Solder Joint Reliability, Uncertainty Quantification and Probability of Failures of eWLB Radar Packages

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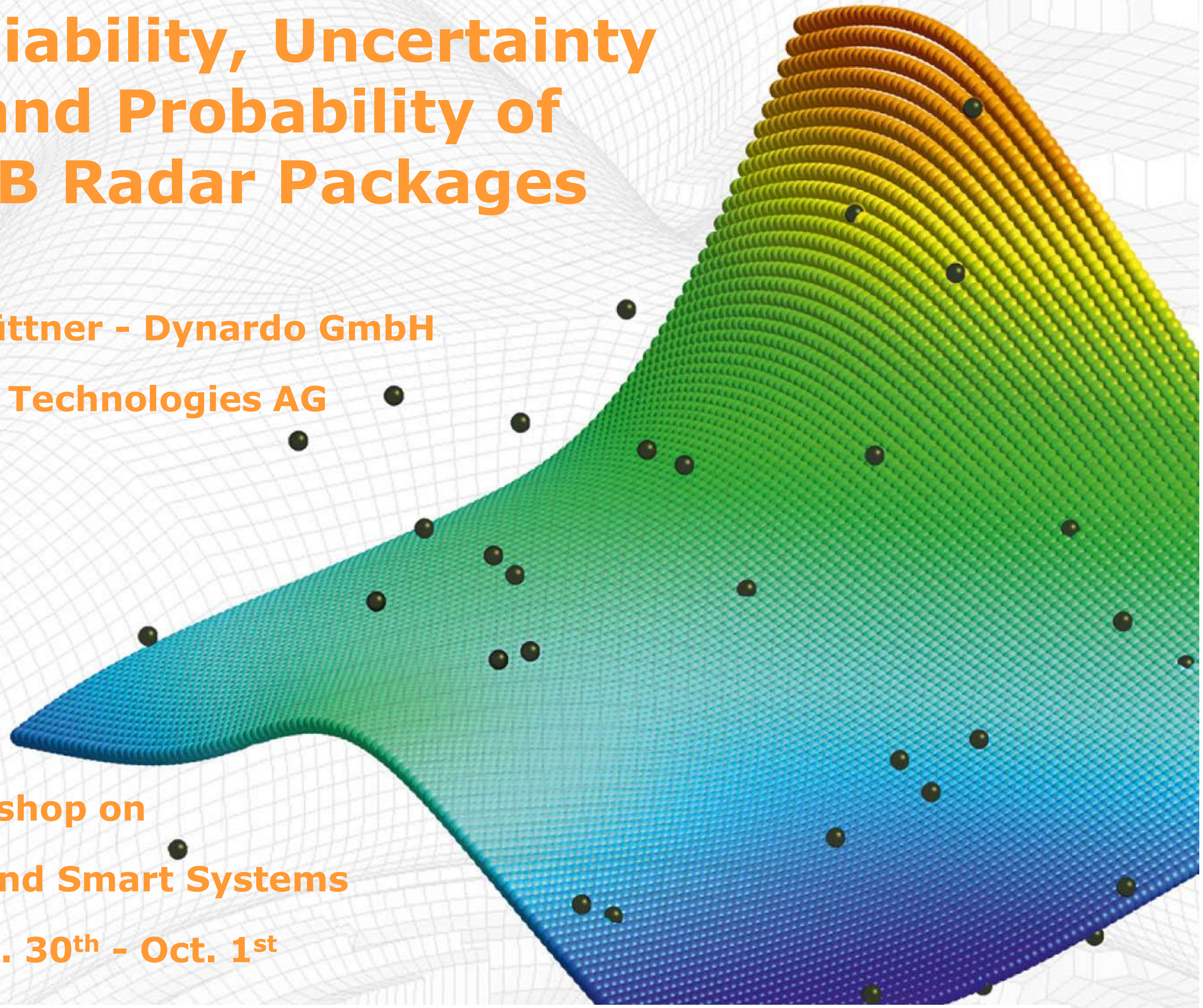


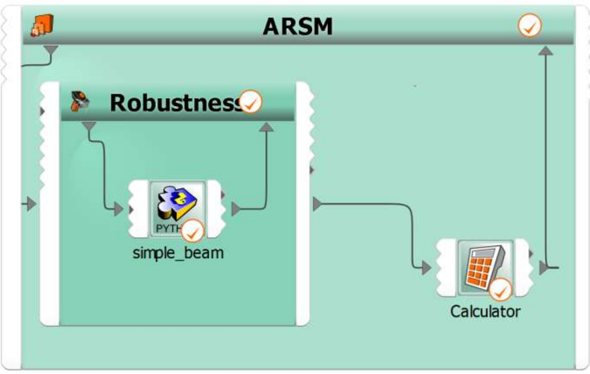
7th European Expert Workshop on

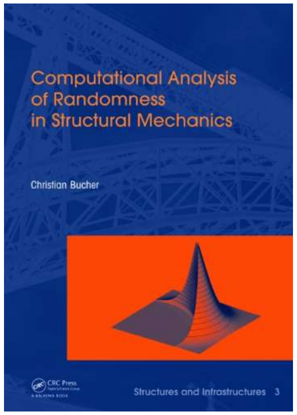
Reliability of Electronics and Smart Systems

2019 EuWoRel; Berlin Sep. 30th - Oct. 1st

Reliability and the Probability of Failure

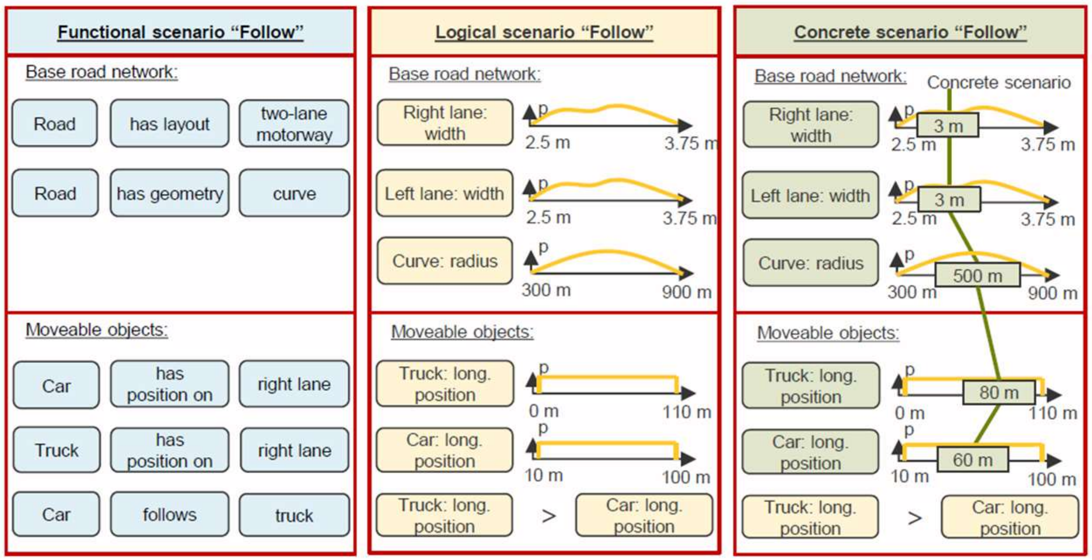
- Optimization is introduced into virtual prototyping for more than 20 years
- Robustness evaluation and reliability analysis are key methodologies for safe, reliable and robust products
- The combination leads to robust design optimization (RDO) strategies

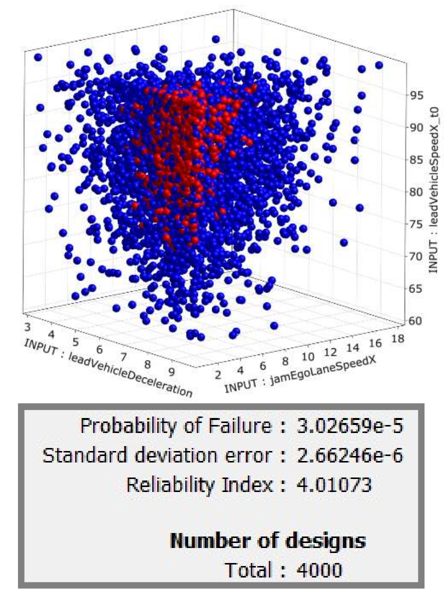




- The complementary of reliability is the probability of failure. This can be computed taking into account the scattering, variations of the input.
- Applications for example in ADAS, Microelectronics, ...:
  - Driving Scenarios
  - Solder Joint Fatique

Key findings presented at EuWoRel 2018
New Reliability Methodologies for Driving Scenarios





Source left picture: http://www.pegasusprojekt.de

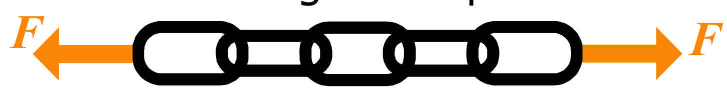
$$P(\text{crash}/\text{km}) = P(\text{crash} \mid \text{scenario}_1)P(\text{scenario}_1/\text{km}) + \cdots + P(\text{crash} \mid \text{scenario}_{rest})P(\text{scenario}_{rest}/\text{km})$$

- Improved understanding of scenarios by sensitivity analysis (i.e. possible analysis of control mechanisms, selection of important parameters)
- With advanced reliability methods the calculations of small probabilities of failures becomes feasible
- Appropriate scenario based automated workflows

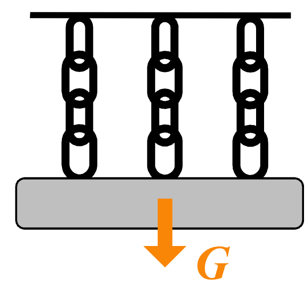
Source right picture: Rasch, M. et al: Safety Assessment and Uncertainty Quantification of Automated Driver Assistance Systems; NAFEMS World Congress, Quebec, 17-20 June 2019

Probability of Failure Calculations in Microelectronics

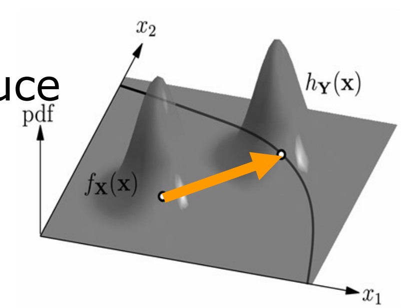
- The complementary of *Reliability* is the *Probability of Failure*
- This can be computed for different failure mechanism, like
  - Solder Joint Fatique (e.g. solder balls)
  - Delamination
  - Interconnect failure (e.g. wire lift-off inside package)
- Total Probability of Failure of the system depends on redundancy, dependencies for example
  - Series system: fails if one single component fails



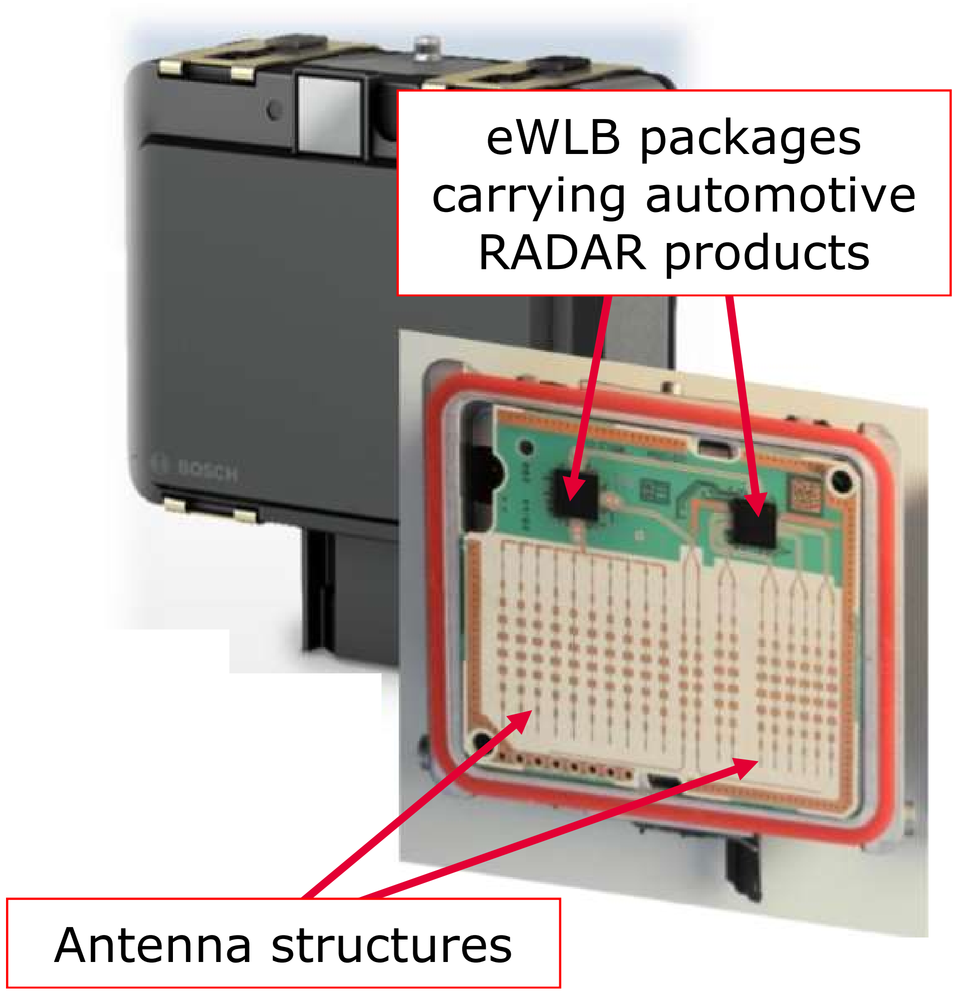
  - Parallel system: fails if all components fail



- Criteria need to be defined for the failure
  - This leads to limit state function(s)
  - Algorithms to detect this limit state function reduce the number of necessary simulation significantly

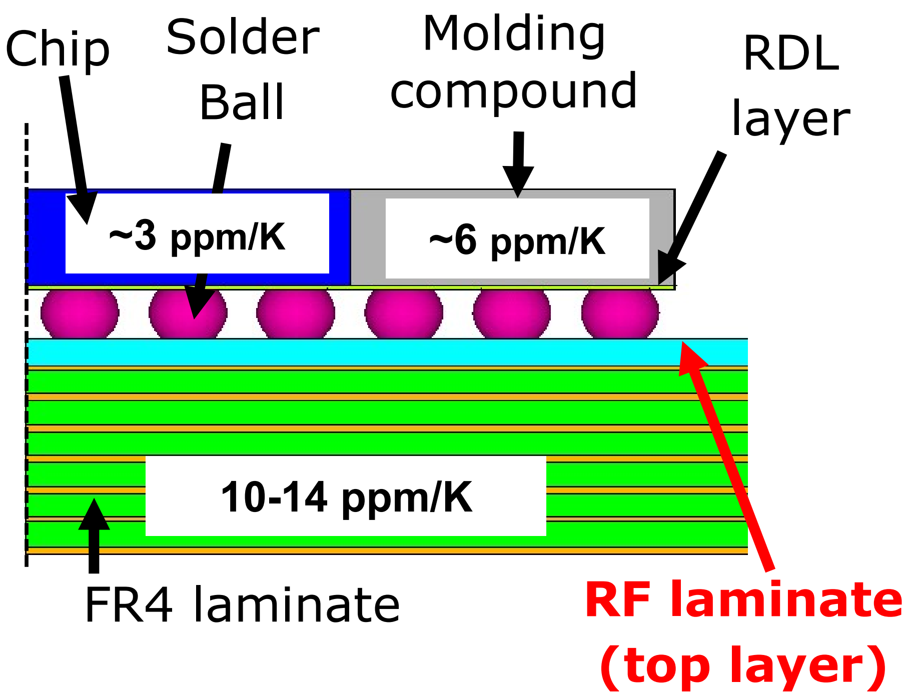


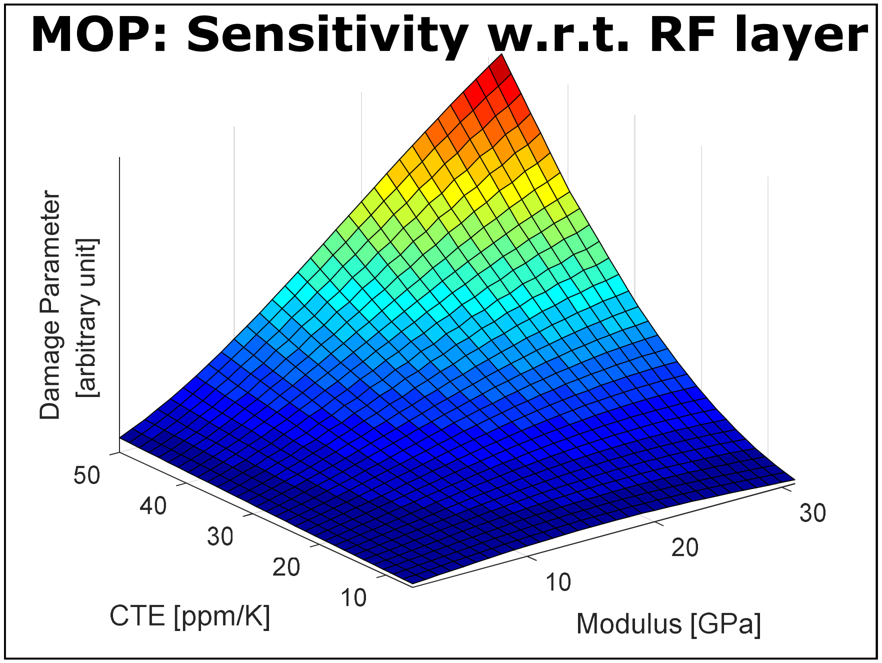
Investigated application
Automotive RADAR



Source: M. Eichhorst *et al.*, VII. SGW-Forum, 2019

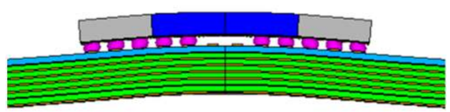
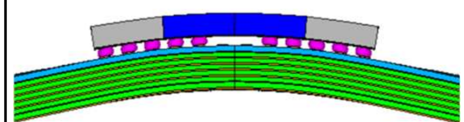
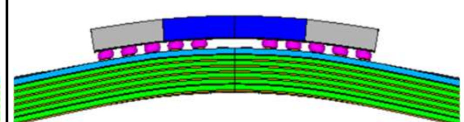
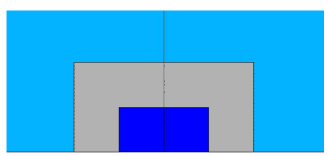
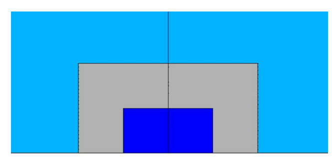
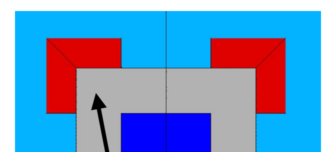
Key findings EuWoRel 2018
Solder joint reliability of eWLB radar package



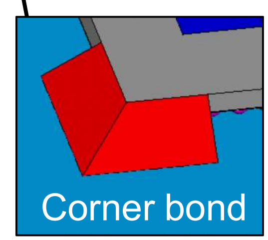


- **Summary of sensitivity study:**
  - For low CTE, the RF laminate generates a “CTE transition” between the PCB and the package
  - For low E modulus, the RF laminate becomes a “buffer layer”
- **Findings from sensitivity study were experimentally verified**

Next steps in EuWoRel 2019
Investigation using MOP along value chain

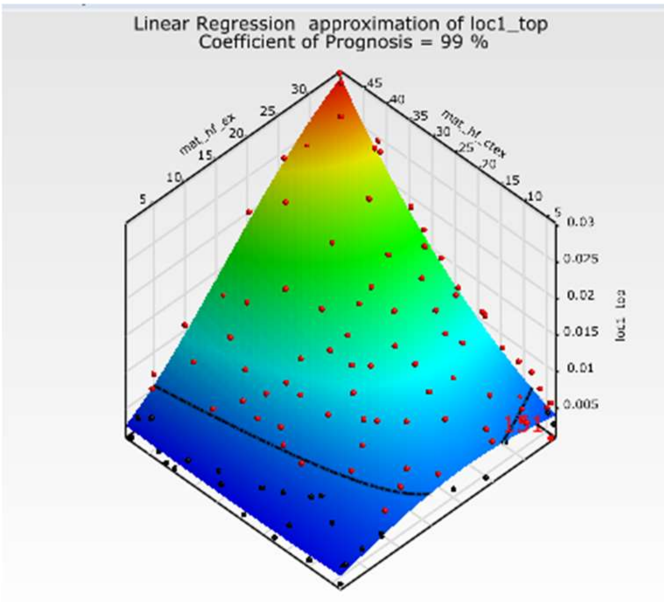
Case	#1	#2	#3
Situation	Tier1 type reliability test	Tier2 type module loading	Tier2 type module loading + improvement
Cyclic loading condition	Temperature	Temperature + bending	Temperature + bending
View of deformation during loading	 100x over-scaled	 100x over-scaled	 100x over-scaled
Top view (half model)			

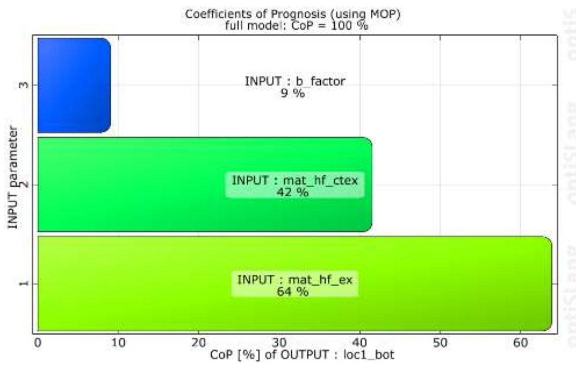
› MOPs are used for studying the solder joint reliability along the value chain, especially regarding the RF material design space

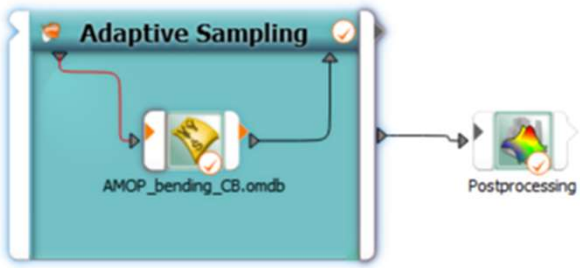


Metamodel of Optimal Prognosis (MOP)

- Selection of the **important variables** by sensitivity indices
- Determination of **best surrogate model** without overfitting
- Objective measure of **prognosis quality**
- Fast **Optimization** based on MOP
- Fast ***Reliability Analysis*** based on MOP







MOP Surface: Case 3 with b_factor = 1.5; isoline loc1_top = 0.0055

Probability of Failure at a constant damage limit level

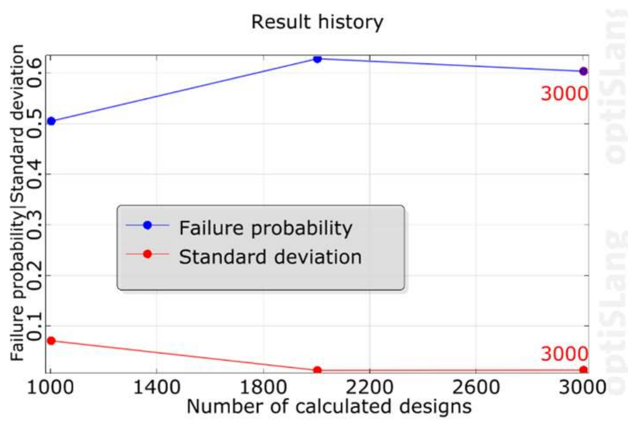
using uniform distribution across full design space

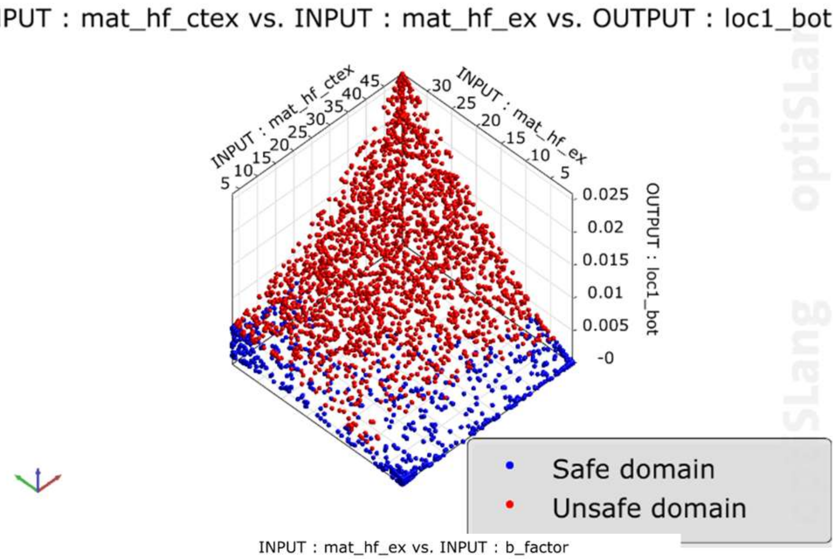
Method : Adaptive Sampling (AS)

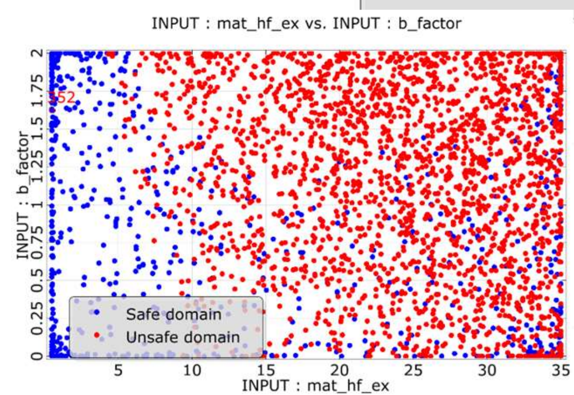
Complete iterations : 3 / 3
Selected data : All designs

Probability of Failure : 0.603392
Standard deviation error : 0.01331
Reliability Index : -0.262136

Number of designs
Total : 3000
Safe domain : 810
Unsafe domain : 2190
Failure strings : 0
Failed : 0







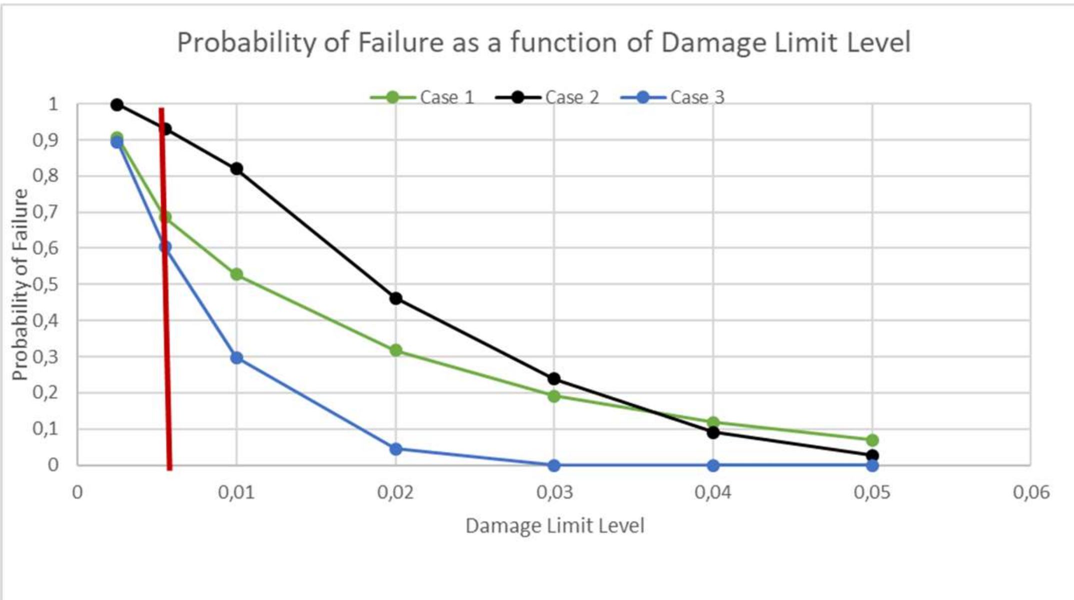
Limit State Function defined by loc1_top < 0.0055
Reliability Algorithm: Adaptive Sampling
Probability of Failure for whole design space with uniform distribution Case 1: 0,69; Case 2: 0,95; Case 3: 0,60
for Case 3 displayed: Reliability Information, Cloud plot, Result History and Anthill Plot

Probability of Failure as a function of damage limit level using uniform distribution across full design space

Adaptive Sampling

Parameter | Start designs | Nominal design | Criteria | Adaptive Sampling | Other | Result de

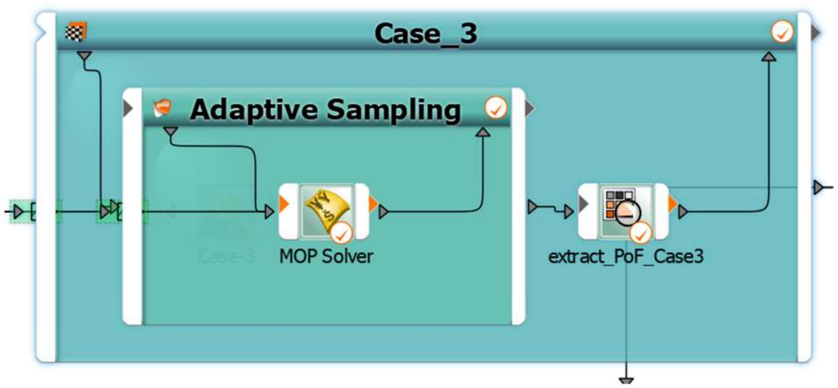
	Name	Parameter type	Reference value	PDF	Type	Distribution parameter
1	b_factor	Stochastic	1		UNIFORM	0; 2
2	mat_hf_ctex	Stochastic	26.5		UNIFORM	3; 50
3	mat_hf_ex	Stochastic	17.75		UNIFORM	0.5; 35

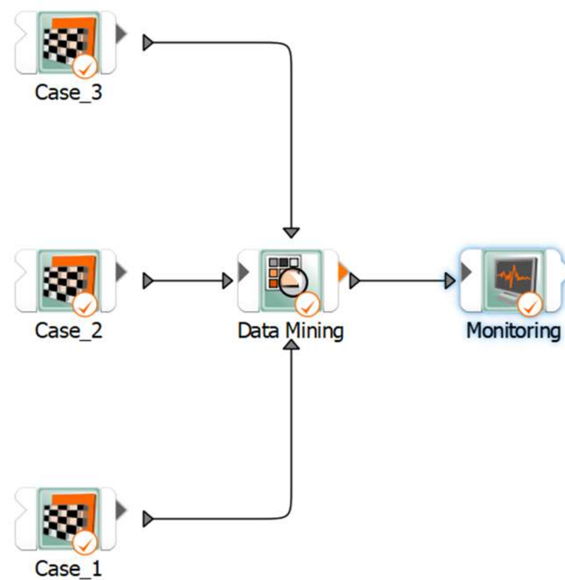


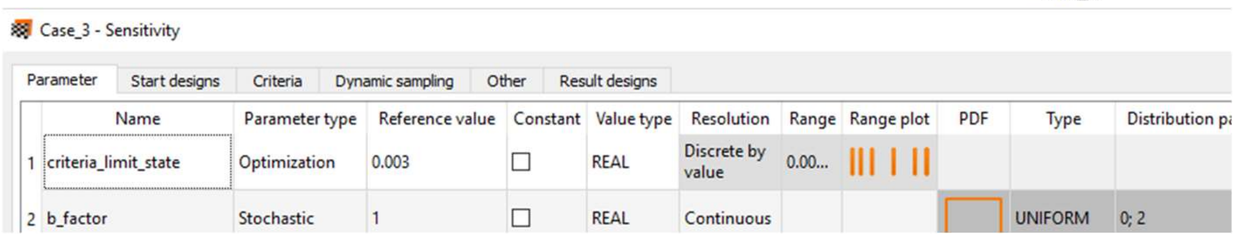
Higher damages are much more probable in Case 2 than in Case 3

Automated Workflows for Reliability Analyses

- Using Reliability Methods Integrated in Workflows
- Loop over threshold values to calculate Probability of Failure curves
- Branches for different cases
- Data Mining to extract relevant information
- Customized Visualization







Case_3 - Sensitivity

Parameter | Start designs | Criteria | Dynamic sampling | Other | Result designs

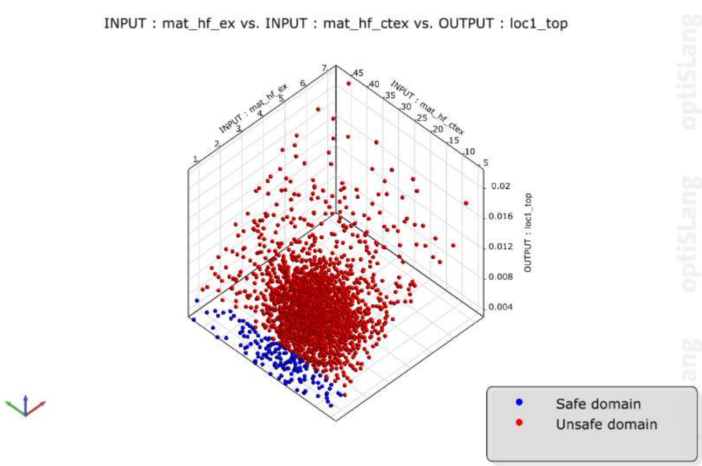
	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range	Range plot	PDF	Type	Distribution pa
1	criteria_limit_state	Optimization	0.003	☐	REAL	Discrete by value	0.00...				
2	b_factor	Stochastic	1	☐	REAL	Continuous				UNIFORM	0; 2

Specific Design Point with a Probability Distribution - Walking on the unsafe side, Case 2

Adaptive Sampling

Parameter | Start designs | Nominal design | Criteria | Adaptive Sampling | Other | Result designs

	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range		Range plot	PDF	Type	Mean	Std. Dev.	CoV	Distribution para
1	b_factor	Optimization	1.5	☑	REAL	Continuous	0	2							
2	mat_hf_ctex	Opt.+Stoch.	21	☐	REAL	Continuous	3	50			NORMAL	21	6.3	30 %	21; 6.3
3	mat_hf_ex	Opt.+Stoch.	2	☐	REAL	Continuous	0.5	35			NORMAL	2	0.6	30 %	2; 0.6



Method : Adaptive Sampling (AS)

Complete iterations : 3 / 3
Selected data : All designs

Probability of Failure : 0.920722
Standard deviation error : 0.00766578
Reliability Index : -1.40994

Number of designs
Total : 3000
Safe domain : 149
Unsafe domain : 2456
Failure strings : 0
Failed : 395

Criteria

Name	Type	Expression	Criterion	Limit	Evaluated expression
lim_st_loc1_top	Limit state	loc1_top	≤	0.0055	0.00830161 ≤ 0.0055

Assuming the b_factor of 1.5 in Case 2 we have a design on the unsafe side

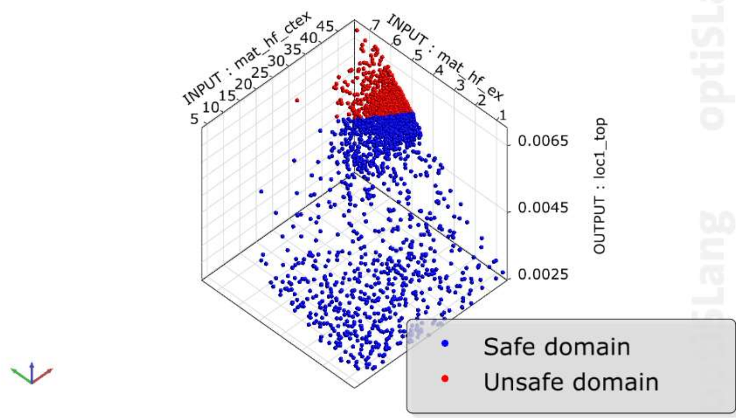
Same Design Point with same Probability Distribution - Walking on the safe side, Case 3

Adaptive Sampling

Parameter | Start designs | Nominal design | Criteria | Adaptive Sampling | Other | Result designs

	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range		Range plot	PDF	Type	Mean	Std. Dev.	CoV	Distribution parameter
1	b_factor	Optimization	1.5	☑	REAL	Continuous	0	2							
2	mat_hf_ctex	Opt.+Stoch.	21	☐	REAL	Continuous	3	50			NORMAL	21	6.3	30 %	21; 6.3
3	mat_hf_ex	Opt.+Stoch.	2	☐	REAL	Continuous	0.5	35			NORMAL	2	0.6	30 %	2; 0.6

INPUT : mat_hf_ctex vs. INPUT : mat_hf_ex vs. OUTPUT : loc1_top



Method : Adaptive Sampling (AS)

Complete iterations : 3 / 3
Selected data : All designs

Probability of Failure : 1.65916e-12
Standard deviation error : 1.36946e-13
Reliability Index : 6.96354

Number of designs
Total : 3000
Safe domain : 1443
Unsafe domain : 644
Failure strings : 0
Failed : 913

Criteria

Name	Type	Expression	Criterion	Limit	Evaluated expression
lim_st_loc1_top	Limit state	loc1_top	≤	0.0055	0.00298585 ≤ 0.0055

Algorithm using MOP detects with only 3000 runs very low probability of failure: 1.7 * 10^{-12}

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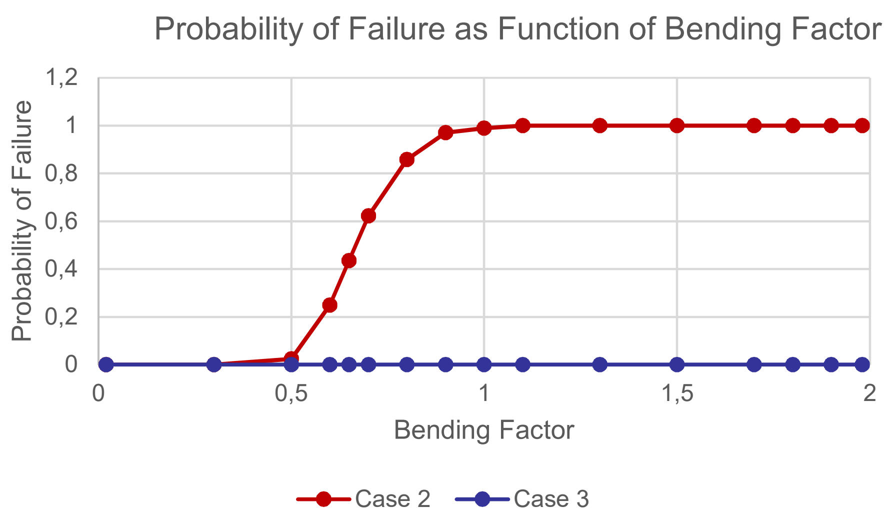
Examples of Fragility Curves:

Studying the Probability of Failure in dependance of important parameters for a specific design



Parameter | Start designs | Nominal design | Criteria | Adaptive Sampling | Other | Result designs

	Name	Parameter type	Reference value	Constant	PDF	Type	Mean	CoV
1	mat_hf_ex	Opt.+Stoch.	2	☐		NORMAL	2	10 %
2	mat_hf_ctex	Opt.+Stoch.	21	☐		NORMAL	21	10 %

Specific design with mean E, CTE const.; Gaussian distribution; CoV 10%; bending factor varying from 0 to 2; limit level loc1_top = 0.0055

Summary and Outlook

- *Superior reliability using additional corner bonds is shown by the reliability analysis*
- *The probability of failure has been used in calculations as the complementary of reliability*
- *This analysis has been done based on MOP as an example for a possible important exchange mechanism between companies*
- *Efficient workflows are developed using the MOP that can be used for simulation runs to calculate probability of failures based directly from simulation runs (i.e. detailed analysis for transition regions, verification)*
- *Fragility Curves are useful to understand the design behavior*

Future possible research include extension of Fragility Curves to several dimensions: Metamodels of Probabilities of Failures

High quality Metamodels of Probabilities of Failures can be an essential component for Digital Twins

Thank you for your attention!