Towards 'Zero Prototype Design' and 'Qualification by Simulation'

THE INTEGRATION OF PHYSICAL AND VIRTUAL TESTING

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Customer Challenge

- "In the past, we'd replace engine components early under warranty if there were reliability issues.

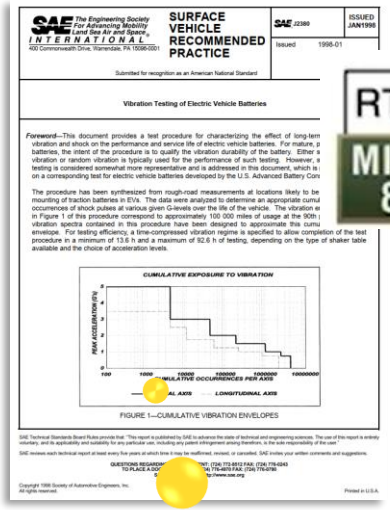
  But EV batteries have thousands of unserviceable components and a 10-year (or 150,000-mile) warranty.

  A reliability issue could bankrupt us.

- Here's what I need:
  - over 10 years (or 150,000 miles),
  - I want fewer than 5% warranty failures in my batteries,
  - with at least 90% confidence before we go to market!"

How do we calculate this?

Qualifying an EV battery

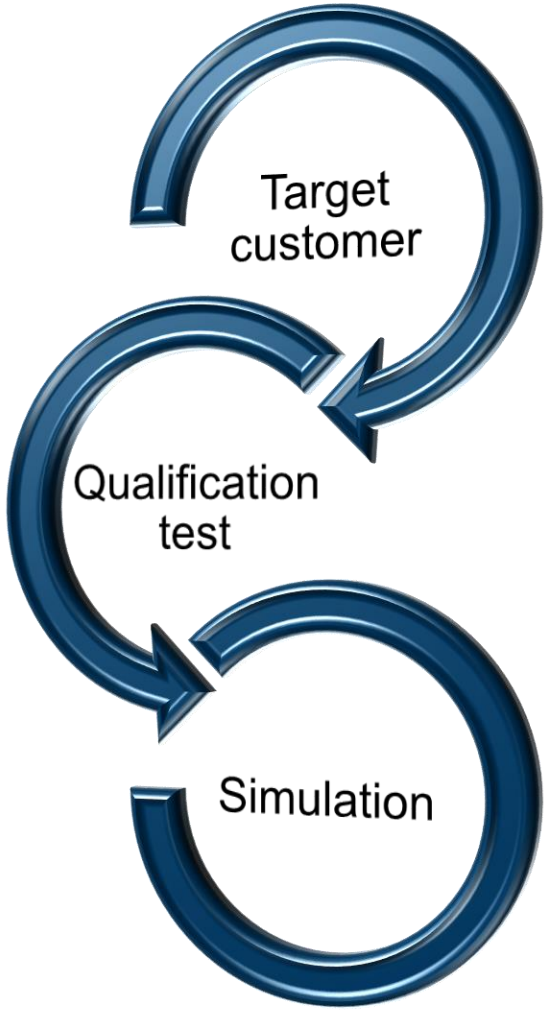


Historical
Customer spec.

Qualify this EV battery system for vibration

Do I have confidence in my historical qualification test?

Qualifying an EV battery



2. Make it scientifically reproducible

1. Statistical target customer analysis

A-Class

B-Class

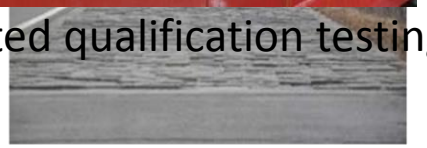
C-Class

D/E-Class

D/E-Class

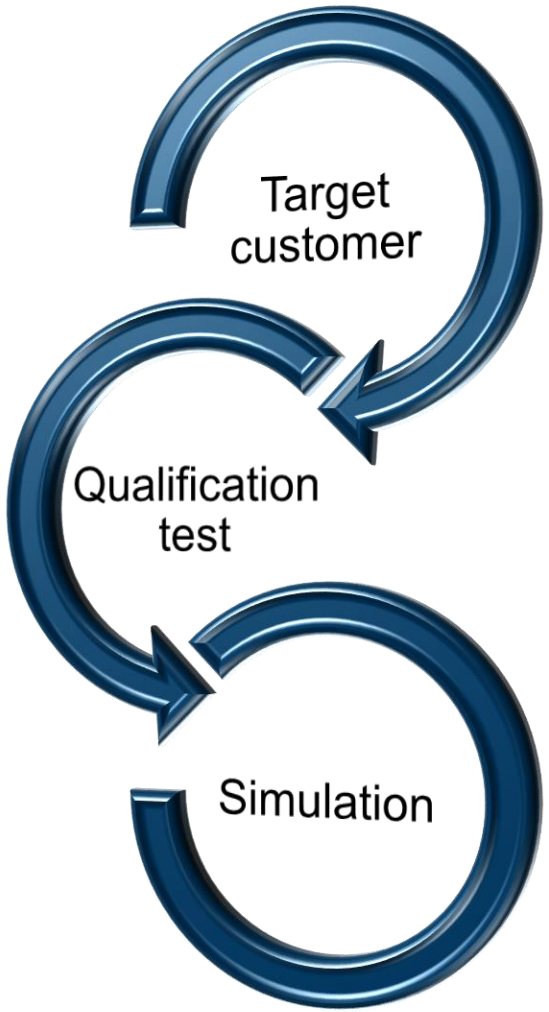
E-Class

3. Accelerated qualification testing



E/F-Class (Pave)

Qualifying an EV battery



2. Make it scientifically reproducible

1. Statistical target customer analysis

Virtual proving ground — Fleet test vehicles

Multi-body Dynamics models

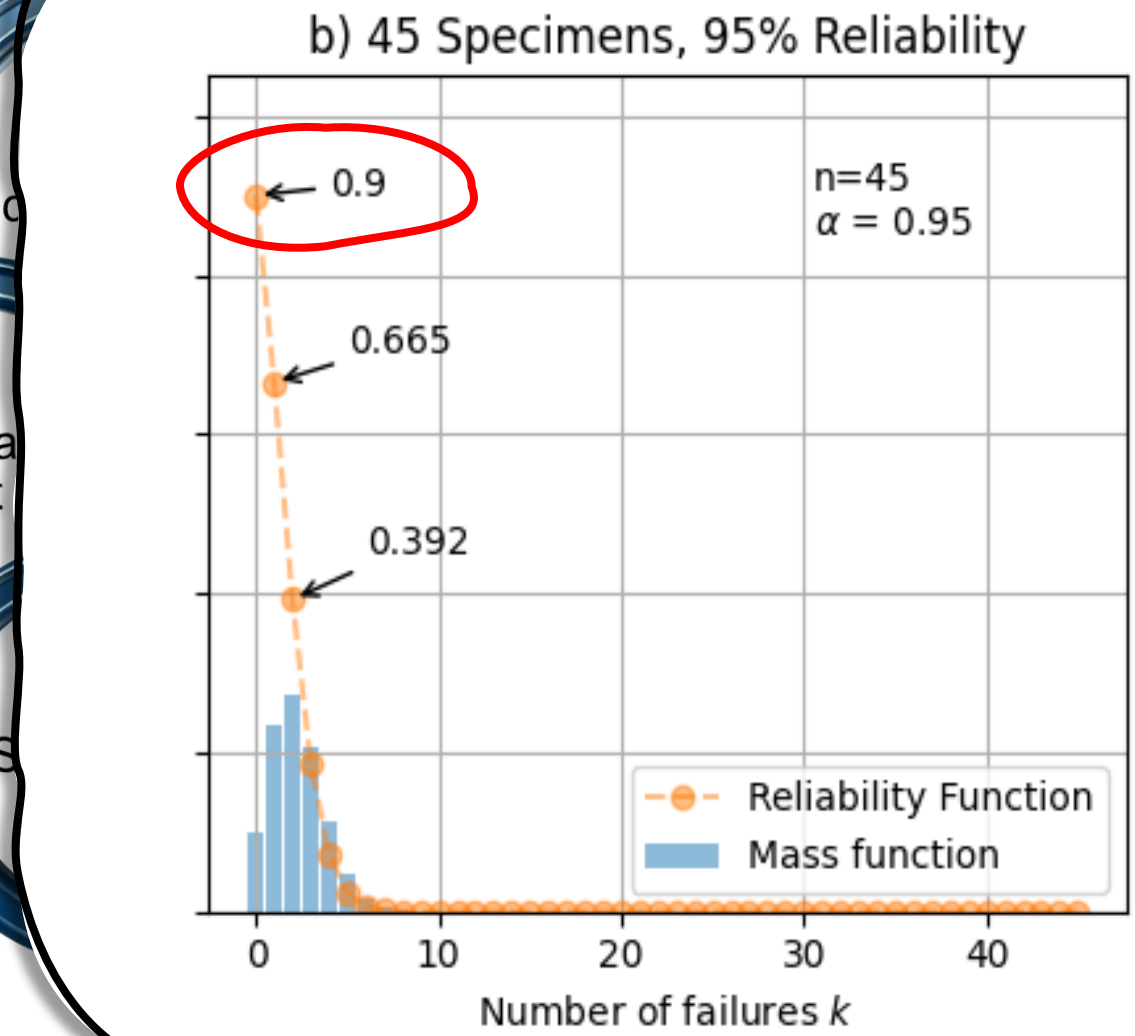
VI-CarRealTime

X in-the-loop

VI-DriveSim

Qualifying an EV battery

Statistical Confidence



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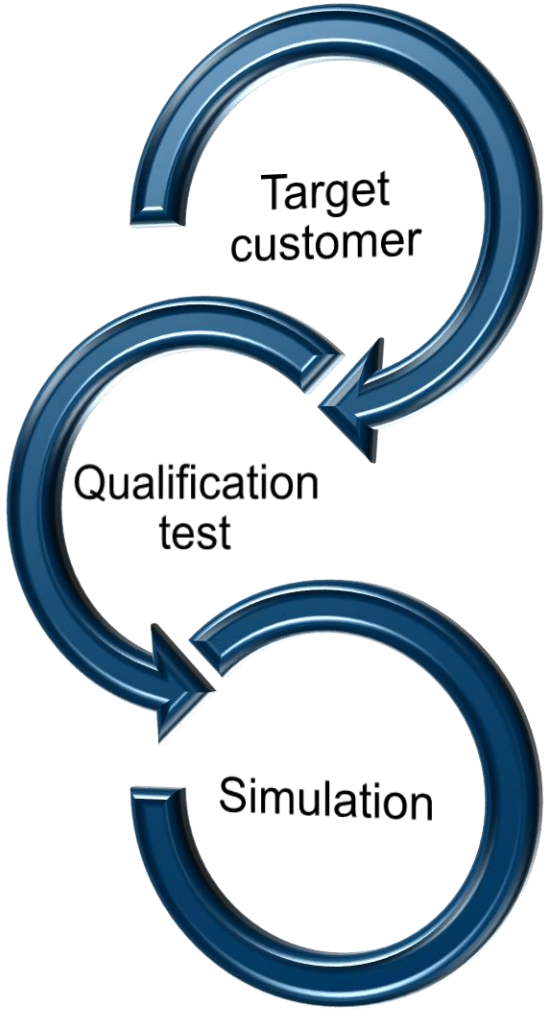
Qualifying an EV battery



Qualify reliability target using a properly **Verified** **Simulation** Model

1. Statistical target customer analysis

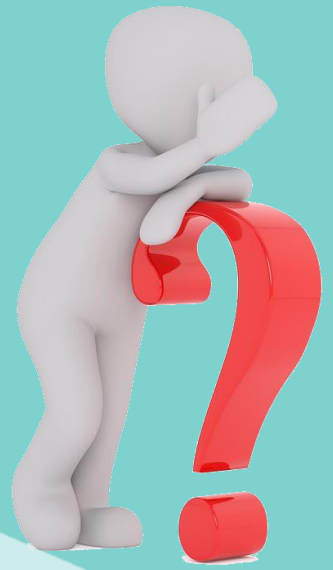
2. Make it scientifically reproducible

Verification loop

3. Accelerated qualification testing

4. Simulate the qualification test

Question:



What are the benefits of Virtual & Physical Testing?

1. **Before** Physical Testing
2. **During** Physical Testing
3. **After** Physical Testing
4. **Long-term** benefits

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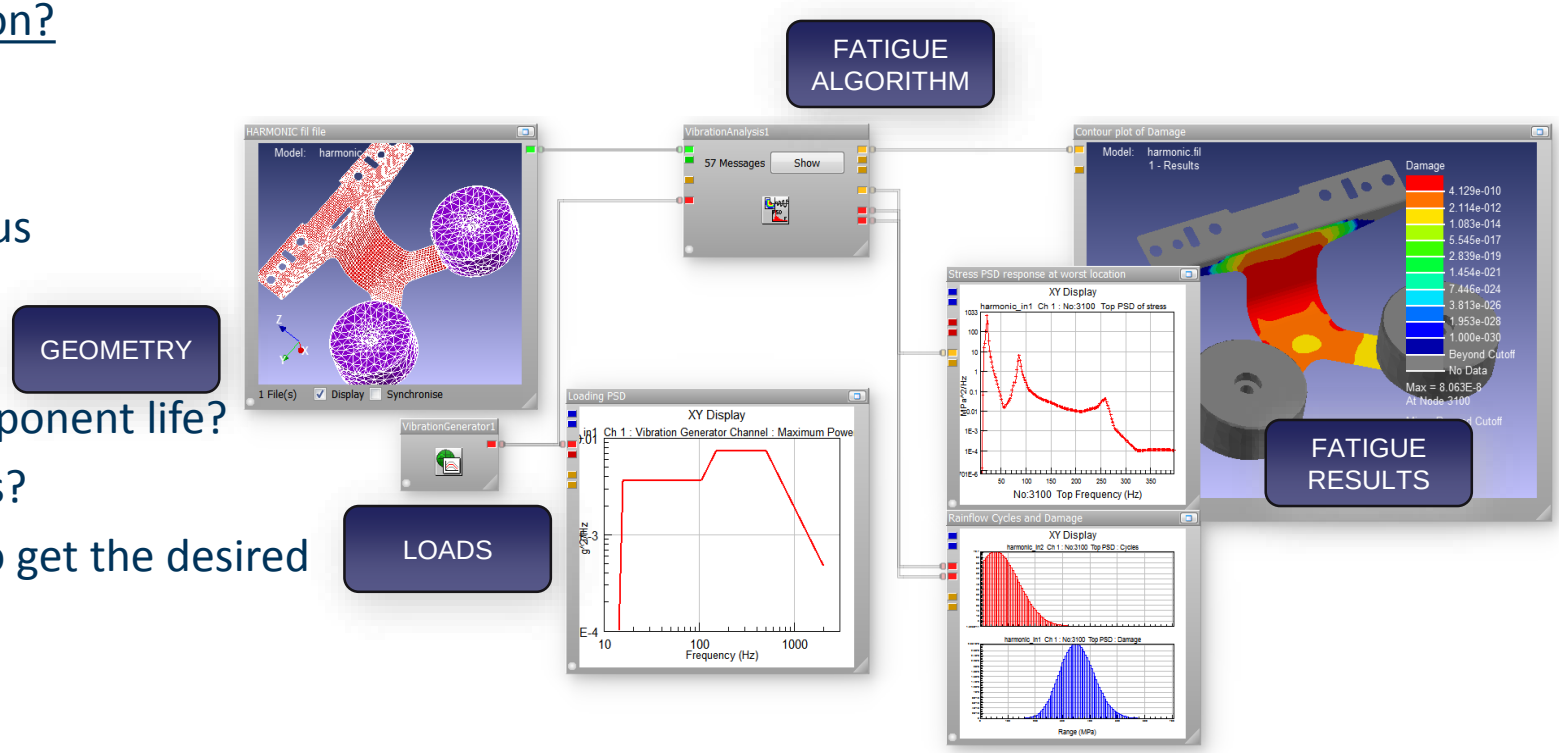
Benefits of Virtual Physical Testing

- **Before physical testing –**
  - Will it pass the test?
    - What's the safety factor?
    - Can it be lighter or cheaper?
    - Am I confident enough to start expensive prototype testing?
  - Spotting failure modes and their location?
    - Where will it fail?
    - Is the failure subtle or obvious?
    - Do the failure modes match previous experiences?
  - Is it ok to simplify the test?
    - How does simplification affect component life?
    - Do I need extra tests or longer tests?
    - What input loads should be used to get the desired responses?



Benefits of Virtual Physical Testing

- **During physical testing –**
  - Adding extra sensors?
    - Sensor optimization (accelerometers, strain gauges, displacement transducers, thermocouples, etc.)
  - Comparing physical and virtual sensors?
    - Virtual sensors to match physical
    - Comparisons made in time, frequency, and Rainflow cycle domains
  - Improving my simulation model?
    - Compare natural frequencies & mode shapes
    - Measure accurate damping parameters

Benefits of Virtual ? Physical Testing

- ✓ **After physical testing –**
  - ✓ What if my component fails the test?
    - ✓ Simulate the failure mode
    - ✓ Check the fixtures/boundary constraints/ damping /material parameters
    - ✓ Play what-if games to fix it
  - ✓ What's my reliability risks?
    - ✓ What's my real safety factor?
    - ✓ Should I test to failure?
    - ✓ How many tests should I do?
  - ✓ What next?
    - ✓ Use the simulation model in the 'Body-in-White'
    - ✓ Use simulation with confidence to explore design space

Simulation:
31 hours to failure

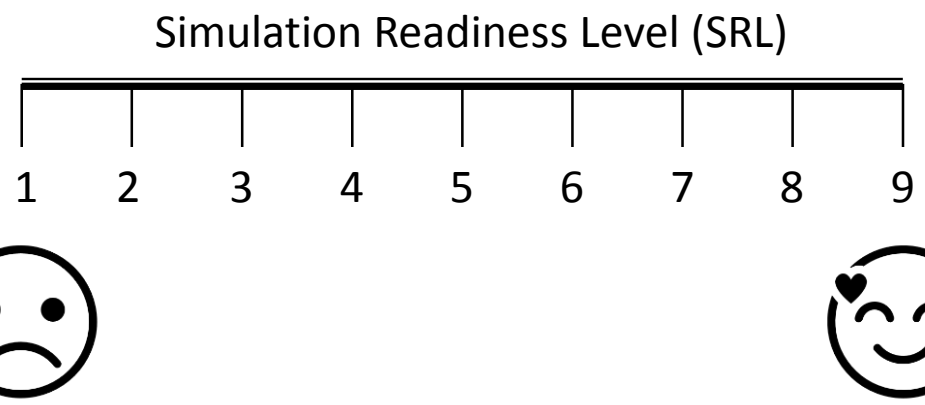
12-hour validation test

Benefits of Virtual ? Physical Testing

- ✓ **<u>Long-term</u> benefits –**

  Improve my “Simulation Readiness Level”

  - ✓ towards “Zero Prototype Design”
  - ✓ towards “Qualification by Simulation”
  - ✓ confidence to further explore design space
  - ✓ fully qualified Digital Twin



No confidence in my simulation

Fully confident in my simulation
No physical testing required!

Conclusions

Here's what I need:

- over 10 years (or 150,000 miles),
- I want fewer than 5% warranty failures in my batteries,
- with at least 90% confidence before we go to market!"

How do we calculate this?

Virtual ? Physical Test → high confidence

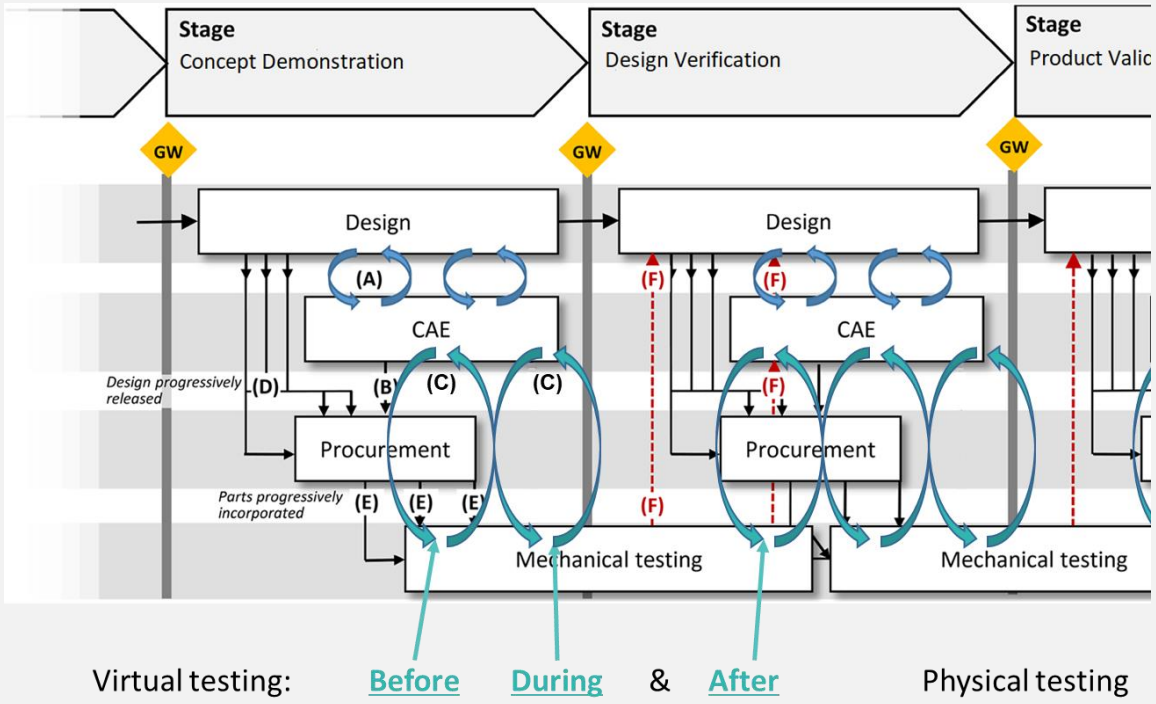
1. Simulate the test – Virtual Testing
2. Use additional measurement instrumentation:
   a) to verify stress/strain simulation results
   b) to obtain improved analysis parameters
3. Run qualification tests to failure to verify fatigue simulation

Challenge 1: How to manage physical testing as part of a stage-gated product design cycle?

1. Physical tests take a long time ∵ fatigue is an ageing failure mode
2. Tests start late in the design stage

Answer:

❖ Introduce flexibility across the Gateway



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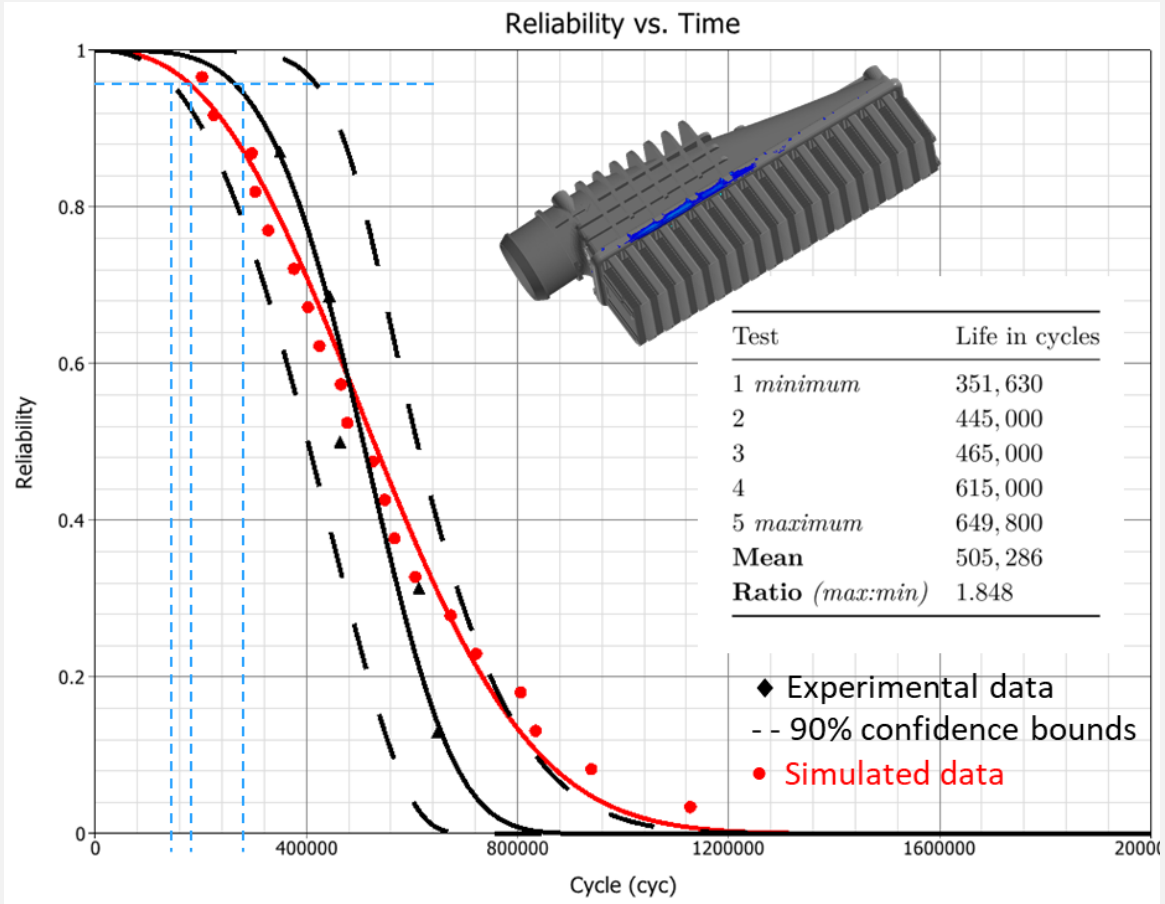
4. Validate reliability target using combination of virtual & physical test

Challenge 2: How to validate high statistical variance?

- Need to model variability as well as mean life
- Uncertainty Quantification & Stochastic Design



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4. Enhance "Simulation Readiness Level" →
   a) towards "Zero Prototype Design"
   b) towards "Qualification by Simulation"
   c) confidence to further explore design space
   d) fully qualified Digital Twin

Thank you

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Fatigue 2024

Integration of Physical and Virtual tests for achieving high confidence in fatigue reliability of automotive battery systems

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Dr. Khadija Tahera[2]
Chris Wynn-Jones[1]

In a concerted effort to minimise humanity's adverse impact on our environment, the automotive industry is keen to develop new and innovative solutions for a carbon-neutral future. They therefore face a critical requirement to offer extended warranties on new and relatively unfamiliar technologies such as advanced battery systems. This paper considers how the existing simulation, verification, and validation design process, may be enhanced to offer significant improvements in predicted confidence. Particular attention is paid to simulating the physical fatigue qualification test using a process called 'virtual testing'. This allows simulation to be better verified using evidence from fewer physical tests. The paper highlights the need for additional low-cost measurements during testing and a need to test to failure. It considers how virtual and physical tests may be integrated into a typical automotive design management process. It demonstrates how these tests mutually benefit one another.

1 Introduction

All new electric vehicles (EV) sold in the US require a 10 year / 150,000 mile (240,000 km) battery warranty. EV batteries are complex mechanical structures that support dynamic masses. They transmit structural loads and vibration through many thousands of joints and components. Fatigue failure therefore presents a significant risk to the overall reliability of the battery system.

Over a population of electric vehicles, the design target is often expressed in terms of a statistical reliability; for example:

"For a **duty cycle** of 10 years / 150,000 miles,
I require a **reliability** exceeding 95% (i.e. fewer than 5% failures),
at a **confidence level** of at least 90%."

The statistical reliability target comprises three parts:

[1]Hottinger Bruel & Kjaer UK Ltd. [2]The Open University Business School. [3]Hottin

Halfpenny. A, et al. ***"Achieving high confidence in fatigue reliability by quantifying the effects of uncertainty."*** Structural Integrity Procedia, Elsevier, 2023

Halfpenny A, et al. "**Integration of Physical and Virtual tests for achieving high confidence in fatigue reliability of automotive battery systems**." International Conference on Fatigue 2024, Engineering Integrity Society, UK.

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Thank You