Reliability of Automotive Tier "X" Supplier: Lesson Learned from Early Failures

Agenda

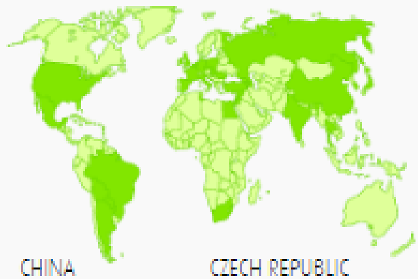
- Introduction
- Reliability of Tier “X” Suppliers
- Engine Cooling Fan System
- Case Study
  - Vibration & Endurance
  - Field Data & Root cause
  - Proactive approach
- Summary
- Questions

Company Name “Y”

“Y” is one of the world’s leading automotive suppliers

82,800
EMPLOYEES

OPERATING IN
30 COUNTRIES



ARGENTINA	BELGIUM	BRAZIL	CANADA	CHINA	CZECH REPUBLIC
EGYPT	FRANCE	GERMANY	HUNGARY	INDIA	INDONESIA
IRELAND	ITALY	JAPAN	MEXICO	MOROCCO	NETHERLANDS
NORWAY	POLAND	ROMANIA	RUSSIA	SOUTH AFRICA	SOUTH KOREA
SPAIN	THAILAND	TUNISIA	TURKEY	UNITED KINGDOM	UNITED STATES

134 PRODUCTION SITES

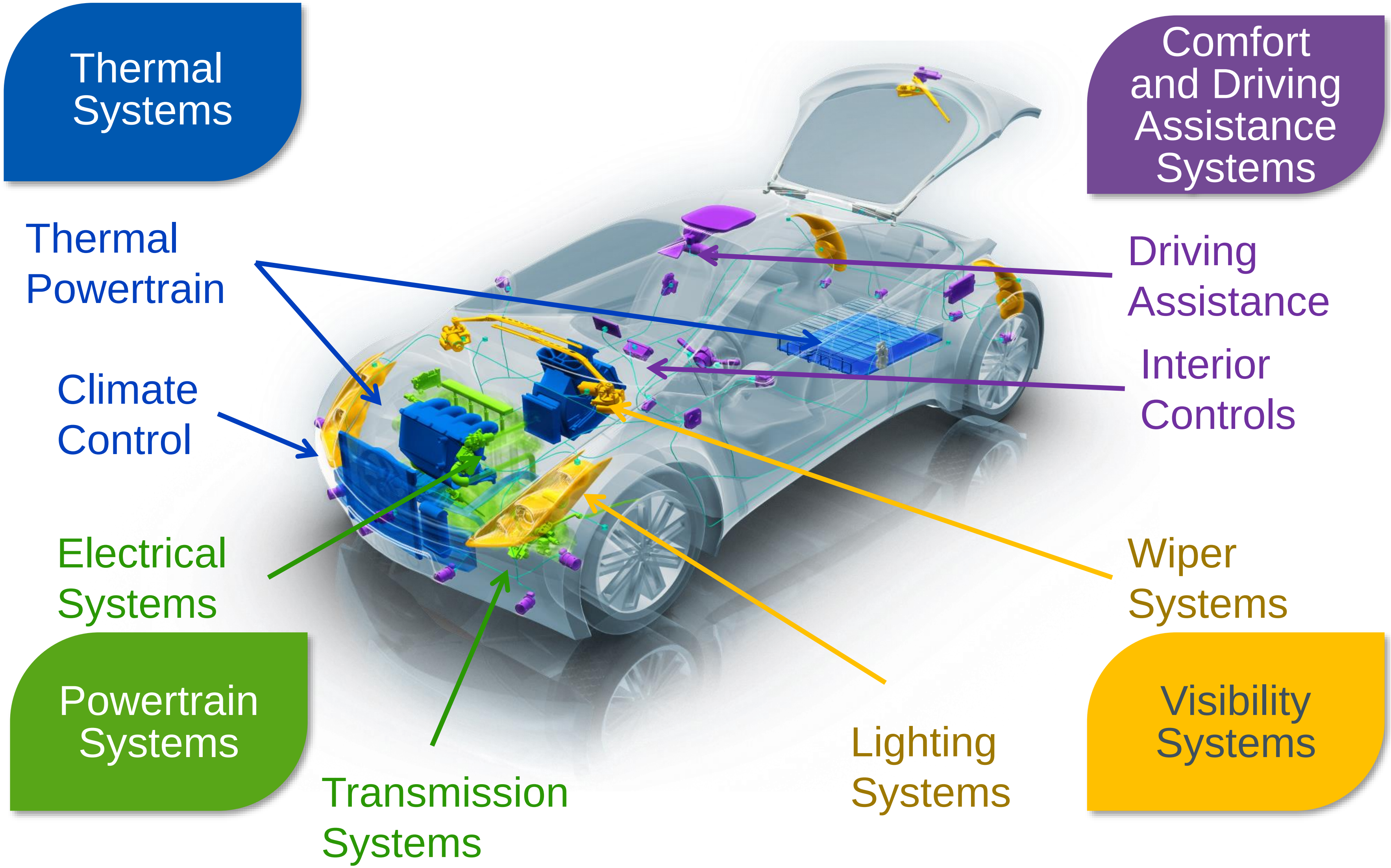
15 DISTRIBUTION PLATFORMS

17 RESEARCH CENTERS

35 DEVELOPMENT CENTERS

€14.5
BILLION IN SALES

"Y" activities

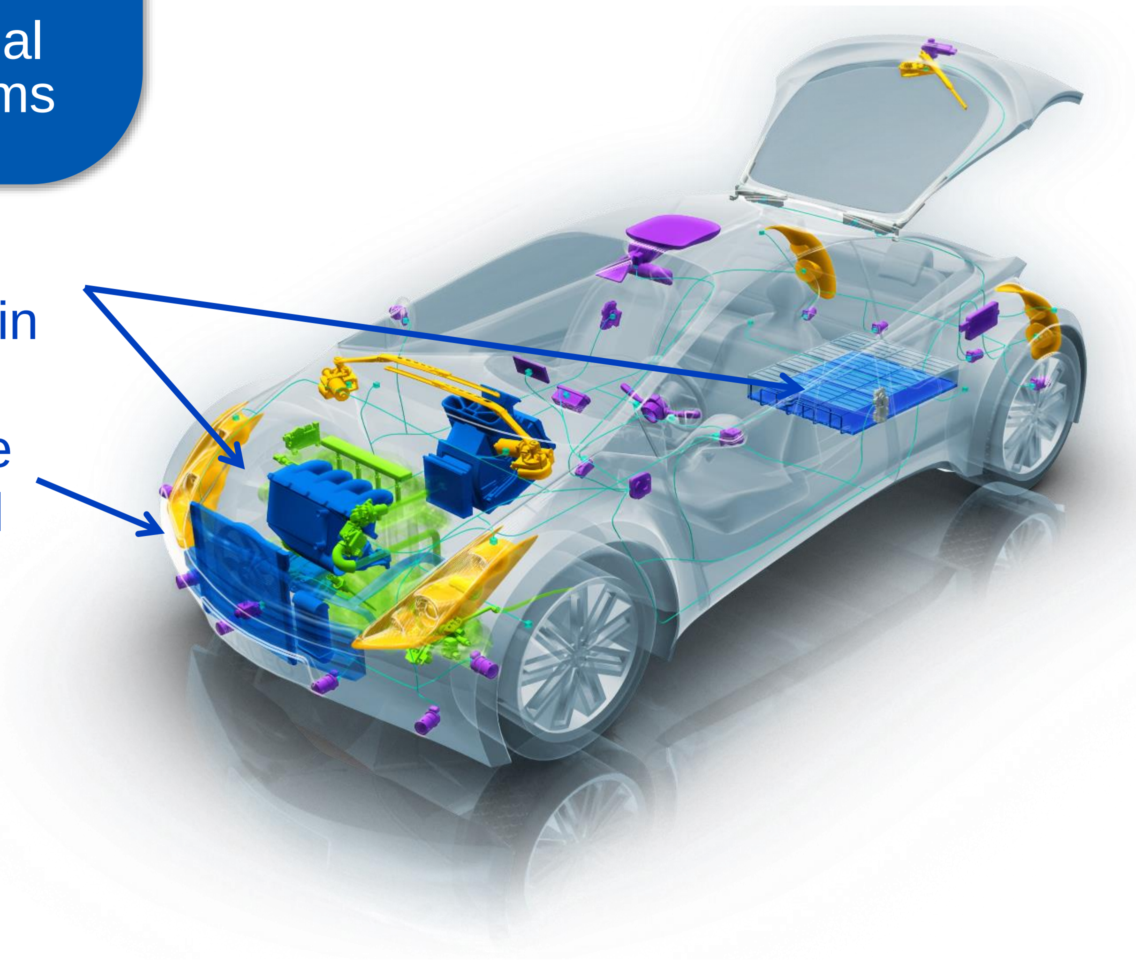


Thermal Systems (THS) activities

Thermal Systems

Thermal Powertrain

Climate Control



Climate Control Compressor

Thermal Front End

Introduction
Automotive market trends

- *Reliability as leading purchase reason*

- *Global scale suppliers*

- *Cost saving – efficiency – productivity*

- *Consequences on product/system reliability?*

Supplier Selection

Process Standardized at Group level

- *Supplier analysis (robustness)*
- *Quality*
- *Financial health*
- *Supplier Quality Assurance*

- *Supplied product technical evaluation*
  - *Business group level*
  - *Product line R&D manager*
  - *Project manager*
  - *Cost / Efficiency / Quality*

Tier “X” Suppliers & Reliability

THS reliability activities

- *Raw Materials*

  (plastic, rubbers, metals…)

  - *Classic* (Young Module, UTS)
  - *New* (Fatigue life curves)
  - *Innovative* (hardening, *elasto-viscoplastic properties, expert material card)*

- *Software*

  - *Tests of new versions (criteria)*
  - *Comparative analysis of results (Round Robin)*
  - *Close relation with suppliers (and OEMs)*

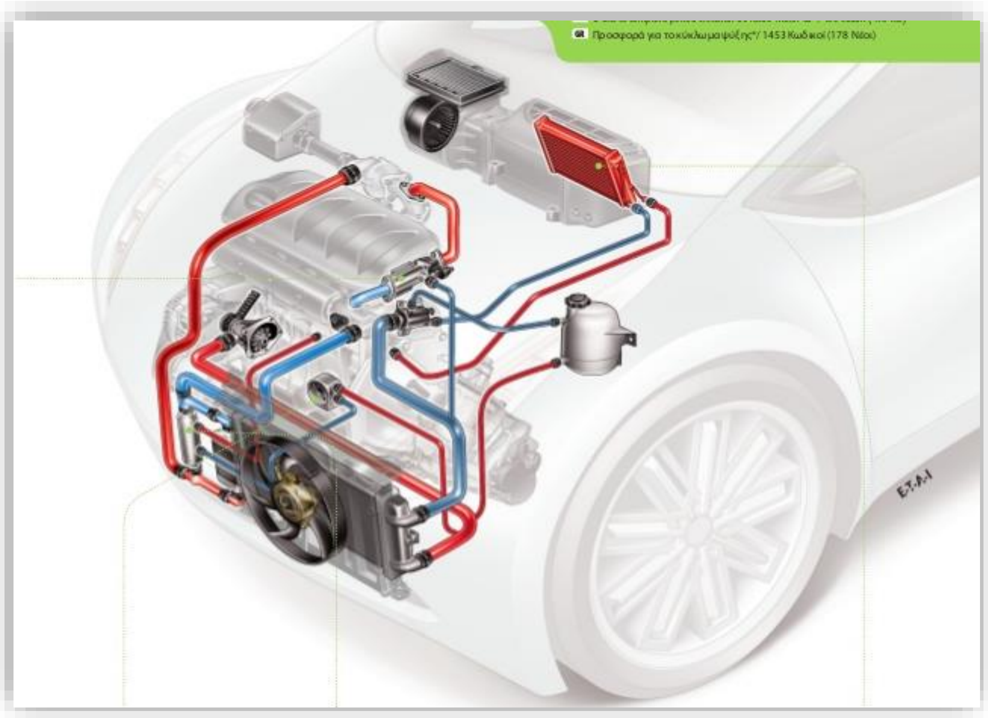
- *Sub components*
- *Sub systems*

  - *Reliability assessment*
  - *Subcomponent vs. system*
  - *Internal testing procedure*
  - *Valeo standard reliability targets*

Engine Cooling Fan System

Scope and functionality

- To ensure a sufficient air flow through the heat exchangers for an adequate thermal exchange
- To maintain a constant optimal temperature of the engine / AC Loop
- *High Efficiency Fan System to Lower Electrical consumption*



ENGINE

Cooling needs :

To improve the thermal exchanges in extreme cases:

- High load of the motor
- Low water rate / load
- High ambient temperature

Air conditioning needs:

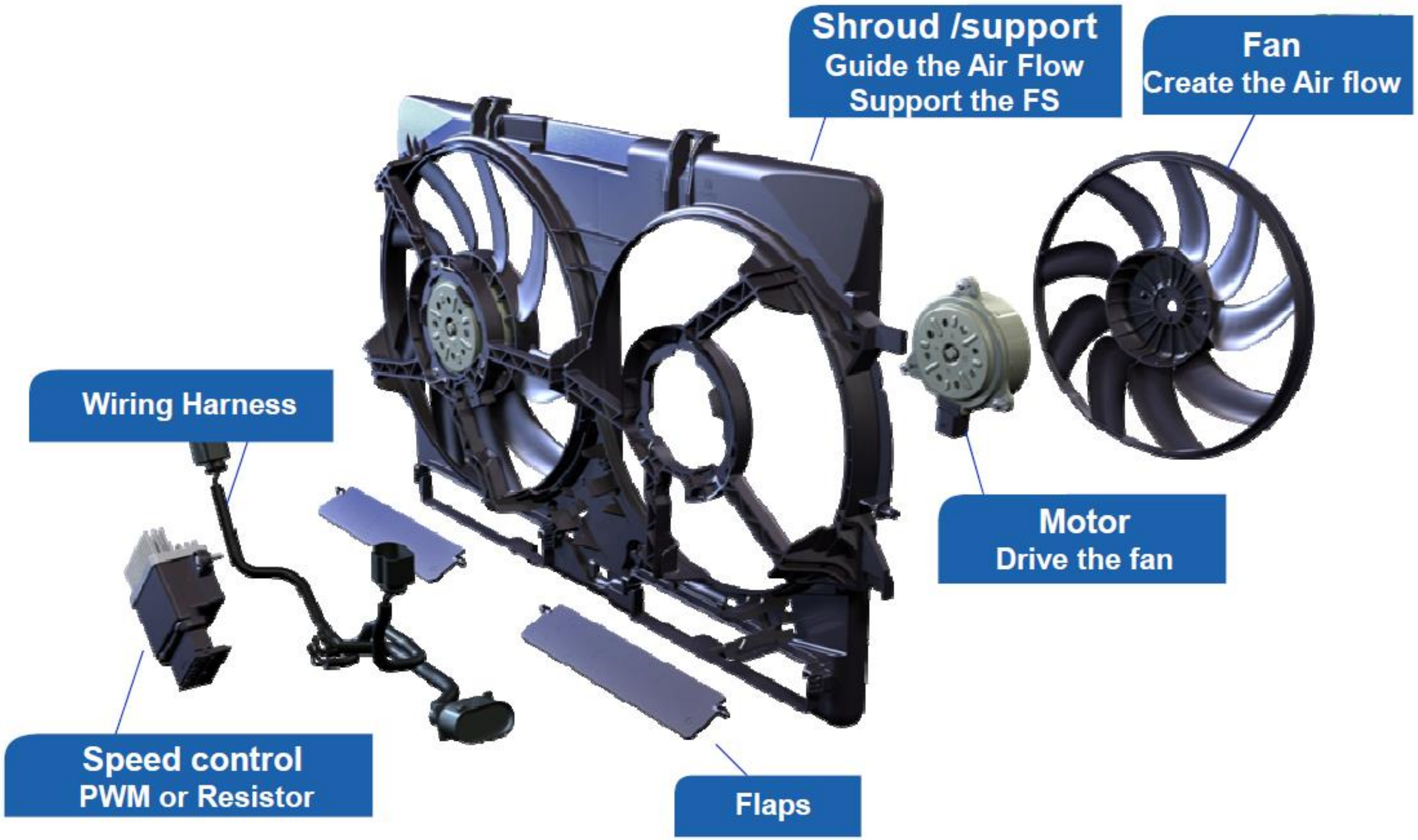
To ensure permanently a sufficient air flow to allow condensation:

- Relatively constant need
- Variations mainly associated with the ambient temperature

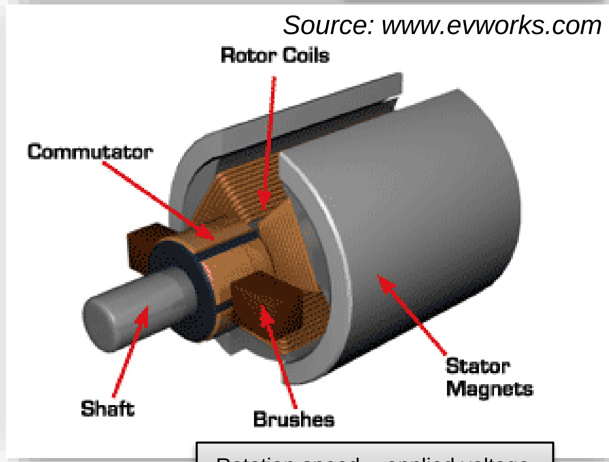
Usual sizing points : **slow running**

CABIN

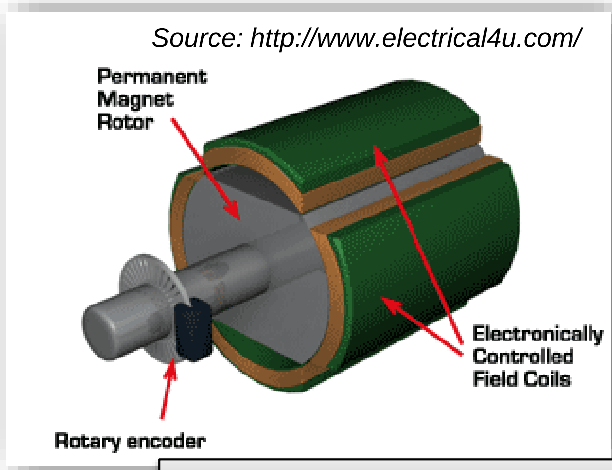
Engine Cooling Fan System
Sub components



Brushed



Rotation speed α applied voltage



Rotation speed α AC frequency and voltage

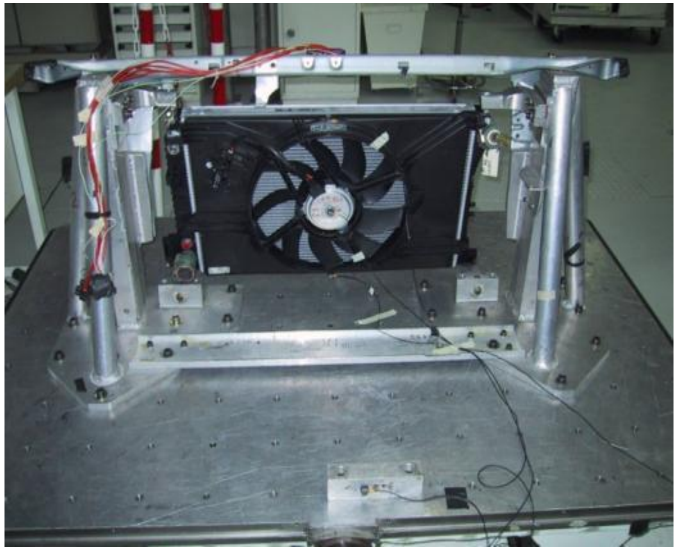
Brushless

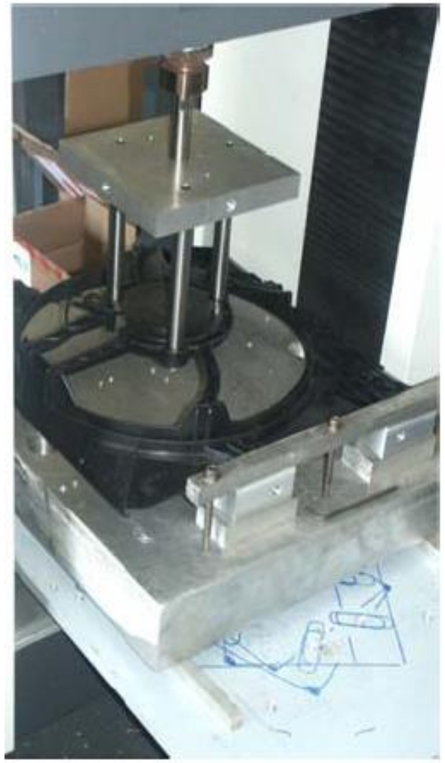
Engine cooling fan system

Product Validation Plan (OEMs specifications)

- Mechanical Endurance (*vibration* + *rotation*)
- Electrical Endurance (*rotation only*)
- Aerolic and Electrical performances
- Qualification tests

✓ Mechanical stresses
✓ Operating Voltage
✓ Electromagnetic compatibility (EMC)
✓ Acoustic and vibrations (NVH)
✓ Water spray and corrosion



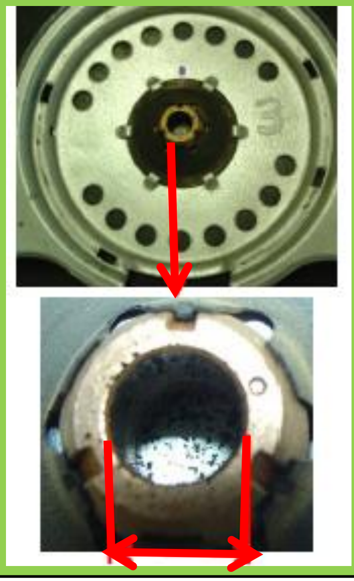


Case Study – Field early failures

Framework

- Nomination of new supplier of brushed electric motors
- In field failures of smaller system (***lower power***, ***small car***, ***small volumes***)

OK part



radius

NOK part

Noise and function lost

Not safety related

Case Study – Procedure

- Problem solving

Part I (experimental)

- Reproduction of the failure mode

Part II (operational)

- Field data analysis (risk assessment, proposed solutions)

Part III (predictive)

- Pro-active reliability investigation for bigger system (*higher power, bigger production volumes*)

Part I - Vibrations and Motor endurance

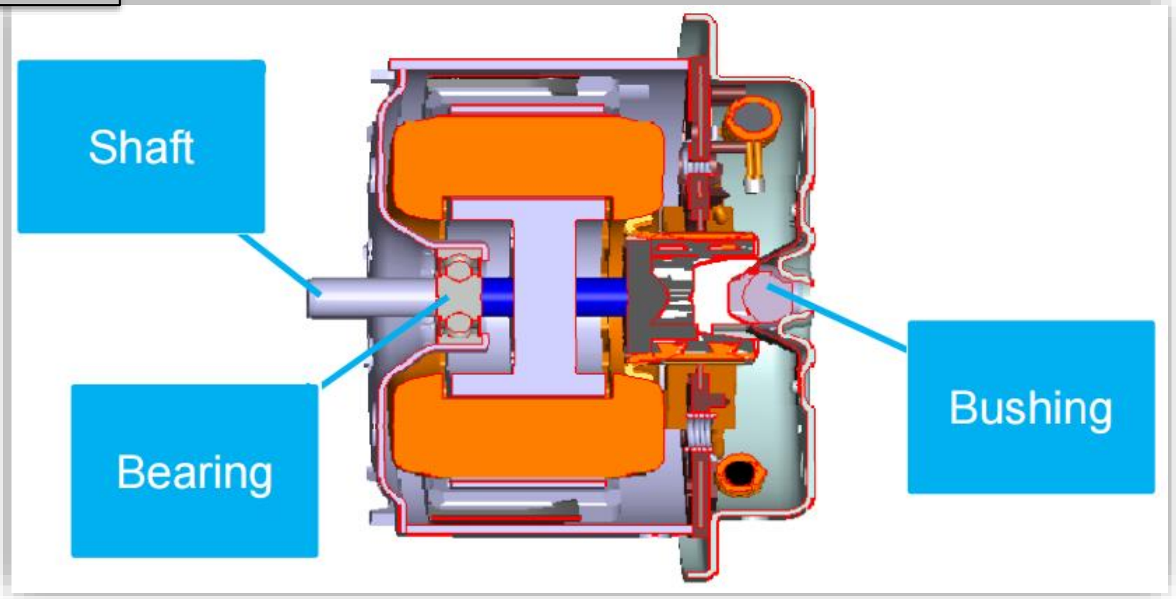
Reproduction of the failure mode:

- Bushes wear – axial play

Intense vehicle measurements campaign (wind tunnel, road data)

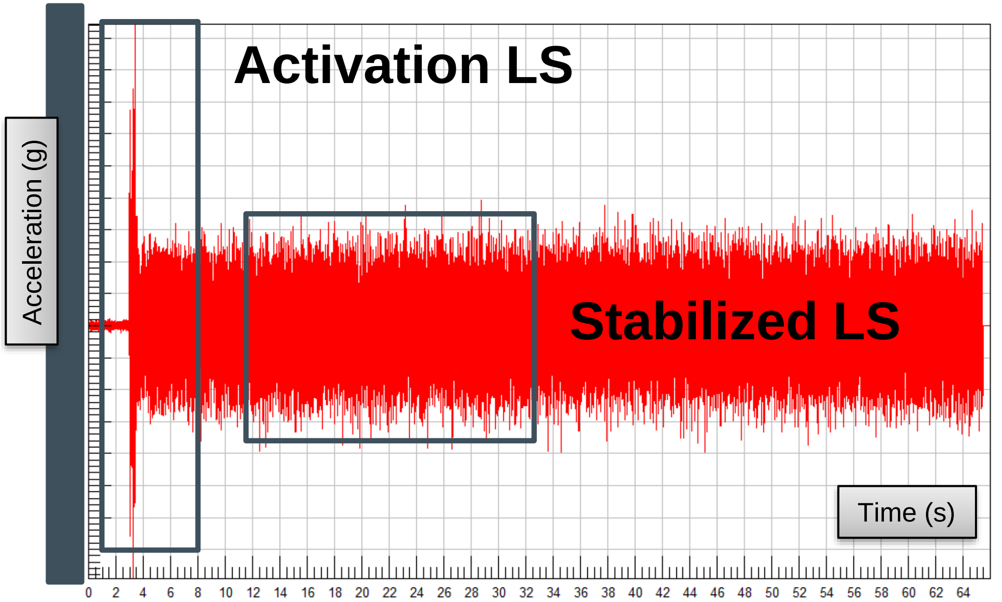
Failure mode reproduced on serial parts

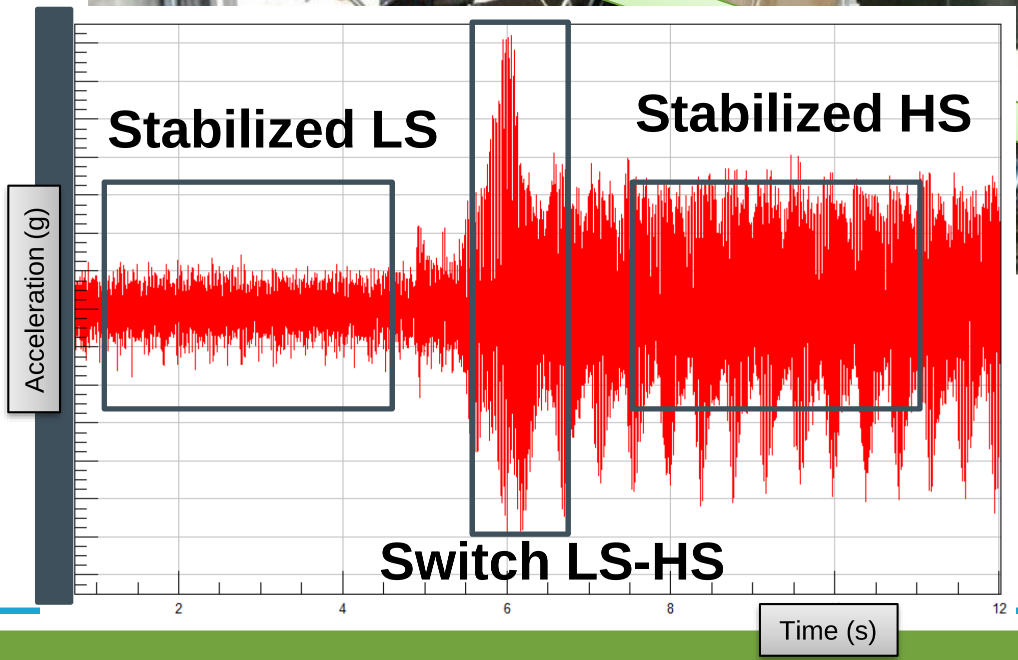
Focus on electrical endurance (roation only, no vibration)



- Vibration damage accumulated during the test?
- Jig geometry to blame?

Endurance test





Output => vibration jig (right and left)

Are the vibration of the jig induced by fan rotation inducing any significant fatigue damage that can provoke the Failure of the DC motor?

Input => rotating fan only (no table excitation)

HS: high speed
LS: low speed
HS-LS activation

OEM mission profile

Jig fatigue damage

- Generation of the endurance cycle equivalent PSD (on jig)

Start-up → FDS_1 — R1 repeats

Stabilized HS → FDS_2 — R2 repeats

Switch → FDS_3 — R3 repeats

Stabilized LS → FDS_4 — R4 repeats

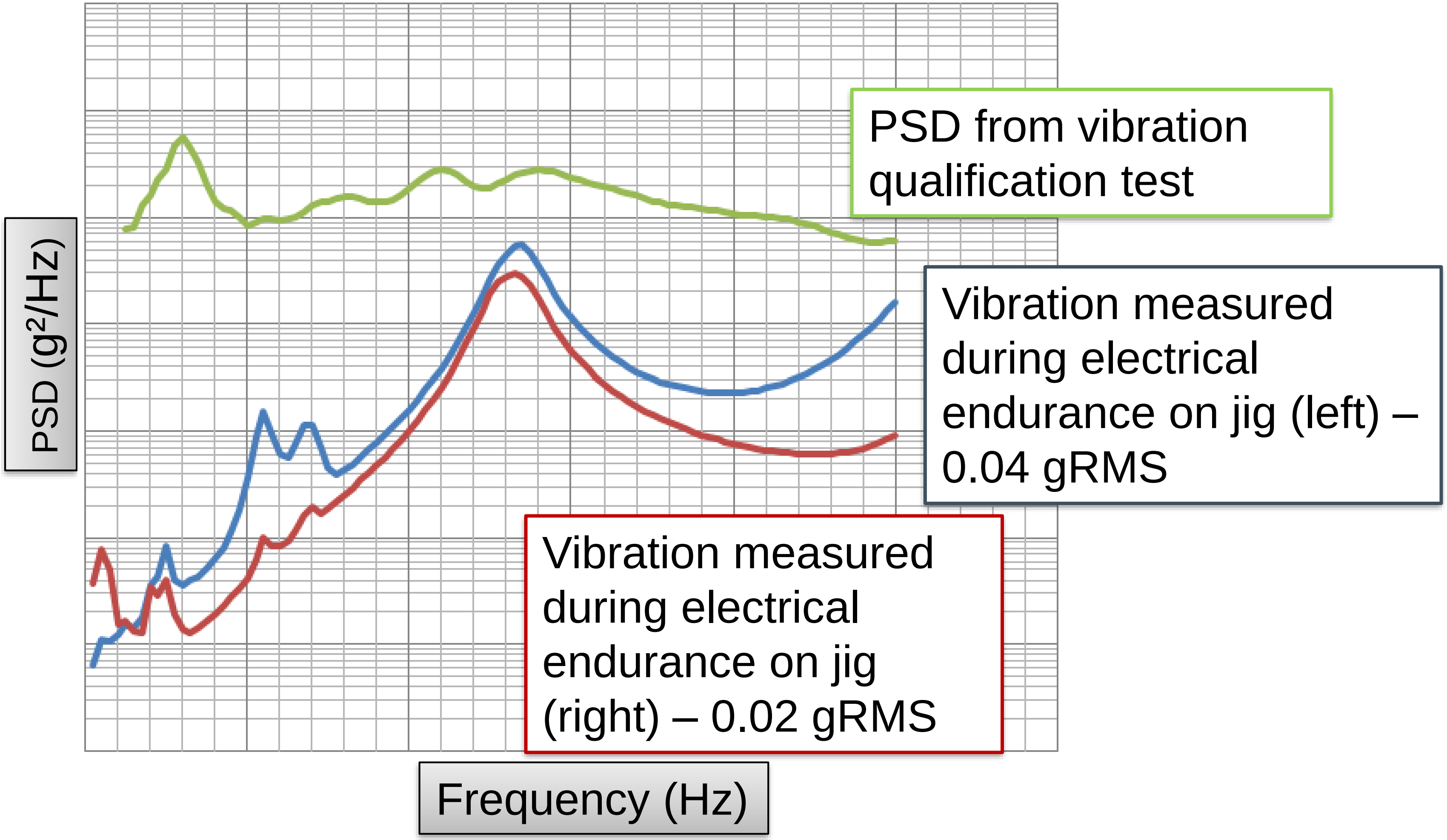
Sum of the FDSs of all events

Equivalent PSD (iso-hours)

Fatigue Damage Spectrum | Mission Profile | Total FDS | Test Synthesis

Jig fatigue damage – Results Z axis

- Jig vibrations are not damaging (5 – 100 Hz)



- Root cause analysis

Search for the Root Cause

- Focus on failed part

PDCA – FTA summary

<u>User effect: problem identification</u>

- Noisy/degraded part

<u>Failure mode considered</u>

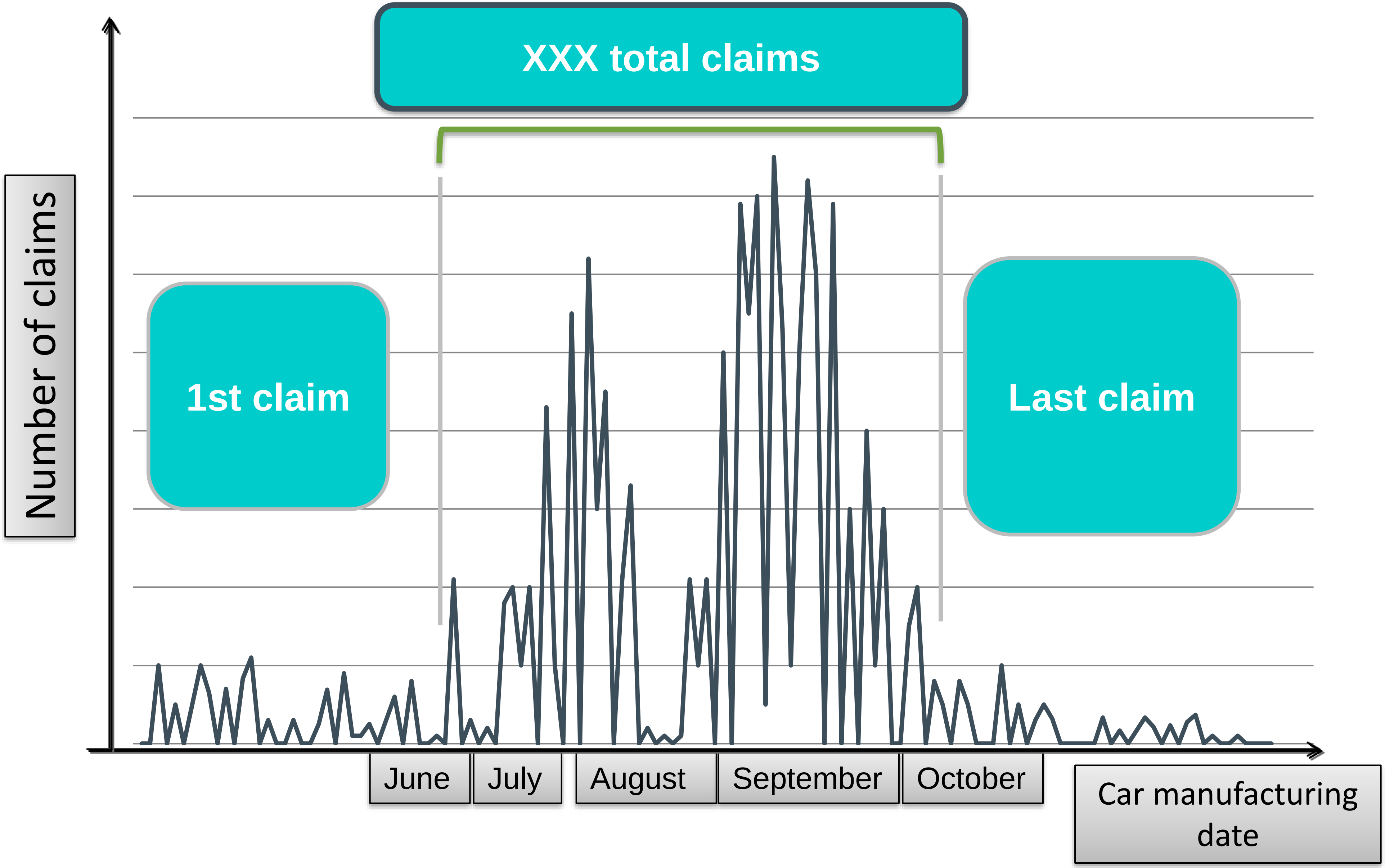
- Bushing wear out

Expected *beta* known from experience ($\beta > 1.5$)

<u>Root cause</u>

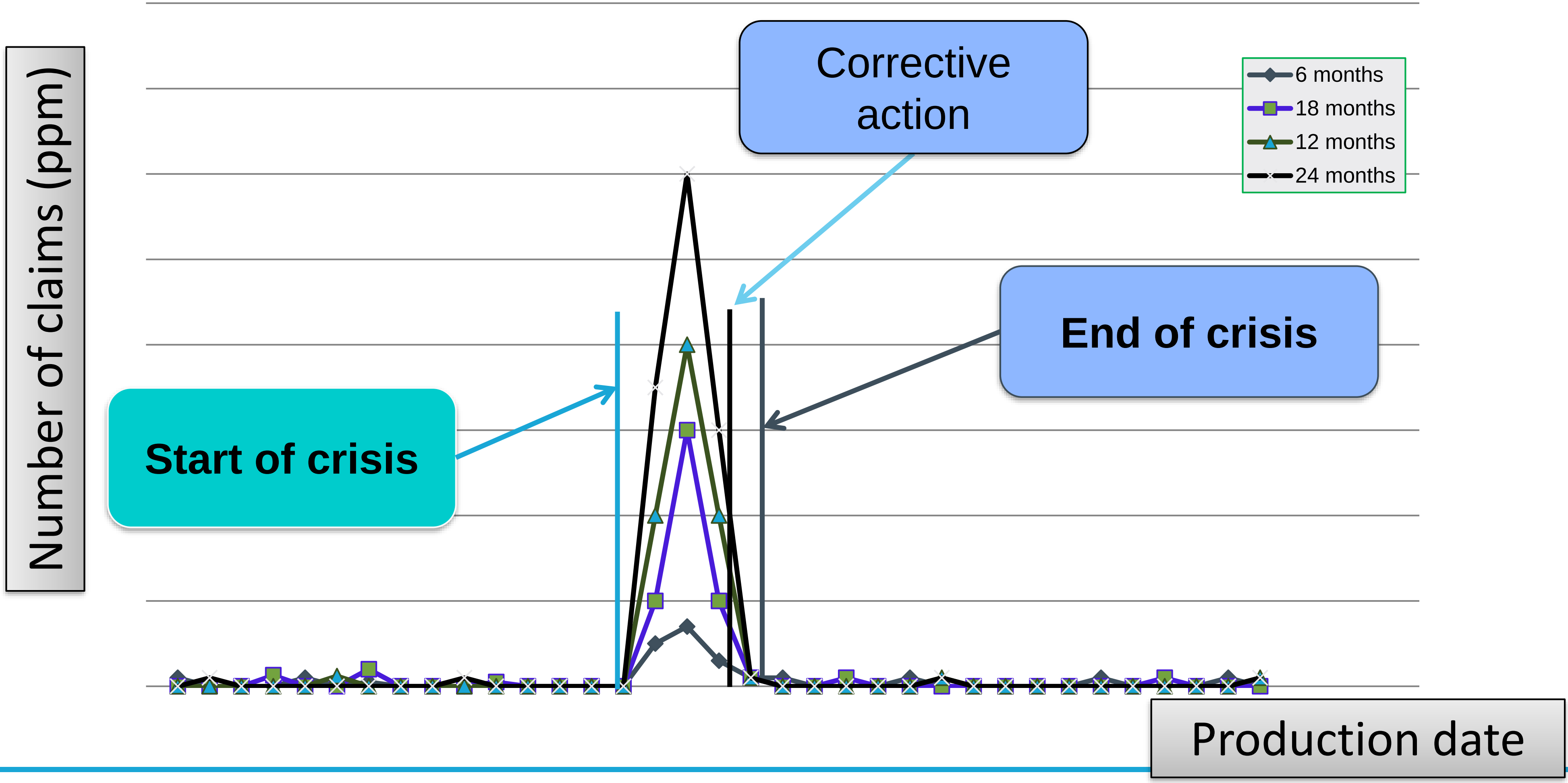
➔ Unsuitable lubrication settings
➔ High ambient temperature
➔ Source: DC motor

Part II - Field Data Example



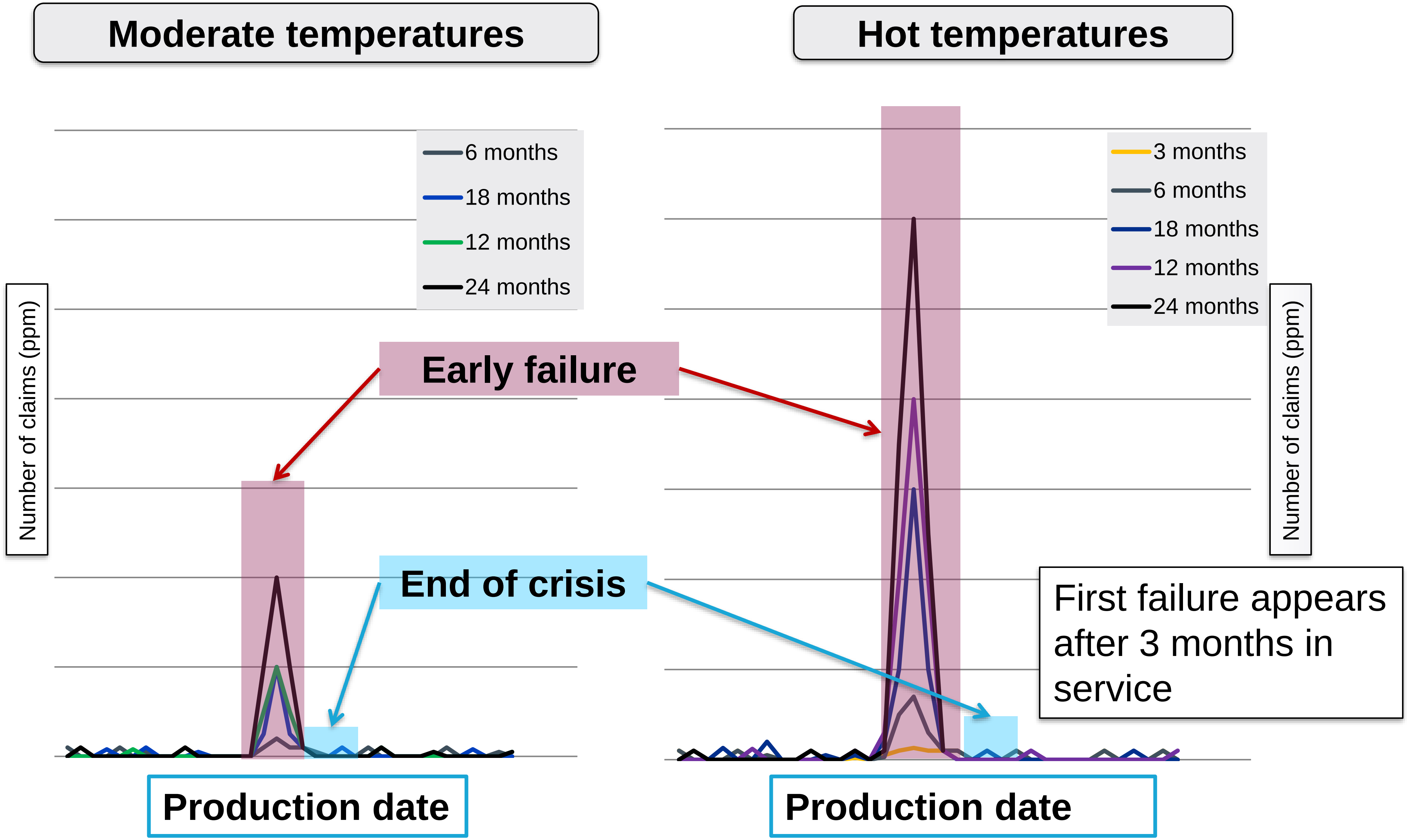
Resume of crisis

- Issued from Isochrone curve (Hot countries)
  - Crisis period: from June to October



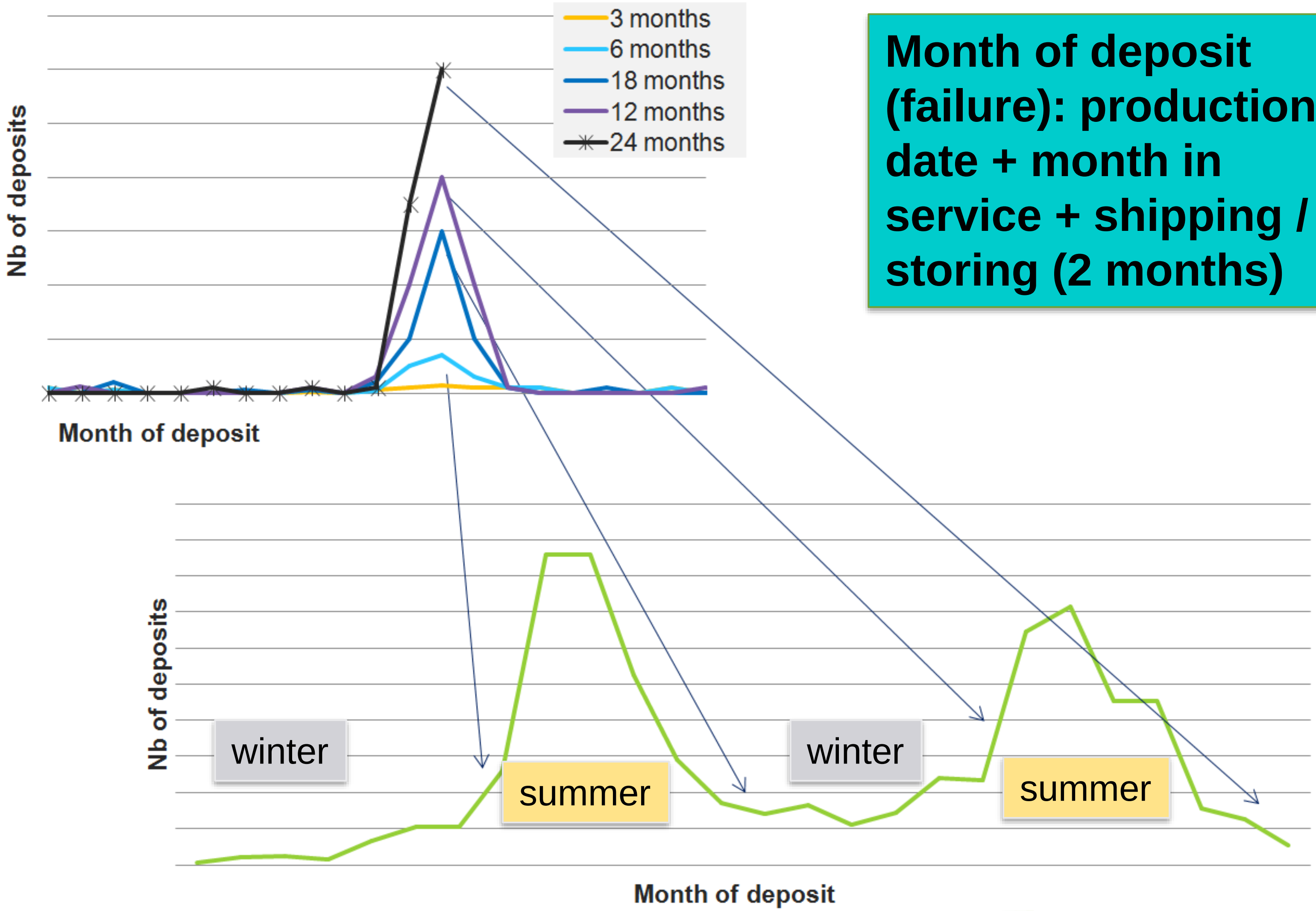
Part II - Field Data
Isochrones curves from OEM

Part II



Isochrones curves
Seasonal effect

- Impact on isochrones curves

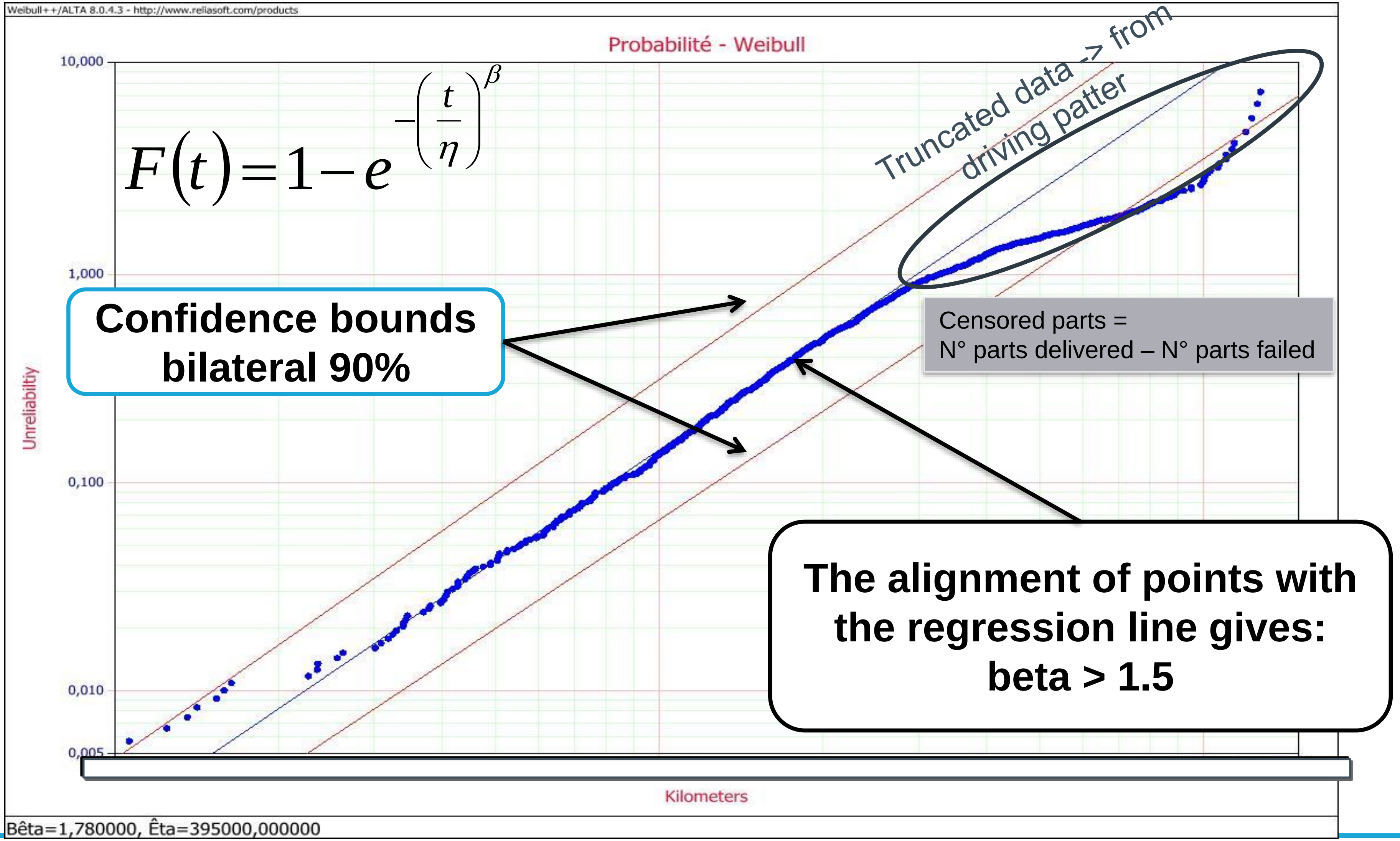


Month of deposit (failure): production date + month in service + shipping / storing (2 months)

Part II

Field Data

- Weibull regression line by mileage



Field Data Forecasts

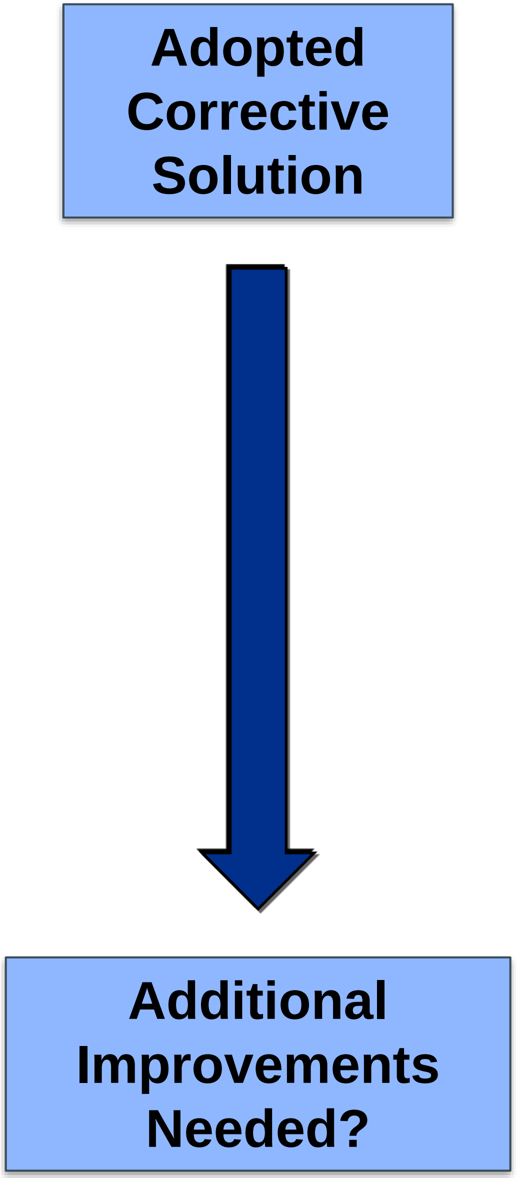
Part II

- Scenarios (for worldwide driving pattern)

- 100 000 Km (warranty period)
  - 2 years 100 000 km
  - 3 years 100 000 km

- Failure forecast
- 150 000 Km (mid life term) => which failure rate expected?
- 240 000 Km (end of life term) => estimation for recall (none/total/partial)

Field Data
Need of new corrective action?



State of the art:

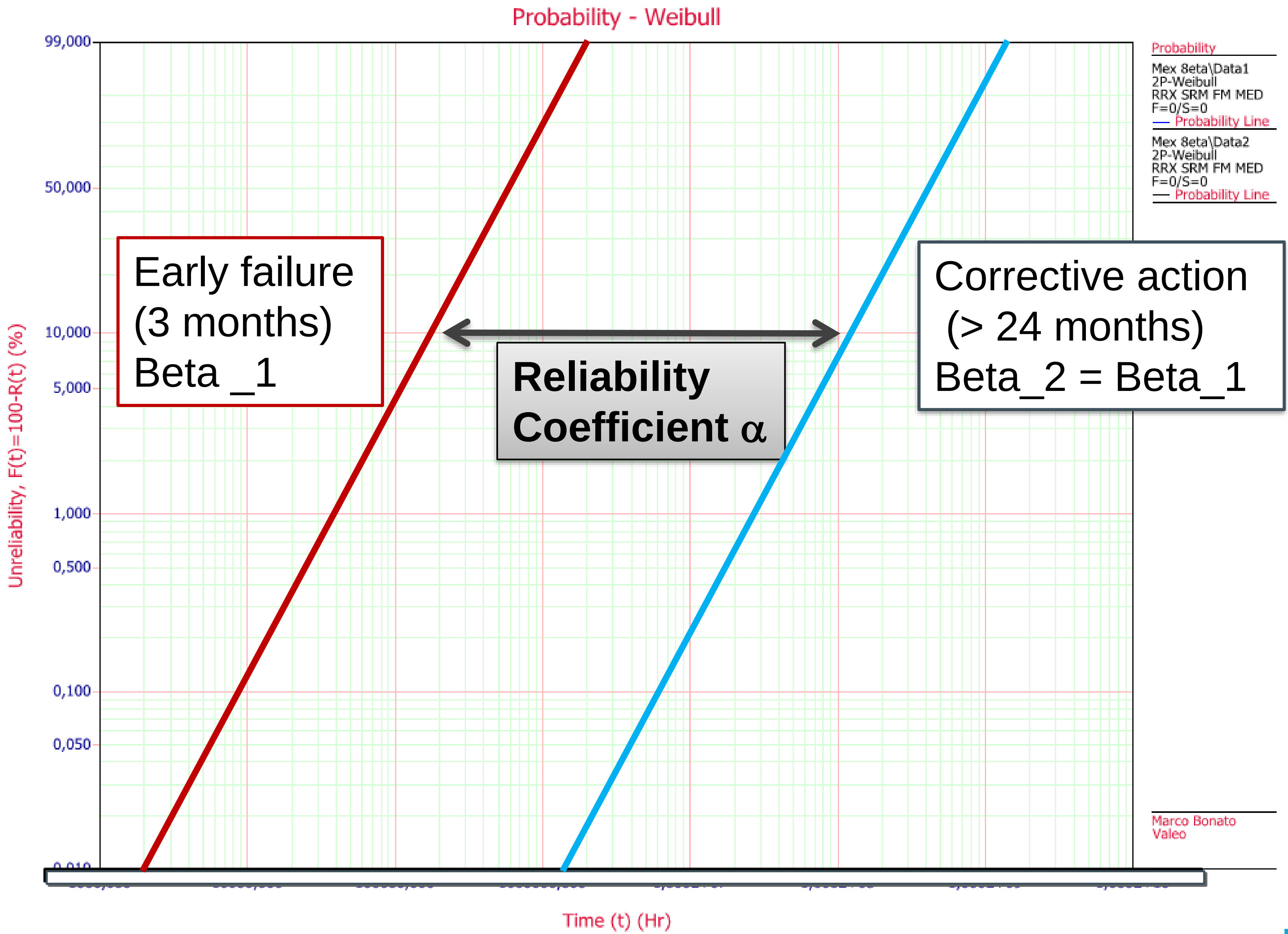
- Initial early failures appear after 3 months in service
- After process adjustment, data available for returned part after 24 months of in-service life
- Failure mode unknown => probably « random failure » with secondary root causes
- **Is the reliability OK or need to new upgraded solution?**

Prediction procedure:

1. For each country, we know the Weibull parameters (beta and eta in Km) and the driving pattern for small cars
2. Estimation were based on stress-strength method (stress is based on Valeo Standard driving pattern for small cars worldwide)
3. With a conservative approach, we assume that DC motor now in service
    - Will fail with the same rate as before (same beta)
    - It will last longer (>24 month instead of 3 months)

Reliability forecast
Scale factor method

Part II

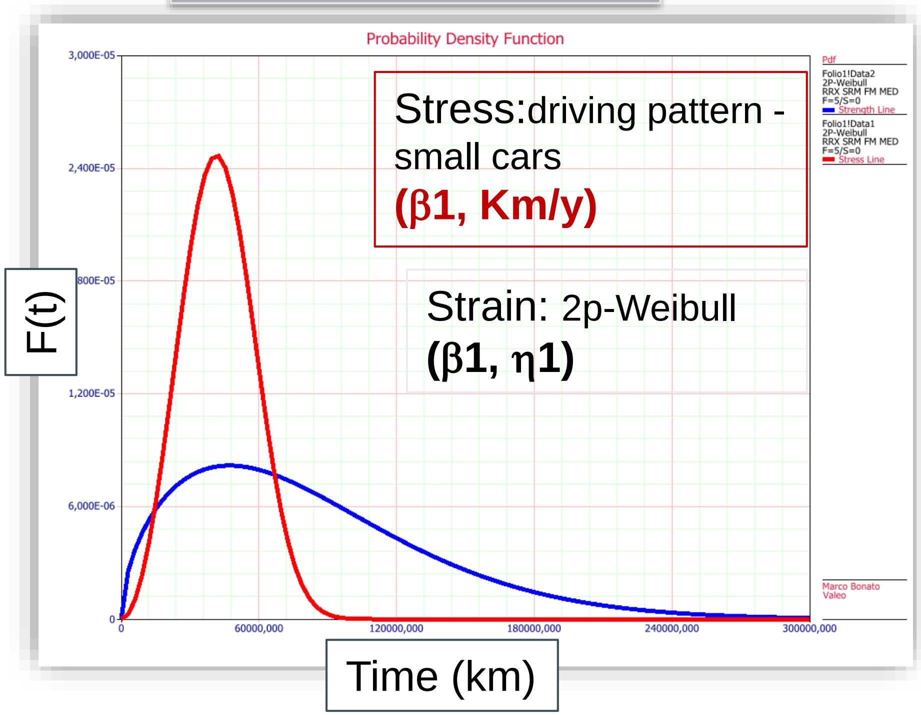


Reliability forecast

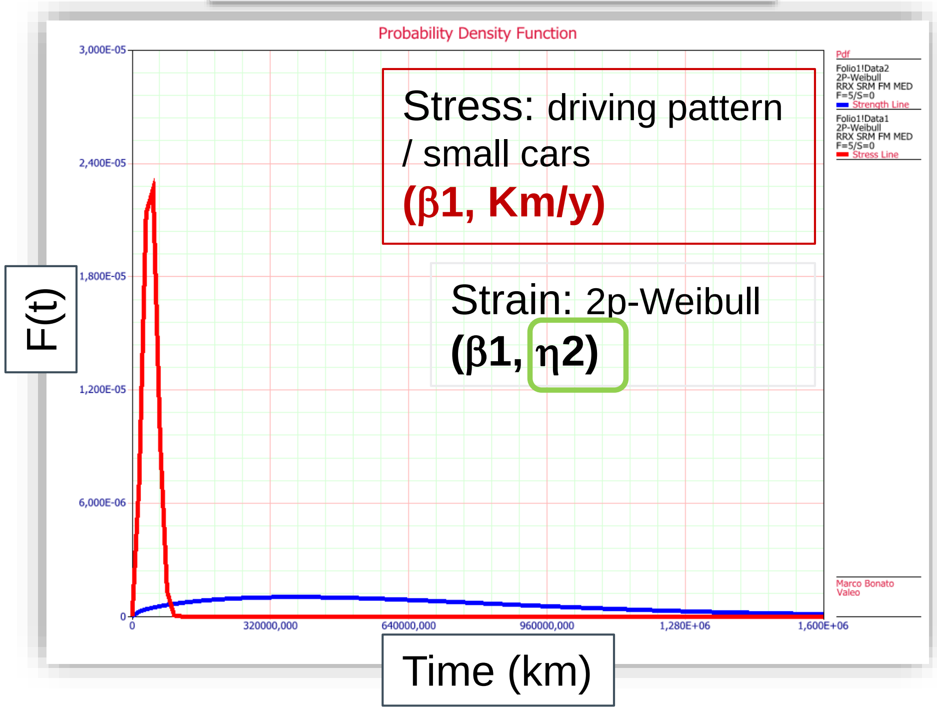
Weibull parametric analysis (“worst” hot country)

Part II

First failure at 3 months



First failure after 24 months



3 years
100 000 Km

Unreliability: 26.9%

Worst case scenario

$\eta 2 = \alpha * \eta 1$

3 years
100 000 Km

Unreliability :1.3%

Results based on conservative assumptions

Part II

Reliability forecast - Results

Early failure

Countries	Unreliability			Warranty commitment
	Beta	Eta	150000km	3 years 100000km
[illegible] #1	1,55	[illegible] km	[illegible]	[illegible]
[illegible]	1,70	[illegible] km	[illegible]	[illegible]
[illegible]	1,80	[illegible] km	[illegible]	[illegible]
[illegible]	2,10	[illegible] km	[illegible]	[illegible]
[illegible]	2,05	[illegible] km	[illegible]	[illegible]
[illegible]	2,30	[illegible] km	[illegible]	[illegible]
[illegible]	1,95	[illegible] km	[illegible]	[illegible]
[illegible]	1,70	[illegible] km	[illegible]	[illegible]
[illegible]	1,95	[illegible] km	[illegible]	[illegible]
Italy	2,35	[illegible] km	[illegible]	[illegible]
[illegible]	1,50	[illegible] km	[illegible]	[illegible]
[illegible]	1,60	[illegible] km	[illegible]	[illegible]
[illegible]	1,60	[illegible] km	[illegible]	[illegible]

Failure %

Driving pattern tailored to each country

Eta * α times

After corrective action

Countries	Warranty Commitment	Mid Life	
	3 years 100 000 Km	5 years 150 000 Km	5 years unlimited Km
[illegible]	1,26%	[illegible]	[illegible]
[illegible]	0,55%	[illegible]	[illegible]
[illegible]	0,61%	[illegible]	[illegible]
[illegible]	0,26%	[illegible]	[illegible]
[illegible]	0,18%	[illegible]	[illegible]
[illegible]	0,12%	[illegible]	[illegible]
[illegible]	0,08%	[illegible]	[illegible]
[illegible]	0,13%	[illegible]	[illegible]
[illegible]	0,08%	[illegible]	[illegible]
[illegible]	0,03%	[illegible]	[illegible]
[illegible]	0,06%	[illegible]	[illegible]
[illegible]	0,06%	[illegible]	[illegible]
[illegible]	0,02%	[illegible]	[illegible]

Failure %

Part III: Proactive Reliability

Wear out of brushes

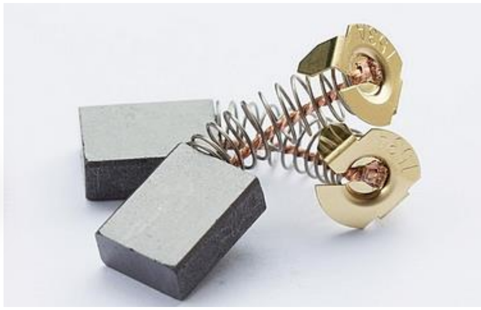
Mounted component

Early field failures – issue solved

Component under development

Proactive reliability study

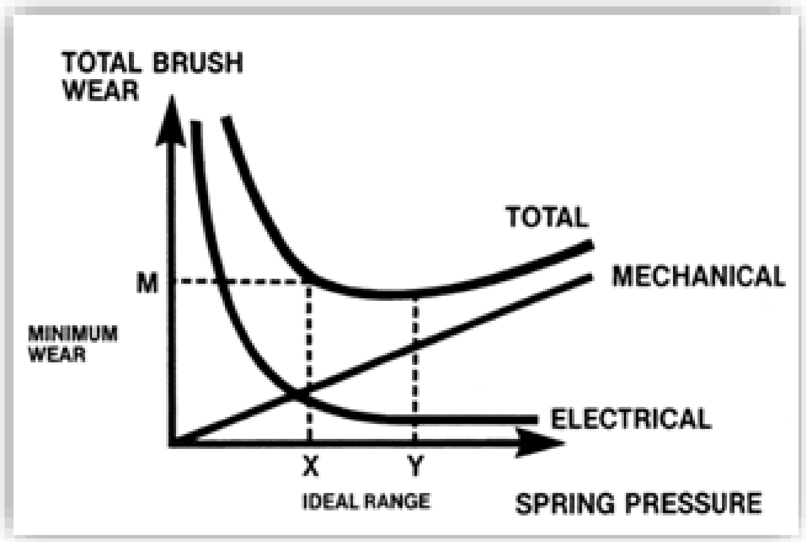
Internal Research Project

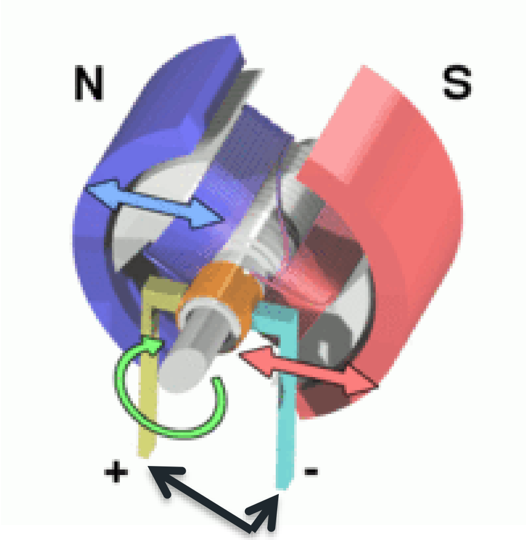


Reliability of brushes wear out

Brushes Degradation Analysis Experiments and Methods

- Accelerated destructive degradation tests
- Preliminary test carried out at full speed
- Destructive analysis
- Decision making based on small sample size
- Influence of the temperature?





brushes

Brushes Degradation Analysis
Validation of the motor design

Part III

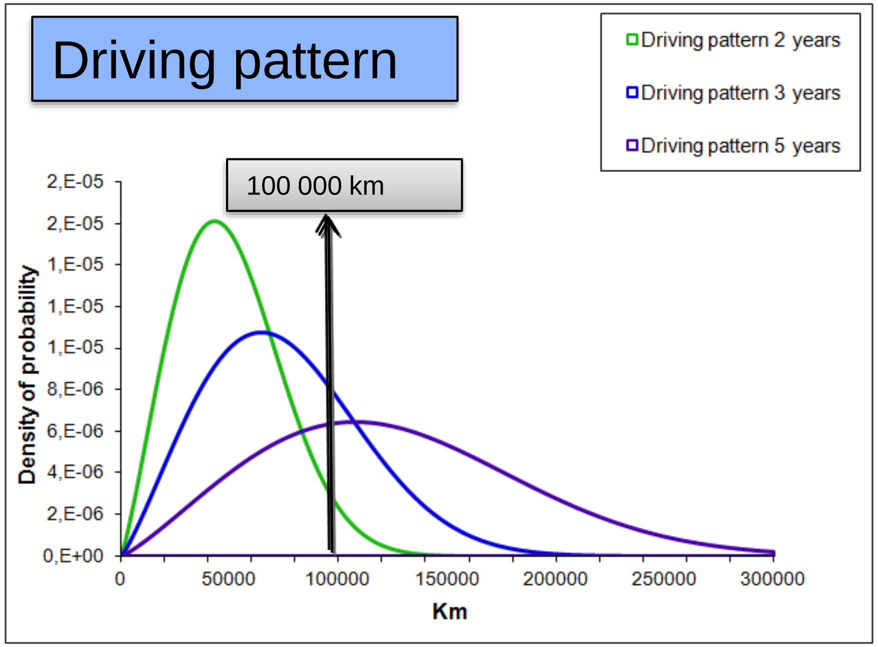
- Correlation with validation test?

Criteria: reliability of brushes wear our related to:

Total mission profile 15 years, 240 000 km	Warranty commitment 3 years, 100 000 km	Warranty extension? 5 years, 100 000 km

- **Stress-strength approach** based on test/simulation results (*beta and eta of brush duration*) and field analysis/driving patterns

Driving pattern

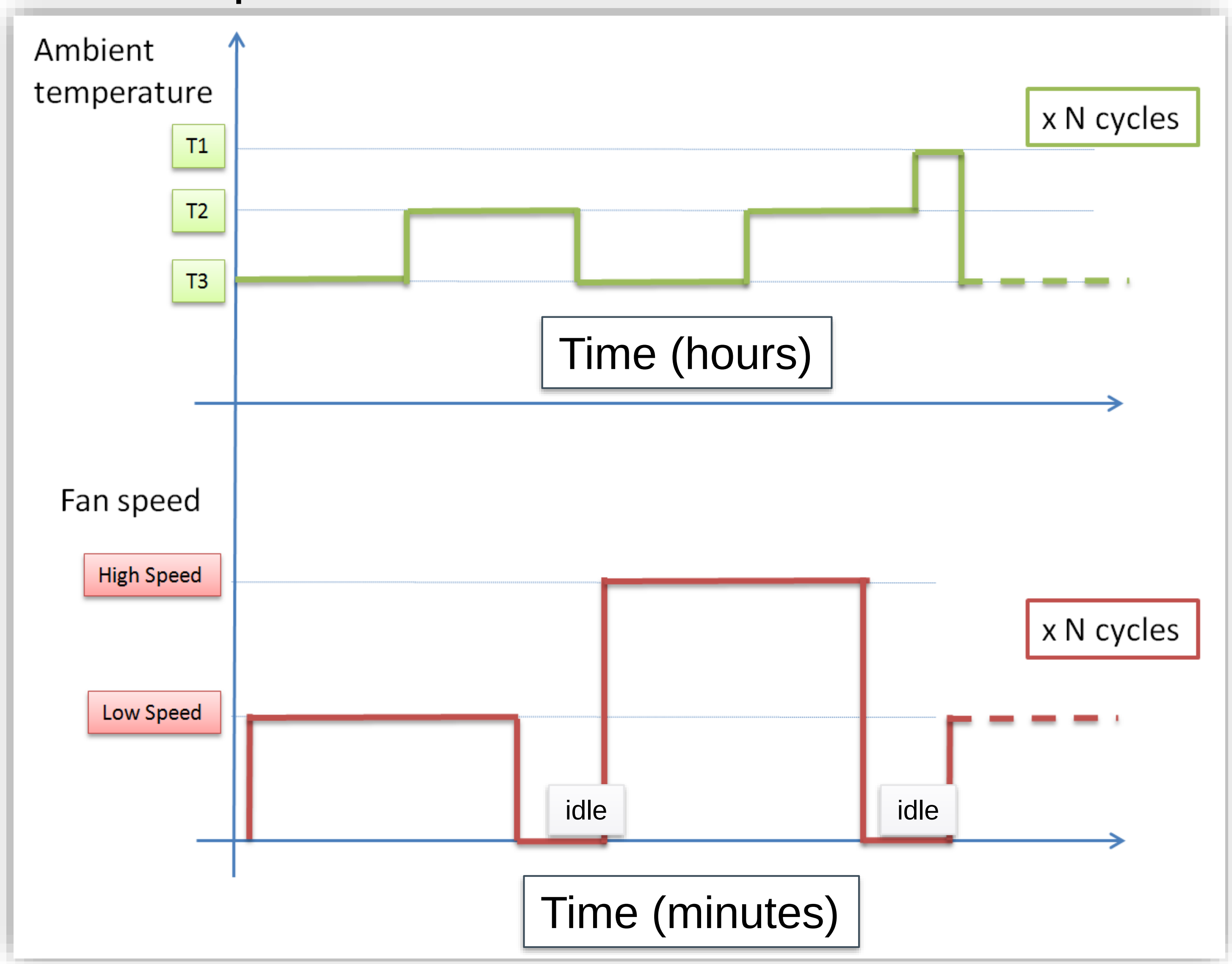


Need to built a degradation model to estimate the reliability of the DC motor brushes

Part III

Brushes Degradation Analysis

- Customer specification – electrical endurance

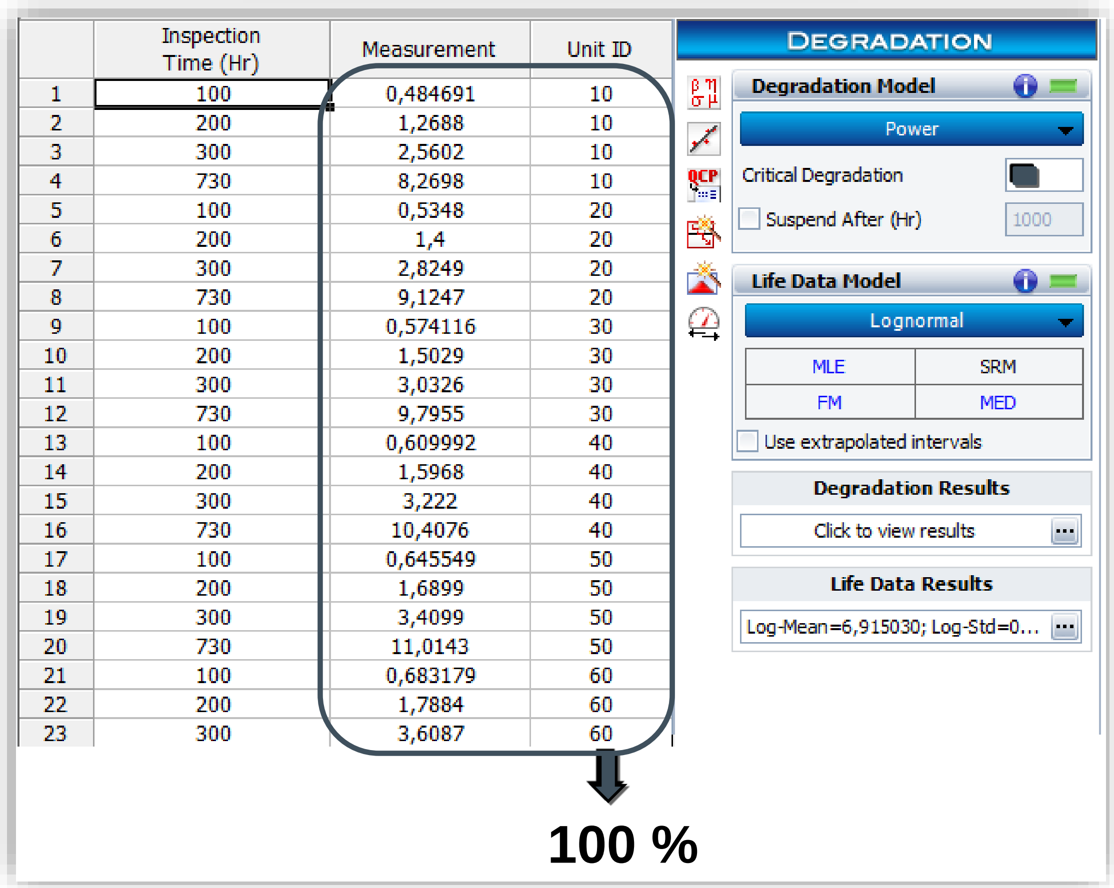


Brushes Degradation Analysis
Bench tests

Part III

- Full speed, underhood temperature
- Destructive inspection of 1 sample at 100 / 200 / 300 / 730 hours
- 4 brushes motor ➔ 4 points per inspection
- Each inspection is fitted to the lognormal or normal distribution
- Various percentiles are calculated for the obtained distributions
- Fit of the degradation model (**power**) to the degradation values for each individual percentage of the distribution

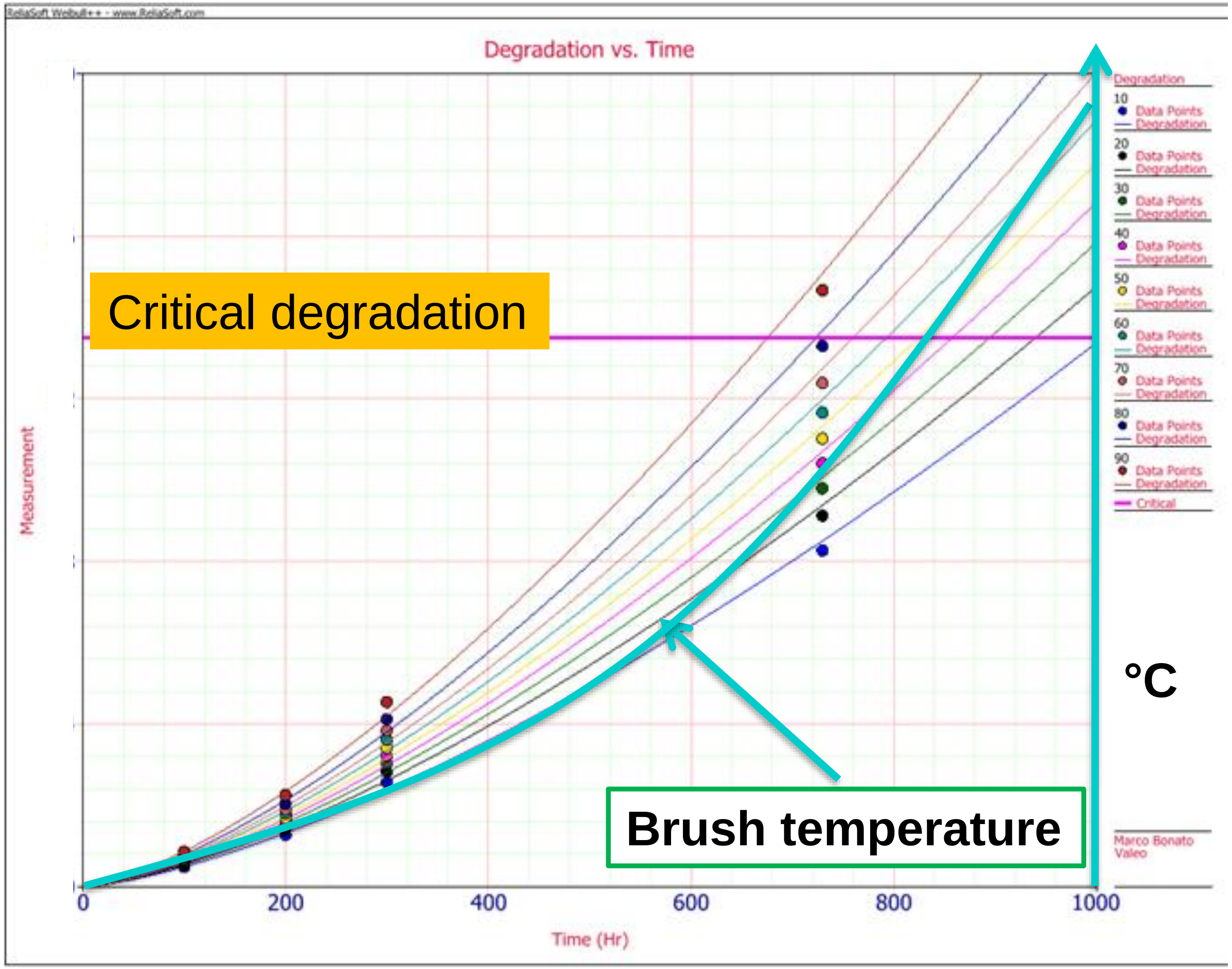
Calculation of percentile



	Inspection Time (Hr)	Measurement	Unit ID
1	100	0,484691	10
2	200	1,2688	10
3	300	2,5602	10
4	730	8,2698	10
5	100	0,5348	20
6	200	1,4	20
7	300	2,8249	20
8	730	9,1247	20
9	100	0,574116	30
10	200	1,5029	30
11	300	3,0326	30
12	730	9,7955	30
13	100	0,609992	40
14	200	1,5968	40
15	300	3,222	40
16	730	10,4076	40
17	100	0,645549	50
18	200	1,6899	50
19	300	3,4099	50
20	730	11,0143	50
21	100	0,683179	60
22	200	1,7884	60
23	300	3,6087	60

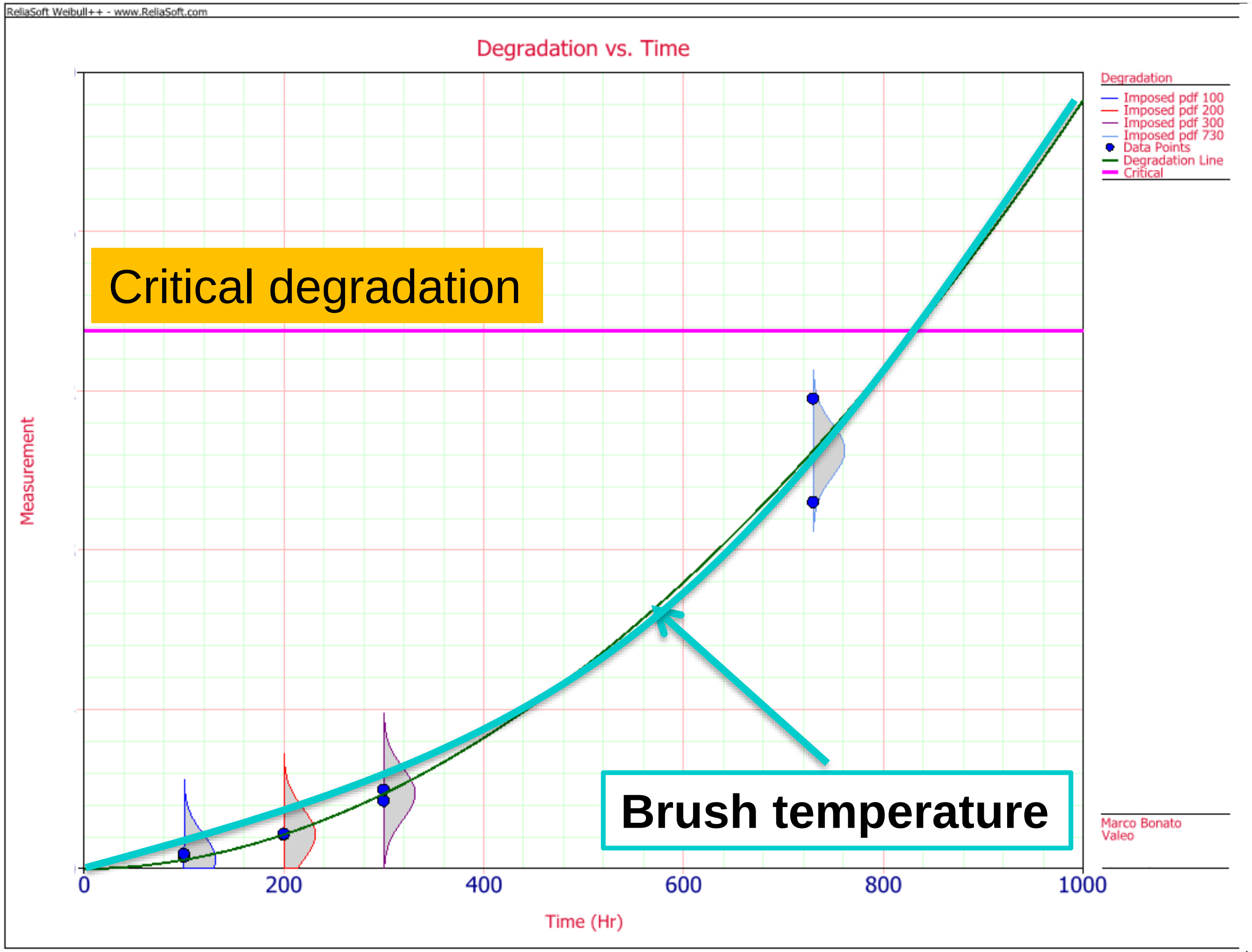
Brushes Degradation Analysis Results (lognormal distribution)

Part III



Brushes Degradation Analysis Results (normal distribution)

Part III



1) Brushes temperature increased with time

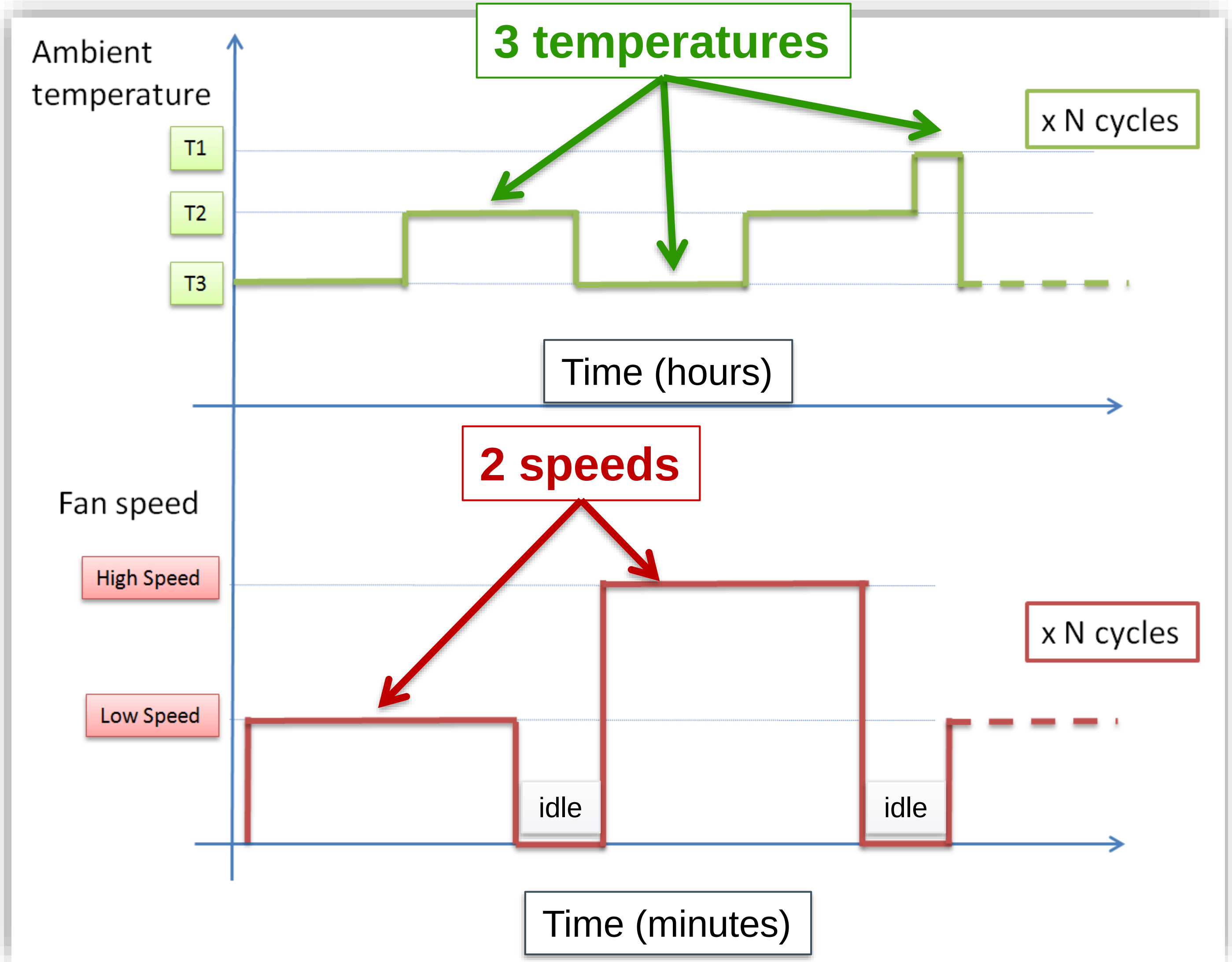
2) Brushes wear increased with increasing time & temperature

3) Need of multi-stress analysis

Brushes Degradation Analysis
Further analysis

Part III

- Correlation specification – mission profile – warranty period



Further investigation:

-New degradation test plan (operative temperature, fan speed and activations)

- Multi-stress analysis

- Correlation between customer specification and fan system usage profile

RESULTS

- Reliability estimation (from bench to field)

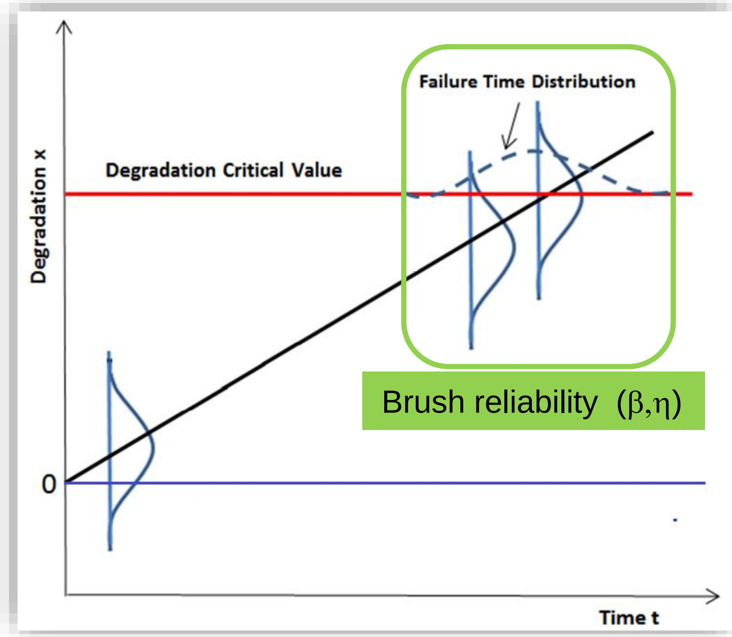
Brushes Degradation Analysis
Model results

Part III

	(Low speed + idle) cycle			(High speed + idle) cycle		
	+ (*)	- (**)	Mean wear out rate (µm/h)	+ (*)	- (**)	Mean wear out rate (µm/h)
T1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5,5
T2	< 1 mm/ 1000 h			[illegible]	[illegible]	8,6
T3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12,7

(*) : brush wear on positive brush ; (**) : brush wear on negative brush ;

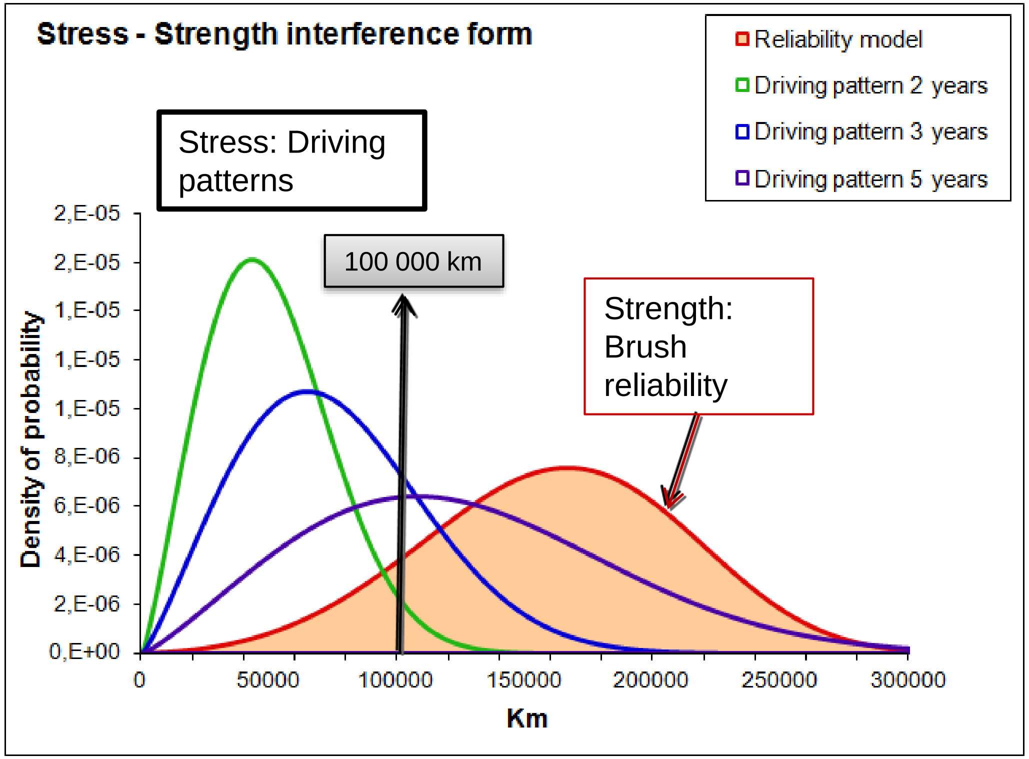
Linear degradation law

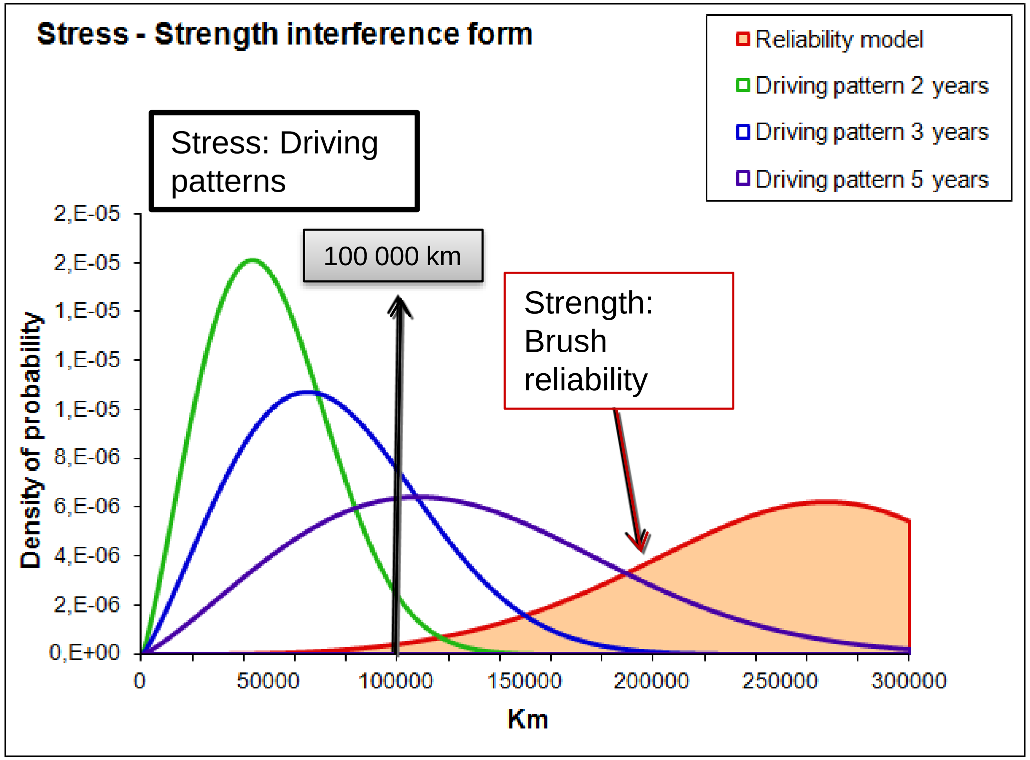


- Results analysis based on limited quantity samples (4 samples per temperature - speed)
- Low speed brush wear speed is constant at all temperatures of testing (<1mm / 1000h)
- High speed brush wear speed is increasing with temperature
- **Hypothesis of linear degradation model and Weibull life distribution, for high speed only, for 1 temperature cycle**

Brushes Degradation Analysis Conclusions

- Reliability estimated from degradation model *vs* driving patterns
- Methodology to be used for internal qualification tests





Bad design → **Reliability target achieved**

Summary

- A reliability evaluation of suppliers should be tailored to their experience/background
- In case of warranty escalation, readiness and a robust procedure are needed
- A proactive mindset is nowadays necessary in order to anticipate potential issues

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