Designing for Reliability with ReliaSoft Software

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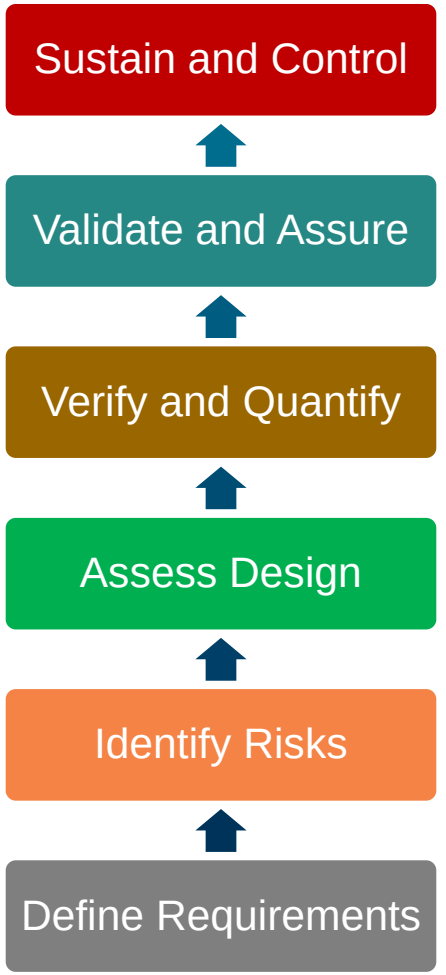
Application Engineer

Goal

- Provide the overall direction and process for Design for Reliability (DFR) program
- Highlight essential techniques, best practices and industry standards for Reliability Engineering
- Demonstrate a set of tools that would support all phases of DFR program
  - How to address the lack of detailed data
  - How the tools can be used for planning and executing test plans
  - And more



Agenda

1. Introduction
2. Define Reliability Requirements
3. Identify Reliability Risks
4. Assess & Analyze Phase
5. Verify & Quantify
6. Validate & Assure
7. Sustain and Control
8. Conclusions

Case study
ReliaSoft Software

Prenscia Overview

Prenscia

Prenscia helps engineers deliver durable and reliable products and avoid the cost of unexpected failures.

Software Brands

nCode

ReliaSoft

Training & Education

- Design for reliability
- Design for durability
- Fatigue theory
- Hands-on software

Services

- Materials testing
- Solutions for design, development and test
- Solutions for asset management

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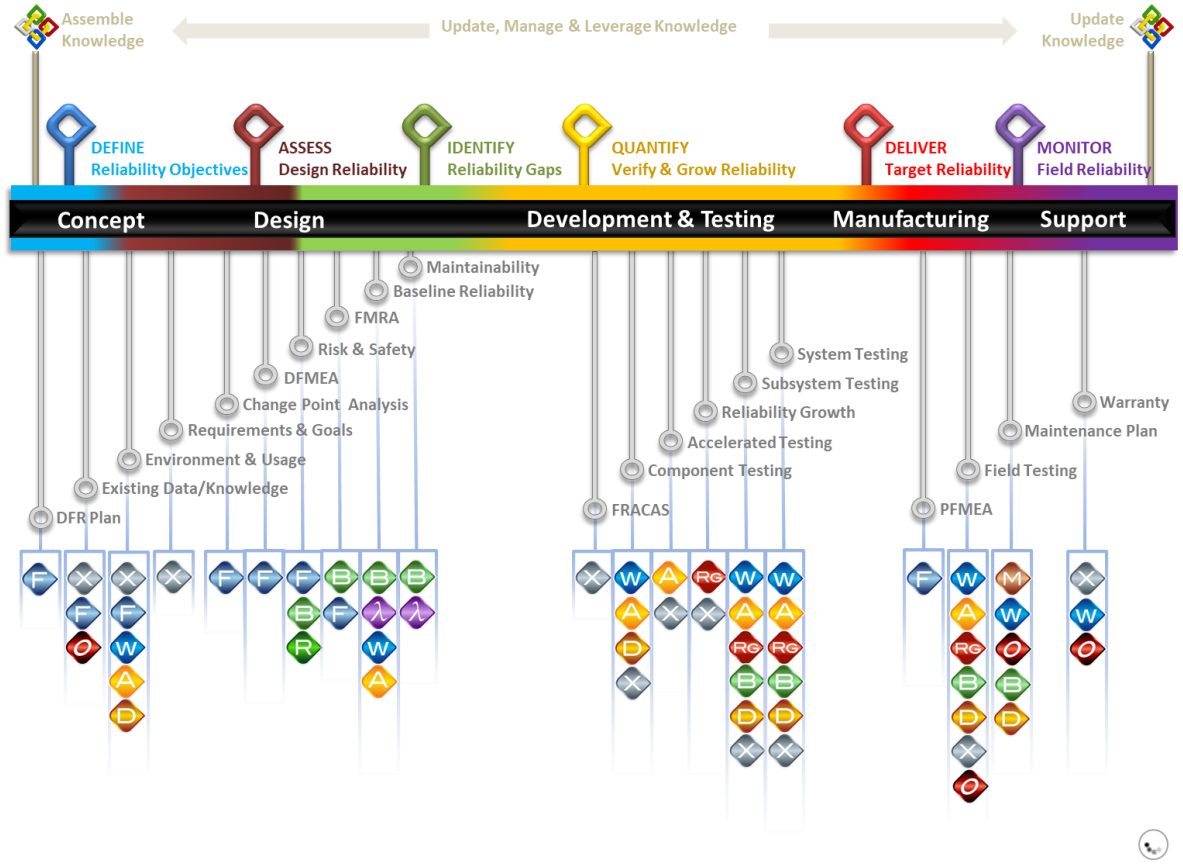
Introduction

What is DFR

- A discipline that refers to the process of **designing reliability into products**
  - Ensure customer expectations for reliability are fully met
  - Minimize costs and increase profit margins

- **DFR is a Process** that an organization needs to have in place in order to drive reliability into their products.
  - Specific order of reliability activities and practices
  - Linkage between development stages
  - Set of engineering, scientific and software tools



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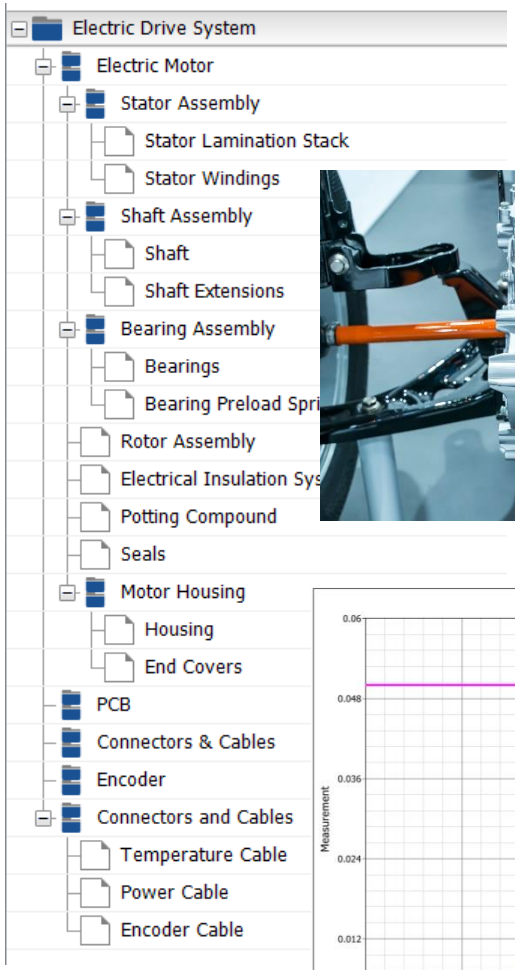
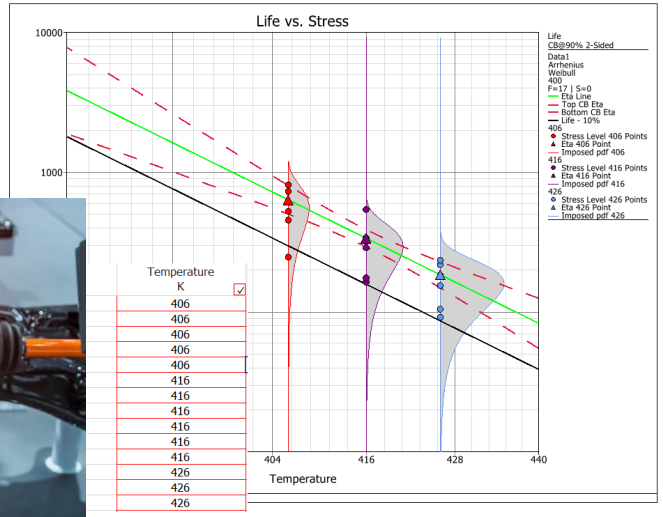
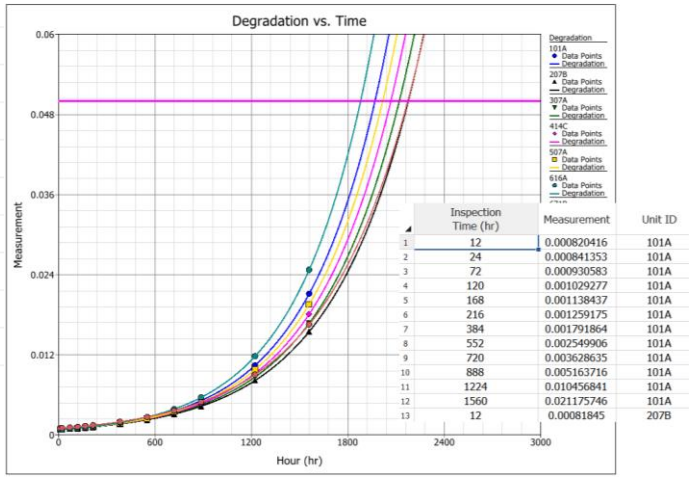
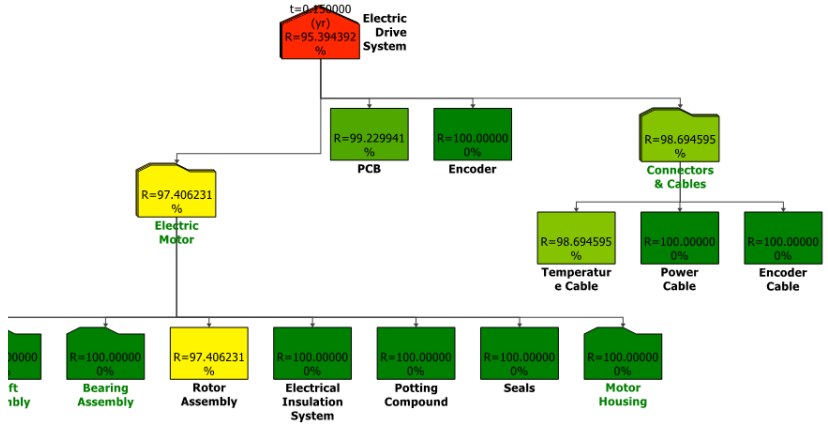
Case study for Seminar – Electric Drive System



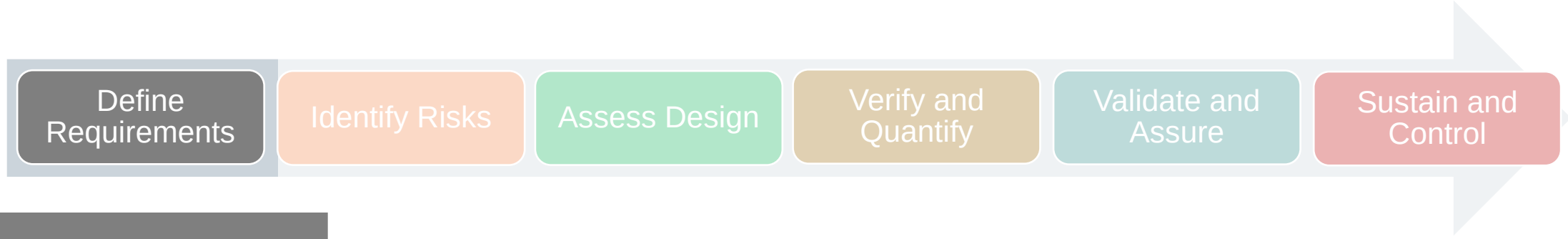






Phase 1 - Define Reliability Requirements

Define Reliability Requirements



Deliverables
Reliability Requirements
Certification Requirements
Baseline Reliability Report
Customer Usage Summary Report

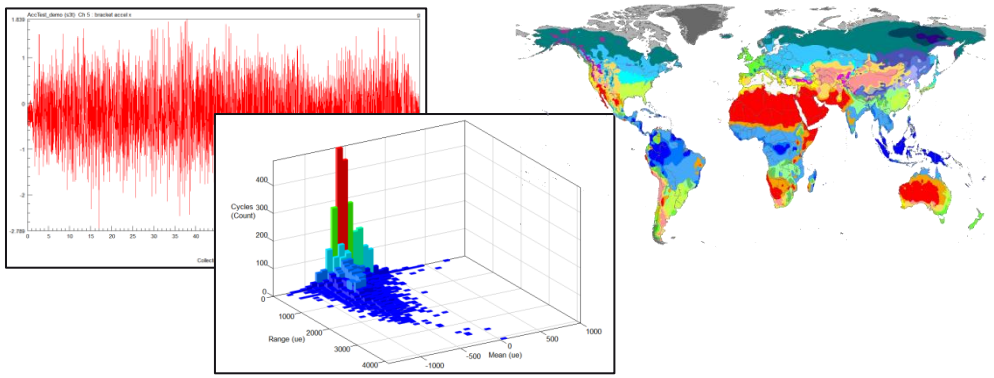
- Clearly and quantitatively define the reliability requirements and goals for our products
- Define end-user product environmental/usage conditions.

This phase forms the basis to which the product success will be measured and will be passed to future steps in DFR process

Get information

- Gather information & Lessons Learned
  - Collect (or at least identify) the information we will need for subsequent steps
  - If similar designs exist, FRACAS data as to observed failure modes, occurrence rates, etc., are invaluable.

- Define Customer Usage and Environment
  - Temperature
  - Humidity
  - Customer usage stress
  - Duty Cycles
  - Limits of operation

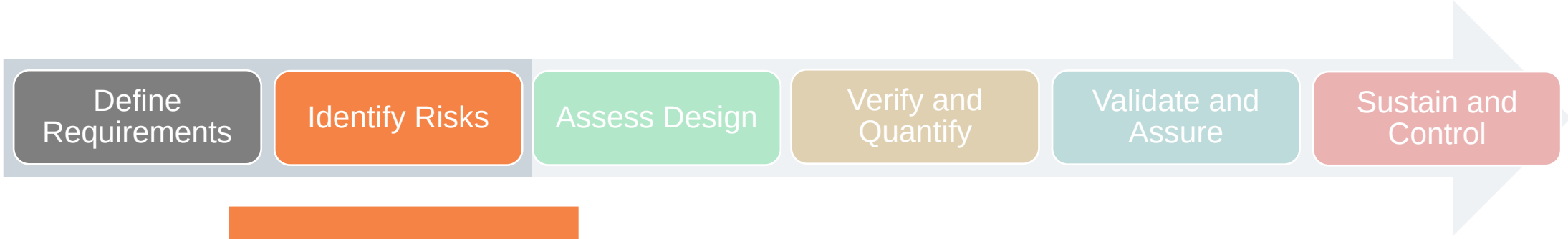


Reliability statement

"95% Reliability for 15,000 hours with 70% confidence for a 98th percentile customer"

Phase 2 - Identify Reliability Risks Phase

Identify Reliability Risks Phase



Deliverables
Risk Discovery Analysis
P-Diagram
DFMEA & Actions
Validation Test Plan
Special Characteristics
FTA

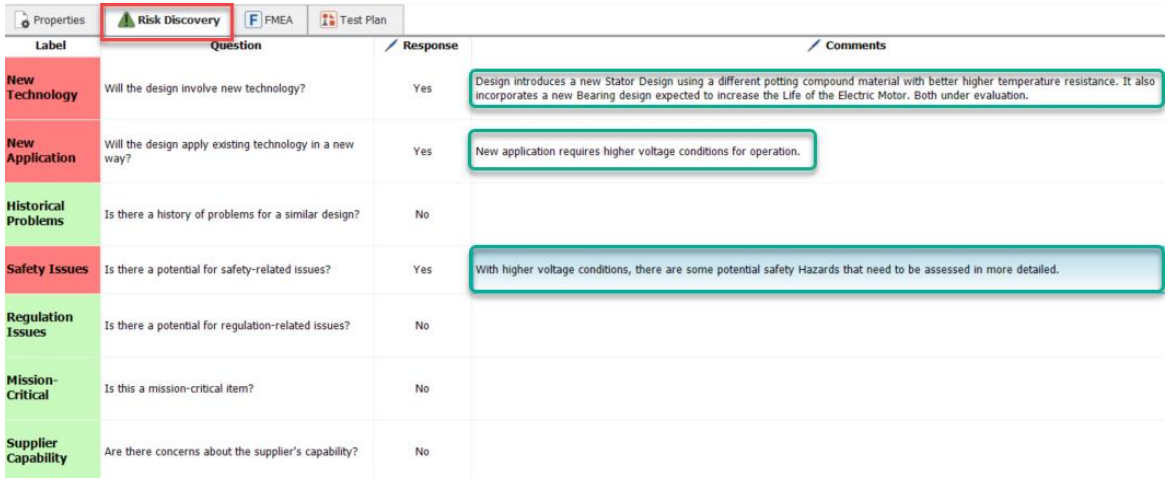
- Understand how much change is introduced to an upgraded product (Change Point of Analysis) or a new (Risk Discovery)
- Drive actions that will help mitigate those risks.

The purpose of this phase is to identify and prioritize the *Key Reliability Risk* items and their corresponding *Risk Reduction Strategy*

Key Tools to Assess Risks

Risk Discovery

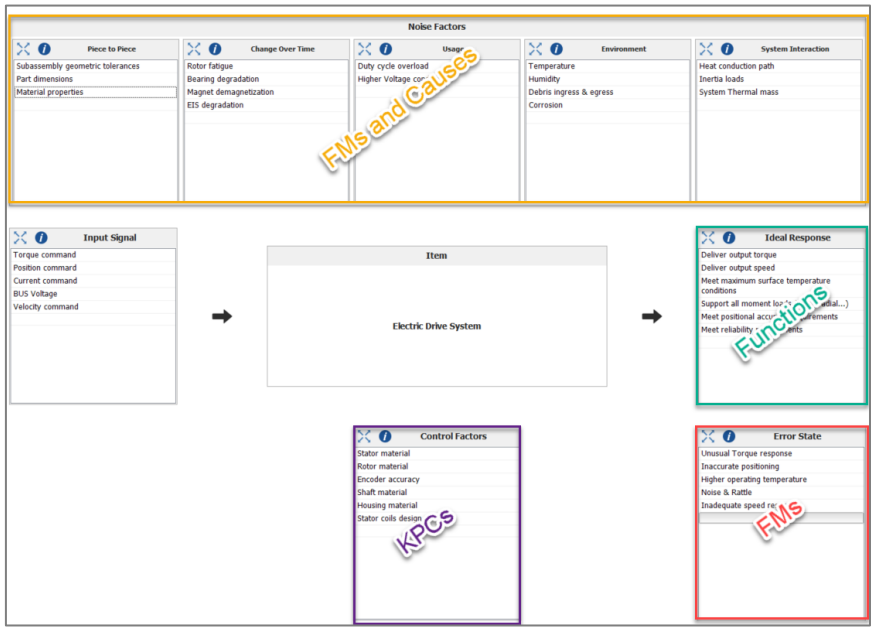
- Preliminary risk analysis that can help you select the elements on your design that will receive more detailed analysis



Label	Question	Response	Comments
New Technology	Will the design involve new technology?	Yes	Design introduces a new Stator Design using a different potting compound material with better higher temperature resistance. It also incorporates a new Bearing design expected to increase the Life of the Electric Motor. Both under evaluation.
New Application	Will the design apply existing technology in a new way?	Yes	New application requires higher voltage conditions for operation.
Historical Problems	Is there a history of problems for a similar design?	No	
Safety Issues	Is there a potential for safety-related issues?	Yes	With higher voltage conditions, there are some potential safety Hazards that need to be assessed in more detailed.
Regulation Issues	Is there a potential for regulation-related issues?	No	
Mission-Critical	Is this a mission-critical item?	No	
Supplier Capability	Are there concerns about the supplier's capability?	No	

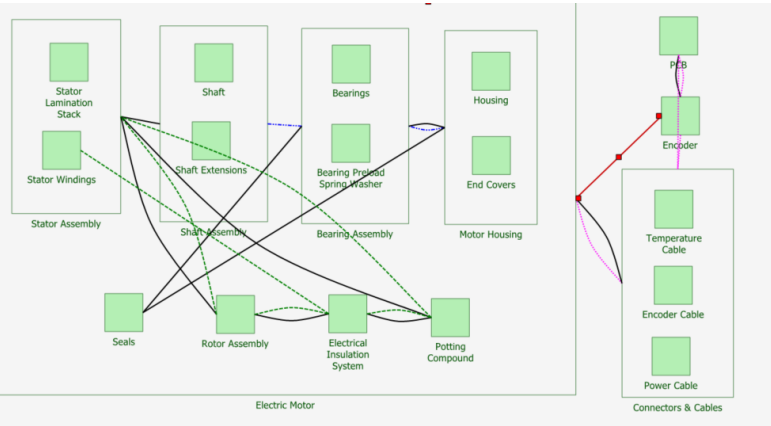
P-Diagram

- Brainstorm! What are the inputs? What are the outputs? What factors must be considered?
- It directly provide inputs to DFMEA
  - Outputs > Functions
  - Control Factors > KPCs
  - Error States > Failure Modes
  - Noise Factors > Failure Modes & Causes



Key Tools to Assess Risks

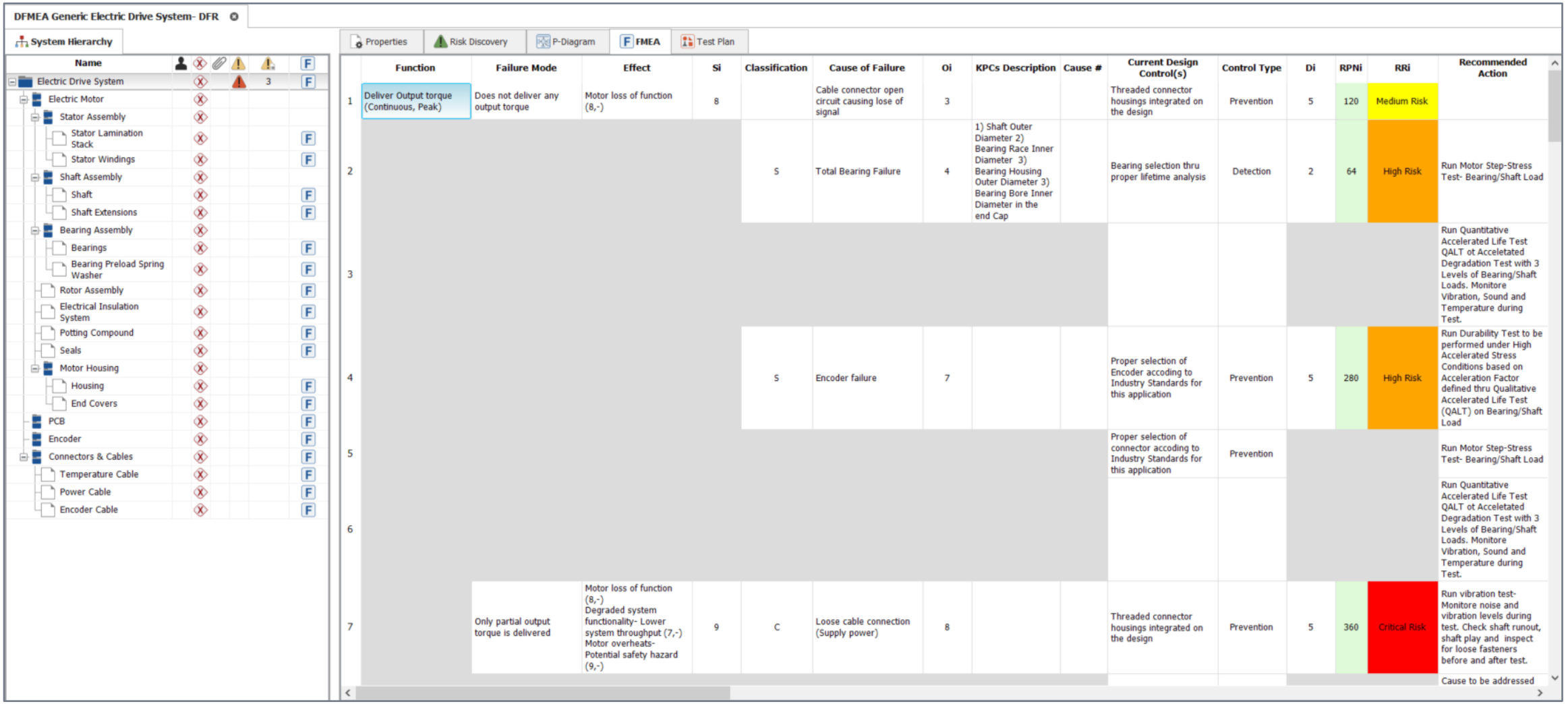
- DFMEA
  - A document that guides one through a systematic process to define the key functions of a system and identify risks to those functions.



- Identify Key Functions and interactions of components
- Discover root cause of failures -- Prioritize by relative risk
- Develop actions to mitigate highest risk causes

Key Tools to Assess Risks

DFMEA

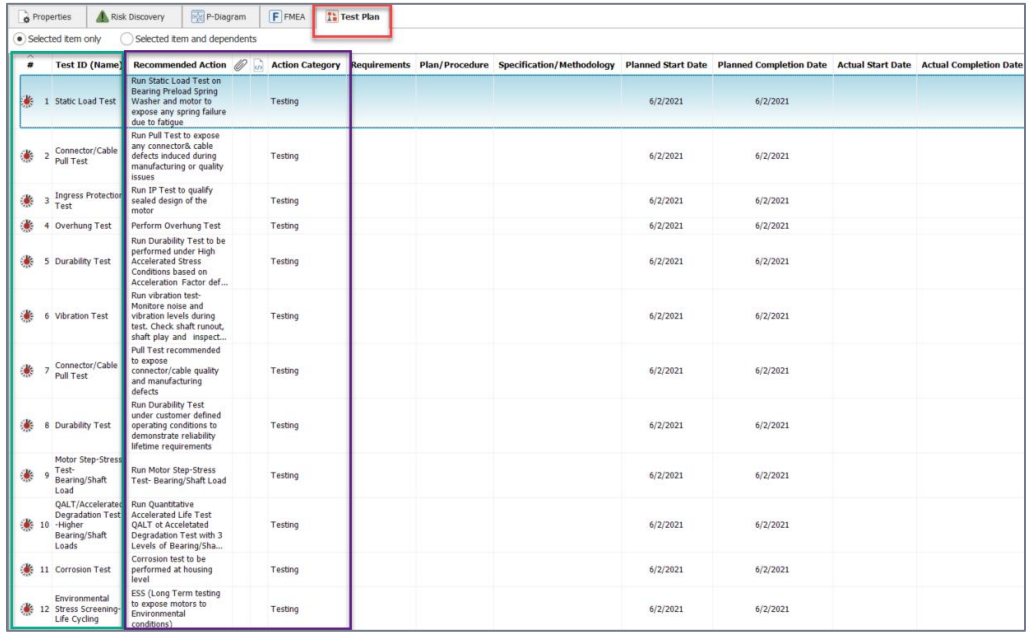


	Function	Failure Mode	Effect	Si	Classification	Cause of Failure	Oi	KPCs Description	Cause #	Current Design Control(s)	Control Type	Di	RPNi	RRi	Recommended Action
1	Deliver Output torque (Continuous, Peak)	Does not deliver any output torque	Motor loss of function (8,-)	8		Cable connector open circuit causing lose of signal	3			Threaded connector housings integrated on the design	Prevention	5	120	Medium Risk	
2					S	Total Bearing Failure	4	1) Shaft Outer Diameter 2) Bearing Race Inner Diameter 3) Bearing Housing Outer Diameter 3) Bearing Bore Inner Diameter in the end Cap		Bearing selection thru proper lifetime analysis	Detection	2	64	High Risk	Run Motor Step-Stress Test- Bearing/Shaft Load
3															Run Quantitative Accelerated Life Test QALT ot Acceletated Degradation Test with 3 Levels of Bearing/Shaft Loads. Monitore Vibration, Sound and Temperature during Test.
4					S	Encoder failure	7			Proper selection of Encoder accoding to Industry Standards for this application	Prevention	5	280	High Risk	Run Durability Test to be performed under High Accelerated Stress Conditions based on Acceleration Factor defined thru Qualitative Accelerated Life Test (QALT) on Bearing/Shaft Load
5										Proper selection of connector accoding to Industry Standards for this application	Prevention				Run Motor Step-Stress Test- Bearing/Shaft Load
6															Run Quantitative Accelerated Life Test QALT ot Acceletated Degradation Test with 3 Levels of Bearing/Shaft Loads. Monitore Vibration, Sound and Temperature during Test.
7		Only partial output torque is delivered	Motor loss of function (8,-) Degraded system functionality- Lower system throughput (7,-) Motor overheats- Potential safety hazard (9,-)	9	C	Loose cable connection (Supply power)	8			Threaded connector housings integrated on the design	Prevention	5	360	Critical Risk	Run vibration test- Monitore noise and vibration levels during test. Check shaft runout, shaft play and inspect for loose fasteners before and after test.
															Cause to be addressed

Key Tools to Assess Risks

Validation Test Plan

- List of actions that describe specific tests that need to be performed.
- Design assessment, design maturity tests and production screening tests should be considered
- Tests results used to populate the Reliability model and assess areas of weakness in the design



#	Test ID (Name)	Recommended Action	Action Category	Requirements	Plan/Procedure	Specification/Methodology	Planned Start Date	Planned Completion Date	Actual Start Date	Actual Completion Date
1	Static Load Test	Run Static Load Test on Bearing Preload Spring Washer and motor to expose any spring failure due to fatigue	Testing				6/2/2021	6/2/2021		
2	Connector/Cable Pull Test	Run Pull Test to expose any connector& cable defects induced during manufacturing or quality issues	Testing				6/2/2021	6/2/2021		
3	Ingress Protection Test	Run IP Test to qualify sealed design of the motor	Testing				6/2/2021	6/2/2021		
4	Overhung Test	Perform Overhung Test	Testing				6/2/2021	6/2/2021		
5	Durability Test	Run Durability Test to be performed under High Accelerated Stress Conditions based on Acceleration Factor def...	Testing				6/2/2021	6/2/2021		
6	Vibration Test	Run vibration test- Monitore noise and vibration levels during test. Check shaft runout, shaft play and inspect...	Testing				6/2/2021	6/2/2021		
7	Connector/Cable Pull Test	Pull Test recommended to expose connector/cable quality and manufacturing defects	Testing				6/2/2021	6/2/2021		
8	Durability Test	Run Durability Test under customer defined operating conditions to demonstrate reliability lifetime requirements	Testing				6/2/2021	6/2/2021		
9	Motor Step-Stress Test- Bearing/Shaft Load	Run Motor Step-Stress Test- Bearing/Shaft Load	Testing				6/2/2021	6/2/2021		
10	QALT/Accelerated Degradation Test -Higher Bearing/Shaft Loads	Run Quantitative Accelerated Life Test QALT ot Acceletated Degradation Test with 3 Levels of Bearing/Sha...	Testing				6/2/2021	6/2/2021		
11	Corrosion Test	Corrosion test to be performed at housing level	Testing				6/2/2021	6/2/2021		
12	Environmental Stress Screening- Life Cycling	ESS (Long Term testing to expose motors to Environmental conditions)	Testing				6/2/2021	6/2/2021		

Special Characteristics - KPCs

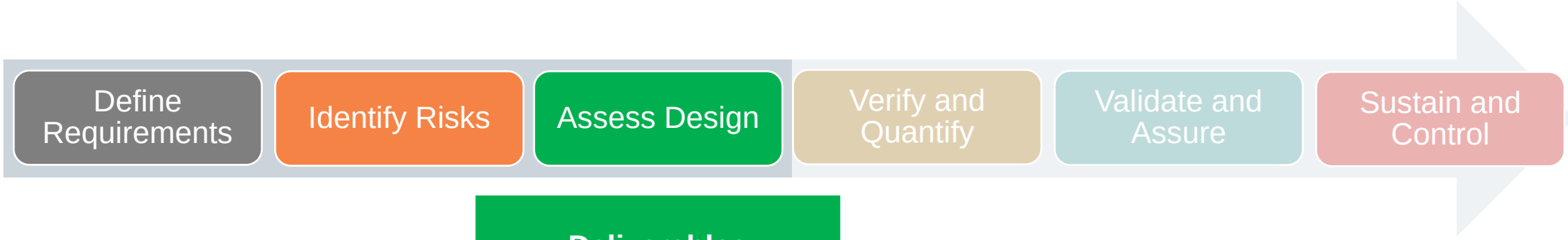
- Product characteristic that can affect fit, function, performance, safety or compliance in a critical way

KPCs

Name	KPCs Description	Cause #	Cause of Failure	Failure Mode	Effect	RRi
Electric Drive System	1) Shaft Outer Diameter 2) Bearing Race Inner Diameter 3) Bearing Housing Outer Diameter 4) Bearing Bore Inner Diameter in the end Cap	1.1.2	Total Bearing Failure	Does not deliver any output torque	Motor loss of function (8,-)	High Risk
Shaft	Bearing and shaft GD&T	3.1.1	Bearing damage caused by fluting or pitting due to bearing currents	Does not prevent bearing currents	Bearing and motor lifetime reduced (7,-) Potential shock hazard to end user (10,-)	Critical Risk
Bearings	1) Housing Bearing Bore Inner Diameter 2)Housing Outer Diameter	1.1.2	Thermal expansion of bearings reduces locating ability	Does not fully align shaft with respect to housing (misalignment/degraded over time)	Motor continuous torque reduced (7,-) Motor lifetime reduced (7,-) Excessive noise (4,-) Catastrophic failure- motor seizure (8,-)	High Risk
Rotor Assembly	1) Shaft Outer Diameter 2) Bearing Race Inner Diameter	4.1.1	Bearing degradation causing the motor to require higher current levels to provide the same torque	Rotor is binding	Motor overheats (9,-)	Critical Risk
Stator Lamination Stack	1) Shaft Outer Diameter 2) Bearing Race Inner Diameter	5.2.2	Failure of Shaft-bearing interface, lost of tight clearance	Air gap is bridged intermittently	Motor transmits irregular torque and rotation with internal damage (7,-) Mechanical failure causing destruction of rotor and/or stator (8,-) Excessive noise (4,-)	High Risk

Phase 3 - Assess & Analyze Phase

Assess & Analyze Phase



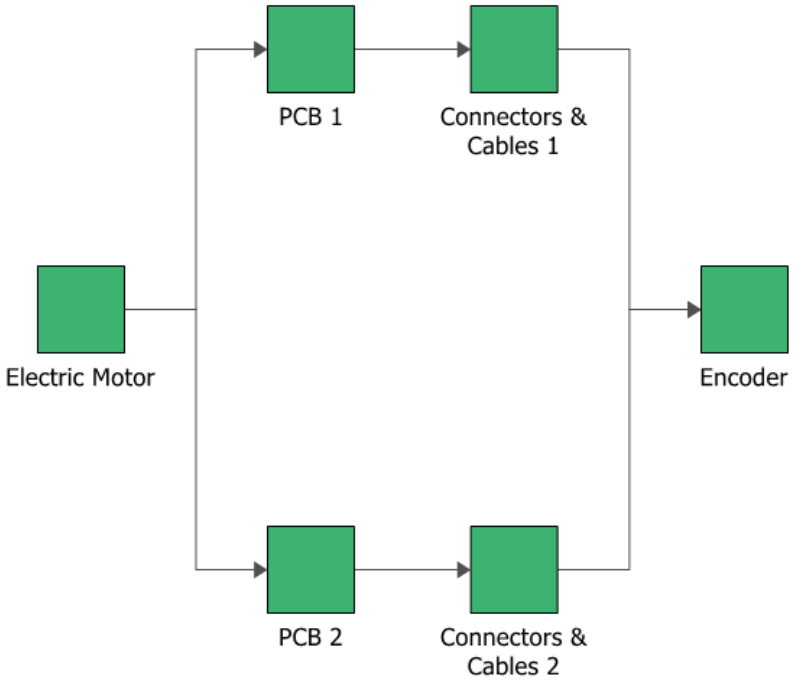
- Create initial System Reliability model
- Investigate Risks identified in DFMEA
- Physics of Failure models

Deliverables
System Reliability Model and Report
Reliability Allocation
Physics of Failure models and Report
DART Test Report

Information may, initially, be ambiguous however there is great value in understanding the effects of each parameter on the reliability of the product

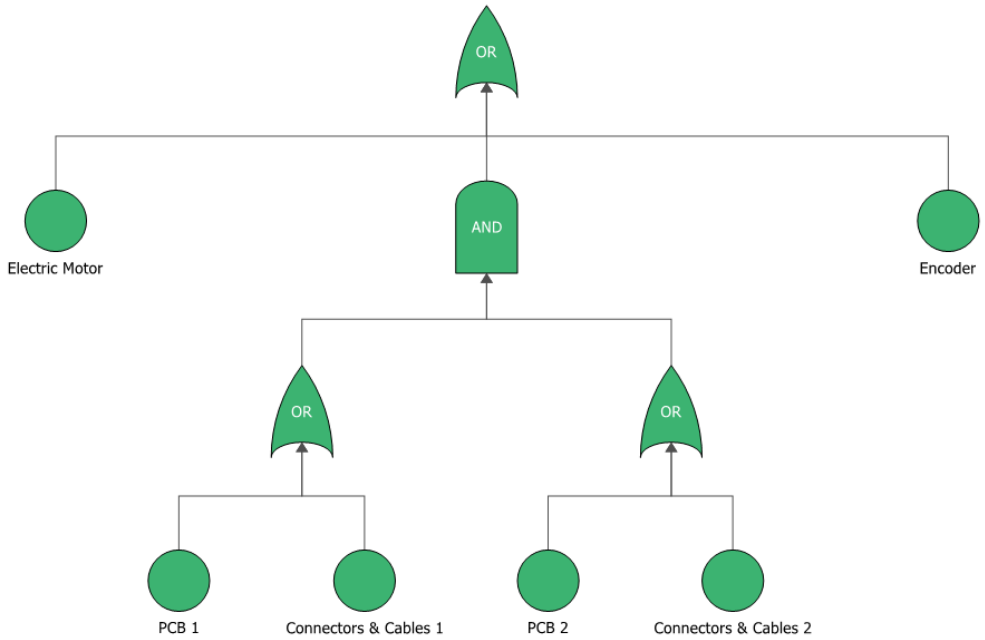
RBDs and FTs

Reliability Block Diagram



- Easier to construct when modeling complex systems
- Can be used to identify design weaknesses
- Better suited for maintainability and throughput analysis

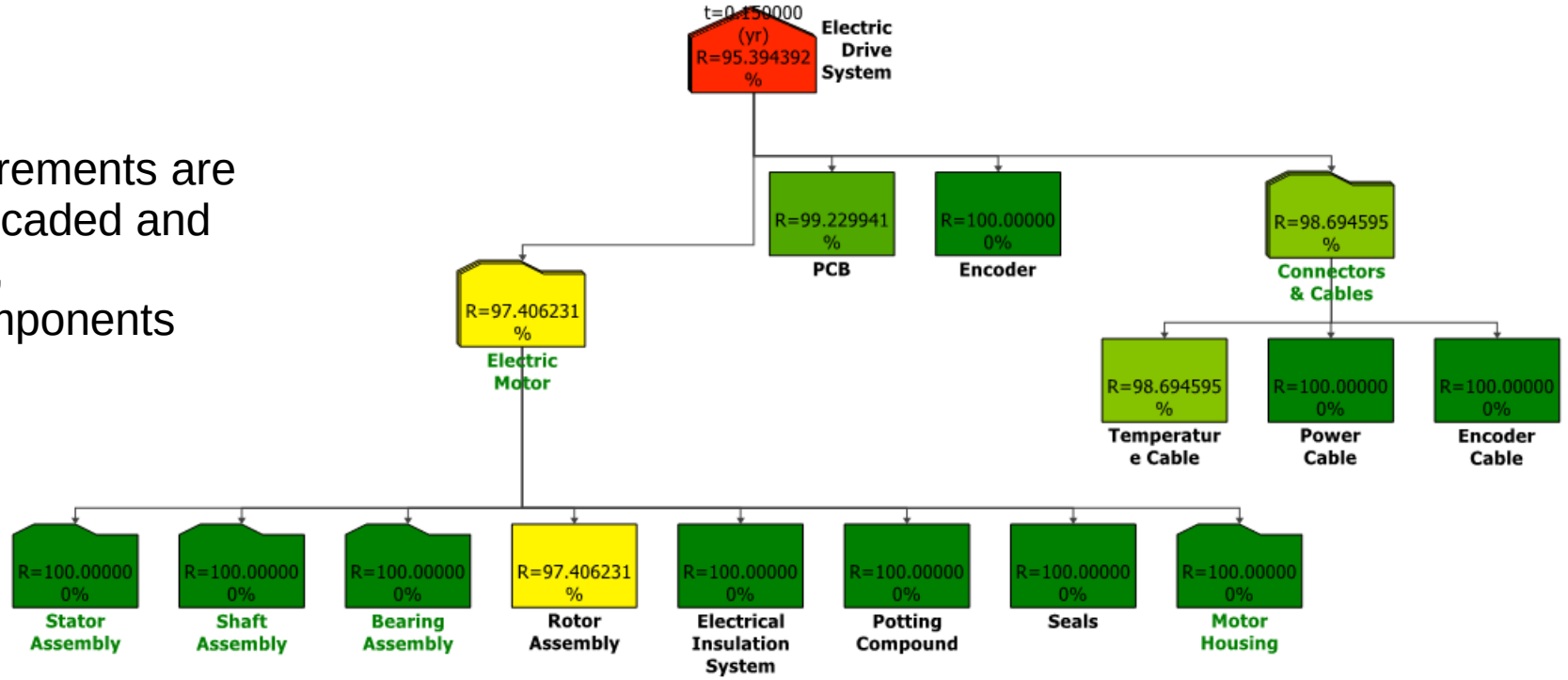
Fault Tree



- Easier to construct for events and failure modes
- Traditionally used in Risk Analysis
- Can be used to analyze failures or as an investigative tool to pinpoint root cause of failures

Reliability Allocation

- Once the reliability requirements are defined, they can be cascaded and allocated to subsystems, components and subcomponents

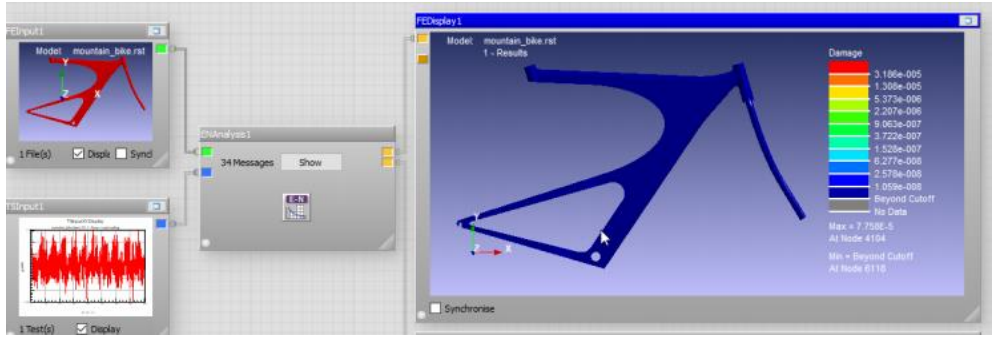


- Completing the allocation task will likely identify some gaps between the required reliability and what is feasible.

Block Name	Reliability Importance	Current Reliability	Weight	Target Reliability
Electric Motor	0.788008	0.740818	49	0.957868
PCB	0.637628	0.915535	99	0.916705
Encoder	0.583771	1.000000	1	0.999122
Connectors & Cables	0.678245	0.860708	36	0.968870

Initial Reliability Models

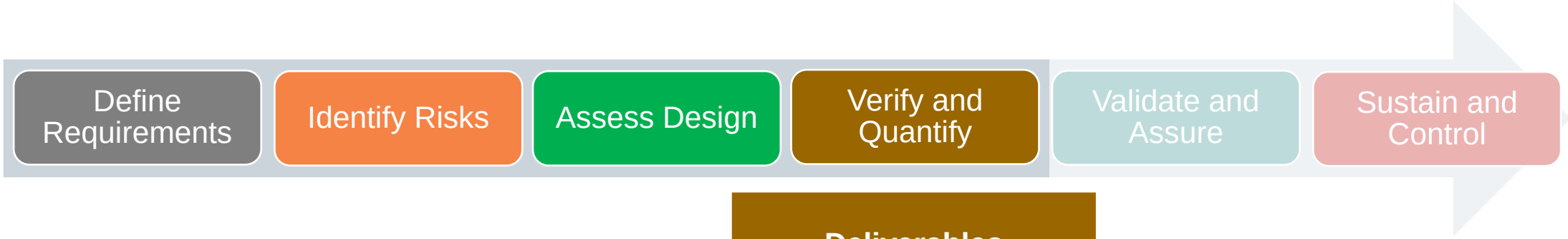
- Use actual data where possible (historical, test, etc.)
- Use manufacturer data were available
- Use/create a Physics-of-Failure model where possible
- Use an estimated value based on occurrence in the DFMEA
- Use standard based reliability values



Name	Category	Quantity	Failure Rate(t=INF)	MTBF
NSWC-11	NSWC-11	1	102.2599 FPMH	9779.0000 hrs
Block 1	Block	1	2.4243	4.1250E+05
Spring, Beam	Spring, Beam	1	2.3398	4.2739E+05
Washer, Belleville	Washer, Belleville	1	0.0250	3.9989E+07
Actuator	Actuator	1	0.0594	1.6822E+07
Block 2	Block	1	3.2260	3.0998E+05
Rod	Rod	1	0.0010	1.0000E+09
Washer, Belleville	Washer, Belleville	1	0.0250	3.9989E+07
Motor Brush	Motor Brush	1	3.2000	3.1250E+05
Pump	Pump [Assembly]	1	38.3262	2.6092E+04
Seal, Static	Seal, Static	1	1.2867	7.7721E+05
Shaft	Shaft	1	5.7333E-06	1.7442E+11
Bearing	Bearing	1	32.5025	3.0767E+04
Housing or Casing	Housing or Casing	1	0.0010	1.0000E+09
Pump Fluid Driver	Pump Fluid Driver	1	4.5360	2.2046E+05
Compressor	Compressor [Assembly]	1	58.2835	1.7158E+04
Shaft	Shaft	1	5.7333E-06	1.7442E+11
Bearing	Bearing	1	32.5025	3.0767E+04
Valve, Poppet	Valve, Poppet	1	10.8217	9.2407E+04
Seal, Static	Seal, Static	1	1.2867	7.7721E+05
Compressor Fluid Driver	Compressor Fluid Driver	1	13.6726	7.3139E+04

Phase 4 - Verify & Quantify Phase

Verify & Quantify Phase



- Areas of weakness in the design identified at earlier phases should be tested and improved
- The results should be quantified and reviewed against targets
- Any gaps should result in the development of a plan to improve the component or system

Deliverables
DMT Test Reports – round 1
System Reliability model update
DFMEA Update
Risk Register Update

This phase of Reliability engineering coincides with Design Maturity Testing (DMT) and it is used to further populate the Reliability model with test results

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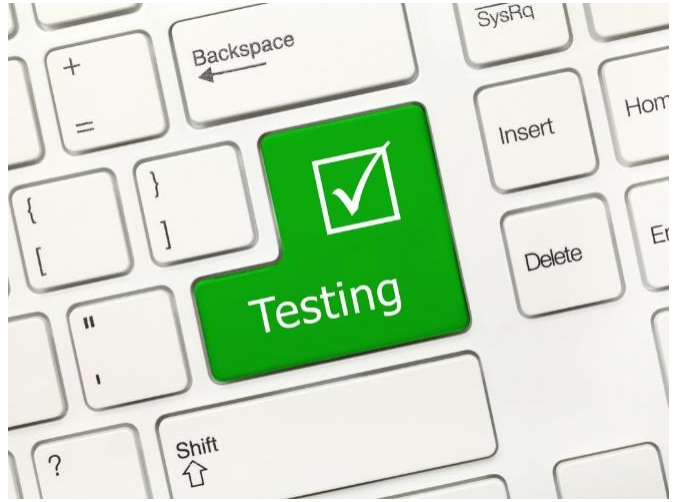
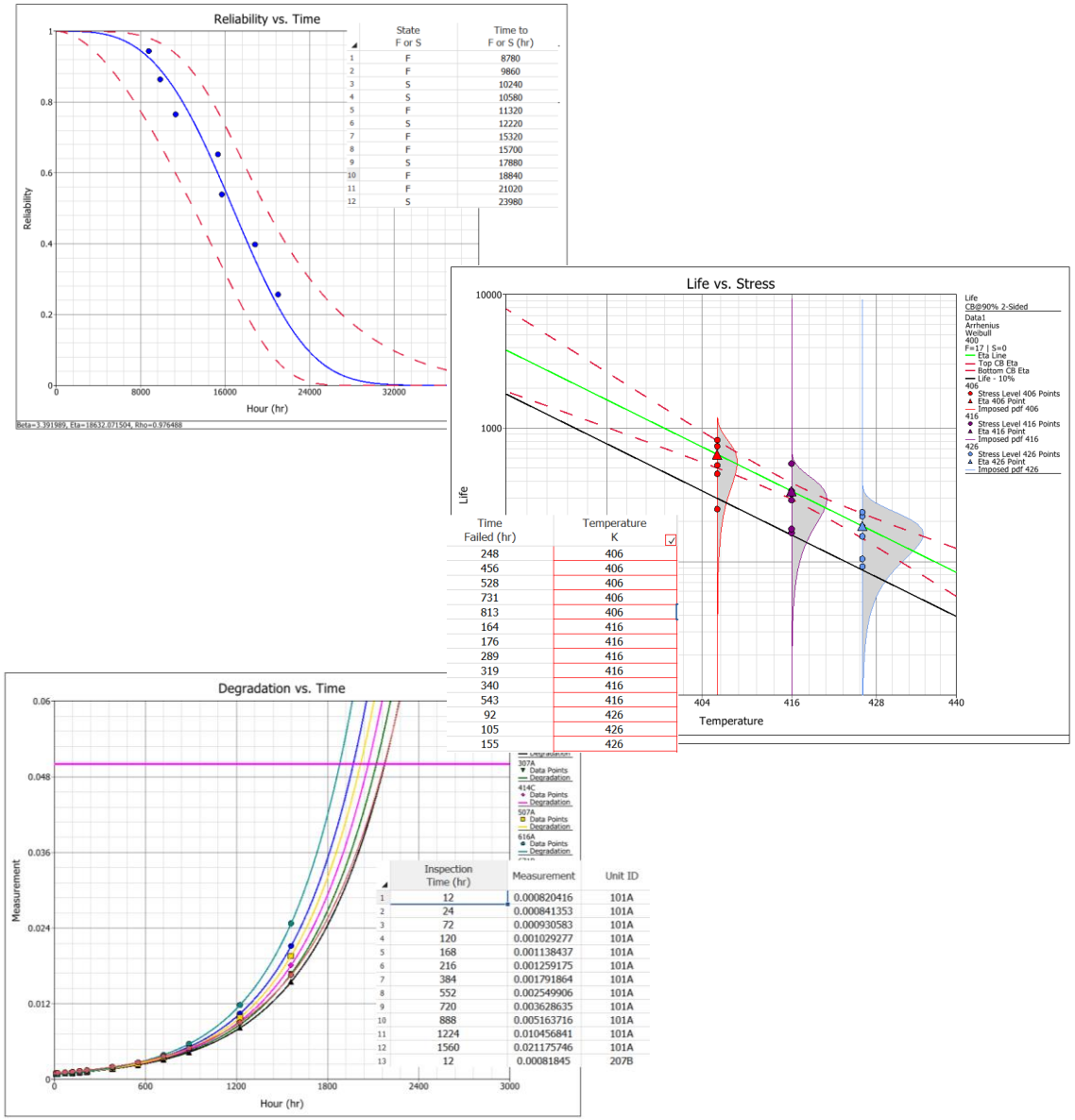
Reliability tests classification

- Design Assessment Reliability Testing
- Design Maturity Testing
- Production Screening Testing
- Reliability Growth Testing



Design Maturity Testing

- A series of tests targeting specific Failure Modes or Design Parameters to quantify the reliability of the product
  - Life test under normal conditions
  - Accelerated life test
  - Degradation test
  - Demonstration test
- Formal, statistical in nature, and requires standard procedures
- Results are used to update Reliability models



Accelerated Life Test

Action

Recommended Action	Run QALT Quantitative Accelerated Life Test - 3 Levels of Coil Temperatures. Measure temperature at motor surface using thermacouples
Name	*
Action Category	Testing
Person Responsible	

Resources

Team	Prenscia (100%)
Facility	Southfield testing facility (100%)
Material	Coils (Qty=10)
Additional Costs	0

Planned Timeline

Planned Start Date	6/15/2021
Planned Duration	9
Planned Completion Date	6/25/2021

Actual Timeline

Action Resolution

User-Defined

Test ID (Name)	QALT- Accelerated Life Test with Higher Coil Temperature Levels

History

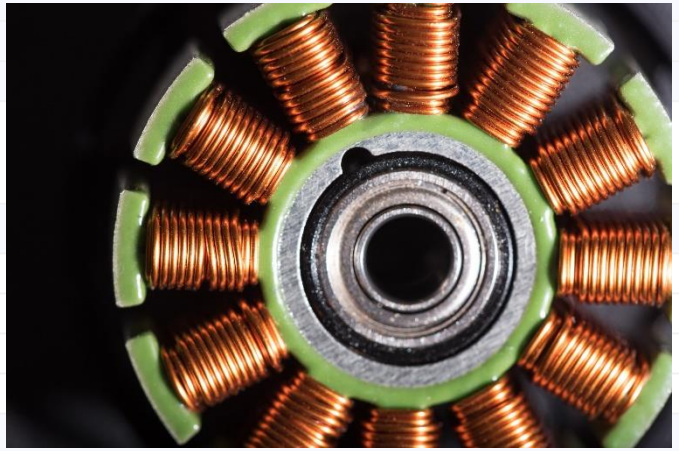
Created By	*Alma Ramirez*
Date Created	*6/7/2021 11:09 AM*
Last Updated By	*Semyon Mikheevskiy*
Last Updated	*6/14/2021 10:29 AM*

Watch

Alert me on changes to this record (no alert preferences enabled)

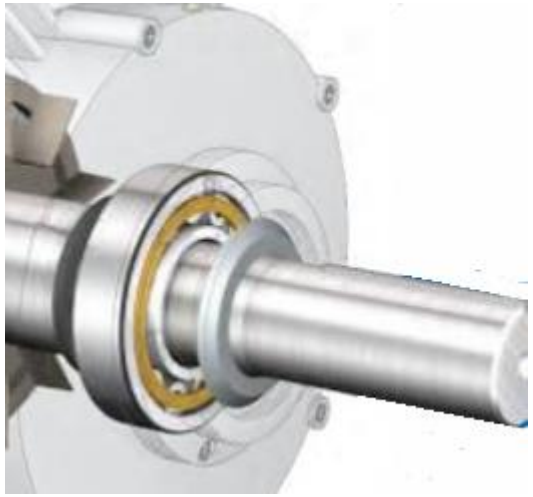
- Limits: 150ºc demagnetization
- Operating temperature: 65ºc
- Sample size: 10

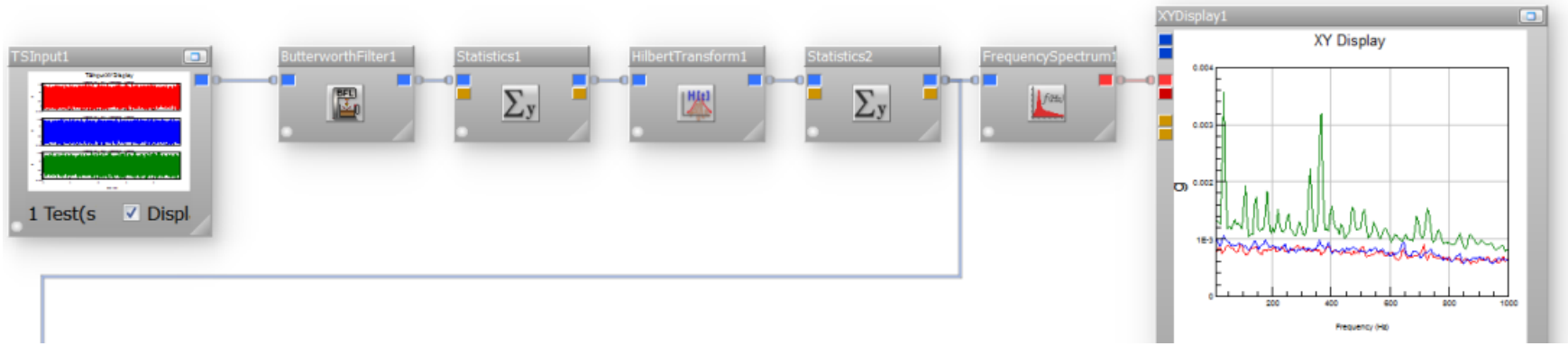
- Perform Coil life test at elevated temperatures
- Determine B10 life for the coil at operating temperature



Degradation Test

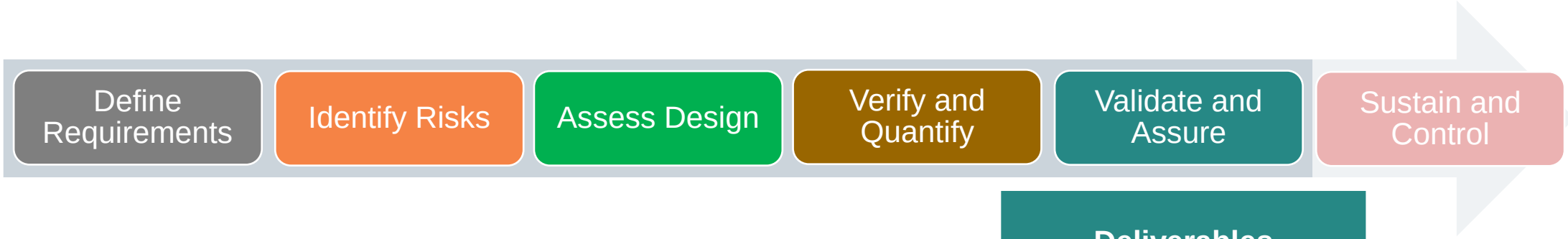
- Run bearing - shaft vibration test, monitor noise and vibration levels.
  - Normal operating conditions for applied forces and torque
  - Degrading quantity: RMS of vibration signal
  - Critical level: RMS = 3Grms
  - Determine MTTF for bearing





Phase 5 - Validate & Assure Phase

Verify & Quantify Phase



- Testing of full system in the actual operating conditions
- Reliability Demonstration test
- Any unexpected failures should be resolved quickly due to the proximity to product launch

Unfortunately, because this is likely the first opportunity to test the system in actual operating conditions, system interaction failures will probably be seen

Deliverables
DMT Test Reports – second round
System Reliability model update
DFMEA Update
PFMEA Update

Demonstration test: non-repairable

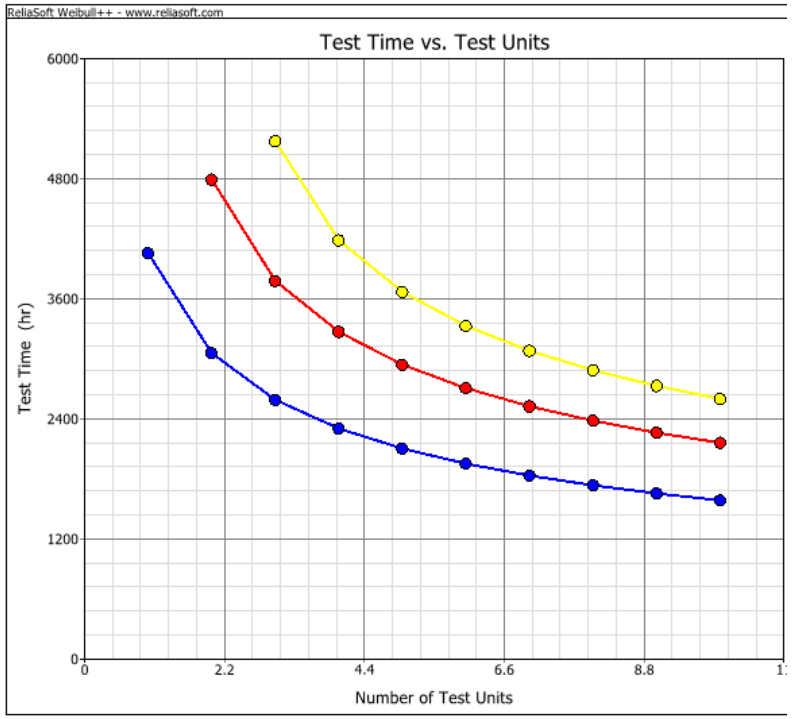
- Run Demonstration Test based on estimated acceleration factor to demonstrate reliability lifetime requirements

Design a reliability demonstration test	
What metric would you like to demonstrate?	
Metric	Reliability value at a specific time
Demonstrate this reliability (%)	90
With this confidence level (%)	70
At this time (hr)	15000
Assume the failure rate behavior is governed by this distribution	
Distribution	2P-Weibull
With this Beta	2.45
Solve for this value	
Value	Required test time
With this sample size	10
With a maximum of this many failures	0
Results	
Test time per unit (hr)	**1583.943714**

Notes

This is based on both the assumed failure rate behavior given the specified distribution and the specified acceleration factor.

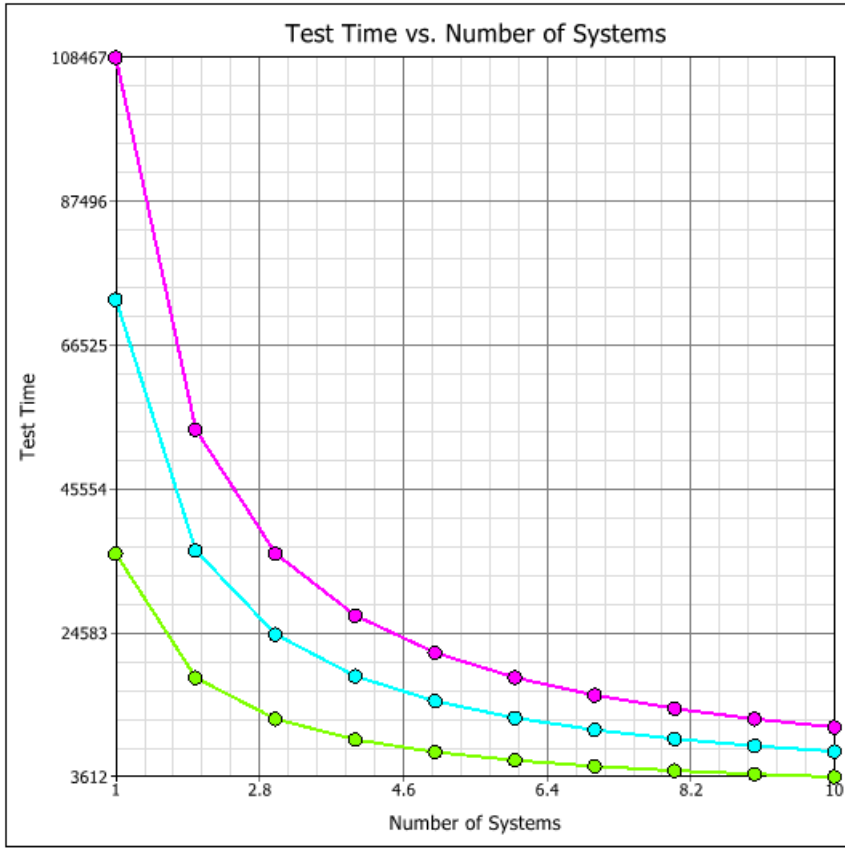
Based on the specified acceleration factor, the equivalent time at the use stress level is 15839.437136(hr).



Demonstration test: repairable

- Run Demonstration Test under customer defined operating conditions to demonstrate reliability lifetime requirements

Design a reliability demonstration test	
What metric would you like to demonstrate?	
Metric	MTBF
Demonstrate this MTBF (hr)	30000
Required Time	N/A
Beta	1
With this confidence level (%)	70
Solve for this value	
Value	Required test time
With this number of systems	10
With a maximum of this many failures	2
Results	
Test Time per System	**10846.704483**



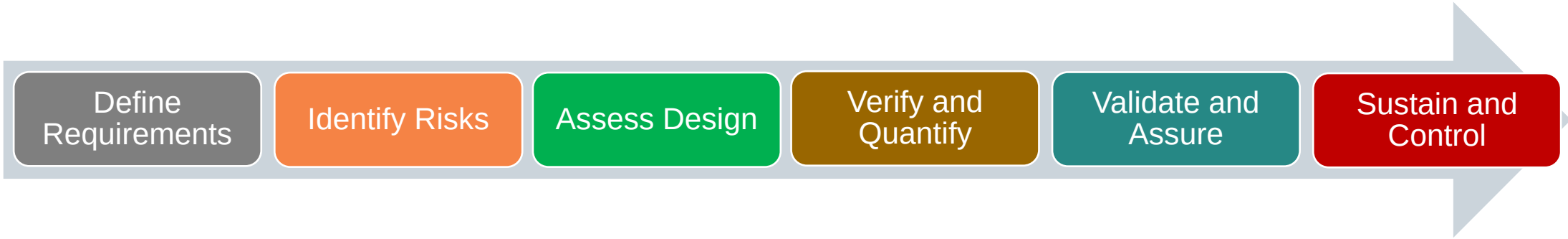
Agenda

1. Introduction
2. Phase 1 - Define Reliability Requirements
3. Phase 2 - Identify Reliability Risks
4. 10 Minute break
5. Phase 3 - Assess & Analyze Phase
6. Phase 4 - Verify & Quantify
7. Phase 5 - Validate & Assure
8. 10 Minute break
9. **Phase 6 - Sustain and Control**
10. Conclusions

Each phase of DFR program covers required Reliability Activities and supported by the software example.

Phase 6 - Sustain and Control Phase

Sustain & Control Phase



- Last but not least…Key step in the DFR program!
- Necessary in order to observe the behavior of the product in its actual use (and abuse) conditions, and use the gained knowledge for further improvements or in future projects

The final phase of DFR focus on monitoring the product as it is manufactured and used by customers

Deliverables
PST Incidents
PFMEA
Control Plan
FRACAS Summary Report
FRB Meetings
Warranty Analysis

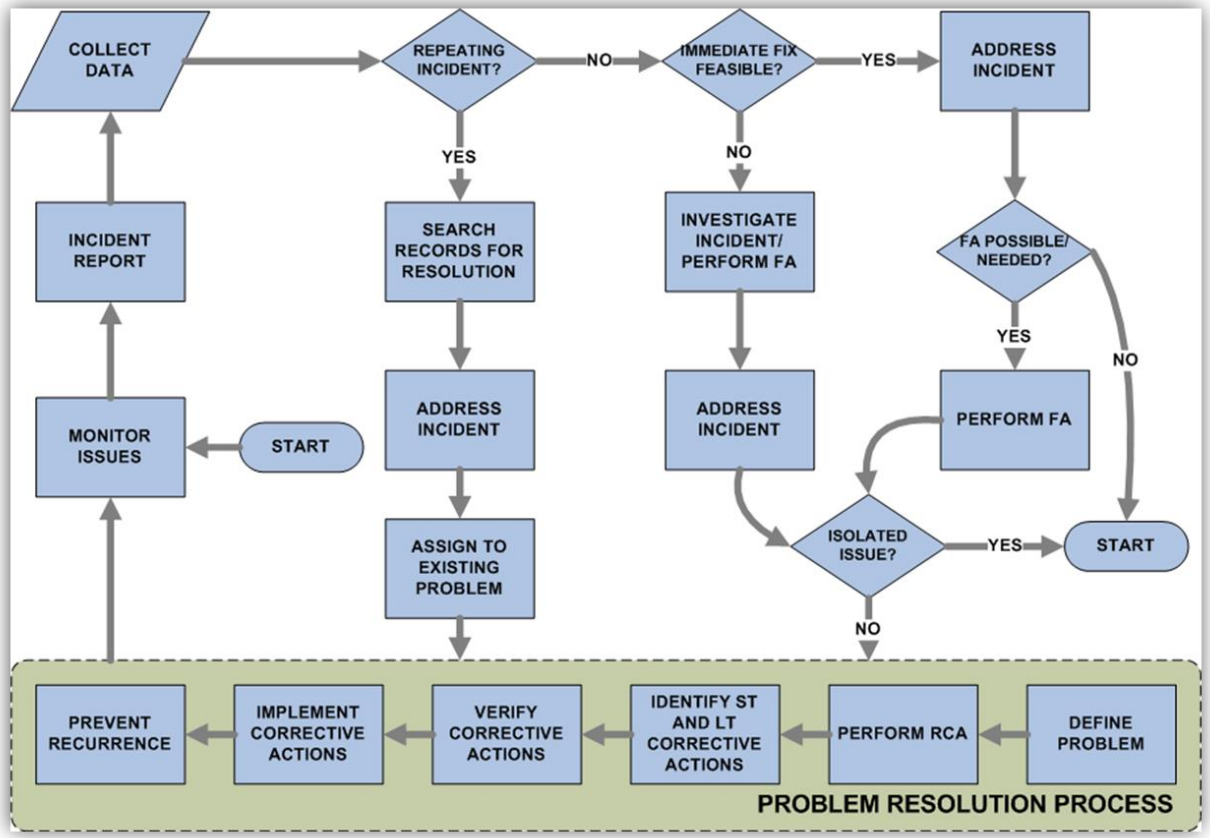
FRACAS

- FRACAS stands for **F**ailure **R**eporting, **A**nalysis and **C**orrective **A**ction **S**ystem

- FRACAS is a disciplined and structured closed-loop process for solving issues at the design, development, production, and deployment stages, through which the reliability of a system can be continually improved.

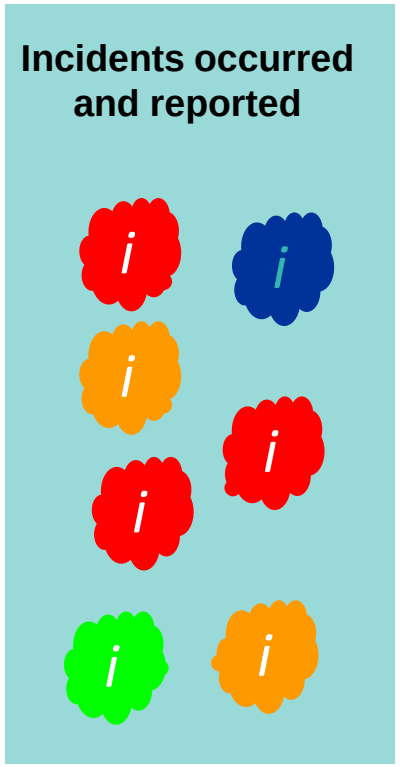
- The basic idea of FRACAS is one of the ***easiest*** concepts to understand!

Yet one of the most ***difficult*** to successfully implement in the context of an effective Reliability Program

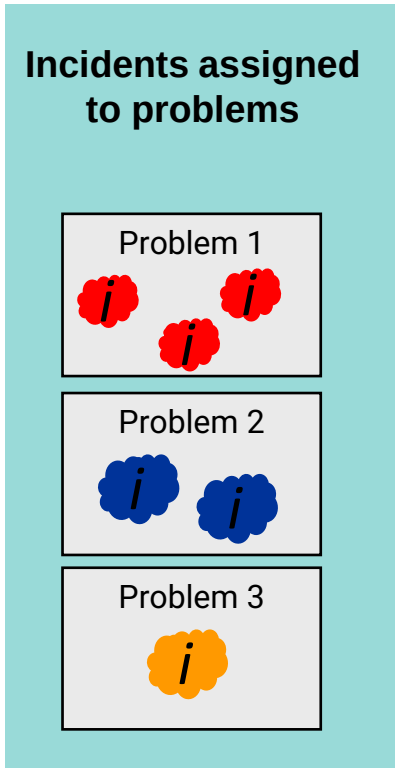


Benefits

- Increase likelihood of meeting reliability requirements
- Decreased equipment downtime & availability
- Decrease overall life Cycle costs
- Reduce product liability exposure
- Reduce Warranty costs
- And one of the most important ones….Satisfied customers!!!



NCRs



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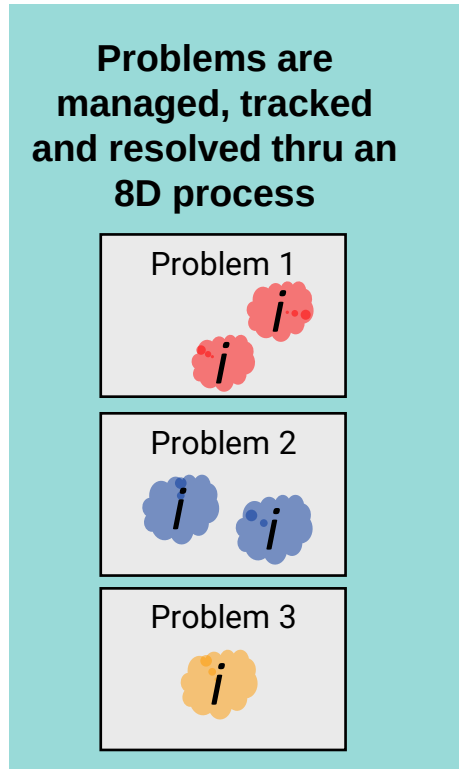
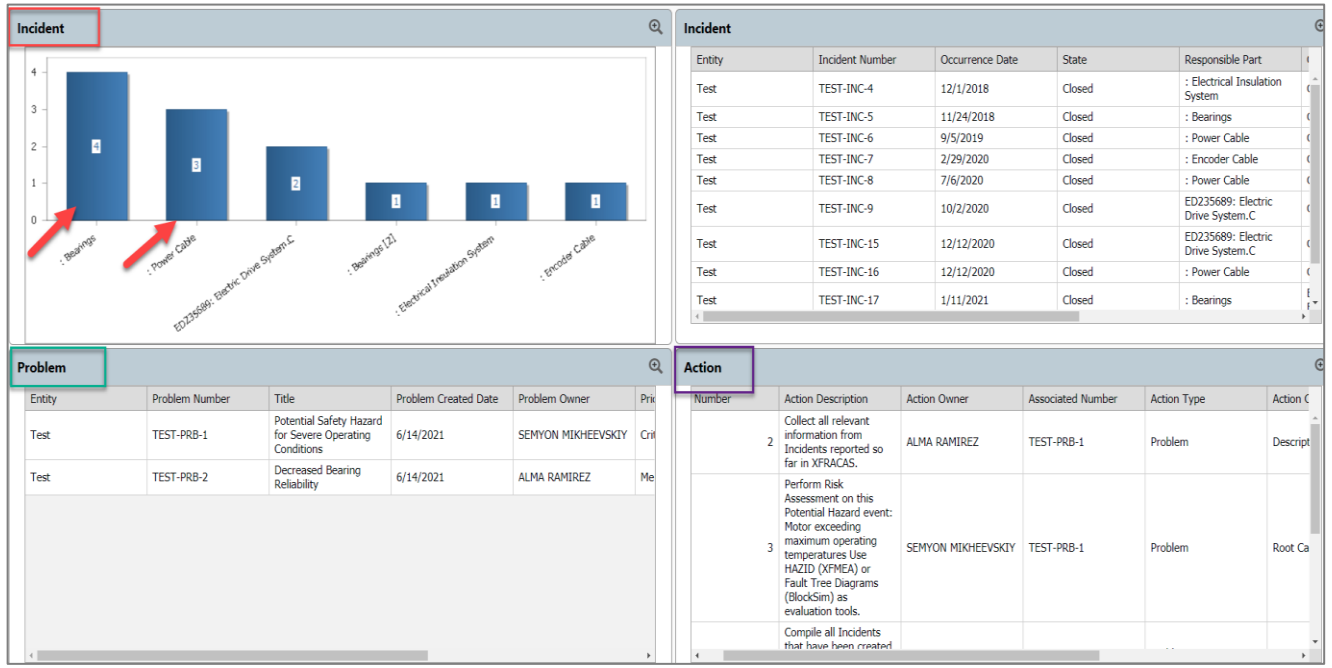


8D

FRACAS Reports & FRBs

- FRB stands for **F**ailure **R**eview **B**oard
- Communication tool to help acknowledge management and team members about the Reliability performance of our products and services over time
- Provides a framework for decision making to allocate resources and drive further actions



Conclusions

- **DFR is a Process** that an organization needs to have in place in order to drive reliability into their products.

- The ReliaSoft tool suite can support the DfR process from beginning to the end of product lifecycle (or for the part only based upon business choices or needs).

Thank You

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