University of Stuttgart
Institute of Machine Components
Reliability Department

Taking Advantage of Smart Data in Reliability Assurance and Product Design

Dr.-Ing. Martin Dazer

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Institute of Machine Components

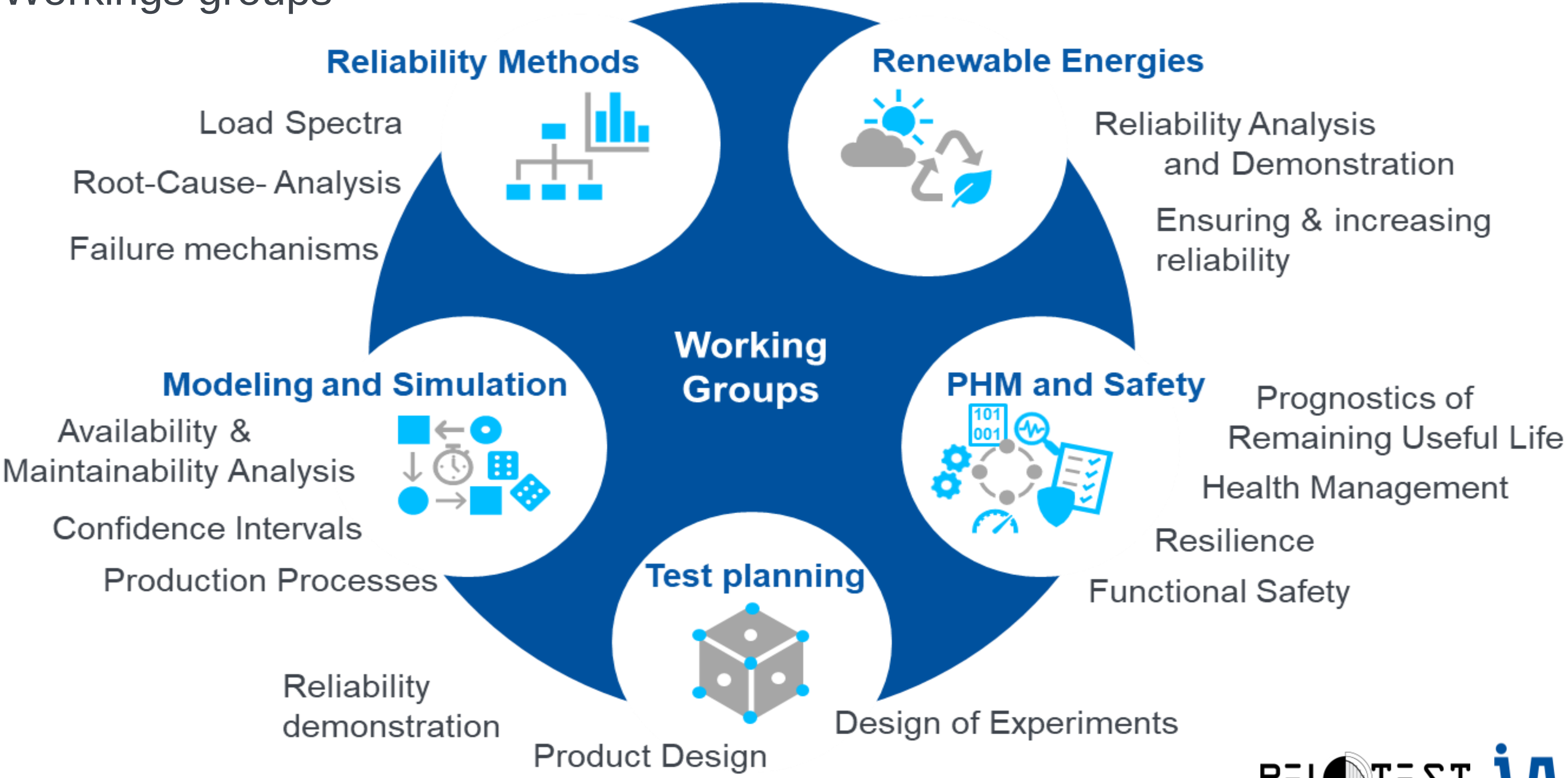
Overview

- Research fields: Reliability Engineering, Sealing Technology, Driveline Technology, Rail Vehicle Technology

- Scientific staff: 2 profs, 5 doctors, about 35 PhD students
- App. 100 bachelor and master theses
- App. 50 publications yearly

Institute of Machine Components

Workings groups



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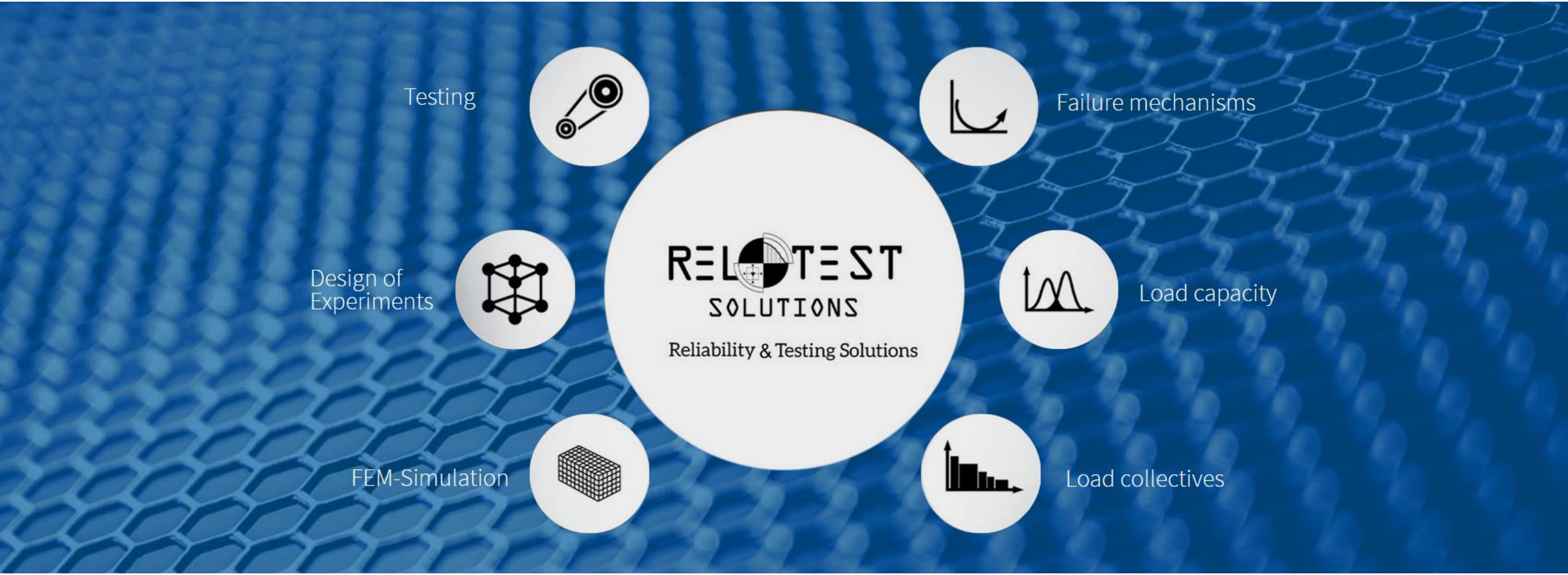
RelTest-Solutions

IMA Spin-Off



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RelTest-Solutions

Background

Martin Dazer
starts PhD at IMA

Establishment of RelTest-Solutions
at TTI GmbH of University Stuttgart

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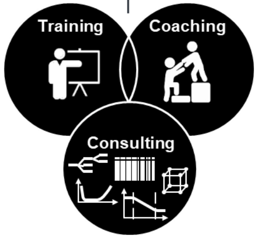
>20 international projects in 3 years

AESCULAP, BOSCH, EKK, hofer, HYUNDAI, KNORR-BREMSE, Leica, Mercedes-Benz, mtu, Nidec, optibelt, SMA, STIHL, testo, VAT, WALTHER FLENDER, WEBER-HYDRAULIK, ZF

2015 | 2017 | 2018 | 2019 | 2020 | today

Kevin Lucan
starts PhD at IMA



Start of
consulting
activities

3 Reliability seminars

Reliability Basics

DOE

Electronics Reliability

Long-term cooperation

holland innovative

University of Stuttgart
Germany

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Scope

1. **Introduction & Challenge**
2. Reliability based product design
3. Efficient risk based test planning
4. Reducing Uncertainty with Bayes Theorem
5. Intelligent operating strategies

Introduction

Life test

Reliability highly necessary to prevent disasters

Target Design

Reliability requirement

0

Lifetime

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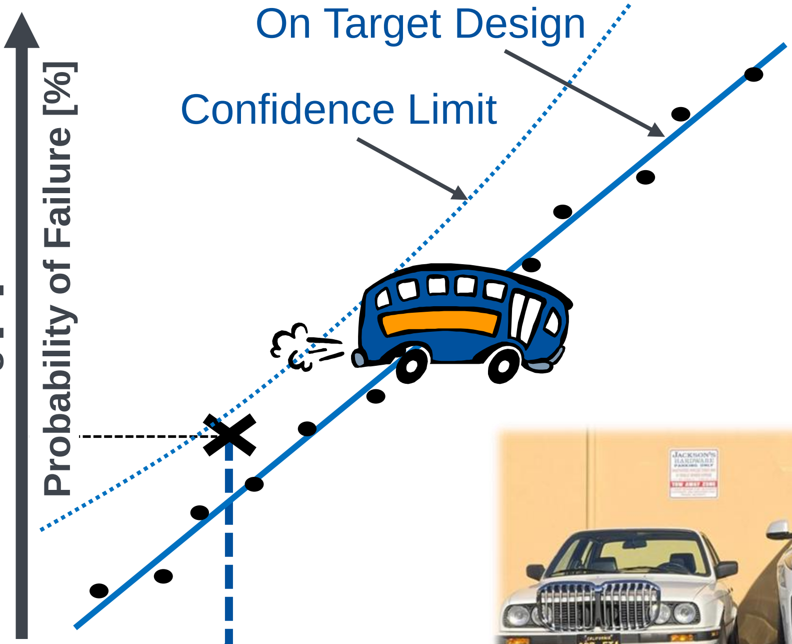
Introduction & Challenge

Reliability highly necessary to prevent disasters



Oversizing

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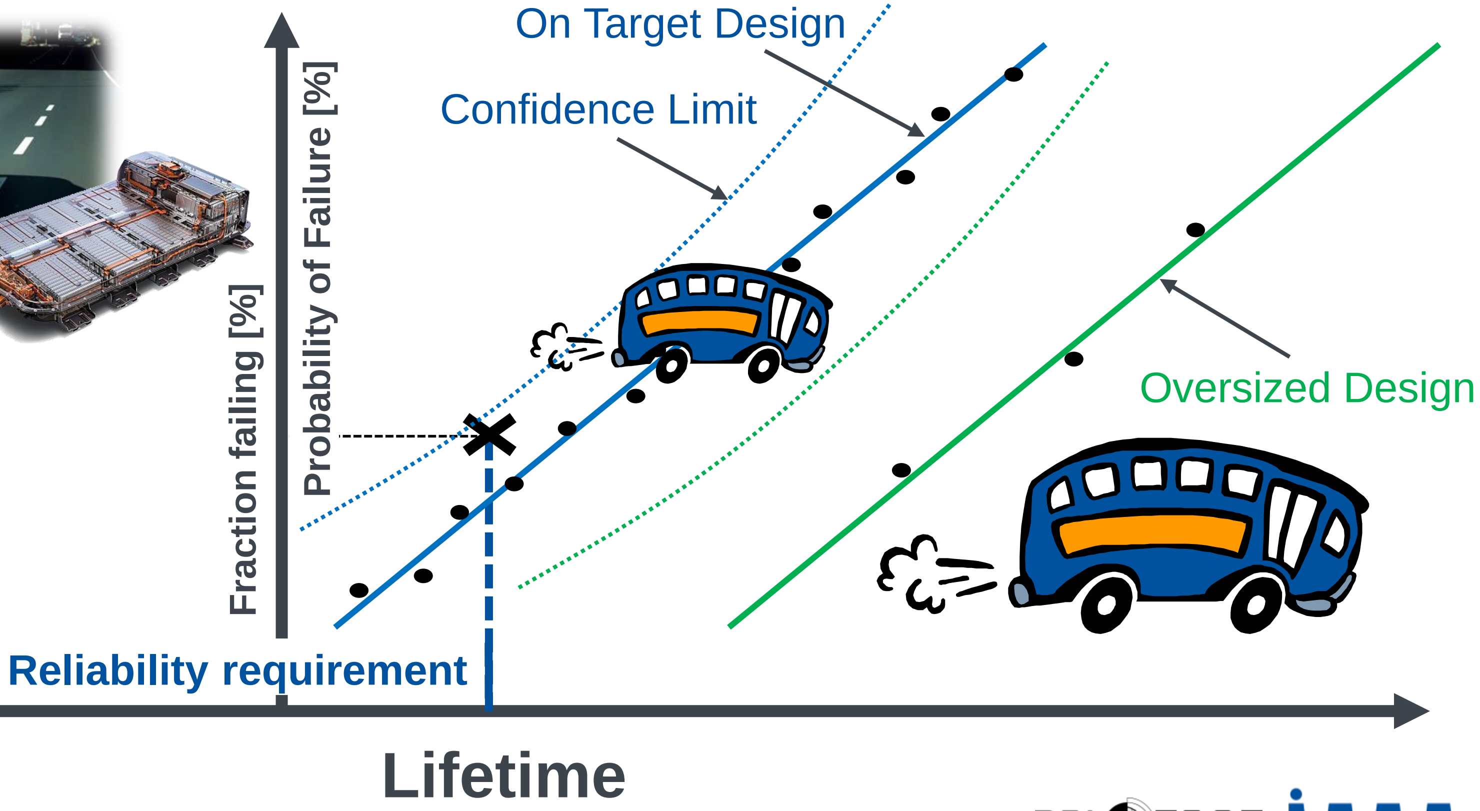
Introduction & Challenge

Reliability highly necessary to prevent disasters



Scope

1 Introduction & Challenge

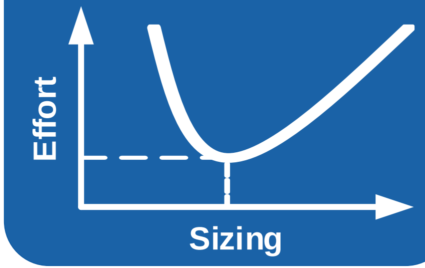
2 **Reliability based product design**

3 Efficient risk based test planning

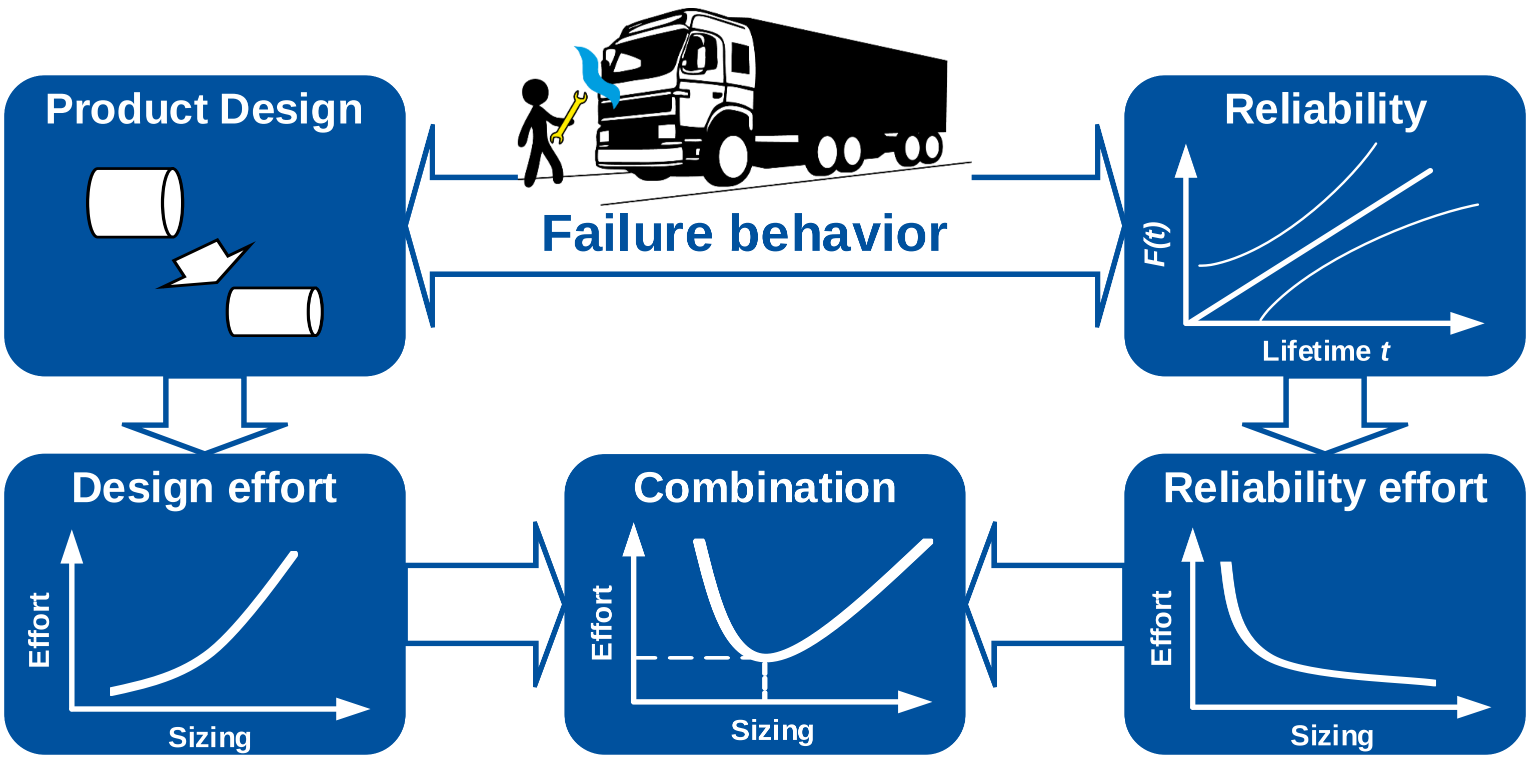
4 Reducing Uncertainty with Bayes Theorem

5 Intelligent operating strategies

Optimal design



Main target



Product Design
Failure behavior
Reliability
F(t)
Lifetime t
Design effort
Effort
Sizing
Combination
Effort
Sizing
Reliability effort
Effort
Sizing

Main target

Reliability

- Necessary to ensure safe product operation
- Design has to meet reliability requirements

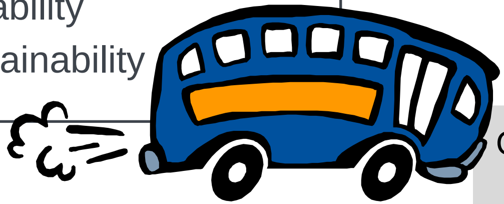
Related parameters
- Probability of failure
- Useful life
- Availability
- Maintainability

Target Design

Sustainability:

- Necessary to reduce global warming potential
- Best Design for low environmental impact

Related parameters
- Material consumption
- Energy demand
- Spare parts requirements
- Useful life



Oversized Design

Weak Design

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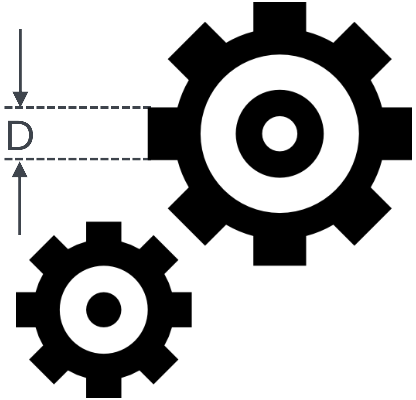
Reliability based gear wheel design

Boundary conditions



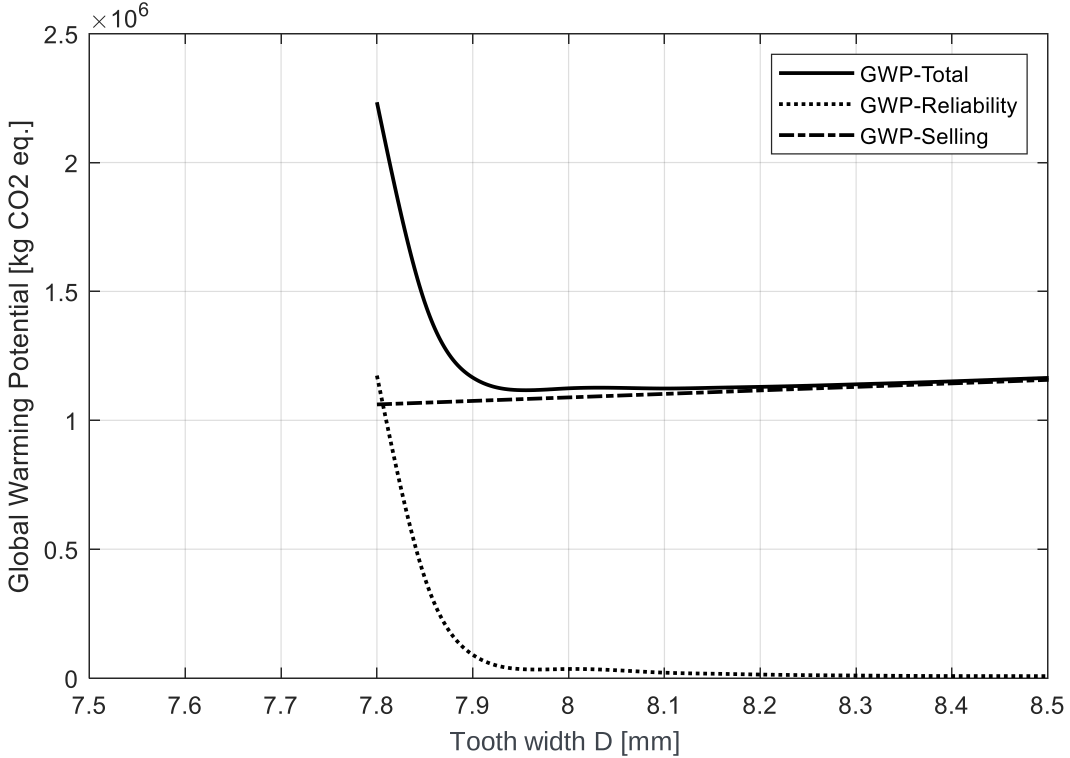
Identification of the best design!

Requirements	
Reliability	99 % with 50 % CL
Lifetime	$1{,}8 \cdot 10^7$ Cycles
Stress	150 Nm Torque

Reliability demonstration

Reliability based gear wheel design

Results



Life test for reliability demonstration

Life cycle assessment for:

- Planned sales units
- Reliability demonstration effort

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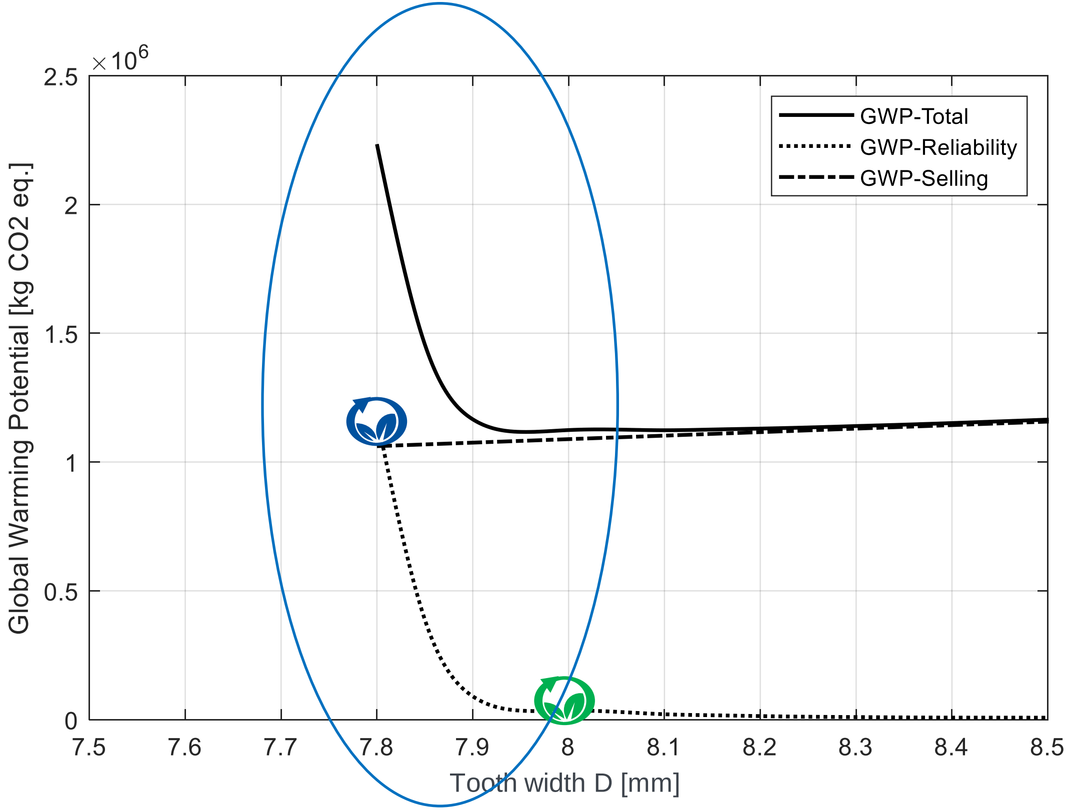
Reliability based gear wheel design

Comparison of different results



GWP-Reliability:

600 Samples → 637 kg CO_2 eq.

103,781 h Test time → $1.25 \cdot 10^6$ kg CO_2 eq.

GWP-Reliability:

500 Samples → 560 kg CO_2 eq.

3,557 h Test time → $4.28 \cdot 10^4$ kg CO_2 eq.

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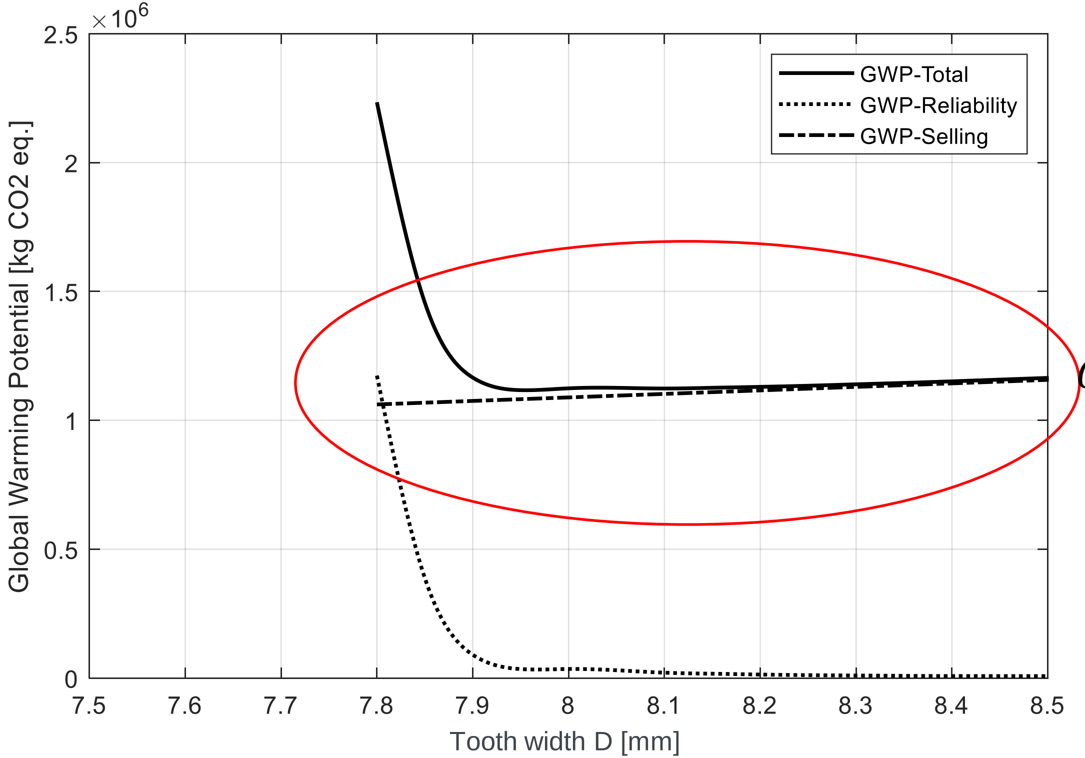
Reliability based gear wheel design

Oversized designs



GWP due to Reliability Demonstration

GWP due to units sold

$$GWP_{sales} = (1{,}16 \cdot m_{gear} - 0{,}0007) \cdot n_{sales}$$

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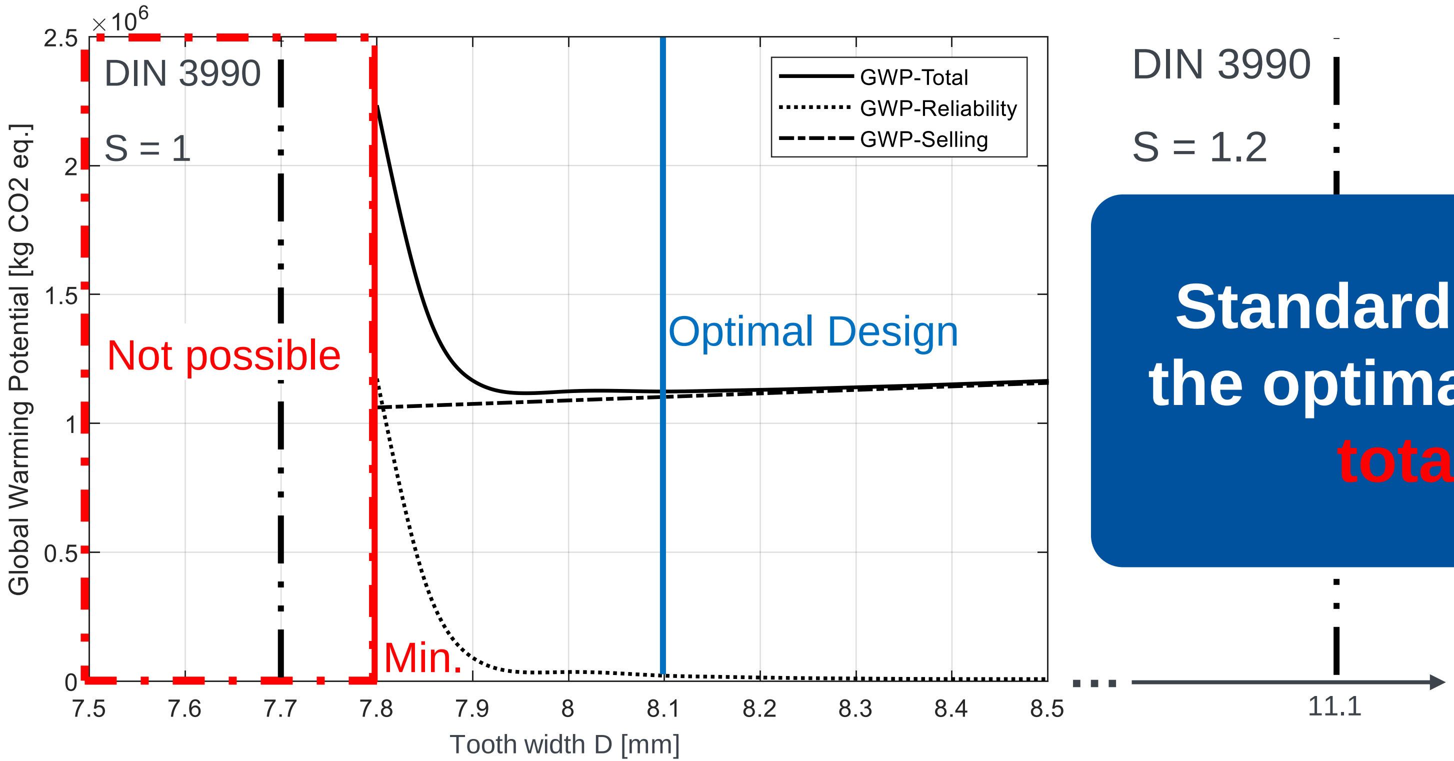
Reliability based gear wheel design

Optimal design



Standard misses the optimal design totally

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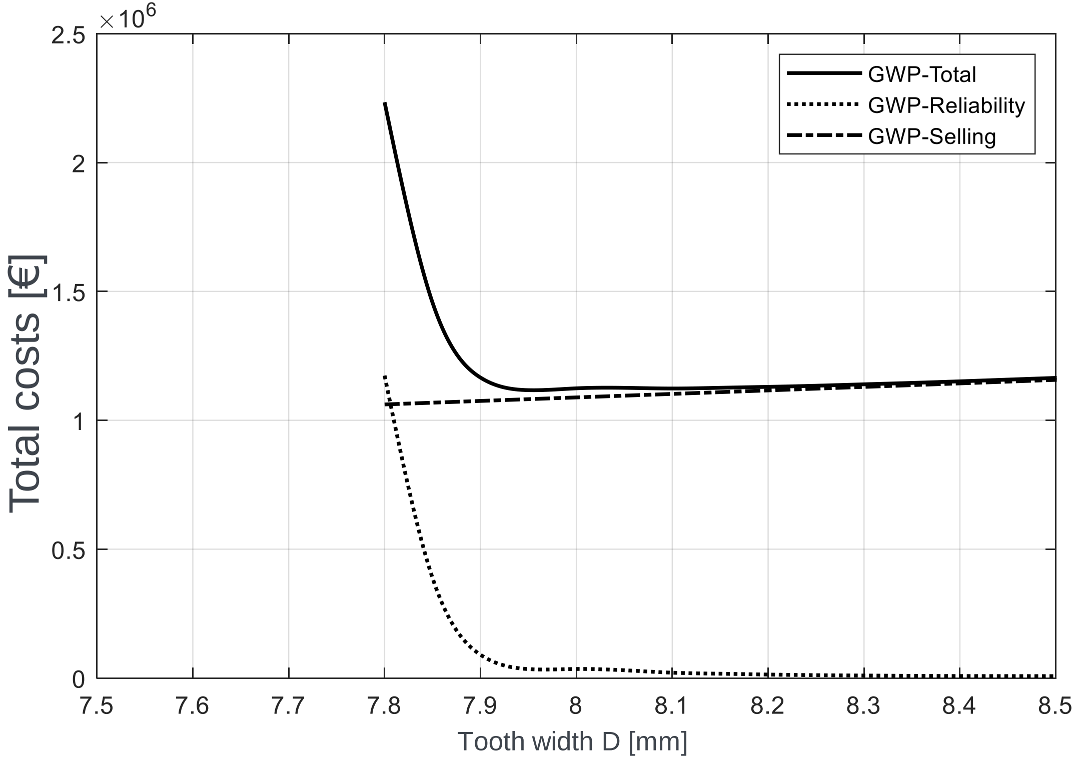
Reliability based gear wheel design

Optimal design



1. Efficient test planning strategies for reliability demonstration

2. Reduction of uncertainty

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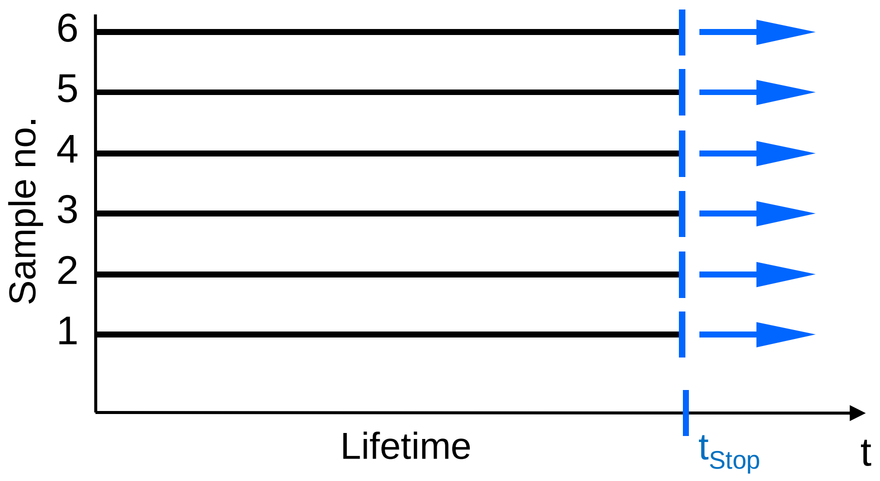
"If I had eight hours to cut down a tree, I'd spend six hours grinding the ax."

Abraham Lincoln

Zero failure / Success Run Testing

Basics



Success Run Test:

- Test stop after specified time
- No failure during the test

Binomial approach

$$C = 1 - \sum_{i=0}^{x} \binom{n}{i} \cdot (1 - R(t))^i \cdot R(t)^{n-i}$$

Binomial approach with no failures

$$C = 1 - R(t)^n$$

How likely is it that the test will be successful?

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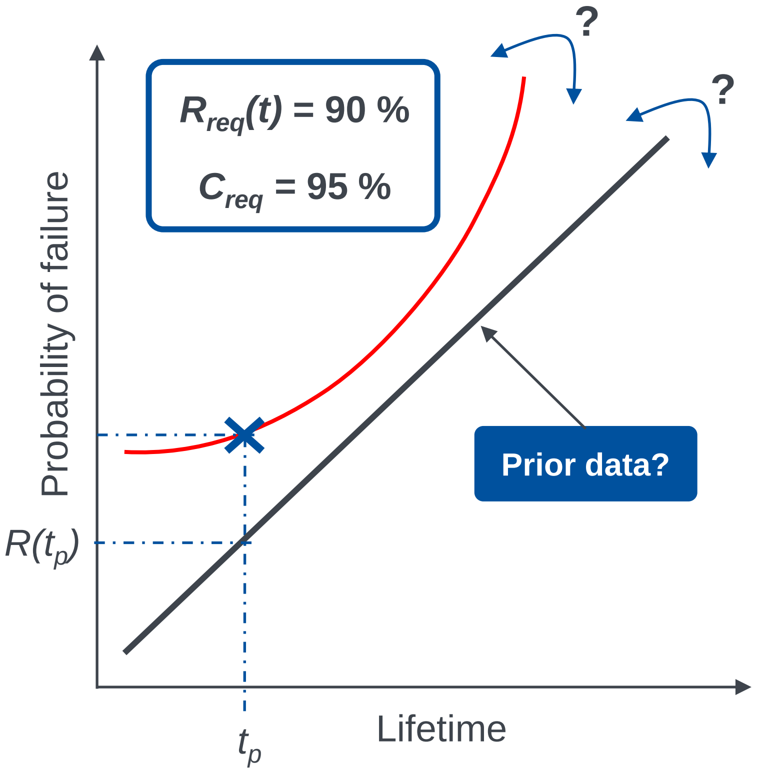
Zero failure / Success Run testing

Probability of Test Success



$$P_{ts} = R(t_p)^n$$

$$P_{ts} = 0{,}97^{29} = 0{,}41 \approx 41\ \%$$

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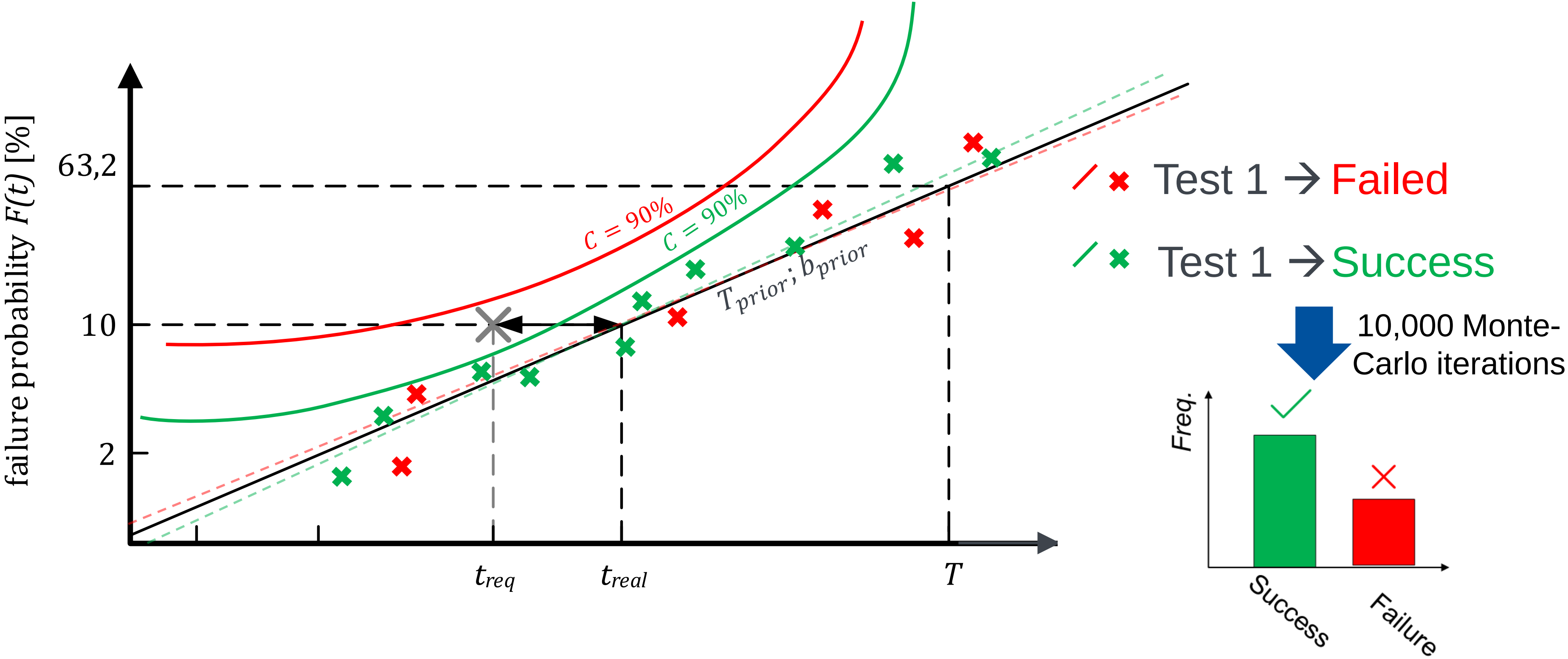
Zero failure / Success Run testing

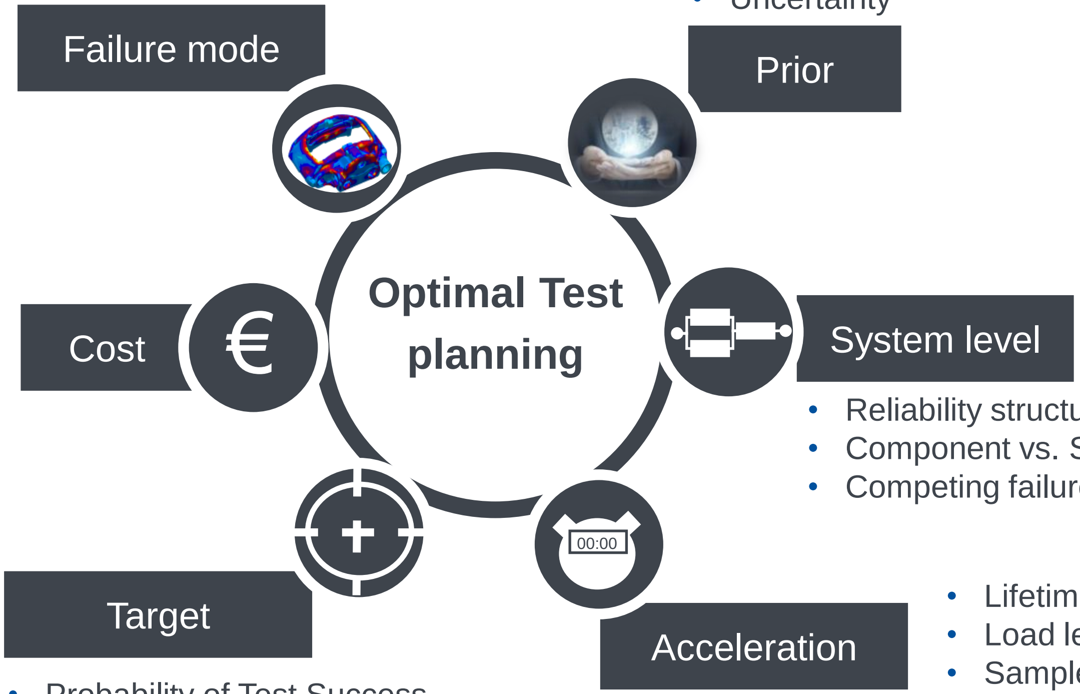


Optimal test planning

Parameter space

- Sizing
- Design
- Material
- Topology

- Failure behavior
- Uncertainty



- Test time
- Cost model
- Test rig capacity

- Reliability structure
- Component vs. System test
- Competing failure modes

- Lifetime model
- Load level height
- Sample distributon

- Probability of Test Success
- Life requirement

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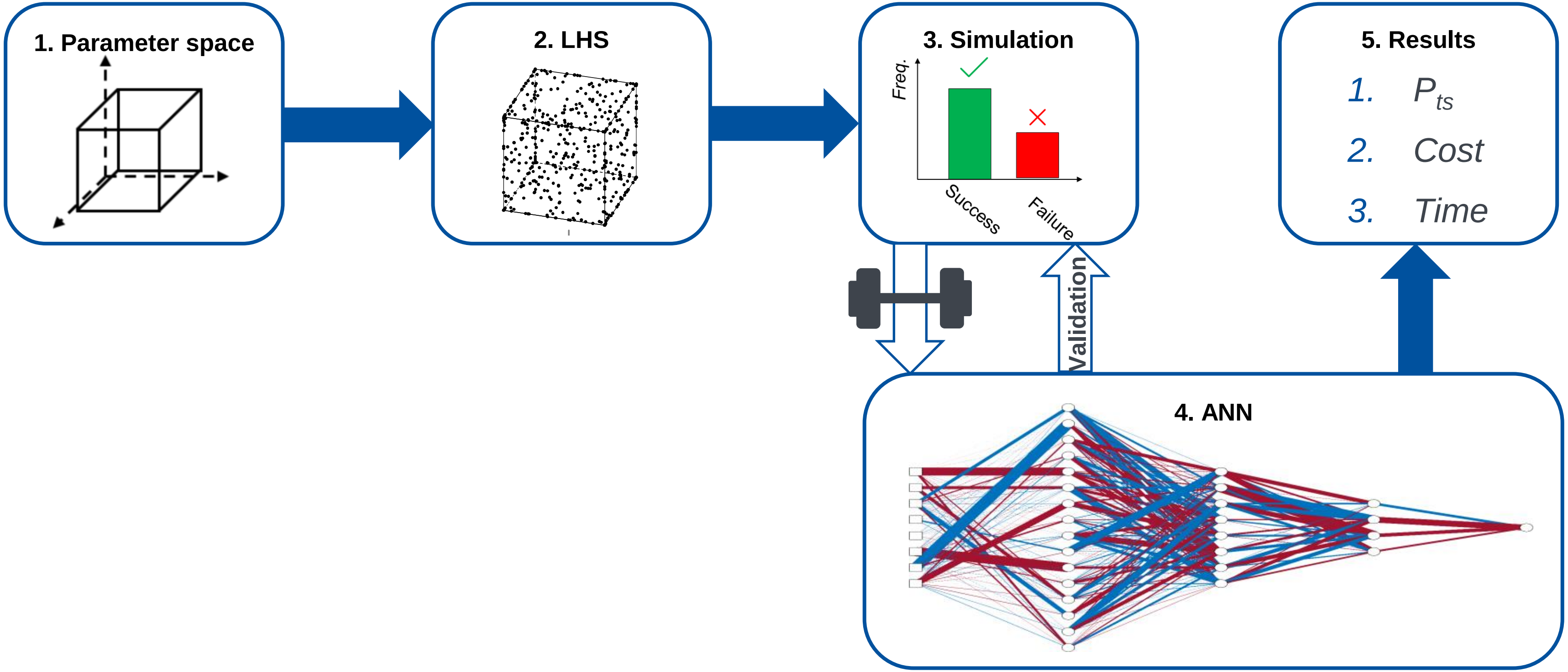
Finding an optimal test strategy

Using Smart Data and Deep Learning



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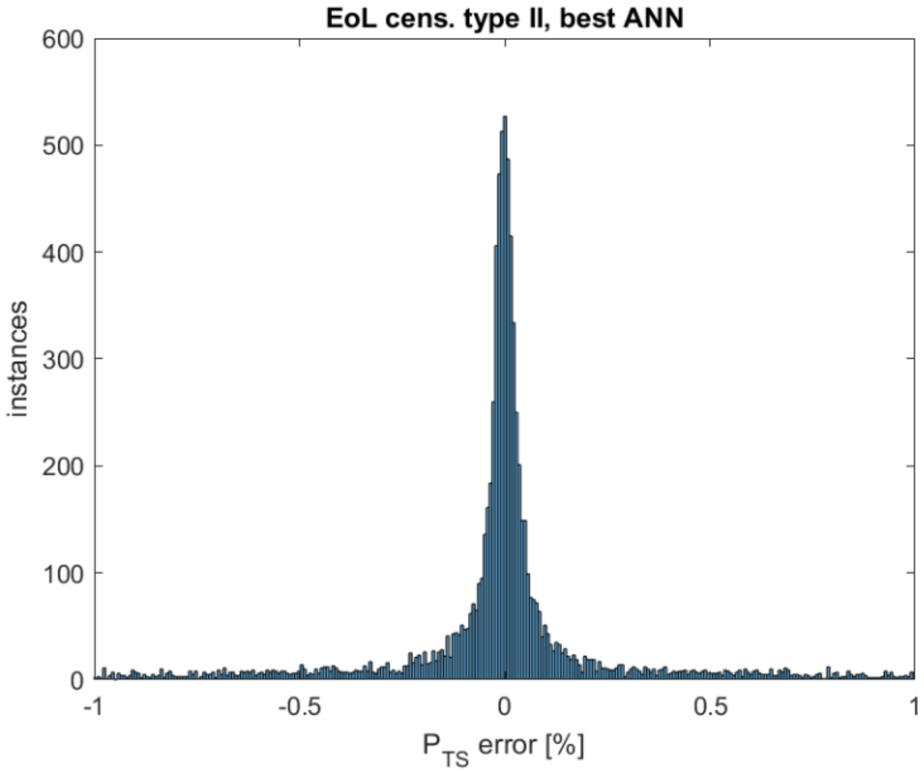
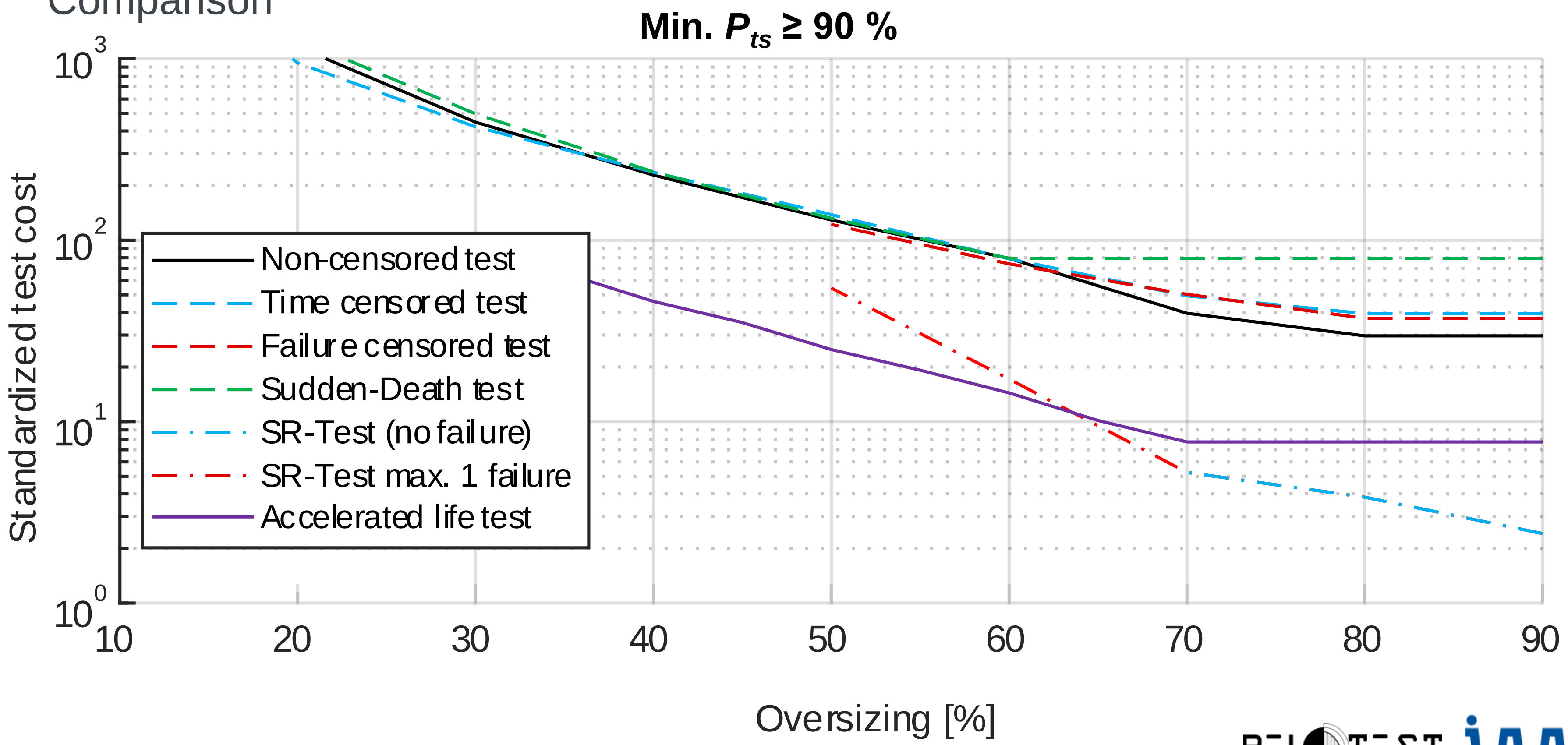
ANN prediction quality



Test type	RMSE (P_{ts}) [%]
EoL	0.68
EoL combined	0.84
Accelerated EoL	1.67
EoL cens. (type I)	2.47
EoL cens. (type I) combined	2.95
EoL cens. (type II)	1.49
EoL SD	1.04
SR	2.12

Some Results

Comparison



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Example

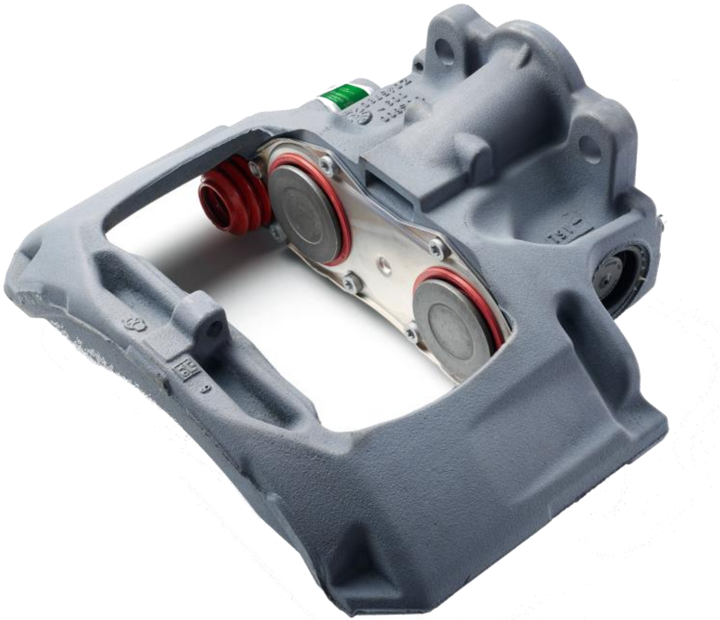
Giving some real numbers

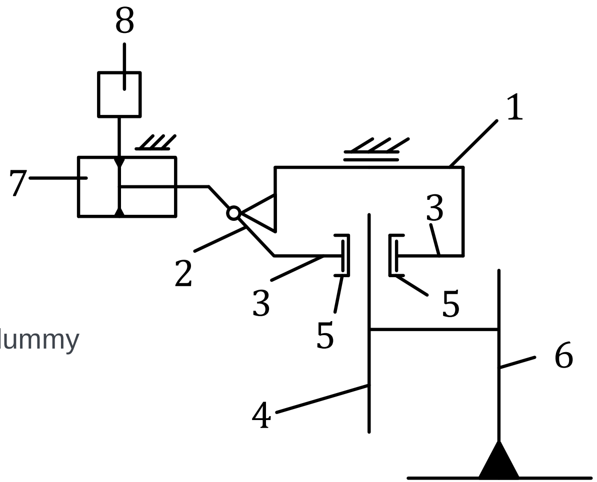
Requirement:

$R(16.000\ \mathrm{LC}) = 94\ \%$

$C = 90\ \%$

$P_{ts} \geq 90\ \%$



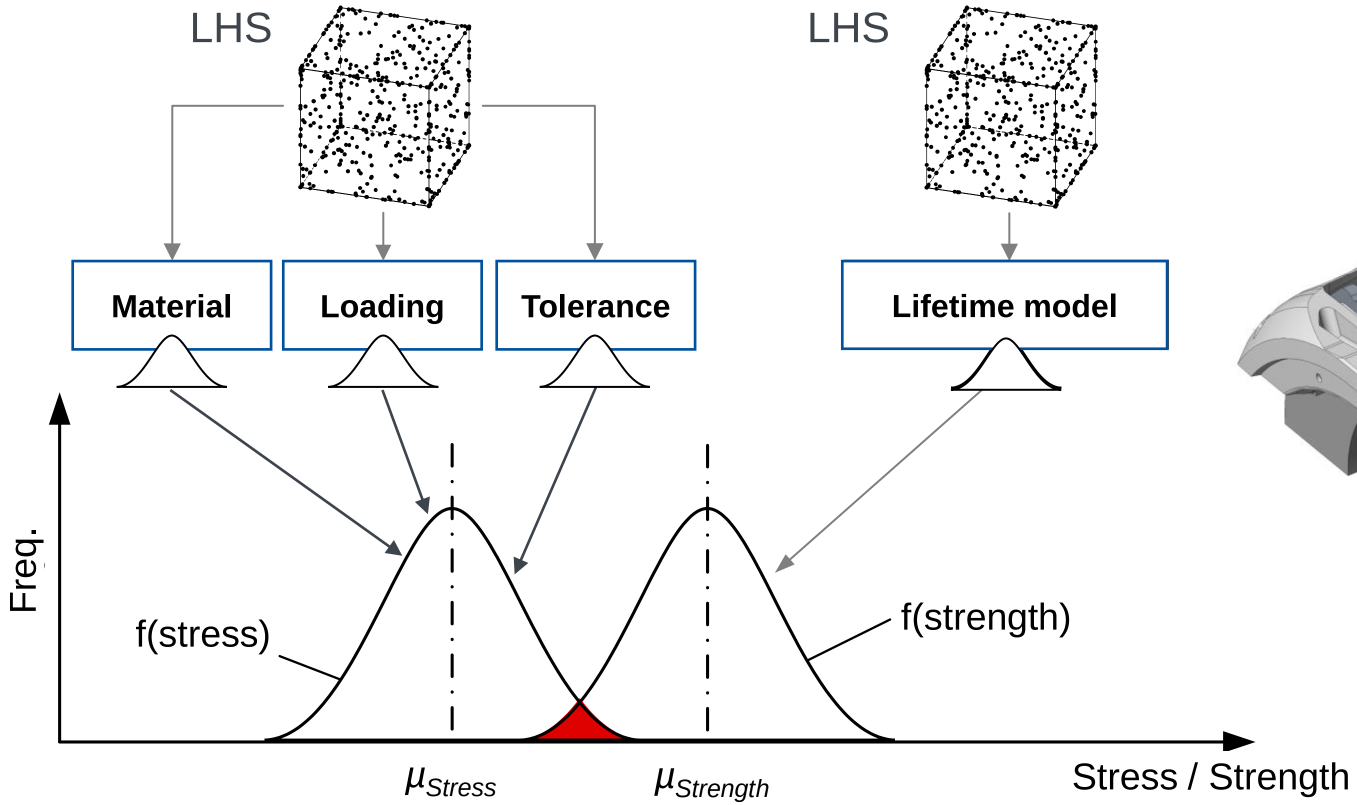


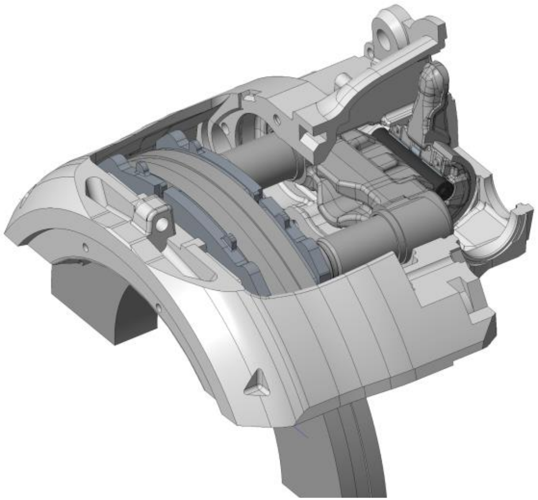
1…Caliper
2…Brake lever
3…Piston
4…Brake disc dummy
5…Brake pads
6…Adjustment
7…Cylinder
8…Counter

Static strength test for reliability proof

Stochastic Life Calculation

Genereting prior information





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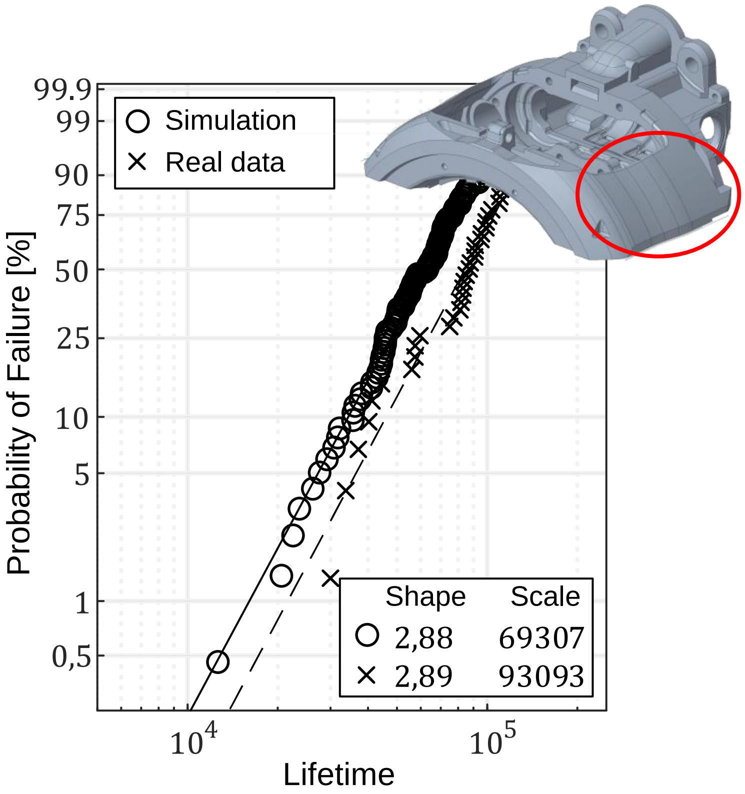
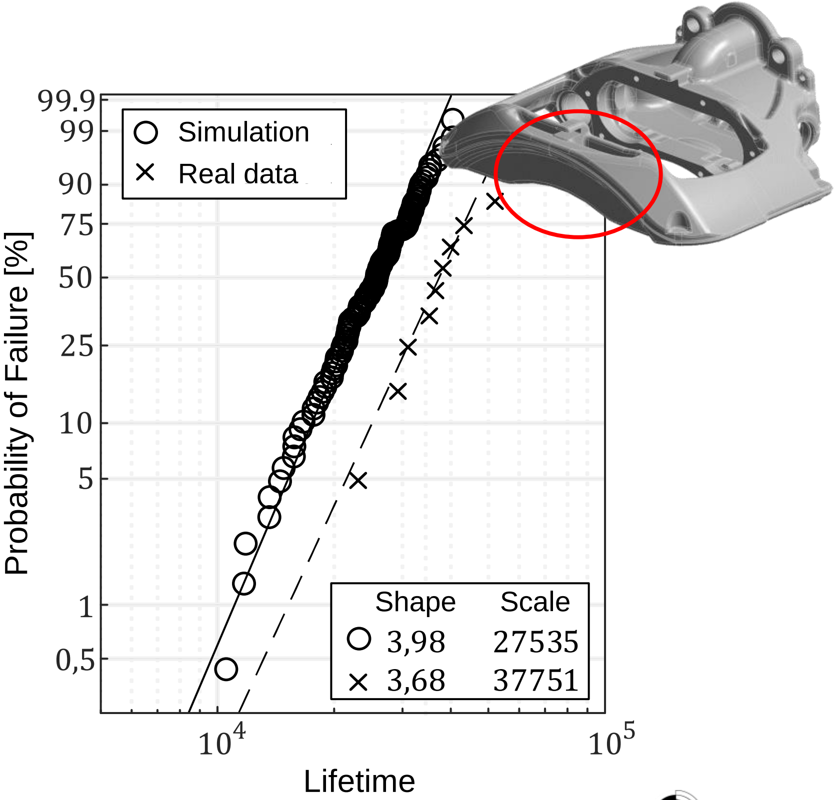
Stochastic Life Calculation

Results





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Example

Giving some real numbers

Requirement:

$R(16.000\ \text{LC}) = 94\ \%$; $C = 90\ \%$; $P_{ts} \geq 90\ \%$

Test strategy	Acc.	Non-censored	Type-I	Type-II	Sudden Death	Success Run $f = 0$	Success Run $f = 1$
P_{ts} [%]	90,0	91,4	90,2	83,4	90,1	60,4	81,6
n	27	30	36	18	56	38	33
Cost [€]	291.353	326.800	391.200	190.400	591.600	389.000	338.000
Time [LC]	111.061	165.500	174.000	81.900	550.400	48.800	62.300

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4 **Reducing Uncertainty with Bayes Theorem**

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Reducing Uncertainty

Bayes Theorem for HV Battery

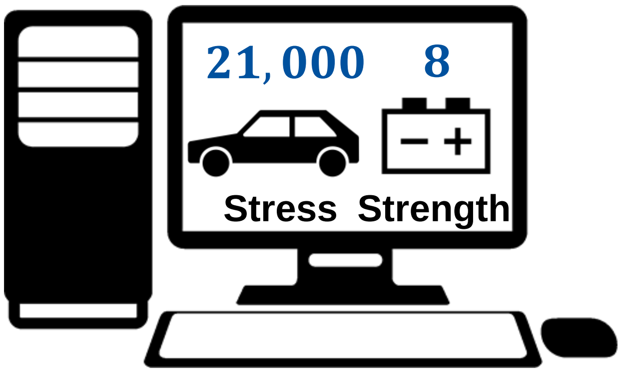
prior information

$$f(R) = \frac{1}{\beta(A_0, B_0)} R^{A_0-1}(1-R)^{B_0-1}$$

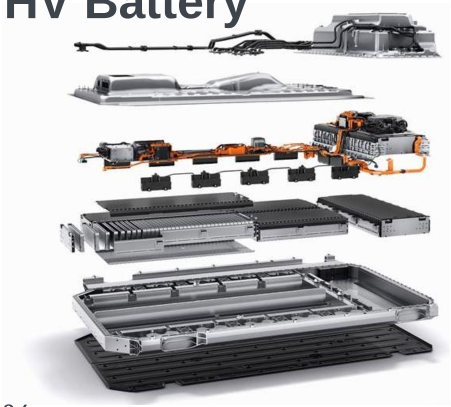
Bayes Theorem

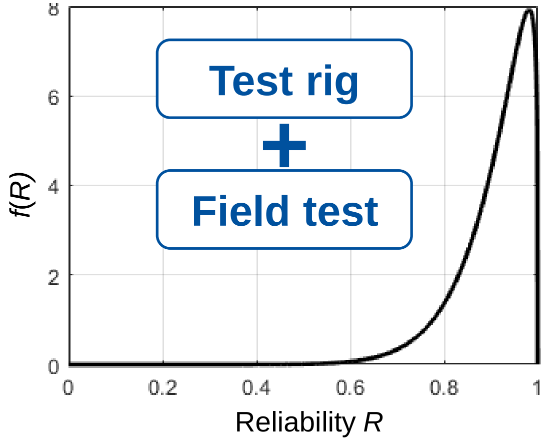
Current information

$$P(E_x|R) = \binom{n}{x} R^{n-x}(1-R)^x$$



HV Battery

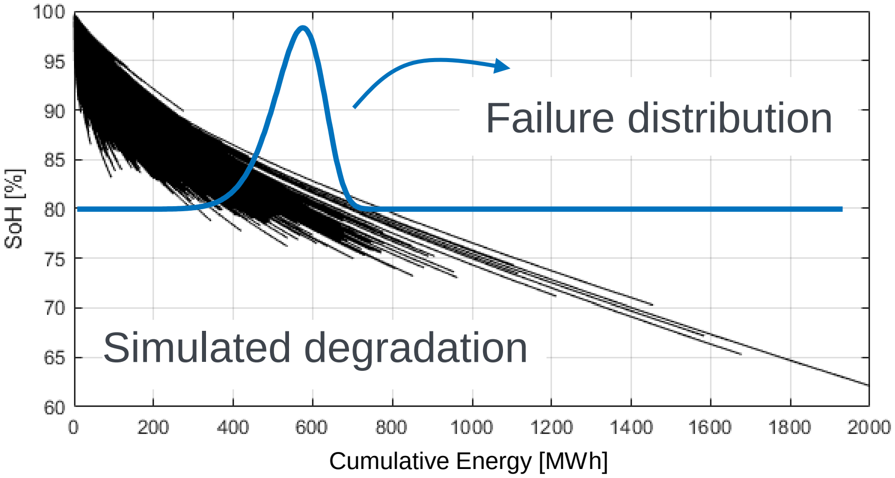


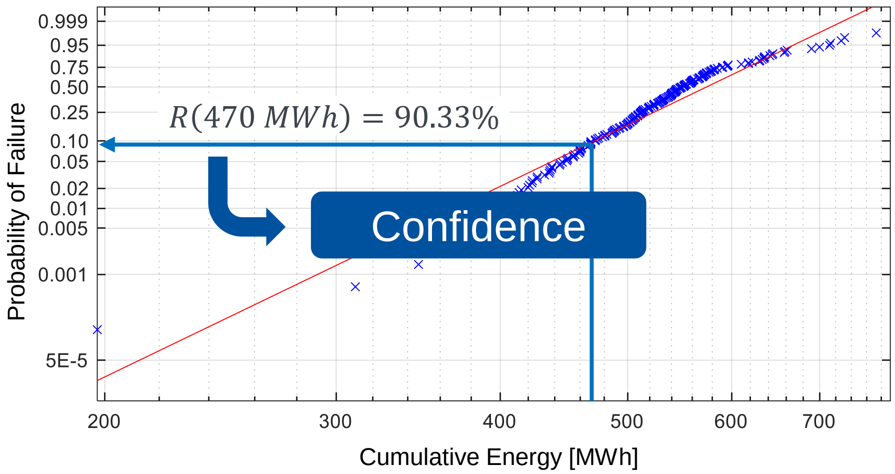


$R_{req}\left(t_{req} = 470\ MWh\right) = 90\%$ with $C = 90\%$

Reducing Uncertainty

Bootstrap approach





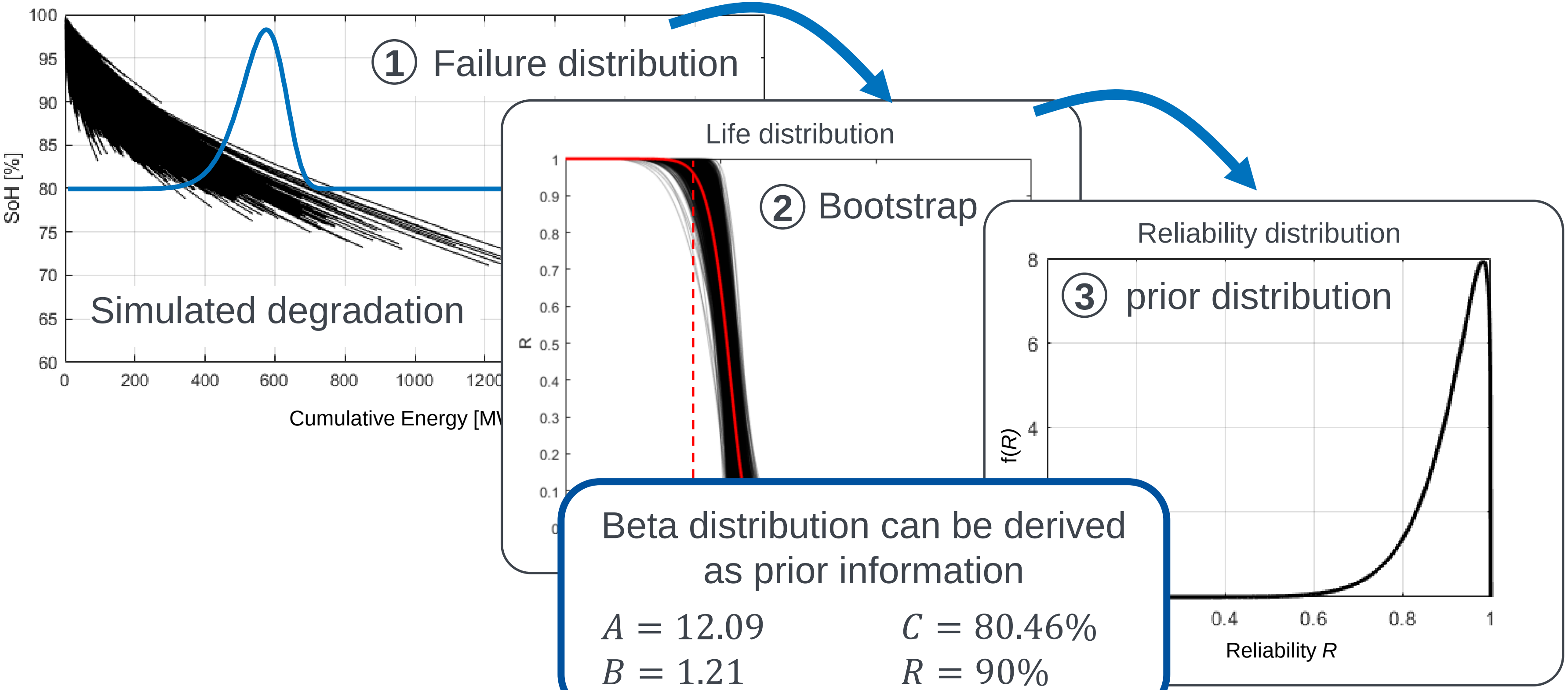
Uncertainty of both sources must be taken into account

$n_1 = 21{,}000$ & $n_2 = 8$

Double Bootstrap Approach

Reducing Uncertainty

Calculation approach



Beta distribution can be derived as prior information

$A = 12.09$ $C = 80.46\%$

$B = 1.21$ $R = 90\%$

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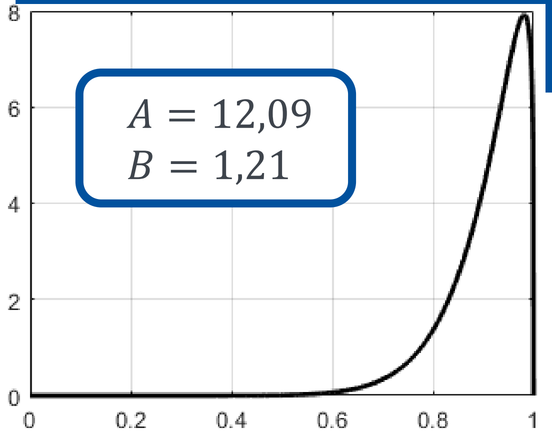
Reducing Uncertainty

Combining the information

prior information



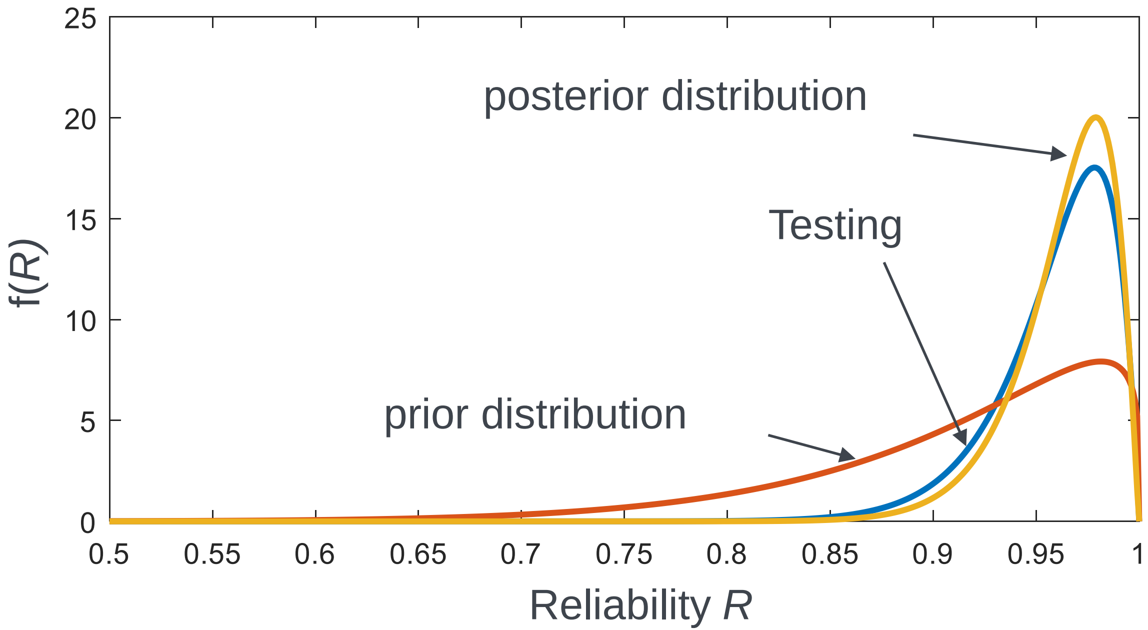
Bayes Theorem

Current information

Test	Start	End	Size	Failure
Field test	01.11.20	27.04.21	15	1 on 01.02.21
Test rig	01.10.20	27.04.21	4	none

$$f_{post}(R) = \frac{R^{\sum\left(\frac{r_i t_i}{t_s}\right)^b} \cdot \prod_j \left(1 - R^{\left(\frac{r_j t_j}{t_s}\right)^b}\right) \cdot R^{A-1} \cdot (1-R)^{B-1}}{\int R^{\sum\left(\frac{r_i t_i}{t_s}\right)^b} \cdot \prod_j \left(1 - R^{\left(\frac{r_j t_j}{t_s}\right)^b}\right) \cdot R^{A-1} \cdot (1-R)^{B-1}\, \mathrm{d}R}$$

Reducing Uncertainty
Results



More accurate prediction

Saving of
8 Field tests
1 Rig tests

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4 Reducing Uncertainty with Bayes Theorem

5 **Intelligent operating strategies**

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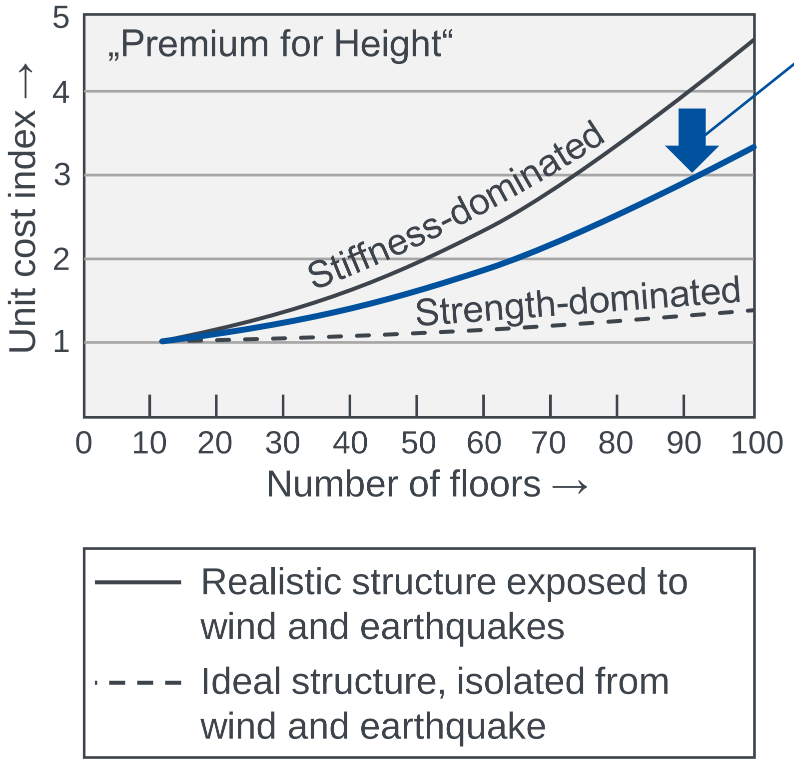
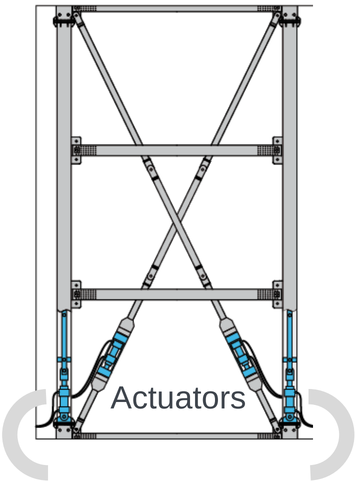
Designing an adaptive high rise structure

Premium for Height problem

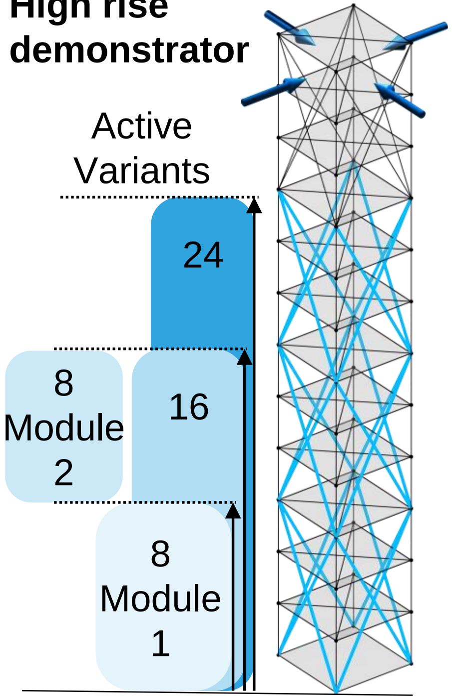


Adaptive structure

Damping by integration of actuators



High rise demonstrator



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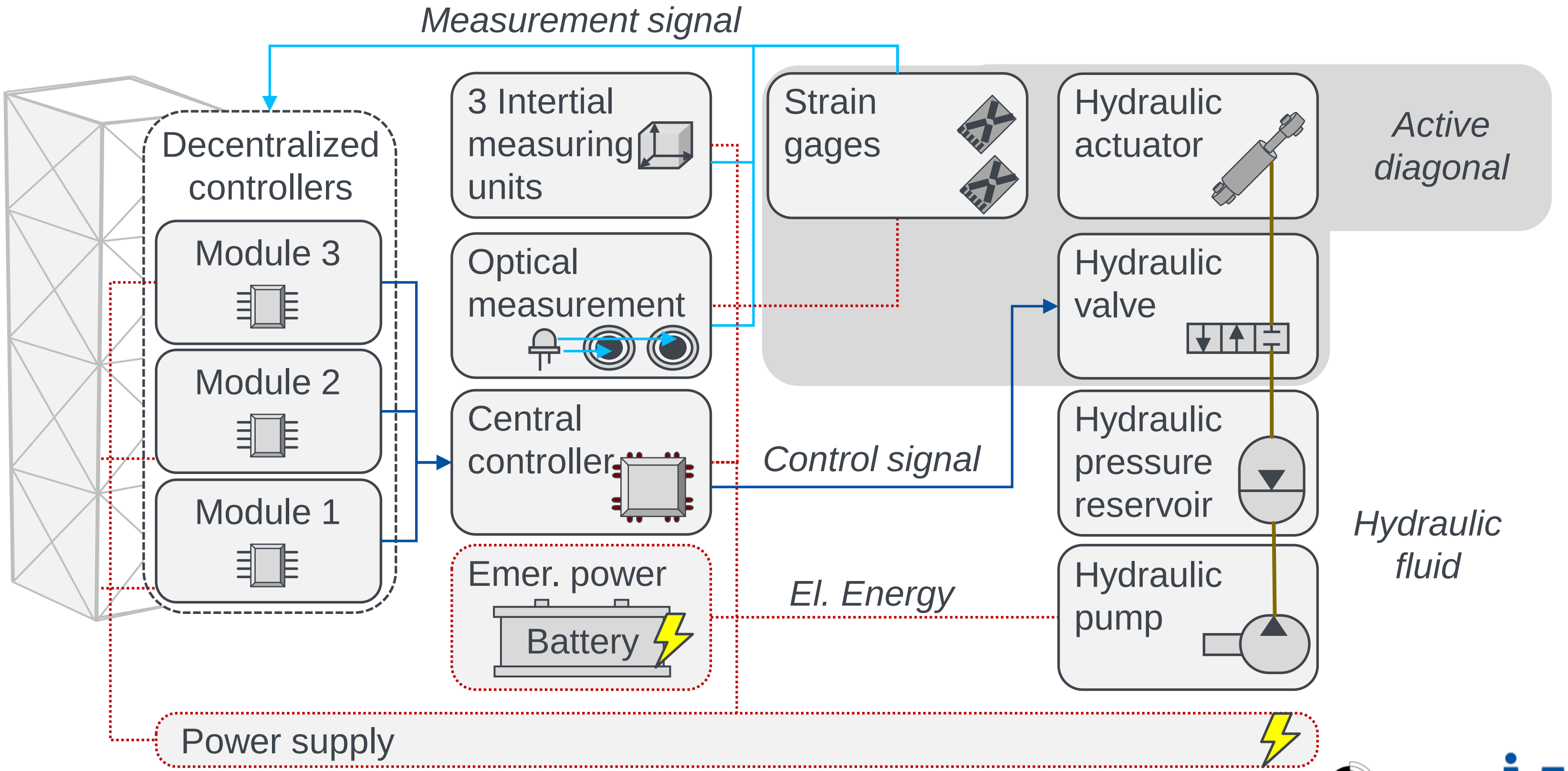
Designing an adaptive high rise structure

System layout



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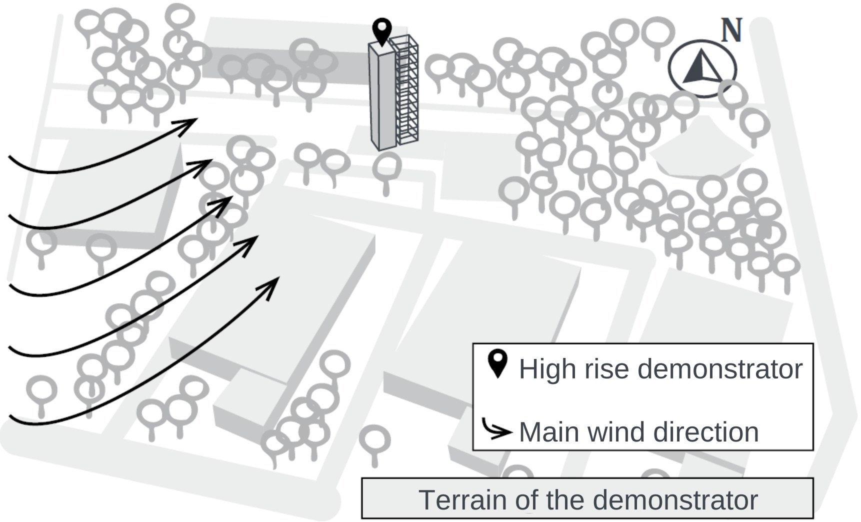
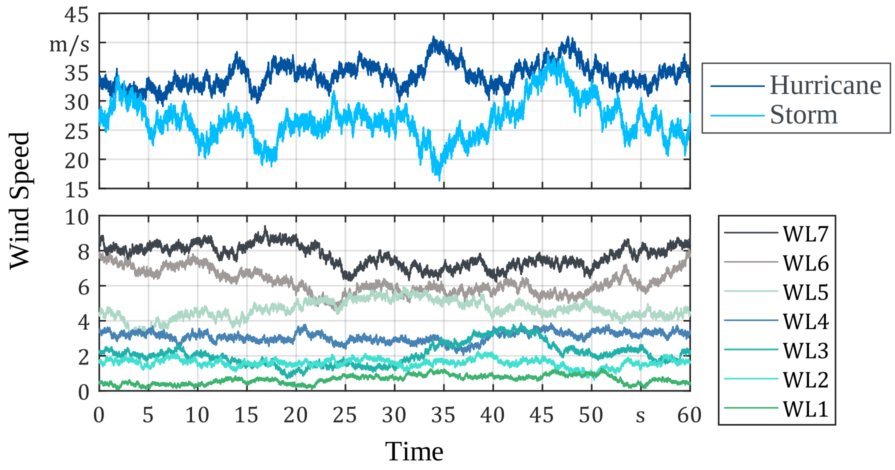
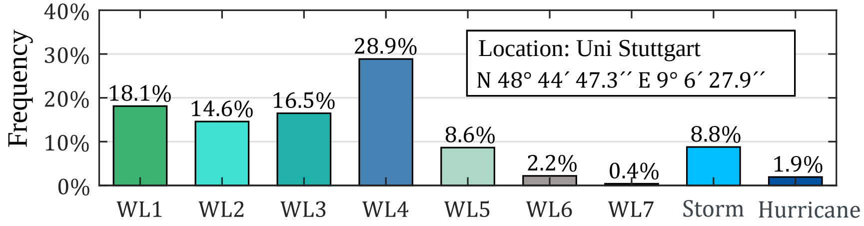
Designing an adaptive high rise structure

Representative load spectra







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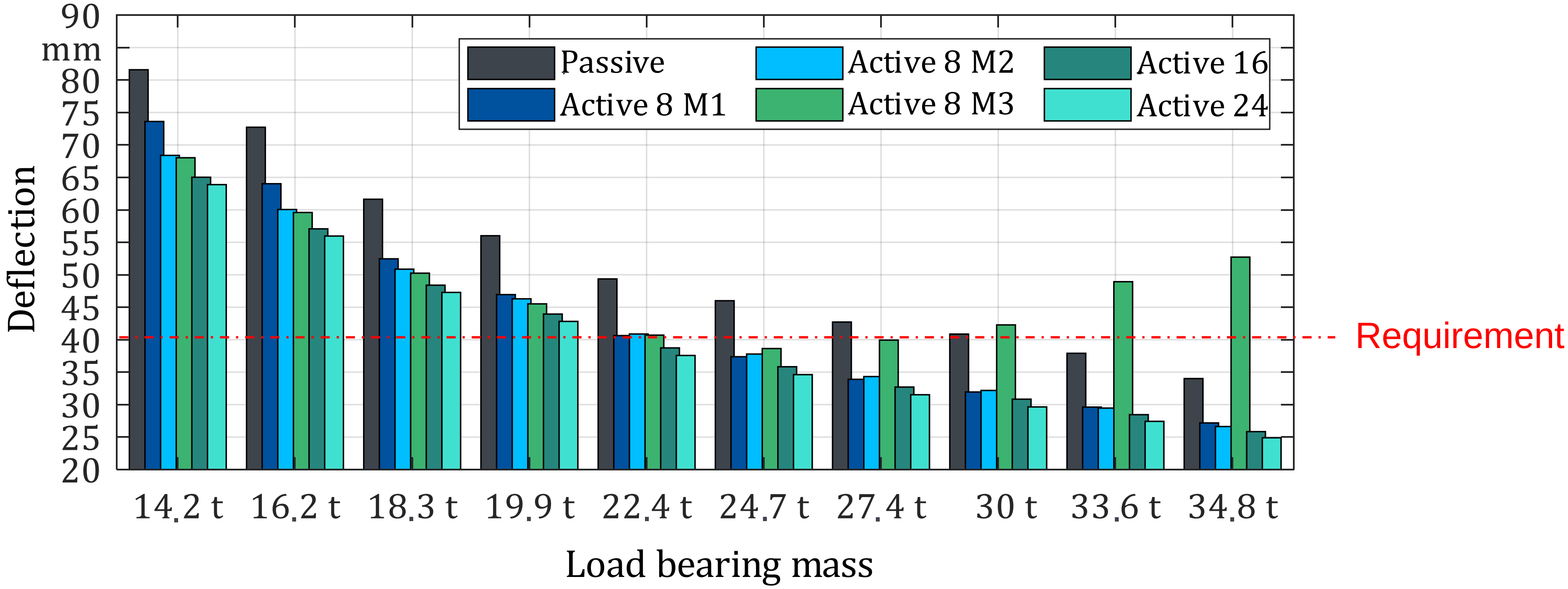
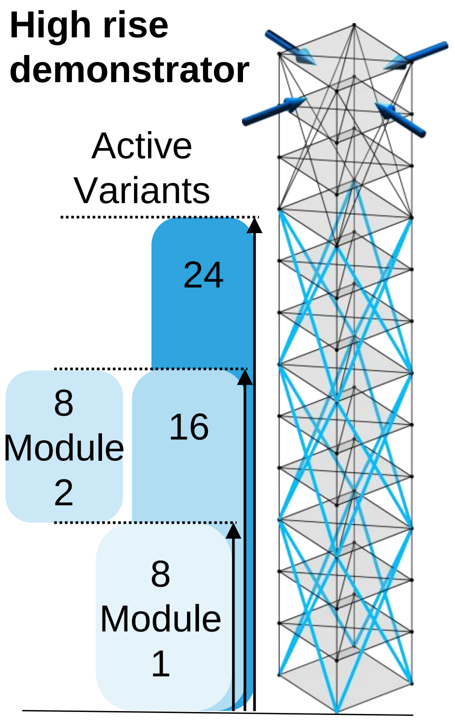
Designing an adaptive high rise structure

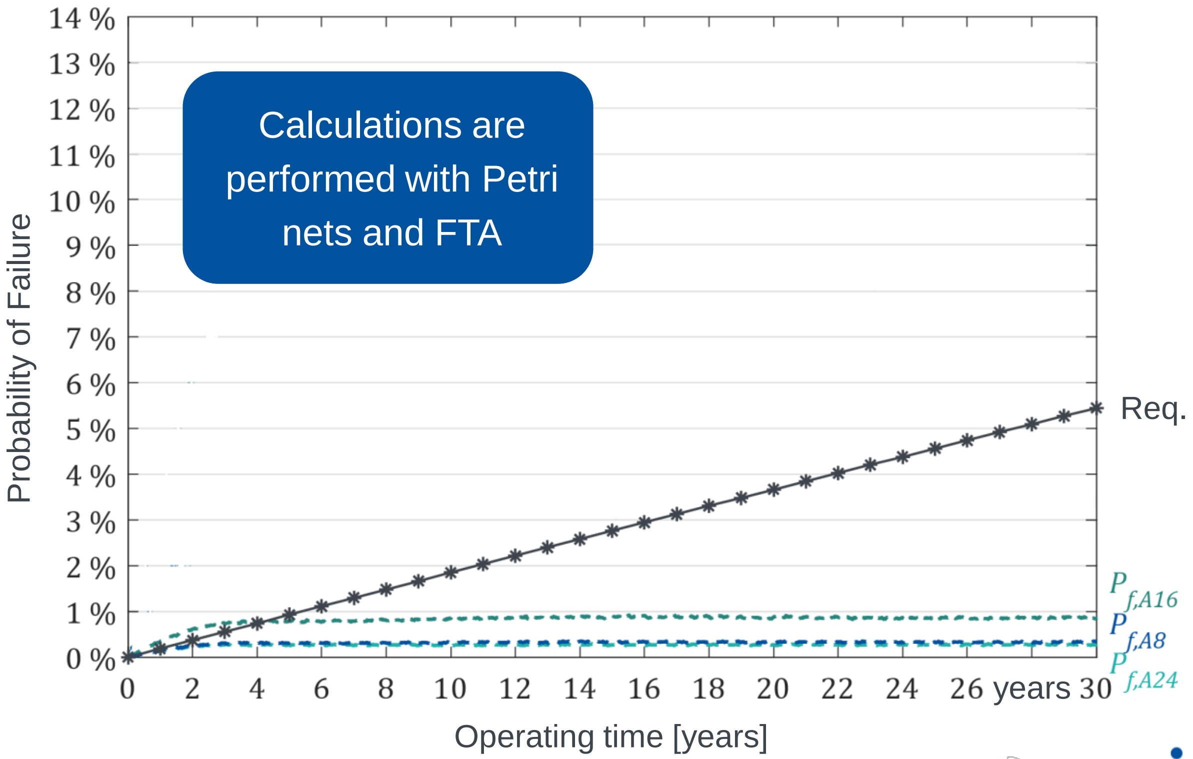
Deflection of the different variants



Designing an adaptive high rise structure

Availability results from the petri net calculation





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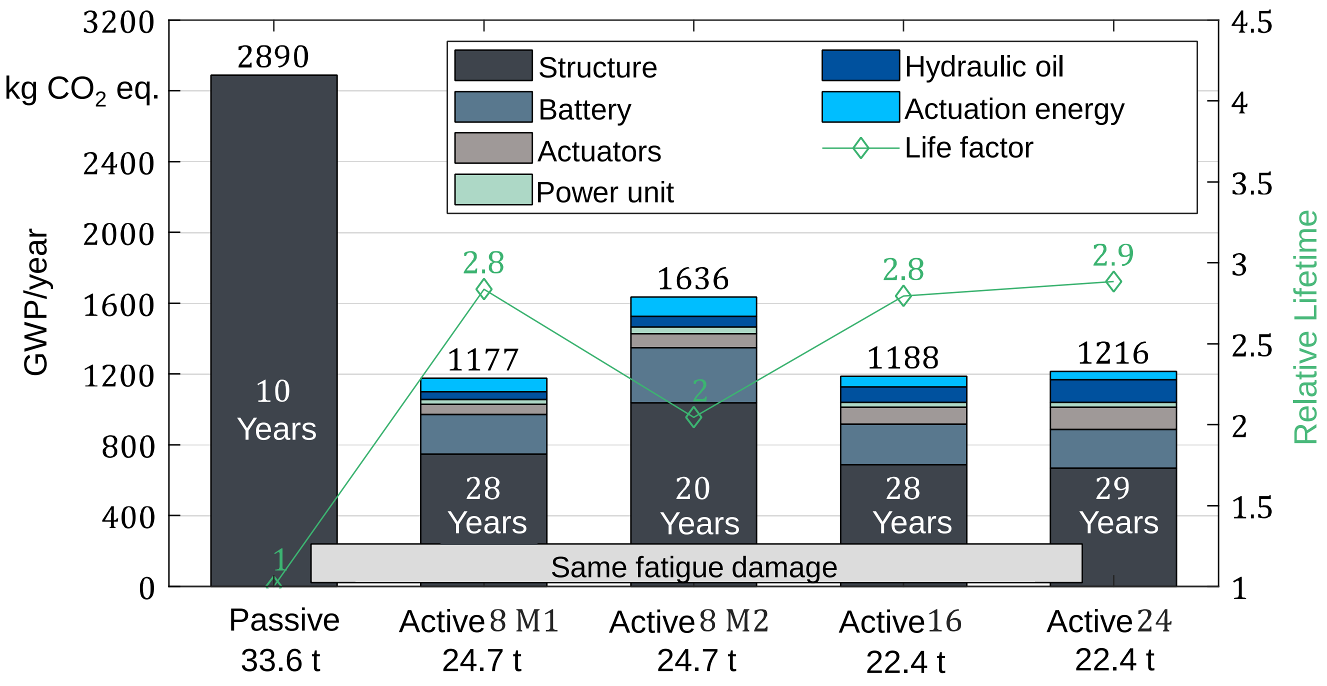
Designing an adaptive high rise structure

Comparison of the different variants



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6 Conclusion

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Summary & Conclusion

- Reliability is one of the key factors to develop high quality products
- High performance reliability methods using smart data can be used to identify optimal product designs
- Bayes Theorem can reduce uncertainty for efficient reliability demonstration
- Reliability methods are generally applicable

University of Stuttgart
Institute of Machine Components
Reliability Department

Thank you!

Dr.-Ing. Martin Dazer

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