HBM Prenscia Technology Day

Virtual Seminar Series

Analysis of Large In-Field Datasets to Understand Duty Cycle Variation and Refine Product Limits

Presented by Mr. David Brown
Group Leader –Low Cycle Fatigue
Cummins Turbo Technologies

Session #4: **Vehicle Fleet Data Analytics**

Analysis of Large In-Field Datasets to Understand Duty Cycle Variation and Refine Product Limits

Abstract

Product limits have generally been established through a combination of testing, analysis and field experience. Obtaining field data that is representative of real world usage has, until recently, been expensive to collect.

With the advent of the vehicle CAN bus and integration of sensors at the component level, large field datasets are now relatively inexpensive to obtain from in-service vehicles.

This presentation discusses some of the work done at Cummins Turbo Technologies to make use of these large in-service datasets to better understand usage variation and refine product limits to suit real world conditions.

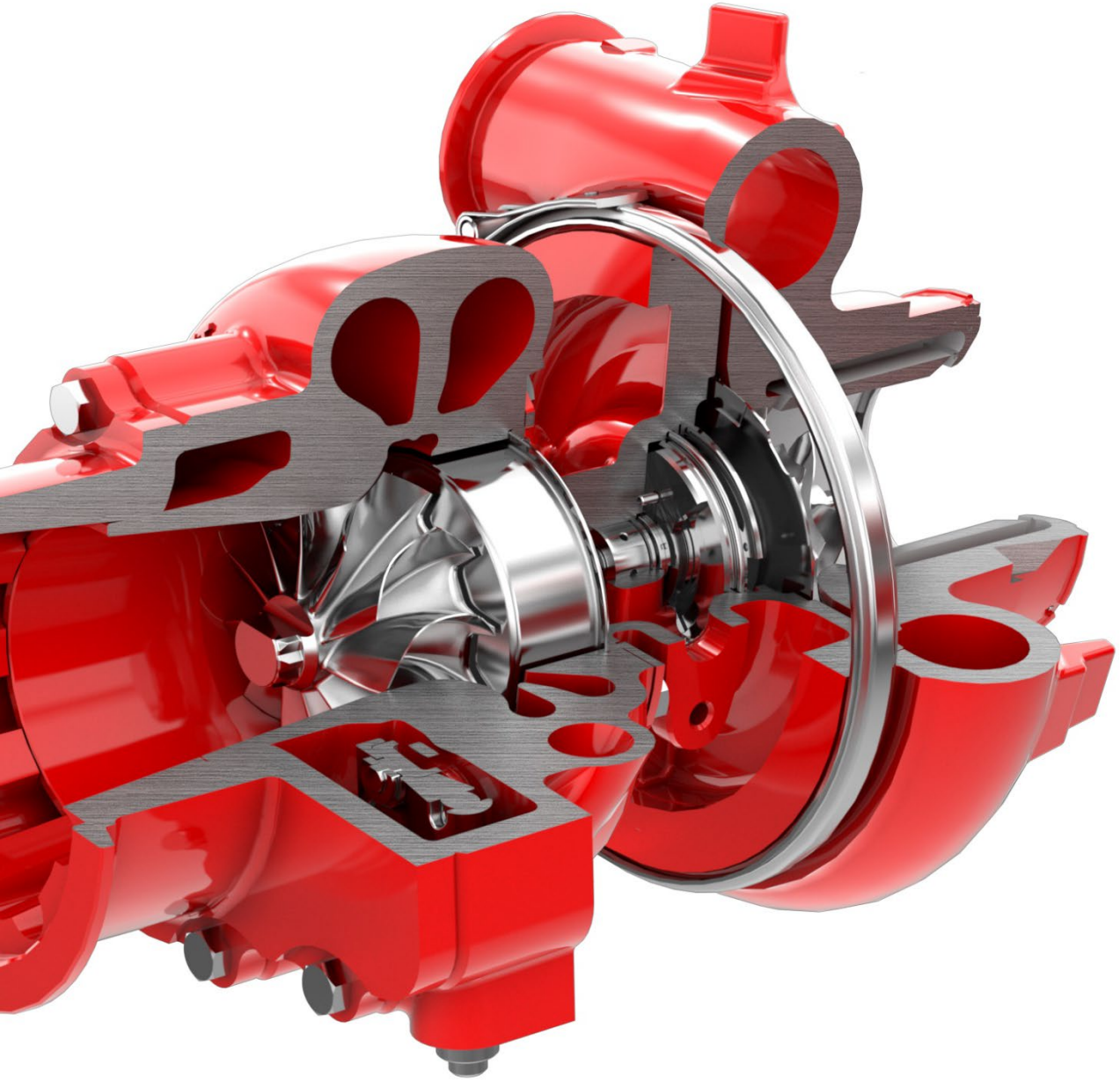
About the presenter, Mr David Brown

David Brown has 24 years of experience working in the automotive industry with Cummins. His career includes development of CFD methods, turbocharger aerodynamic design and systems/reliability engineering.

He is currently a Group Leader in the Applied Mechanics function responsible for fatigue evaluation of turbocharger components.

Prior to joining Cummins, he worked in the aerospace industry as a Systems and Performance Engineer for Hurel-Dubois.

David holds an M.Eng in Aeronautical Engineering from the University of Glasgow.



Turbo Technologies

Analysis of Large In-Field Datasets to Understand Duty Cycle Variation and Refine Product Limits

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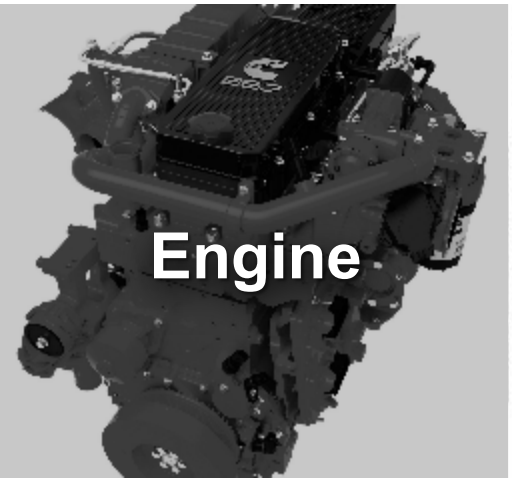
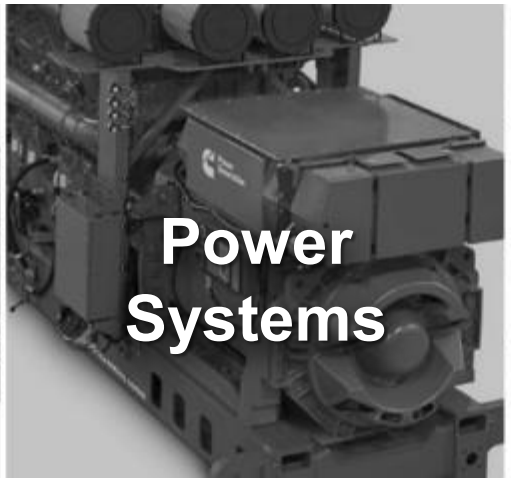
David Brown

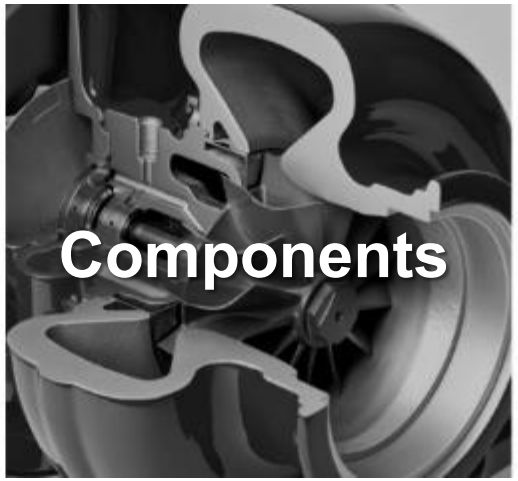
Nov 2020

About Cummins

- Cummins Inc., a global power technology leader, is a corporation of complementary business units that design, engineer, manufacture, distribute and service engines and related technologies.







Global partnerships

Companies listed on this slide reflect a view of top customers globally but is not an exhaustive list of global partnerships. Companies are listed in no particular order.

Cummins Turbo Technologies

HOLSET® TURBOCHARGERS

2L & above

60+
Years of turbo experience

6 Manufacturing facilities across four continents

7,500
Distributors worldwide, selling genuine parts to the customer

Core Technologies



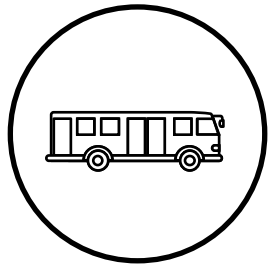


- Turbochargers
  - Holset VGT™
  - Wastegate Technologies
  - Fixed Geometry
- Power Turbines
- Two-Stage Systems
- Exhaust Throttle Valve
- Componentry

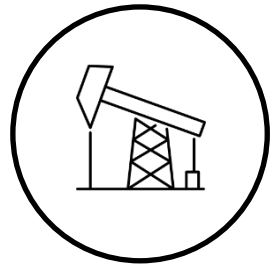
The markets we serve


Heavy-duty Truck

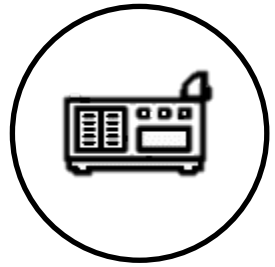

Medium-duty Truck

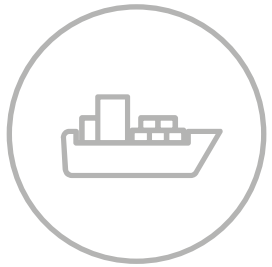

Bus


Construction

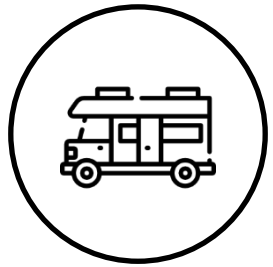

Oil & Gas


Fire & Emergency

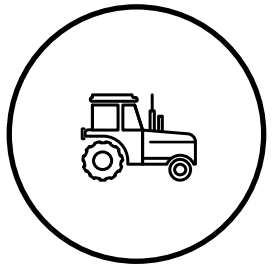

Power Generation


Marine


Mining


Light-duty Automotive & Recreational Vehicle


Defense


Agriculture


Rail

This is not an exhaustive display of Cummins-powered markets. Please refer to cummins.com for the most updated product information.

Agenda

1. Introduction

2. Field Data Logging & CAN data

3. Application to Turbo Low Cycle Fatigue

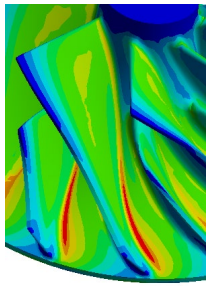
4. Improving Product Limits

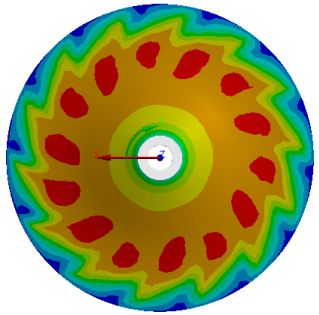
Introduction

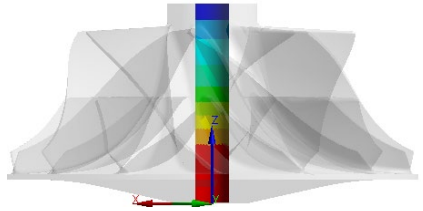
- Product design limits are determined from a combination of :
  - Testing

Material and Component Fatigue testing

  - Simulation







FEA / CFD Analysis

  - Field experience

Real world experience from a range of applications

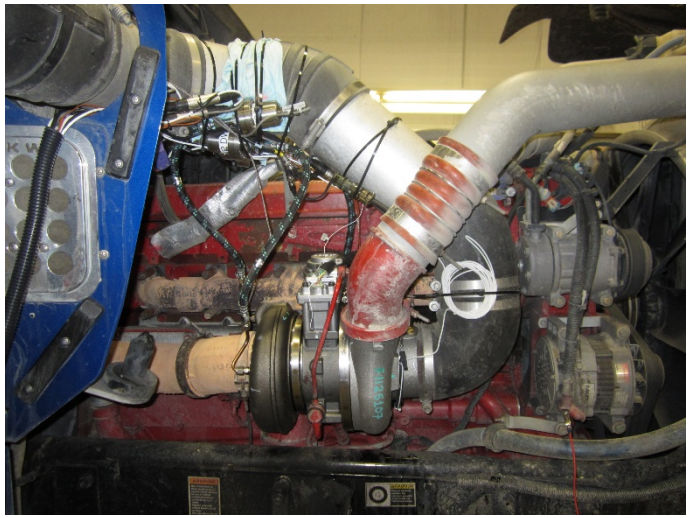
Introduction

- While advances in simulation have reduced reliance on testing, we still need a good understanding of real world use.

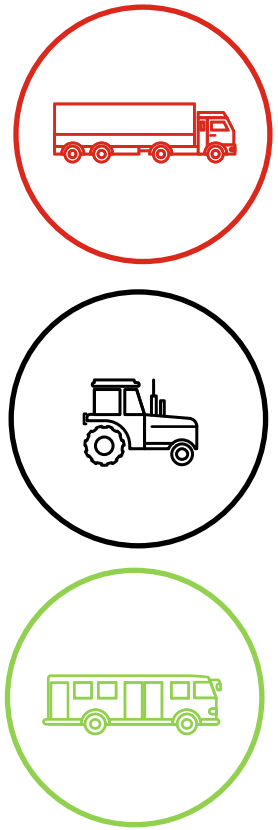
Field Data Logging

- CTT have historically logged data in the field to understand how duty cycles differ between applications and to set appropriate product limits.

- Involves sending a logger and technician with an instrumented turbo to a customer site
  - Time consuming
  - Expensive
  - Limited time window to collect data

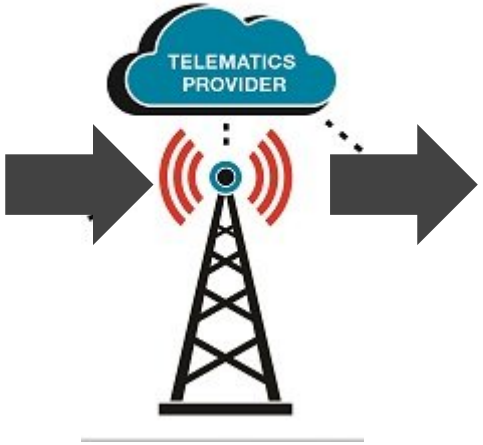


Field Data Logging Today

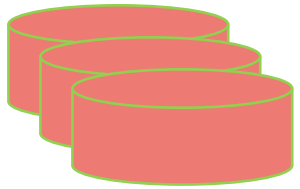


In Service Vehicles

Production Sensors + CAN Logger



Data Transmission



Data Storage

GlyphWorks

MathWorks®

MATLAB®

Extraction, Cleaning and Analysis

Field Data Logging Today

Benefits of CAN data

☺ Quantity of data for different applications and end users

☺ Data availability

☺ Geographic and seasonal variations

☺ Low cost to collect

Challenges

☹ Inherently dirty compared with dedicated logger data

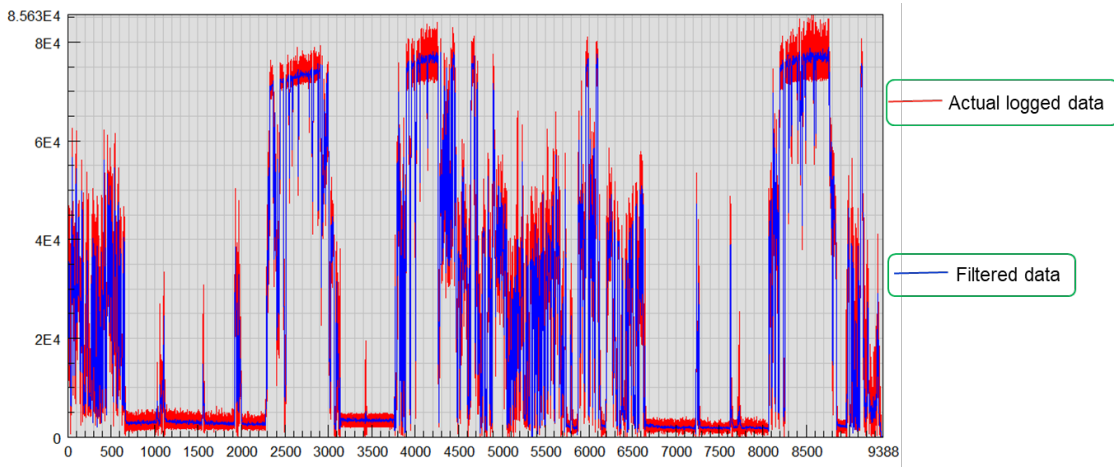
☹ Non-constant sample rate

☹ Time & resource for cleaning

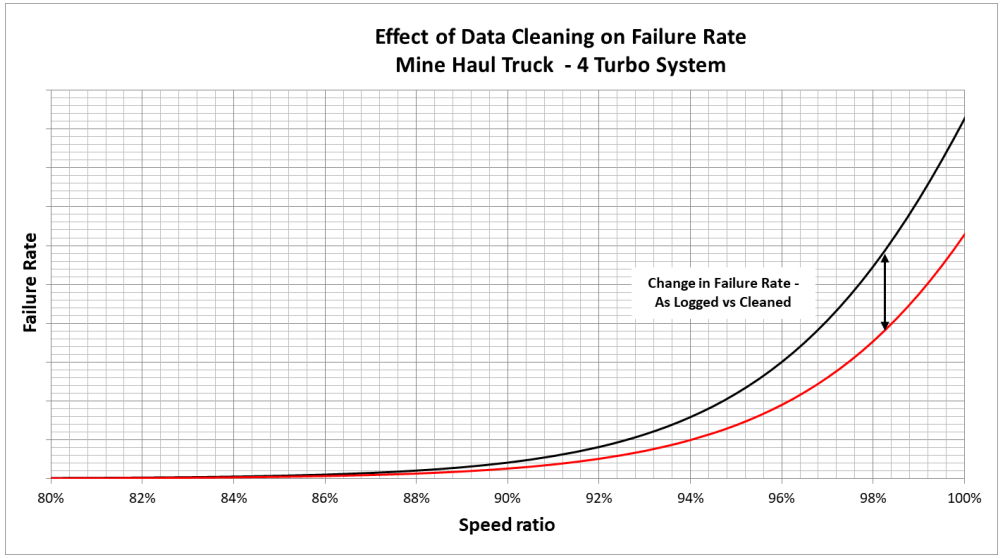
☹ Selecting time windows

Processing CAN data

- Data cleaning before analysis
  - How to handle “bad” data
  - Spike / noise removal
  - Outlier, NaN detection etc.
  - Can be automated but still requires sanity checking.

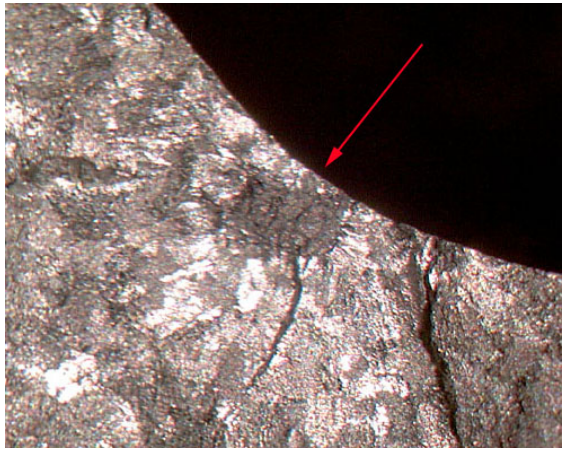
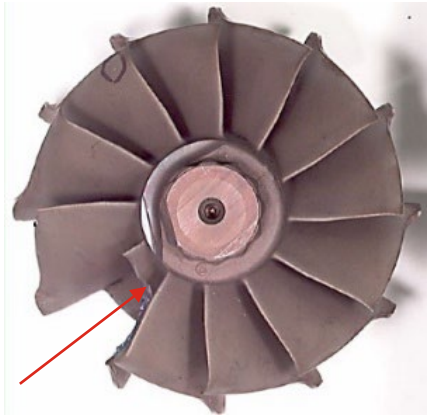
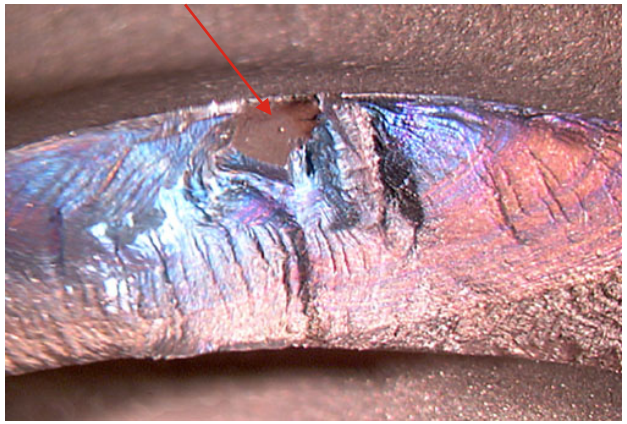


- How much data do we need ?
  - How repeatable is the data
  - Window size to characterize the duty cycle
  - Varies with application
    (eg Line Haul, Refuse Truck, Powergen)



Application to Turbo Fatigue Prediction

- Impeller and Turbine Wheel fatigue are major failure modes in a Turbo

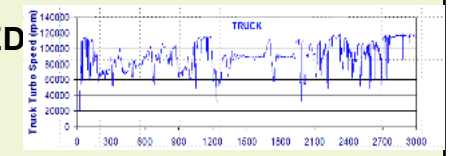





- Main mechanisms of damage accumulation are through Low Cycle Fatigue (LCF) and High Cycle Fatigue (HCF).
- LCF failures occur due to the cyclic nature of the engine/turbo operation which varies for different applications.
- LCF failures are generally avoided by having appropriate application speed limits.

LCF Life Prediction

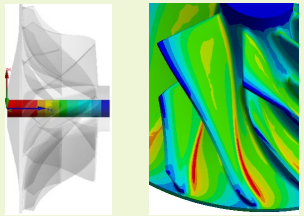
FIELD DATA

PROCESSED CAN DATASETS



MATERIAL FATIGUE TEST

FEA RESULTS

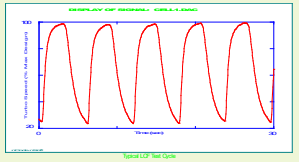


FATIGUE ANALYSIS

GlyphWorks

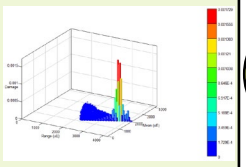
DesignLife

ACCELERATED COMPONENT FATIGUE TEST



TEST & SIMULATION

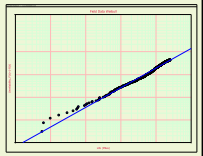
LIFE PREDICTION & LIMITS



COMPARE

SERVICE & WARRANTY

SERVICE DATA WEIBULL



LCF Life Prediction

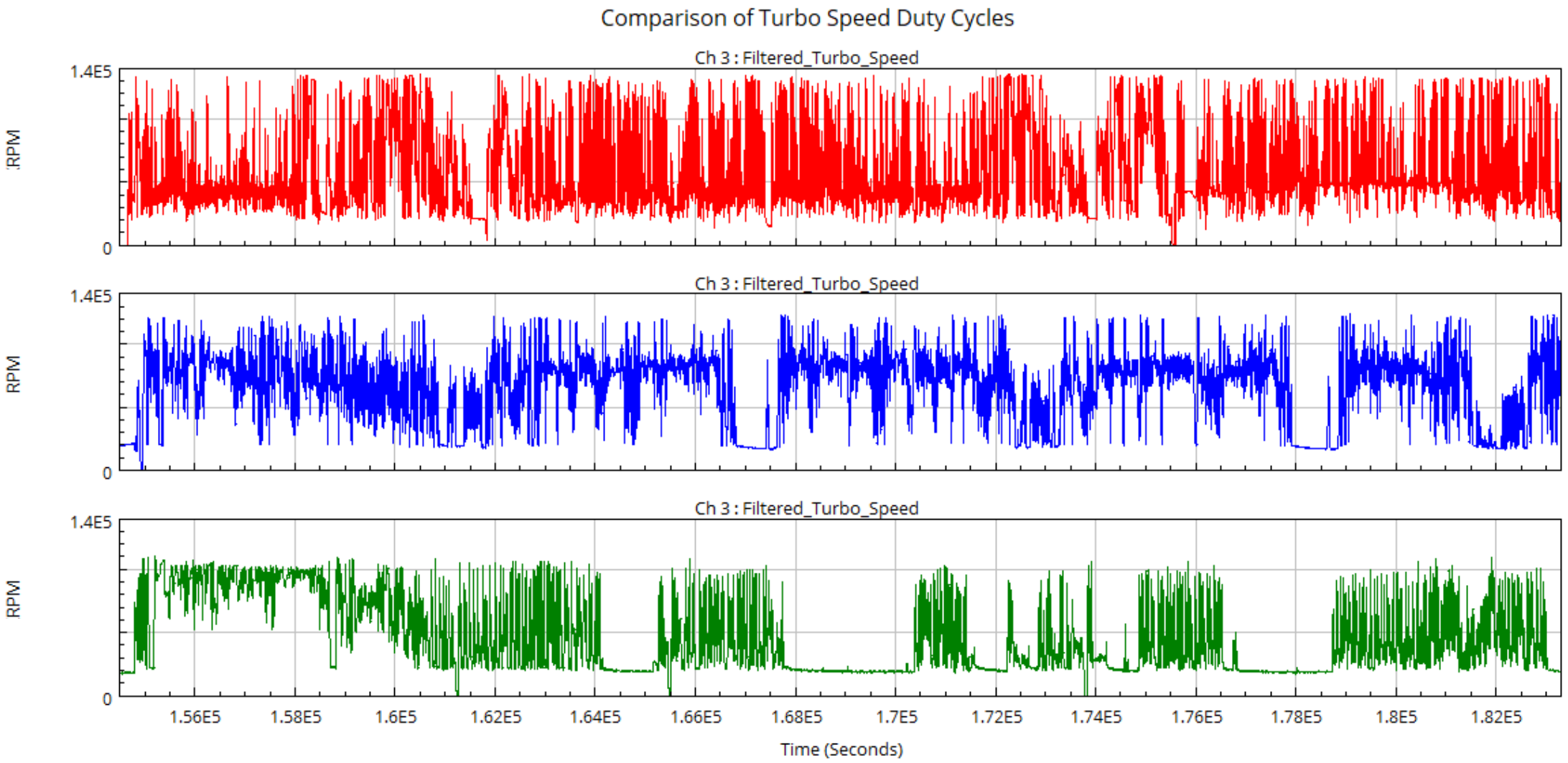
Improvements made to life prediction due to -

- Better analysis methods and simulation capability
- Better understanding of materials and processing
- Smarter testing

Large in field CAN datasets offer the opportunity to better understand real world variation and further develop the prediction method.

- Range of applications from Heavy Duty and Mine Haul trucks to Pick Ups and Marine

Turbo Speed Duty Cycles

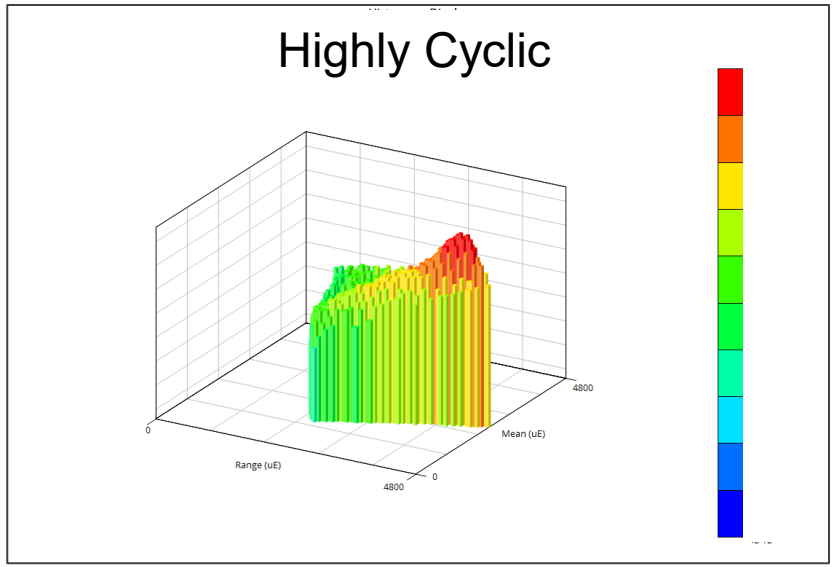


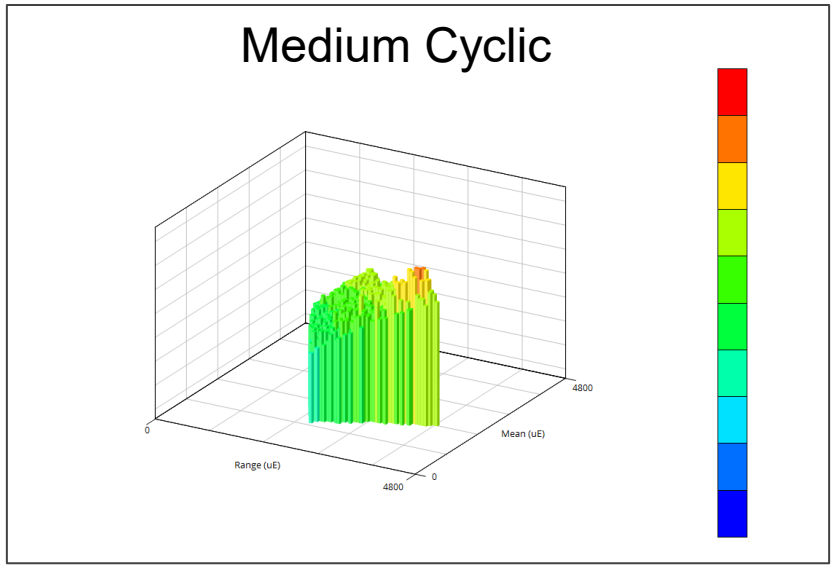
Highly Cyclic

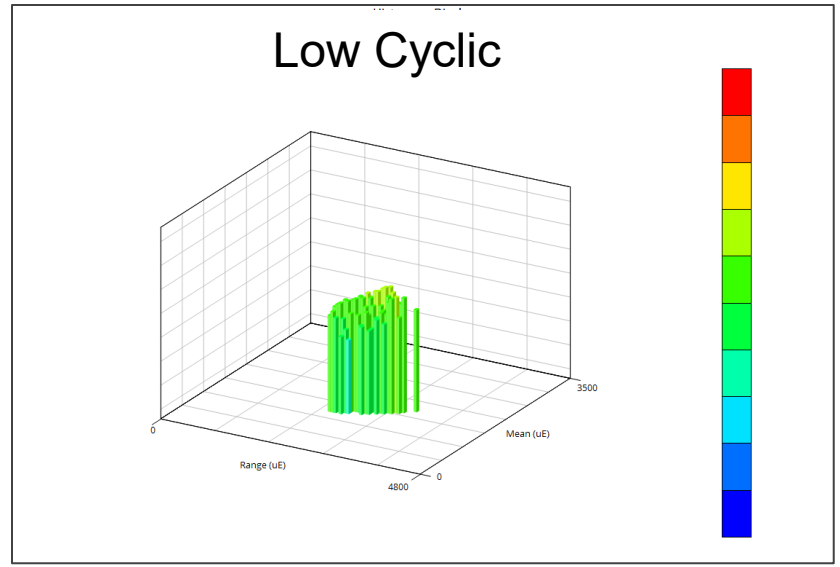
Medium Cyclic

Low Cyclic

Fatigue Analysis Results

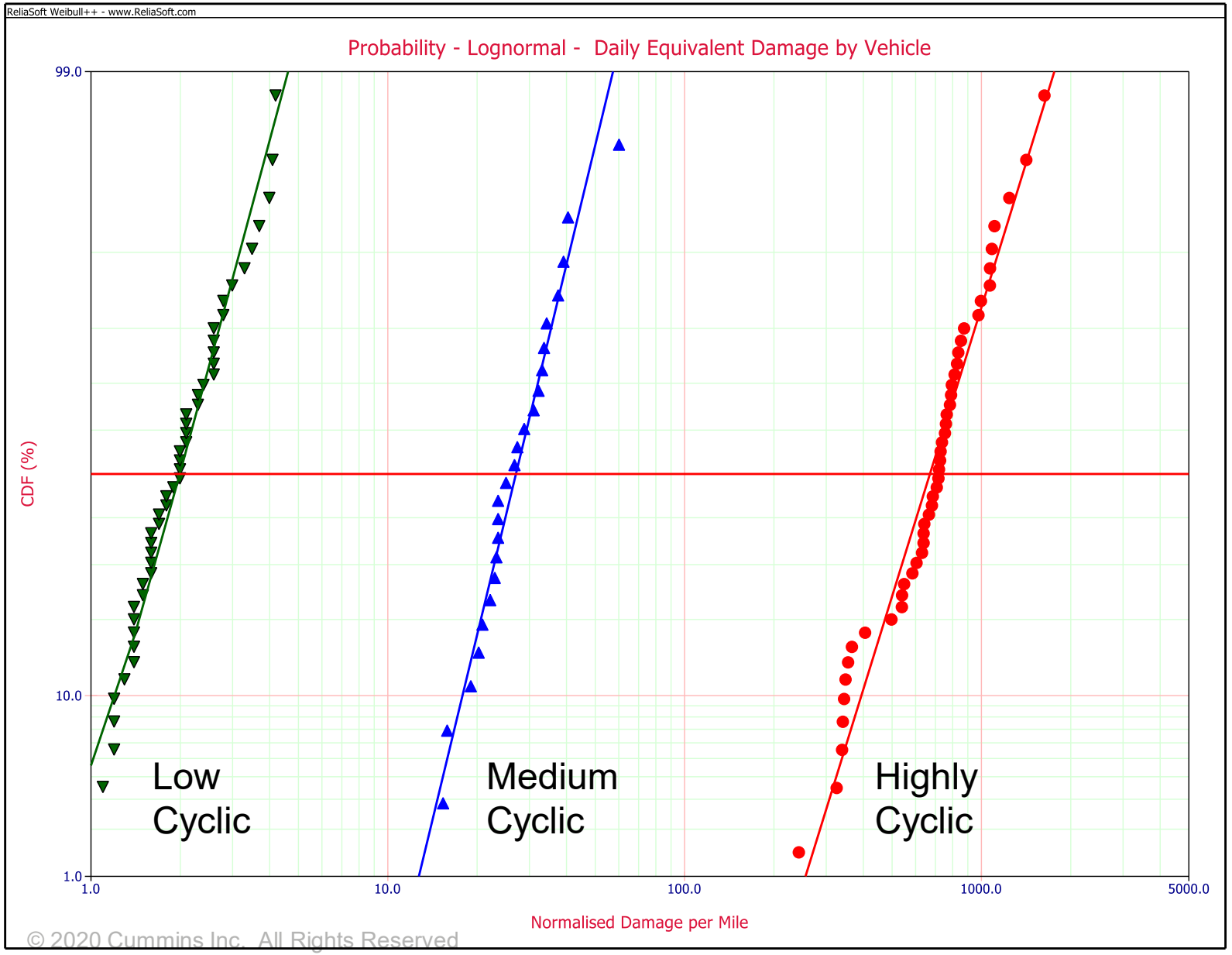






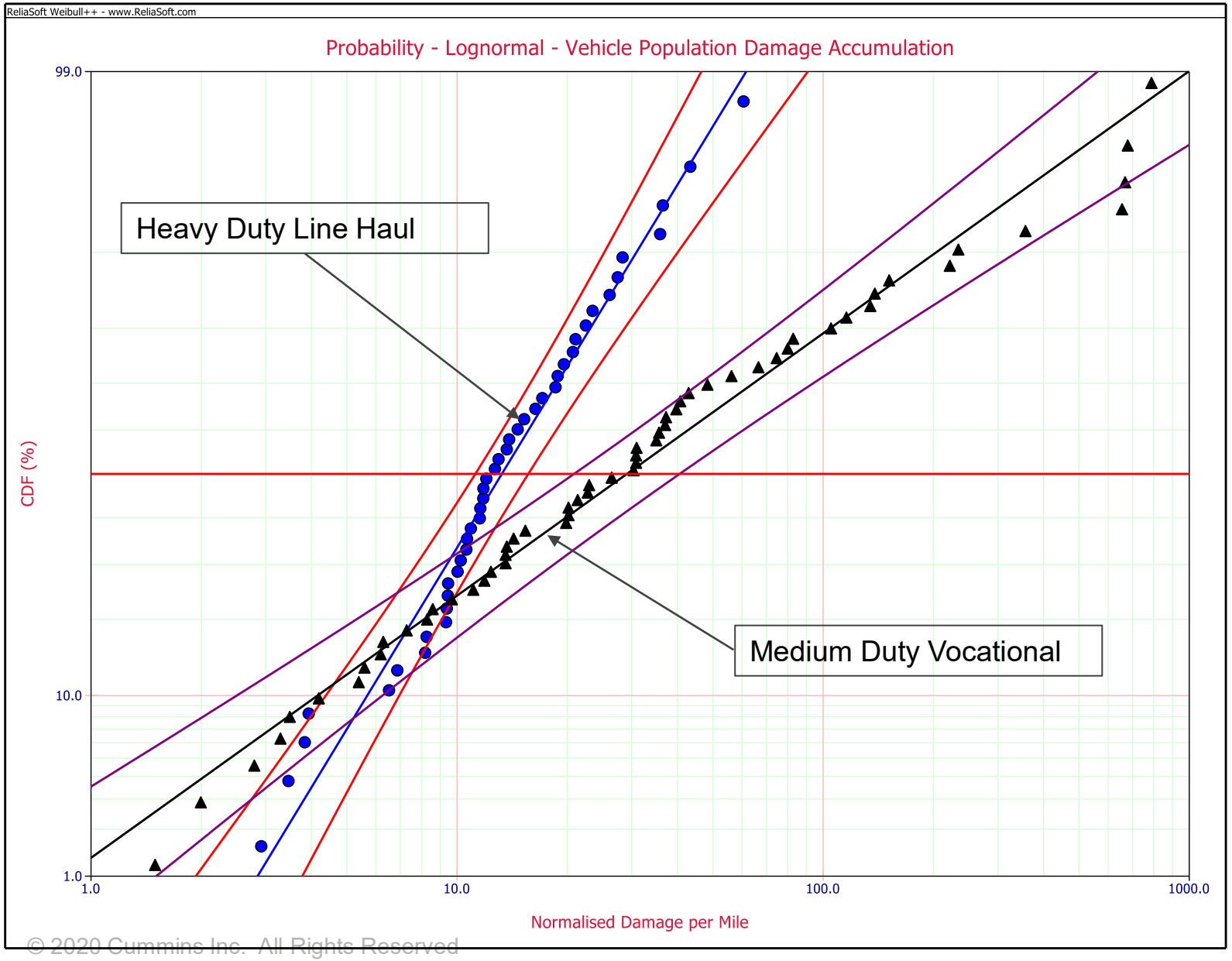
- Damage results clearly show differences in duty cycles
- How does this compare over the longer term ?

Damage Accumulation Distribution



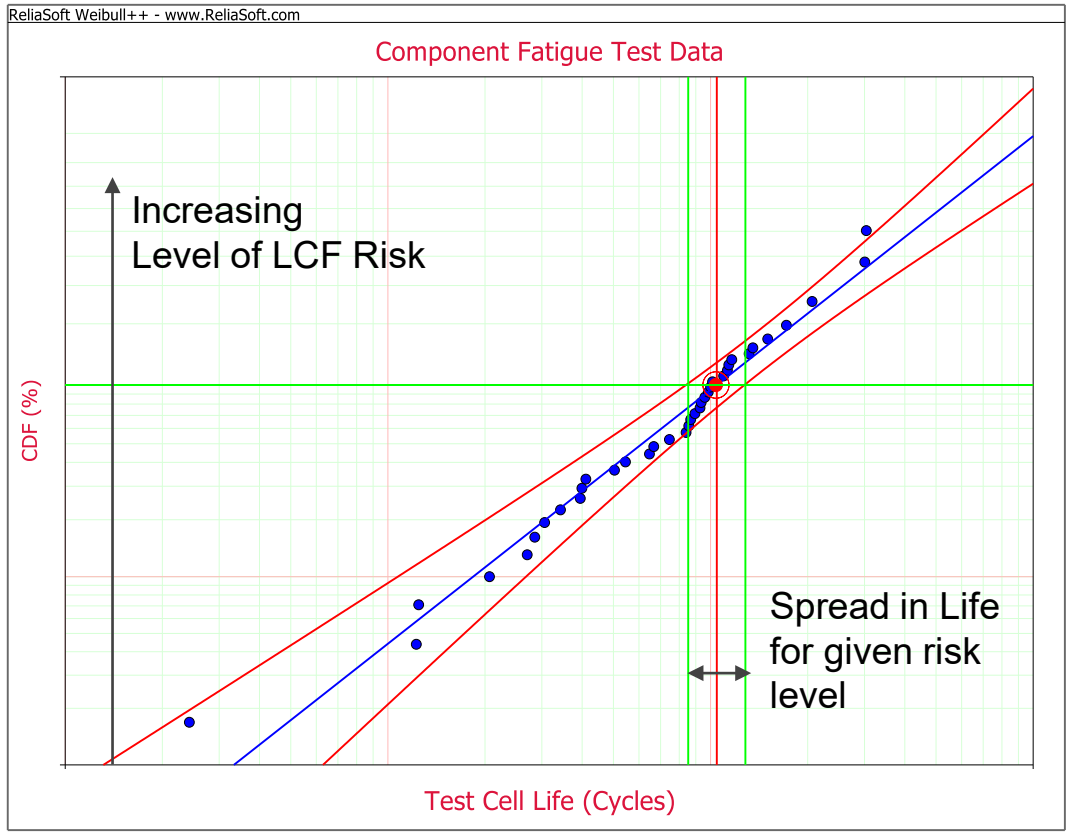
- Daily damage accumulation at a vehicle level.
- Can quantify the range of damage we might expect from normal day to day usage
- Large difference in mean values, but similar shape - similar variation in daily use.

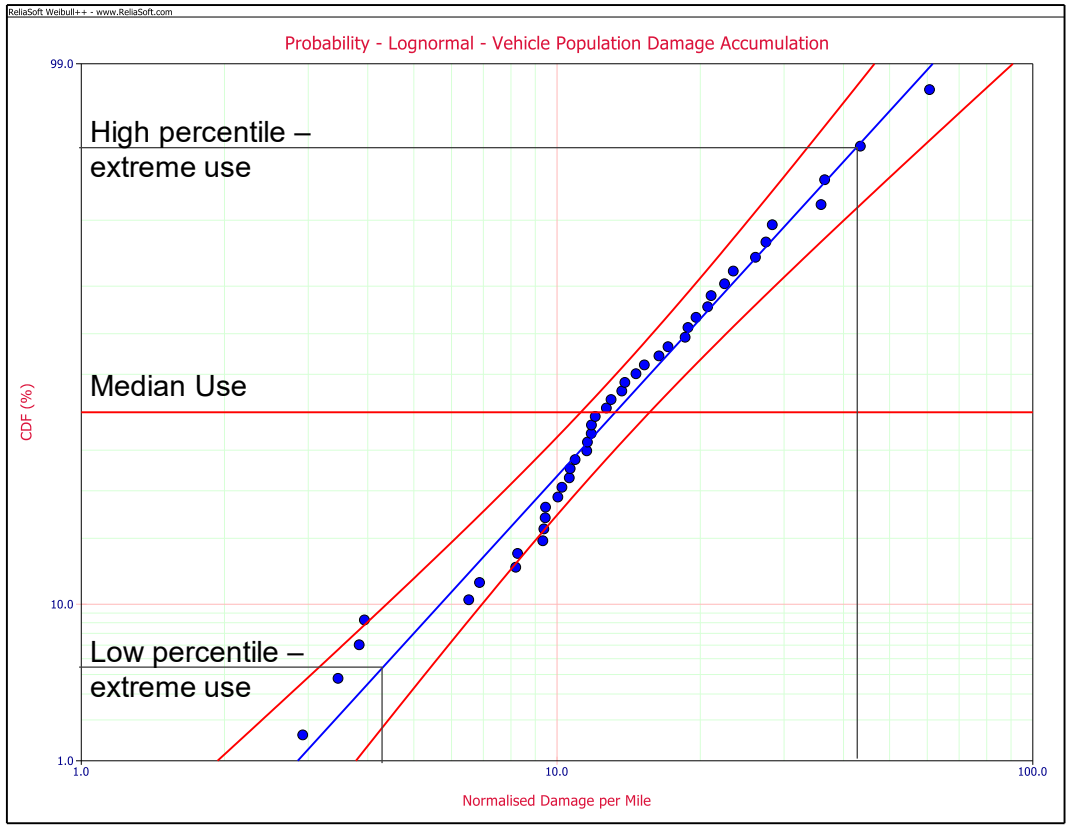
Damage Accumulation Distribution



- Scaling up to vehicle population level.
- Can quantify the range of damage we might expect from a class of vehicle.
- Rates of Damage Accumulation different according to class.
- Subdivide each class into Application (eg Regional Line Haul, Transit Bus, Refuse Truck etc.)

Application to Limits – Strength vs Stress

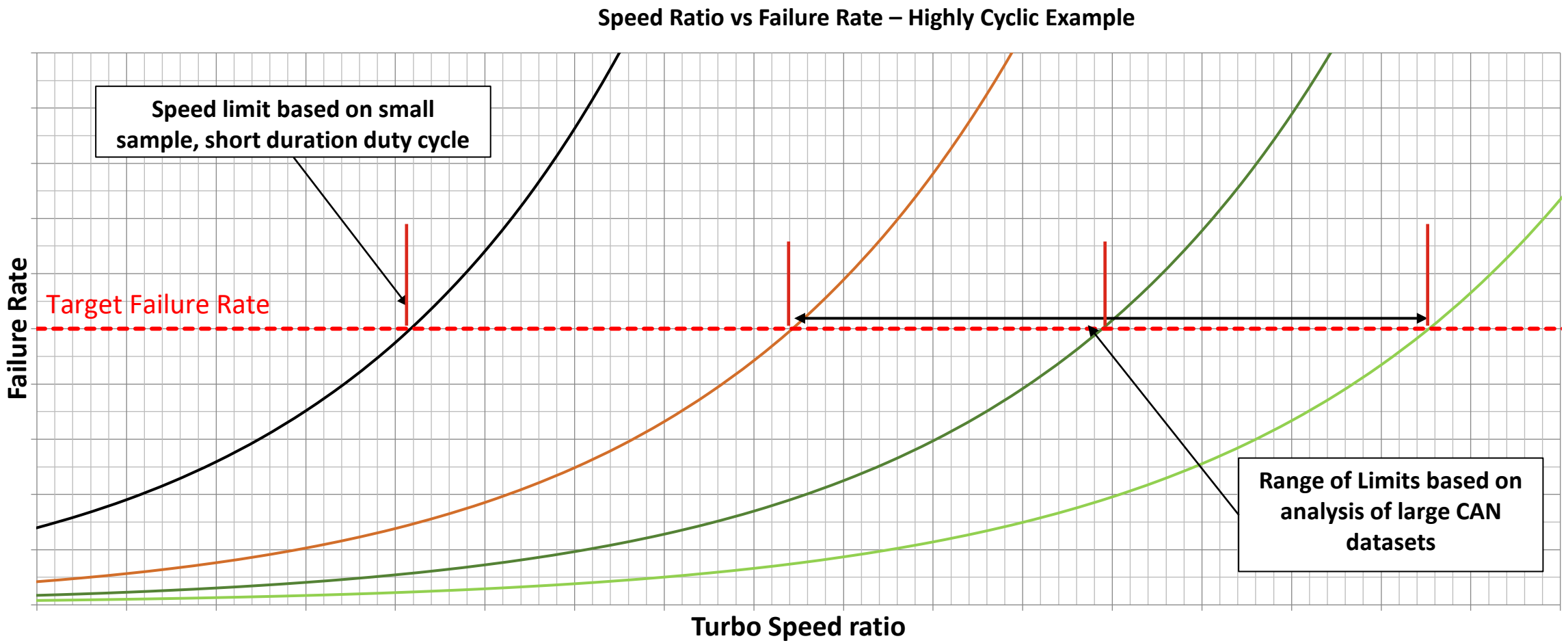




- Component Fatigue Life Characterisation
- Duty Cycle Severity Characterisation

- Component fatigue life distribution can be combined with the duty cycle severity from CAN data to help define limits.

Speed Limits using CAN duty cycles



- Duty cycles based on long term CAN data show a significant improvement in speed limits.
- New limits could be based on the mean duty cycle or by taking a probabilistic approach using Monte Carlo simulation.

Summary & Conclusion

- The availability of large CAN datasets from the field has allowed better understanding of real world duty cycles.
- Duty cycle characterization provides valuable input to the fatigue prediction process.
- Better defined limits and improved engine performance that are aligned with customer usage.
- Wider use of CAN data useful for customer correlated validation as inputs to testing and analysis.

Final thoughts on Statistical Models

- Can we model the fatigue behaviour of components and the loading behaviour from duty cycles to make accurate life predictions ?
- To quote British statistician George E P Box from a 1976 paper published in the Journal of the American Statistical Association where he stated ***"All models are wrong".***
- Subsequent to that rather harsh assessment, he qualified the statement a little more during a statistics workshop in 1978 by saying that ***"All models are wrong but some are useful".***
- Further refinement came in 1987 from his book "Empirical Model-Building and Response Surfaces", where he stated ***"Remember all models are wrong; the practical question is how wrong do they have to be in order not to be useful".***
- Large CAN datasets can provide models that are right enough to be of some use!

Q+A


Cummins

Q&A

- Andre Kleyner (Aptiv, USA)
  - What's your user severity distribution looks like, (e.g. lognormal distribution) and if you select certain prercentile user for your predictions?
    - *Severity distribution is lognormal. By characterizing the severity (stress) and fatigue capability (strength) distributions, a probabilistic approach can be used rather than target specific percentiles.*

- Muhammad Afzal (Omnicell, USA)
  - How LCF and HCF analysis is used to improve the design?
    - *LCF & HCF analysis are used to understand product capability.*
  - How much characteristic life is improved?
    - *Not easy to answer, it is dependent on application and component.*

- Ovidiu Moraru (Mahindra NATC, USA)
  - David congratulation for your presentation. Improved performance is good for the brand and clients.
    I see you consider a bundle of data for several heavy duty turbines as a HPP, have you tested as NHPP?
    [(N)HPP : (Non) Homogeneous Poisson Population]
    - *For the turbo as a “non-repairable” system, we have not considered modelling as an NHPP.*
      Considering the engine system as a whole (“repairable”) , an NHPP would be more appropriate.

HBK
HOTTINGER BRÜEL & KJÆR

Q&A

- Phil Irving (Cranfield University, UK)
  - In the life predictions do you apply safety factors? If you do how do you correlate the predicted life with actual service lives.
    - *A factor of safety is not applied directly in the calculation, though the setting of an appropriate speed limit for the population can be considered as a safety factor.*

- Peter Bebbington (Brainpool Ltd, UK)
  - Have you considered using a classification model such as Boosting or SVM to predict fatigue?
    - *We have not considered any AI methods for fatigue prediction.*

- Vijaykumar Ghantimath (Renault Nissan, India)
  - What is the % diference in the normal LCF with respect to Duty cycles in real field?
  - How do we find safety factor for duty cycles?
    - *Both these questions are dependent on your vehicle, your vehicle's application, and specific components – you will need to combine known failure information, warranty information, design targets, component/system testing and material testing.*

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Session #4: **Vehicle Fleet Data Analytics**