Realistic and customer correlated test schedules

Unrestricted © Siemens 2020

Target setting & procedures
Physical product optimization & validation.
Understanding operational loads.
Design optimization. Virtual product validation.
Final product test.

Target setting & procedures
Physical product optimization & validation.
Understanding operational loads.
Design optimization. Virtual product validation.
Final product test.

Agenda

SIEMENS
Ingenuity for life

Loads and damage

Load characterization

Customer correlation

Accelerated testing and analysis

Customer application case

Unrestricted © Siemens 2020

Agenda

Loads and damage

Load characterization

Customer correlation

Accelerated testing and analysis

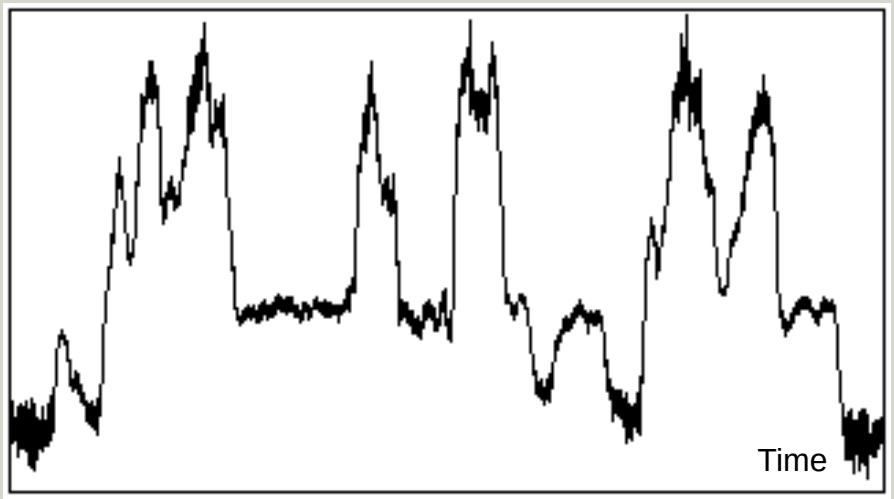
Customer application case

Unrestricted © Siemens 2020

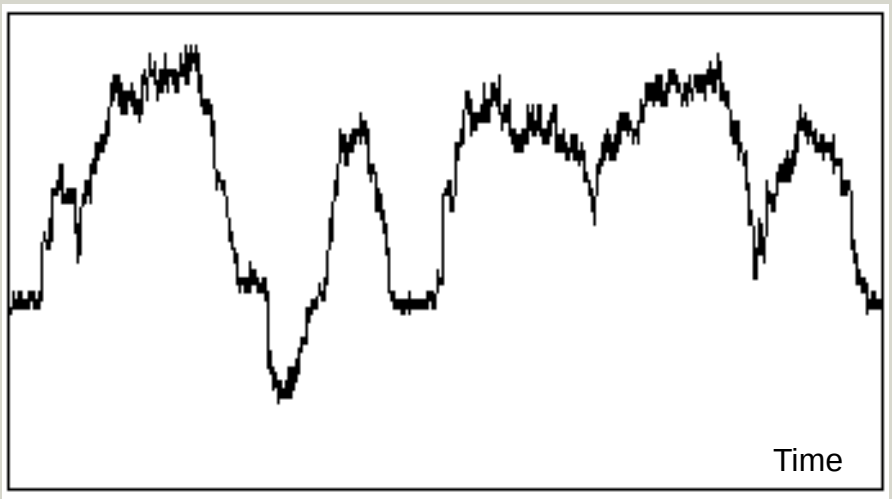
How to understand fatigue content of loads ?
Comparison of two measurements

SIEMENS
Ingenuity for life

Road A



Road B



?

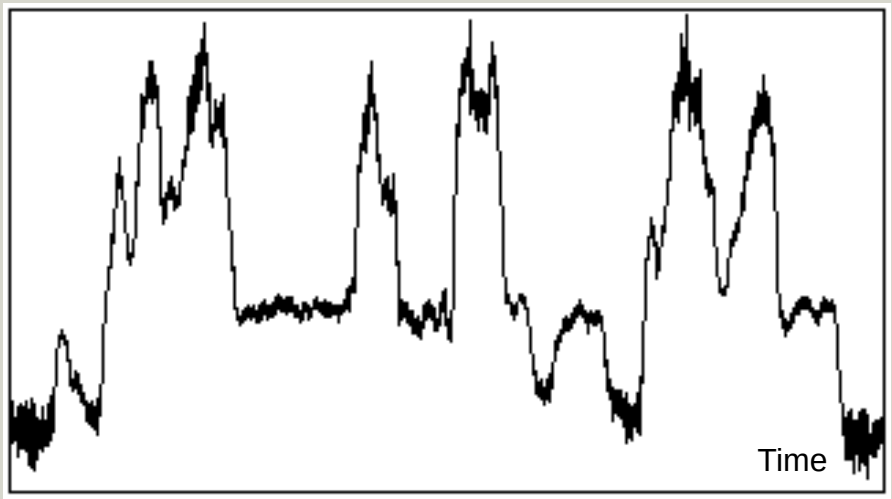
Hard ☹

Unrestricted © Siemens 2020

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

SIEMENS
Ingenuity for life

Road A

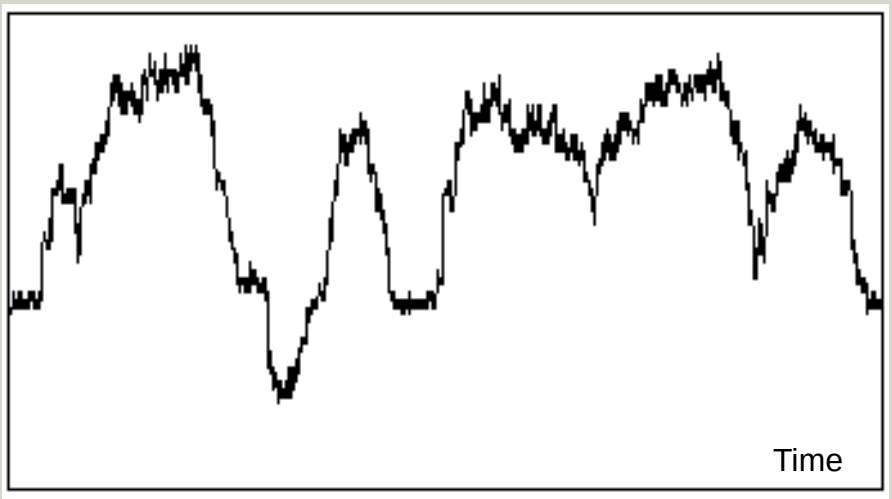


Damage

!

Easy ☺

Road B



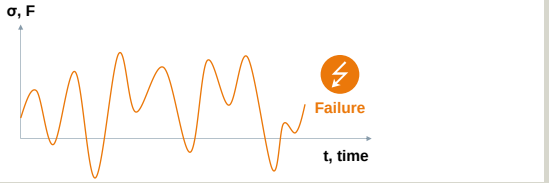
Damage

Unrestricted © Siemens 2020

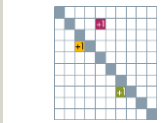
How to understand fatigue content of loads ?
Damage calculation

SIEMENS
Ingenuity for life

Loads



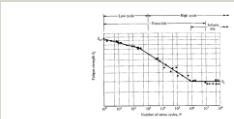
Rainflow counting
→ Range, mean & cycles



n_i

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

S-N curve for CA loading



N_i

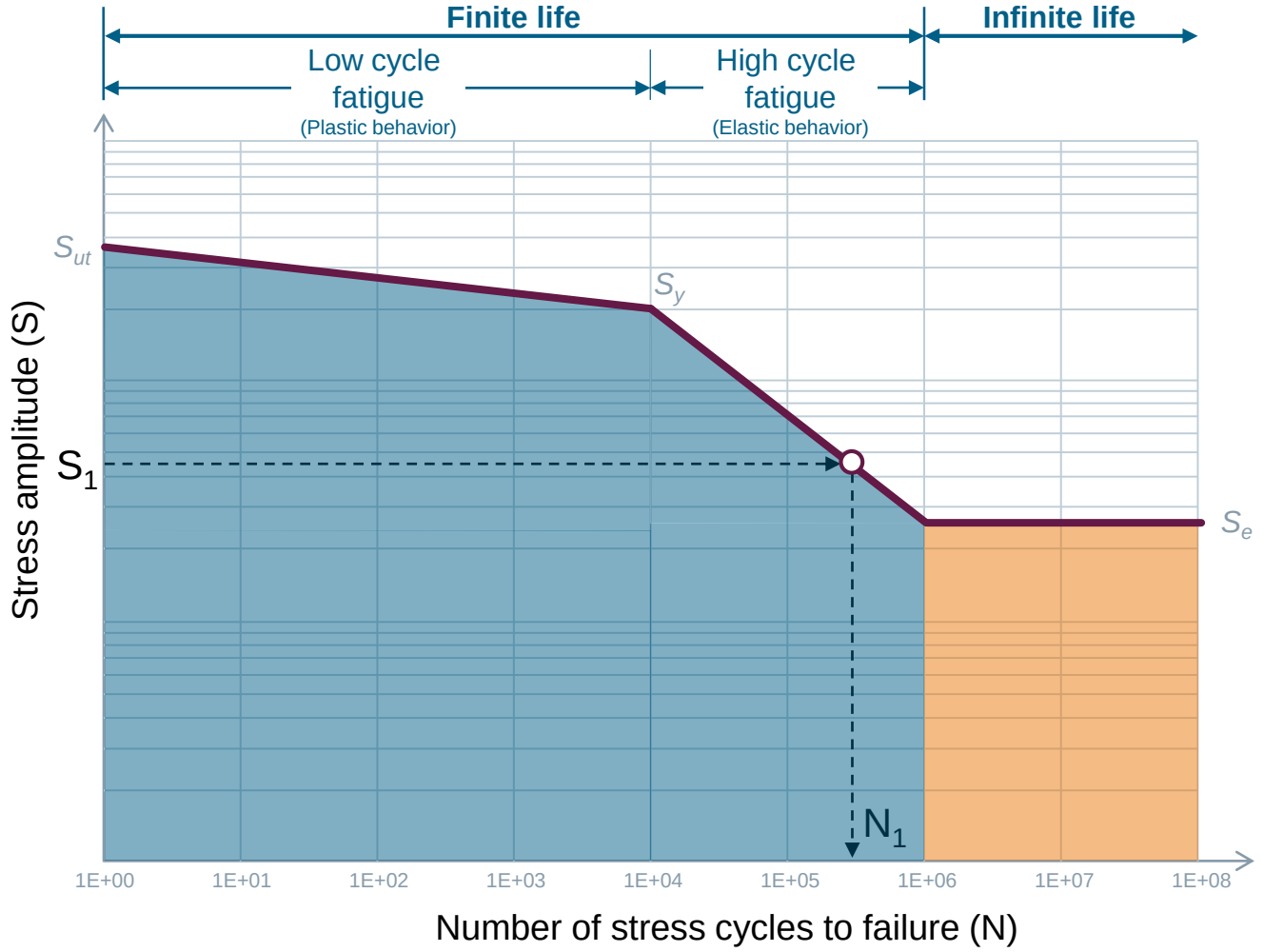
Damage accumulation

Damage
Fatigue life (= 1/Damage)

Unrestricted © Siemens 2020

What is an S-N curve ?
Characteristics

SIEMENS
Ingenuity for life



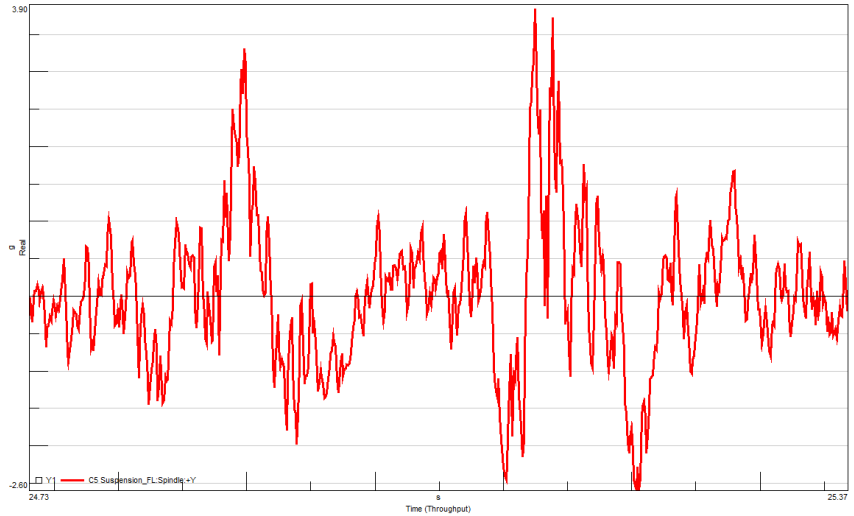
Unrestricted © Siemens 2020

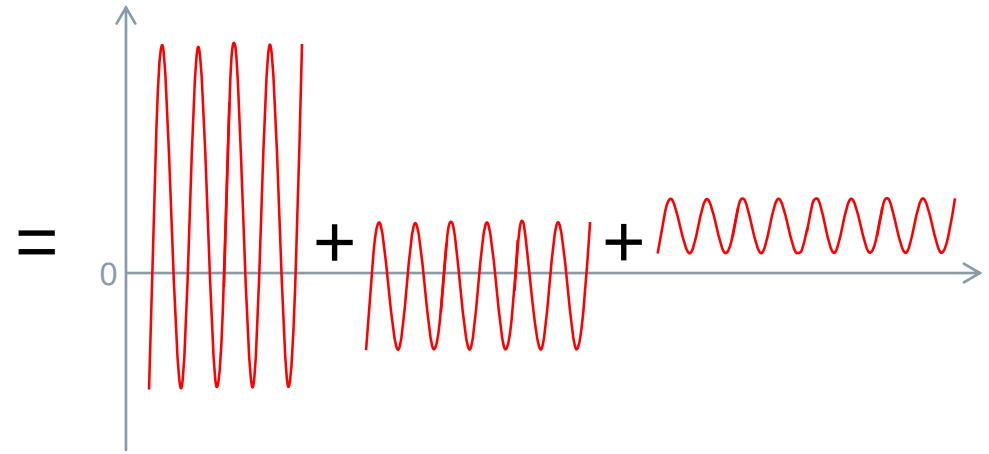
How to understand fatigue content of loads ?
Endo (1968). Rainflow counting for variable loads

SIEMENS
Ingenuity for life

Tatsuo Endo
***1925 ✝1989**

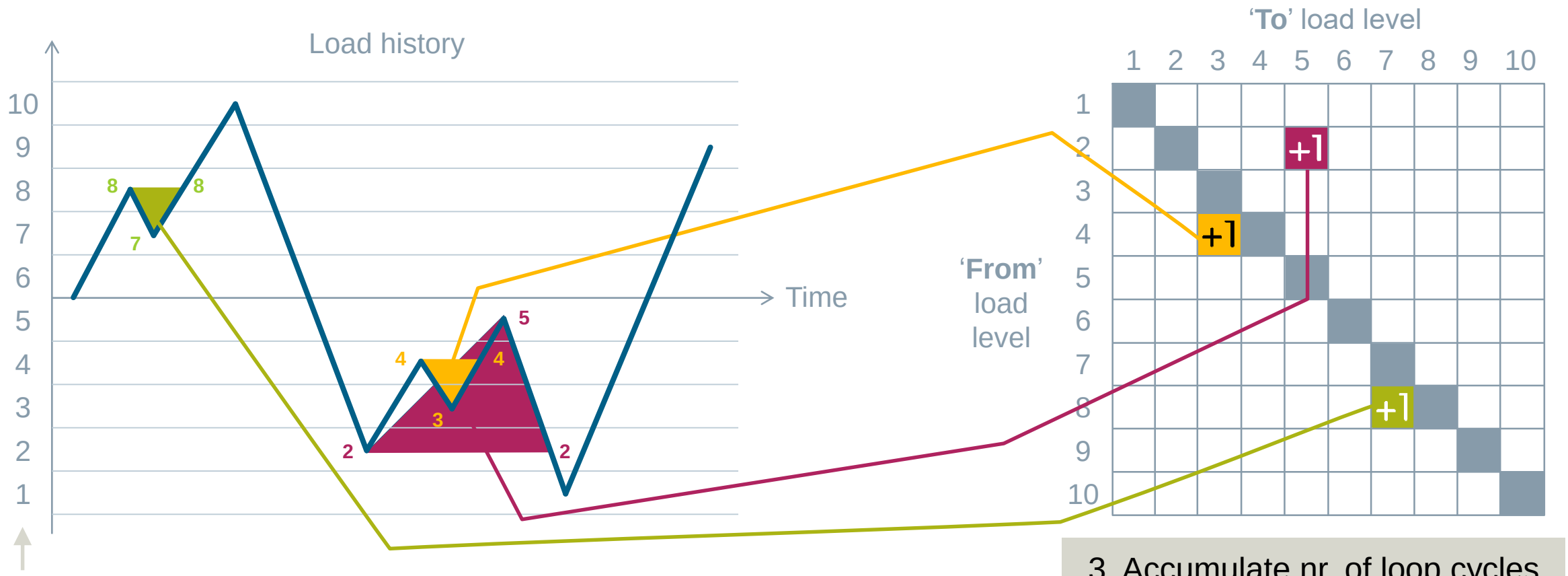
Rainflow counting
= technique to decompose a spectrum of varying, complex stress
into a set of simple stress reversals





Unrestricted © Siemens 2020

Rainflow counting



1. Classification into bins

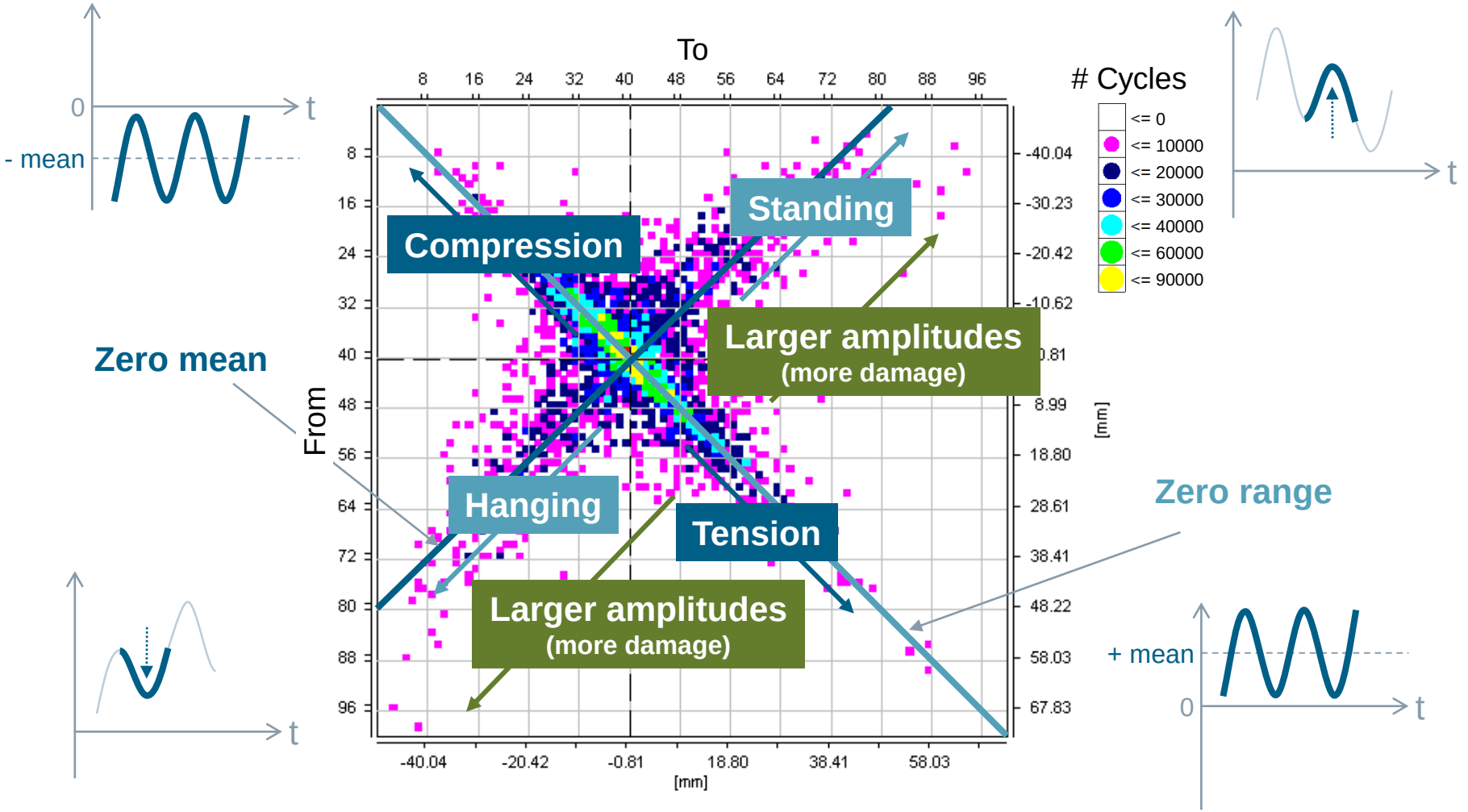
2. Look for closed loops

3. Accumulate nr. of loop cycles in 'From-To' cells of table

= Rainflow-matrix

Unrestricted © Siemens 2020

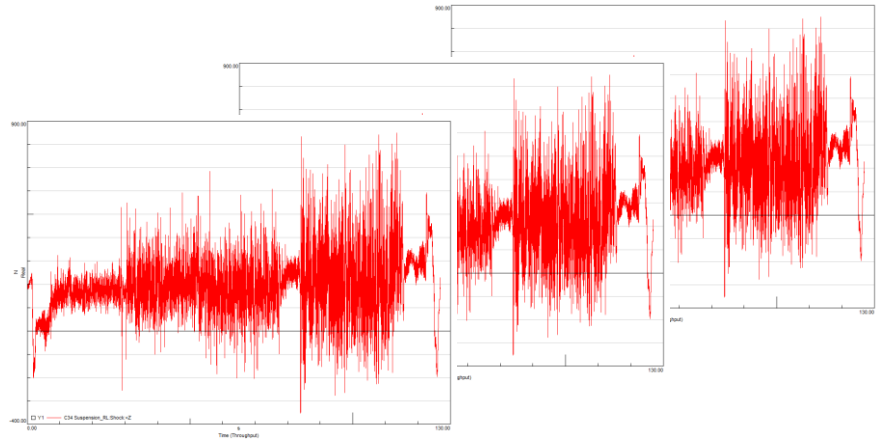
How to understand fatigue content of loads ?
Rainflow characteristics



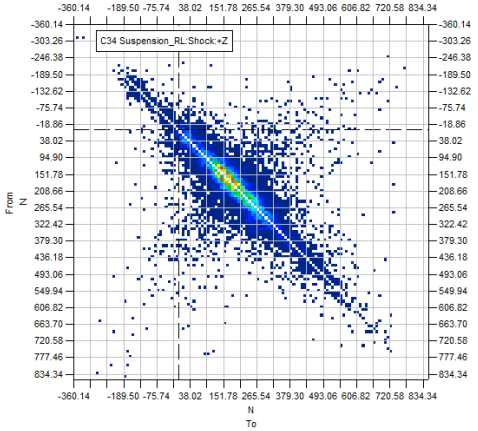
Unrestricted © Siemens 2020

Counting methods in fatigue analysis
Benefits

SIEMENS
Ingenuity for life



Counting method

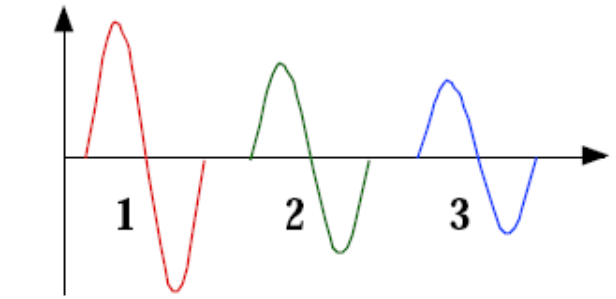


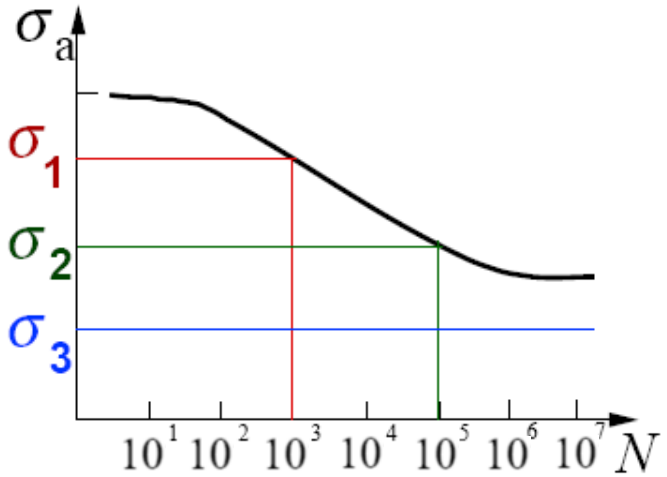
- Representations → easy to understand
- Ability for fatigue related data manipulation (editing, extrapolation, superposition)
- Easy way to compare data
- Simple counting algorithms
- Substantial reduction of data amount

Same counting result = Same fatigue potential

Unrestricted © Siemens 2020

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:

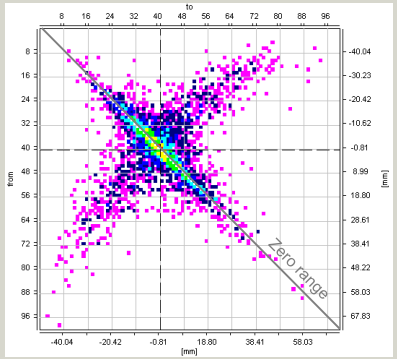
- n_i = the number of actual applied load cycles of type i
- N_i = the pertinent fatigue life for that specific applied load cycle i

Unrestricted © Siemens 2020

How to understand fatigue content of loads ?
Rainflow → Range-pair → Damage → Cumulative damage

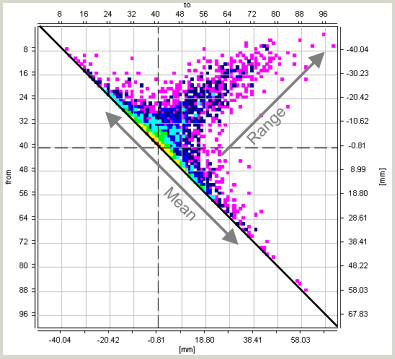
SIEMENS
Ingenuity for life

1 Rainflow



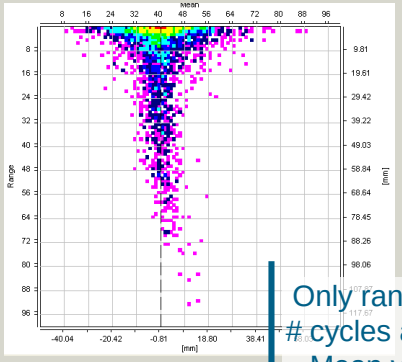
Folding:
No distinction between standing /hanging cycles

2 Rainflow (symmetric)



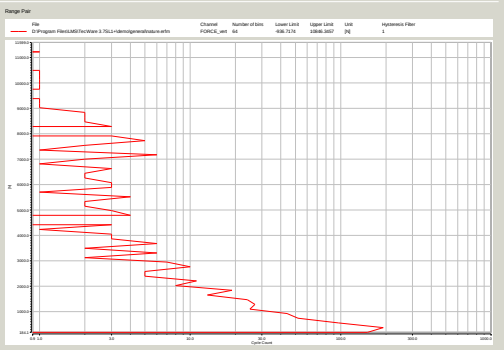
Axes rotating:
X-axis = Mean
Y-axis = Range

3 Rainflow (range/mean)



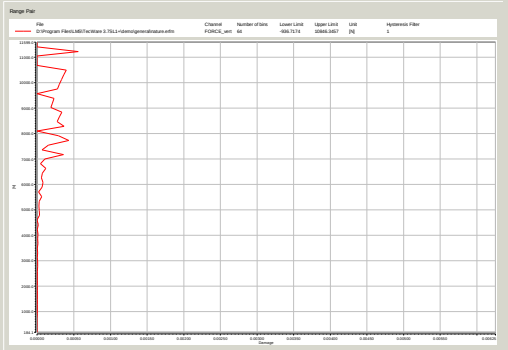
Only ranges and # cycles are kept. Mean value is ignored.

4 Range-pair (cycle count)



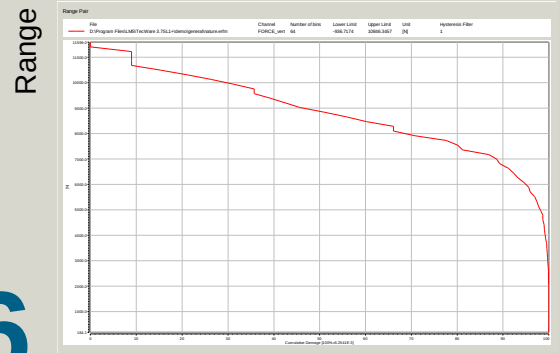
Take S-N curve into account for pseudo-damage distribution

5 Range-pair (damage)



Damage accumulation (Miner's rule)

6 Cumulative damage

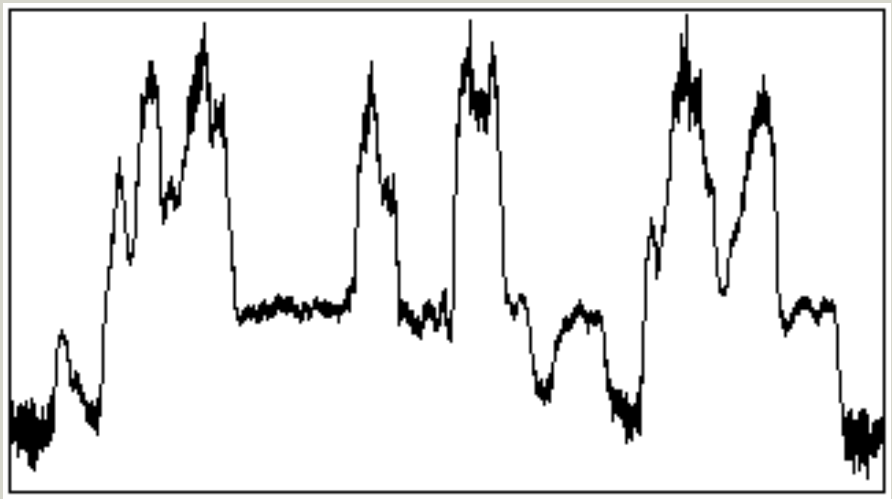


Unrestricted © Siemens 2020

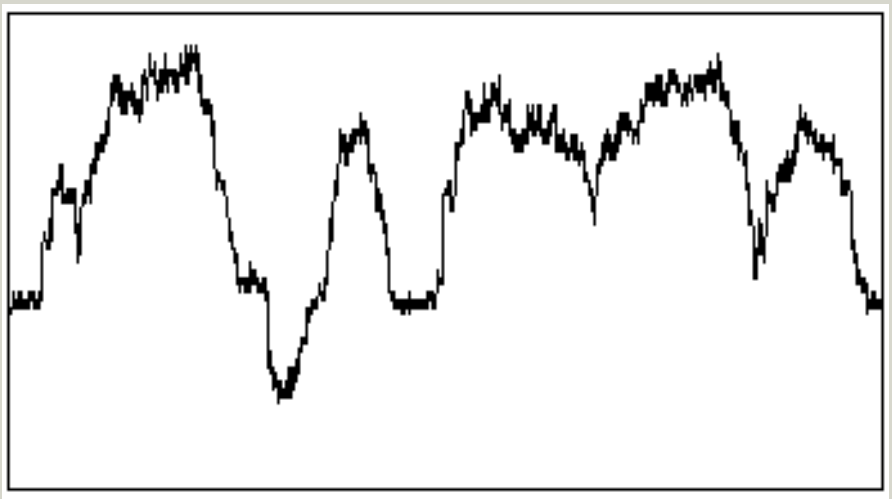
How to understand fatigue content of loads ?
Comparison of two measurements

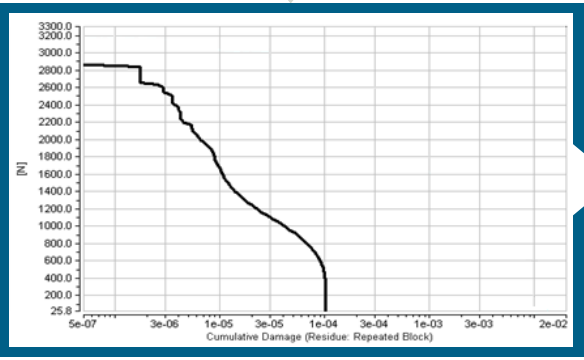
SIEMENS
Ingenuity for life

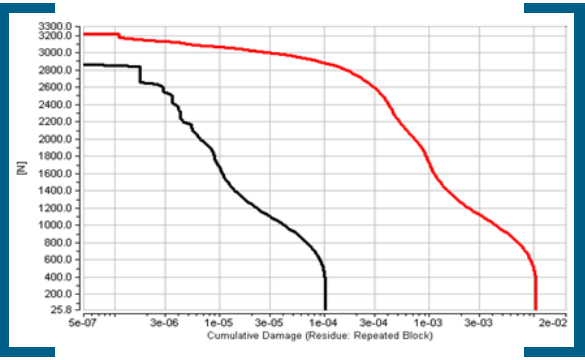
Road A

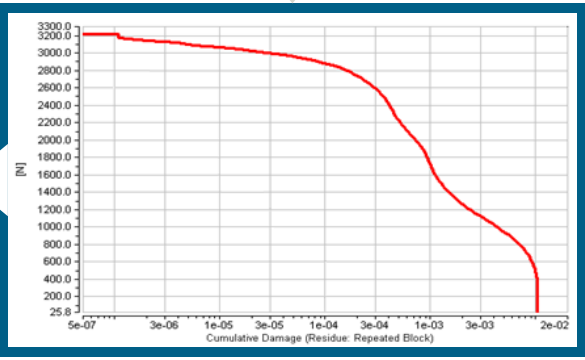


Road B









Unrestricted © Siemens 2020

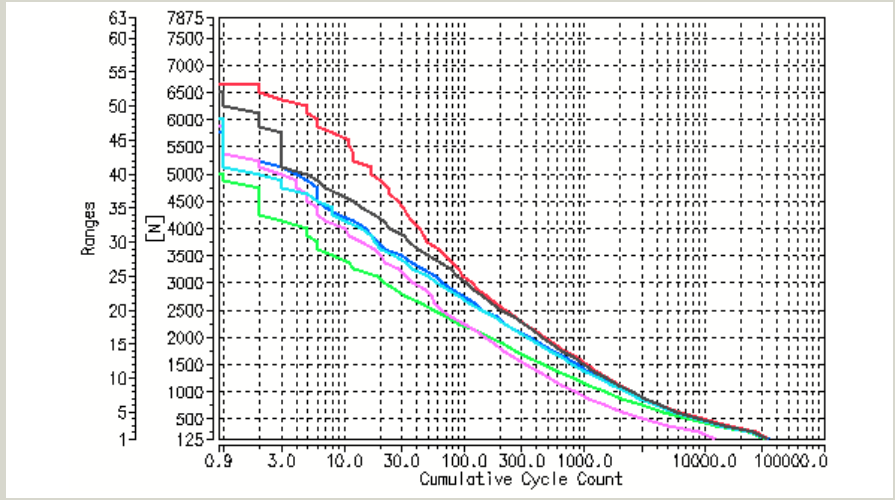
How to understand fatigue content of loads ?
Scatter in loadings

SIEMENS
Ingenuity for life

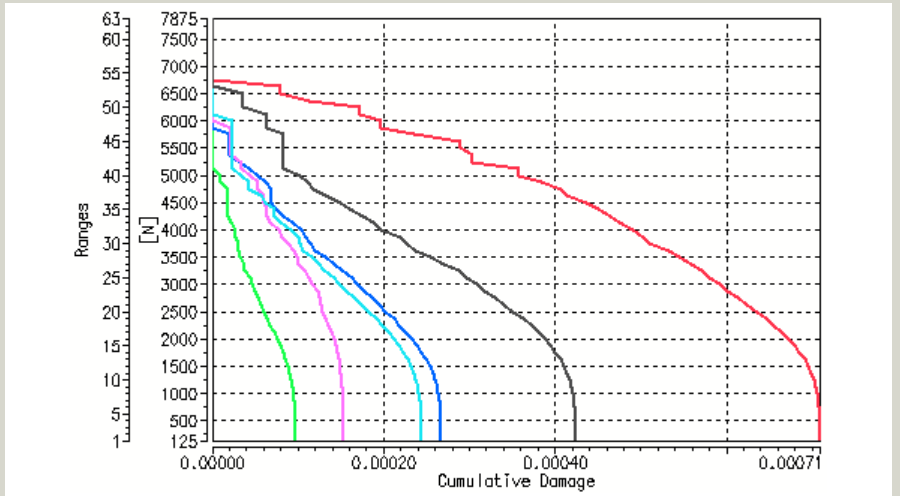
Scenario: 6 measurements
One lap on same road
Same weather conditions
Six different drivers

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

Range-pair histograms (cycle count)



Damage histograms (cumulative damage)



Unrestricted © Siemens 2020

Agenda

Loads and damage

Load characterization

Customer correlation

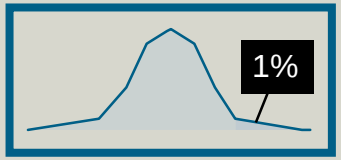
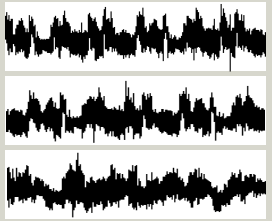
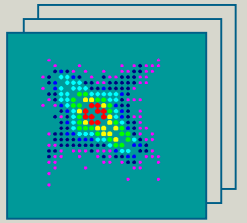
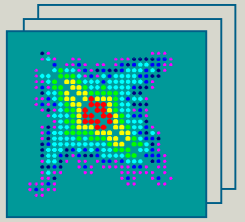
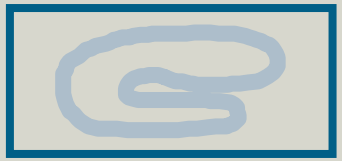
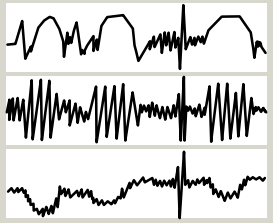
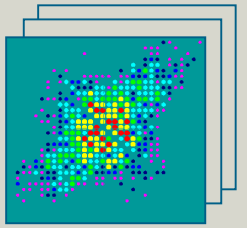
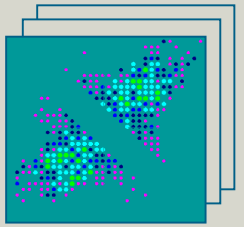
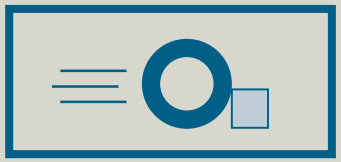
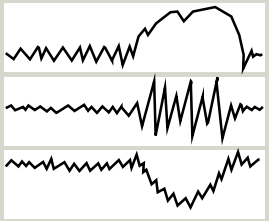
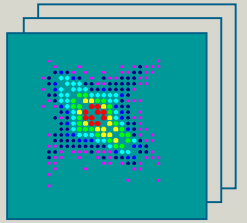
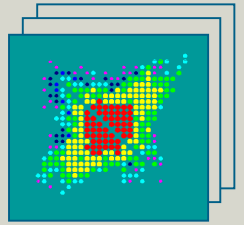
Accelerated testing and analysis

Customer application case

Unrestricted © Siemens 2020

How to design realistic test schedule ?
Target setting, handling multiple events

SIEMENS
Ingenuity for life

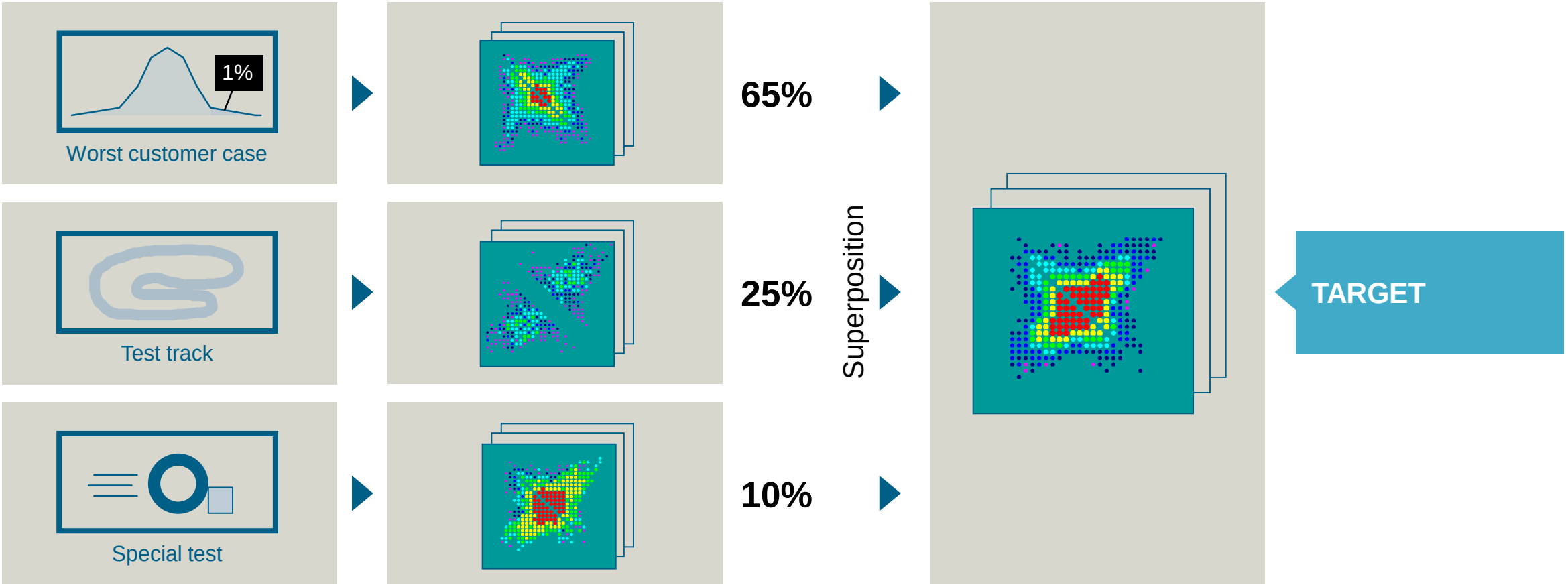
Load cases	Load histories	Rainflow matrices		Rainflow manipulation
 Worst customer case			Extrapolation	
 Test track			Edit	
 Special test			Design	

Unrestricted © Siemens 2020

How to design realistic test schedule ?
Target setting, handling multiple events

SIEMENS
Ingenuity for life

Load cases

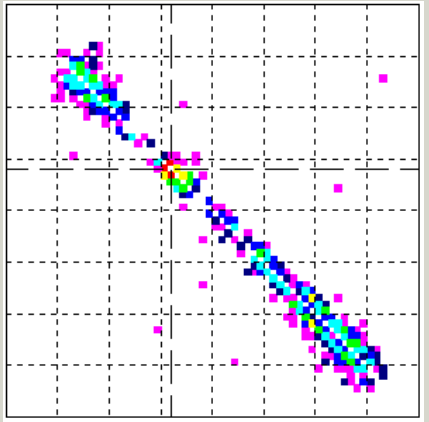


Unrestricted © Siemens 2020

How to design realistic test schedule ?
Target setting – Extrapolation for longer duration

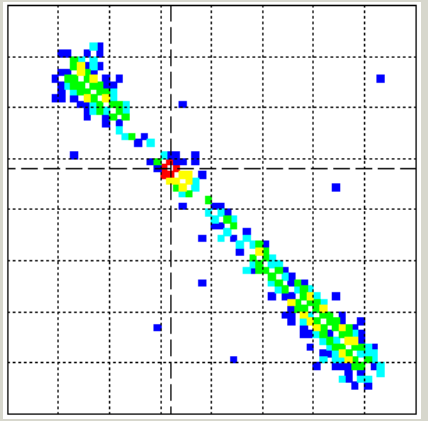
SIEMENS
Ingenuity for life

Single lap (measured)



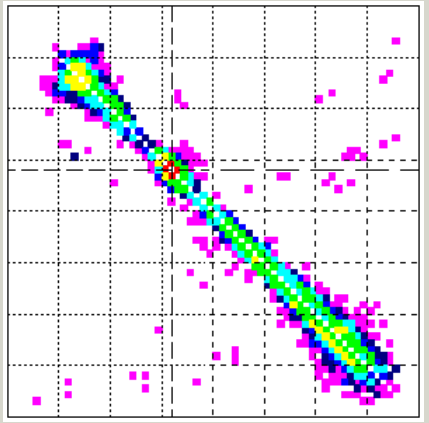
Multiplying not sufficient!

Simply multiplied x6



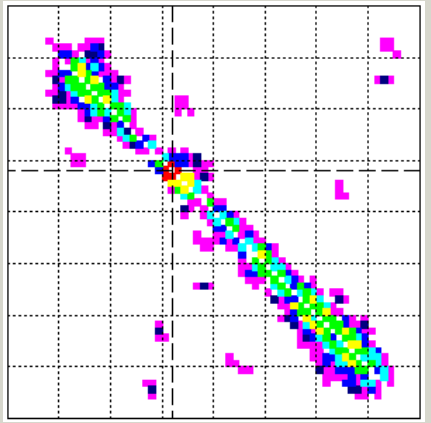
Six laps ?

Six laps (measured)



Extrapolation

Extrapolated



Similar to real measurement !

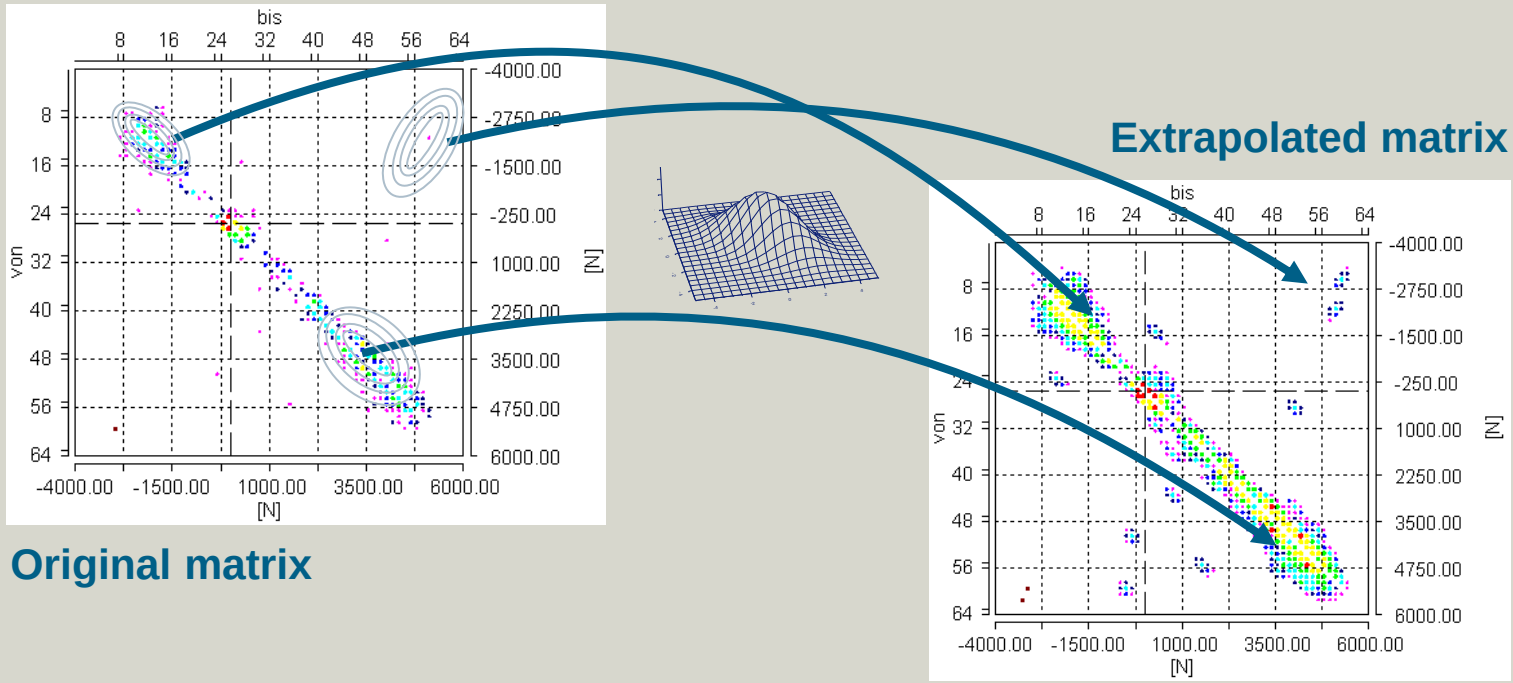
Unrestricted © Siemens 2020

How to design realistic test schedule ?
Target setting – Extrapolation for longer duration

SIEMENS
Ingenuity for life

Parameterization

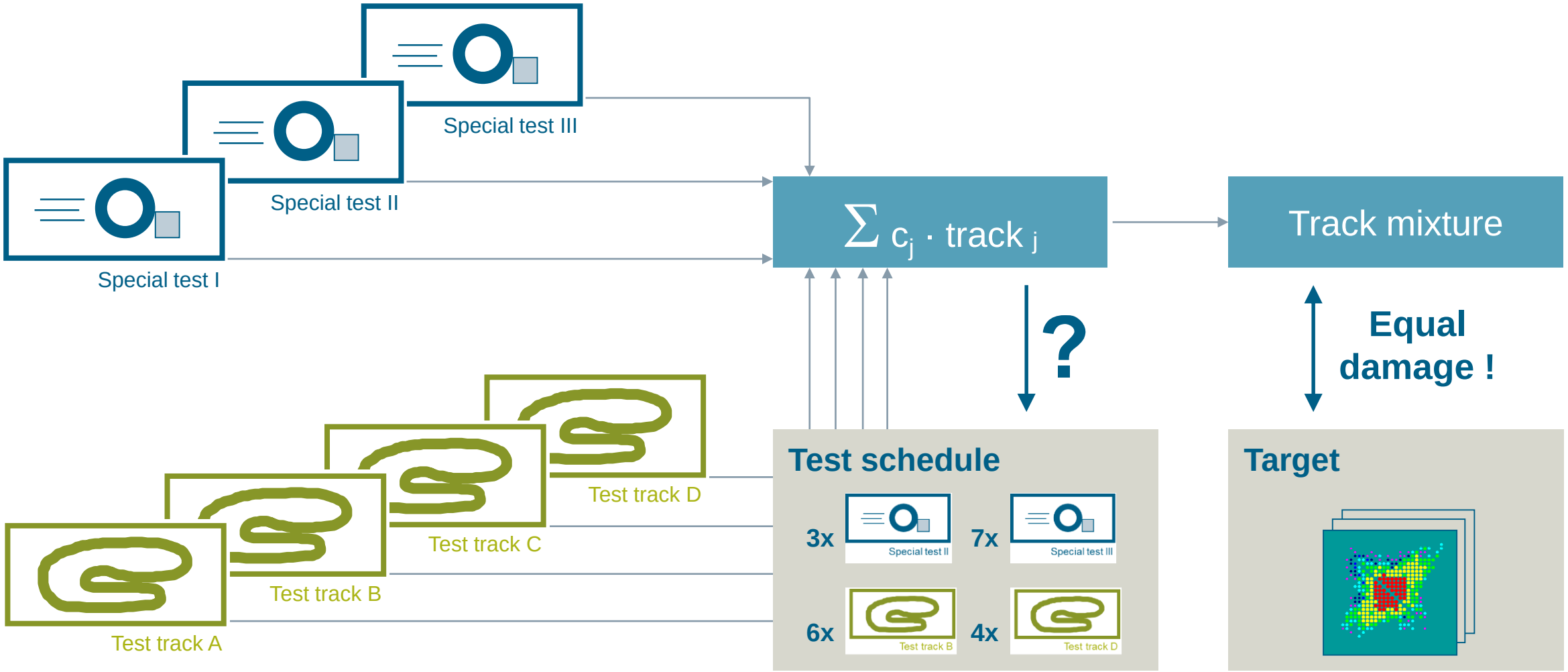
- Extrapolation factor (“number of laps”)
- Smoothing factor (“reliability of data”) → **Compensate for scattering on:**
  Type of drivers, load data, component dimensions, material properties, ...



Unrestricted © Siemens 2020

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

SIEMENS
Ingenuity for life



Unrestricted © Siemens 2020

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

SIEMENS
Ingenuity for life

CombiTrack File : C:\DOCUME~1\sht\LOCALS~1\Temp\sht\rM3e5001.ctr

[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

Target

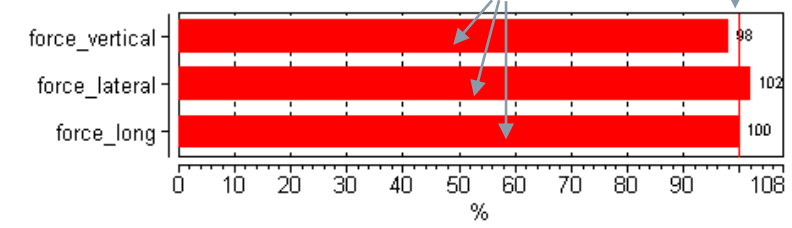
[Coefficients]

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

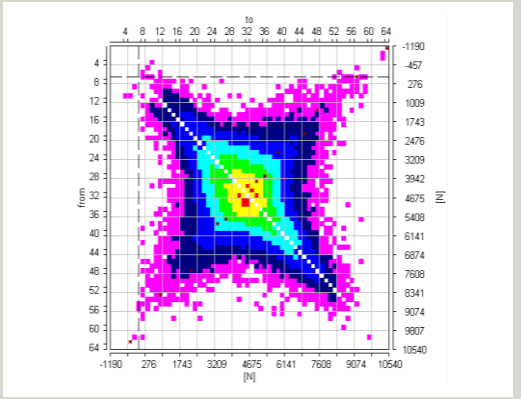
Nr. of track repetitions

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

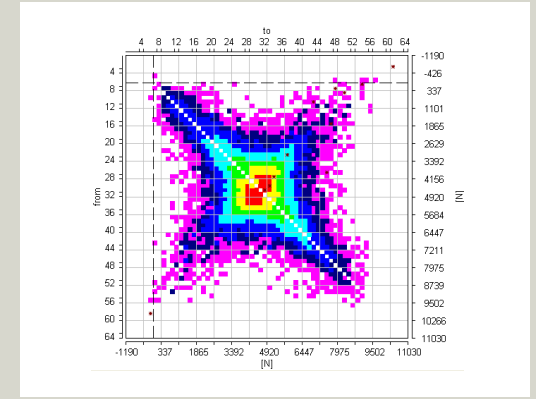
CombiTrack/Target:

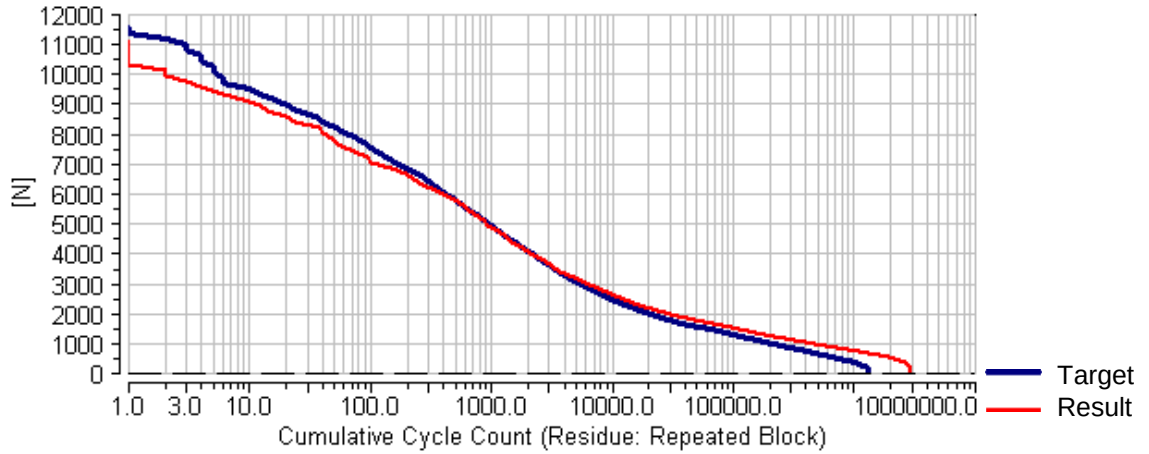


Target



Result





Agenda

Loads and damage

Load characterization

Customer correlation

Accelerated testing and analysis

Customer application case

Unrestricted © Siemens 2020

Customer correlation
Statistical approach ⇨ Fleet measurement required

SIEMENS
Ingenuity for life

Traditional customer correlation

Very limited sample size (1 car, few weeks)

Extensive measurement setup (50+ channels)

Limited customer relevance !

Siemens CuCo: Traditional RLDA + Fleet

Lean CuCo measurement setup (8 channels)

Extended sample size (Fleet: 5+ cars, 2-6 months)

High customer relevance !

Unrestricted © Siemens 2020

Customer correlation
Combined CuCo approach, ‘Traditional RLDA & fleet’

SIEMENS
Ingenuity for life

Traditional RLDA
⇨ to capture
detailed load information

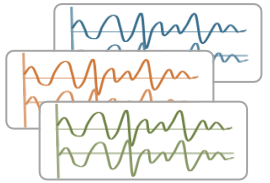
- Full RLDA (50-100 ch.) on public roads
- One vehicle
- Limited time/mileage

+

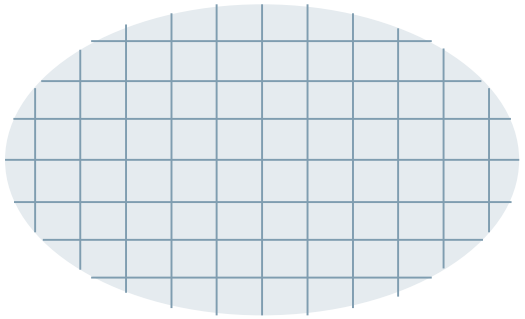
Fleet measurements
⇨ to capture
usage statistics

- Observation of customer behavior
- Many customers/vehicles
- Extended accumulated observation time/mileage

Detailed loading per usage condition

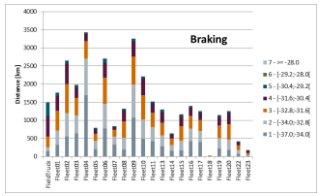


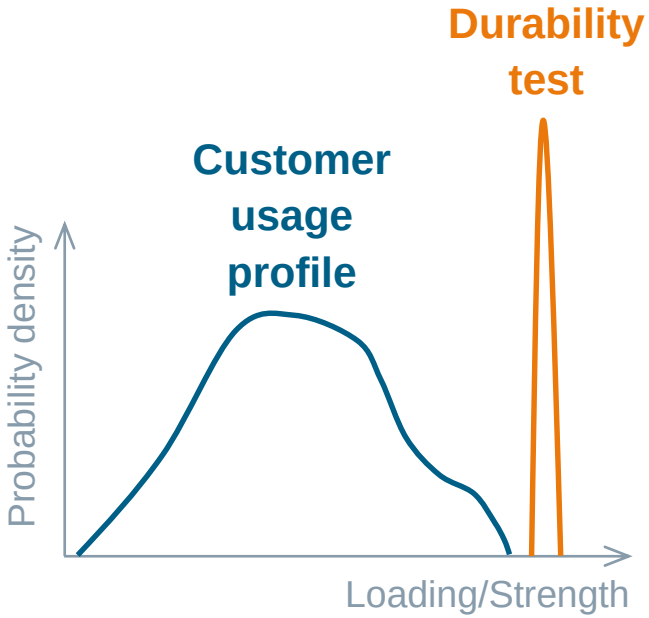
Usage space



Discretization (cells)

Statistical frequency of usage conditions



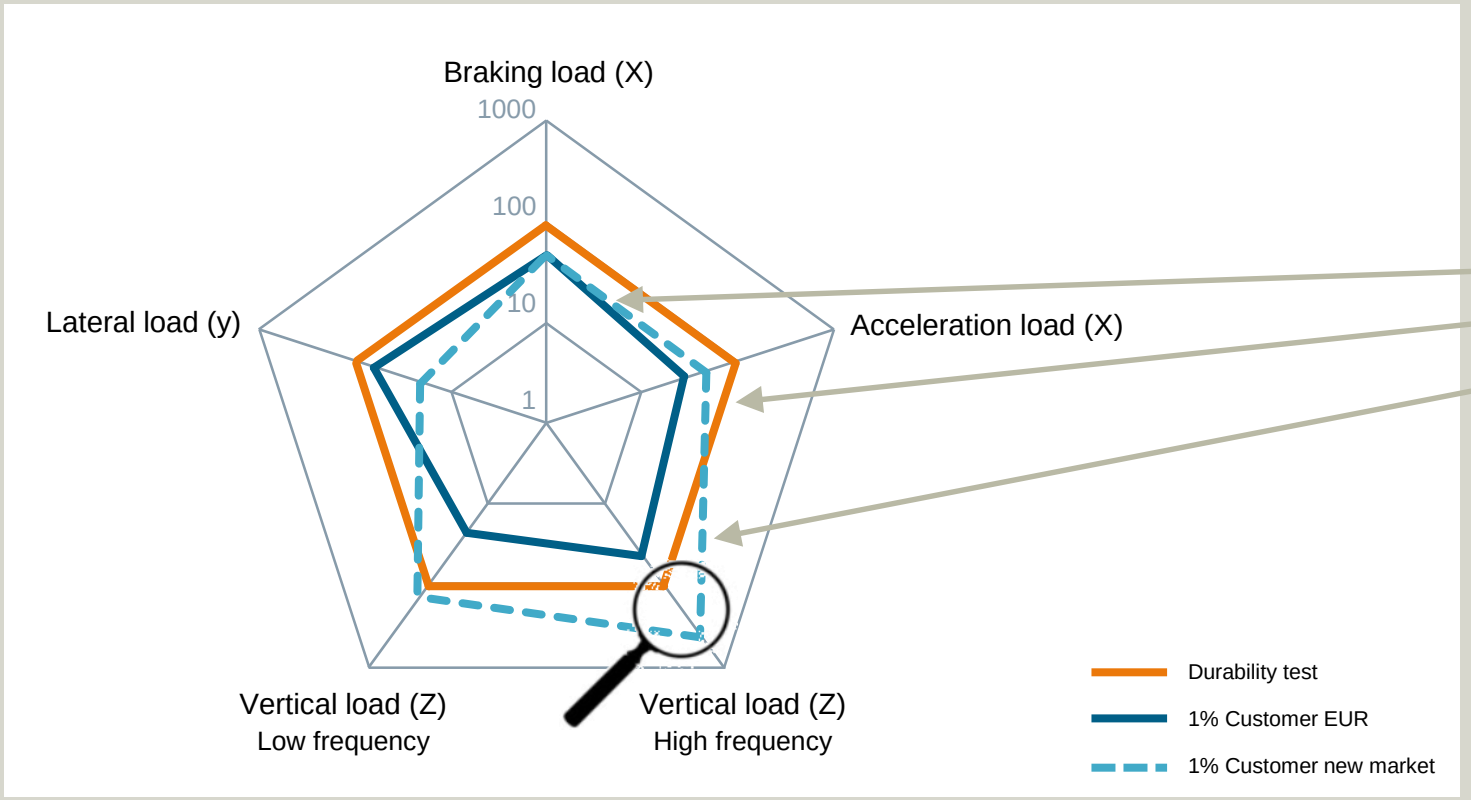


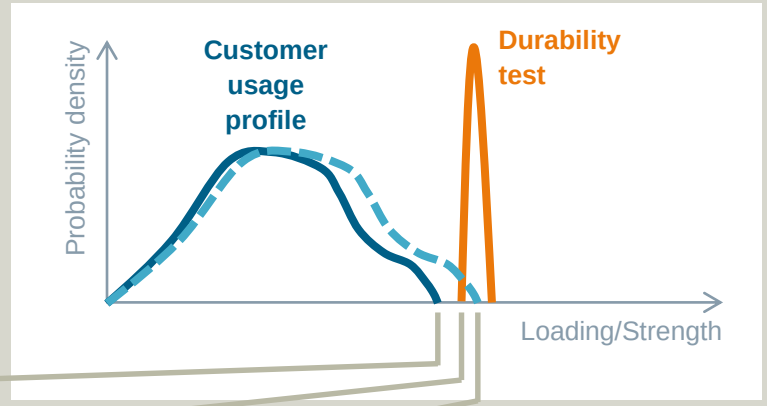
Unrestricted © Siemens 2020

Customer correlation
Result: “Fingerprint” of customer representative loading

SIEMENS
Ingenuity for life

“Fingerprint” of major vehicle loading components





Unrestricted © Siemens 2020

Agenda

SIEMENS
Ingenuity for life

Loads and damage

Load characterization

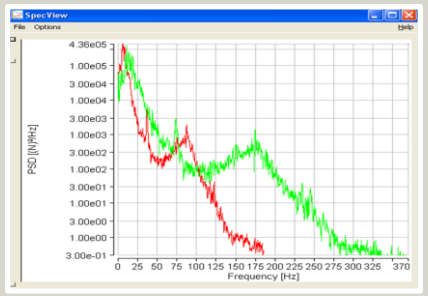
Customer correlation

Accelerated testing and analysis

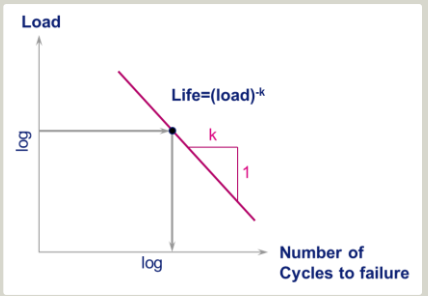
Customer application case

Unrestricted © Siemens 2020

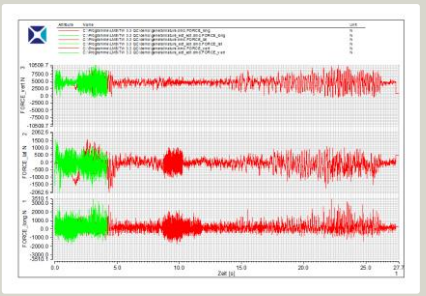
How can you accelerate a test ?



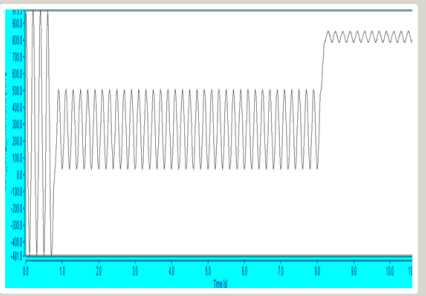
1 Increase speed



2 Increase amplitude



3 Omit non-damaging events



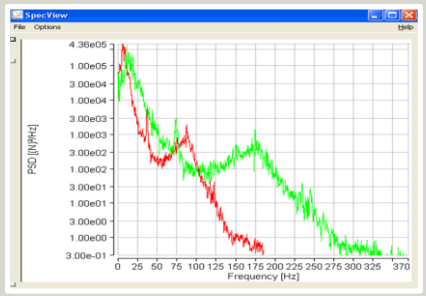
4 Simplify the test

Basic principle = conservation of damage

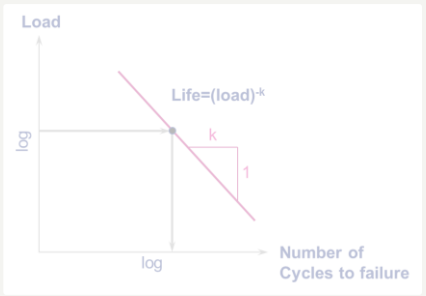
Unrestricted © Siemens 2020

How can you accelerate a test ?
Increase testing speed

SIEMENS
Ingenuity for life



1 Increase speed



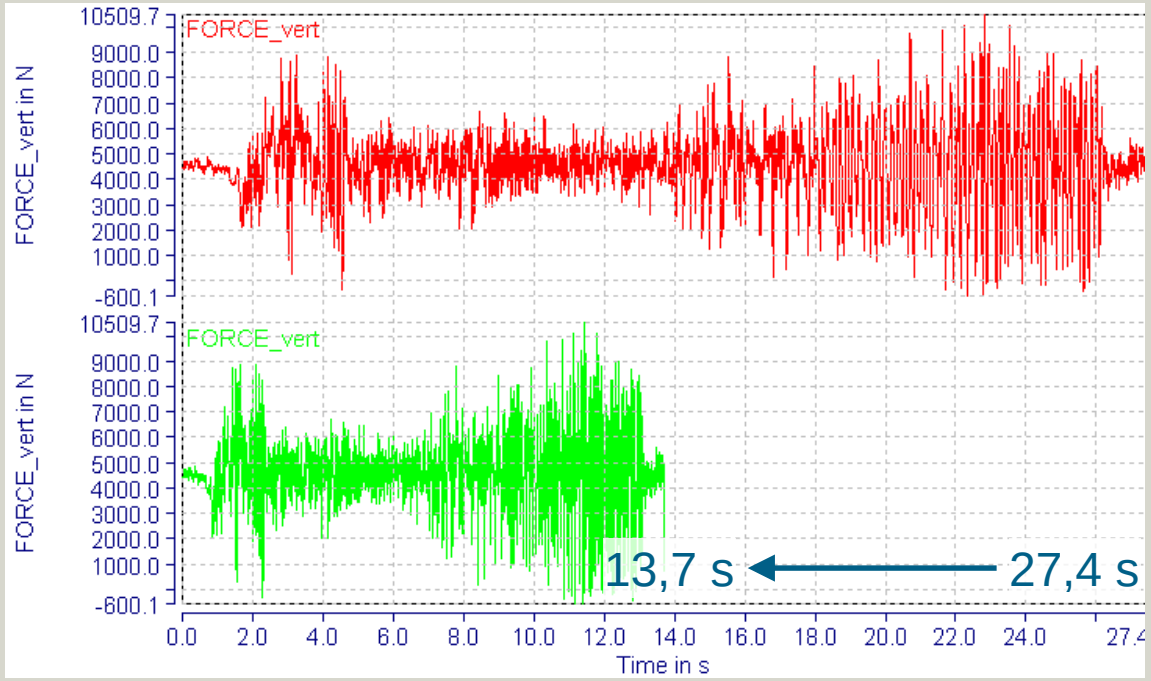
2 Increase amplitude

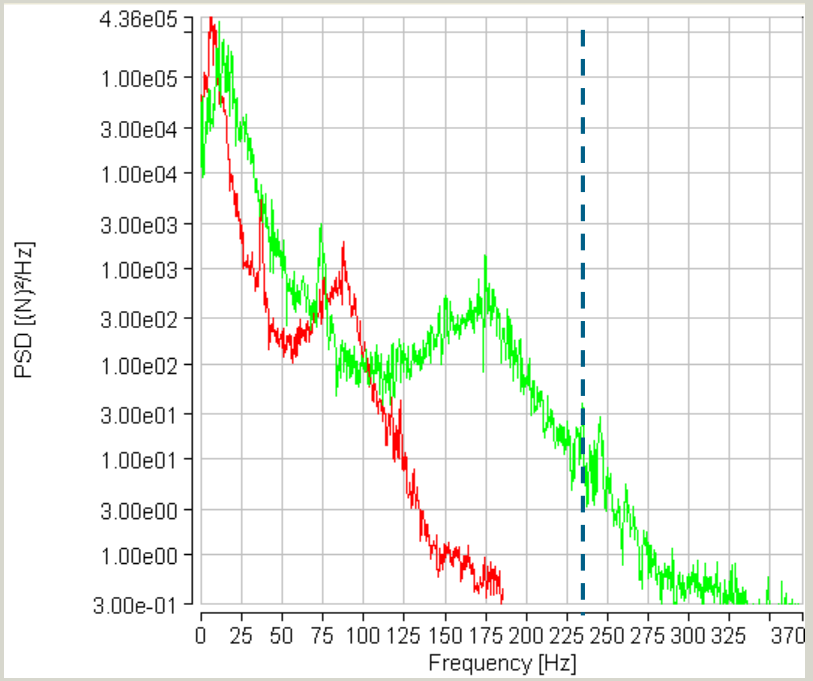
3 Omit non-damaging events

4 Simplify the test

Unrestricted © Siemens 2020

How can you accelerate a test ?
Increase testing speed





▶ 1st natural frequency

Important: Avoid too high compression !

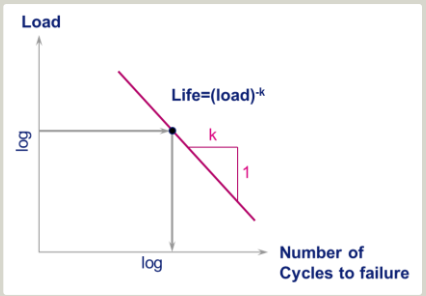
Frequency content should stay reasonably below 1st natural frequency (resonances)

Unrestricted © Siemens 2020

How can you accelerate a test ?
Increase amplitude

SIEMENS
Ingenuity for life

1 Increase speed



2 Increase amplitude

3 Omit non-damaging events

4 Simplify the test

Unrestricted © Siemens 2020

How can you accelerate a test ?
Increase amplitude

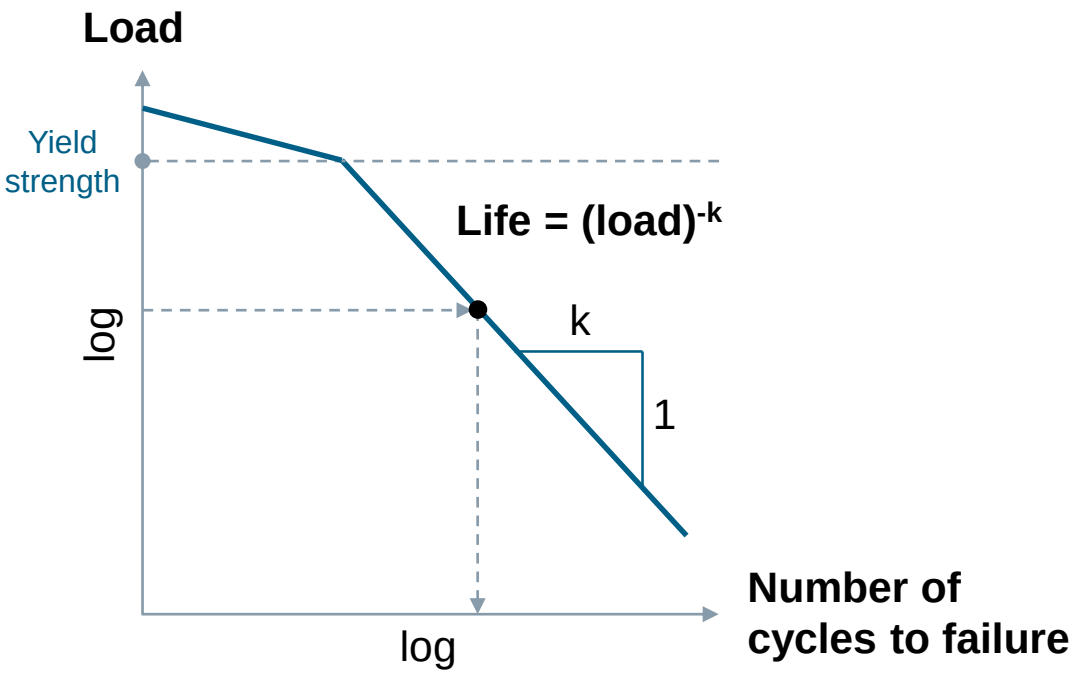
SIEMENS
Ingenuity for life

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

+15%

÷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



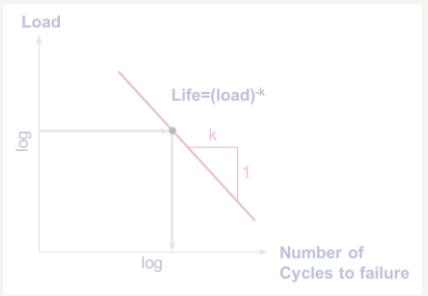
Important:
Do not increase amplitude too much !

Be careful not to generate an uncharacteristic failure mode (plastic vs. elastic).

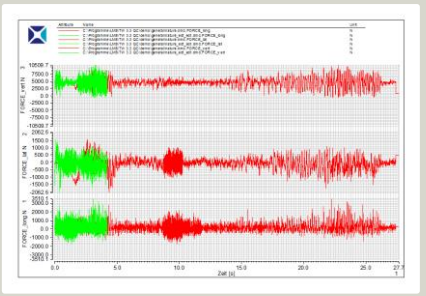
Unrestricted © Siemens 2020

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

1 Increase speed



2 Increase amplitude



3 Omit non-damaging events

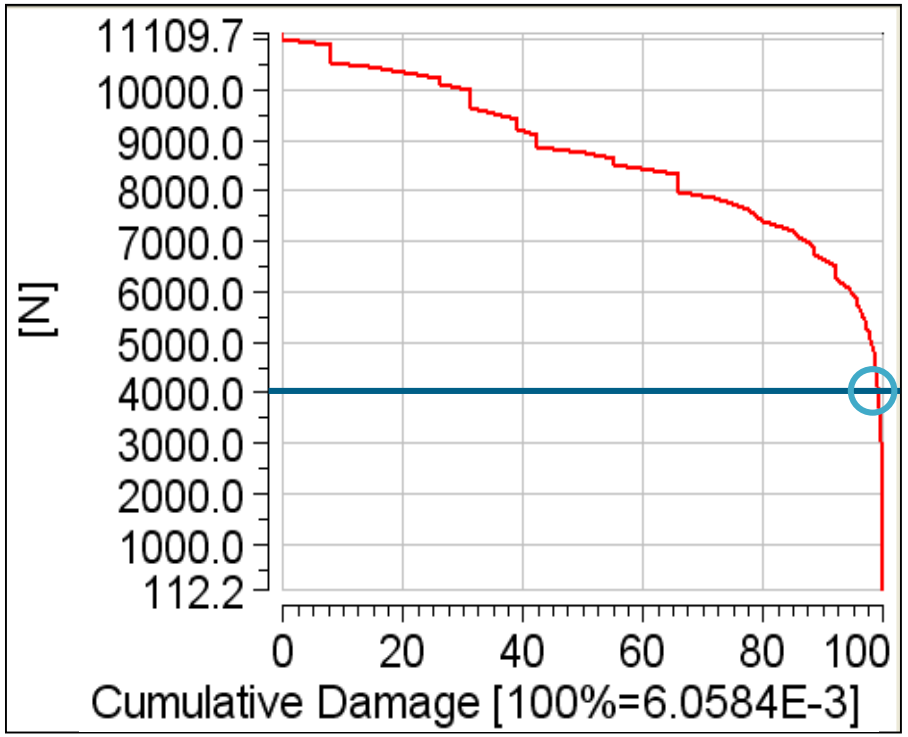
4 Simplify the test

Unrestricted © Siemens 2020

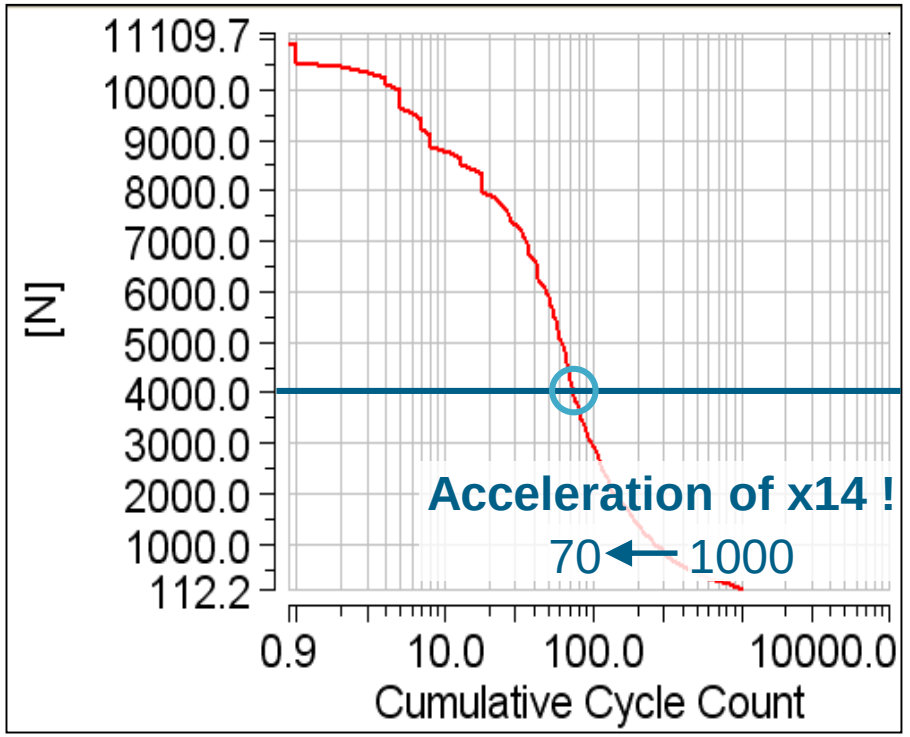
How can you accelerate a test ?
Omit non-damaging events – Uni-axial

SIEMENS
Ingenuity for life

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



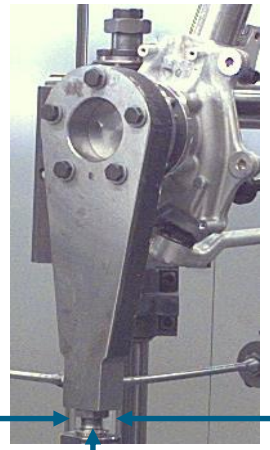
If you remove these from the loading, you end up with 70 cycles instead of 1000



Unrestricted © Siemens 2020

How can you accelerate a test ?
Omit non-damaging events – Multi-axial – RP-filtering

SIEMENS
Ingenuity for life



Longitudinal

Lateral

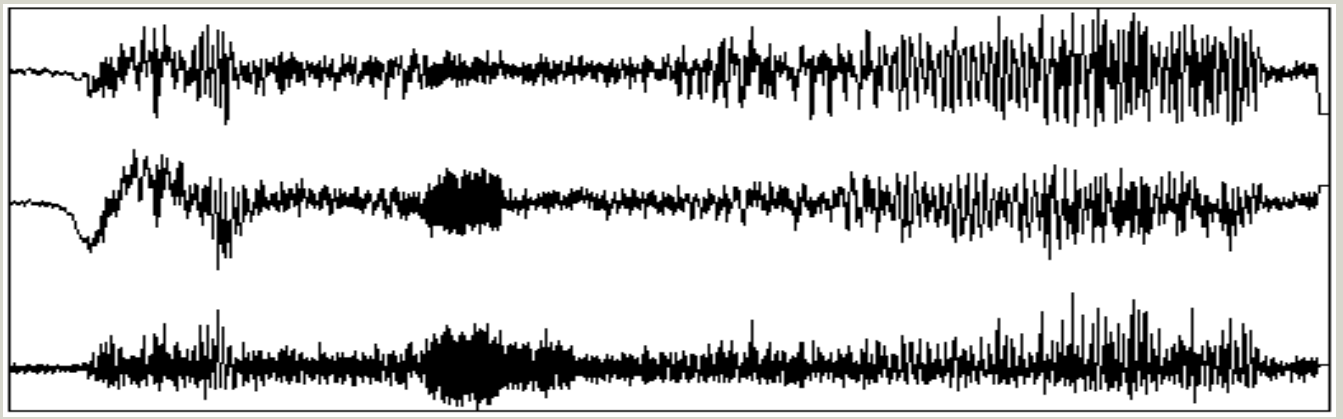
Vertical

Uni-axial rainflow channel-per-channel is not OK
→ Phase relation lost !

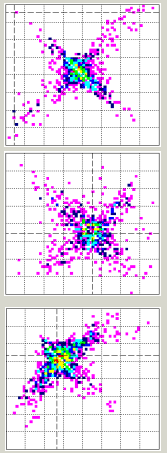
Vertical

Lateral

Longitudinal



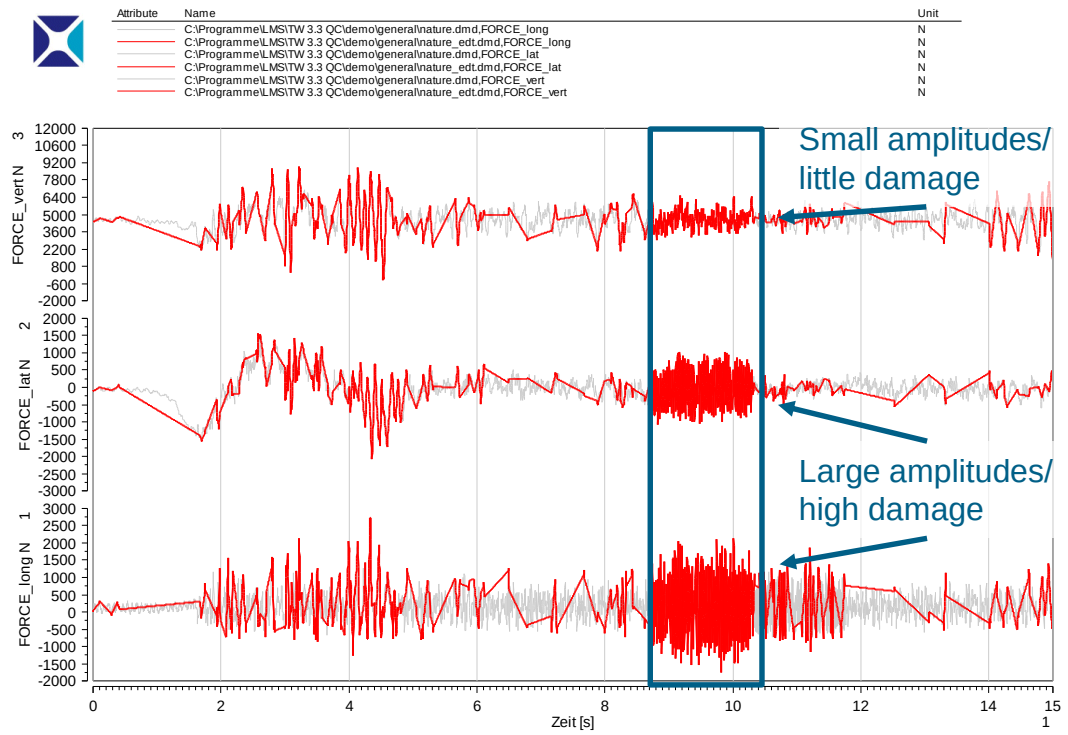
Different loads !

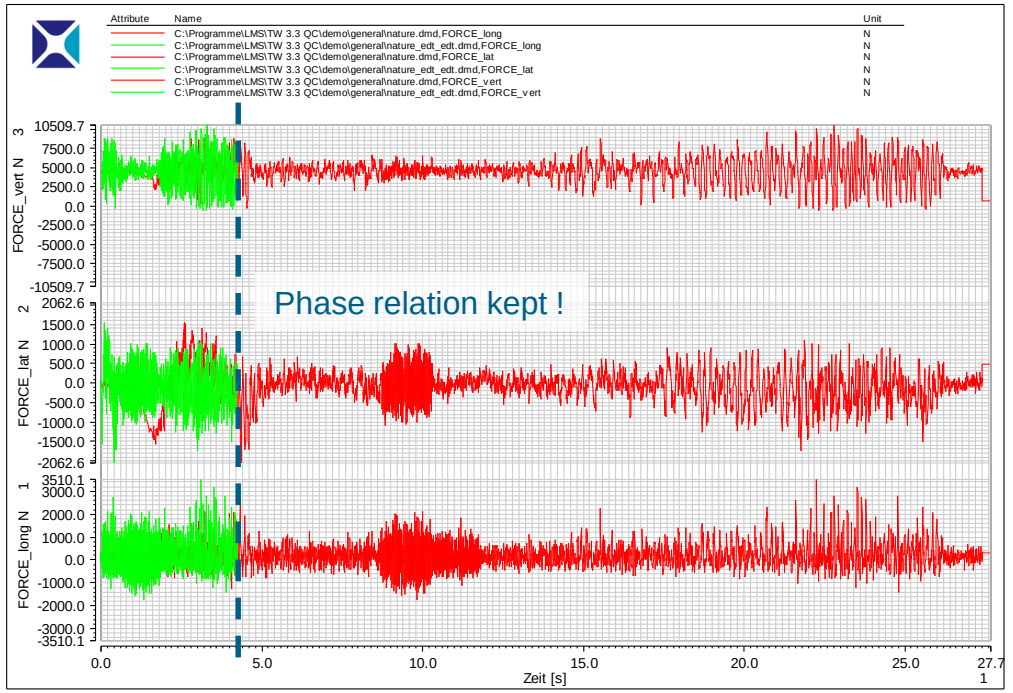


Unrestricted © Siemens 2020

How can you accelerate a test ?
Omit non-damaging events – Multi-axial – RP-filtering

SIEMENS
Ingenuity for life



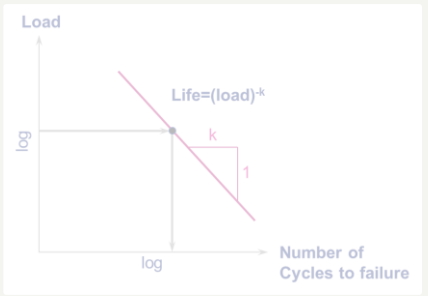


Unrestricted © Siemens 2020

How can you accelerate a test ?
Simplify the test

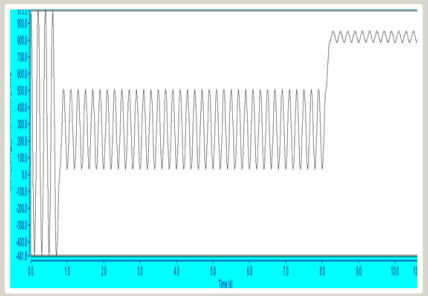
SIEMENS
Ingenuity for life

1 Increase speed



2 Increase amplitude

3 Omit non-damaging events



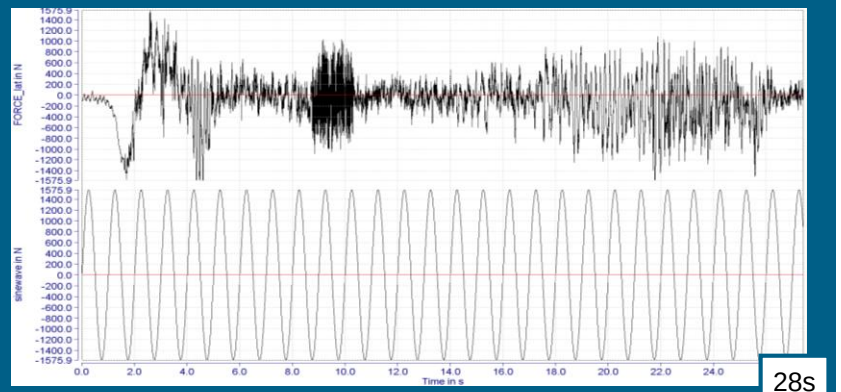
4 Simplify the test

Unrestricted © Siemens 2020

How can you accelerate a test ?
Simplify the test – Constant amplitude test

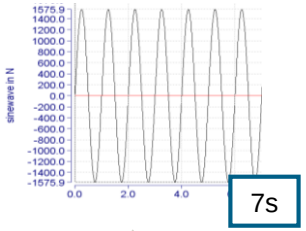
SIEMENS
Ingenuity for life

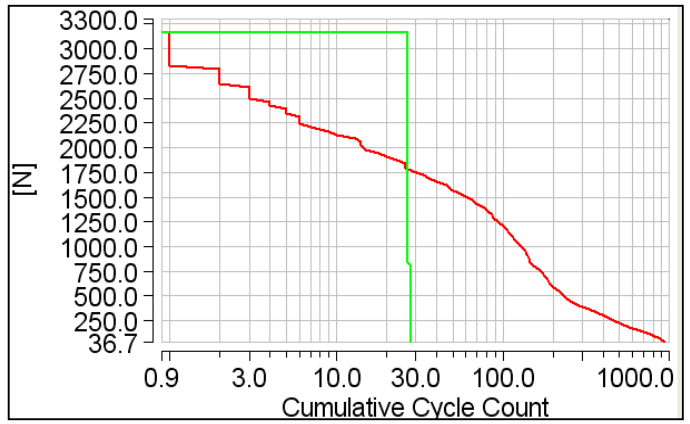
Testing with maximum amplitude

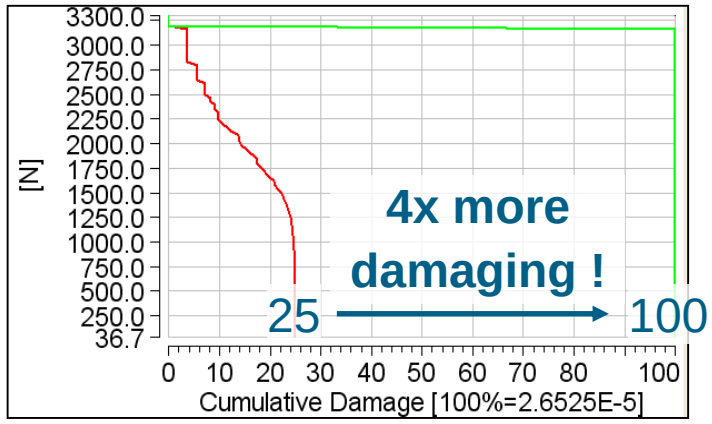


Accelerate by 4x

Increase sine wave frequency ?







C:\LMS\TecWare_36SL1\demo\general\nature_4.erfm
C:\LMS\TecWare_36SL1\demo\general\nature_FORCE_lat_sinewave_1.erfm

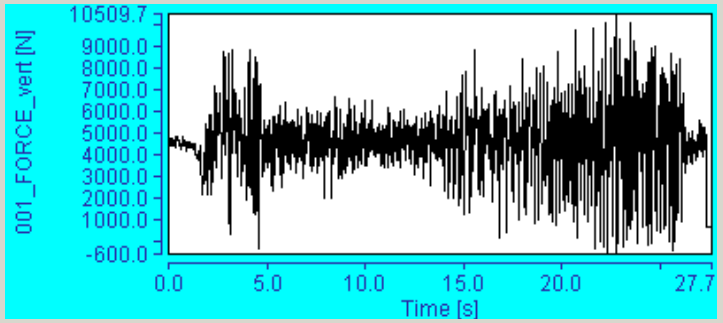
Unrestricted © Siemens 2020

How can you accelerate a test ?
Simplify the test – Block cycle test

SIEMENS
Ingenuity for life

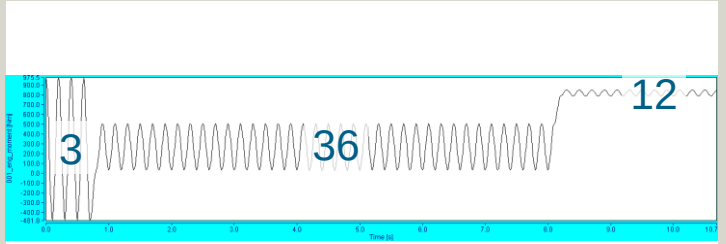
Mix of different ‘Constant-amplitude’ tests for more representative results

Original time series

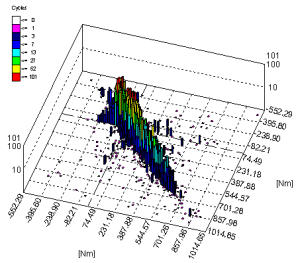


Damage equivalent

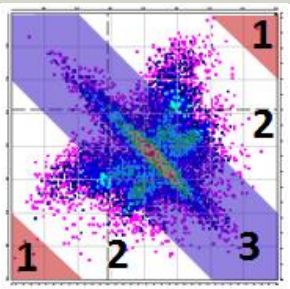
Block cycle test



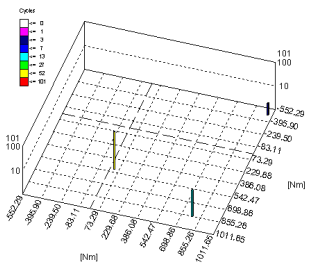
Rainflow matrix



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



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



Unrestricted © Siemens 2020

Agenda

Loads and damage

Load characterization

Customer correlation

Accelerated testing and analysis

Customer application case

Unrestricted © Siemens 2020

Application case Ford Otosan
Driving 1.2 million kilometers in 8 weeks

SIEMENS
Ingenuity for life

Accelerated durability tests for PVG and test rig

- 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

➡ **Target setting & Test schedule definition**

➡ Resulting in

- 6-8 week **test track schedule**
- 4 week accelerated **rig test scenario**

➡ Test acceleration of factor **100**

Siemens 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.

Unrestricted © Siemens 2020

Application case Ford Otosan
Project steps

SIEMENS
Ingenuity for life

Preparation

Loads definition
- Target vehicle
- Current usage (full & empty)

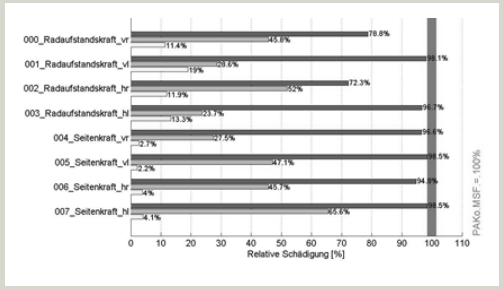
Route selection
- 16 routes with 140 sections in total
- = +/- 5.000 km

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 for 1 Mio km

Goal
- 10.000 km PVG Durability test

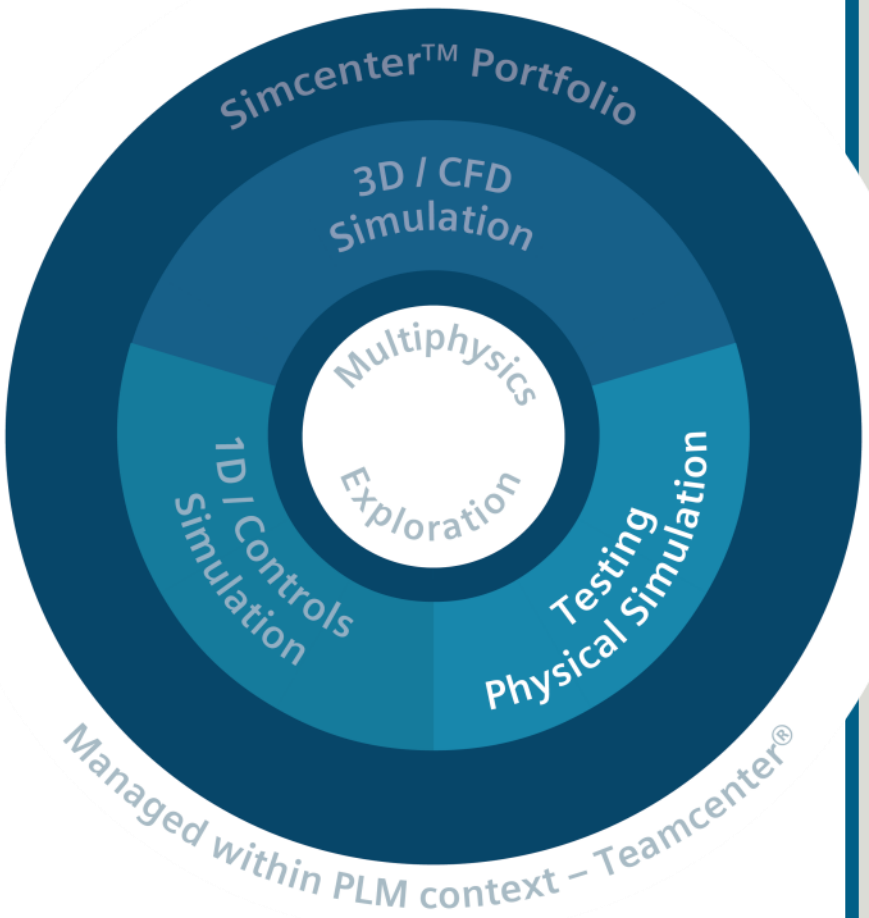
Validation

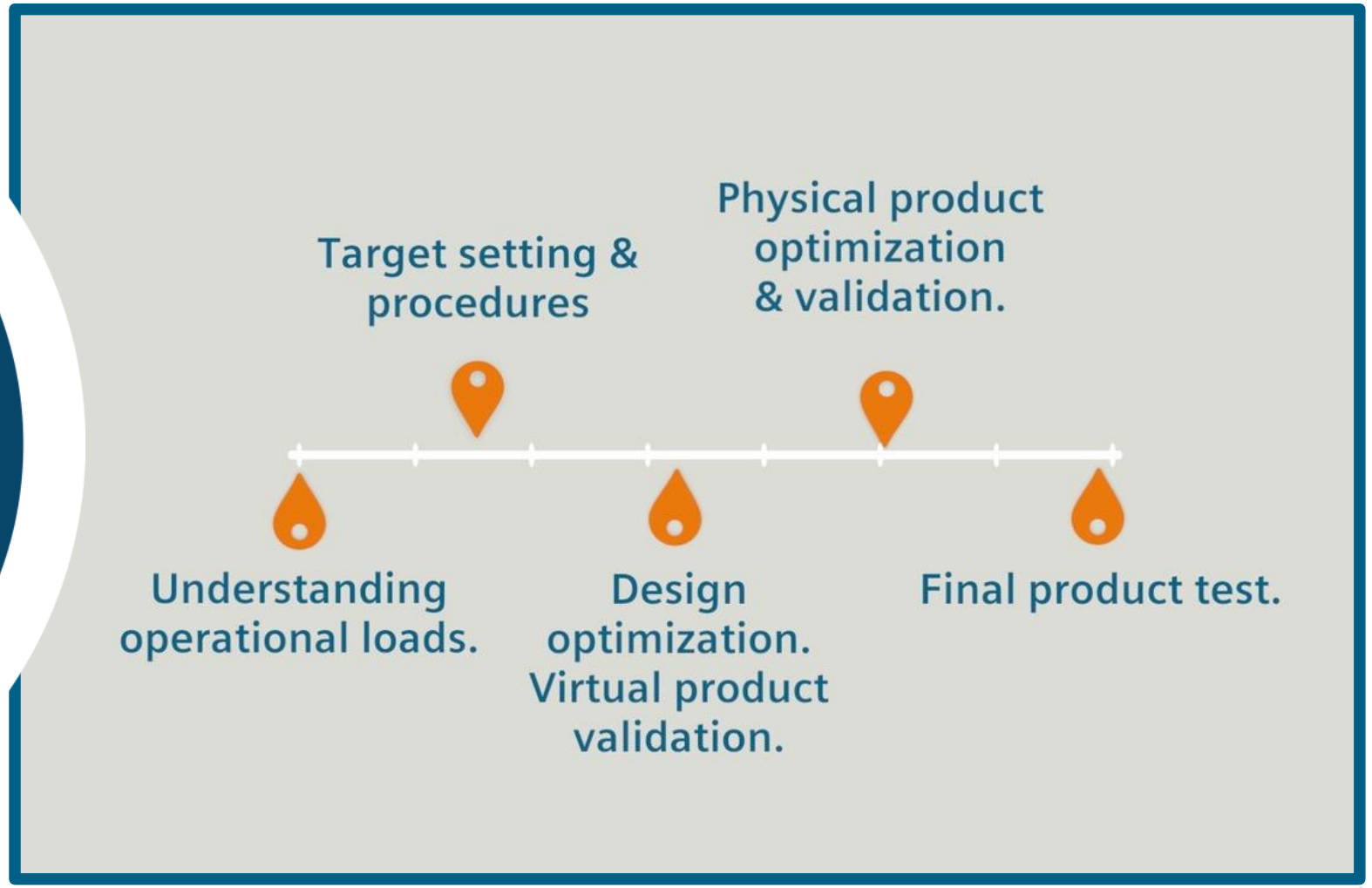
- PVG test
- 4-poster test of the cabin
- 4-poster virtual test of the cabin

Unrestricted © Siemens 2020

Simcenter durability solutions throughout the development process

SIEMENS
Ingenuity for life





Unrestricted © Siemens 2020

Thank you!
Want to know more?

SIEMENS
Ingenuity for life

Read more

Explore, share and learn

Watch videos

Contact the expert

Unrestricted © Siemens 2020