

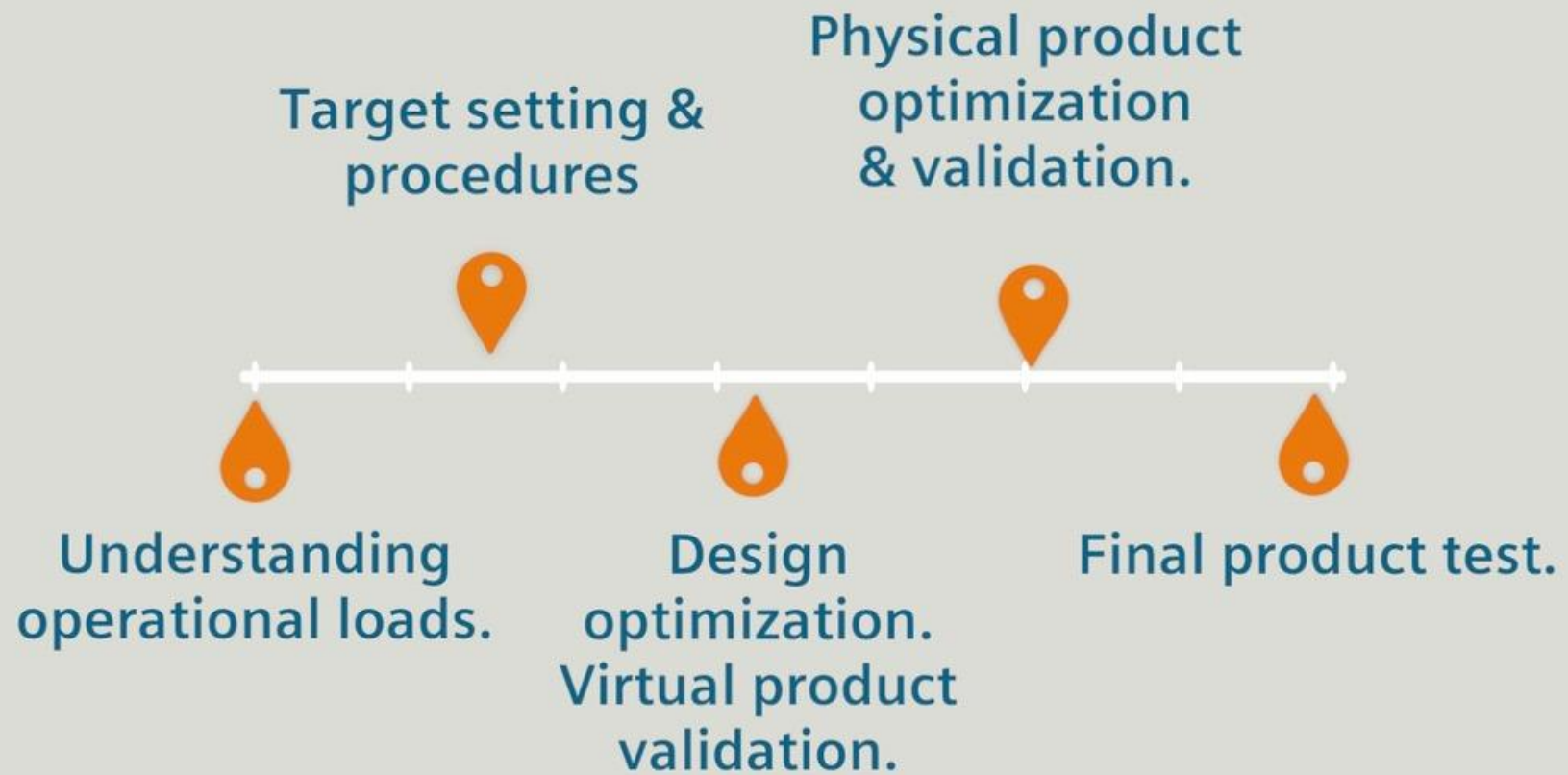


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Ingenuity for life

Realistic and customer correlated test schedules

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Realize innovation.



Target setting & procedures

Physical product optimization & validation.



Understanding operational loads.

Design optimization.
Virtual product validation.

Final product test.

Agenda

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Loads and damage

Load characterization

Customer correlation

Accelerated testing and analysis

Applications

Agenda

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Ingenuity for life



Loads and damage

Load characterization

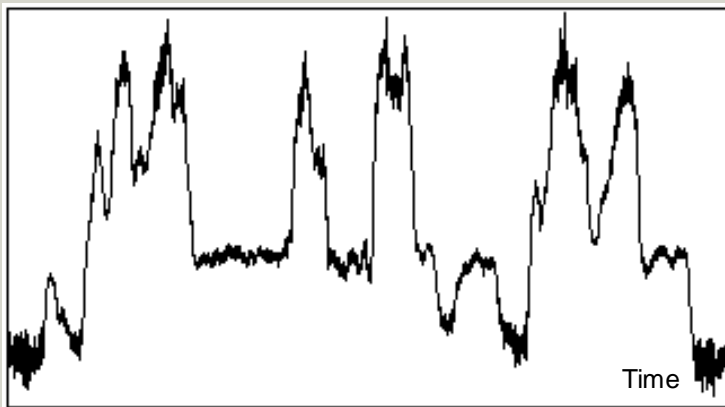
Customer correlation

Accelerated testing and analysis

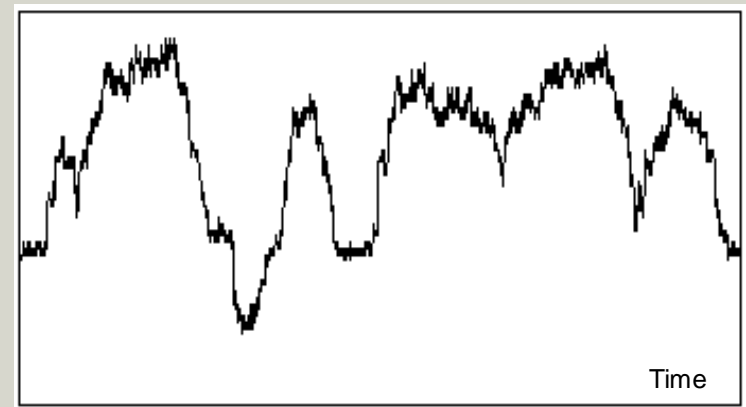
Applications

How to understand the fatigue content of loads ? Comparison of two measurements

Road A



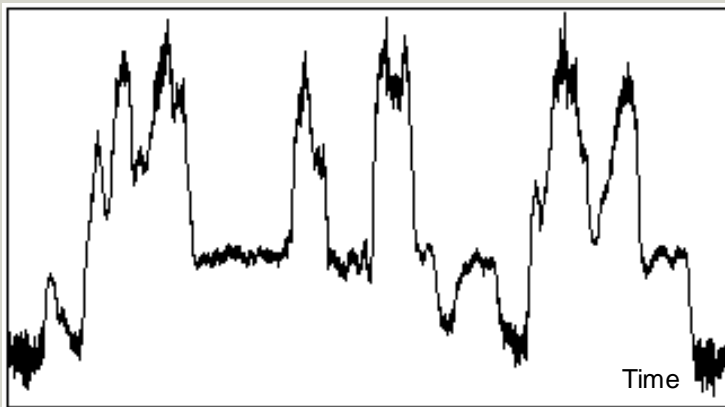
Road B



How to understand the fatigue content of loads ? Comparison of two measurements

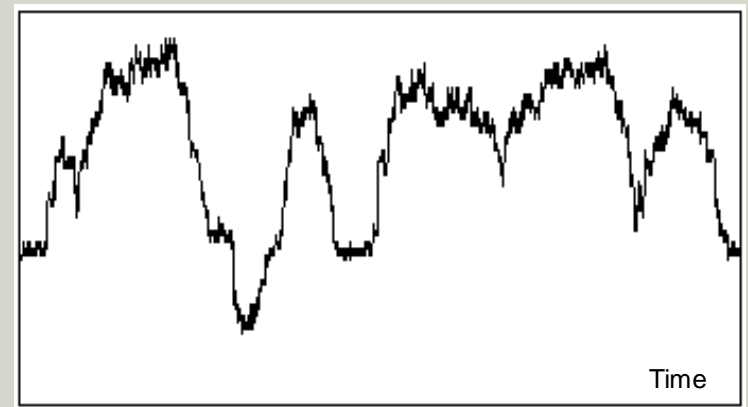
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Road A

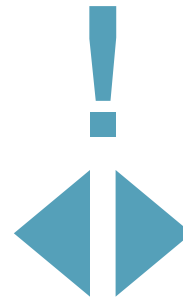


Damage

Road B

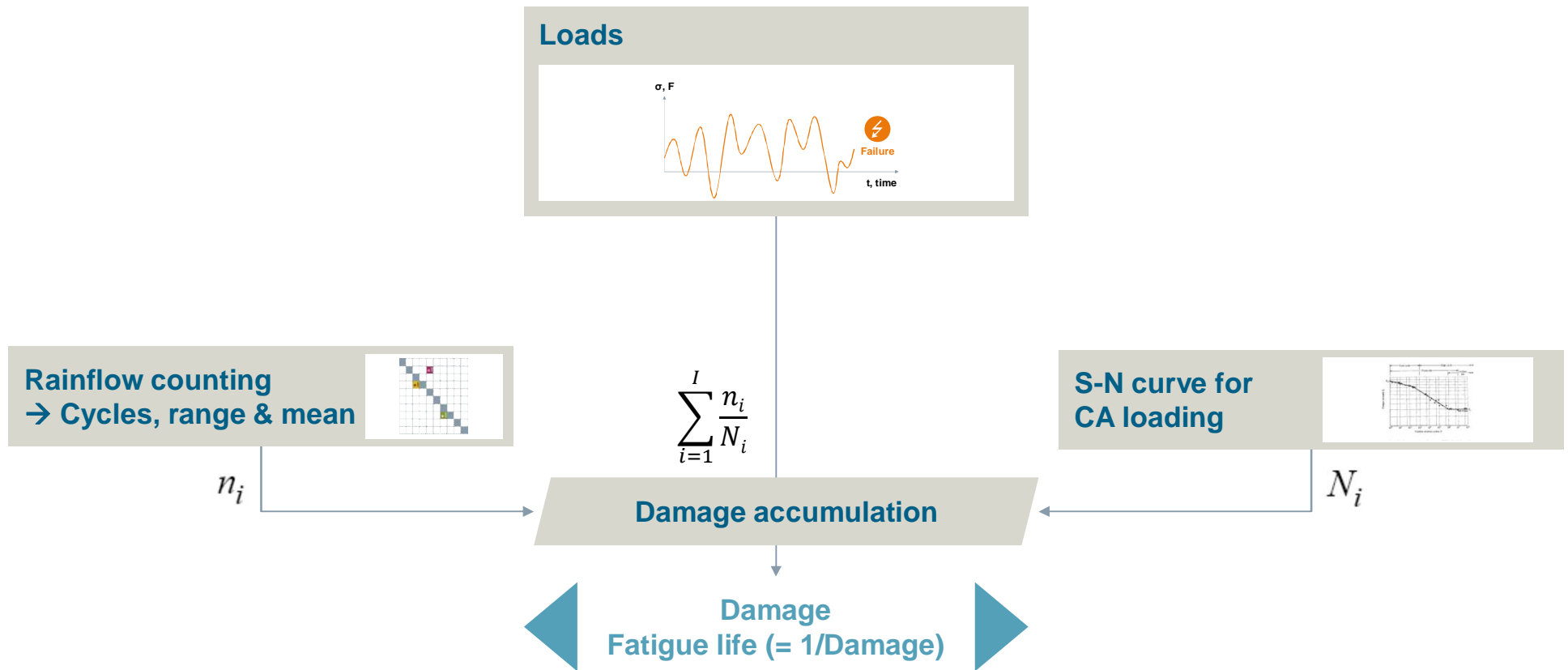


Damage

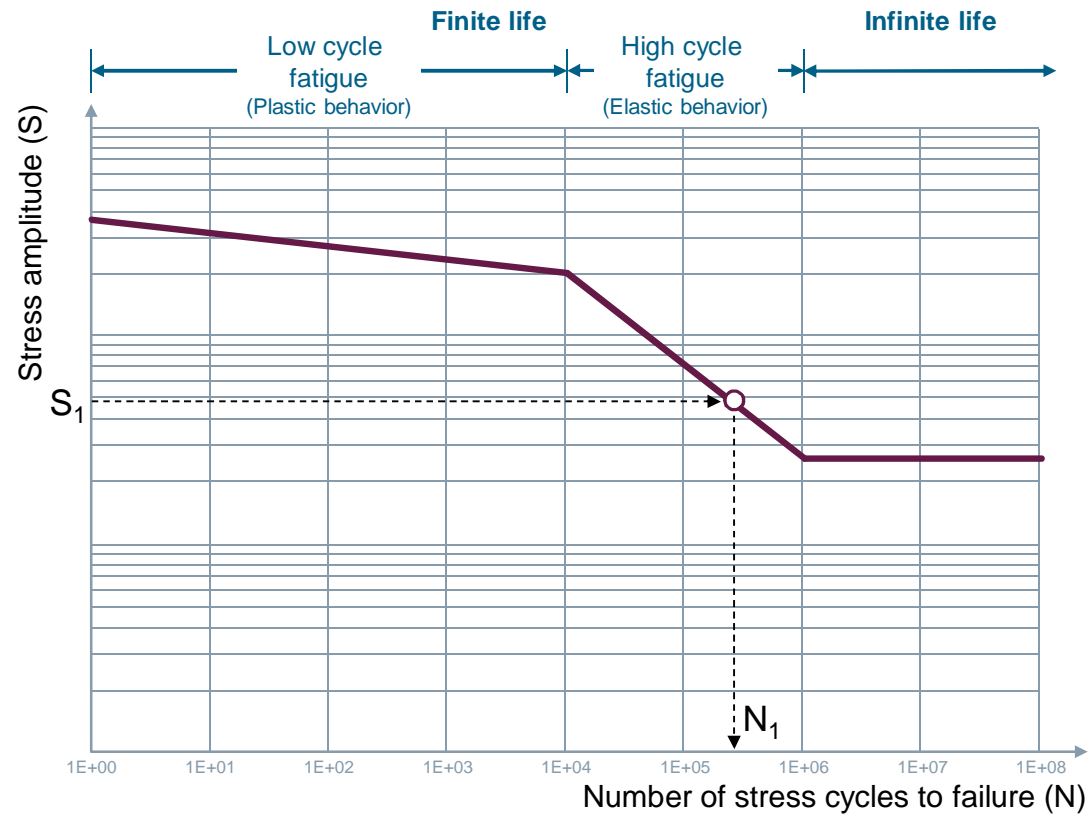


How to understand the fatigue content of loads ?

Damage calculation



How to understand fatigue content of loads ? What is an S-N curve ?



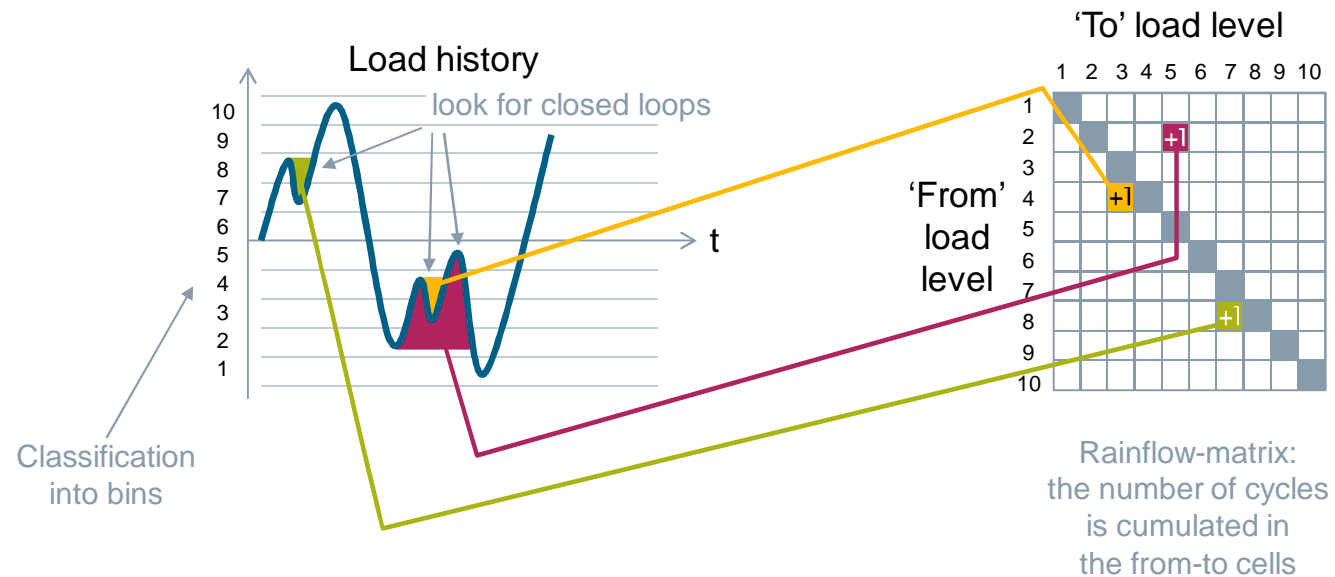
How to understand fatigue content of loads ?

Endo (1968). Rainflow counting for variable loads

Rainflow counting = technique to decompose a spectrum of varying, complex stress into a set of simple stress reversals

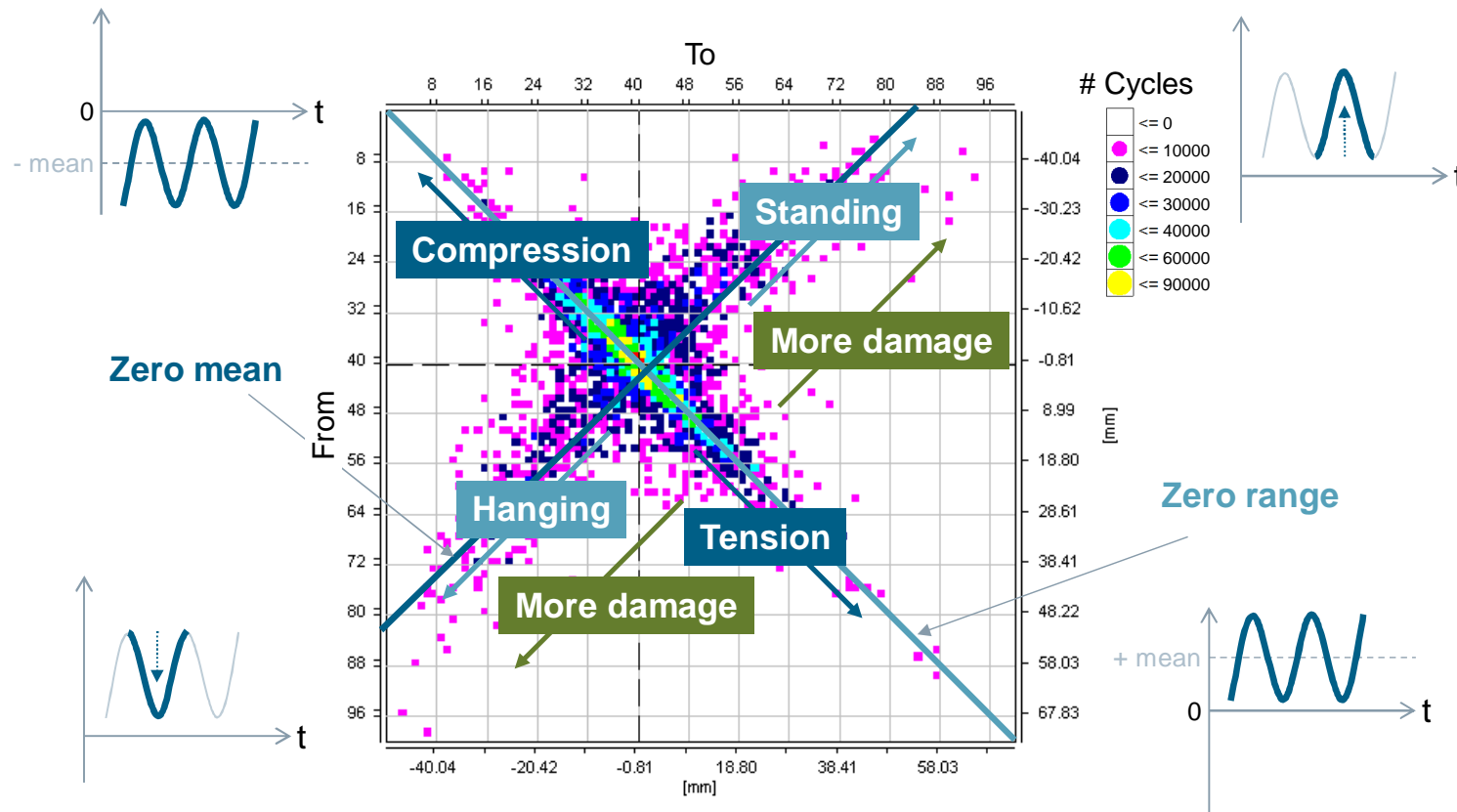


Tatsuo Endo
*1925 †1989

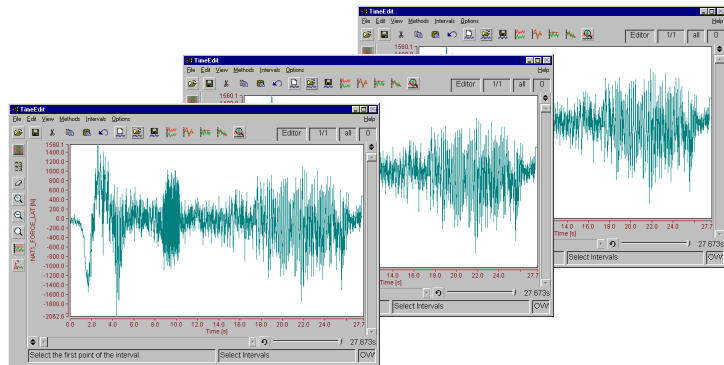


How to understand fatigue content of loads ?

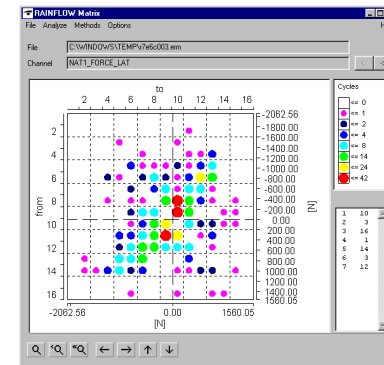
Rainflow characteristics



How to understand fatigue content of loads ? Counting methods benefit



Counting
method

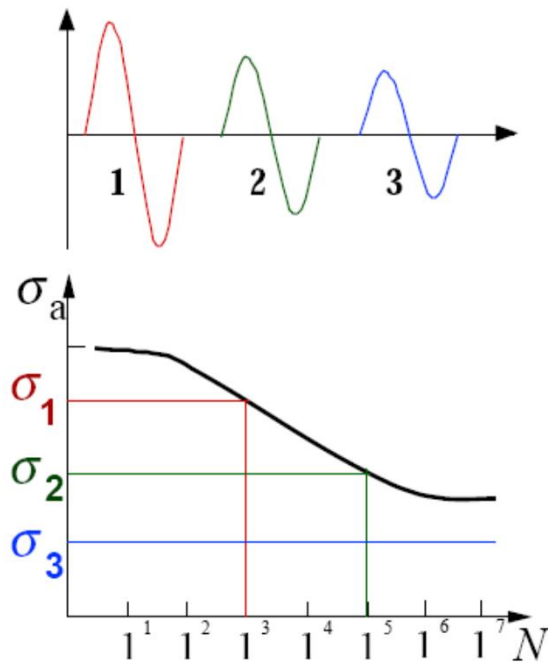


- Representations → easy to understand
- Ability for fatigue related data manipulation (editing, extrapolation, superposition)
- Easy way to compare data
- Simple counting algorithms
- Substantial reduction of data amount

Same counting result = Same fatigue potential

How to understand fatigue content of loads ?

Palmgren (1924) – Miner (1945). Damage accumulation rule



$$\sum_{i=1}^I \frac{n_i}{N_i} = \frac{500}{10^3} + \frac{10^3}{10^5} + \frac{10^4}{\infty} = 0.51 < 1$$

$= 0.5$
 $= 0.01$
 $= 0$

Assume that, during the service life, we have

- 500 cycles of load type 1 (defined by mid-value and magnitude)
- 1000 cycles of load type 2
- and 10000 cycles of load type 3

the **Palmgren-Miner** rule states that failure occurs when

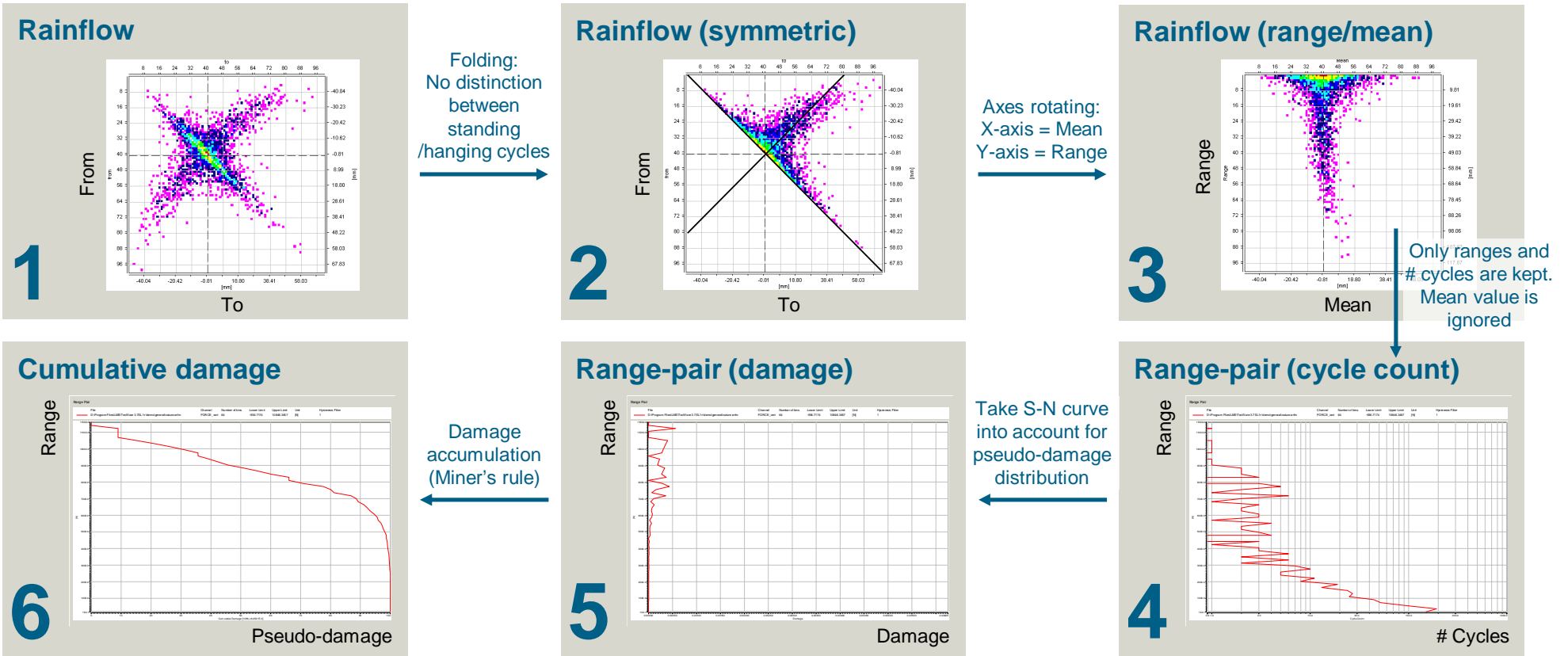
$$\sum_{i=1}^I \frac{n_i}{N_i} = 1$$

with:

- n_i = the number of actual applied load cycles of type i
- N_i = the pertinent fatigue life for that specific applied load cycle i

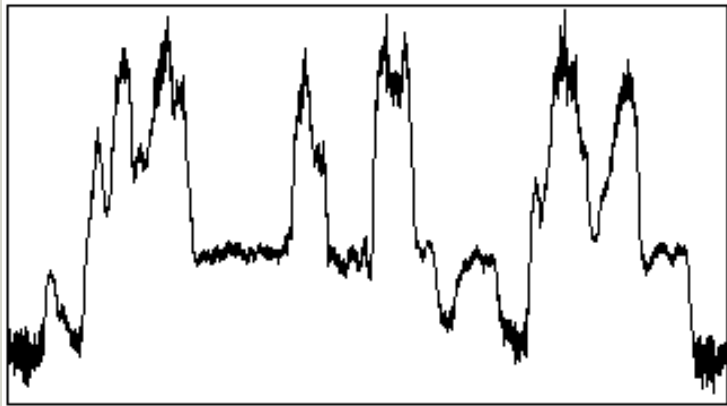
How to understand fatigue content of loads ?

Rainflow → Range-pair → Damage → Cumulative damage

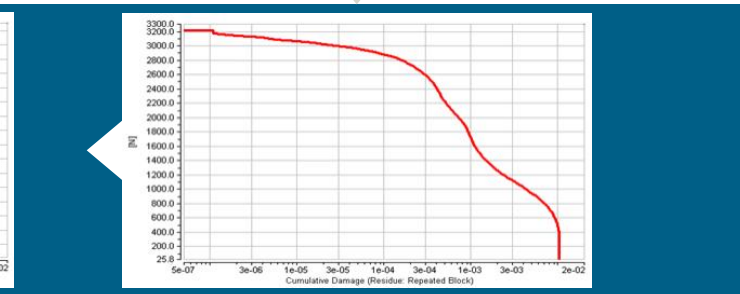
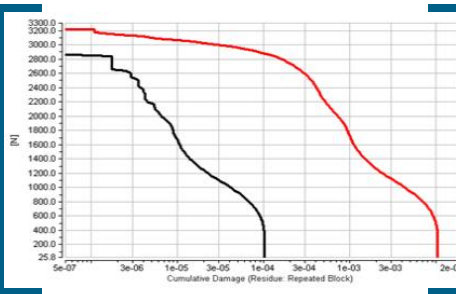
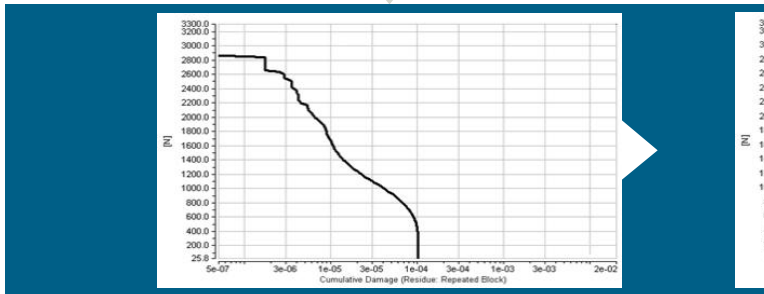
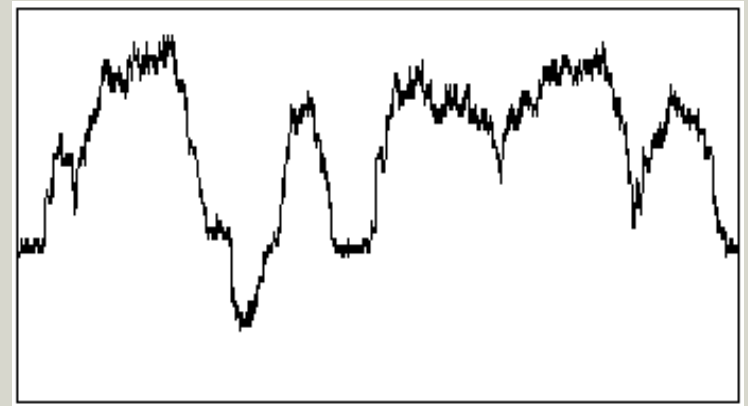


How to understand fatigue content of loads ? Comparison of two measurements

Road A



Road B

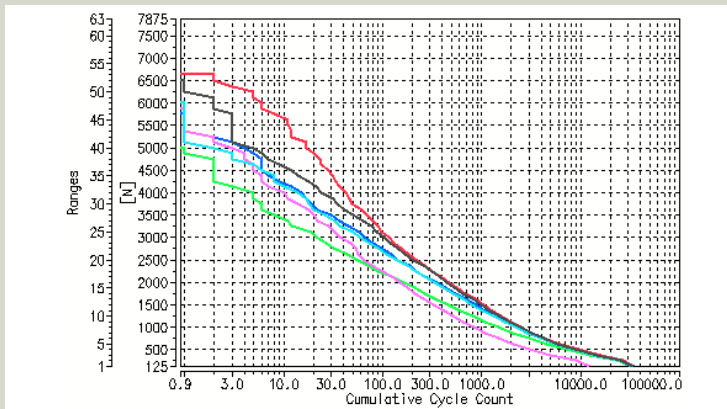


How to understand fatigue content of loads ? Scatter in loadings

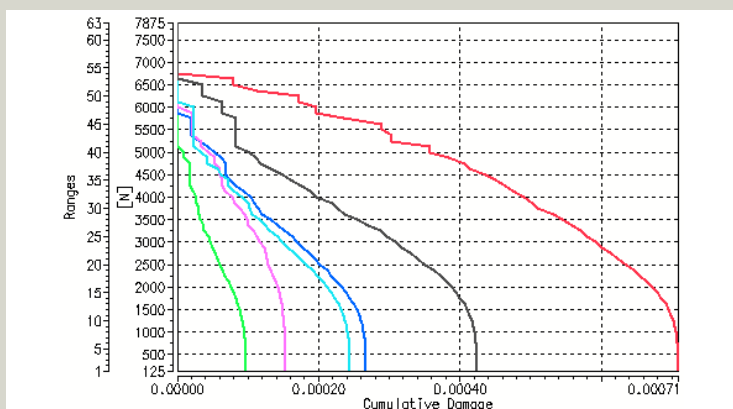
Scenario: 6 measurements
One lap on same road
Same weather conditions
Six different drivers

Six different load histories
Six different range-pair histograms
Six different damage values
Six different fatigue lives

Range-pair histograms (cycle count)



Damage histograms (cumulative damage)



Agenda

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Loads and damage

Load characterization

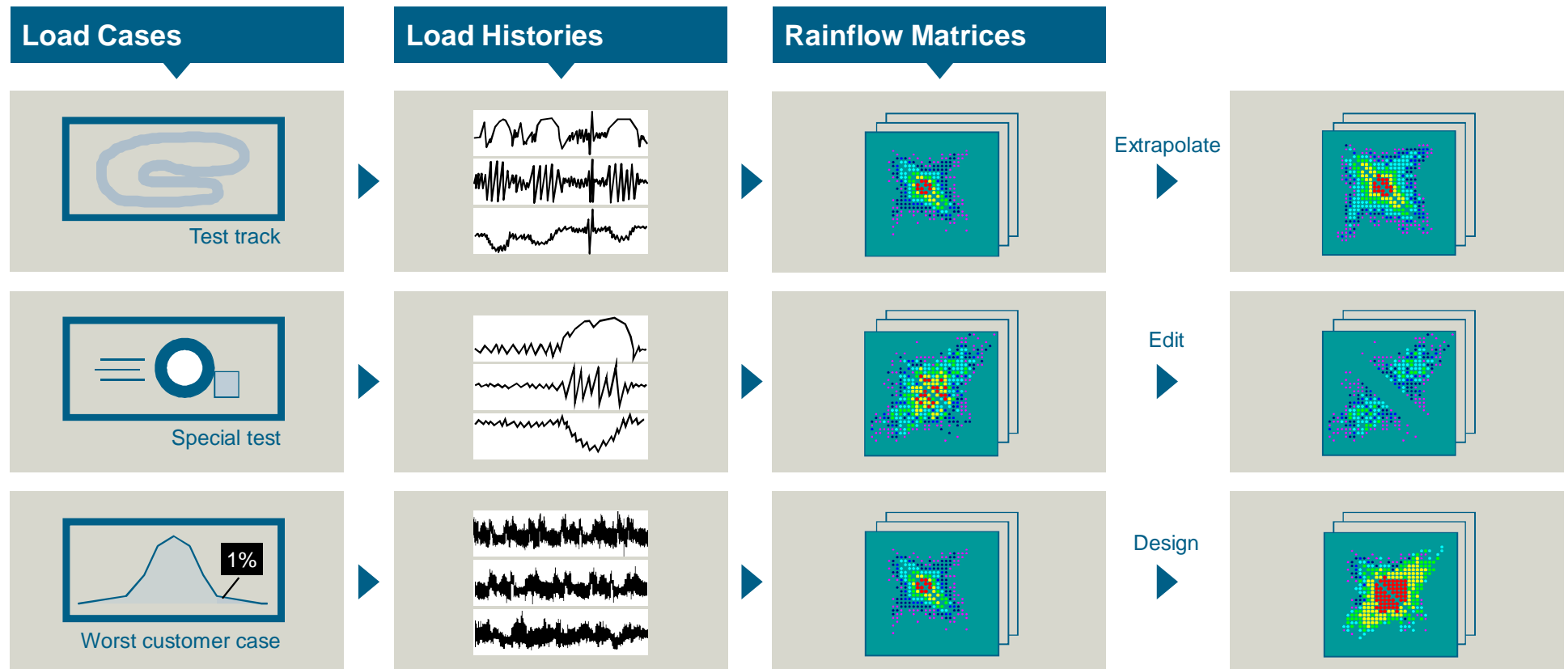
Customer correlation

Accelerated testing and analysis

Applications

How to design realistic test schedule ?

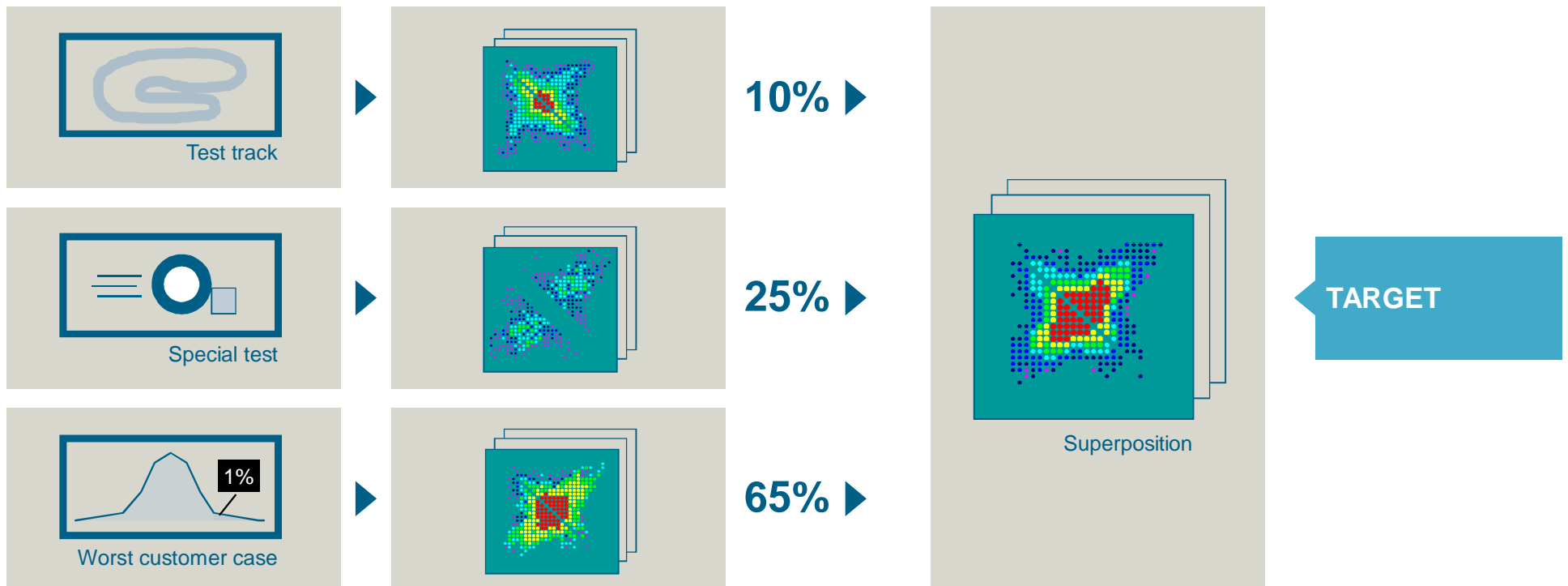
Target setting, handling multiple events



How to design realistic test schedule ?

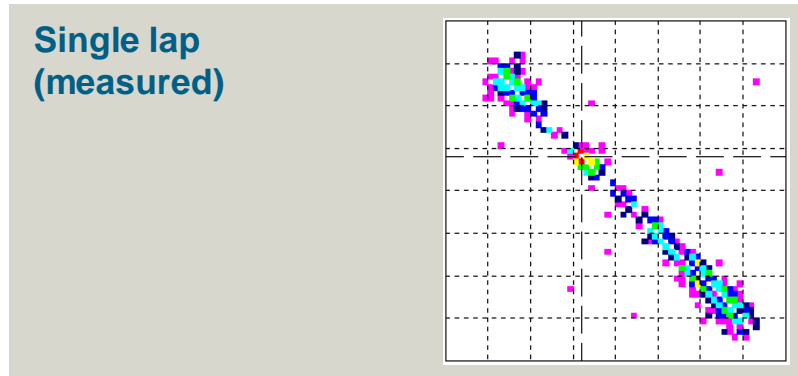
Target setting, handling multiple events

Load Cases

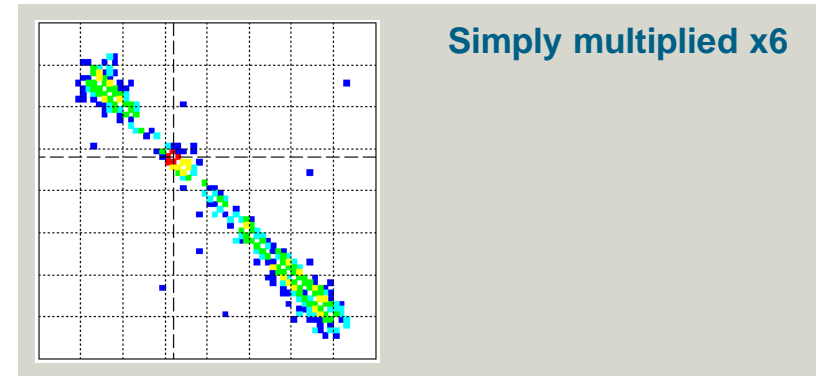


How to design realistic test schedule ?

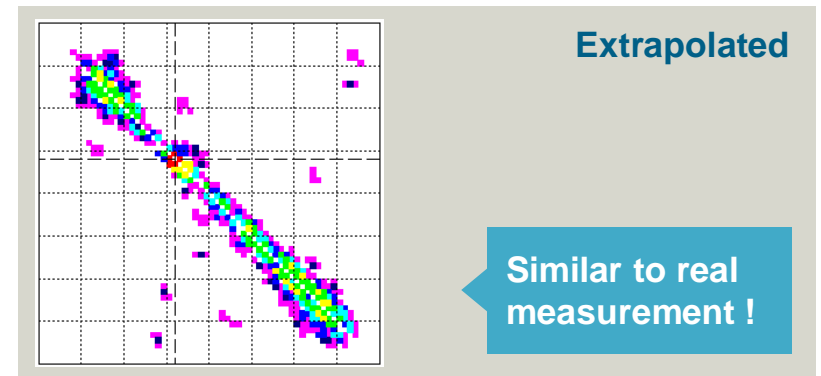
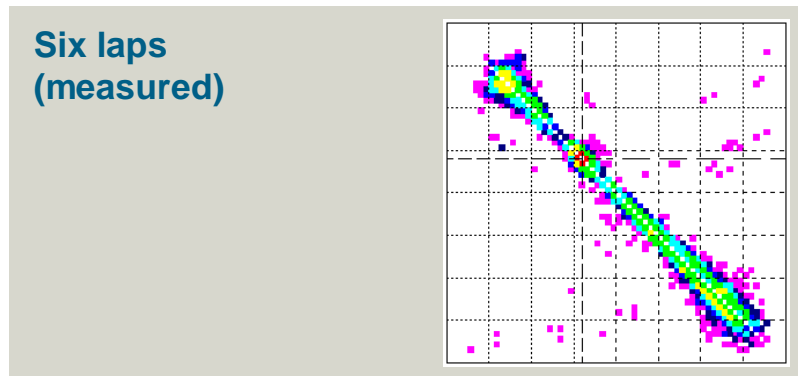
Target setting – Extrapolation for longer duration



Multiplying
not sufficient!



Six laps ?

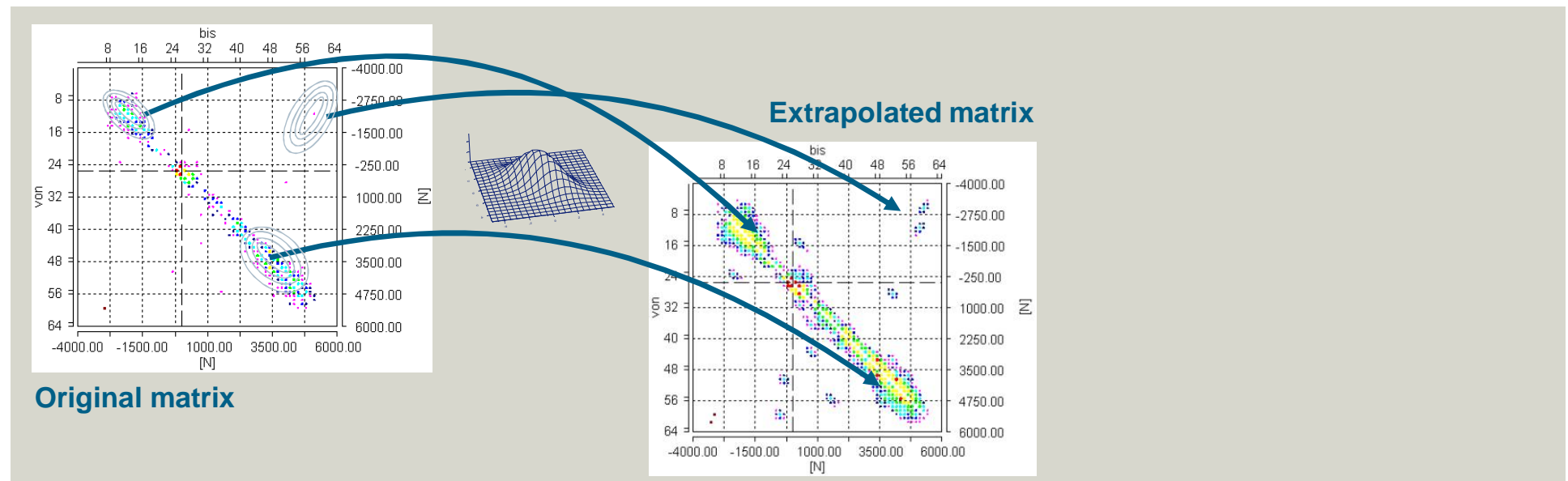


How to design realistic test schedule ?

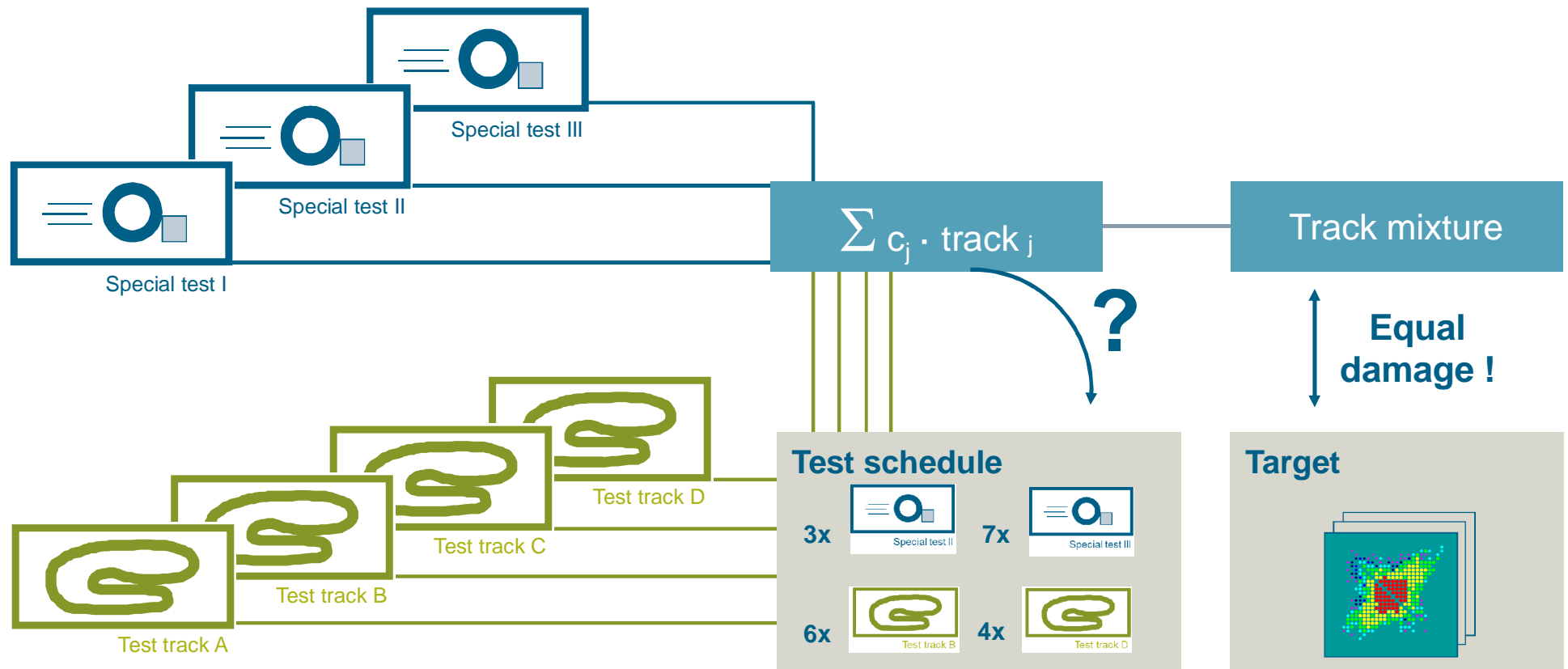
Target setting – Extrapolation for longer duration

Parameterization

- Extrapolation factor (“number of laps”)
- Smoothing factor (“reliability of data”) → **Compensate for scattering on:**
Type of drivers | Load data | Component dimensions | Material properties | ...



How to design realistic test schedule ? From target to test procedure



How to design realistic test schedule ?

From target to test procedure using LMS Tecware CombiTrack



CombiTrack File : C:\DOCUME-1\stt\LOCALS-1\Temp\stt\3e5001.ctb

[General]
 Date: 08/19/2011 15:36:03
 Mode: Histogram optimization
 Runtime: 30

[Target]
 Comparison: Global
 Load variable 1: RAINFLOW | %TECWAREHOME%\demo\combitrack\target.erfm | force_vertical
 Load variable 2: RAINFLOW | %TECWAREHOME%\demo\combitrack\target.erfm | force_lateral
 Load variable 3: RAINFLOW | %TECWAREHOME%\demo\combitrack\target.erfm | force_long

[Coefficients]

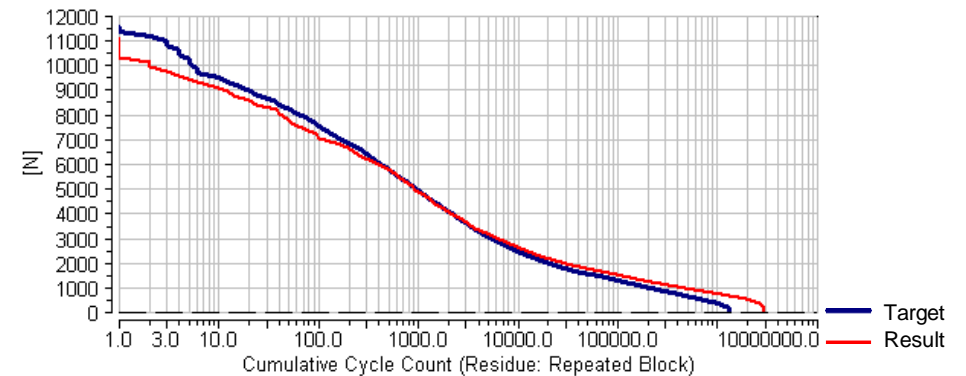
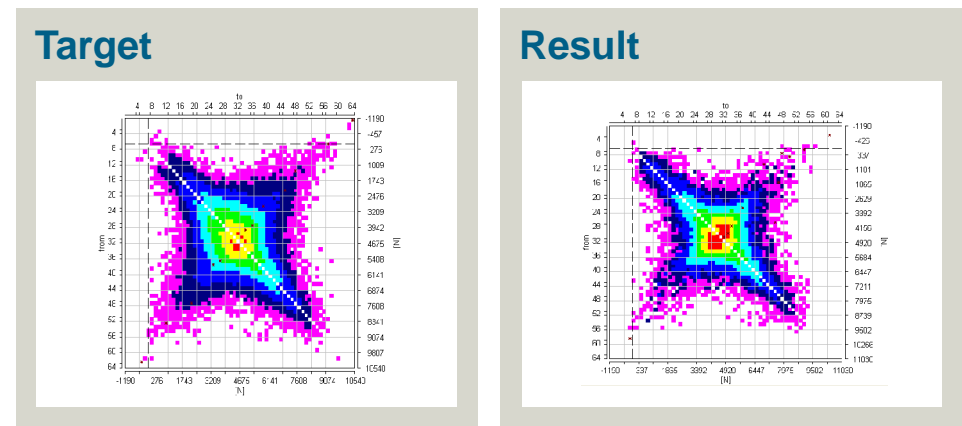
Track	Weight	Track	Weight
RaceTrackA	1	RaceTrackB	0
NatureTrackAA	0	NatureTrackAB	0
Track1	10	Track2	0
Track3	0	Track4	1
Track5	1	Track6	1
Track7	15	Track8	1

Nr. of track repetitions

Channel	Target	CombiTrack
force_vertical	0.0508	0.05
force_lateral	9.7823E-3	1E-2
force_long	2.1153E-3	2.1173E-3

CombiTrack/Target:

Damage per channel: force_vertical (98%), force_lateral (102%), force_long (100%). Target damage is indicated for force_vertical.



Agenda

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Loads and damage

Load characterization

Customer correlation

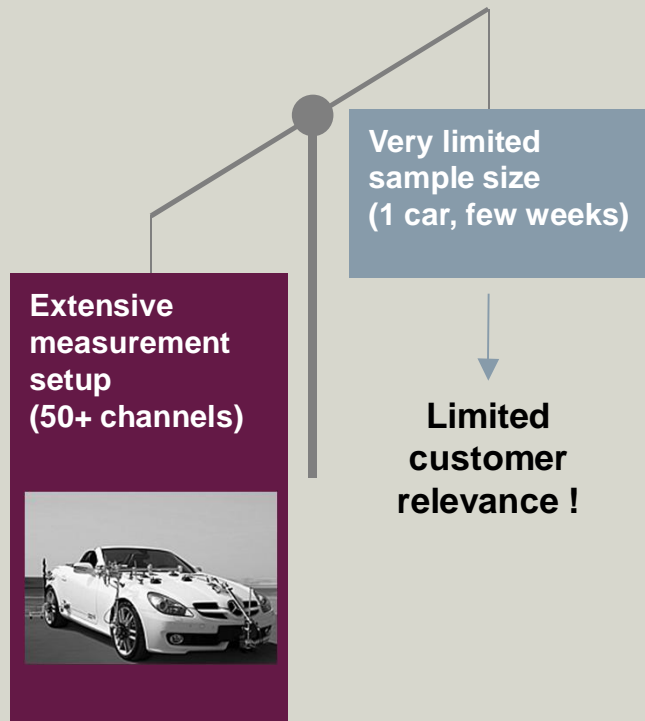
Accelerated testing and analysis

Applications

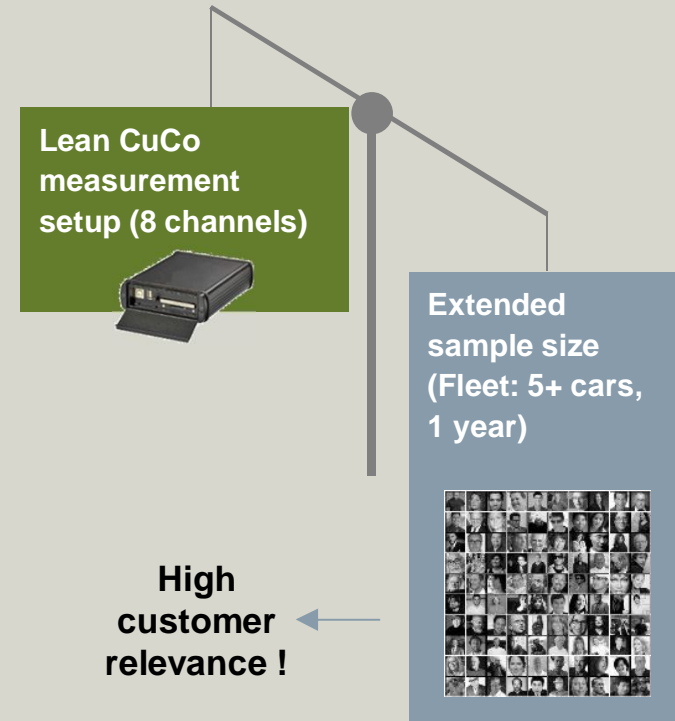
Customer correlation

Statistical approach ⇒ Fleet measurement required

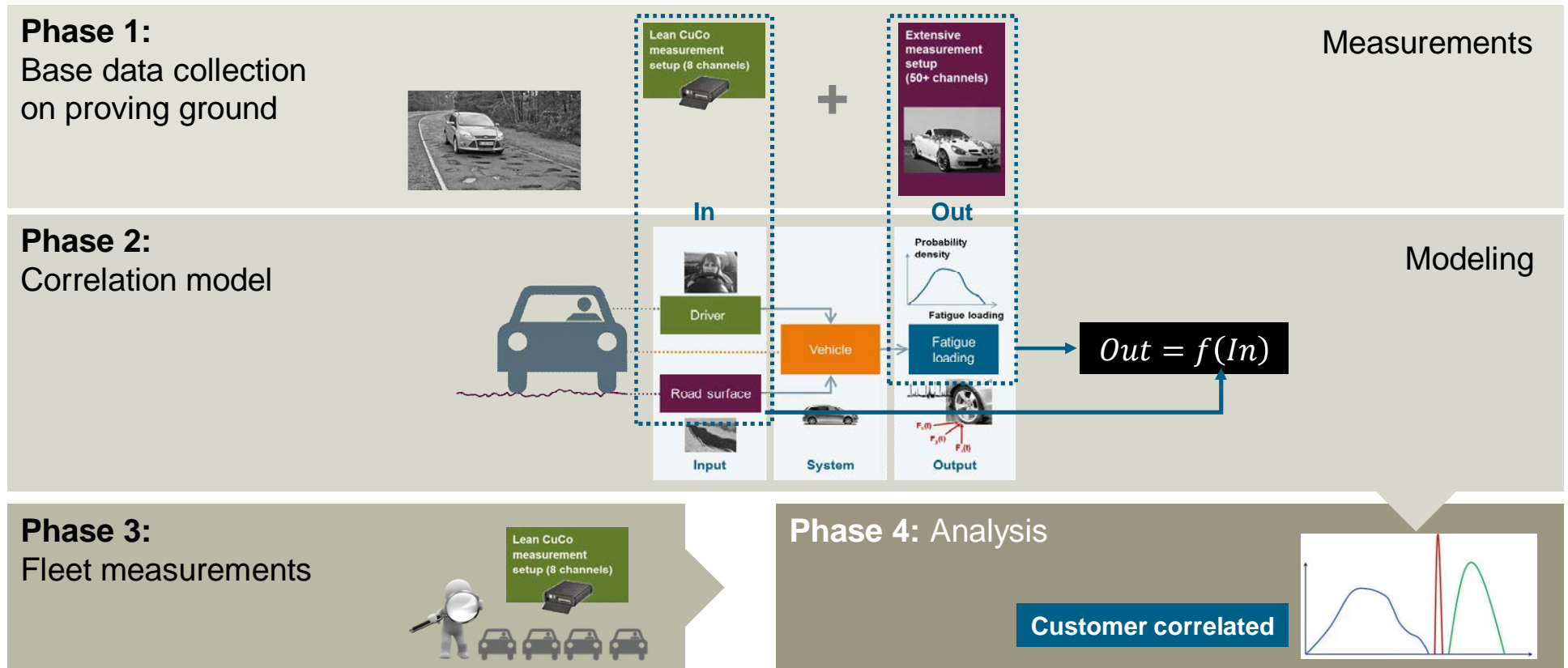
Traditional customer correlation



LMS CuCo: Fleet measurement



Customer correlation CuCo project structure

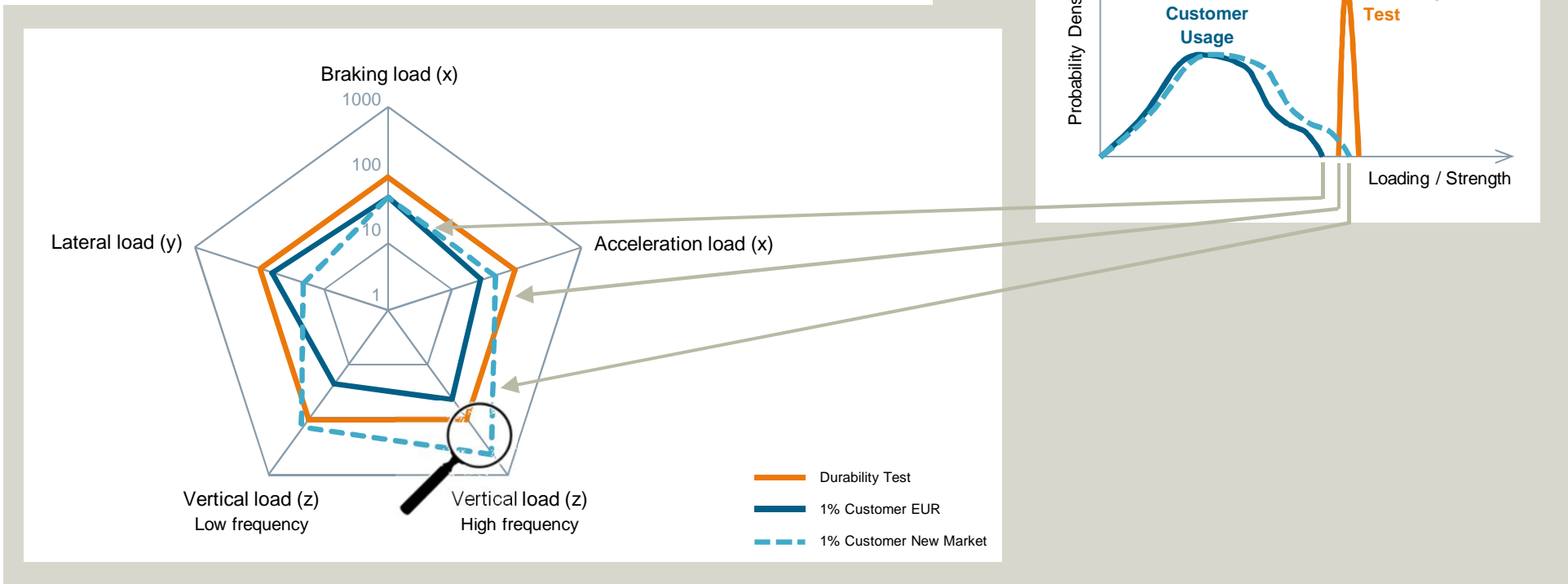


LMS Customer Correlation

Result: "Fingerprint" of Customer Representative Loading



"Fingerprint" of major vehicle loading components



Agenda

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Loads and damage

Load characterization

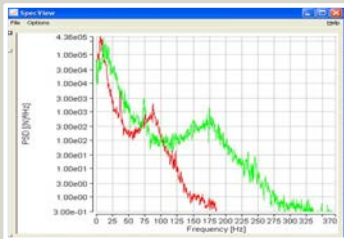
Customer correlation

Accelerated testing and analysis

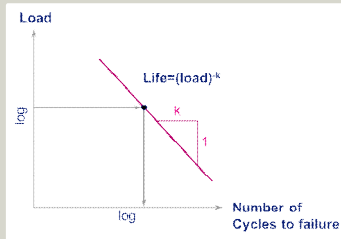
Applications

How can you accelerate a test ?

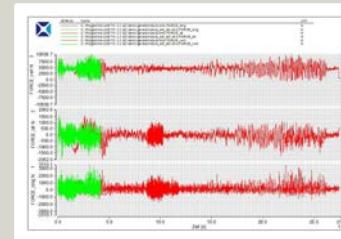
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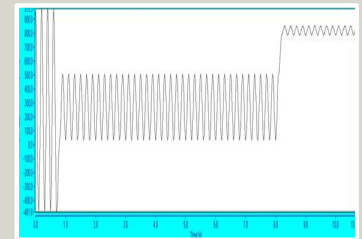
1 Increase speed



2 Increase amplitude



3 Omit non-damaging events

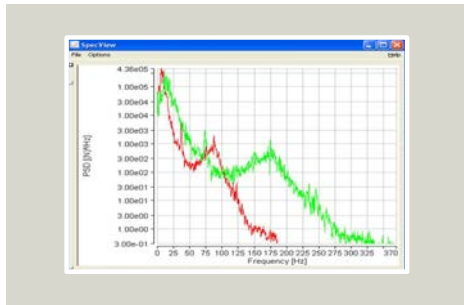


4 Simplify the test

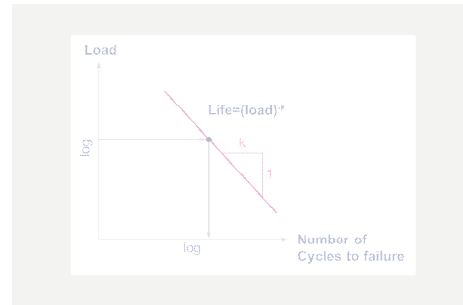
Basic principle = conservation of damage

How can you accelerate a test ? Increase testing speed

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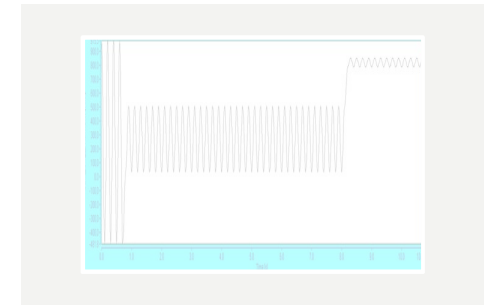
1 Increase speed



2 Increase amplitude



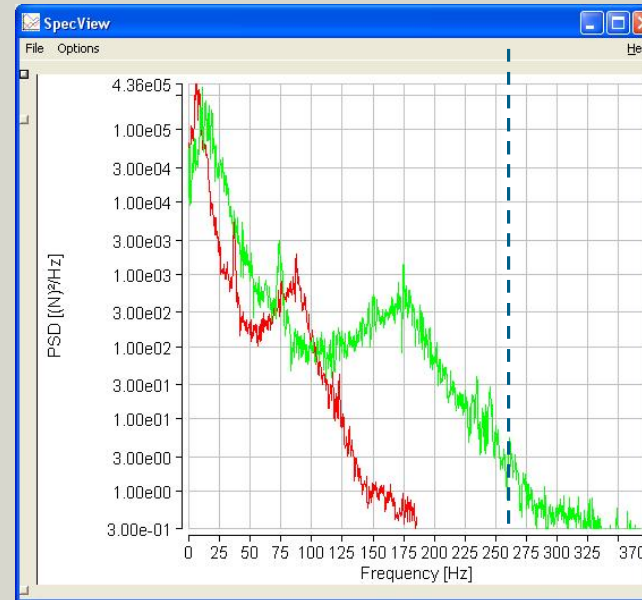
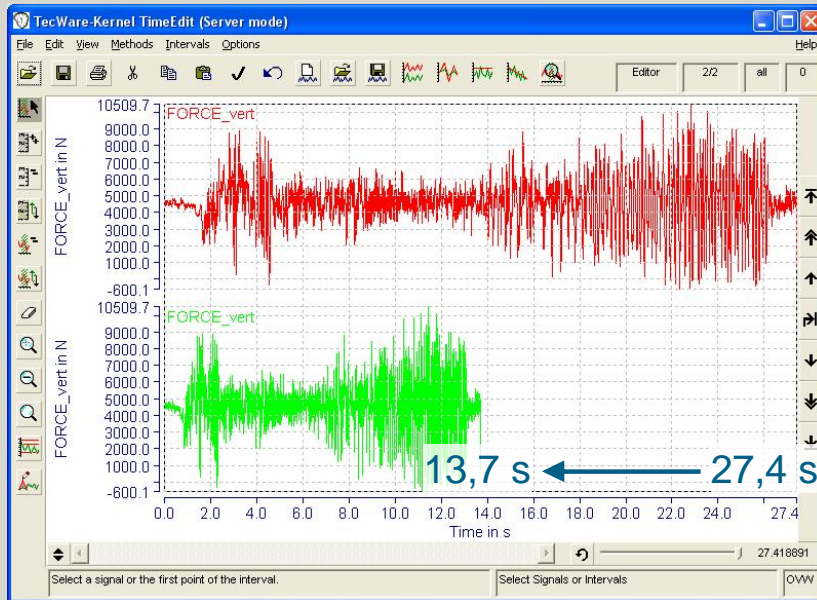
3 Omit non-damaging events



4 Simplify the test

How can you accelerate a test ? Increase testing speed

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▶ **1st natural frequency**

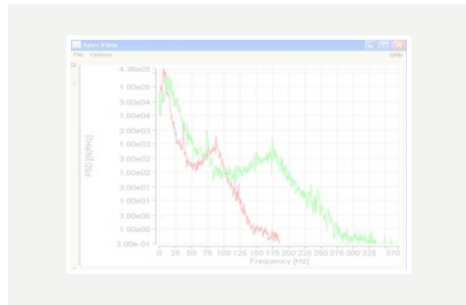
Important: Avoid too high compression!

Frequency content should stay reasonably below 1st natural frequency (resonances)

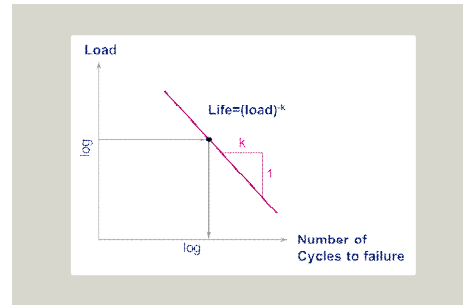
How can you accelerate a test ?

Increase amplitude

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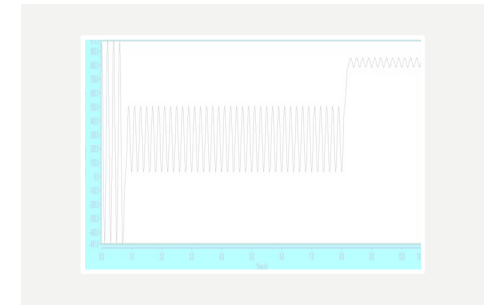
1 Increase speed



2 Increase amplitude



3 Omit non-damaging events



4 Simplify the test

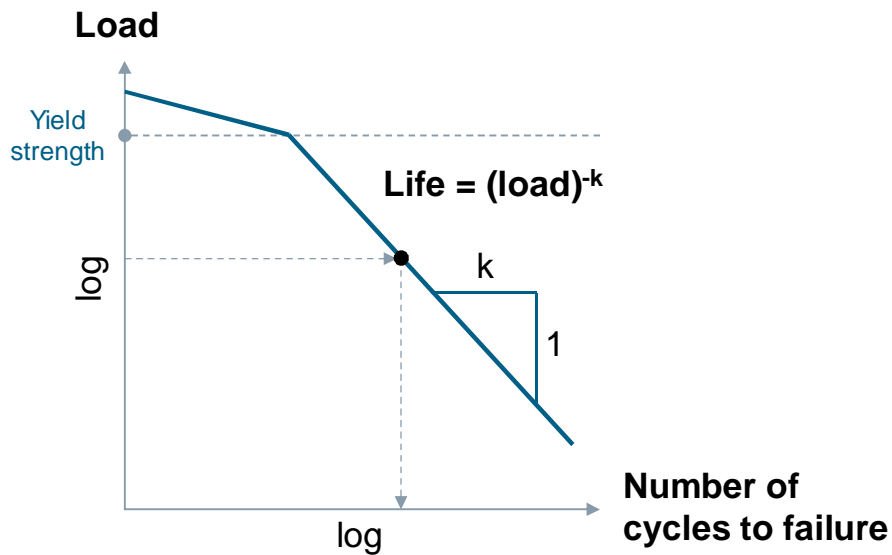
How can you accelerate a test ? Increase amplitude

Load (%)	Number of cycles (%)
100	100
115	50
87	200

+15% $\div 2!$

Logarithmic nature of fatigue

Changing slightly the cyclic load applied to an optimally shaped steel component, has a big influence on the life time of this component

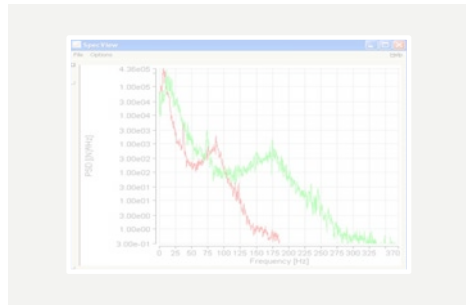


Note:

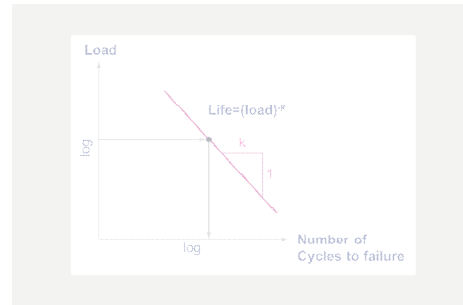
Be careful not to generate an uncharacteristic failure mode.

How can you accelerate a test ? Omit non-damaging events

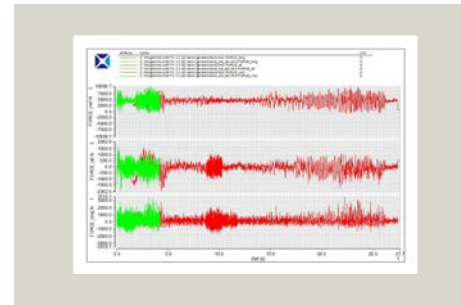
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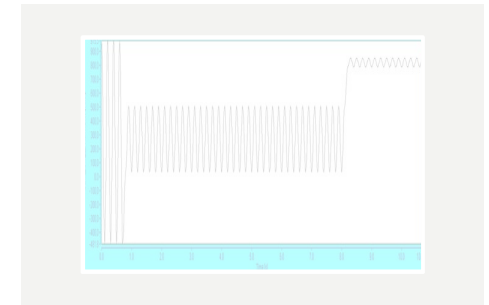
1 Increase speed



2 Increase amplitude



3 Omit non-damaging events



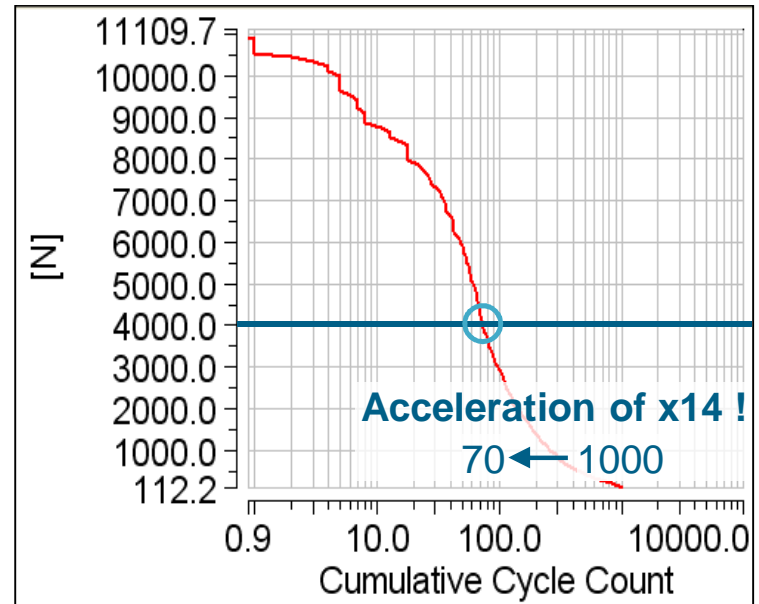
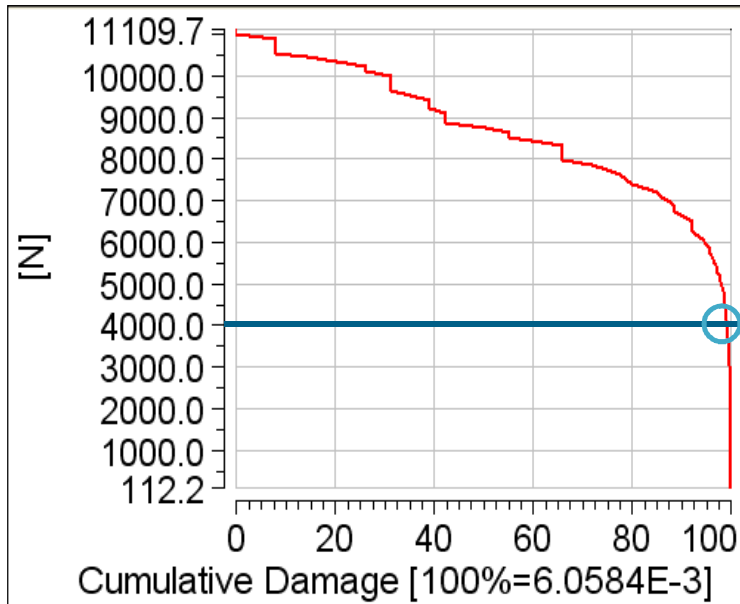
4 Simplify the test

How can you accelerate a test ?

Omit non-damaging events – Uni-axial

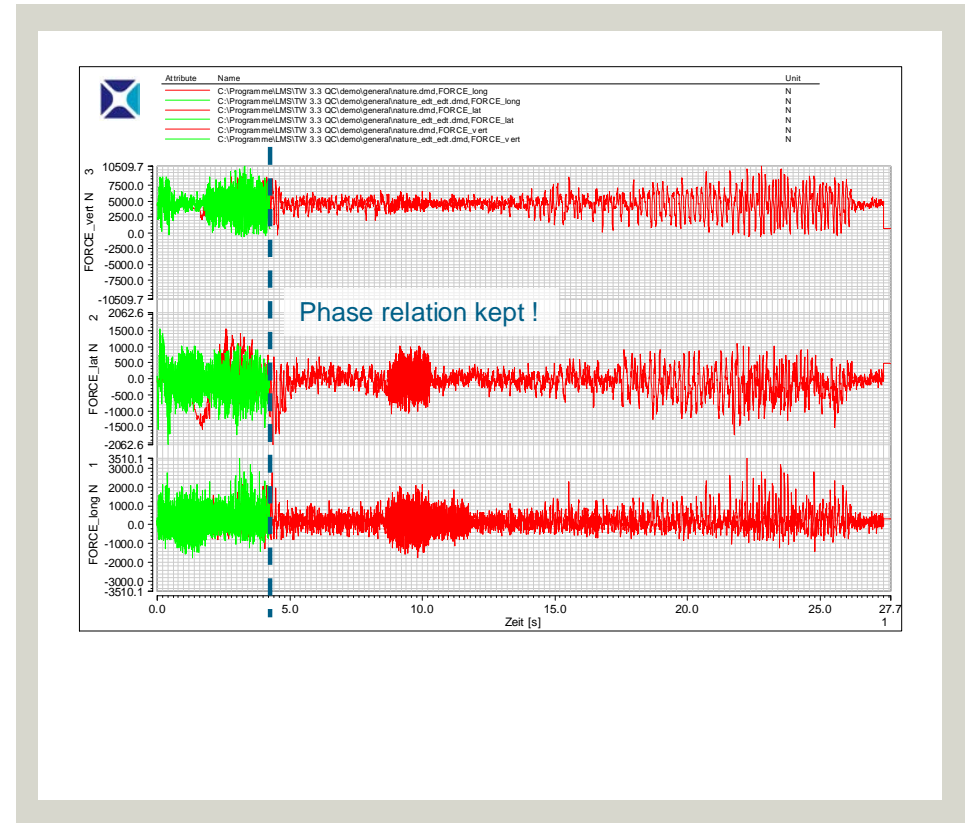
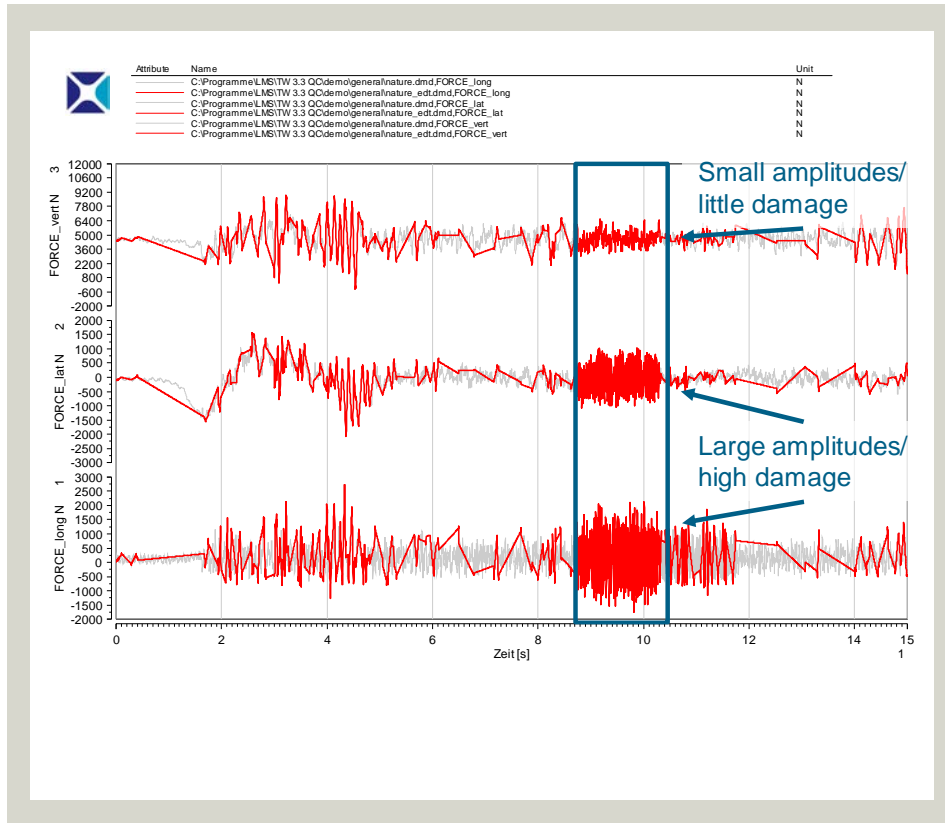
All cycles below 4000N only contribute less than 0.5% of the total damage

If you remove these from the loading, you end up with 70 cycles instead of 1000



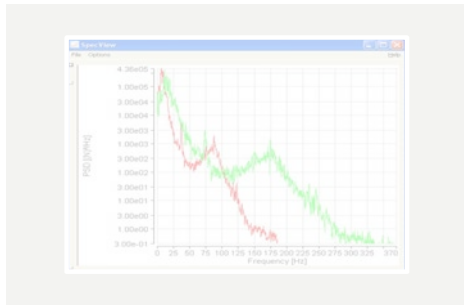
How can you accelerate a test ?

Omit non-damaging events - Multi-axial – RP-filtering

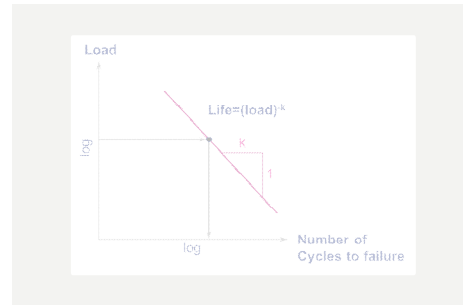


How can you accelerate a test ? Simplify the test

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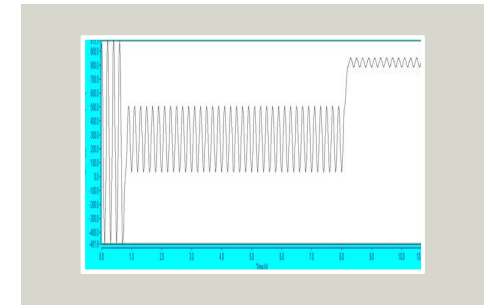
1 Increase speed



2 Increase amplitude



3 Omit non-damaging events

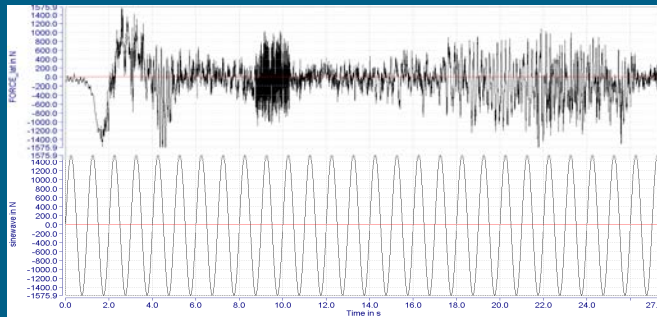


4 Simplify the test

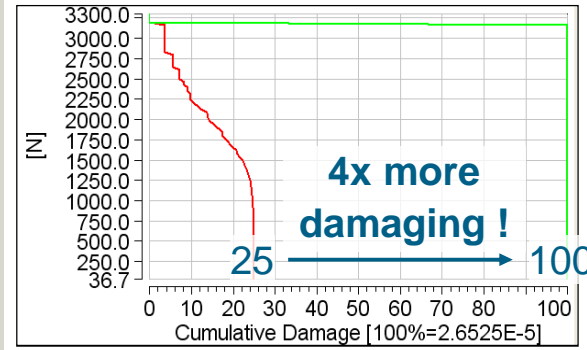
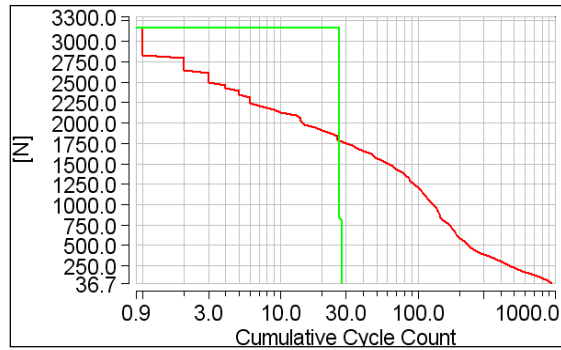
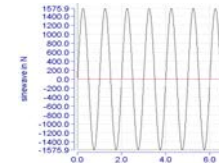
How can you accelerate a test ?

Simplify the test – Constant amplitude test

Testing with maximum amplitude



Accelerate by 4x
Increase sine wave frequency ?



C:\LMSTecWare_36SL1\demo\general\nature_4_erm
C:\LMSTecWare_36SL1\demo\general\nature_FORCE_lat_sinewave_1.erm

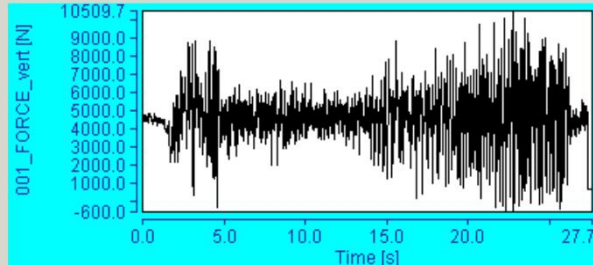
Unrestricted © Siemens AG 2017

How can you accelerate a test ?

Simplify the test – Block cycle test

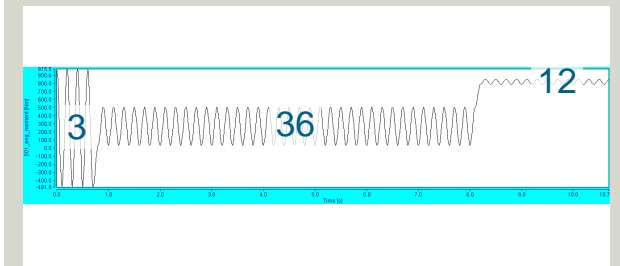
Mix of different 'Constant-amplitude' tests for more representative results

Original time series

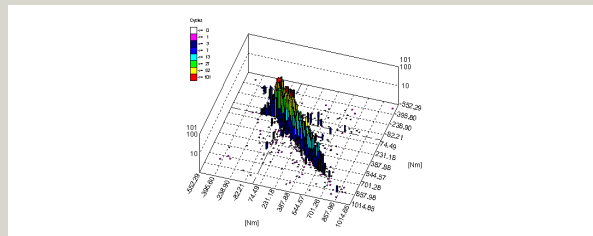


Damage equivalent

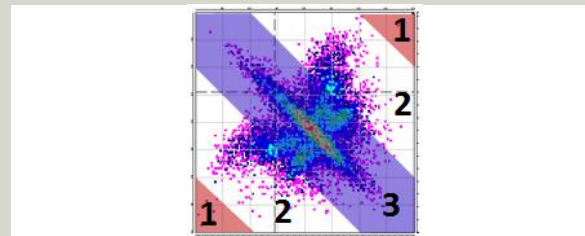
Block cycle test



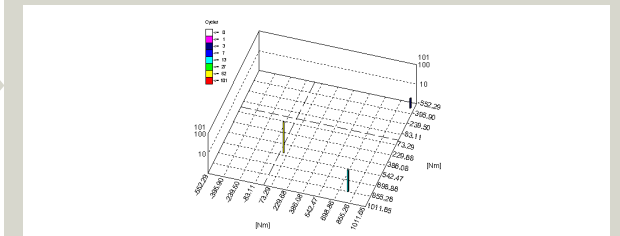
Rainflow matrix



Normal/incidental/accidental
(automatic or user-defined)



Damage calculation
(Standard S-N curve or user-defined)



Agenda

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Loads and damage

Load characterization

Customer correlation

Accelerated testing and analysis

Applications

Application case Ford Otosan Driving 1.2 million kilometers in 8 weeks

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Accelerated durability testing cycles

- Meeting 1.2 million km durability requirement
 - Real tests would take 3 years
- ↓
- Large-scale customer data collection
 - **5000 km Turkish public road data**
 - **Ford Lommel proving ground**
 - Development of accelerated rig test
 - **Target setting**
 - **Test schedule definition**
 - Resulting test schedule 8 weeks
 - Test acceleration of factor **100**



LMS engineers performed dedicated data collection, applied extensive load data processing techniques and developed a 6- to 8-week test track sequence and 4-week accelerated rig test scenario that matched the fatigue damage generated by 1.2 million km of road driving.

Application case Ford Otosan

Project steps

Preparation



Loads definition

- Target vehicle
- Current usage (full & empty)

Route selection

- 5.000 km
- 16 routes with 140 sections in total

Instrumentation

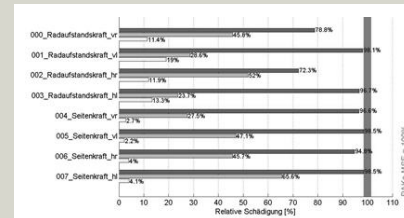
- +/- 60 channels (acc., strain, displ.)

Data collection



- 4 months on Turkish roads
- 1 week proving ground

Test schedule definition



- Data consolidation
- Data analysis
- Target 1 Mio km

Goal

- 10.000 km PVG Durability test

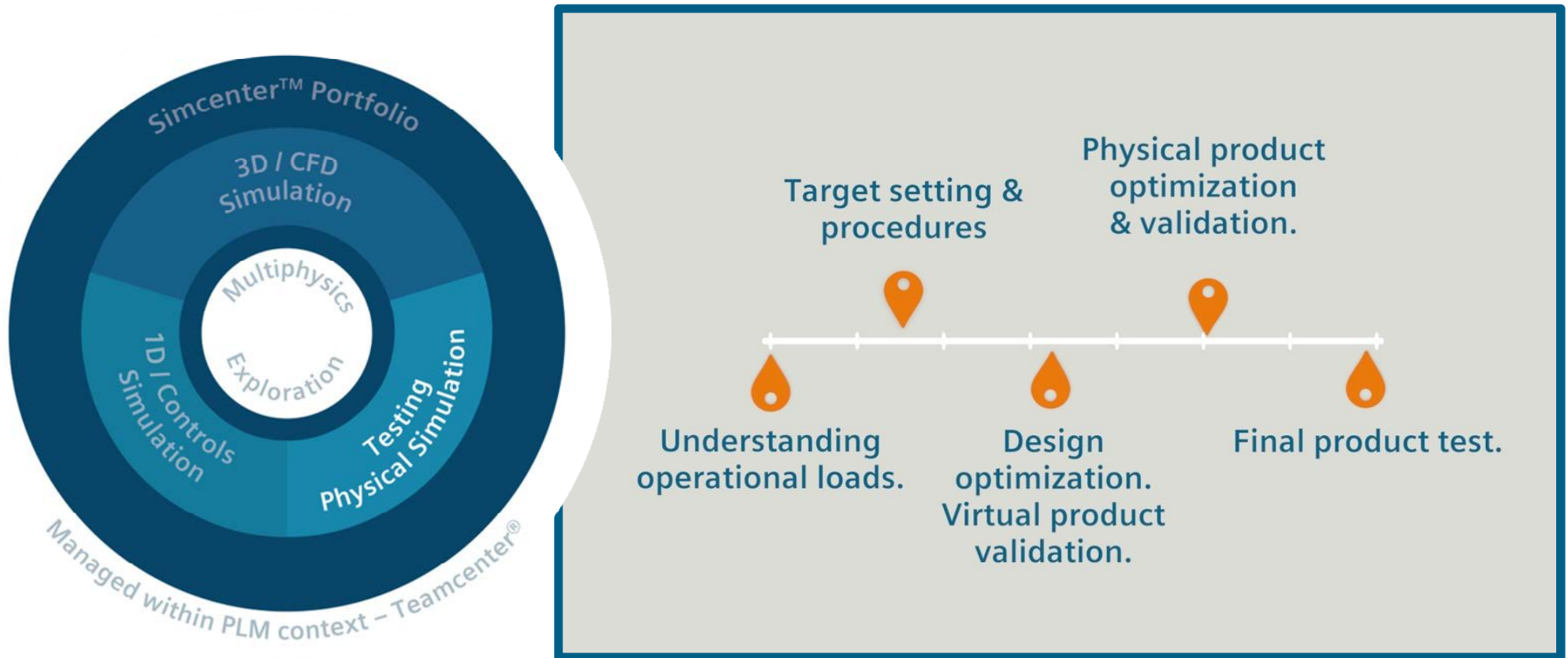
Validation



1. PVG test
2. 4-poster test of the cabine
3. 4-poster virtual test of the cabine

Simcenter durability solutions throughout the development process **SIEMENS**

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