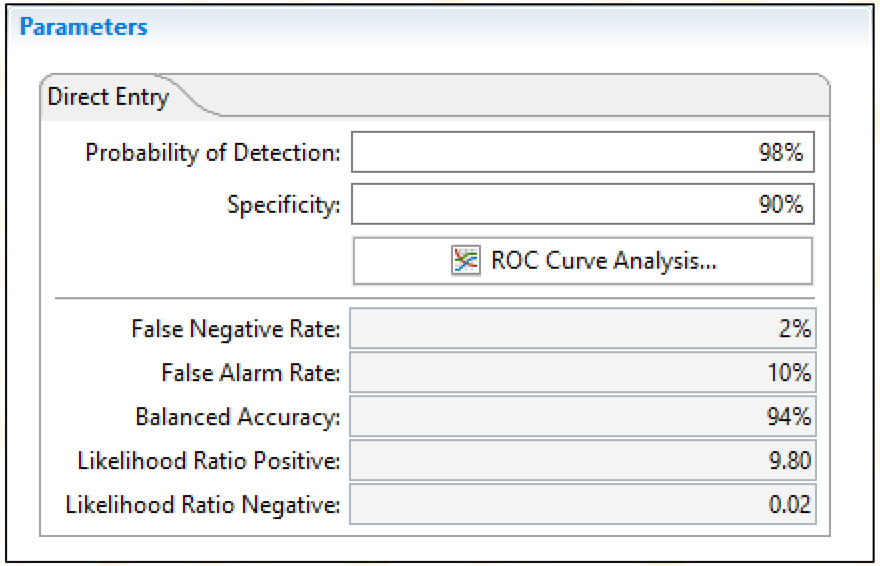
Session 6.1: Sensor Library

<u>EXERCISE 6.1.7 CREATE A NEW SENSOR (CONTINUED)</u>

- Enter the following sensor Parameters:
  - Estimated POD (Sensitivity): **98%**

  (Likelihood that sensor correctly detects failure condition)
  - Estimated Specificity: **90%**

  (Likelihood that sensor will not suffer a false alarm)
- Verify additional fields:
  - False Negative Rate: **2%**
  - False Alarm Rate: **10%**
  - Balanced Accuracy: **94%**
  - Likelihood Ratio Pos.: **9.80**
  - Likelihood Ratio Neg.: **0.02**



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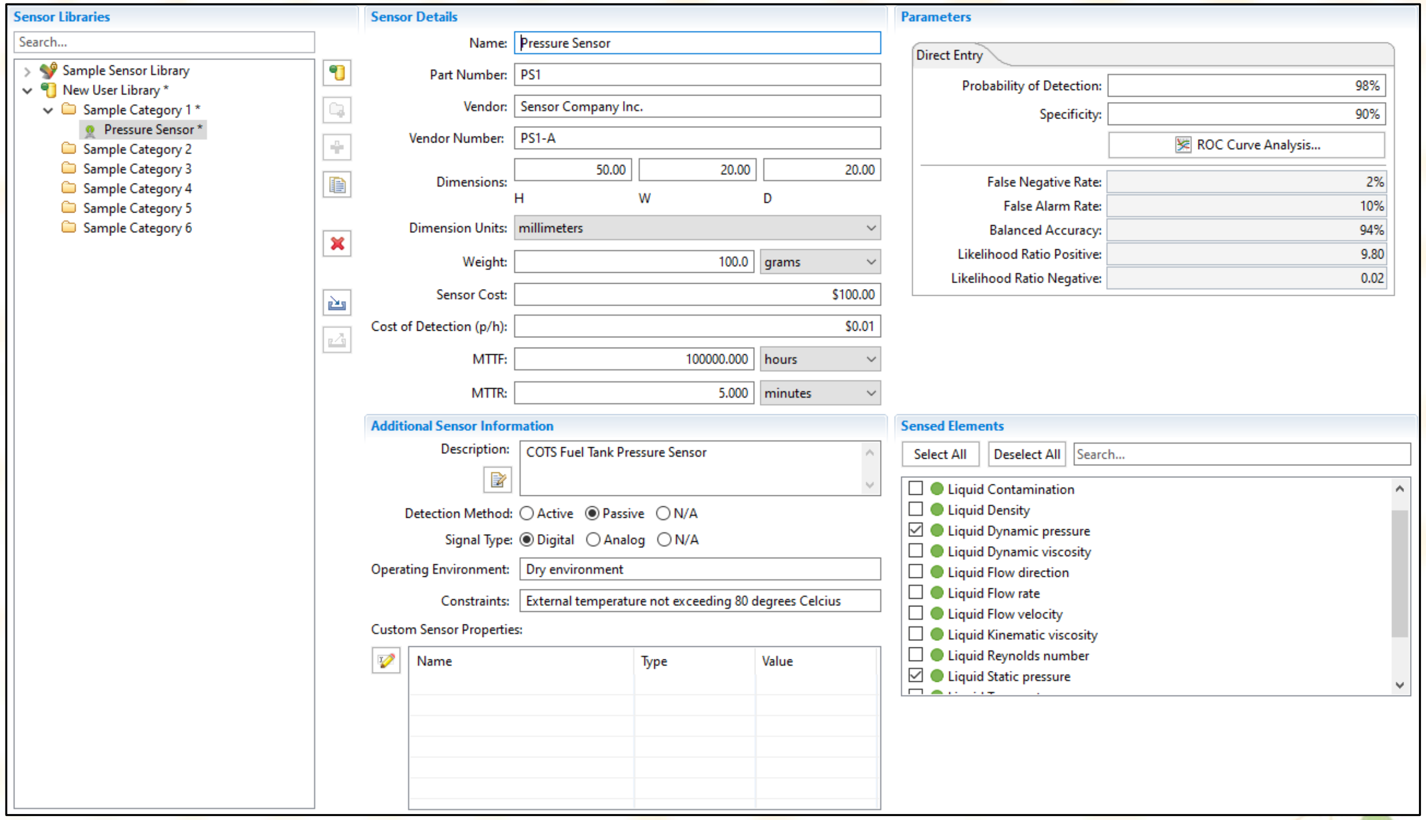
Session 6.1: Sensor Library

EXERCISE 6.1.7 CREATE A NEW SENSOR (CONTINUED)

- Enter the following into the Additional Sensor Information category:
  - Description: **COTS Fuel Tank Pressure Sensor**
  - Detection Method: **Passive**
  - Signal Type: **Digital**
  - Operating Environment: **Dry environment**
  - Constraints: **External temperature not exceeding 80 degrees Celsius**



Session 6.1: Sensor Library

Exercise 6.1.7 Create a new Sensor (continued)

- Create several more sensors with the following details

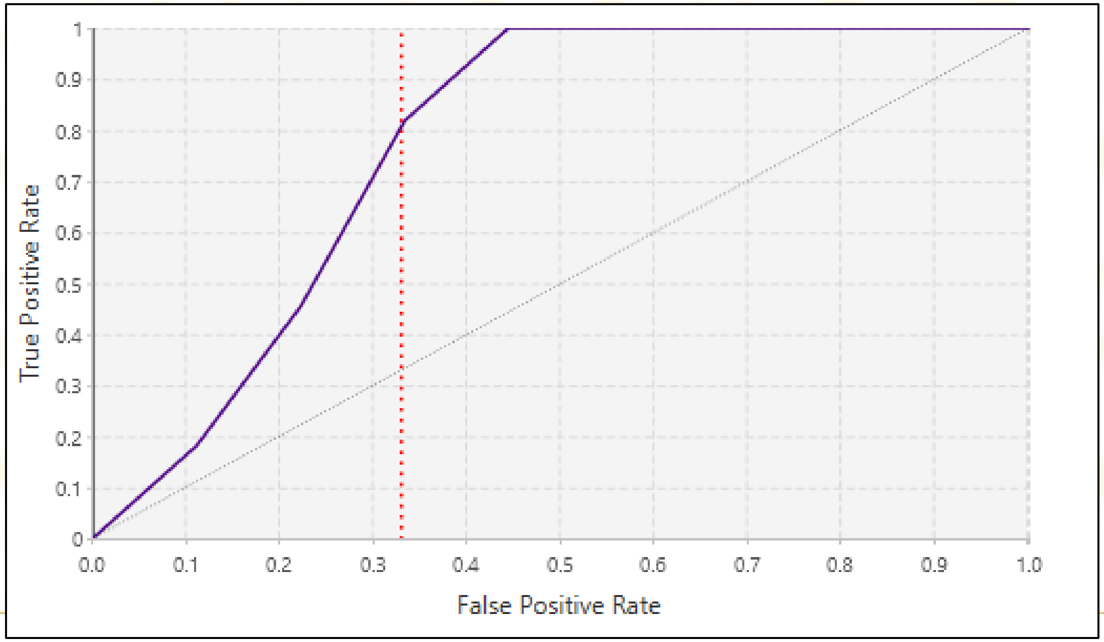
Category	Flow Property	Name	Dimensions	Units	Weight	Sensor Cost	Cost of Detection
Sample Category 2	Torque	Rotary Transformer	15, 10, 30	mm	10 g	3500	0.35
Sample Category 2	Angular Velocity	Angular Velocity Sensor 1	10, 10, 10	mm	60 g	6000	0.30
Sample Category 2	Angular Velocity	Angular Velocity Sensor 2	5, 15, 20	mm	120 g	2000	0.60
Sample Category 2	Angular Velocity	Angular Velocity Sensor 3	15, 15, 15	mm	75 g	3500	0.55
Sample Category 3	Linear Velocity	Optical Tracker and Velocimeter	30, 40, 10	mm	90 g	10000	0.30
Sample Category 4	Mass Flow Rate (Gas)	Tube Anemometer	4, 10, 8	mm	75 g	1200	2.00
Sample Category 5	Flow Rate (Liquid)	Orifice Plate	10, 20, 20	mm	300 g	3000	0.80
Sample Category 6	Continuous Amplitude	Amplitude Detector	5, 10, 15	mm	15 g	1500	0.10

Session 6.1: Sensor Library

Discussion 6.1.8 Receiver Operating Characteristic (ROC) Curves

Receiver Operating Characteristic (ROC) curves use sensor failure data to plot the relationship between True Positives and False Positives observed based on a sensor's test threshold. This aids in:

- Determining the POD and Specificity for a sensor
- Selecting the most appropriate threshold based on the above



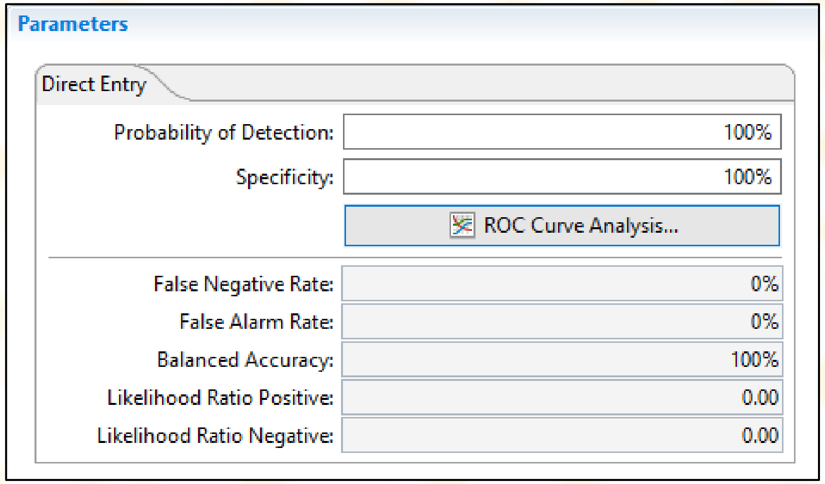
Session 6.1: Sensor Library

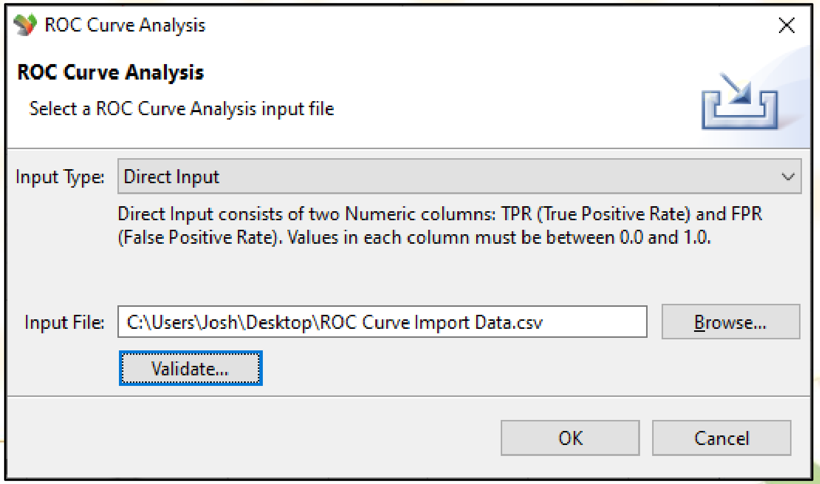
Exercise 6.1.8 Receiver Operating Characteristic (ROC) Curves

To import ROC setting:

- Download the spreadsheet attached to this slide
- Select the **Tube Anemometer** from **Sensor Category 4** and select ROC Curve Analysis... from the **Parameters** section
- In the new window click the + button
- Select Input Type as **Direct Input**
- Browse for the **ROC Curve Import Data.csv**
- To validate the .csv file, select Validate...
- Once validated, select OK

Microsoft Excel Worksheet

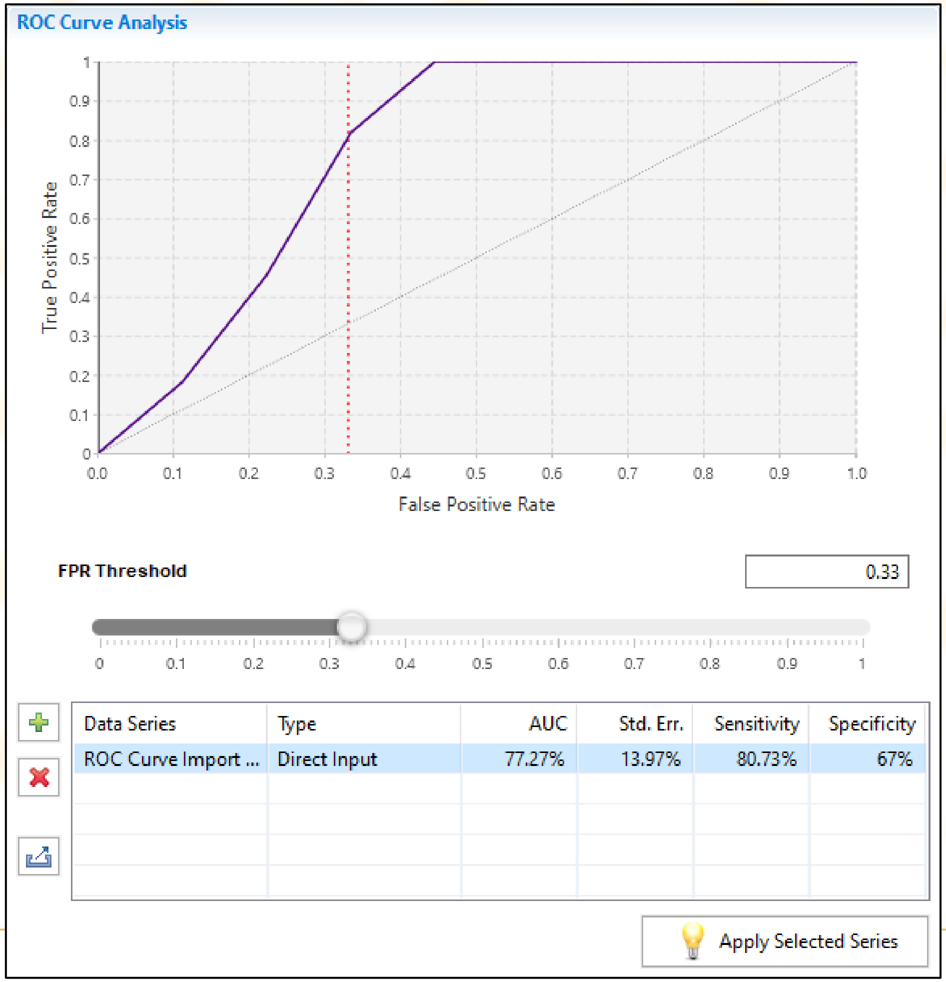




Session 6.1: Sensor Library

EXERCISE 6.1.8 RECEIVER OPERATING CHARACTERISTIC (ROC) CURVES (CONTINUED)

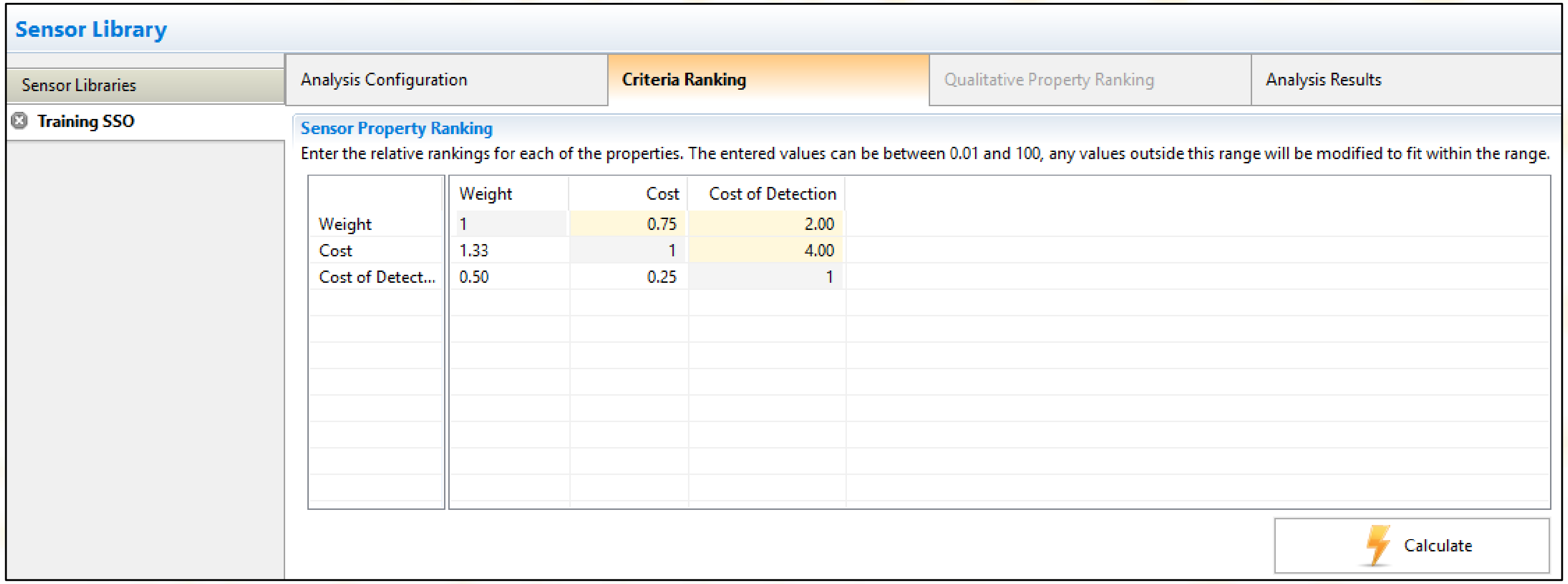
- ROC Curve will be graphed and allow the user to determine the FPR Threshold that will define the Sensitivity and Specificity of the sensor:
  - Input **0.33** as the threshold and check that the numbers match as pictured, then select Apply Selected Series



Session 6.1: Sensor Library

DISCUSSION 6.1.9 SENSOR SELECTION OPTIMIZER (SSO)

- To aid in the selection and allocation of a specific sensor from the sensor library to a location.
- This uses the Analytical Hierarchy Process (AHP) to compare otherwise disparate parameters (for example weight, cost, and MTTF)

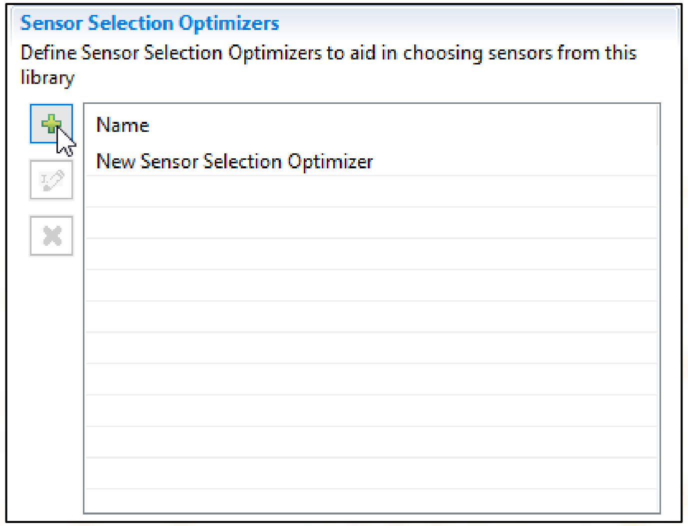


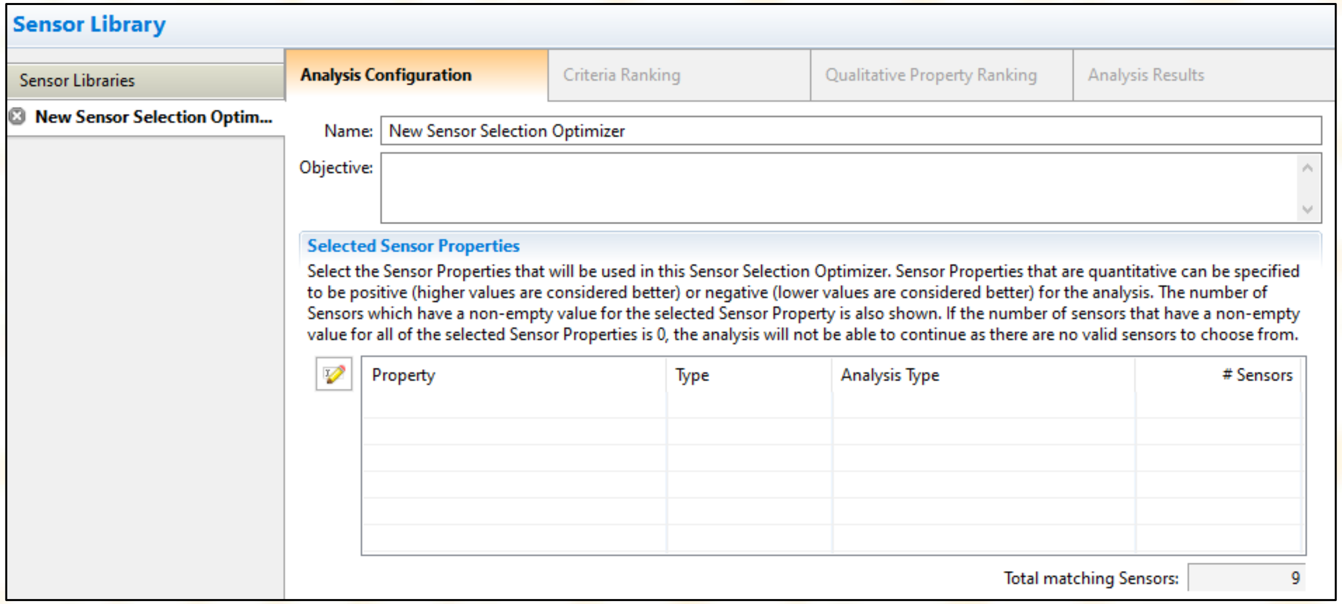
Session 6.1: Sensor Library

EXERCISE 6.1.9 SENSOR SELECTION OPTIMIZER (SSO)

To select the Sensor Selection Optimizer:

➢ Select the **New User Library** and select [+] under Sensor Selection Optimizers

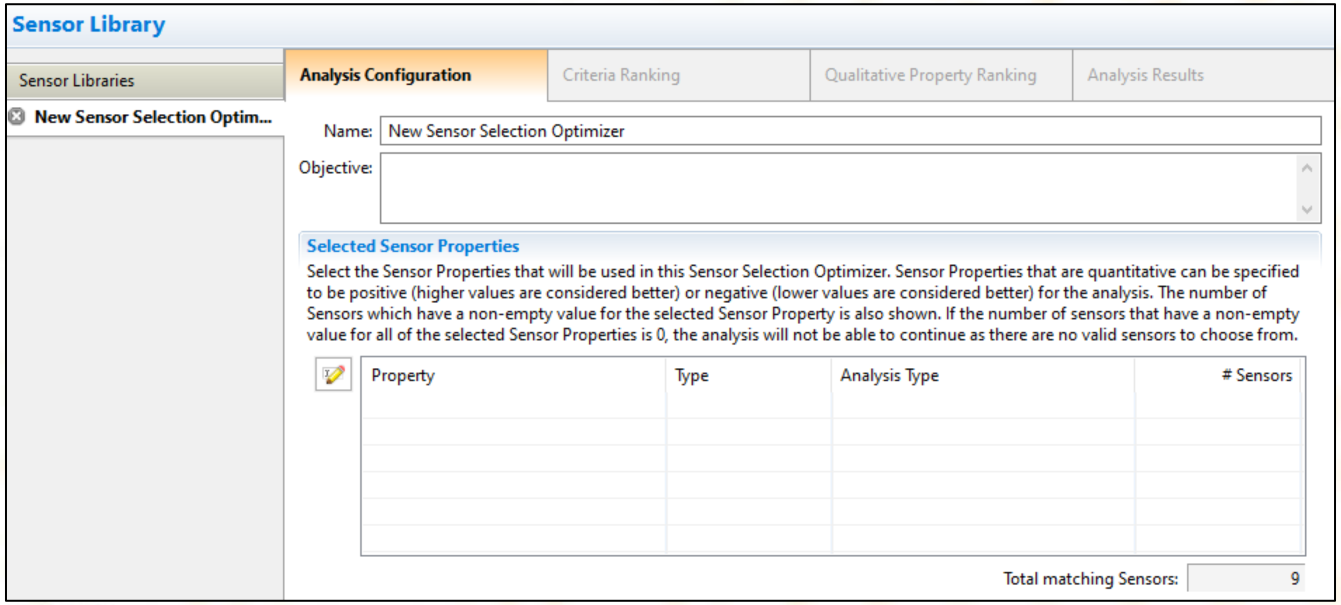


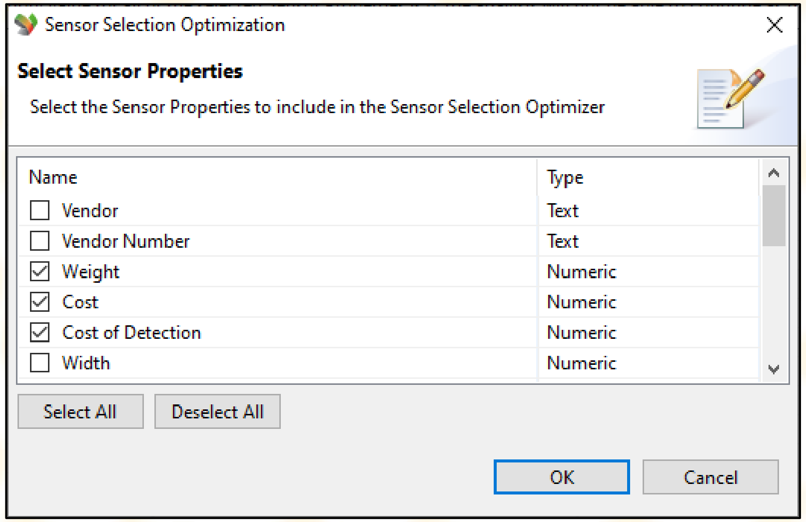


Session 6.1: Sensor Library

Exercise 6.1.9 Sensor Selection Optimizer (SSO) (Continued)

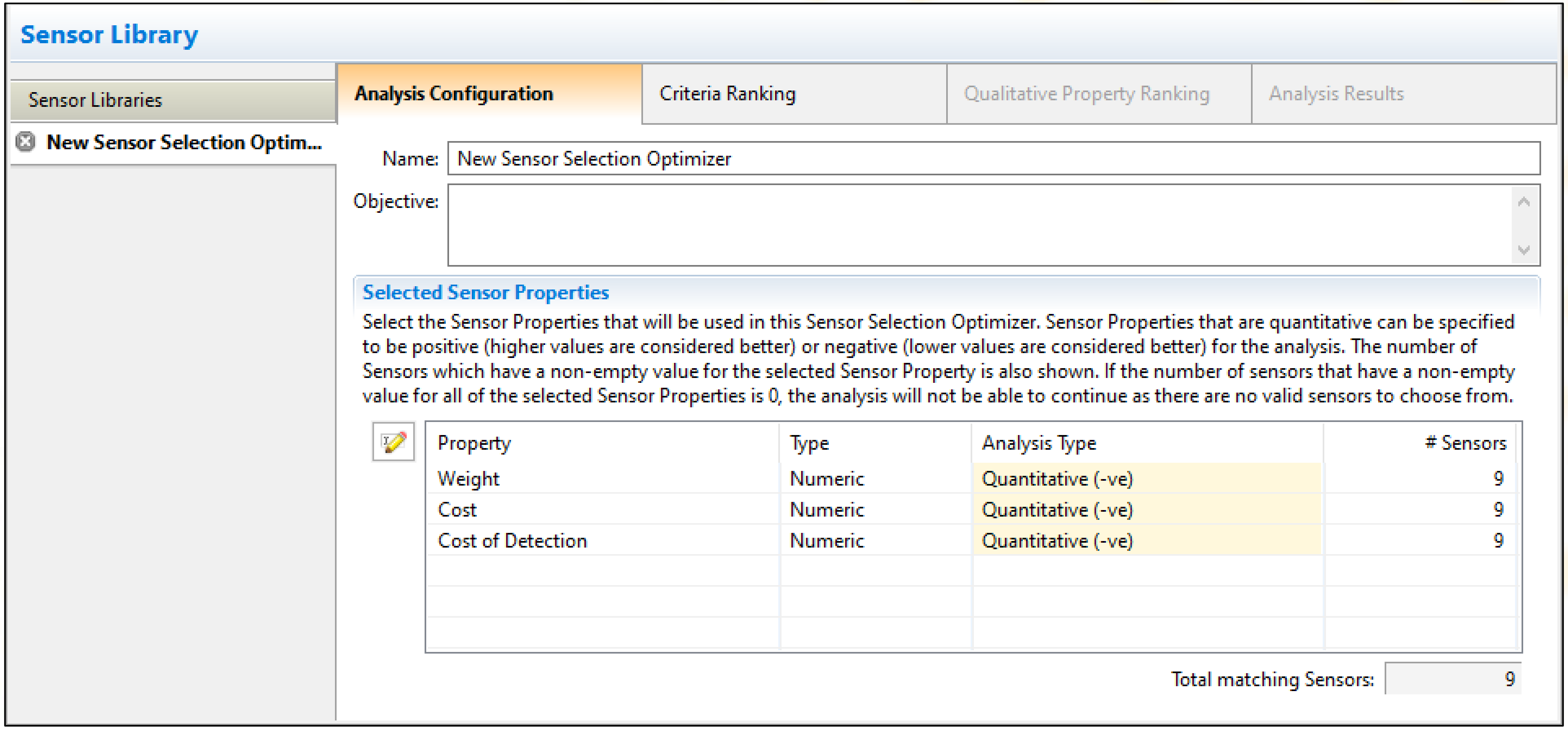
- Select the button and from the pop-up dialogue select the checkboxes for:
  - **Weight**
  - **Cost**
  - **Cost Of Detection**





Session 6.1: Sensor Library

Exercise 6.1.9 Sensor Selection Optimizer (SSO) (Continued)

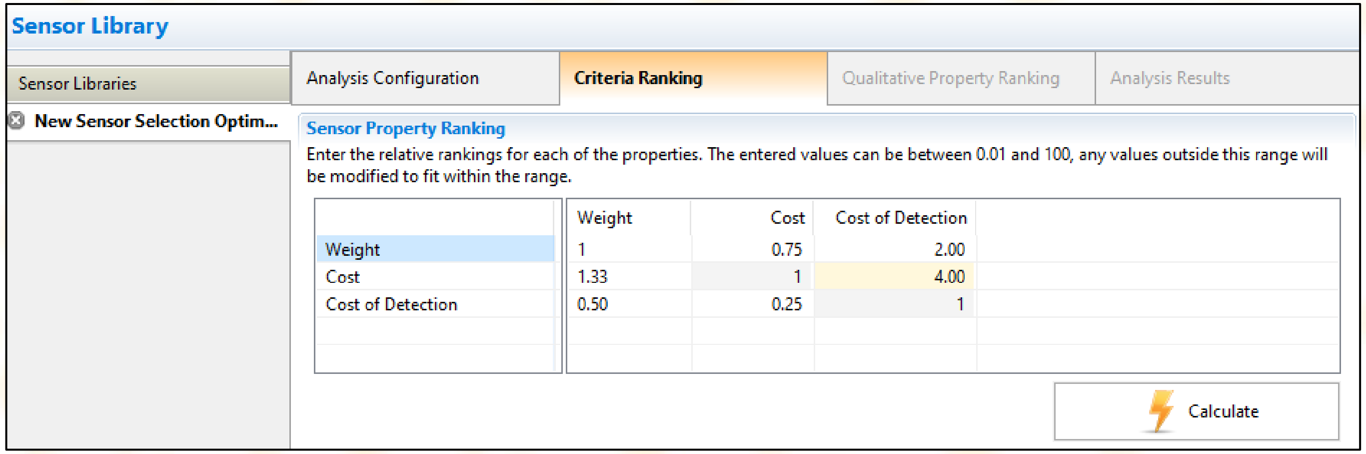


Session 6.1: Sensor Library

<u>Exercise 6.1.9 Sensor Selection Optimizer (SSO) (Continued)</u>

- Change the Name of the SSO to **Training SSO**
- Select the **Criteria Ranking** tab
- Enter the following values into the **Sensor Property Ranking** matrix
  - Note that only fields above and to the right of the principal diagonal require entry

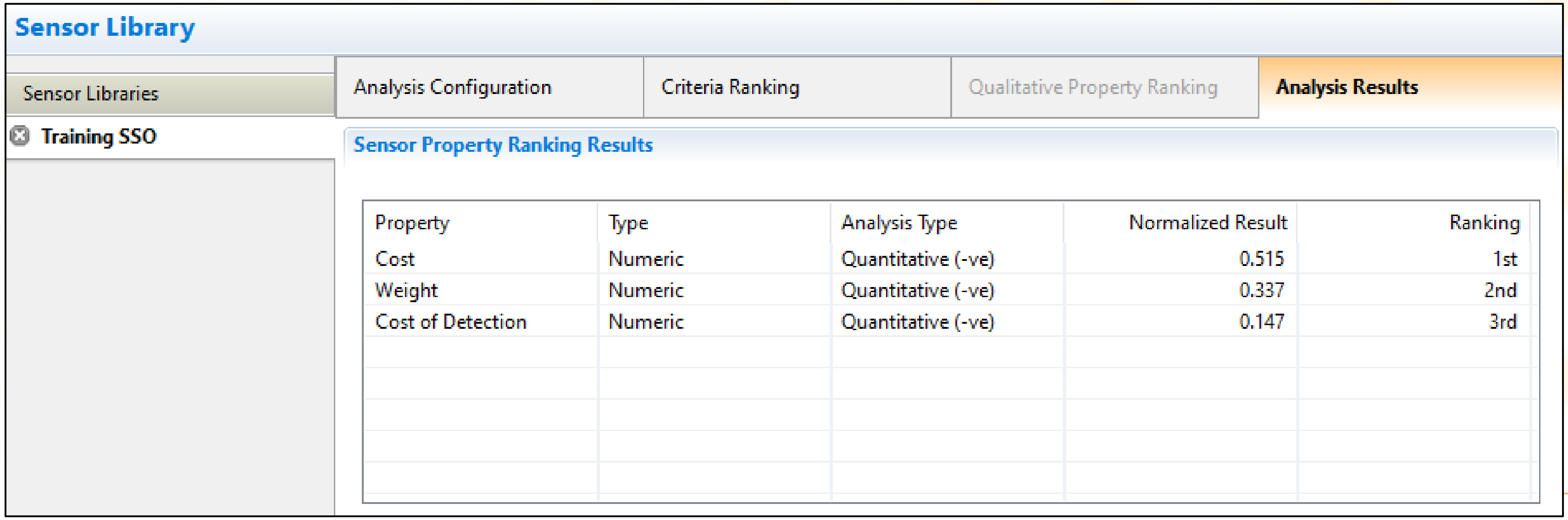
	Weight	Cost	Cost of Detection
Weight	1	0.75	2.00
Cost	1.33	1	4.00
Cost of Detection	0.5	0.25	1



Session 6.1: Sensor Library

EXERCISE 6.1.9 SENSOR SELECTION OPTIMIZER (SSO) (CONTINUED)

- Select the Calculate button and select the **Analysis Results** tab
- The results show that when selecting sensors the priority should be minimizing in the following order:
  - **Cost**
  - **Weight**
  - **Cost of Detection**
- The Normalized Result displays the weightings that will be used when automating the allocation of sensors



Property	Type	Analysis Type	Normalized Result	Ranking
Cost	Numeric	Quantitative (-ve)	0.515	1st
Weight	Numeric	Quantitative (-ve)	0.337	2nd
Cost of Detection	Numeric	Quantitative (-ve)	0.147	3rd

Session 6.1: Sensor Library

Session 6.1 Summary

- ✓ 6.1.1: Sensor Library
- ✓ 6.1.2: Access Sensor Library
- ✓ 6.1.3: Sensor Library Editor
- ✓ 6.1.4: Create a Sensor Library
- ✓ 6.1.5: Sensor Library Categories
- ✓ 6.1.6: Sensor Detail Sections
- ✓ 6.1.7: Creating Sensors
- ✓ 6.1.8: ROC Curves
- ✓ 6.1.9: SSO

Session 6.2: Test Points

Session 6.2 Outline

6.2.1: Test Points

6.2.2: Accessing a Test Point

6.2.3: Test Point Editor

6.2.4: Assigning Test Point Sensors

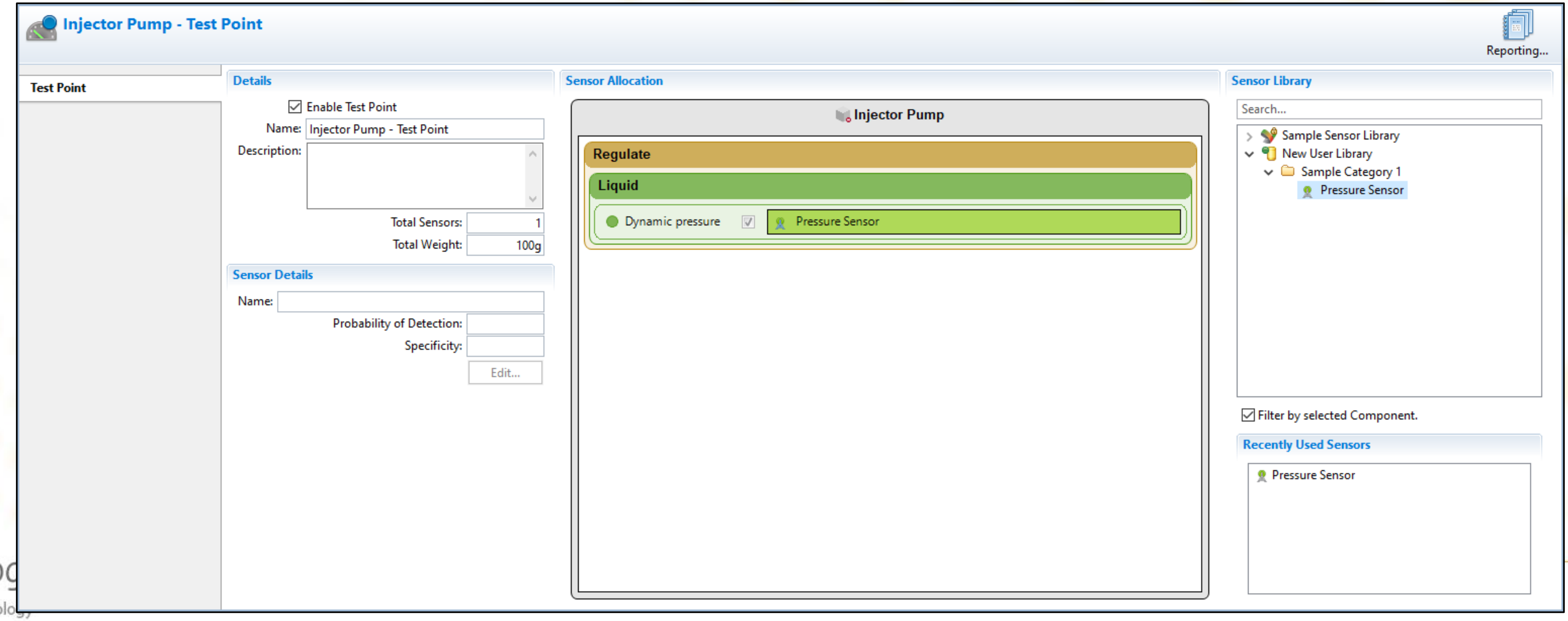
6.2.5: Allocate a Sensor Using the SSO

6.2.6: Test Point Report

Session 6.2: Test Points

Discussion 6.2.1 Test Points

- Shows Flow Property & Symptoms of an item
- Test Points are only applicable for subsystem & components
- Allows user to assign Test Point sensors considered in Legacy & Analysis Sensor Sets

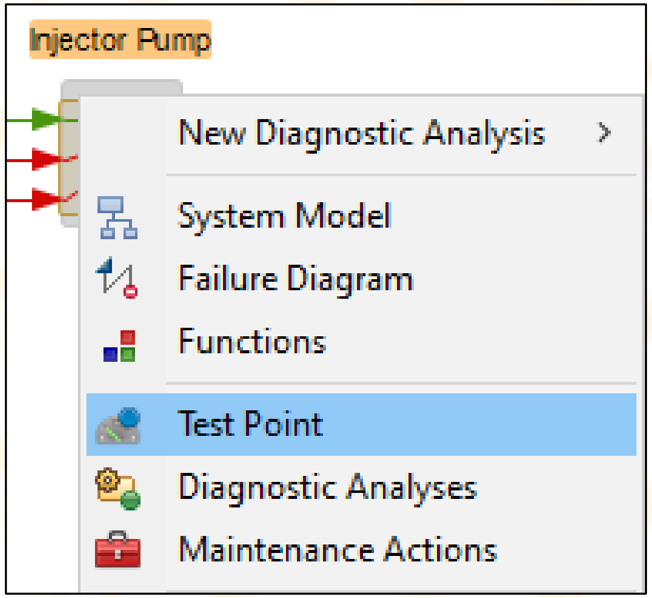


Session 6.2: Test Points

<u>Exercise 6.2.2 Accessing a Test Point</u>

To input a Test Point:

- Open the System Model of the **'Diesel Engine'**
- Right-click on the **'Injector Pump'** component
- Select **Test Point** from the menu
- Alternatively, right-click on the **'Injector Pump'** in the Project Explorer and select **Test Point** from the menu

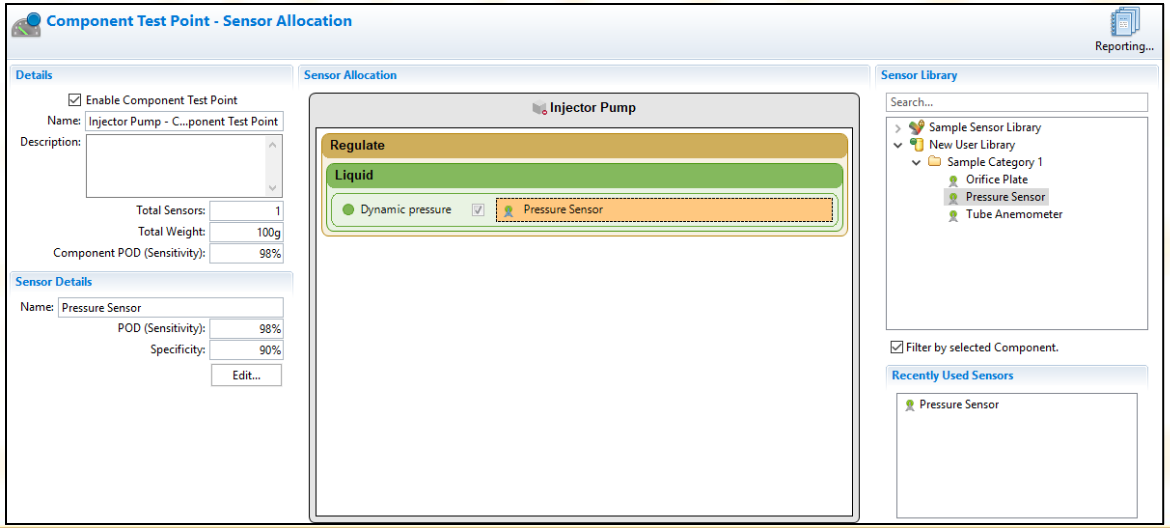


Session 6.2: Test Points

Discussion 6.2.3 Test Point Editor

The editor consists of 5 sections:

1. **Details** show the name and description of the test point, total sensors, weight and sensitivity
2. **Sensor Details** show the name, probability of detection (POD) and specificity of a selected sensor
3. **Sensor Allocation** is the main area displaying flow properties and assigned sensors
4. **Sensor Library** shows available libraries and sensors
5. **Recently Used Sensors** shows a list of the latest sensors allocated from all component test points

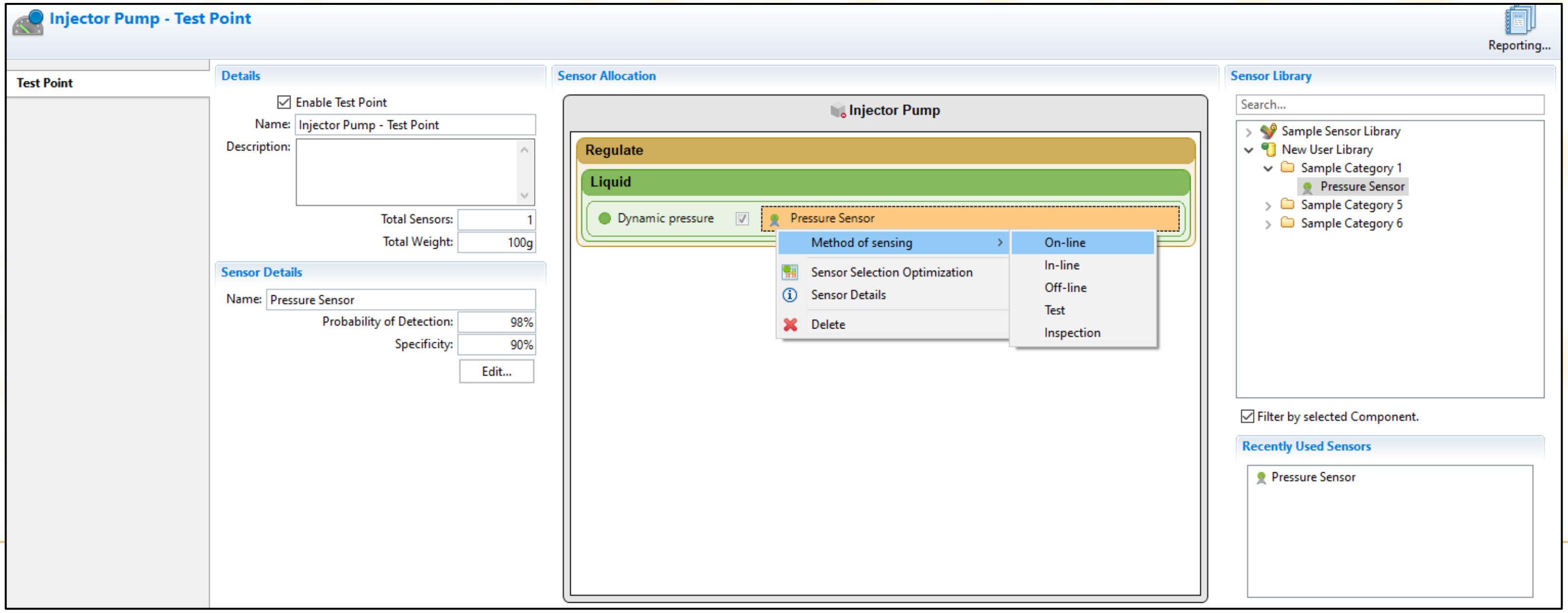


Session 6.2: Test Points

EXERCISE 6.2.4 ASSIGNING TEST POINT SENSORS

To assign a Test Point:

- In the **'Injector Pump'** Test Point editor, select the **Enable Test Point** check box under the **Details** section
- Locate **Pressure Sensor** in **New User Library**
- Select and drag the Pressure Sensor and assign it to the **Liquid Dynamic Pressure** output
- Right-click the sensor and select **Method of Sensing → On-line**

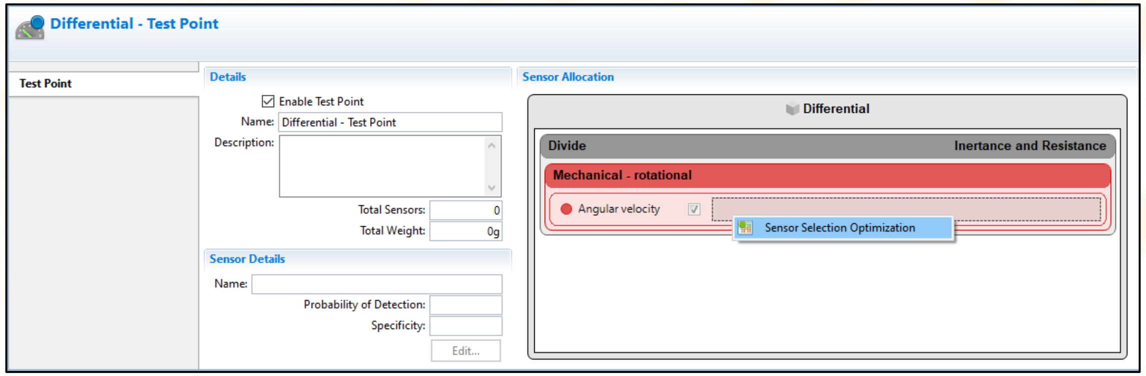


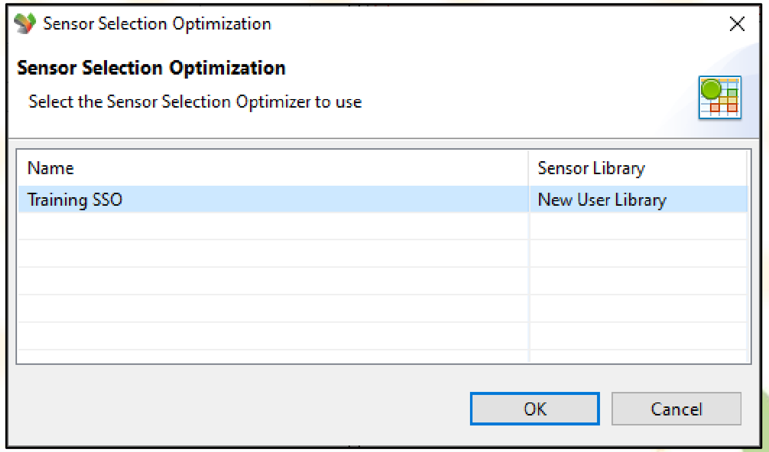
Session 6.2: Test Points

Exercise 6.2.5 Allocate a Sensor Using the SSO

Use the previously created **Sensor Selection Optimizer (SSO)** to automatically allocate the best sensor from the library to the requirement sensor location:

- Open the **'Driveline'** system model
- Right click on the **'Differential'** component and select **Test Point** from the context menu
- Within the **Test Point** editor select the **Enable Test Point** checkbox and then right-click on the **Angular Velocity** allocation area
- Select **Training SSO** from the dialogue
- Select OK

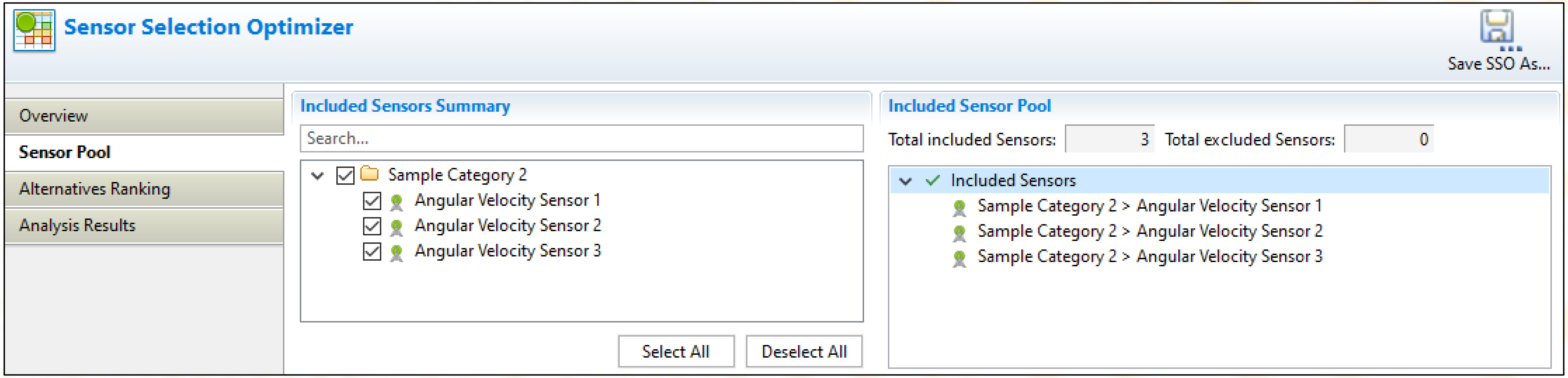




Session 6.2: Test Points

Exercise 6.2.5 Allocate a Sensor Using the SSO (Continued)

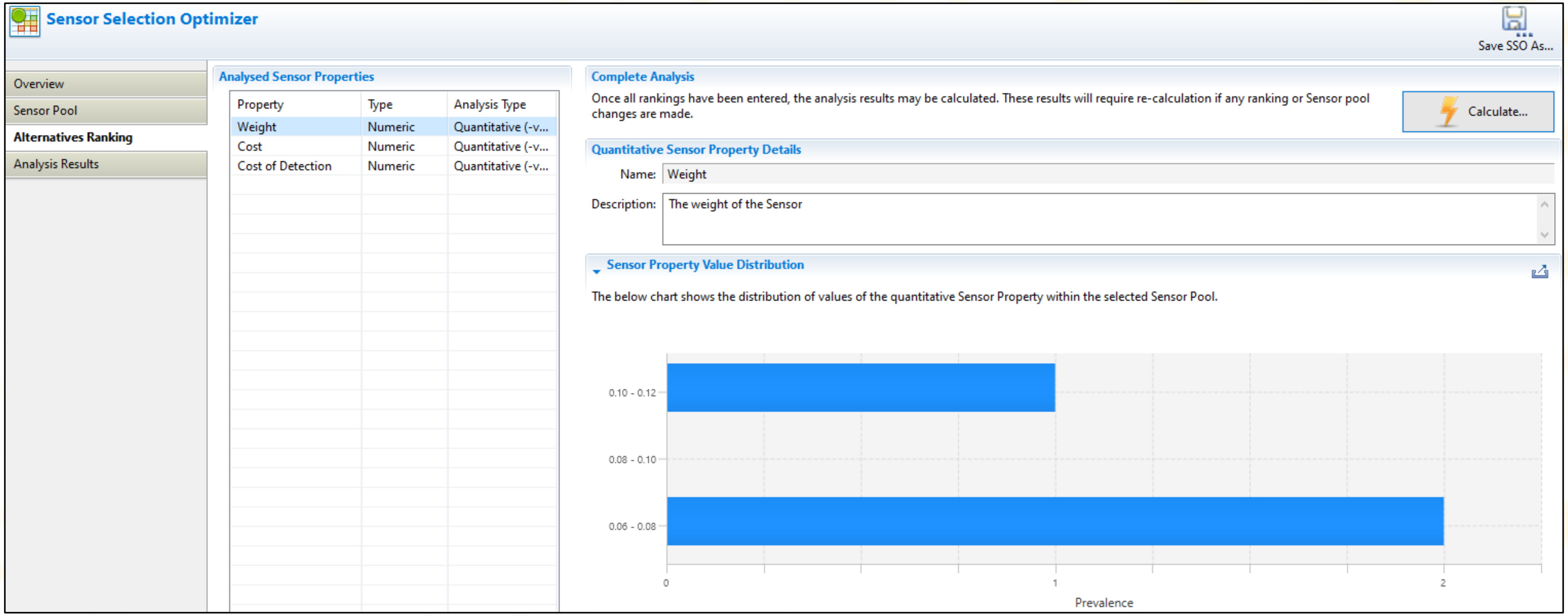
- In the newly opened SSO editor, select the **Sensor Pool** tab
- Select the checkboxes for the **3 Angular Velocity Sensors** in the **Included Sensors Summary** section



Session 6.2: Test Points

Exercise 6.2.5 Allocate a Sensor Using the SSO (Continued)

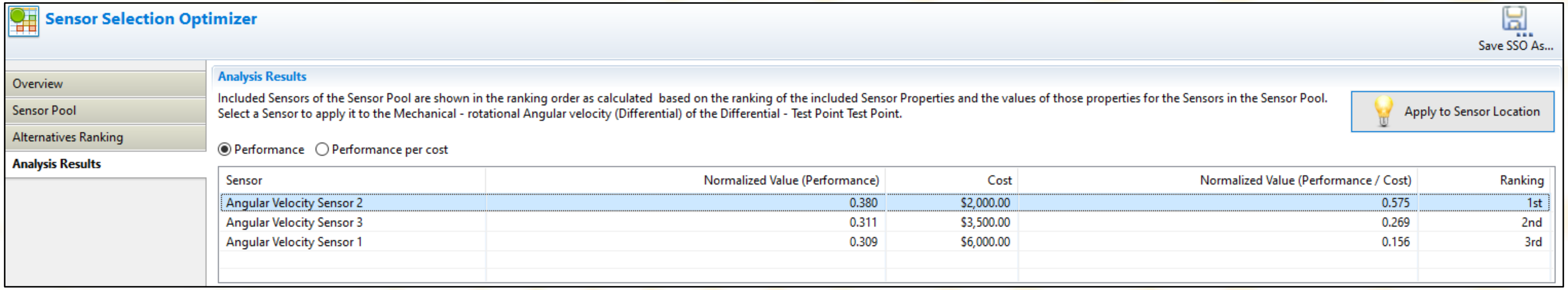
- Select the **Alternatives Ranking** tab and click the Calculate button



Session 6.2: Test Points

Exercise 6.2.5 Allocate a Sensor Using the SSO (Continued)

- Go to the **Analysis Results** tab. Here displayed will be the a table showing the most to least optimal sensors for the proposed application.
- Select the highest performing sensor **(Angular Velocity Sensor 2)** and select Apply to Sensor Location



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Session 6.2: Test Points

Discussion 6.2.6 Test Point Report

The Test Point report consists of several sections:

- **Overview** table lists components with Test Points sensors assigned
- **Sensor Summary** table shows flow properties/symptoms, their assigned sensors, methods of sensing and Probability of Detection
- **Symptom Sensor Coverage Details** table lists fault coverage based on assigned symptom sensors
- **Sensor Details** table lists vendor and reliability data, dimensions and costs for each sensor
- **Sensor Parameters** table lists percentage and numerical parameters for each sensor

Session 6.2: Test Points

Exercise 6.2.6 Test Point Report

To generate a Test Point report:

- Select **Reports → Report Wizard** from the main menu
- Select **Component Test Point Report** then Next >
- Select the **'Injector Pump'** component from the list
- Select Next > to go through report formatting options
- Select Finish to generate the report

Session 6.2: Test Points

Session 6.2 Summary

- ✓ 6.2.1: Test Points
- ✓ 6.2.2:Accessing a Test Point
- ✓ 6.2.3: Test Point Editor
- ✓ 6.2.4: Assigning Test Point Sensors
- ✓ 6.2.5: Allocate a Sensor Using the SSO
- ✓ 6.2.6: Test Point Report

Session 6.3: Automated Diagnostic Analysis

Session 6.3 Outline

6.3.1: Diagnostic Analysis

6.3.2: Overview/Management

6.2.3: Diagnostic Analysis (Landing Page)

6.3.4: Propagation Table

6.3.5: Diagnostic Inclusions

6.3.6: Diagnostic Exclusions

6.3.7: Sensor Set Analysis

6.3.8: Ambiguity Groups

6.3.9: Sensor Allocation

6.3.10: Sensor Parameters

6.3.11: Diagnostic Sets

6.3.12: Metric Optimisation

6.3.13: Sensor Set Comparison

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Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.1 Diagnostic Analysis

- Used to analyse coverage of system failures using allocated sensors
- Two main analysis types:
    - **Automated Diagnostic Analysis**: Uses a proprietary algorithm to generate sensor sets that provide maximum system coverage when allocated with sensors. This analysis also captures legacy (component/subsystem test point) sensors if present.
    - **User-defined Diagnostic Analysis**: Provides users with the ability to freely allocate sensors throughout a selected system, or allocate sensors based on an optimised solution from the automated diagnostic analysis.

Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.1 Diagnostic Analyses (Continued)

Recommended Sensor Analysis approach:

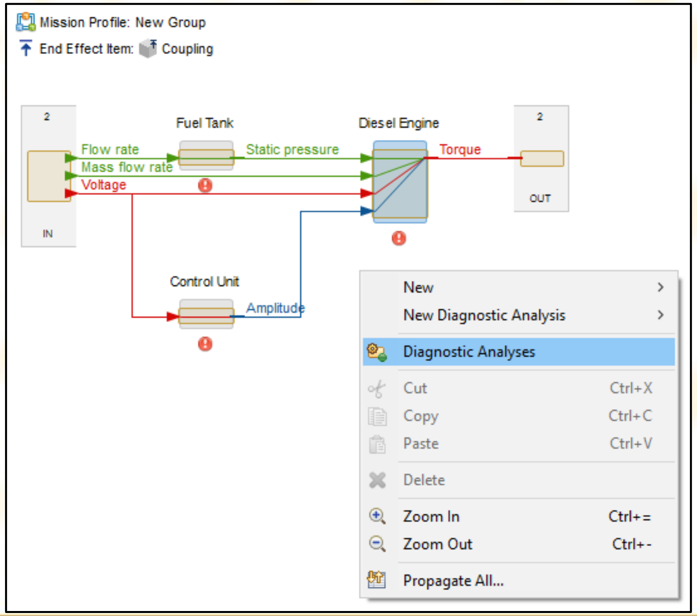
1. **Automated Diagnostic Analysis**: Analyse effectiveness of legacy (component/subsystem test point) sensors
2. **Automated Diagnostic Analysis**: Analyse potential sensor combinations and perform trade-studies for a desired performance metric. For example:
   a. Optimising for Cost
   b. Optimising for Weight
   c. Optimising for Coverage
3. **Automated Diagnostic Analysis**: Define final (optimised) sensor configuration

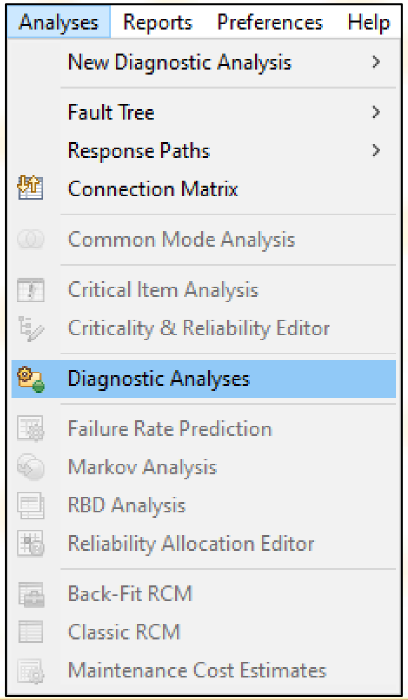
Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.1 ACCESSING DIAGNOSTIC ANALYSIS EDITOR

To access the Diagnostic Analysis Editor:

- Open the System Model of the **'Power Generation'** subsystem
- Right-click the canvas and select **Diagnostic Analysis** from the menu options
- Alternatively, select **Analyses → Diagnostic Analysis** from the main menu

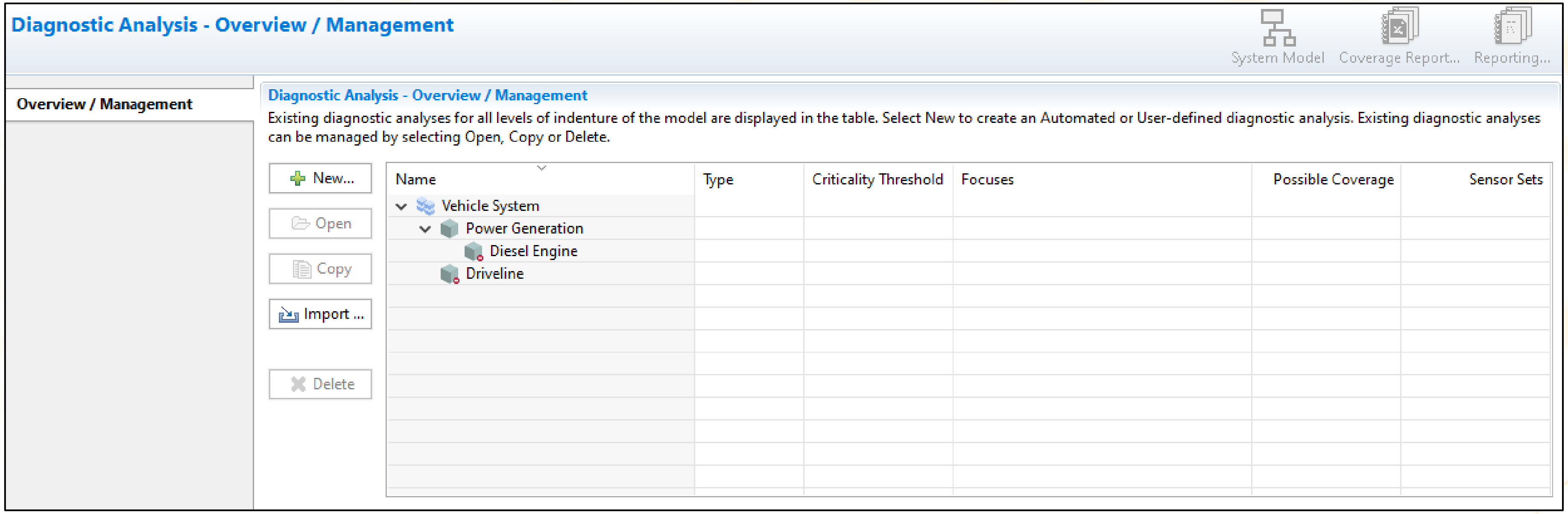




Session 6.3: Automated Diagnostic Analysis

DISCUSSION 6.3.2 OVERVIEW/MANAGEMENT

- Used to create all new diagnostic analyses
- Lists all diagnostic analyses conducted on the model
- Provides summary of diagnostic details:
  - Type
  - Threshold
  - Focus
  - Coverage
  - # of Sensor Sets

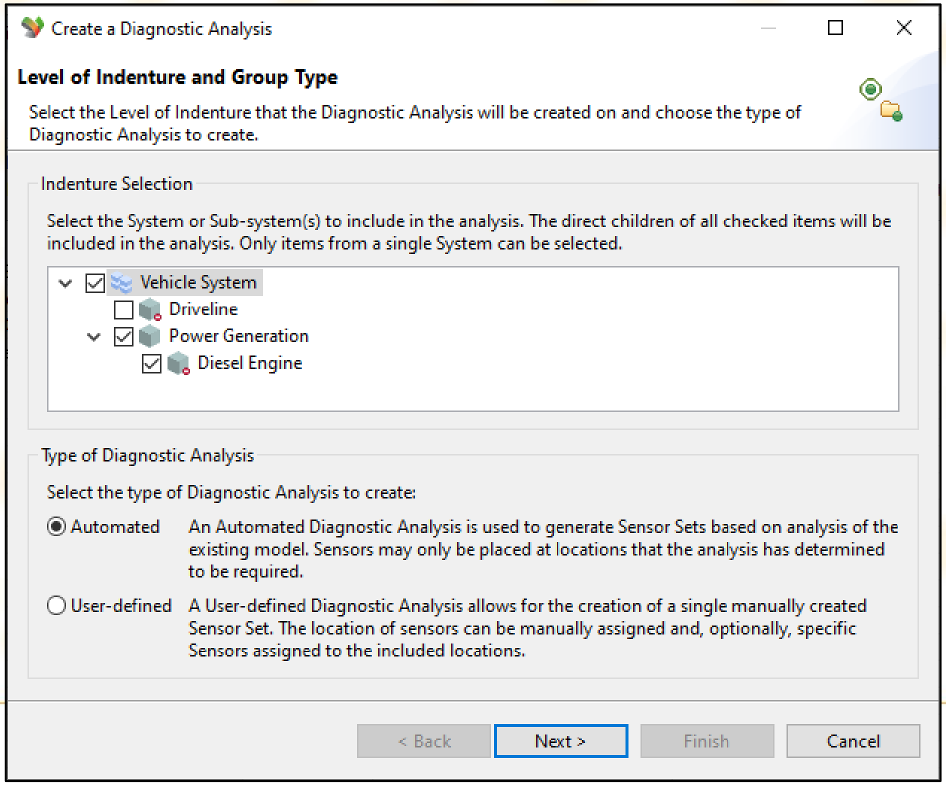


Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.2 CREATING A NEW DIAGNOSTIC ANALYSIS

To create a new Diagnostic Analysis:

- Select New... to open the **Create a Diagnostic Analysis** dialog
- Expand the **‘Power Generation’** system and select the check box for the following items:
  - **‘Vehicle System’**
  - **‘Power Generation’**
  - **‘Diesel Engine’**
- Set the Type of Diagnostic Analysis to **Automated**
- Select Next > to proceed



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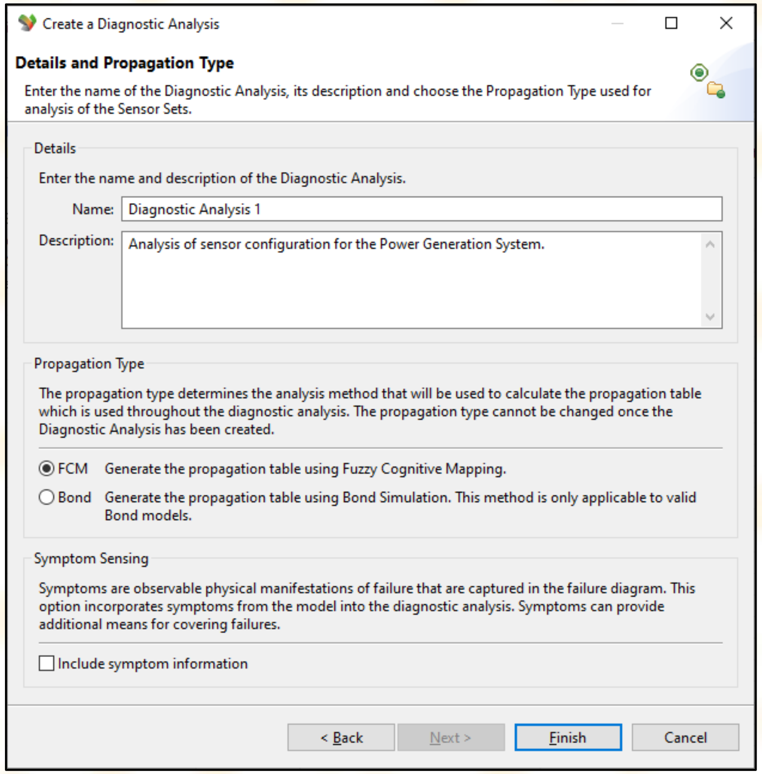
Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.2 CREATING A NEW DIAGNOSTIC ANALYSIS (CONTINUED)

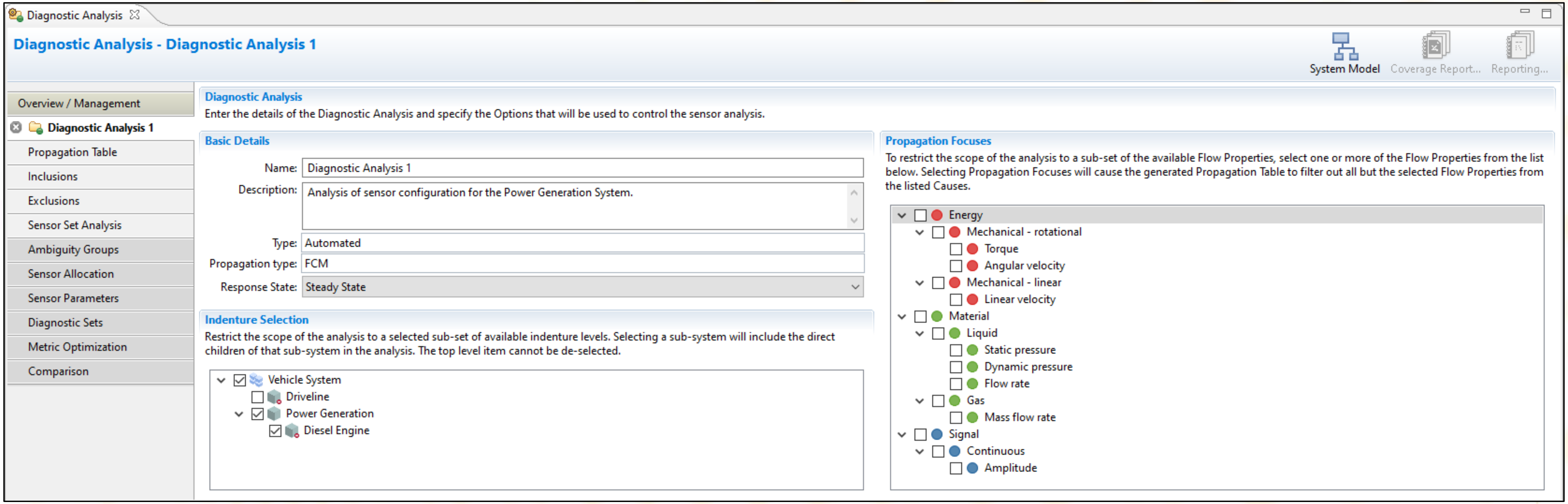
- Populate the details of the Diagnostic Analysis with the following details:
- Name: **Diagnostic Analysis 1**
- Description: **Analysis of sensor configuration for the Power Generation System.**
- Set the **Propagation Type** to **FCM**
- Select Finish to close the dialog and create the analysis



Session 6.3: Automated Diagnostic Analysis

DISCUSSION 6.3.3 DIAGNOSTIC ANALYSIS (LANDING PAGE)

- Used to view basic analysis details, indenture selection & propagation focuses



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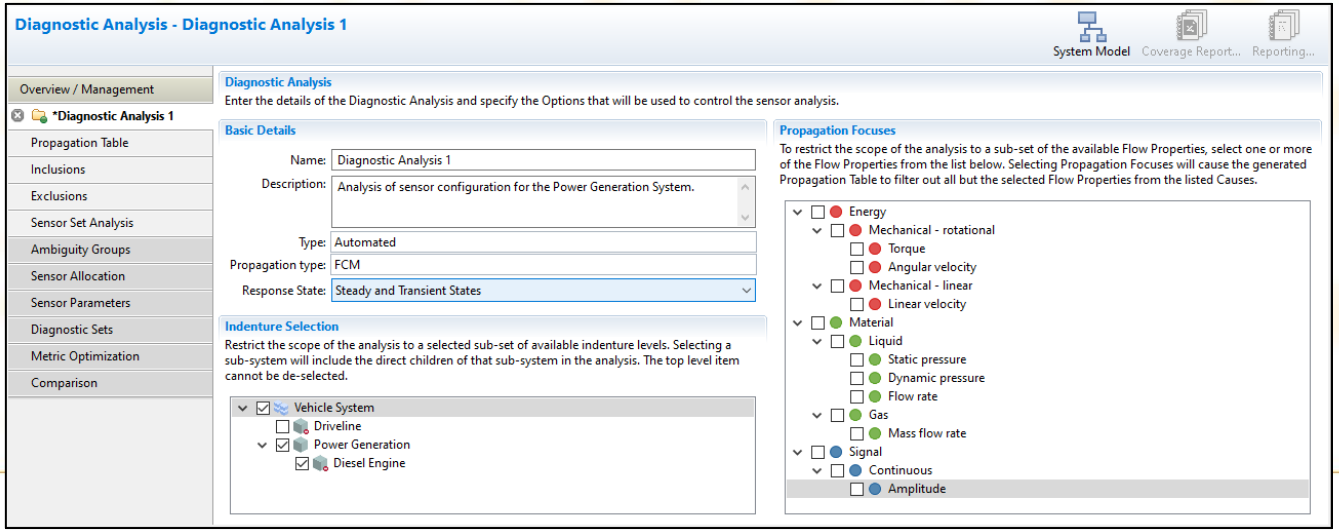
Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.3 DIAGNOSTIC ANALYSIS (LANDING PAGE)

- Verify information in **Basic Details** section & Indenture dialog (from dialog)
  - Name: **Diagnostic Analysis 1**
  - Description: **Analysis of sensor configuration for the Power Generation System.**
  - Type: **Automated**
  - Propagation Type: **FCM**
  - Response State: **Steady and Transient States**
- Verify **Propagation Focuses**: None selected (By default meaning all flow types are considered)



Session 6.3: Automated Diagnostic Analysis

DISCUSSION 6.3.4 PROPAGATION TABLE

- Shows **item failures** (rows) vs **item responses** to those failures (header)
- **Failure responses** ⇧ (high), ⇩ (low) & ⬄ (nominal) at intersections show for connected items.
    - Example: Lift Pump failing **Low** will cause the Injector Pump to show a **Low** response
- Table is configured based on system model and diagnostic analysis page (propagation focuses, LOI)

Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.4 Propagation Table

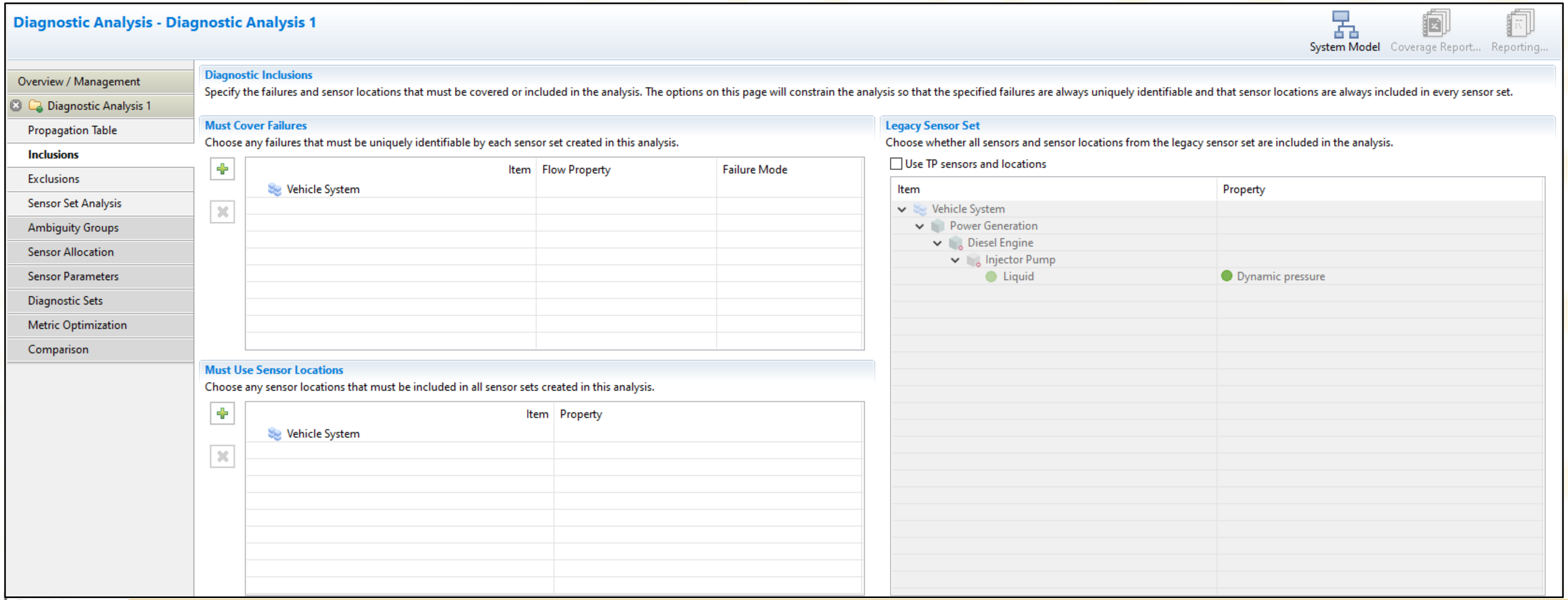
- Verify that when **‘Fuel Tank’** static pressure **decreases** it causes ‘**Diesel Engine’** torque to show a **Low** failure
  - This shows that there is one or more flow connections/downstream impact
- Verify that **‘Primary Fuel Filter’** flow rate **decreases** will have a **nominal** effect on **‘Air Filter’** mass flow rate
  - This shows that there is no flow connection/downstream impact

Item	Flow Property	Failure	Air Filter Gas Mass flow rate	Control Unit Continuous Amplitude	Coupling 1 Mechanical - rotational Angular velocity	Coupling Mechanical - rotational Torque	Diesel Engine Mechanical - rotational Torque	Driveline Mechanical - rotational Angular velocity	Driveline Mechanical - rotational Angular velocity
Vehicle System		Healthy System (SS,TR)	⇔	⇔	⇔	⇔	⇔	⇔	⇔
Air Filter	Gas - Mass flow rate	⇩ Low (SS,TR)	⇩ Low	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low
Control Unit	Continuous - Amplitude	Intermittent operation (Control Unit) (SS,TR)	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low
Control Unit	Continuous - Amplitude	⇩ Decrease (SS,TR)	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low
Coupling	Mechanical - rotational - Torque	⇧ High (SS,TR)	⇔	⇔	⇔	⇧ High	⇔	⇧ High	⇧ High
Coupling	Mechanical - rotational - Torque	⇩ Low (SS,TR)	⇔	⇔	⇔	⇩ Low	⇔	⇩ Low	⇩ Low
Coupling 1	Mechanical - rotational - Angular velocity	⇩ Low (SS,TR)	⇔	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low
Diesel Engine	Mechanical - rotational - Torque	⇩ Low (SS,TR)	⇔	⇔	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low
Engine	Mechanical - rotational - Torque	⇩ Low (SS,TR)	⇔	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low
Fuel Tank	Liquid - Static pressure	⇩ Decrease (SS,TR)	⇔	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low
Governor	Mechanical - linear - Linear velocity	⇩ Low (SS,TR)	⇔	⇔	⇩ Low	⇩ Low	⇩ Low	⇩ Low	⇩ Low

Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.5 Diagnostic Inclusions

- Enables user to specify sensor locations that must be included in generated sensor sets
- Specify failures that must be covered by any generated sensor sets

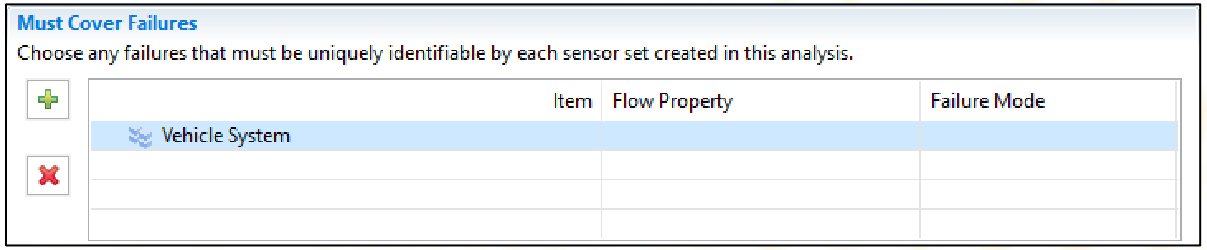


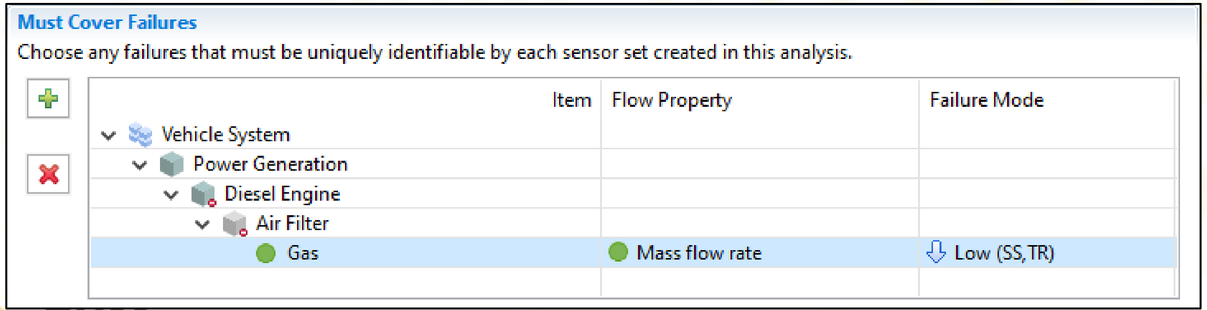
Session 6.3: Automated Diagnostic Analysis

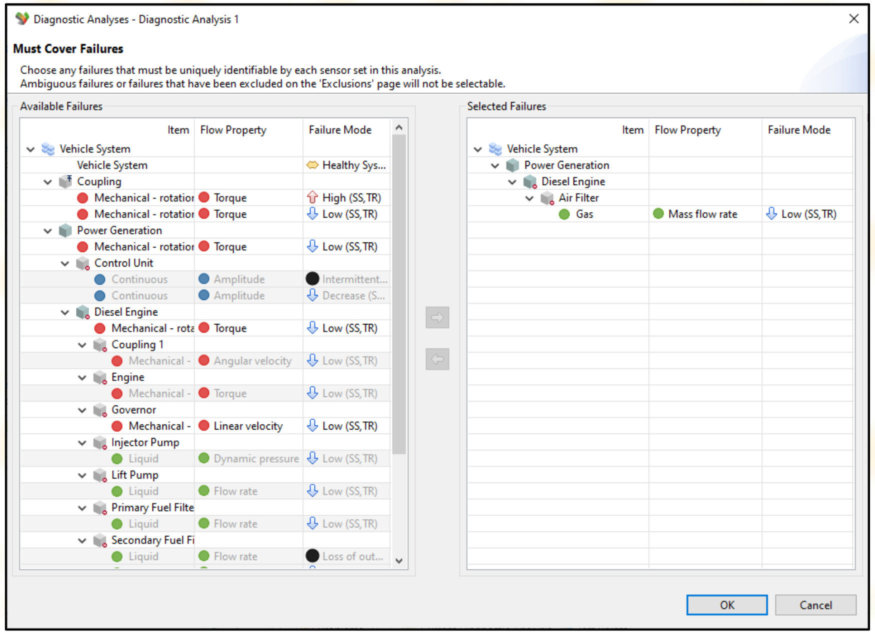
Exercise 6.3.5 Diagnostic Inclusions

To include failure detection in the diagnostic analysis, in the **Inclusions** tab:

- Under the **Must Cover Failures** section, select
- From the dialog box select **'Air Filter'** to include in the analysis
- Select to move the item to the Included Failure Modes table
- Select OK





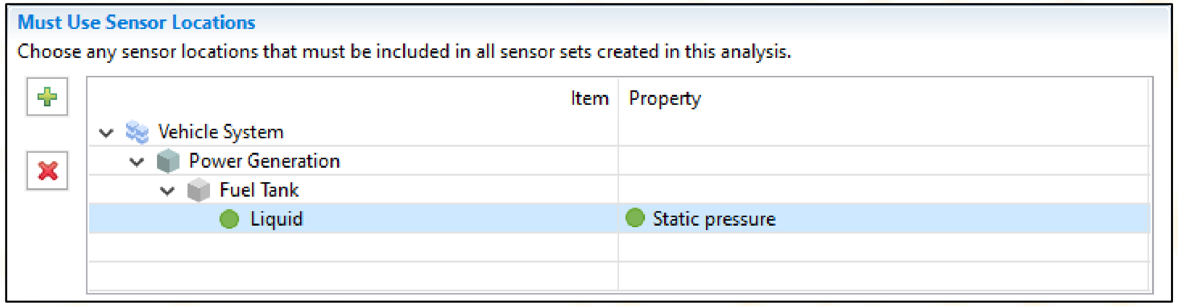


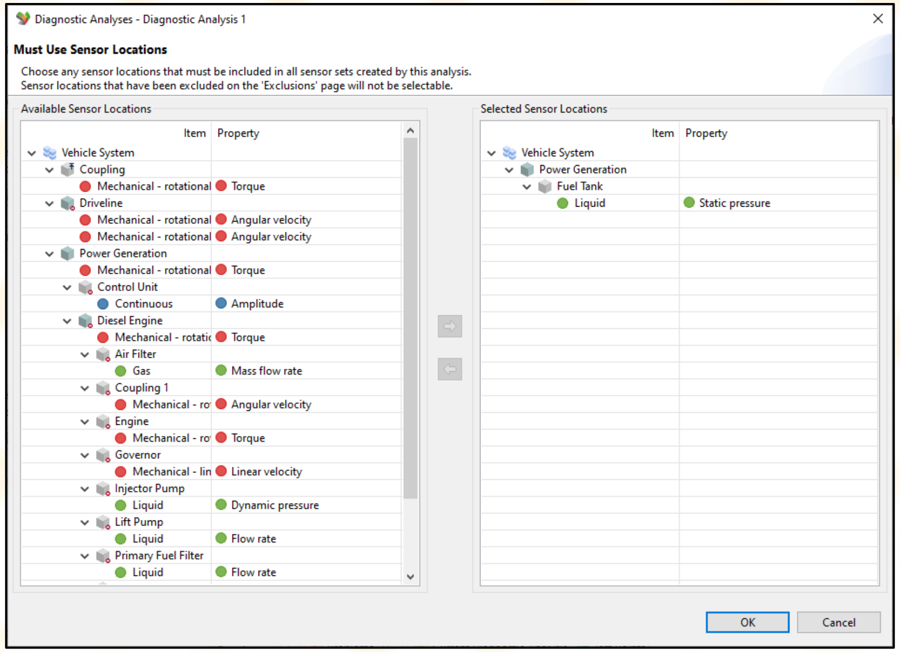
Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.5 Diagnostic Inclusions (continued)

In the Must Use Sensor Locations section:

- Select and select **'Fuel Tank'**
- Select to move the item to the Must Use Sensor Locations
- Select OK



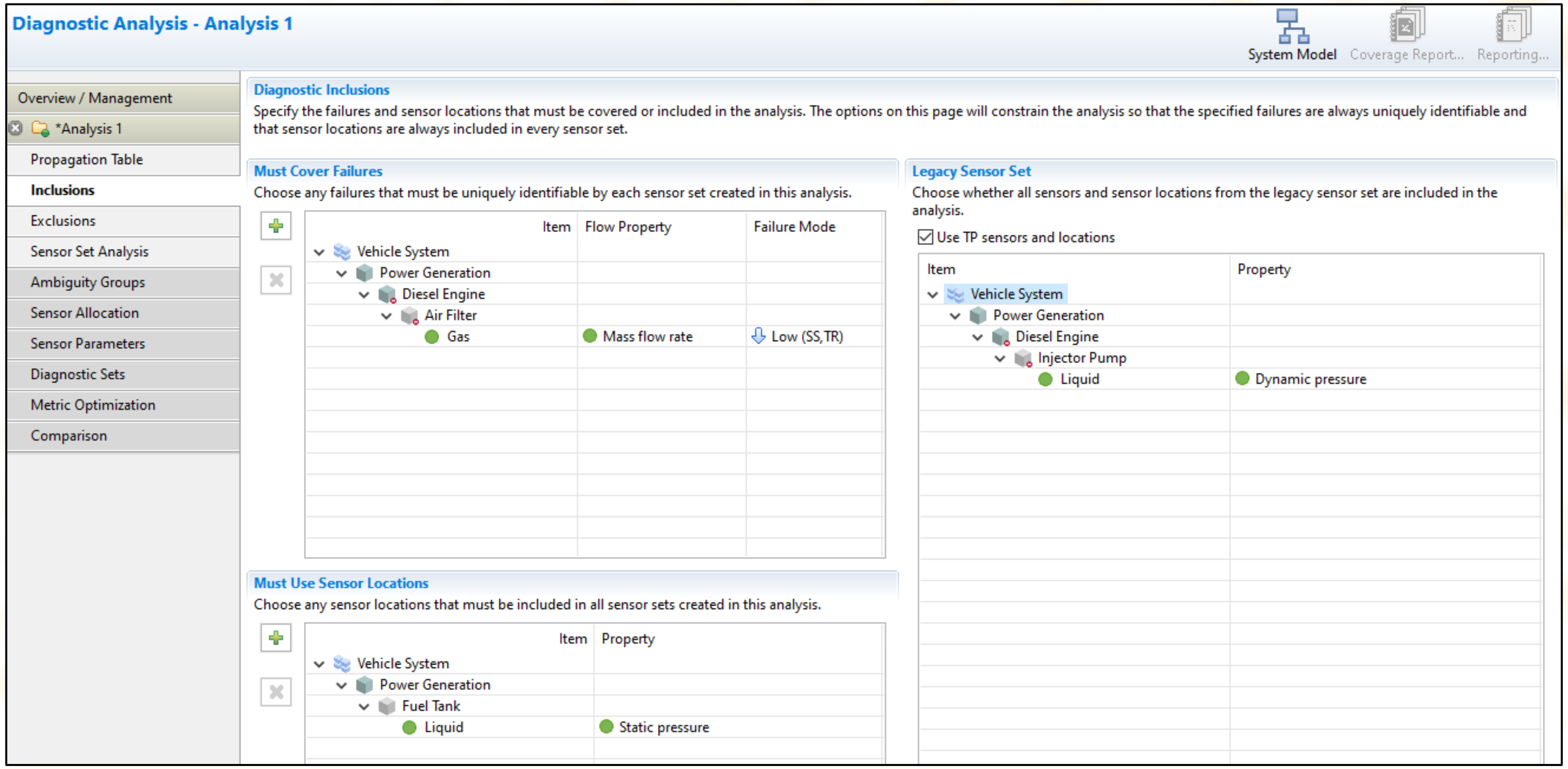


Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.5 DIAGNOSTIC INCLUSIONS (CONTINUED)

In the Legacy Sensor Set Section:

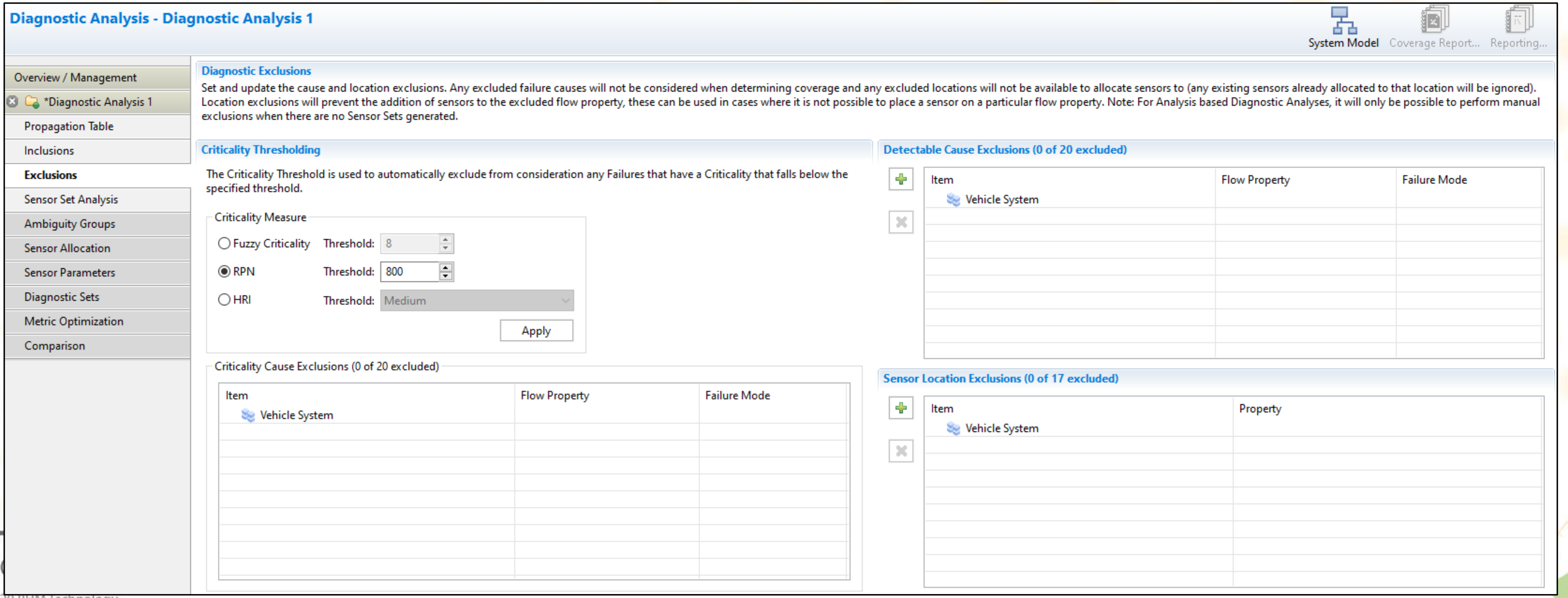
- Select **Use TP sensors and locations** check box to include the Legacy Test Point sensors in the analysis



Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.6 Diagnostic Exclusions

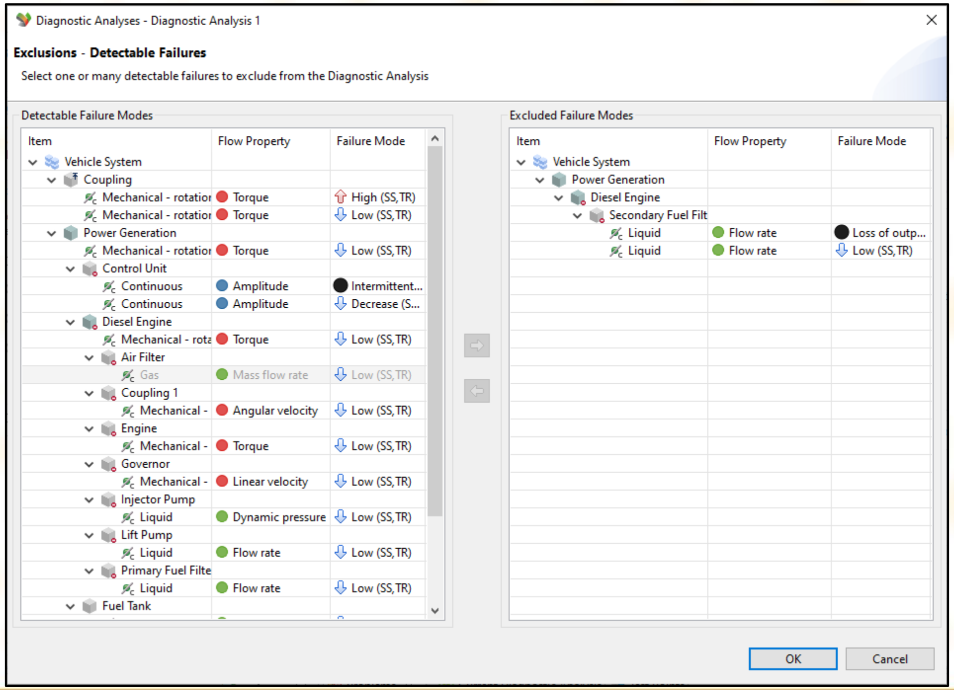
- Enables user to threshold (exclude) sensor locations based on criticality, flow property type or item
- Exclusions are not considered in Sensor Set Analysis



Exercise 6.3.6 Diagnostic Exclusions

To assign an exclusion to the diagnostic analysis, in the **Detectable Cause Exclusions** Section:

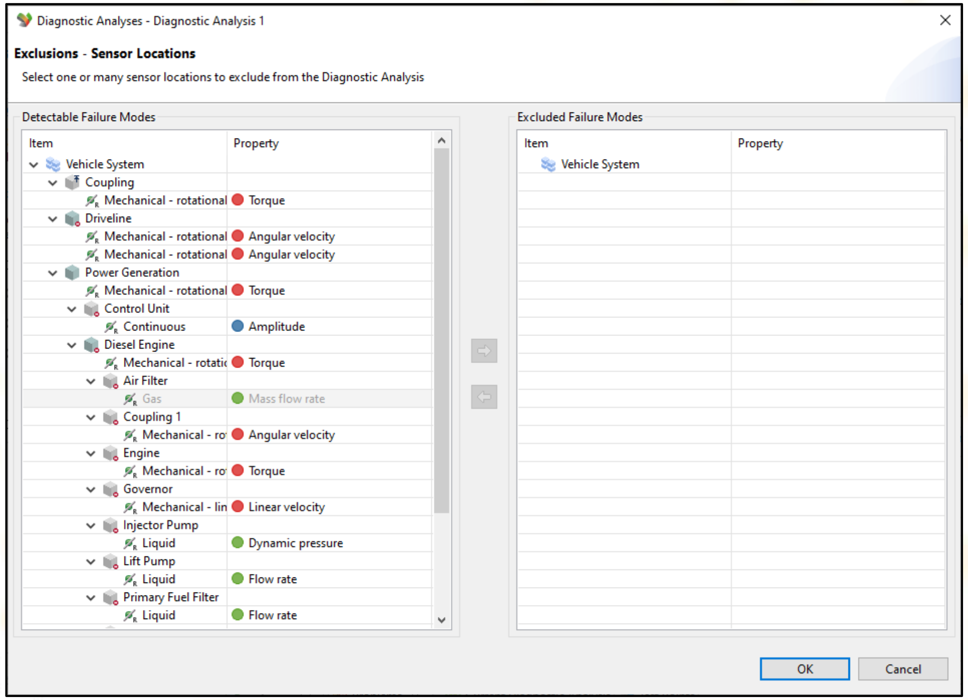
- Select and select **'Secondary Fuel Filter'**
- Select to move the item to the **Excluded Failure Modes** table
- Select OK

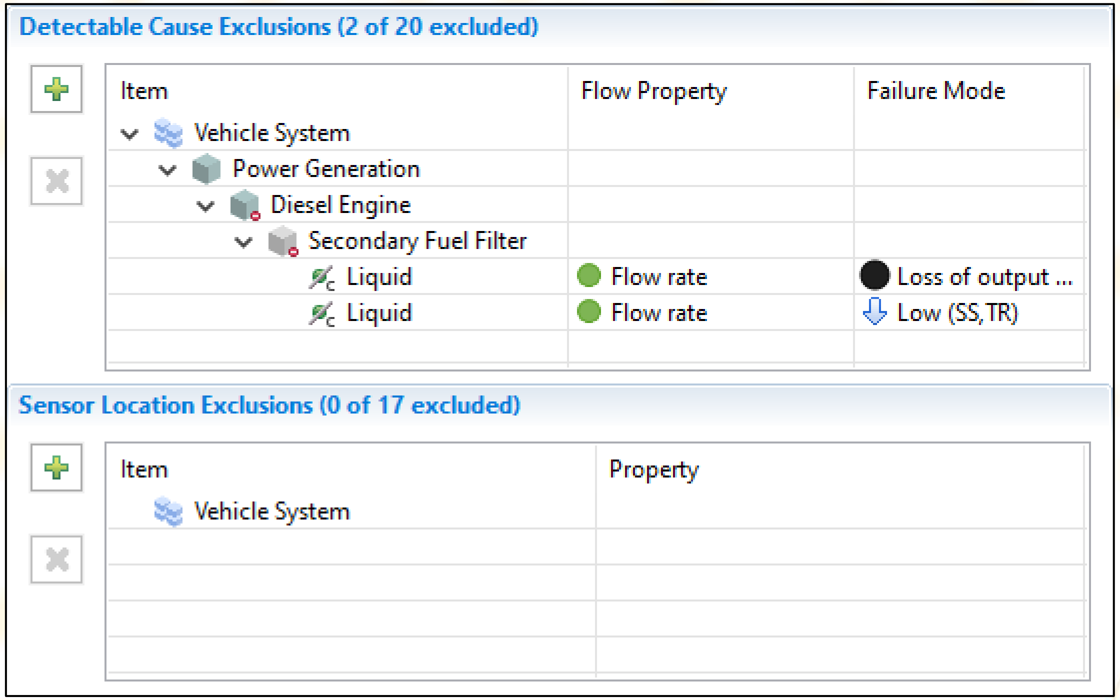


Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.6 Diagnostic Exclusions (continued)

- Sensor Location Exclusion Selection works the same as the previous inclusion and exclusion editors
- For the purpose of this demonstration we will not exclude any failure modes

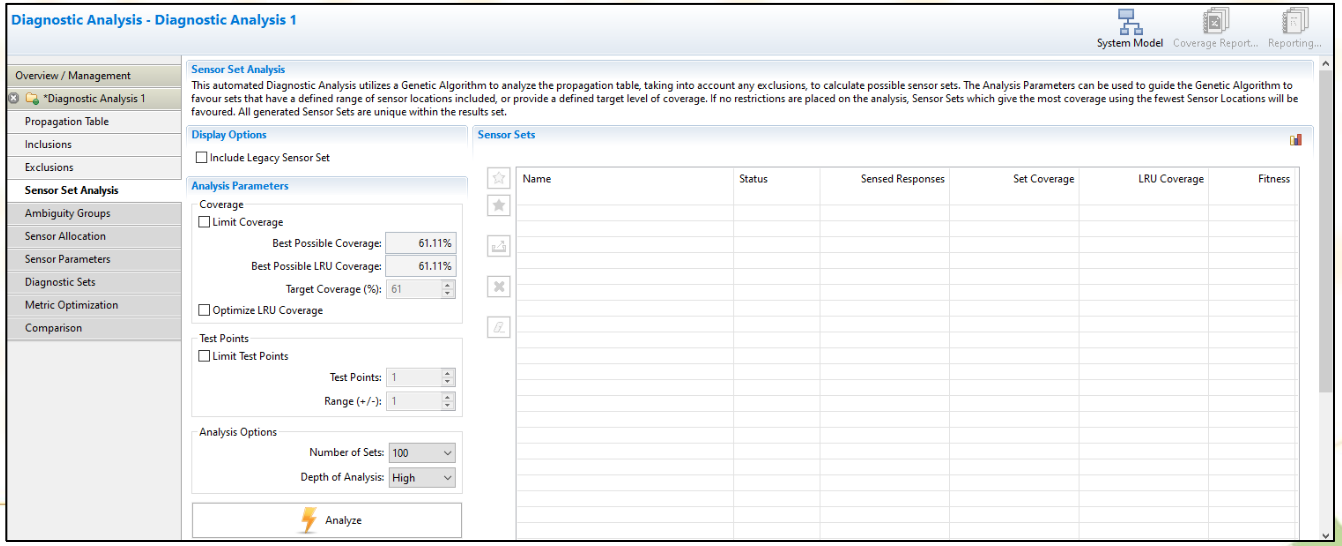




Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.7 Sensor Set Analysis

- Main page to analyse the propagation table then calculates and generates possible sensor sets
- User sets the analysis parameters
  - No restrictions = maximum coverage with least number of sensor locations
  - Defines the minimal failure coverage
  - The **Include Legacy Sensor Set** checkbox allows the displays the Legacy Sensors as a set
  - Test point number limiting within a defined range
  - Number of unique sensor sets generated
  - Optimization level of analyses

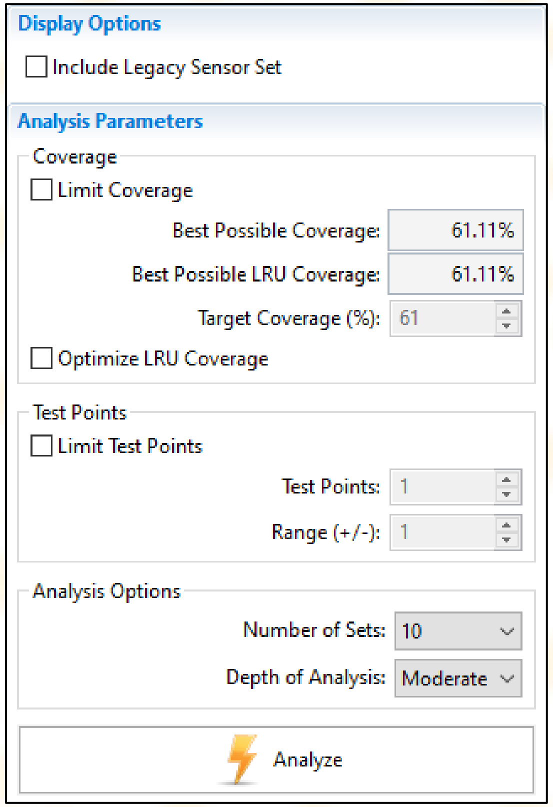


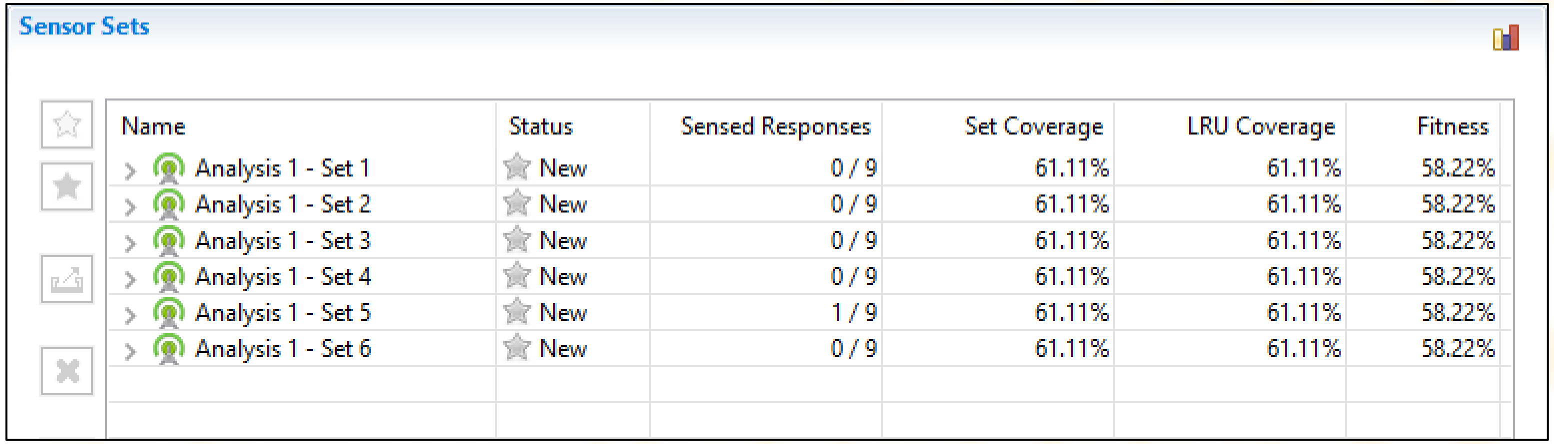
Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.7 SENSOR SET ANALYSIS

To generate a Sensor Set analysis:

- Select the **Sensor Set Analysis** tab
- Set Number of Sets to **10**
- Set Depth of Analysis to **Moderate**
- Select Analyze to generate the diagnostic sets



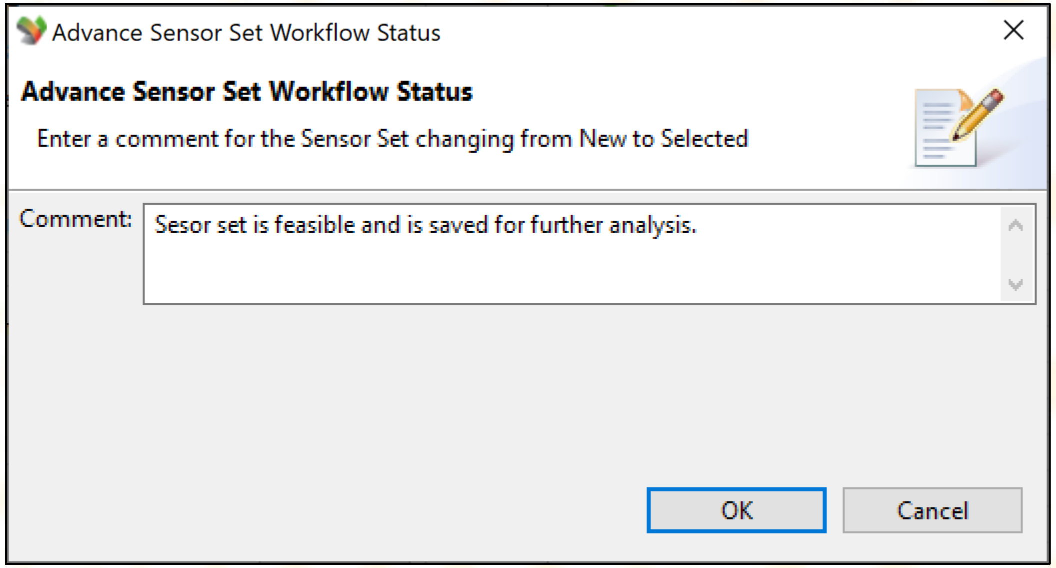


Name	Status	Sensed Responses	Set Coverage	LRU Coverage	Fitness
Analysis 1 - Set 1	New	0 / 9	61.11%	61.11%	58.22%
Analysis 1 - Set 2	New	0 / 9	61.11%	61.11%	58.22%
Analysis 1 - Set 3	New	0 / 9	61.11%	61.11%	58.22%
Analysis 1 - Set 4	New	0 / 9	61.11%	61.11%	58.22%
Analysis 1 - Set 5	New	1 / 9	61.11%	61.11%	58.22%
Analysis 1 - Set 6	New	0 / 9	61.11%	61.11%	58.22%

Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.7 Sensor Set Analysis (Continued)

- Review Sensor Sets Table
  - Select **Set 1** and select to save and advance the workflow status for the set
  - Comment: **Sensor set is feasible and is saved for further analysis.**

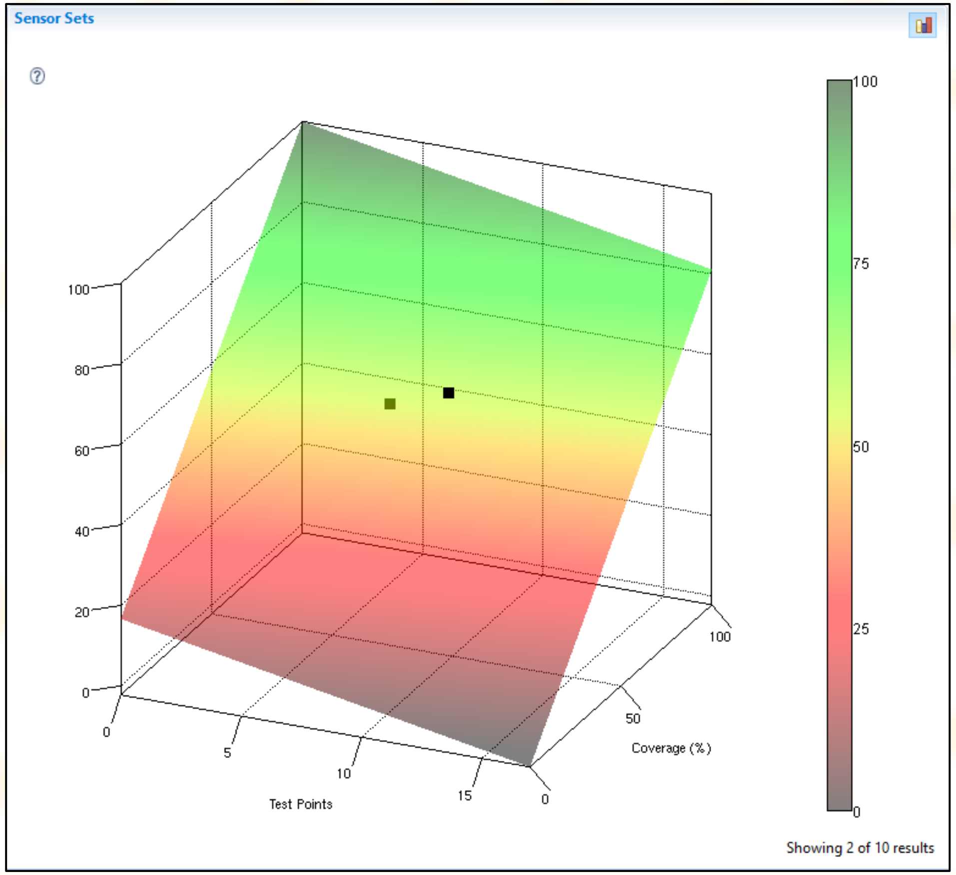


Name	Status	Sensed Responses	Set Coverage	LRU Coverage	Fitness
Analysis 1 - Set 1	Selected	1 / 9	61.11%	61.11%	N/A

Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.7 Sensor Set Analysis (continued)

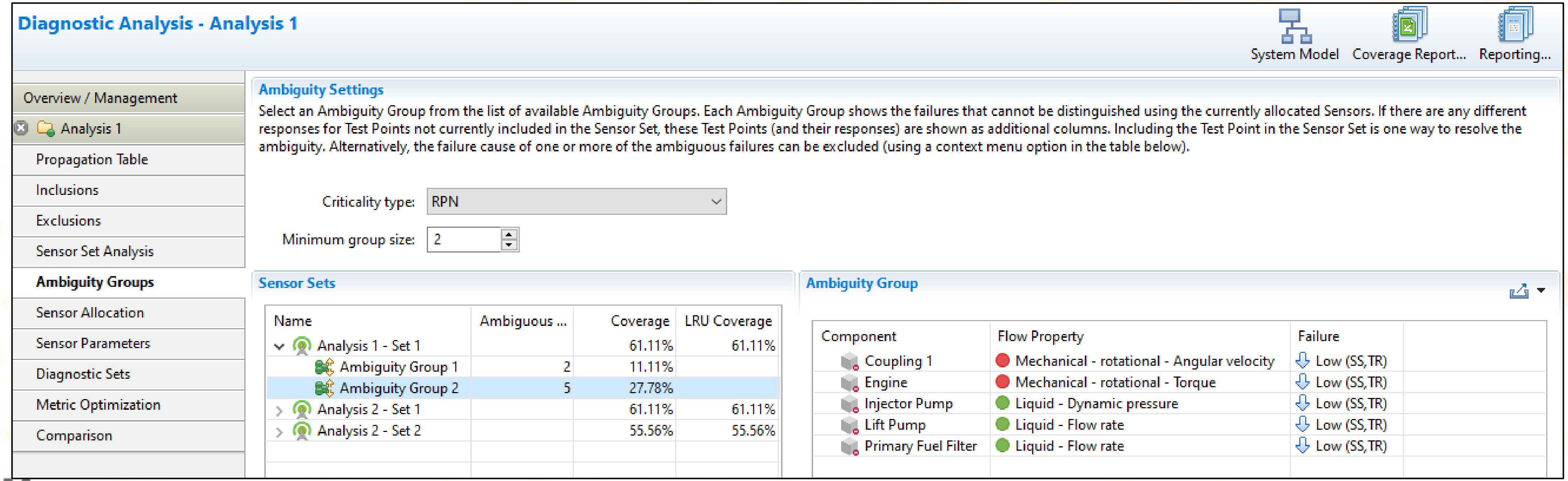
- Select to view the fitness chart for the analysis
- Use left-click an drag to rotate Fitness chart
- Select Analyze again



Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.8 Ambiguity Groups

- Shows failures from each sensor set that cannot be distinguished by currently allocated sensors
  - Example: Legacy Sensor Set has two Ambiguity Groups
- Failures are resolved by exclusion, reconfiguring the system or adding sensors (user-defined analysis)



Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.8 AMBIGUITY GROUPS

To view the Ambiguities Groups of the generated diagnostic sets:

- Select the **Ambiguity Group** tab
- Select **Analysis 1 – Set 1, Ambiguity Group 2**
  - Identify ambiguities between 5 items that have ambiguous failures (see below)

Ambiguity Settings

Select an Ambiguity Group from the list of available Ambiguity Groups. Each Ambiguity Group shows the failures that cannot be distinguished using the currently allocated Sensors. If there are any different responses for Test Points not currently included in the Sensor Set, these Test Points (and their responses) are shown as additional columns. Including the Test Point in the Sensor Set is one way to resolve the ambiguity. Alternatively, the failure cause of one or more of the ambiguous failures can be excluded (using a context menu option in the table below).

Criticality type: RPN

Minimum group size: 2

Sensor Sets

Name	Ambiguous ...	Coverage	LRU Coverage
Analysis 1 - Set 1		61.11%	61.11%
Ambiguity Group 1	2	11.11%	
Ambiguity Group 2	5	27.78%	
Analysis 2 - Set 1		61.11%	61.11%
Analysis 2 - Set 2		55.56%	55.56%

Ambiguity Group

Component	Flow Property	Failure
Coupling 1	Mechanical - rotational - Angular velocity	Low (SS,TR)
Engine	Mechanical - rotational - Torque	Low (SS,TR)
Injector Pump	Liquid - Dynamic pressure	Low (SS,TR)
Lift Pump	Liquid - Flow rate	Low (SS,TR)
Primary Fuel Filter	Liquid - Flow rate	Low (SS,TR)

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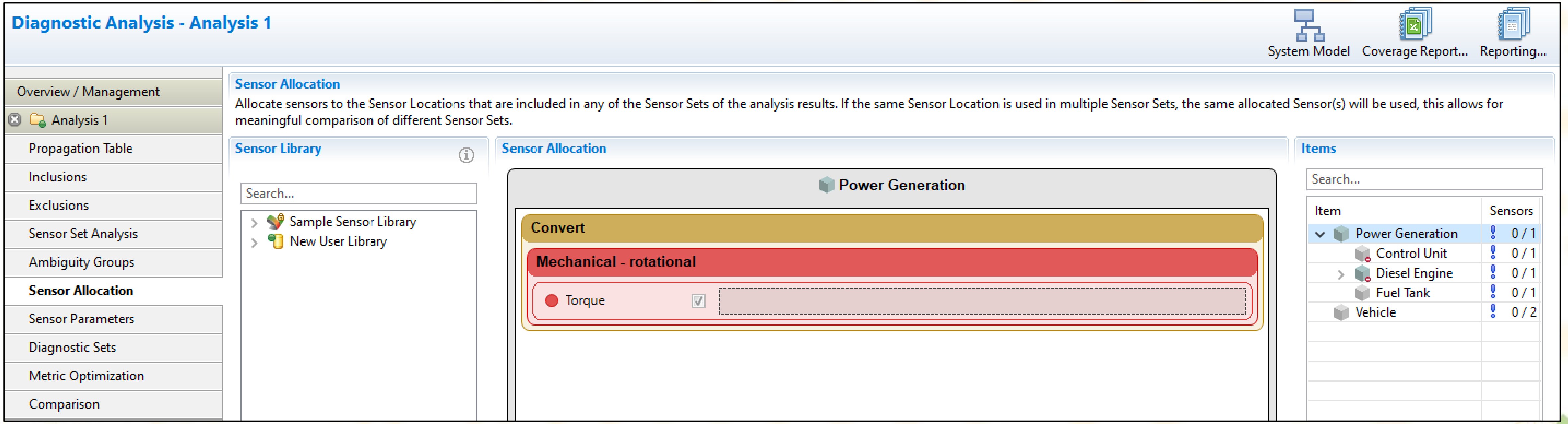
Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.9 Sensor Allocation

- Used to identify item functional flows i.e. sensor locations
- Sections: Sensor Library, Recently Used Sensors, Sensor Allocation & Items
- Shows sensor libraries & sensors – these can be filtered based on flow type selected



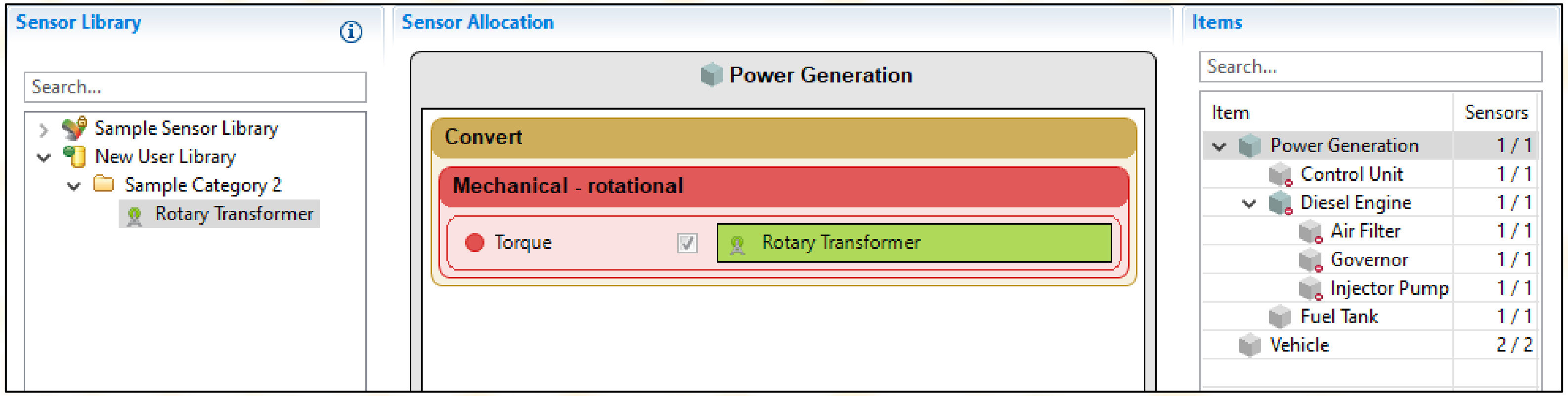
Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.9 SENSOR ALLOCATION

To allocate sensors to the system:

- Select the **Sensor Allocations** tab
- Expand all items in the Items list
- Expand **User Sensor Library** and select flow-specific sensors to each item flow
- Allocate the previously created sensors according to the table below

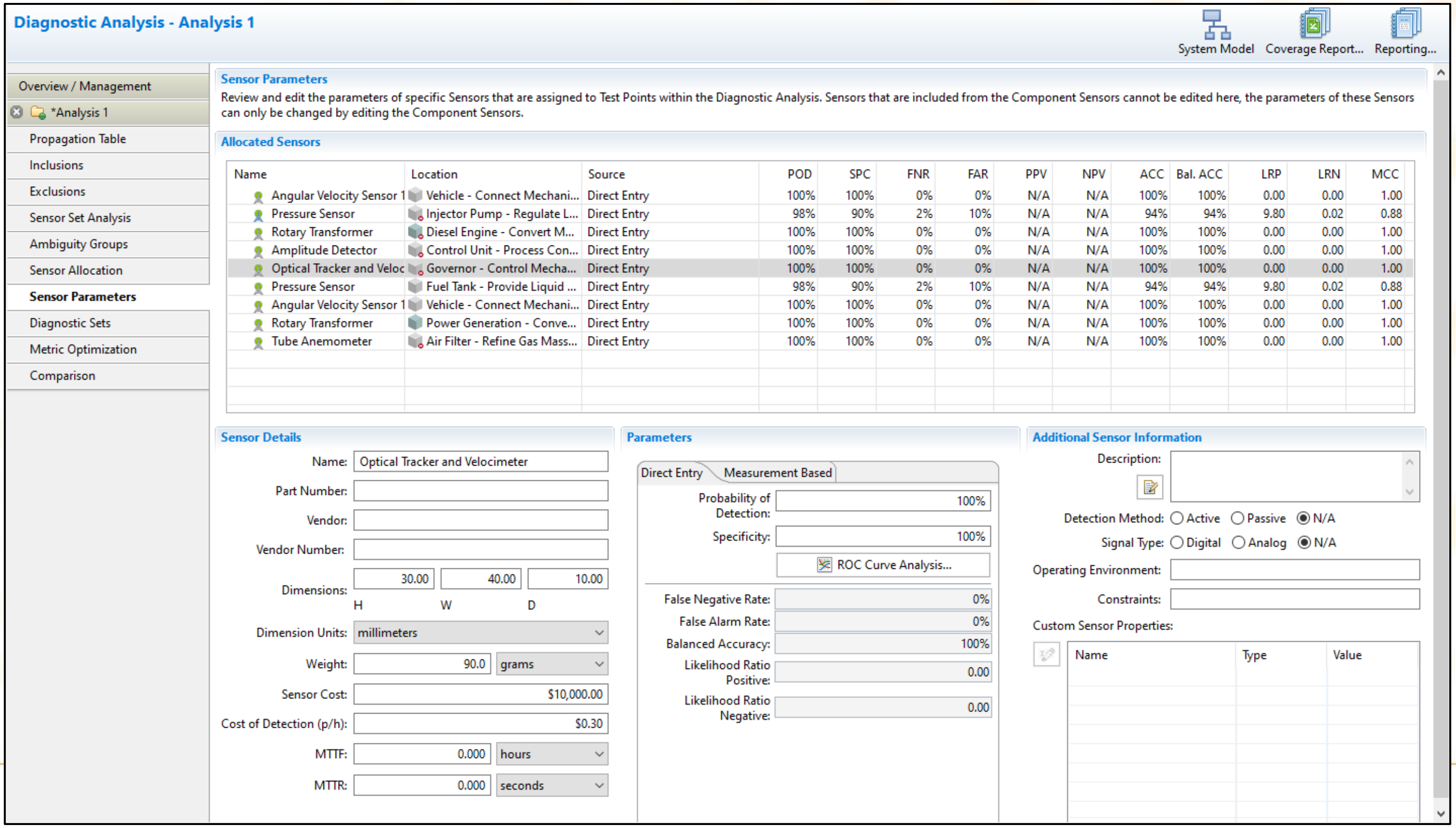
Flow Property	Name
Torque	Rotary Transformer
Angular Velocity	Angular Velocity Sensor 1
Amplitude	Amplitude Detector
Mass Flow Rate (Gas)	Tube Anemometer
Linear Velocity	Optical Tracker and Velocimeter
Flow Rate (Liquid)	Orifice Plate
Static Pressure	Pressure Sensor



Session 6.3: Automated Diagnostic Analysis

DISCUSSION 6.3.10 SENSOR PARAMETERS

- This page enables the user to edit each sensor parameter selected
- Sections: Allocated Sensors, Sensor Details, Parameters & Additional Sensor Information

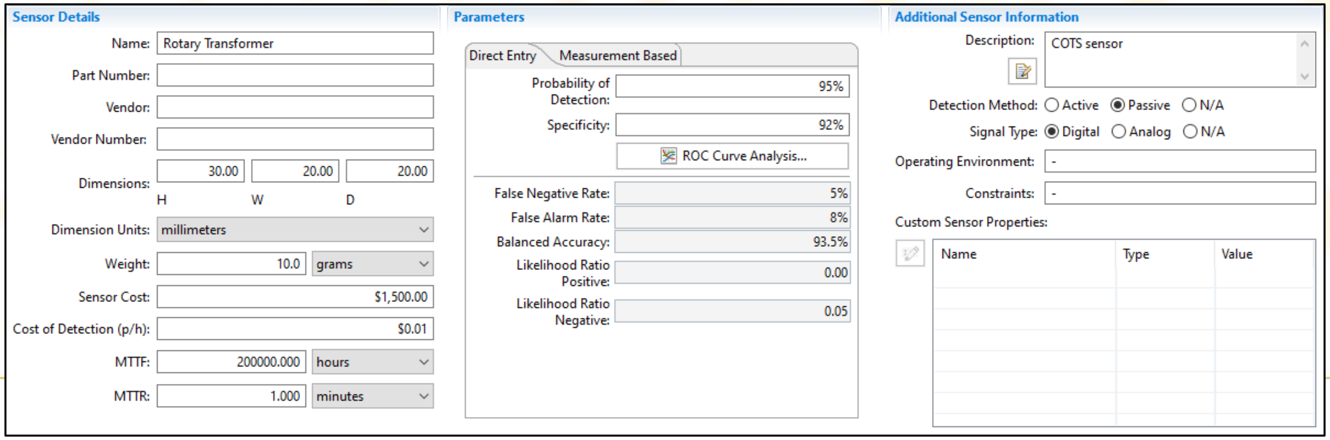


Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.10 Sensor Parameters

To edit the Sensor Parameters:

- Select the **Rotary Transformer** of the **'Diesel Engine'** and enter/modify the following sensor details:
  - Dimensions: **30.0 (H), 20.0 (W), 20.0 (D)**
  - Dimension units: **Millimetres**
  - Weight: **10.0 grams**
  - Sensor Cost: **$1500**
  - Cost of Detection: **$0.01 (per hour)**
  - MTTF: **200,000 hours**
  - MTTR: **1 minute**
  - Estimated POD: **95%**
  - Estimated Specificity: **92%**
  - Description: **COTS sensor**
  - Detection method: **Passive**
  - Signal type: **Digital**
  - Operating Environment: **-**
  - Constraints: **-**



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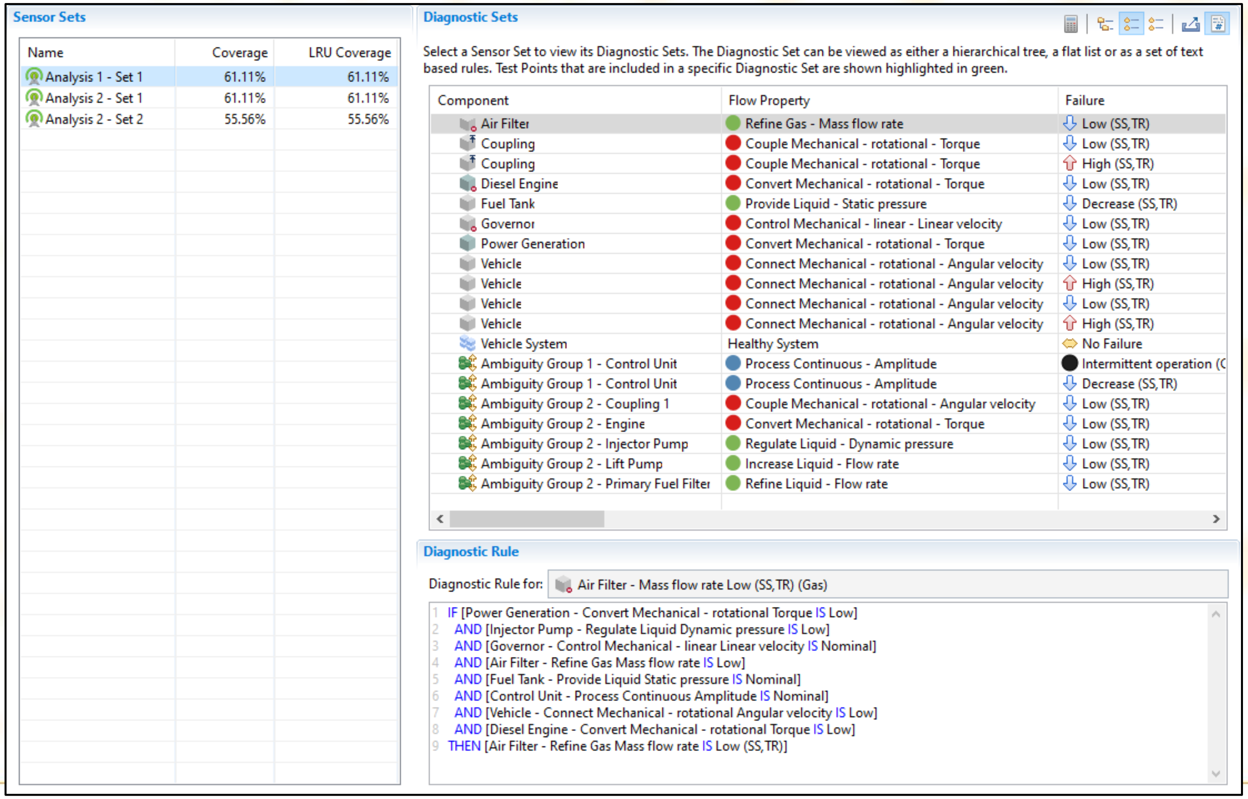
Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.11 Diagnostic Sets

- Page shows the failure diagnosis based on the sensor set selected
- Shows how to diagnose an item or ambiguity group using **Diagnostic Rules**

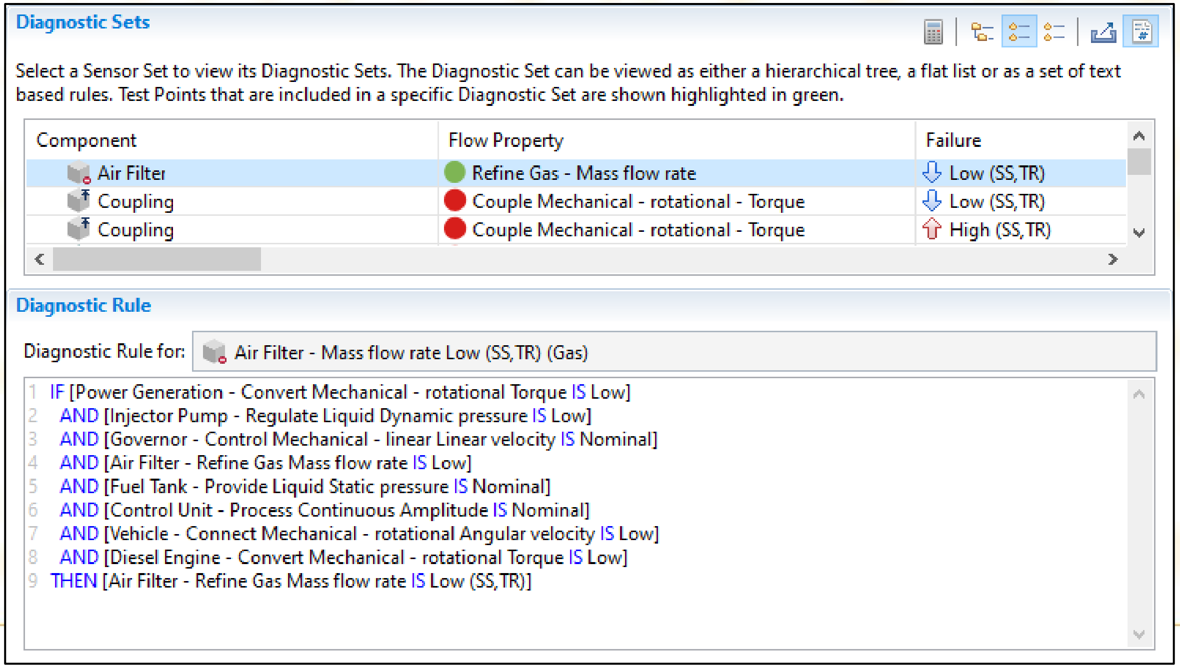


Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.11 Diagnostic Sets

To access the Diagnostic rules:

- Select the **Diagnostic Sets** tab
- Select an analysis set in the **Diagnostic Sets** section
- Select the **'Air Filter'** component and read the diagnostic rule



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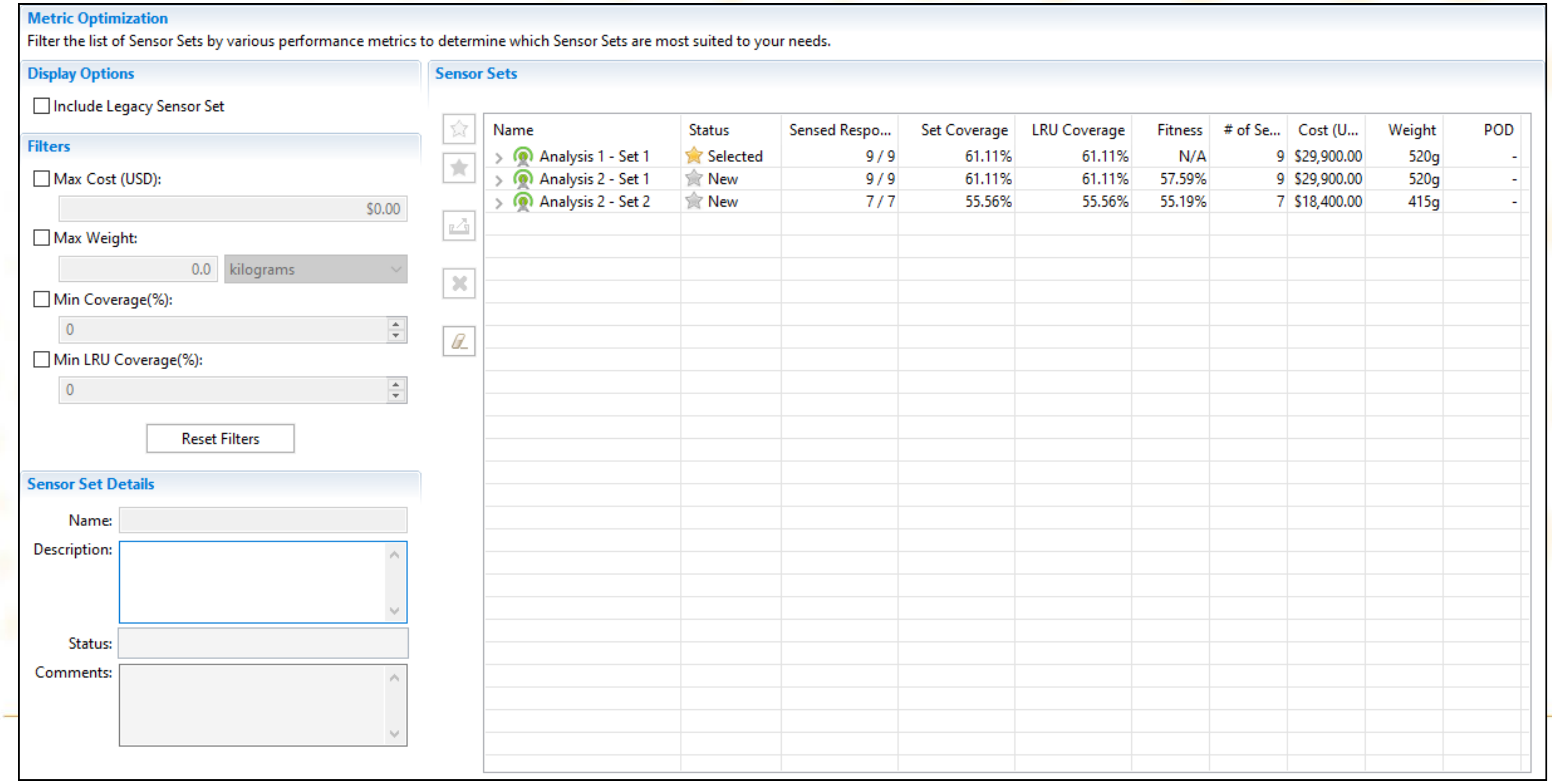
Session 6.3: Automated Diagnostic Analysis

made
decisions better MADe...

Discussion 6.3.12 Metric Optimisation

- Lists all Sensor Sets shows the details of sensed test points
- Provides filters (cost, weight, coverage) for user to optimise sensor set selection

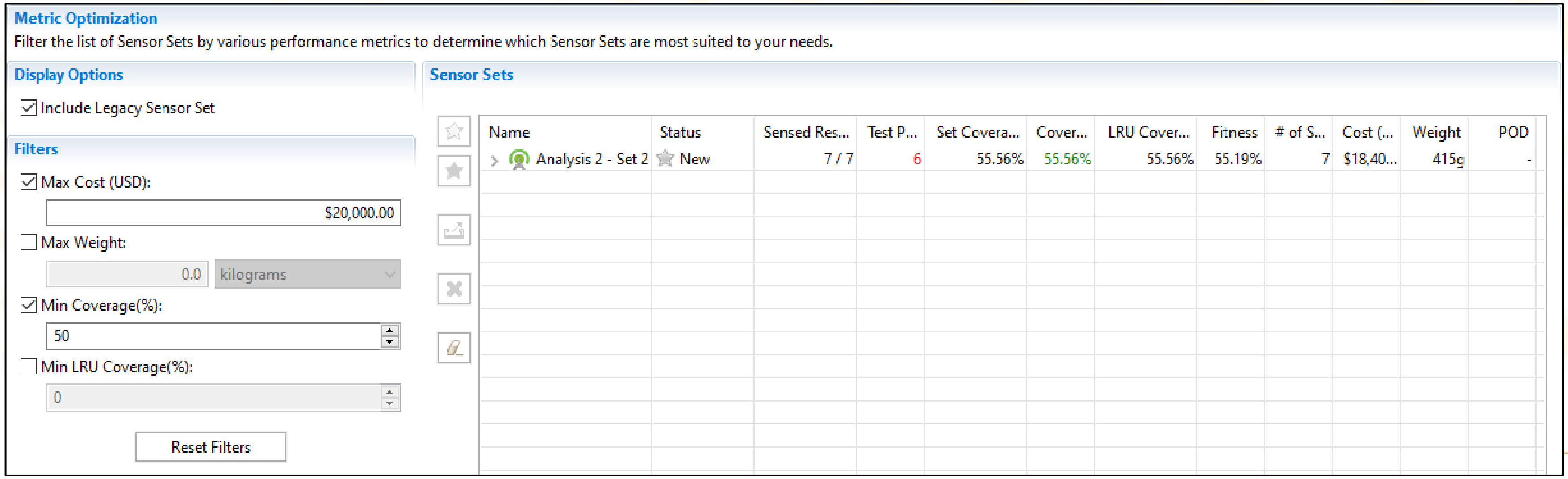


Session 6.3: Automated Diagnostic Analysis

EXERCISE 6.3.12 METRIC OPTIMIZATION

To set the metric optimization for the generated sensor sets:

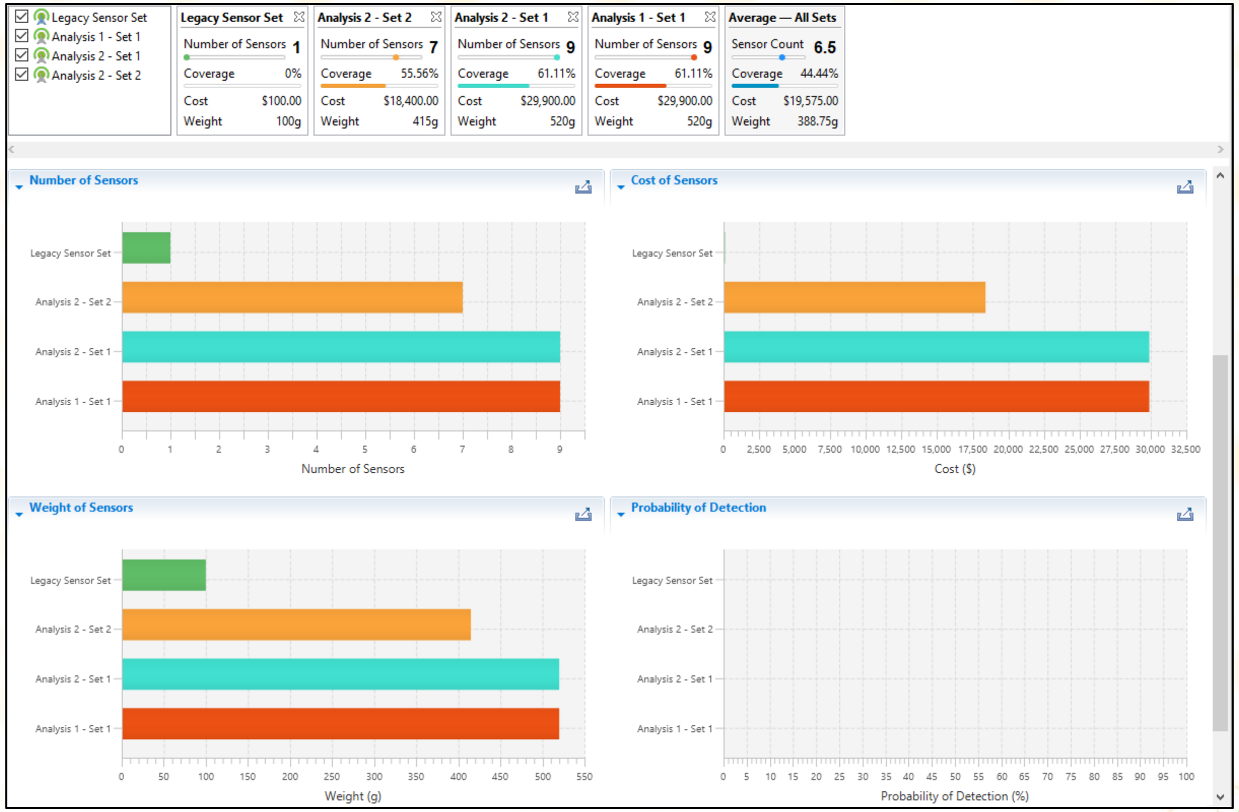
- Select the **Metric Optimization** tab
- Verify that Legacy Sensor Sets are included (check box selected)
- Under the Filters section:
  - Select check box for Max Cost and enter: **$20000**
  - Select check box for Min Coverage and enter: **50%**



Session 6.3: Automated Diagnostic Analysis

Discussion 6.3.13 Sensor Set Comparison

- This page allows users to compare sensor sets based on criteria which includes:
  - Coverage
  - Number of Sensors
  - Cost of Sensors
  - Weight of Sensors
  - Probability of Detection
  - Cost of Detection
- Multiple sensors sets can be compared
- All charts can be exported

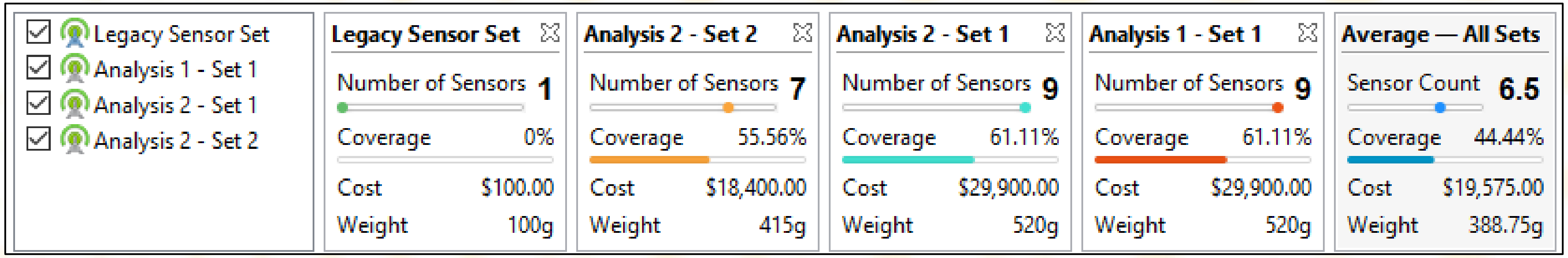


Session 6.3: Automated Diagnostic Analysis

Exercise 6.3.13 Sensor Set Comparisons

To compare sensor sets:

- Select the **Comparisons** tab
- Select the analysis sets to be compared
- The graphs can be used to visually compare the following metrics:
  - Coverage
  - LRU Coverage
  - Number of Sensors
  - Cost
  - Weight
  - Probability of Detection
  - Cost of Detection



Session 6.3: Automated Diagnostic Analysis

Session 6.3 Summary

- ✓ 6.3.1: Diagnostic Analysis
- ✓ 6.3.2: Overview/Management
- ✓ 6.3.3: Diagnostic Analysis (Landing Page)
- ✓ 6.3.4: Propagation Table
- ✓ 6.3.5: Diagnostic Inclusions
- ✓ 6.3.6: Diagnostic Exclusions
- ✓ 6.3.7: Sensor Set Analysis
- ✓ 6.3.8: Ambiguity Groups
- ✓ 6.3.9: Sensor Allocation
- ✓ 6.3.10: Sensor Parameters
- ✓ 6.3.11: Diagnostic Sets
- ✓ 6.3.12: Metric Optimisation
- ✓ 6.3.13: Sensor Set Comparison

Session 6.4: User-Defined Diagnostic Analysis

Session 6.4 Outline

6.4.1: Create a User-defined Sensor Analysis

6.4.2: Export a Sensor Set from an Automated Analysis

6.4.3: Sensor Set Details Report

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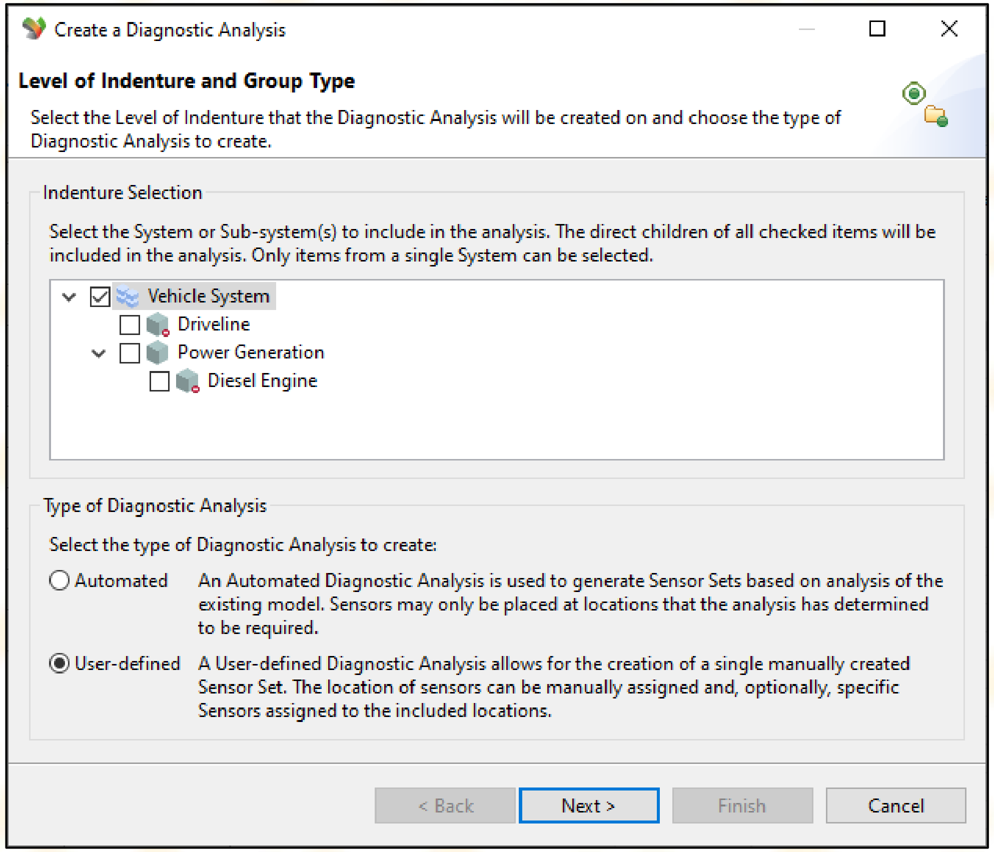
Session 6.4: User-Defined Sensor Analysis

DISCUSSION 6.4.1 CREATE A USER-DEFINED ANALYSIS

There are two methods to create a user-defined analysis:

Method 1: Use the 'Create a Diagnostic Analysis

- Open the Overview/Management page
- Select New... to open the **Create a Diagnostic Analysis** dialog
- Select the check box for the **'Vehicle system'** level of indenture
- Set the Type of Diagnostic Analysis to **User-defined**
- Select Next > to proceed to the final dialog page to enter the **analysis name**, **description** & **propagation type**



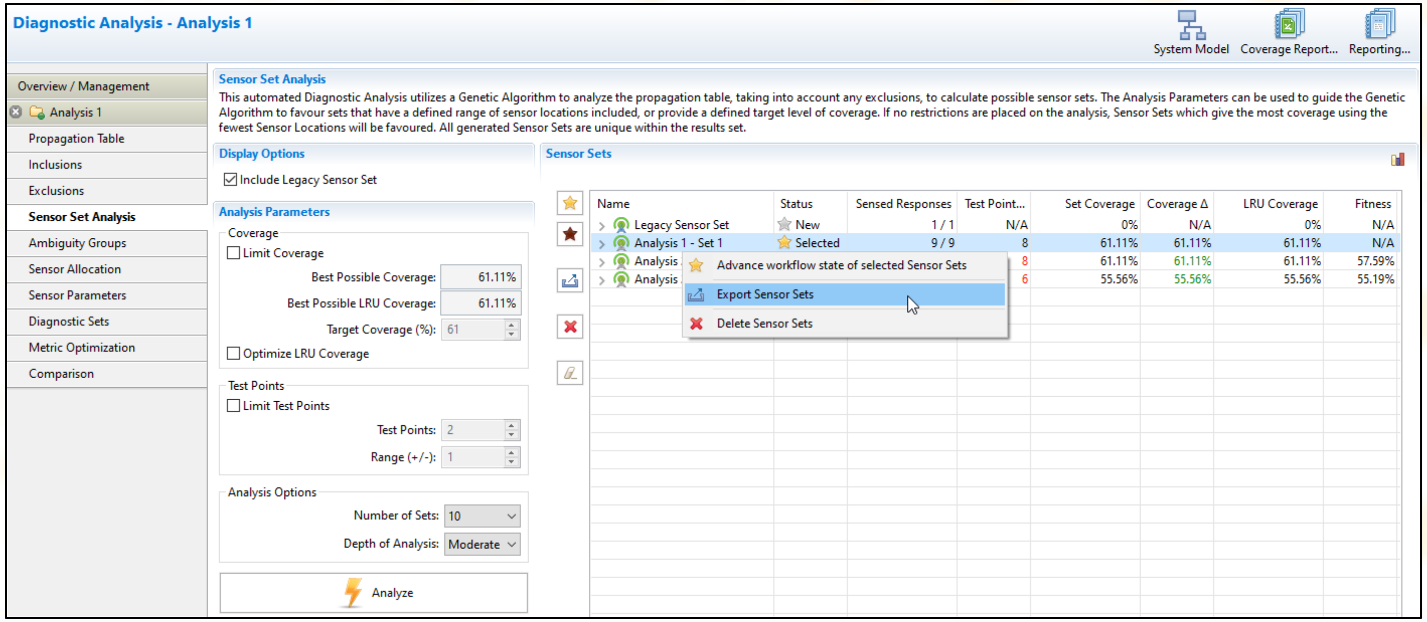
❖ Note: This method follows the same process as the Automated diagnostic analysis

Session 6.4: User-Defined Sensor Analysis

Discussion 6.4.2 Export a Sensor Set from an Automated Analysis

Method 2: Export a sensor set from Automated diagnostic Analysis

- Allows user to select a candidate sensor set and export it into its own analysis
- This analysis only focuses on the exported sensor set – no additional sets can be created
- Exported sensor set can be compared to legacy sensor set
- Additional information can be used to populate sensor parameters

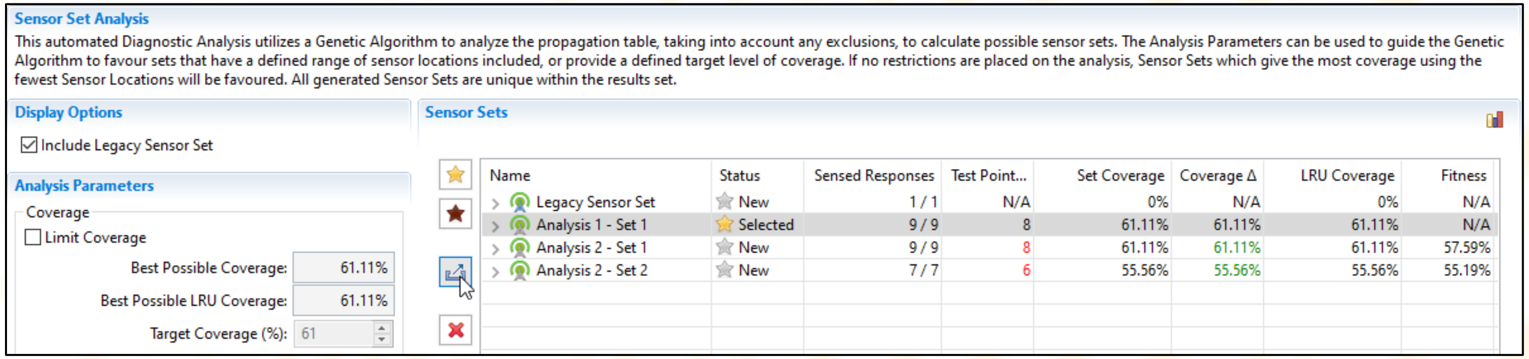


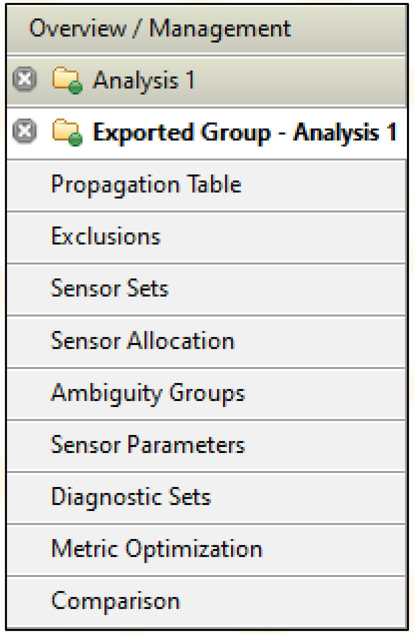
Session 6.4: User-Defined Sensor Analysis

Exercise 6.4.2 Export a Sensor Set from an Automated Analysis

Using method 2: Export a sensor set from Automated diagnostic Analysis by:

- Selecting the **Sensor Set Analysis** page
- Select the starred analysis set in the table
- Select to export the analysis
- Verify that a new analysis has been created
  - Check tabs on left for **Exported Group**





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Session 6.4: User-Defined Sensor Analysis

Discussion 6.4.3 Sensor Set Details Report

The Sensor Set Details report consists of several sections:

- **Sensor Set Group** provides an overview of the Sensor Analysis details
- **Sensor Sets Overview** table shows sensor data for each analysis set
- **Test Points/Sensors** table shows sensor data for the legacy sensor set
- **Diagnostic Sets** table lists diagnostic data for each analysis set
- **Ambiguity Groups** table lists each ambiguity group and corresponding causes & criticality

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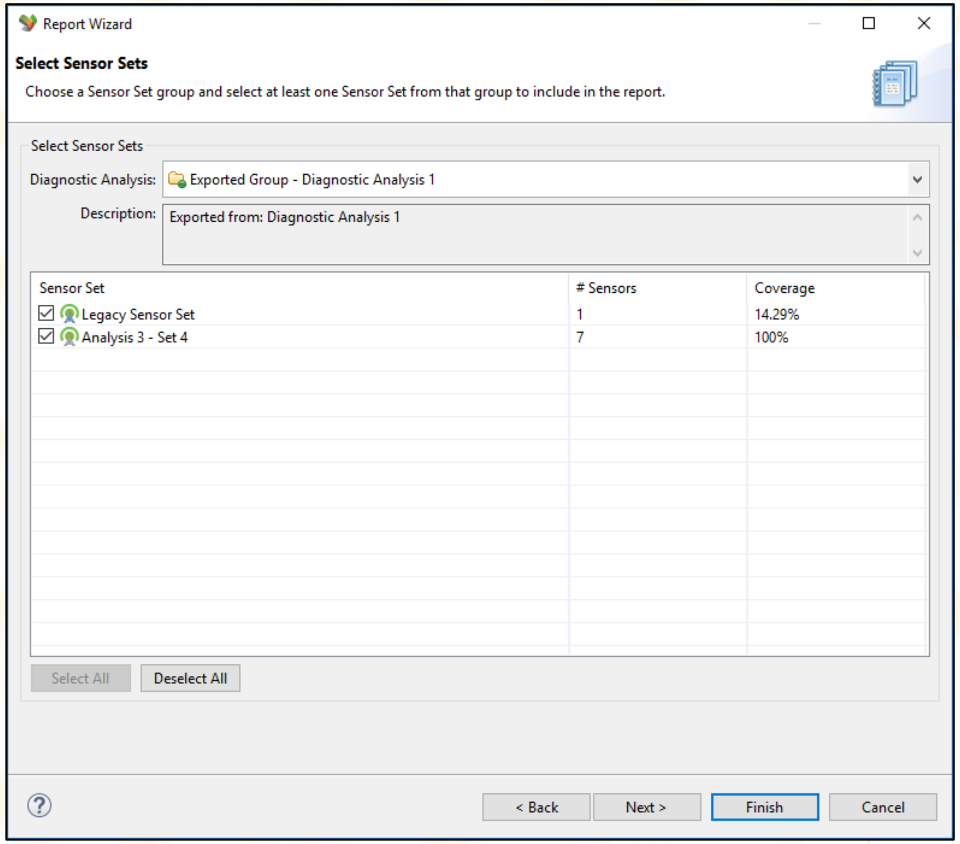
Session 6.4: Component Test Points

EXERCISE 6.4.3 SENSOR SET DETAILS REPORT

To generate a Sensor Set Details report:

- Select **Reports → Report Wizard** from the main menu
- Select **Sensor Set Details Report** then Next >
- Set the Diagnostic Analysis to **Exported Group – Diagnostic Analysis 1**
- Select both the **Legacy Sensor Set** and **Analysis 1 – Set 1**
- Select Next > to go through report formatting options
- Select Finish to generate the report



Session 6.4: Automated Diagnostic Analysis

SESSION 6.4 SUMMARY

- ✓ 6.4.1: Create a User-defined Sensor Analysis
- ✓ 6.4.2: Export a Sensor Set from an Automated Analysis
- ✓ 6.4.3: Sensor Set Details Report

Session 6.5: Modeling for PHM and Additional Features

SESSION 6.5 OUTLINE

6.5.1: Create Diagnostic Groups in the Model

6.5.2: Add Symptoms to Failure Diagrams

6.5.3: Use Diagnostic Groups and Symptoms in Diagnostic Analyses

Session 6.5: Modeling for PHM and Additional Features

Discussion 6.5.1: Create Diagnostic Groups in the Model

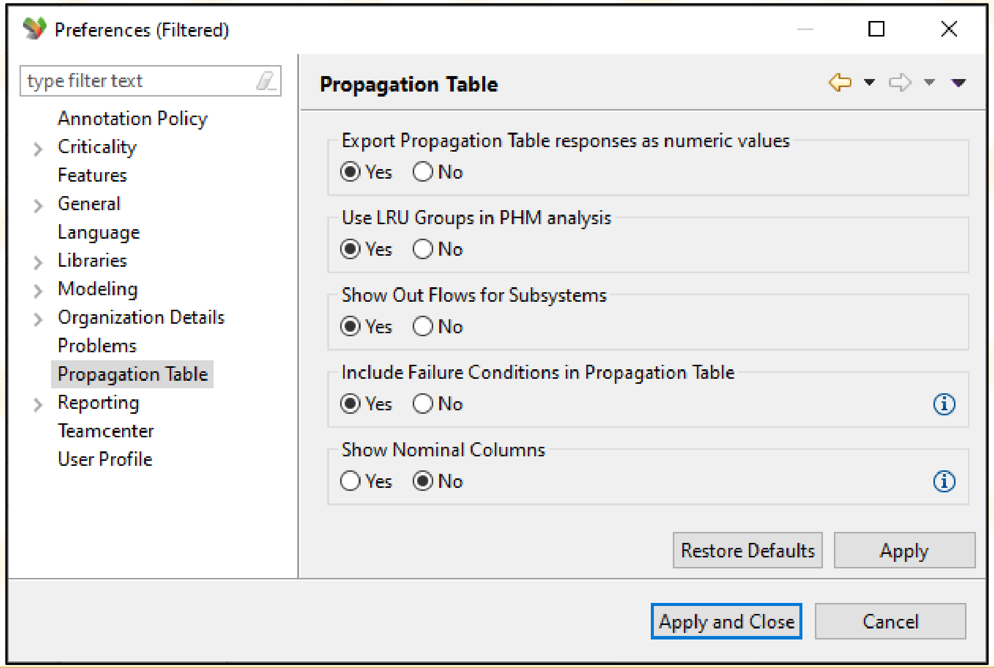
- Diagnostic Groups in MADe are groupings of failures that do not require complete diagnostic coverage, rather the failures may acceptably be ambiguous with one another.
- Failure would be grouped due to several circumstances:
  - Items are in an LRU (entire group is replaced at one time so further specific diagnosis is not required)
  - Items are physically close to one another so any maintenance that is directed by the diagnostic suite will allow access to further testing by maintenance personnel
  - Sensor numbers are limited and grouping failures gives greater control over where the inevitable ambiguities end up as a result

Session 6.5: Modeling for PHM and Additional Features

Exercise 6.5.1: Create Diagnostic Groups in the Model

To turn on the preference for **Diagnostic Groups** to be included in analysis:

- Select **Preferences → Application Preferences** from the main menu
- Go to the **Propagation Table** section and within select the preference set **Use LRU Groups in PHM Analysis** to **Yes** (this option may have already been selected)
- Select Apply and Close to apply the changes and close the dialog

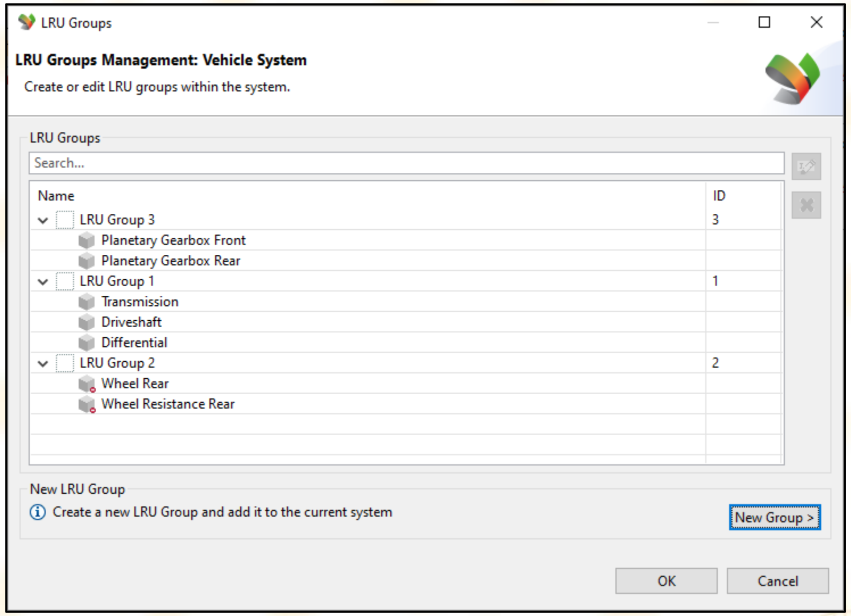


Session 6.5: Modeling for PHM and Additional Features

EXERCISE 6.5.1: CREATE DIAGNOSTIC GROUPS IN THE MODEL (CONTINUED)

To create **Diagnostic Groups** in the model:

- Open the **'Driveline'** system model
- Select the **'Transmission'** component
- From the **Properties** viewer select [icon] from the **Maintainability** section
- In the LRU Groups dialog, select New Group >
- Select the checkboxes for the following items:
  - **'Transmission'**
  - **'Driveshaft'**
  - **'Differential'**
- Select Create and then OK to close the dialog



Session 6.5: Modeling for PHM and Additional Features

Exercise 6.5.1: Create Diagnostic Groups in the Model (Continued)

- Repeat so that the following groupings are created:
  - Group 1: **Transmission, Driveshaft, Differential**
  - Group 2: **Wheel Rear, Wheel Resistance Rear**
  - Group 3: **Planetary Gearbox Front, Planetary Gearbox Rear**

Session 6.5: Modeling for PHM and Additional Features

Discussion 6.5.2: Create Symptoms and Symptom Groups in the Model

- **Symptoms** are physical events that occur due to a failure and may be used to provide or aid in the diagnosis of failures.
- Symptoms are added into the model via the **Failure Diagram** and will then appear in the **PHM Propagation Table** and **Analysis** given certain conditions are met.
  1. Does the symptom provide observability of all paths that lead to each failure mode it (the symptom) interacts with?

     If yes; include the symptom in the propagation table as a column (used for coverage and syndrome POD calculations)

     If no; go to test 2
  2. Does the symptom have ambiguity between multiple failure modes? (i.e. the associated faults are connected to multiple failure modes)

     If no; include in path POD (then used in overall POD calculation)

     If yes; invalid symptom (not used in coverage or POD)

Discussion 6.5.2: Create Symptoms and Symptom Groups in the Model (Continued)

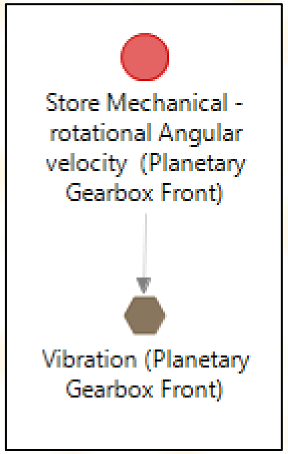
- **Symptom Groups** are when two or more symptoms are grouped for the purpose of failure detection and diagnosis.
- This is to represent the circumstance where multiple failures manifest the same physical symptom and that the **symptom** may potentially be sensed using the one sensor (or location).
- An example of this may be two similar components with common failure modes in the system resulting in the same vibration.
- This vibration could potentially be sensed at either location and may indicate that either of the similar components have failed.

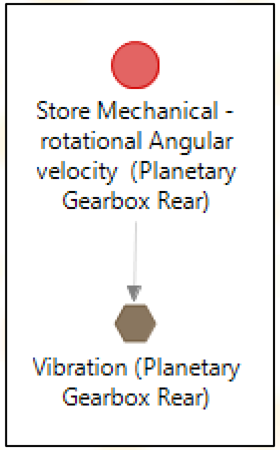
Session 6.5: Modeling for PHM and Additional Features

Exercise 6.5.2: Create Symptoms and Symptom Groups in the Model

Create a **Symptom Group** in the model:

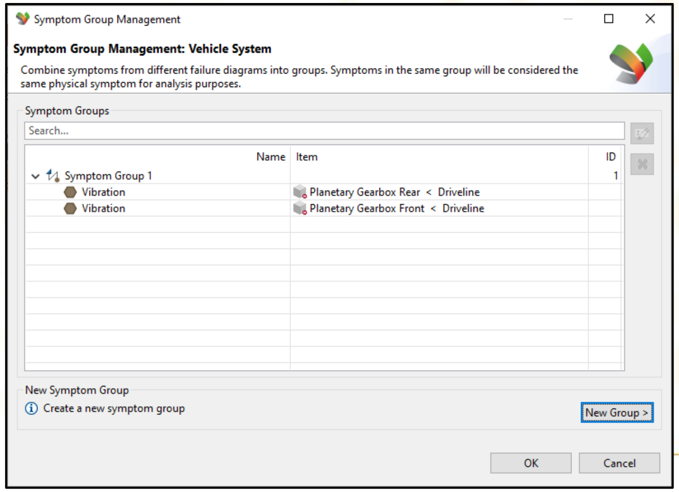
- Open the **'Driveline'** system model
- Right-click the **'Planetary Gearbox Front'** component and select the **Failure Diagram** from the menu
- Select in the **Failure Concepts** window
- Select **Vibration** and place it onto the **Failure Diagram** canvas
- Connect the **Functional Failure Mode** to the **Vibration** concept
- Repeat for the **'Planetary Gearbox Rear'** component

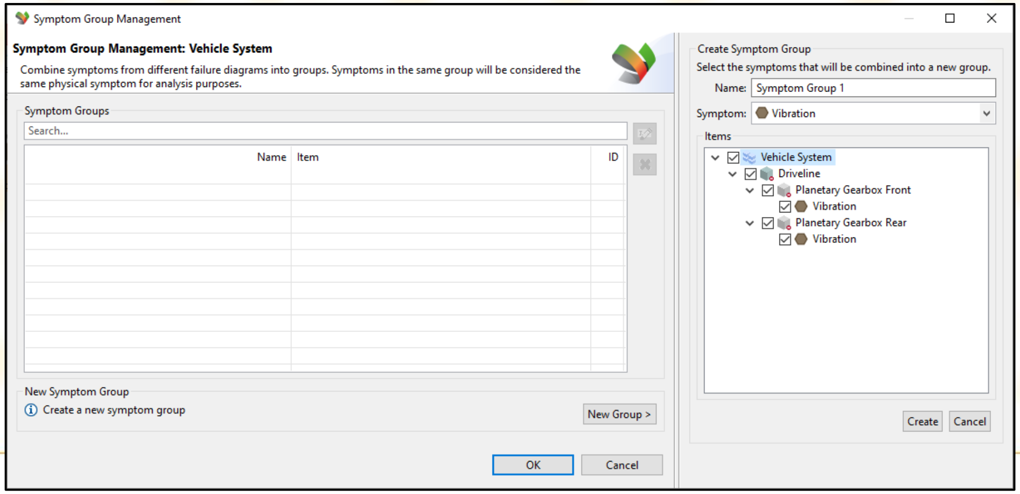




Exercise 6.5.2: Create Symptoms and Symptom Groups in the Model (Continued)

- Select one of the **Vibration** concepts
- In the **Properties** viewer go to the **Symptom Groups** tab and select
- From the dialogue, select **New Group**
- In the **Symptom** field drop down menu, select **Vibration**
- Within the **Items** section select the two **Vibration** symptom check boxes
- Select Create and then select OK

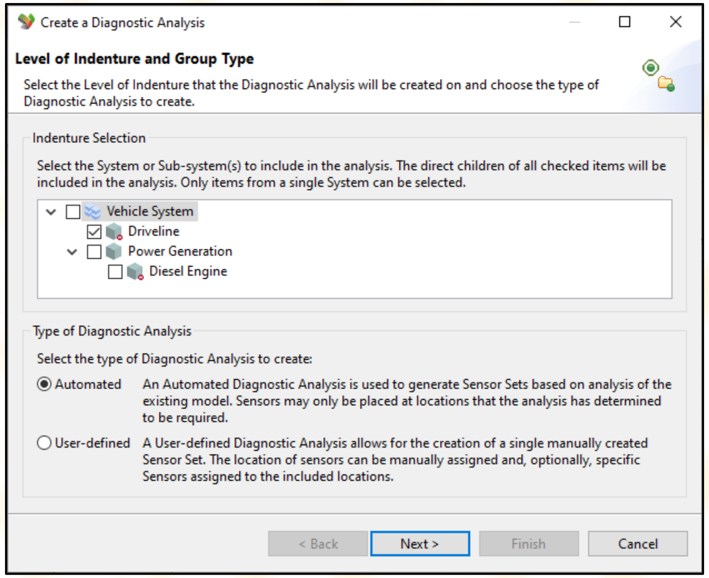


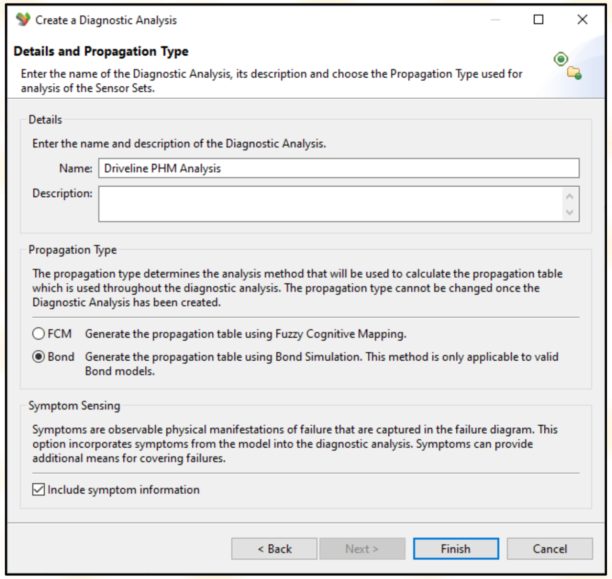


EXERCISE 6.5.3: RUN A DIAGNOSTIC ANALYSIS WITH THE UPDATED MODEL

To run a **Diagnostic Analysis**:

- Select **Analyses → Diagnostic Analyses** from the main menu
- Select New...
- In the dialogue, select the following:
  - Indenture Selection: **'Driveline'**
  - Type of Diagnostic Analysis: **Automated**
- Select Next >
  - Enter the following details for the Analysis:
  - Name: **Driveline PHM Analysis**
  - Propagation Type: **Bond**
  - Check the **Include symptom information** check box
  - Select Finish



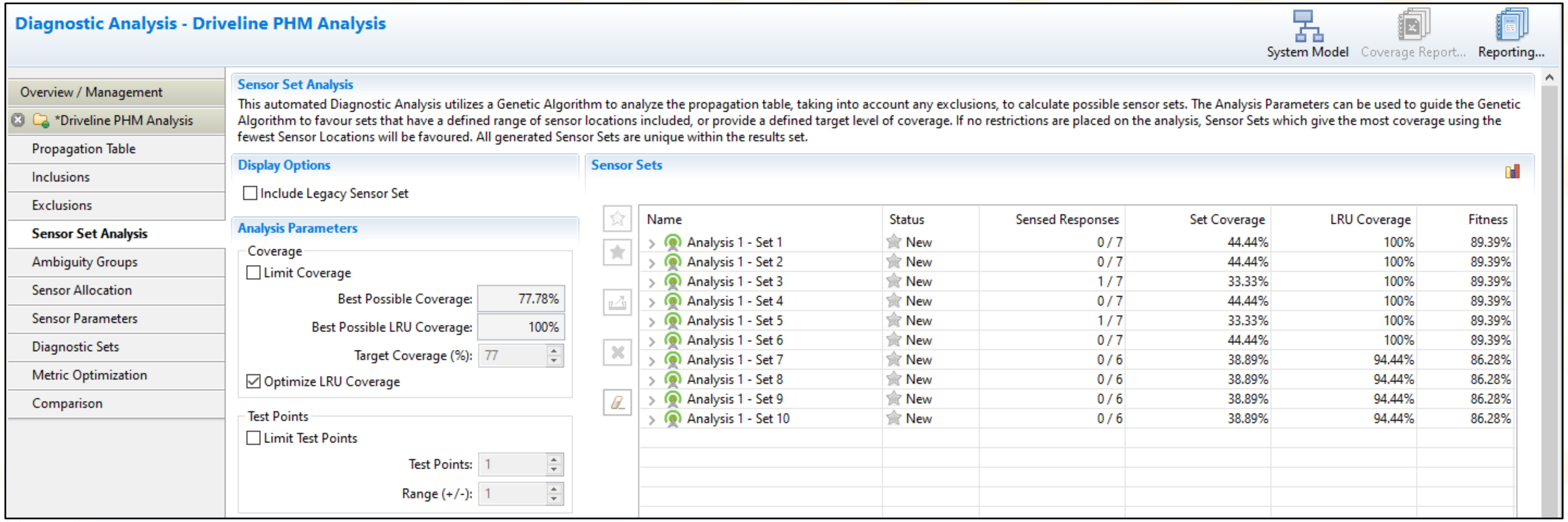


Session 6.5: Modeling for PHM and Additional Features

Exercise 6.5.3: Run a Diagnostic Analysis with the Updated Model (Continued)

- Select the **Optimize LRU Coverage** check box
- Under Analysis Options set Number of Sets to **10**
- Select 

  - If there are errors in the bond model, a warning message will appear.



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Session 6.5: Modeling for PHM and Additional Features

Session 6.5 Summary

- ✓ 6.5.1: Create Diagnostic Groups in the Model
- ✓ 6.5.2: Add Symptoms to Failure Diagrams
- ✓ 6.5.3: Use Diagnostic Groups and Symptoms in Diagnostic Analyses

Session 6: Prognostics & Health Management Analyses

Session 6 Summary

- ✓ 6.1: Sensor Library
- ✓ 6.2: Test Points
- ✓ 6.3: Automated Diagnostic Analysis
- ✓ 6.4: User-defined Diagnostic Analysis
- ✓ 6.5: Modeling for PHM and Additional Features

Conclusion: Using MADe

CONSOLIDATING TRAINING SESSIONS 1 – 6

- Understand MADe capabilities
- Understand how MADe can be used/applied
- Informing PHM Technology of which features/processes are of most interest
- Identify projects that MADe can be used
- Use existing material to expedite modeling process
- Request for modeling assistance from PHMT (follow-up support, reviews etc.)
- Set project targets and identify deliverables that MADe will be used for
- Consult PHMT engineering with deliverables you expect to meet
- Request PHMT for custom reports and templates for software outputs

Conclusion: MADe Feature Check List

- **1: MADe Modeling**
- 1.1: Navigation
- 1.2: Project Creation
- 1.3: Mission Profile Definition
- 1.5: Functional Modeling (FHA)
- 1.6: System Modeling
- 1.7: MADe Library
- **2: Failure Simulation**
- 2.1: Annotations
- 2.2: Failure Simulation
- 2.3: Mission Profile Groups
- 2.4: Failure Analysis
- 2.5: Features & Characteristics
- **3: Safety Analyses**
- 3.1: FMEA
- 3.2: Criticality Analysis
- 3.3: Revised FMECA
- 3.4: Critical Item Analysis
- 3.5: Failure Conditions (FHA)
- 3.6: Common Mode Analysis (CMA)
- 3.7: Functional Fault Tree Analysis
- **4: Reliability Analyses**
- 4.1: Reliability Block Diagram
- 4.2: Reliability Allocation
- 4.3: Reliability Editing
- 4.4: Failure Rate Prediction
- 4.5: Markov Analysis
- 4.6: Hardware Fault Tree Analysis
- **5: Maintenance Analyses**
- 5.1: Maintenance Cost Estimates
- 5.2: Maintenance Properties
- 5.3: Reliability Centered Maintenance (Classic)
- 5.4: Reliability Centered Maintenance (Back-Fit)
- **6: PHM Analyses**
- 6.1: Sensor Library
- 6.2: Test Points
- 6.3: Automated Diagnostic Analysis
- 6.4: User-Defined Sensor Analysis
- 6.5: Modeling for PHM and Additional Features

Conclusion: MADe Workflows

WHAT CAN MADE DO?

MADe covers several analyses & deliverables including:

- Functional modeling (FBDs)
- Failure Analysis (Root Cause Analysis)
- Failure Simulations
- Failure Mode Effects Analysis
- Criticality Analysis
- Mission Profile (Usage Profile, Mission Scenarios)
- Reliability Allocation
- Markov Analysis
- Failure Rate Prediction
- Fault Tree Analysis
- Maintenance Cost Estimation
- Reliability Centered Maintenance
- Back-fit Reliability Centered Maintenance
- Maintenance Task Analysis
- Inherent Diagnostic Capability (Testability)
- Functional Hazards Assessment
- Common Mode Analysis

Conclusion: MADe Processes

How can MADe be used?

MADe can be used to facilitate numerous engineering processes:

- FMEA Process
- FMECA Process
- ARP Safety Process
- RAM Analysis Process
- Safety Integrity Process
- FRACAS Process
- Defect Remediation Process
- More in Development…

Conclusion: MADe Roadmap

made
decisions better MADe...

What is planned for the future?

- The MADe software is continually growing using customer feedback
- We provide customers visibility to review and comment engineering specifications
- Specifications currently on the Roadmap include:

General	Criticality	Reliability
• New reporting templates (Delta Reports, FMEA reports, FMECA, Reliability) • Customisable reporting (more export formats, ability to trim down reports) • Analysis Quality Index (AQI) • Upgrades to Annotations (embedded annotations, review capabilities)	• New criticality methods (ASIL, IDAL, SAE, AIAG) • Hazard Analysis (taxonomy and diagram) • Fuzzy Fault Tree (LPIC)	• Reliability Simulation • Level Of Repair Analysis (LORA) • LSAR Export (B-Tables)

Conclusion: MADe Example Systems

<u>REFERENCING EXEMPLAR ITEMS/SYSTEMS</u>

- MADe Palette
  - Generic components
  - Generic parts
- MADe Models (Example Library)
  - Generic systems
  - In-progress or unreleased systems
  - Used as a guide/reference for modeling
- Domains of Interest
  - Electrical
  - Mechanical
  - Hydraulics
  - Pneumatic
  - Software

Conclusion: Additional Resources

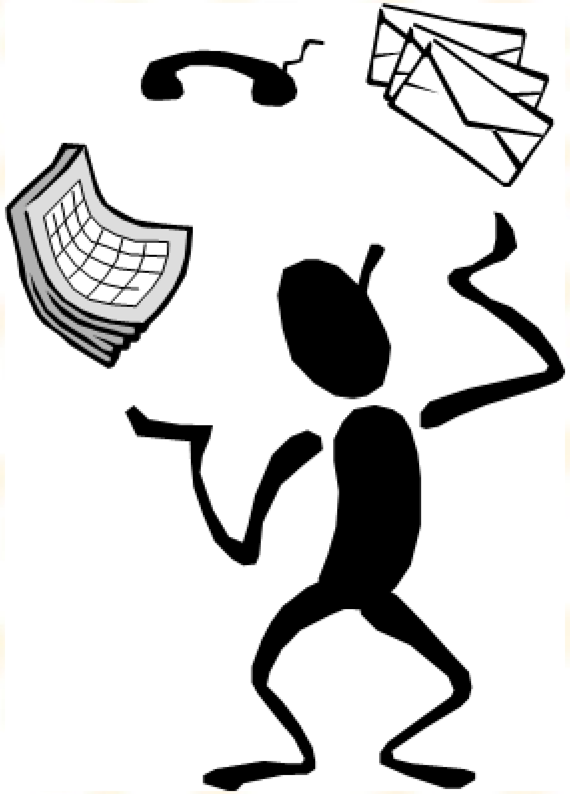
Additional Information

- PHMT website - http://www.phmtechnology.com/resources/
  - Technical Papers
  - Published Papers
  - Presentations given at conferences
  - Training
  - Currently available training courses
  - Build Updates and Guides: http://www.phmtechnology.com/resources/downloads.html
- MADe HELP
- MADe Glossary

Conclusion: Ongoing Support

<u>WHAT IF WE HAVE QUESTIONS?</u>

- Training Feedback
  - Records training course
  - Attendees
  - Questions
  - Bugs
  - Enhancements
- Follow-up Meetings
  - Teleconferencing
  - Model Validation
  - Workflow Consolidation
  - General Q&A
  - Specification/Implementation Review



Conclusion: Certification

Course Completion

- All attendees can be provided with MADe Training certification
  - Soft/Hard Copy Available
- Congratulations!