
**HBK Technology Days – Virtual Seminar Series**

**Tuesday, November 22, 2022**

# Building a Reliability Validation Plan for Electrified Powertrains

Presented by Andrew Brown,
*Reliability & Validation Methods Chapter Lead,*
*Jaguar Land Rover*

# Building a Reliability Validation Plan for Electrified Powertrains

## Abstract

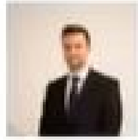
The transition from ICE to EV powertrains has been rapid and the array of configurations including Mild-Hybrid (MHEV), Plug-In Hybrid (PHEV) and fully Electric (BEV) creates a multitude of customer use-cases that need to be accounted for in the validation plan. The relative cost of failure has more than doubled for the electrified powertrain, and the warranty period of high-cost systems (such as the battery) extends beyond the conventional 3 years, putting more emphasis on reliability improvements of the powertrain.

## About the presenter, Andrew Brown, Reliability & Validation Methods Chapter Lead, Jaguar Land Rover

Andrew graduated from Sheffield University in 2006 with a degree in Aerospace Engineering. Since then, he has worked in product development of Internal Combustion Engines, starting his career working on large diesel gensets for Perkins Engines and then transferring to Automotive ICE engine development at JLR. Andrew began working in the field of Reliability and Validation Methodology for base engines back in 2016, before leading the validation team on the new Range Rover PHEV battery (the first in-house developed battery at JLR). More recently he has transferred to a lead role in the Validation Methods & Reliability Technical Chapter, responsible for developing common Reliability Engineering practices for the Electric Propulsion System.

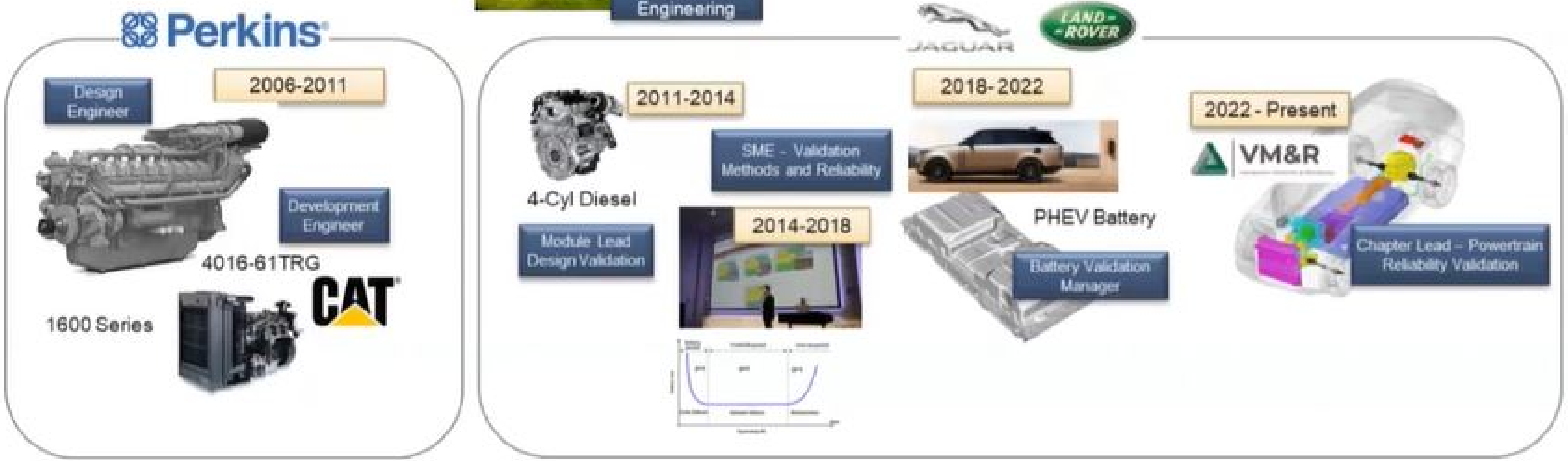
# RELIABILITY VALIDATION
FOR ELECTRIFIED POWERTRAINS

Andrew Brown CEng MSaRS
Chapter Lead - Powertrain Reliability Validation
Jaguar Land Rover Ltd
Gaydon, UK



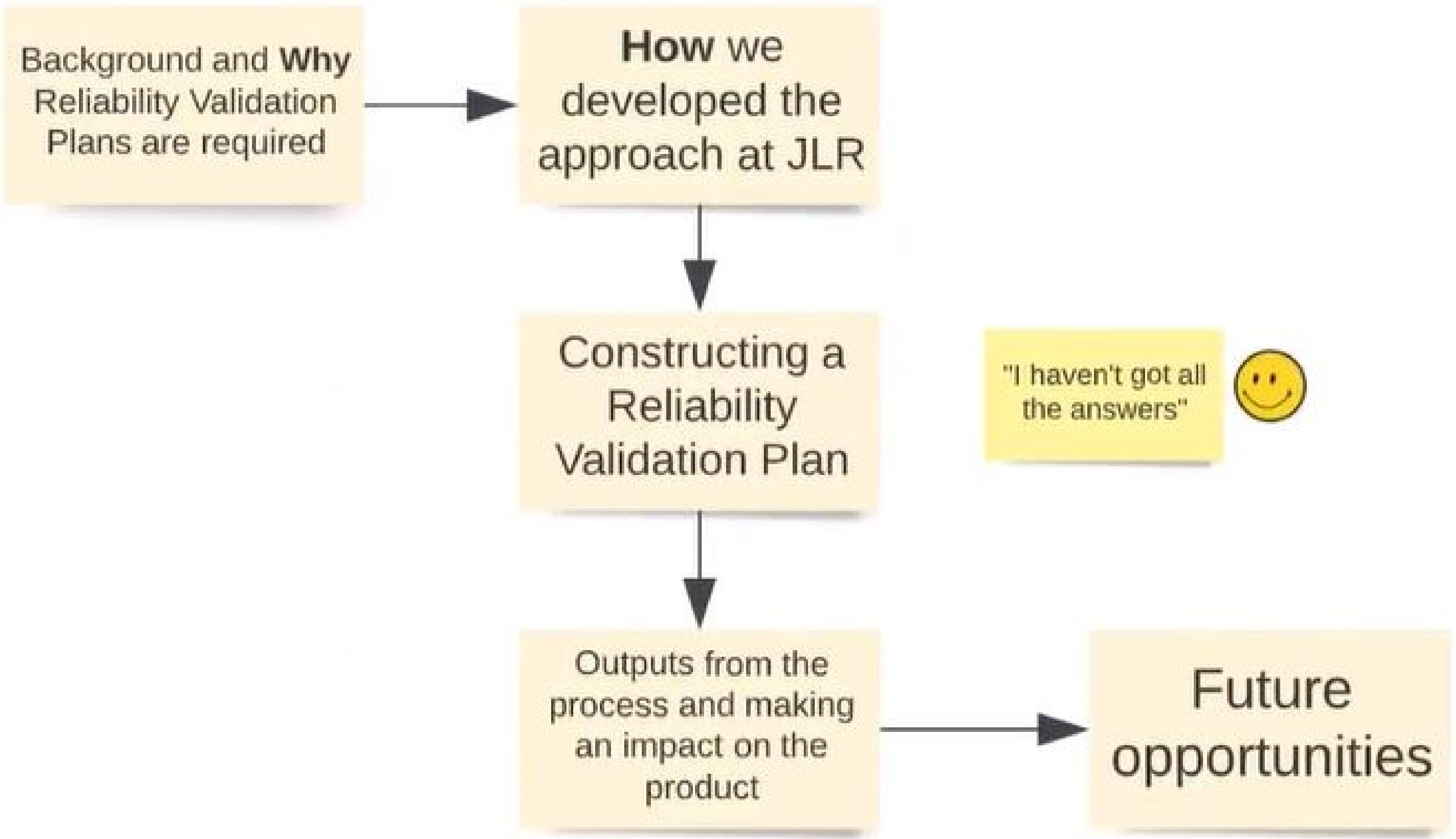
# Andrew Brown

MSaRS
Chapter Lead - Powertrain Reliability Validation


Presentation in LucidChart

Lucidchart




"I haven't got all the answers"

**2008**

Jaguar and Land Rover acquired by Tata Motors

**2011**

£400m invested at Halewood to start Range Rover Evoque production

**2012**

Joint venture in China saw the formation of Chery Jaguar Land Rover

**2014**

The Engine Manufacturing Centre was opened by Her Majesty the Queen

**2016**

New plant in Itatiaia, Brazil was the first overseas facility owned by a UK OEM

**2018**

Production started at our state-of-the-art manufacturing facility in Slovakia

**2019**

The Advanced Product Creation Centre at Gaydon was unveiled

**2021**


New Global Strategy, Reimagine is announced

The electrification of the Jaguar and Land Rover brands is at the heart of Reimagine, set against a canvas of true sustainability. Our accelerated path towards electrification through Reimagine will contribute to our goal of becoming net zero carbon by 2039

- **Reimagination of Jaguar as an all-electric luxury brand from 2025**
- **First all-electric Land Rover model in 2024**
- **All Jaguar and Land Rover nameplates to be available in pure electric form by end of the decade**


JAGUAR LAND-ROVER


### ELECTRIFIED PORTFOLIO

Electrification across our product range continues with **1 battery electric vehicle (BEV),**
**8** models now on sale with **plug-in electric hybrids** (PHEV) and **11** with **mild-hybrids** (MHEV).

### ELECTRIFIED PERFORMANCE

Our latest models offer segment-leading electrified performance. The New Range Rover and New Range Rover Sport introduce plug-in electric hybrid propulsion with an electric driving range of **over 100km.**


### ELECTRIFIED SALES

Achieved **66% electrified sales** in 2022, with a commitment to launch the first all-electric Land Rover model in 2024, and the reimagination of Jaguar as an all-electric luxury brand from 2025.

# Automotive Electrification brings challenges to Product Development

Complexity of Powertrain Technology


ICE + MHEV

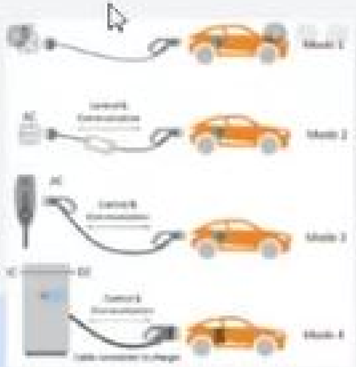
PHEV

ICE

BEV

Complexity of customer use cases

Special Vehicles



Off-road capability

EV operating modes

Charging behaviour

Competition is fierce


Customers want to depend on our vehicles

J.D. POWER

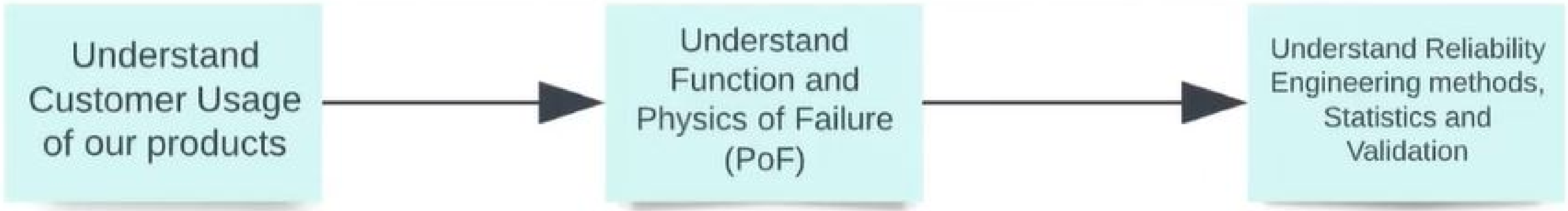
EV warranty could bankrupt some OEM's

### So how can we address these challenges?

## "Engineering reliable products efficiently"

### What do we mean by Reliability?

"Probability that a component, module, or system will perform its prescribed function without failure for a certain period of time when operated correctly in a specified environment and under stated conditions".



**So how can we address these challenges?**

# "Engineering reliable products efficiently"

**What do we mean by Reliability?**

"Probability that a component, module, or system will perform its prescribed function without failure for a certain period of time when operated correctly in a specified environment and under stated conditions".

Understand Customer Usage of our products → Understand Function and Physics of Failure (PoF) → Understand Reliability Engineering methods, Statistics and Validation

Reliability advocates at JLR joined forces to make a change → Brought in consultants and measured ourselves against IEEE1624 → Realisation

Buy-in from Executive Directors → Recruited a team with diverse skillset

**6.1.4 Level 4** **Standard for Organizational Reliability Capability**

At level 4, organizations change product designs based on reliability consideration. Reliability plans are detailed, and the defined reliability activities are specifically tailored to the product being developed. All employees are trained to appreciate the impact of reliability on the business. These organizations evaluate reliability very early in the product lifecycle and can change product designs to achieve desired reliability targets. These organizations enlist their supply chain members to help them ensure product reliability. They make some design or manufacturing test modifications based on test and field failure mechanisms as well as failure modes. Reliability is expressed as a distribution rather than a point estimate, and detailed stress and damage models may be included as part of reliability prediction. All the failure mechanisms affecting the reliability of the products are investigated and documented. These organizations are proactive in preventing the recurrence of failure modes and mechanisms in future products. They promote the establishment of closed-loop processes to utilize existing reliability lessons learned and formally identify, approve, and distribute new reliability lessons learned.

*(Extract from IEEE 1624 – Standard for Organisational Reliability Capability)*

"Evaluate reliability very early in product lifecycle"

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noun: **realisation**

1. an act of becoming fully aware of something as a fact.
   "a growing realization of the need to create common economic structures"

   Similar: awareness | understanding | comprehension | consciousness

Realisation → Buy-in from Executive Directors → Recruited a team with diverse skillset → Initiated pilot project on Battery and EDU

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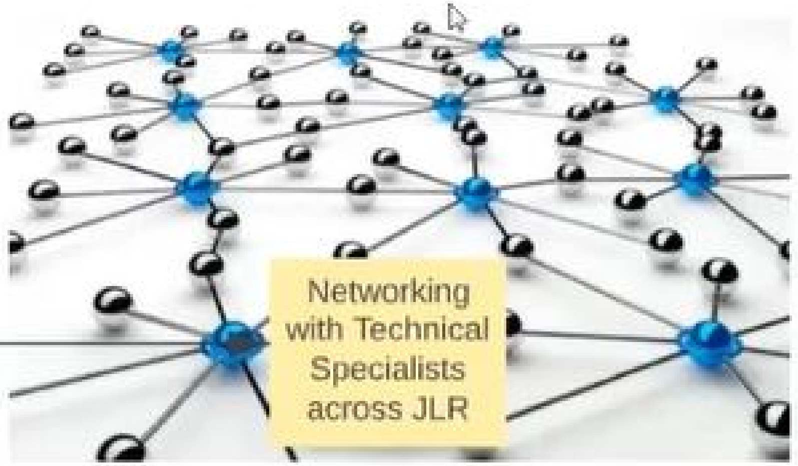
Realisation → Buy-in from Executive Directors → Recruited a team with diverse skillset → Initiated pilot project on Battery and EDU → Networking with Technical Specialists across JLR



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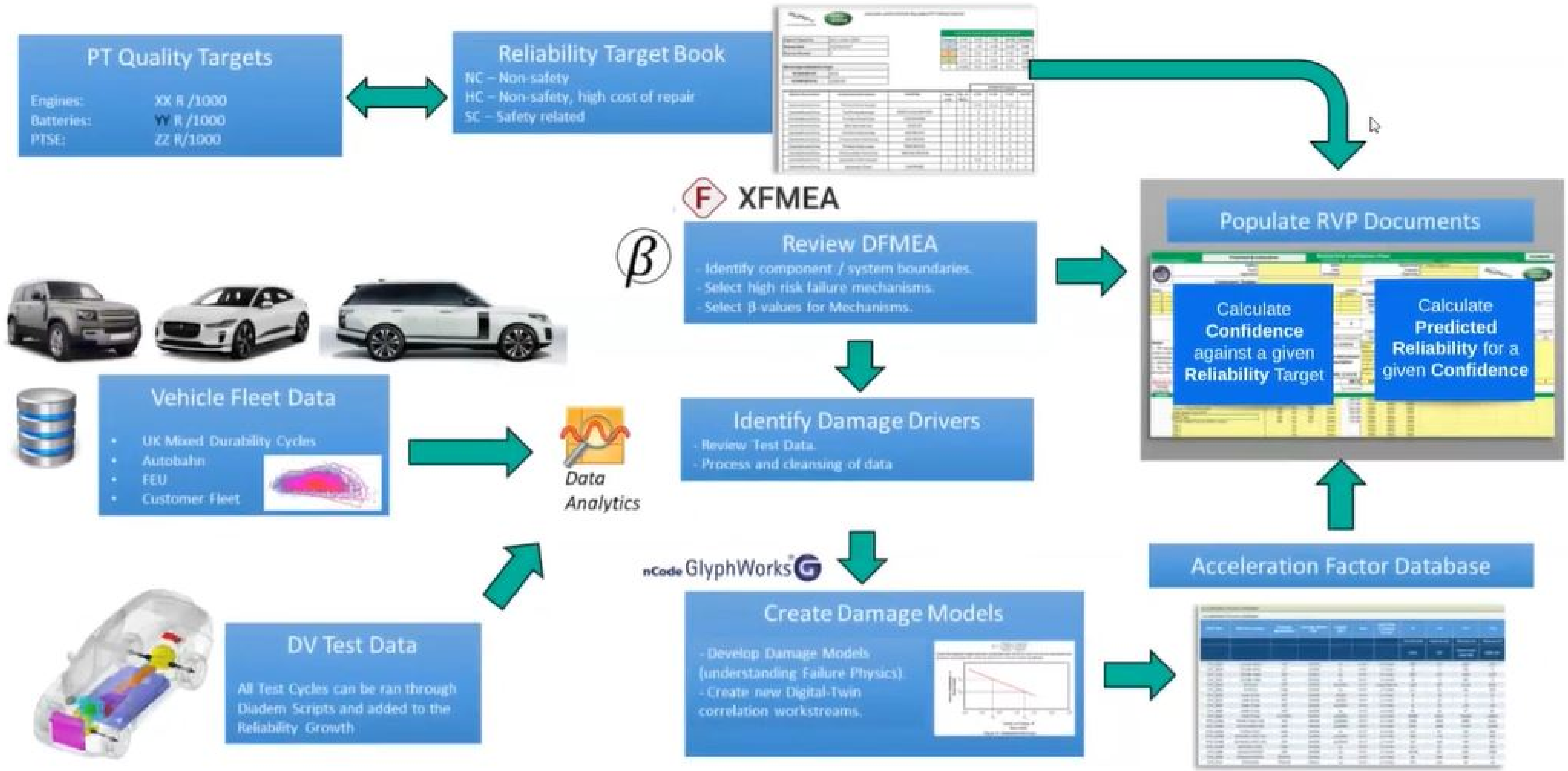
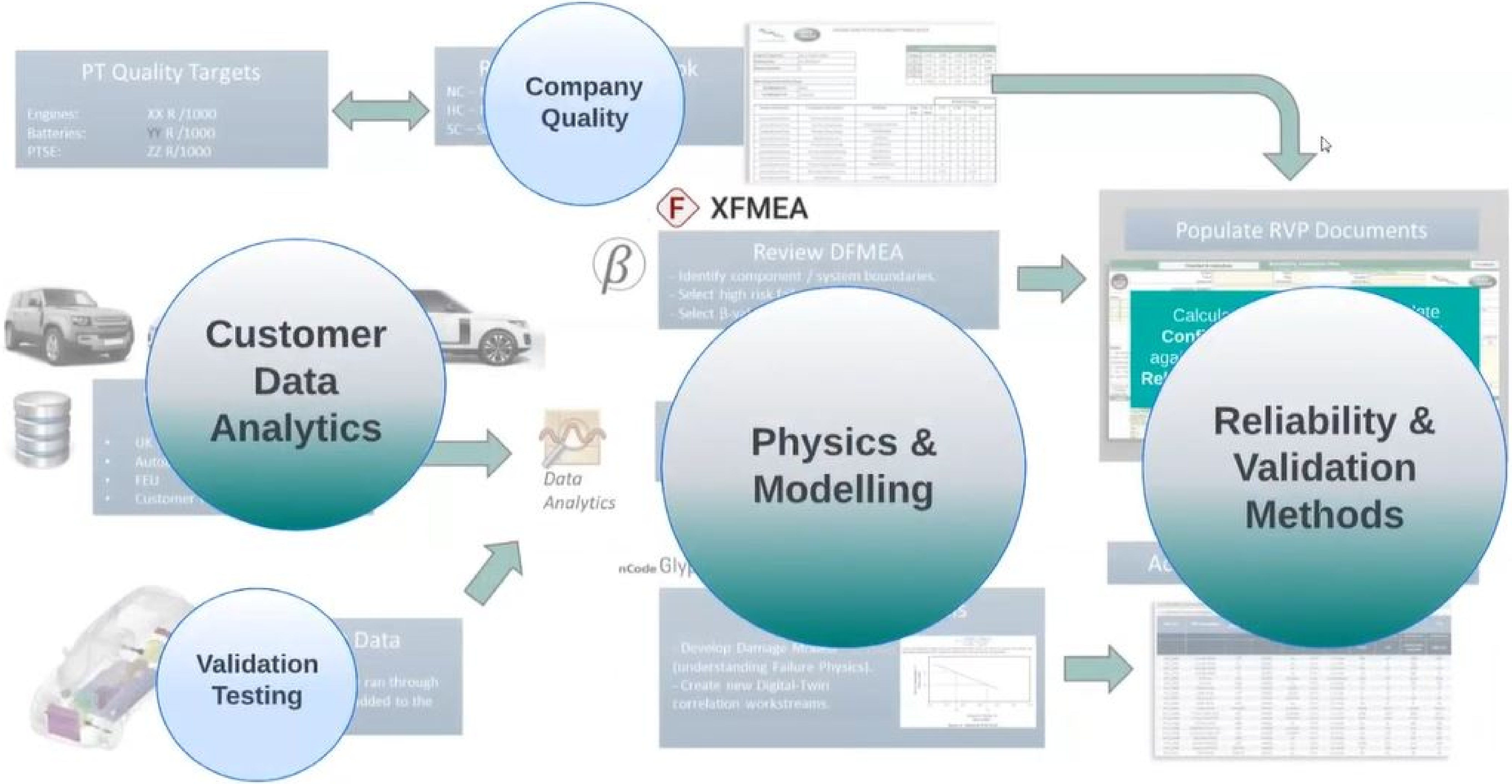
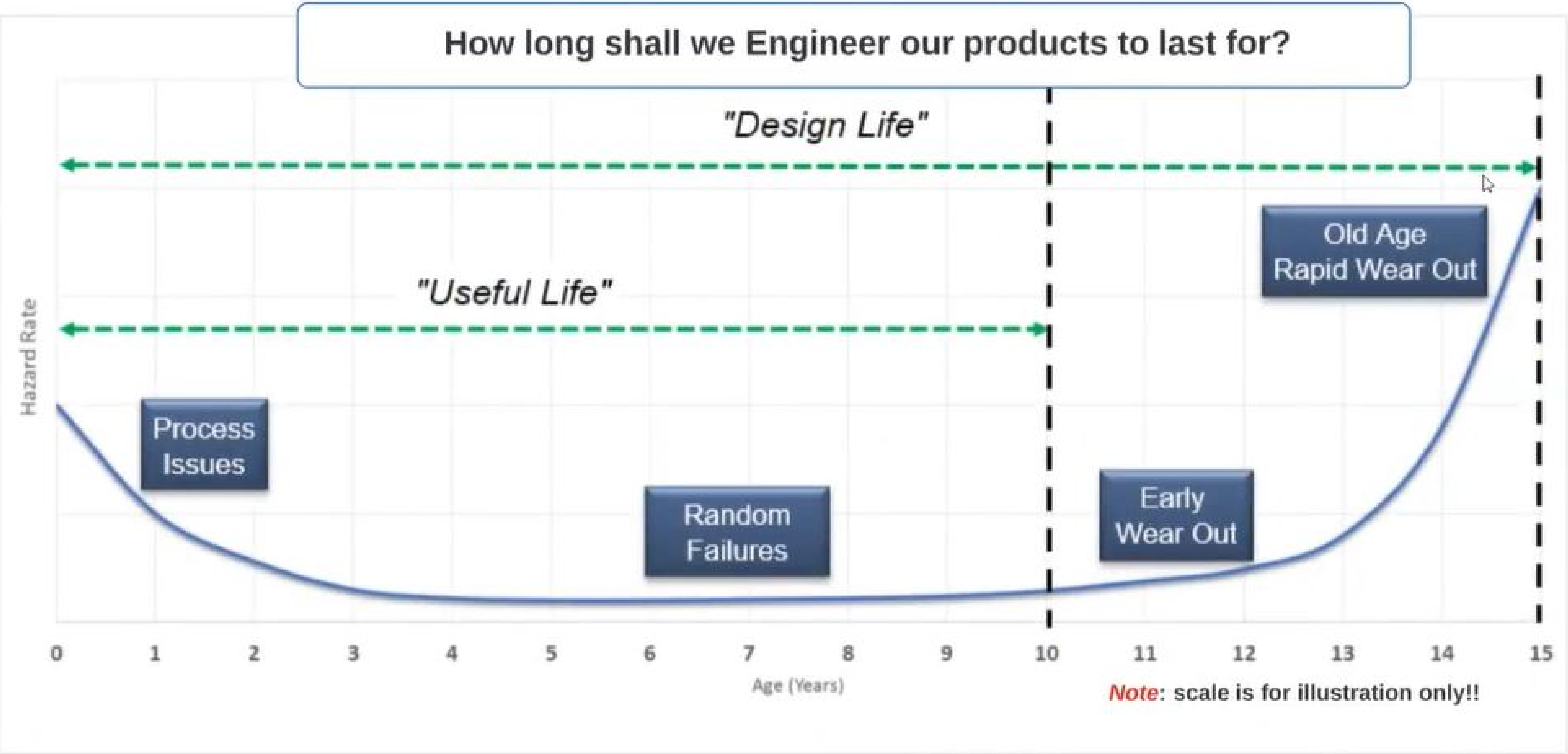
# Reliability Validation Process

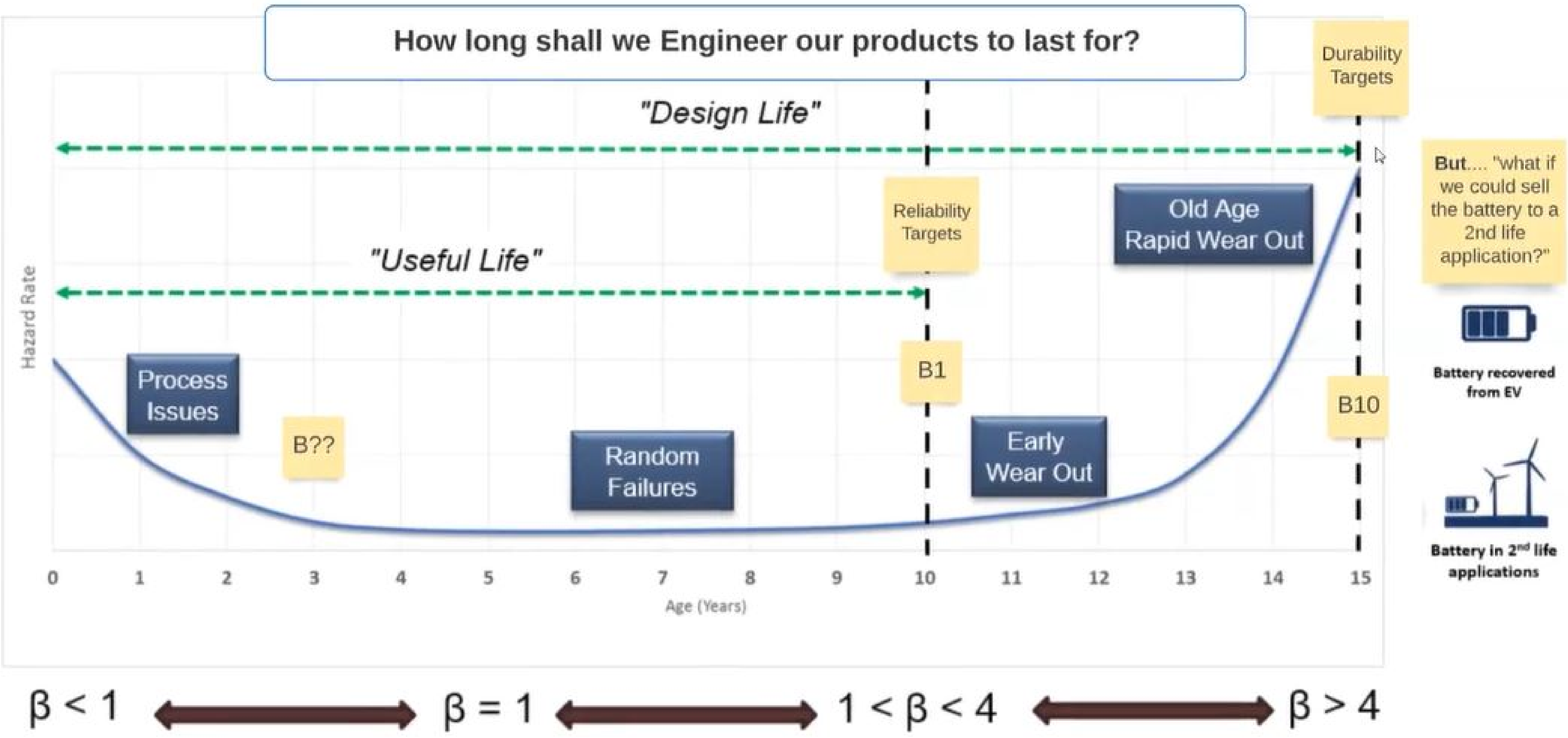


# New Team Structure






$\beta < 1$ ⟷ $\beta = 1$ ⟷ $1 < \beta < 4$ ⟷ $\beta > 4$



How long shall we Engineer our products to last for?
Durability Targets
"Design Life"
Reliability Targets
Old Age Rapid Wear Out
"Useful Life"
But.... "what if we could sell the battery to a 2nd life application?"
Hazard Rate
Process Issues
B??
Random Failures
B1
Early Wear Out
B10
Battery recovered from EV
Battery in 2nd life applications
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Age (Years)
β < 1
β = 1
1 < β < 4
β > 4

# Target Setting

Develop a full set of component reliability targets to benchmark performance against and **demonstrate** prior to Start of Production (SOP)

1 Consider system structure and complexity


2 Classify component and



3 Group components

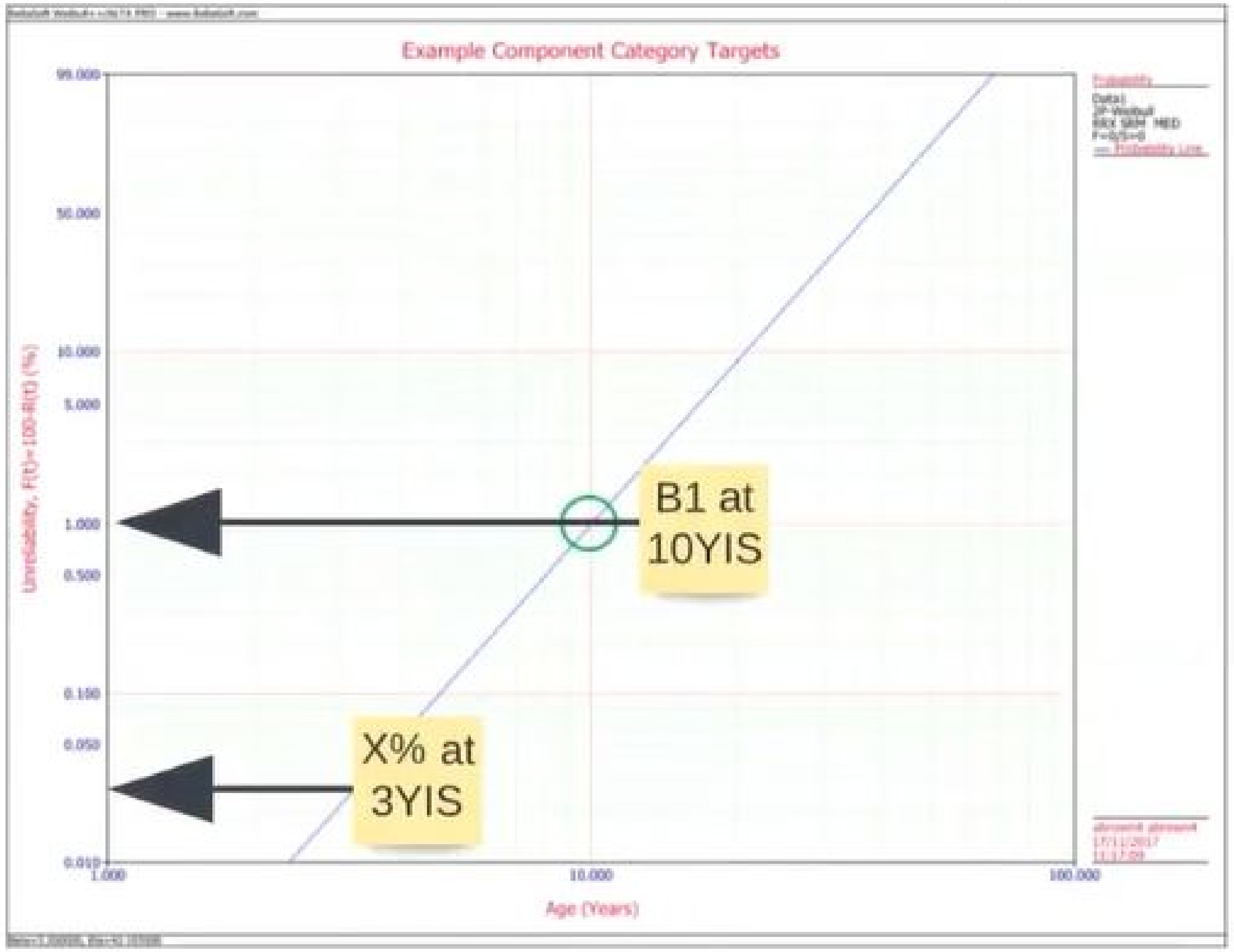
# 2 Classify component and assign targets

Component Classification

Pistons

*Ingenium (AJ20-D4)*

| Component Category | Definition |
|---|---|
| **Cat. A: Wear** | Pa[illegible] e en[illegible] n as[illegible] |
| **Cat. B: Degradation** | Pa[illegible] e en[illegible] e ex[illegible] n in [illegible] |
| **Cat. C: Structural** | Structural parts that are designed to last for the Useful Life of the engine and of which the customer would not expect a failure to occur within this period. |
| **Cat. S: Safety** | C[illegible] se c[illegible] EA a[illegible] ve n[illegible] |



## 2 Classify component and assign targets

Component Classification

Pistons
*Ingenium (AJ20-D4)*

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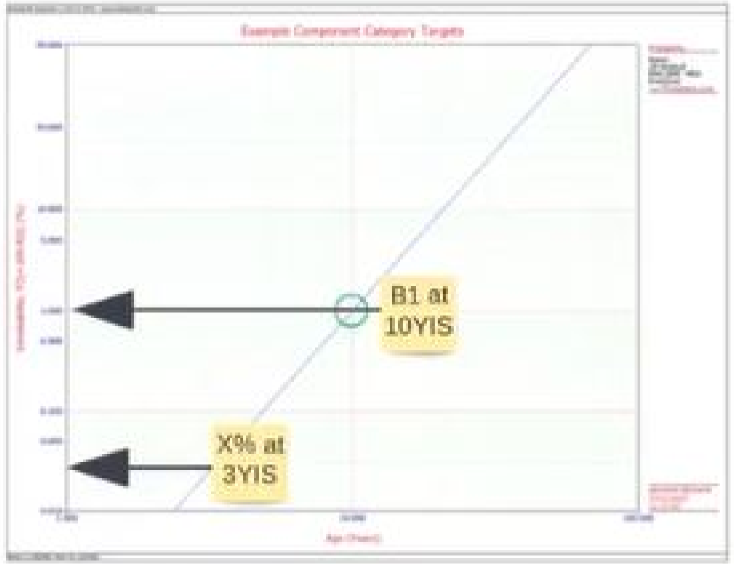
| Cat. D: Safety | [illegible] |




New classifications to consider

| FMEA Severity | Cost of Repair |
|---|---|
| Safety Critical | n/a |
| Non-safety critical | High CPU repair |
| Non-safety critical | Low CPU repair |

Impact to Customer

Impact to Business

# 3 Group components by service strategy


- Review Boundary Diagrams and group components according to in-field service strategy.
- Sum up the reliability targets for the entire engine and cross check system reliability (% or R/100) with Company Quality metrics (R/1000).

JAGUAR LAND ROVER RELIABILITY TARGET BOOK

| | |
|---|---|
| Engine Programme | AJ20-D4 16MY |
| Release Date | 09/11/2016 |
| Revision Number | 1 |

| | |
|---|---|
| R/1000 @3 YIS | |

| Reliability Target Line Categories | | | | | |
|---|---|---|---|---|---|
| Category | 3 YIS | 5 YIS | 7 YIS | 10 YIS | β-Slope |
| A | | | | | |
| B | | | | | |
| C | | | | | |
| S | | | | | |

| System Description | Component Description | PADB Ref. | Target Line | No. of Parts | Per Part 3 YIS | Per Part 10 YIS | Per System 3 YIS | Per System 10 YIS |
|---|---|---|---|---|---|---|---|---|
| Chain System | Fuel Pump Sprocket | SPRKT FU/INJ PMP DRV | C | 1 | | | | |
| Chain System | Primary Drive Chain | CHN TM | | | | | | |
| Chain System | Idler Sprocket Asy. | IDLER ASY | | | | | | |
| Chain System | Primary Chain Guide | GID-TM CHN | | | | | | |
| Chain System | Primary Chain Top Guide | GID-TM CHN | | | | | | |
| Chain System | Primary Chain Lever | TENS TM CHN | | | | | | |
| Chain System | Primary Chain Tensioner | TENS ASY-TM CHN | | | | | | |
| Pistons | Piston | PST & RG ASY-ENG | C | 4 | | | | |
| Pistons | Piston Pin | PIN-PST | | | | | | |
| Pistons | Circlip | RET-PST PIN | | | | | | |
| Pistons | Top Ring | RG-PST COMPR UPR | | | | | | |
| Pistons | Lower Compression Ring | RG-PST COMPR LWR | | | | | | |
| Pistons | Oil Control Ring | RG-PST OIL CONTR | | | | | | |
| FEAD | Idler Asy. | IDL ASY ACC DRV BEL | C | 1 | | | | |
| FEAD | FEAD tensioner | TENSIONER & IDLER ASSY-ACC DRV BEL | C | 1 | | | | |
| FEAD | Water Pump Pulley | PLY ASY-WTR PMP | C | 1 | | | | |
| FEAD | FEAD Drive Belt | BEL DRV | C | 1 | | | | |
| FEAD | Tensioner Asy. | | C | 1 | | | | |

## Group components by service strategy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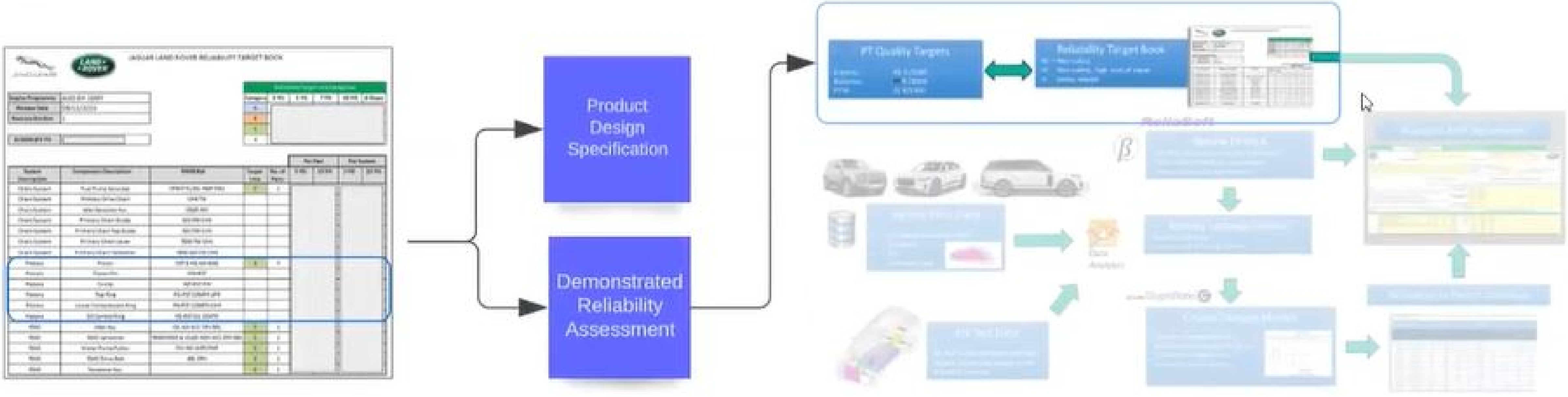

# Failure Potential Review

**Purpose:**

Bring together component owners and technical specialists to discuss Failure Modes, Mechanisms and Physics of Failure (PoF)

Agree on those mechanisms that are associated with "degradation over time"

Scrutinise the DFMEA and "UPDATE" .... This is our Body of Knowledge!!

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Agree on those mechanisms that are associated with "degradation over time"
Scrutinise the DFMEA and "UPDATE" .... This is our Body of Knowledge!!

Identify Failure Mechanisms assocated with "Degradation over time"

**DFMEA**

**Failure Effect**

**Failure Mode**

**Failure Mechanism (Cause)**

Keep asking the "due to?" question

Discuss the physics and the damage promoting conditions

Physics of Failure field now added to ReliaSoft 2021

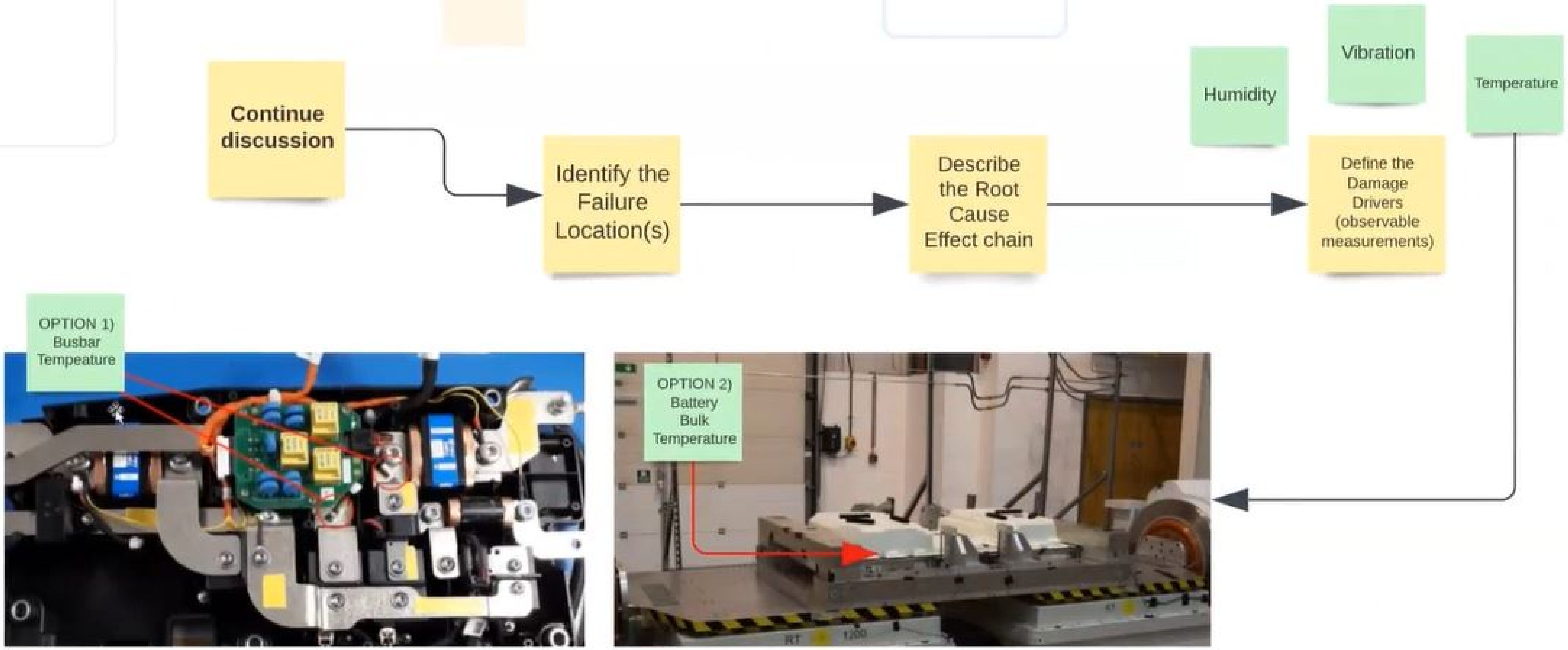

***Driver***

*Firing Cycles*
*Actuator Movements*
*Engine Revolutions*

***Initiators***

Micro cracking
Brinelling
Pitting Corrosion

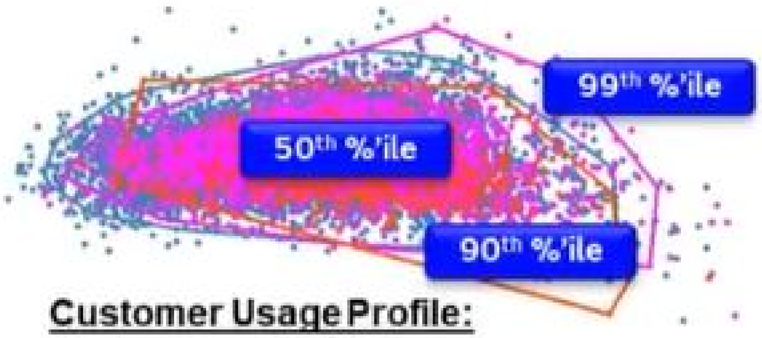
**High Cycle Fatigue**
Low Cycle Fatigue
Thermal Cracking
Abrasive Wear
Adhesive Wear
Galvanic Corrosion



Continue discussion
Identify the Failure Location(s)
Describe the Root Cause Effect chain
Define the Damage Drivers (observable measurements)
Humidity
Vibration
Temperature
OPTION 1) Busbar Tempeature
OPTION 2) Battery Bulk Temperature

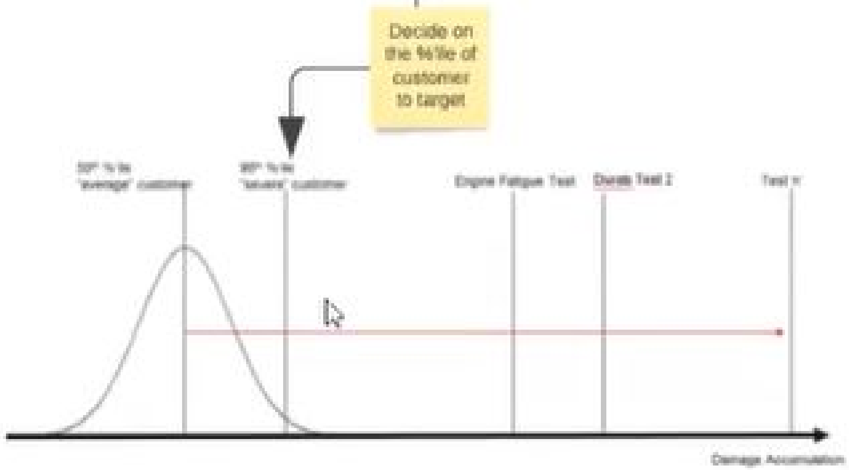
# Customer Usage Profiling

> **Certain Period of Time**
> we have a limited understanding of component specific duty cycles in the time domain.
>
> **Specified Environment and Stated Conditions**
> we can't always specify **where** and **how** our customers will use our products (e.g. off-road, track cars, towing, hot climate, cold climate etc…..)




**Customer Usage Profile:**

- ❑ Average = 50th %'ile
- ❑ Severe = 90th %'ile
- ❑ Extreme = 99th %'ile



## "Stated Conditions" = Customer Usage Profiles

Rural | Urban / City | Long Distance | Mountain

A simple approach to look at duty cycle and % mix of road usage

| Driver Profile | High Speed | City / Town | A&B Roads | Driven Distance expectation at 10YIS (km) |
|---|---|---|---|---|
| Rural | ++ | + | +++ | 240,000 |
| Urban | + | +++ | + | 240,000 |
| Long Distance | +++ | + | + | 300,000 |
| Mountain | ++ | + | ++ | 240,000 |

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|---|---|---|---|---|
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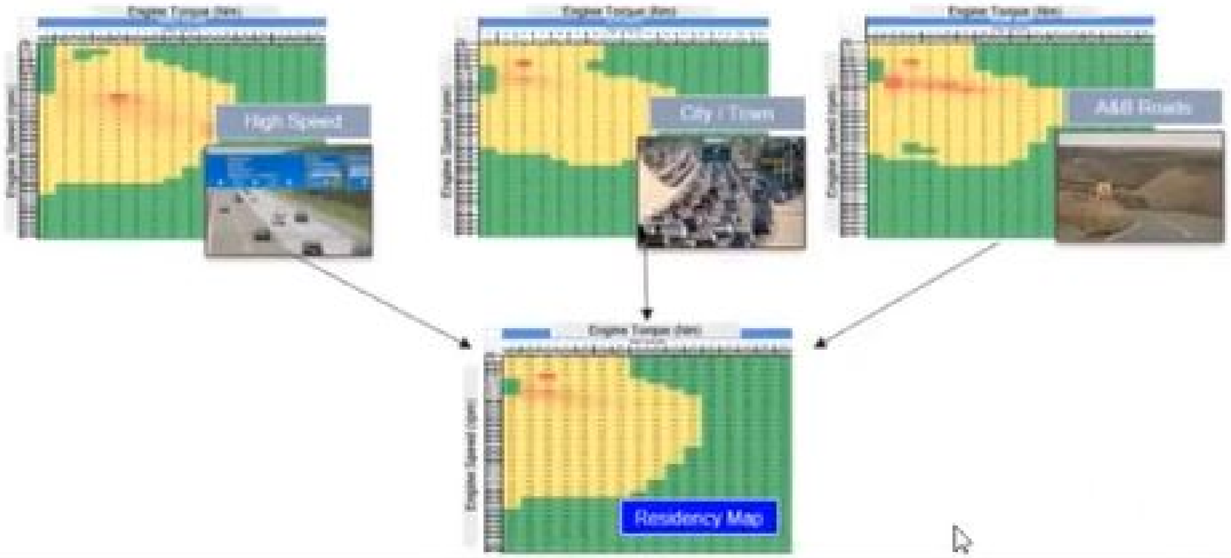


AC Charge

DC Fast Charges

Charge Sustain

Charge Attain

Now much more complex !!

EV Only Mode

Humidity and Altitude

…ling of component specific duty cycles in the

…onditions

…re and how our customers will use our products

…ing, hot climate, cold climate etc…..)

## "Stated Conditions" = Customer Usage Profiles

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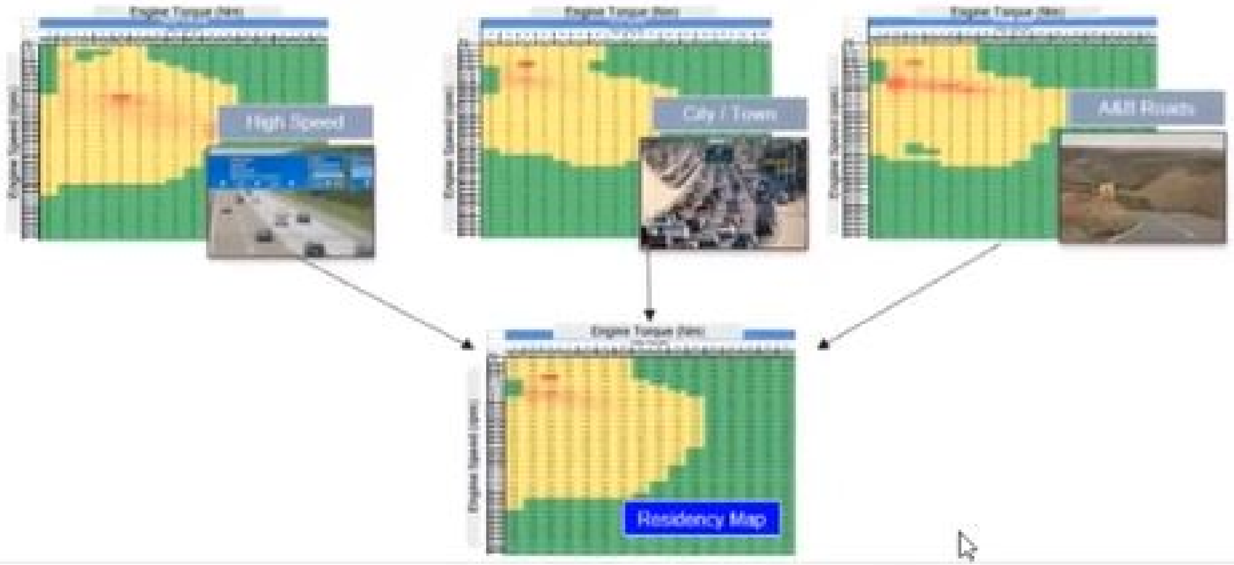



AC Charge

DC Fast Charges

Charge Sustain

Charge Attain

Now much more complex !!

Conditions (Hot / Cold Climate)

EV Only Mode

Market specific driving behaviours

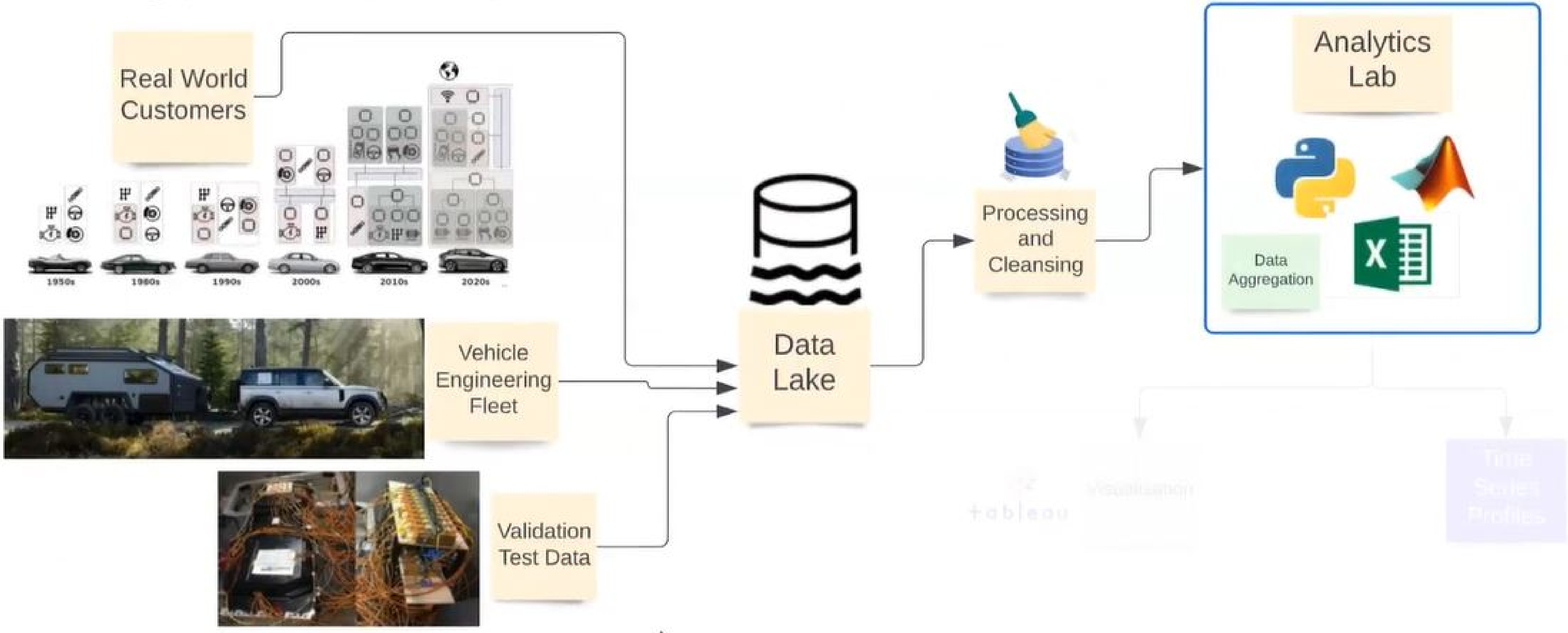
Seasonal usage behaviours

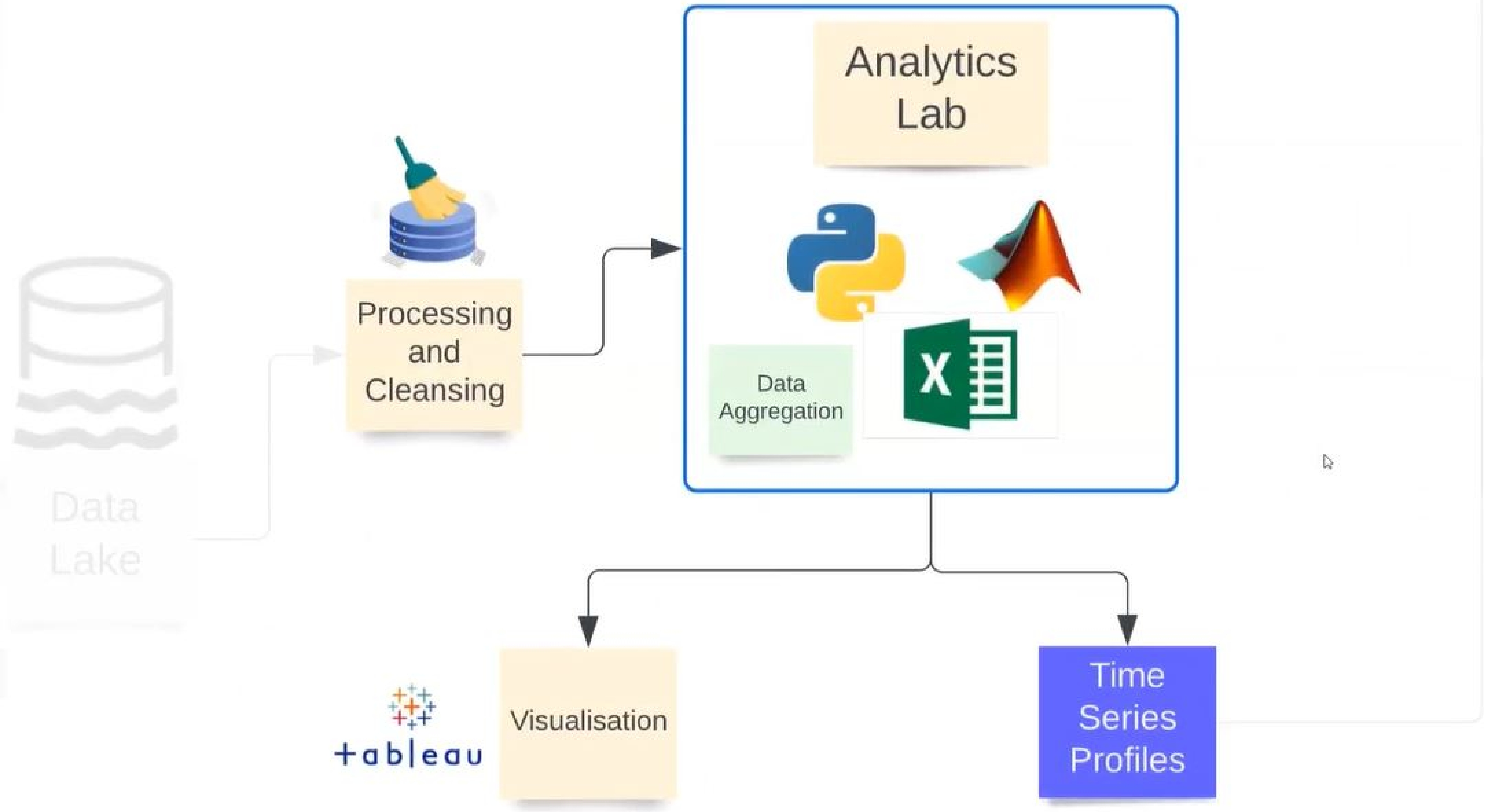
Humidity and Altitude

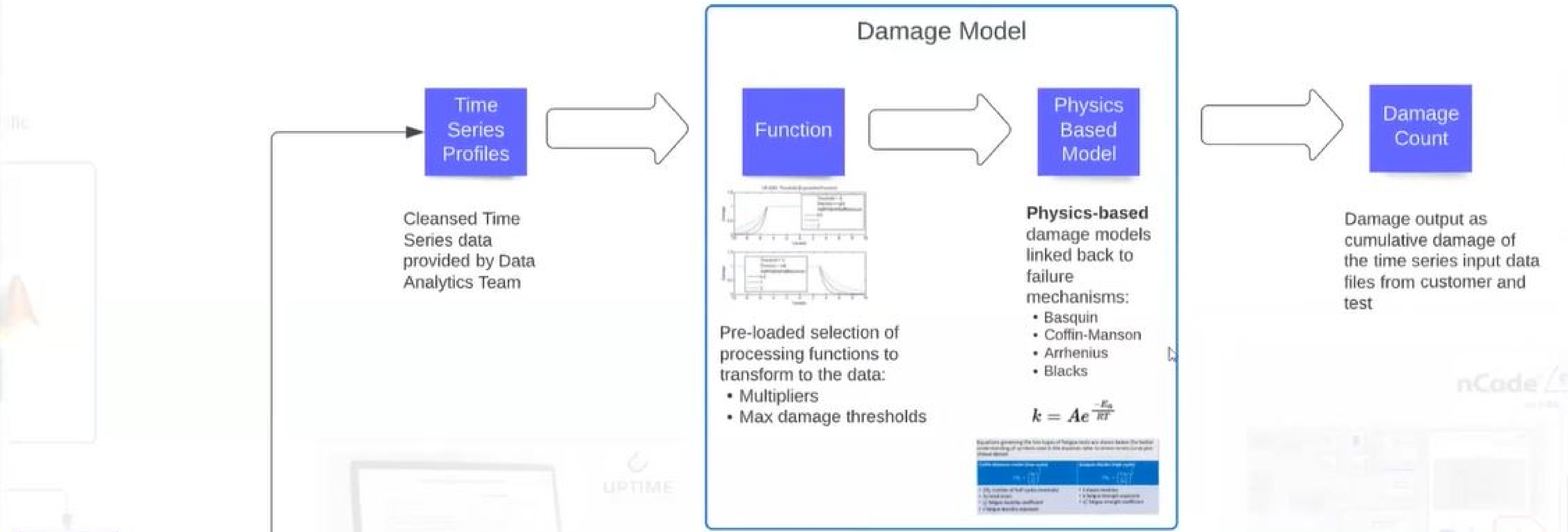
# Data Pipeline and Analytics

**Purpose:**

Collect customer data and validation test data from multiple sources, cleanse the data to ensure suitability and generate component specific customer usage profiles to feed into the damage models.




Data
Lake
Processing
and
Cleansing
Analytics
Lab
Data
Aggregation
tableau
Visualisation
Time
Series
Profiles

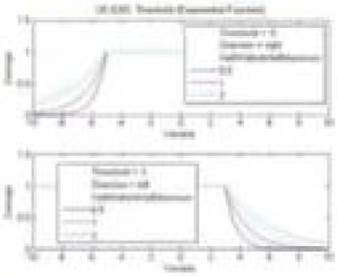



**Damage Model** transforms Time Series data to a normalised **Damage Count**

## Damage Model

**Time Series Profiles** → **Function** → **Physics Based Model** → **Damage Count**

Cleansed Time Series data provided by Data Analytics Team



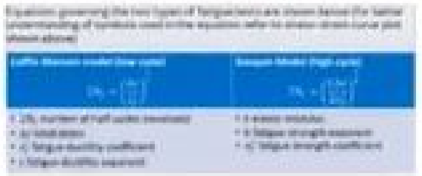
Pre-loaded selection of processing functions to transform to the data:

- Multipliers
- Max damage thresholds

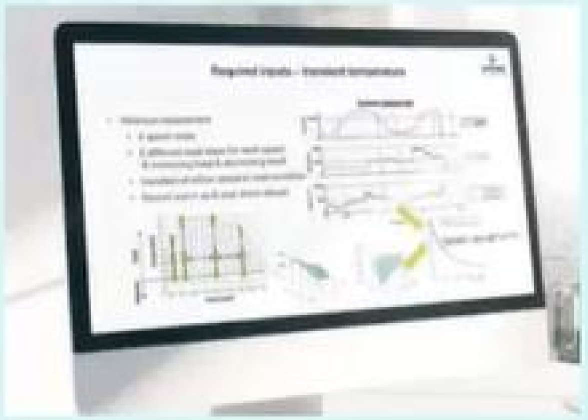
**Physics-based** damage models linked back to failure mechanisms:

- Basquin
- Coffin-Manson
- Arrhenius
- Blacks

$$k = Ae^{\frac{-E_a}{RT}}$$



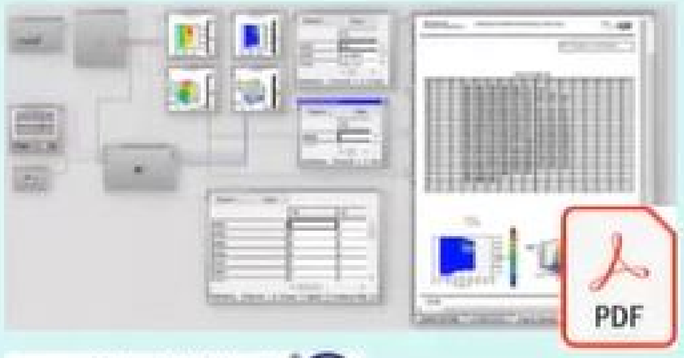
Damage output as cumulative damage of the time series input data files from customer and test



UPTIME ENGINEERING

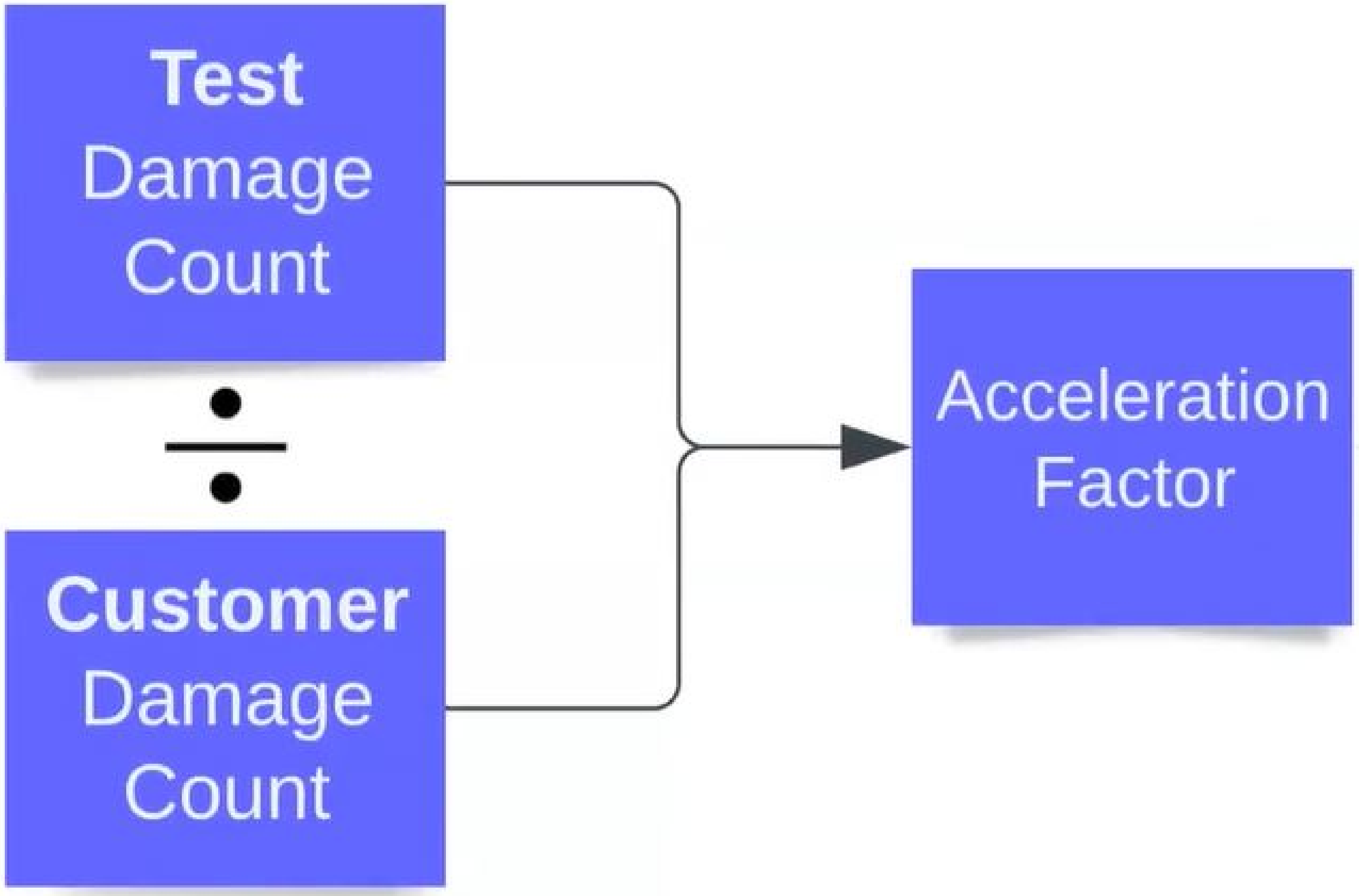
**Damage Model** transforms Time Series data to a normalised **Damage Count**

nCode ...an HBM brand

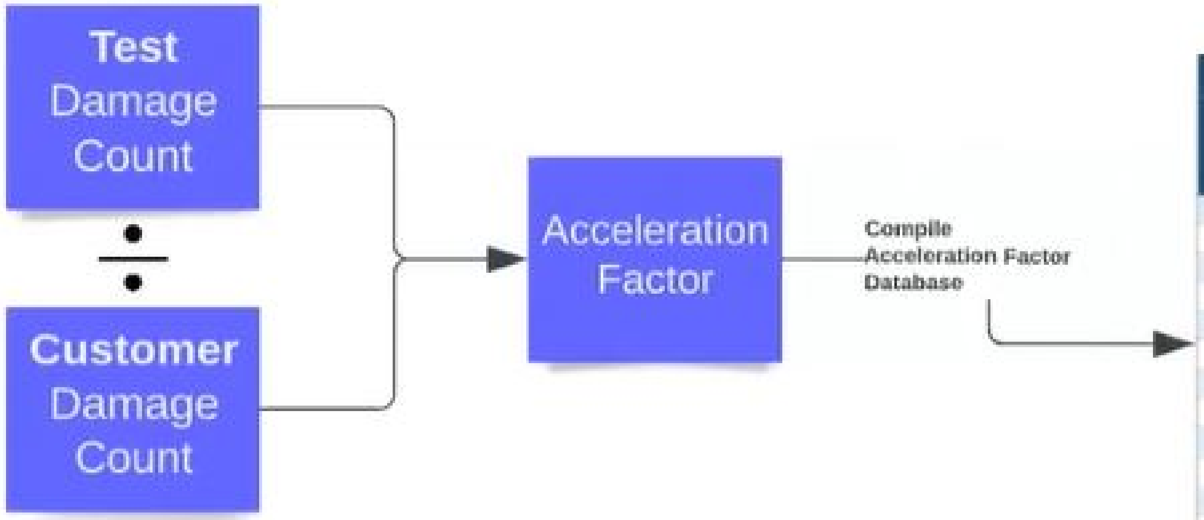



nCode GlyphWorks

**Acceleration Factors** are derived for each Validation Test making reference to the customer duty cyle:



**Acceleration Factors** are derived for each Validation Test making reference to the customer duty cyle:




**Test Assessment -** this stage of the process gives the Validation Methods team the opportunity to spot gaps in the DVP prior to the reliability calculations

| | | | | | TPJLR.00.001 | TPJLR.00.002 | TPJLR.00.003 | TPJLR.00.004 |
|---|---|---|---|---|---|---|---|---|
| Component | Failure Mechanism | Location | Damage Model Ref. | Customer Reference Cycle | Durability Cycle A | Durability Cycle B | Durability Cycle C | Durability Cycle D |
| Thermal Interface Material | Wear | TIM | DM001 | 1 | 78 | 78.6 | 79.3 | 3.4 |
| Thermal Interface Material | Aging | TIM | DM002 | 1 | 50 | 50.6 | 51.3 | 3.4 |
| Thermal Interface Material | HCF | TIM | DM001 | 1 | 20 | 20.6 | 21.3 | 3.4 |
| Stacks | HCF | Connection | DM002 | 1 | 0.5 | 1.1 | 1.8 | 0.8 |
| Stacks | Corrosion | Internals | DM003 | 1 | 0.4 | 1 | 1.7 | 0.6 |
| Seals | HCF | Lid to Frame | DM004 | 1 | 0.3 | 0.9 | 0.5 | 0 |
| Lid | Corrosion | Lid | DM005 | 1 | 0.8 | 1.4 | 2.1 | 0 |
| Frame | HCF | Frame | DM005 | 1 | 0.5 | 1.1 | 1.8 | 0 |
| Frame | Corrosion | Frame | DM005 | 1 | 0.4 | 1 | 1.7 | 0 |
| Coolant Plates | Corrosion | Hot surfaces | DM006 | 1 | 3 | 3.6 | 4.3 | 1 |
| Cooling Pipes and Hoses | Aging | Nylon Pipes | DM007 | 1 | 177 | 177.6 | 178.3 | 1 |
| Battery Harness | HCF | Connectors | DM008 | 1 | 41 | 41.6 | 42.3 | 0 |
| Battery Harness | Aging | Terminal | DM008 | 1 | 1.4 | 2 | 2.7 | 0 |
| Battery Harness | Aging | insulation wires | DM004 | 1 | 41 | 41.6 | 42.3 | 0.8 |
| Battery Harness | HCF | Metal contacts | DM008 | 1 | 0.5 | 1.1 | 1.8 | 0.9 |

Good coverage from validation test plan

**Test Assessment -** this stage of the process gives the Validation Methods team the opportunity to spot gaps in the DVP prior to the reliability calculations

Efficient testing - covers wide range of Failure Potentials

| | | | | | TPJLR.00.001 | TPJLR.00.002 | TPJLR.00.003 | TPJLR.00.004 |
|---|---|---|---|---|---|---|---|---|
| Component | Failure Mechanism | Location | Damage Model Ref. | Customer Reference Cycle | Durability Cycle A | Durability Cycle B | Durability Cycle C | Durability Cycle D |
| Thermal Interface Material | Wear | TIM | DM001 | 1 | 78 | 78.6 | 79.3 | 3.4 |
| Thermal Interface Material | Aging | TIM | DM002 | 1 | 50 | 50.6 | 51.3 | 3.4 |
| Thermal Interface Material | HCF | TIM | DM001 | 1 | 20 | 20.6 | 21.3 | 3.4 |
| Stacks | HCF | Connection | [illegible] | 1 | 0.5 | 1.1 | 1.8 | 0.8 |
| Stacks | Corrosion | Internals | [illegible] | 1 | 0.4 | 1 | 1.7 | 0.6 |
| Seals | HCF | Lid to Frame | [illegible] | 1 | 0.3 | 0.9 | 0.5 | 0 |
| Lid | Corrosion | Lid | [illegible] | 1 | 0.8 | 1.4 | 2.1 | 0 |
| Frame | HCF | Frame | [illegible] | 1 | 0.5 | 1.1 | 1.8 | 0 |
| Frame | Corrosion | Frame | DM005 | 1 | 0.4 | 1 | 1.7 | 0 |
| Coolant Plates | Corrosion | Hot surfaces | DM006 | 1 | 3 | 3.6 | 4.3 | 1 |
| Cooling Pipes and Hoses | Aging | Nylon Pipes | DM007 | 1 | 177 | 177.6 | 178.3 | 1 |
| Battery Harness | HCF | Connectors | DM008 | 1 | 41 | 41.6 | 42.3 | 0 |
| Battery Harness | Aging | Terminal | DM008 | 1 | 1.4 | 2 | 2.7 | 0 |
| Battery Harness | Aging | insulation wires | DM004 | 1 | 41 | 41.6 | 42.3 | 0.8 |
| Battery Harness | HCF | Metal contacts | DM008 | 1 | 0.5 | 1.1 | 1.8 | 0.9 |

Poor coverage from validation testing = RISK

Inefficient test

Count

Frame
Coolant Plates
Cooling Pipes and Hoses
Battery Harness
Battery Harness
Battery Harness
Battery Harness

# Reliability Calculations

**Reliability Validation Planning** is based around a Weibayes Zero Failure Testing Principle and a combination of the Weibull Formula and Binominal Confidence calculations.

*Consider;*

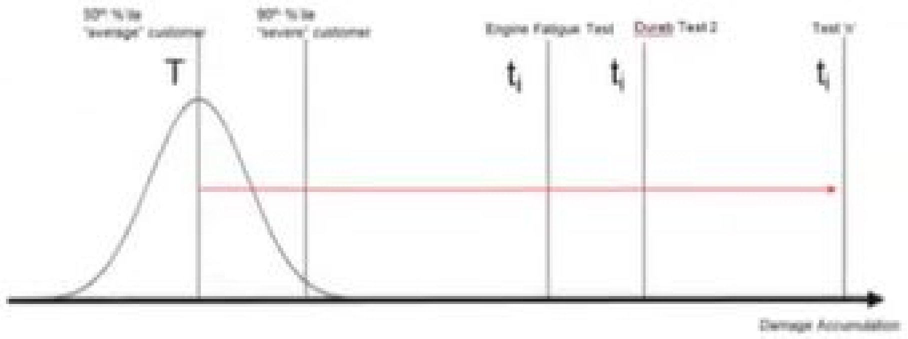
$$R = e^{-\left(\frac{T}{\eta}\right)^{\beta}} \quad [1]$$

$$1 - C = R^{n} \quad [2]$$

$$\boxed{C = 1 - R_T^{\sum_{i=1}^{n}\left(\frac{t_i}{T}\right)^{\beta}}}$$

$C$ = "Confidence Level"
$R_T$ = Component Reliability Target
$\beta$ = Shape Parameter
$n$ = number of test samples
$T$ = Target life
$t_i$ = Test duration

**Beta Database**
HCF = 2.8
Corrosion = 3.0
LCF = 3.1 - 3.5
Wear = 2.5 - 2.7




Sum each test contribution, ti to an *Equivalent sample size* 'n'

$$1 - C = R^n$$

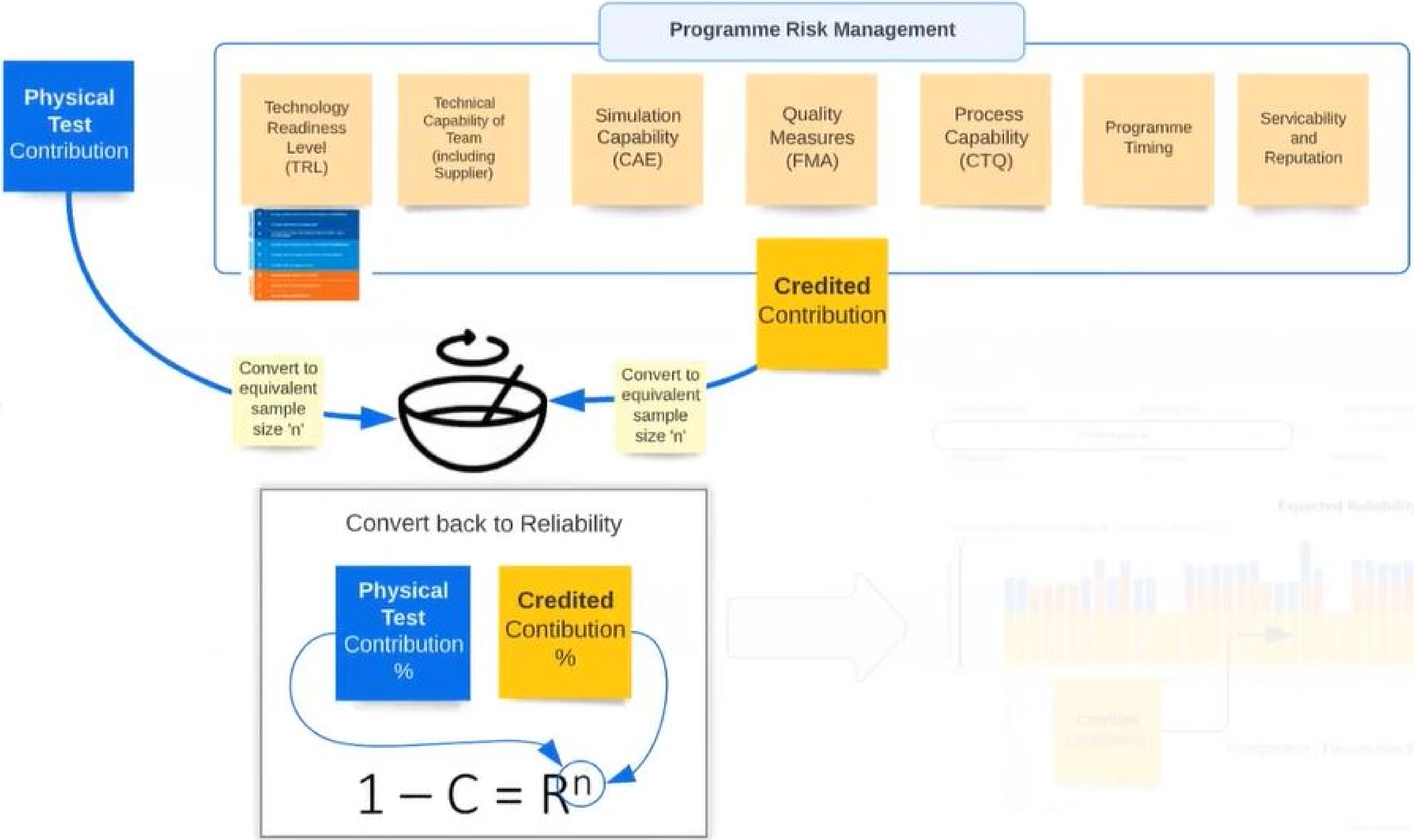
Calculate **Confidence** against a given **Reliability** Target

**OR**

Calculate **Predicted Reliability** for a given **Confidence**

*However* **Expected Reliaiblity** is not just a function of how much testing has been completed !!

# There are a number of other factors that affect Product Reliability




**Some questions to ask yourselves in this context:**

What is the maximum allowable "reliability demonstration" would you apportion to non-test activity?

How confident are you in your CAE capabiltiy?

How much confidence do you have in your Tier 1 suppliers?

How confident are you in your CAE capability?

How much confidence do you have in your Tier 1 suppliers?

### Convert back to Reliability

**Physical Test** Contribution %

**Credited** Contibution %

$$1 - C = R^n$$


UPTIME ENGINEERING

**Credited** Contribution

Technical Capability of Team (including Supplier)

Simulation Capability (CAE)

Quality Measures (FMA)

Process Capability (CTQ)

Programme Timing

Servicability and Reputation

Risk Management

**Develop risk mitigation plan between cross-functional teams:**

- Product Owner
- STA Engineer
- Quality Team
- Manufacturing
- Suppliers

**Physical Test Contribution**

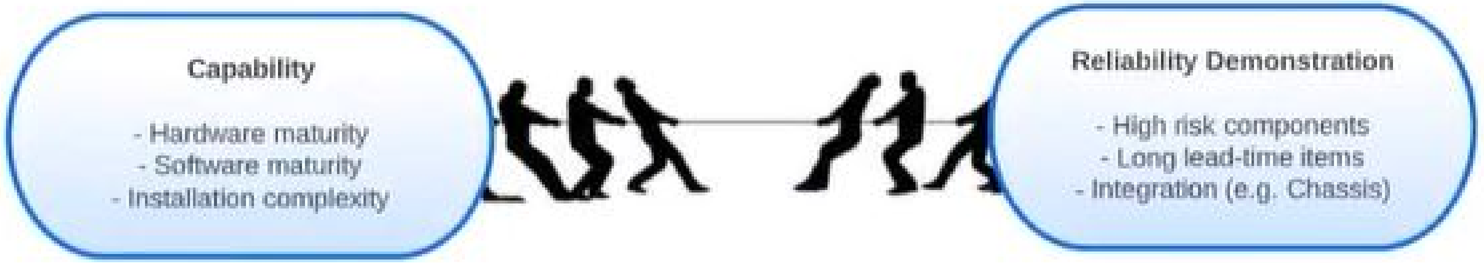
**Optimisation of Validation Test Plan:**

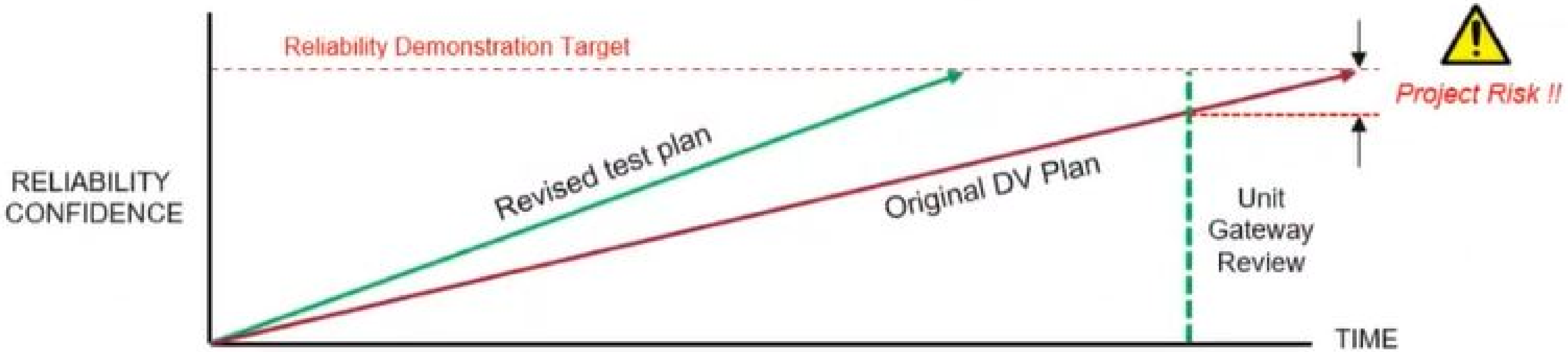
Which test cycles provide maximum rate of "confidence growth" per hour of test?

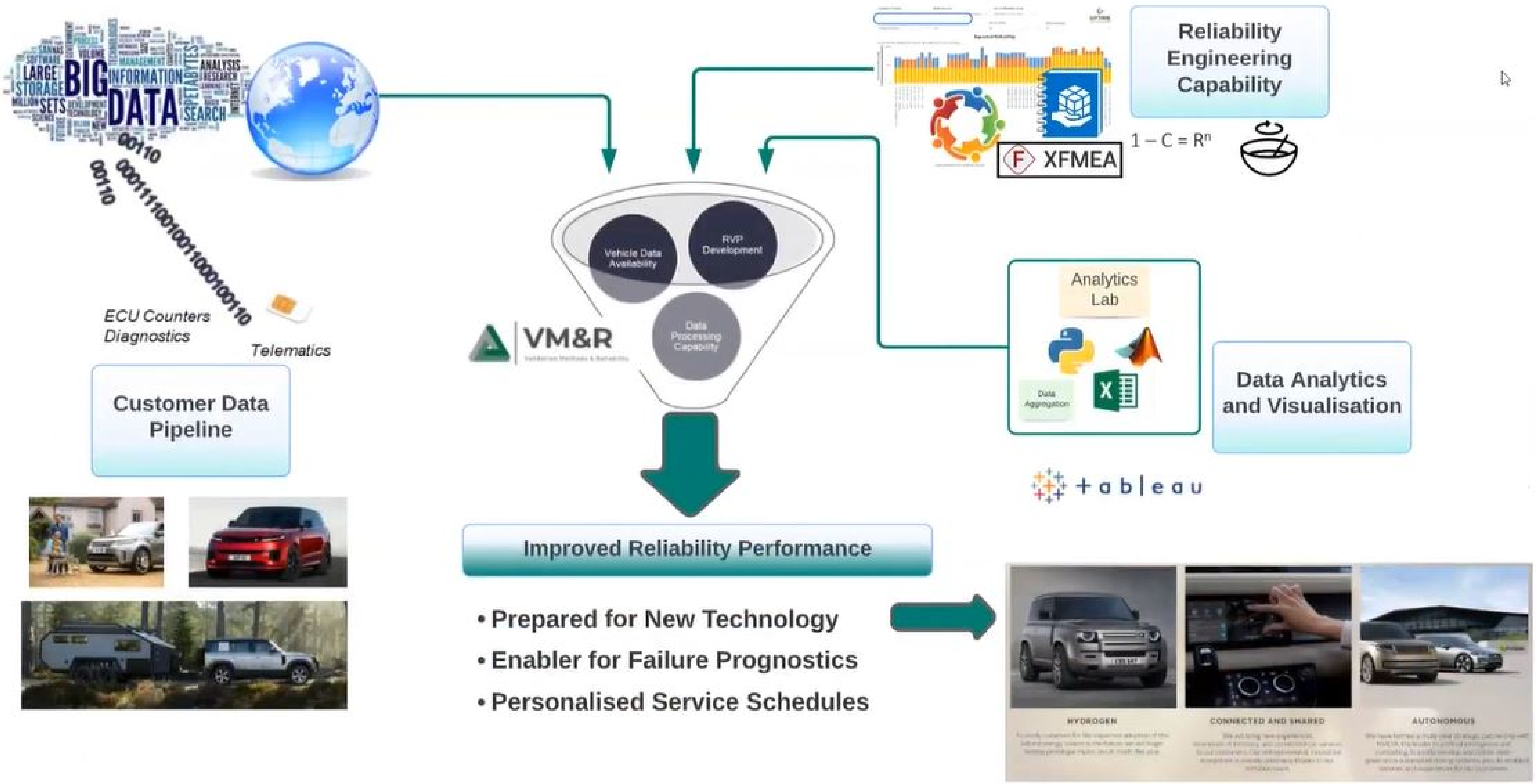
Which test cycles inflict the most damage across multiple components?

Can we simplify setup of test cycles?

Can we develop component / system rig tests (left shift)?



BIG DATA
ECU Counters
Diagnostics
Telematics
Customer Data Pipeline
Vehicle Data Availability
RVP Development
Data Processing Capability
VM&R
Reliability Engineering Capability
XFMEA
1 – C = Rⁿ
Analytics Lab
Data Aggregation
Data Analytics and Visualisation
tableau
Improved Reliability Performance
• Prepared for New Technology
• Enabler for Failure Prognostics
• Personalised Service Schedules
HYDROGEN
CONNECTED AND SHARED
AUTONOMOUS

# Reliability Validation for Electrified Powertrains

If you are interested in the material that's been presented today and would like to network and share ideas, please reach out!!

Our team would be happy to discuss this with you

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Powertrain Advanced Engineering

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VM&R


**HBK Technology Days – Virtual Seminar Series**

**Tuesday, November 22, 2022**

# Building a Reliability Validation Plan for Electrified Powertrains

Presented by Andrew Brown,
*Reliability & Validation Methods Chapter Lead,*
*Jaguar Land Rover*