Neue Entwicklungen in LS-OPT 4.0
– Ausblick auf Version 4.1

New Developments in LS-OPT 4.0 – Outlook V4.1

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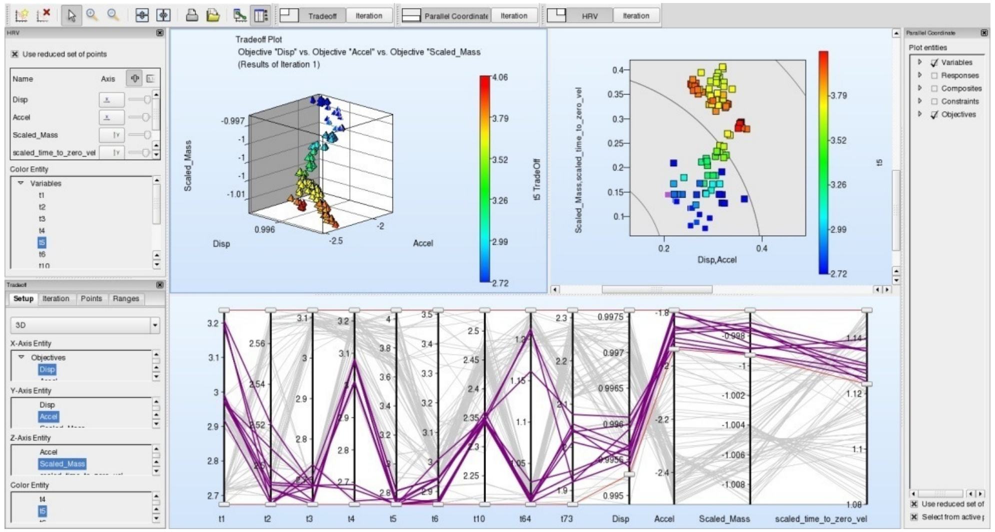
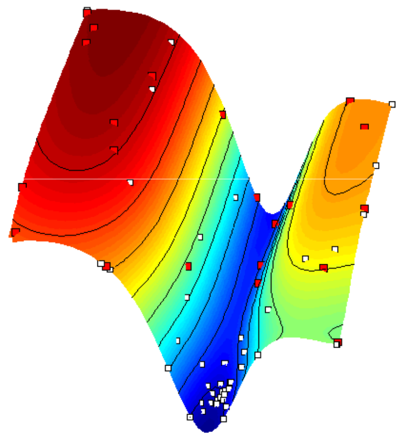
Overview

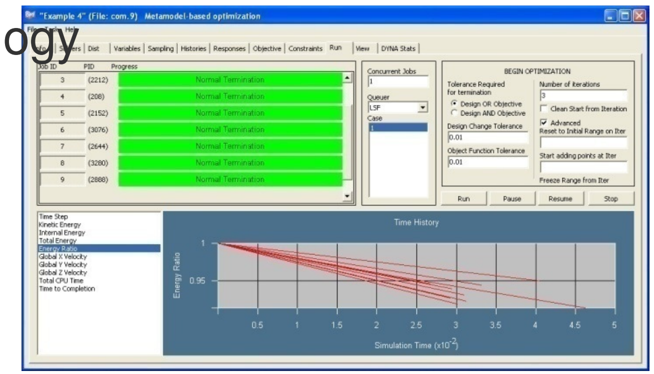
- Introduction/Features of current Version 4.0
- Methodologies – Optimization
- Methodologies - Robustness
- Examples - Optimization
- Examples – Robustness
- Outlook Version 4.1



About LS-OPT

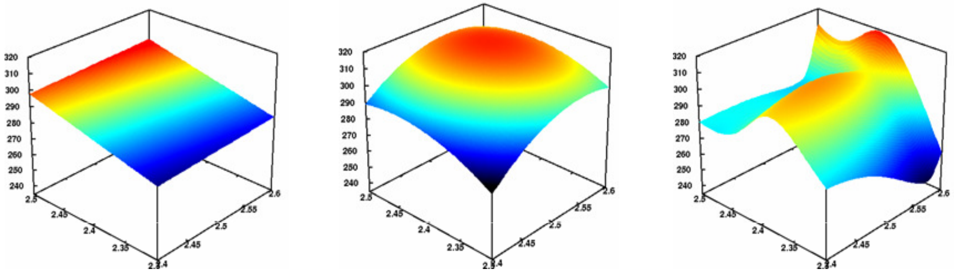
- LS-OPT is a product of LSTC, current version: V4.0
  - *major new release with many new feature particularly within the viewer (visualization of results) → next presentation "Methoden zur Visualisierung von Ergebnissen aus Optimierungs- und DOE-Studien"*
- Beta version 4.1 available by end of this year
- LS-OPT can be linked to any simulation code – stand alone optimization software
- Perfect suitable in combination with LS-DYNA
- Two main products LS-OPT and LS-OPT/Topology



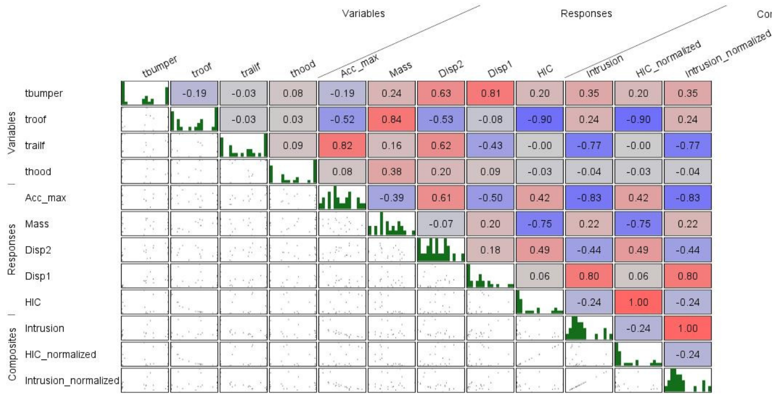


LS-OPT – Overview Methodologies

- Successive Response Surface Method (SRSM)
- Meta-Models
  - *Polynomials*
  - *Radial Basis Functions*
  - *Neural Nets (FFNN)*

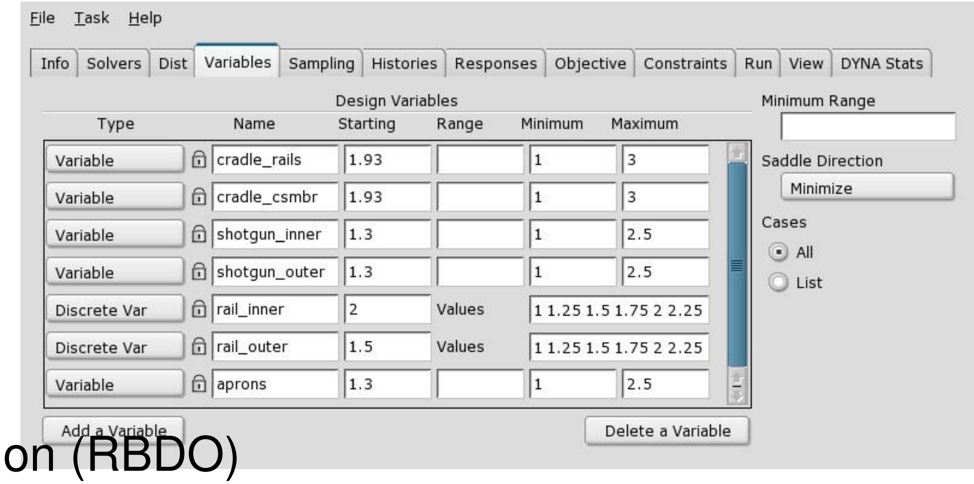


- Genetic Algorithm (MOGA->NSGA-II)
- Multidisciplinary optimization (MDO)
- Multi-Objective Optimization (Pareto Front)
- DOE-Studies (ANOVA, Sobol)
- Parameter/System Identification
- Stochastic/Probabilistic Analysis
- Monte Carlo Analysis using Meta-Models



LS-OPT – Overview Methodologies

- Mixed Discrete-Continous Optimization
    - *Specify sets of discrete variables (e.g. sheet thicknesses)*

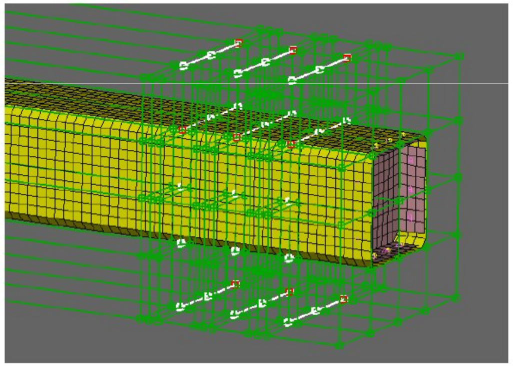


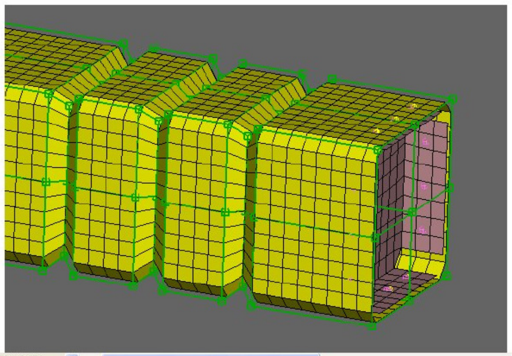
- Robust Parameter Design (RDO)
    - *Improve/Maximizing the robustness of the optimum*
- Reliability Based Design Optimization (RBDO)
    - *Improve failure probability of optimum*
- Visualization of Stochastic Results
    - *Confidence Intervals, reliability quantities*
    - *Fringe of statistic results on the FE-Model*

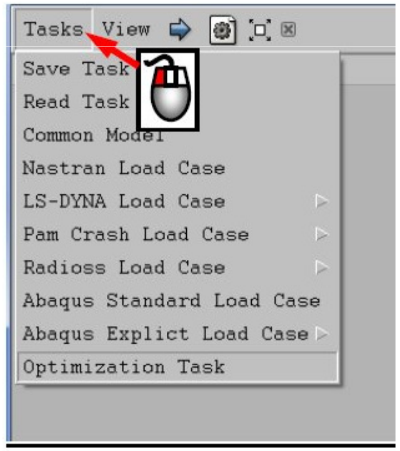
Introduction / Features

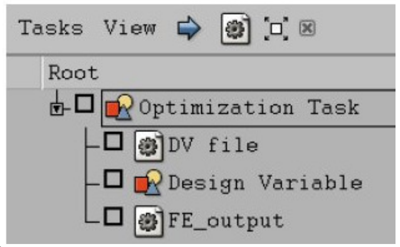
About LS-OPT

- Job Distribution - Interface to Queuing Systems
  - *PBS, LSF, LoadLeveler, SLURM, AQS, etc.*
  - *Retry of failed queuing (abnormal termination)*
- LS-OPT might be used as a “Process Manager”
- Shape Optimization
  - *Interface to **ANSA**, HyperMorph, DEP-Morpher, SFE-Concept*
- META Post interface
  - *Allows extraction of results from any package (Abaqus, NASTRAN, …) supported by META Post (ANSA package)*





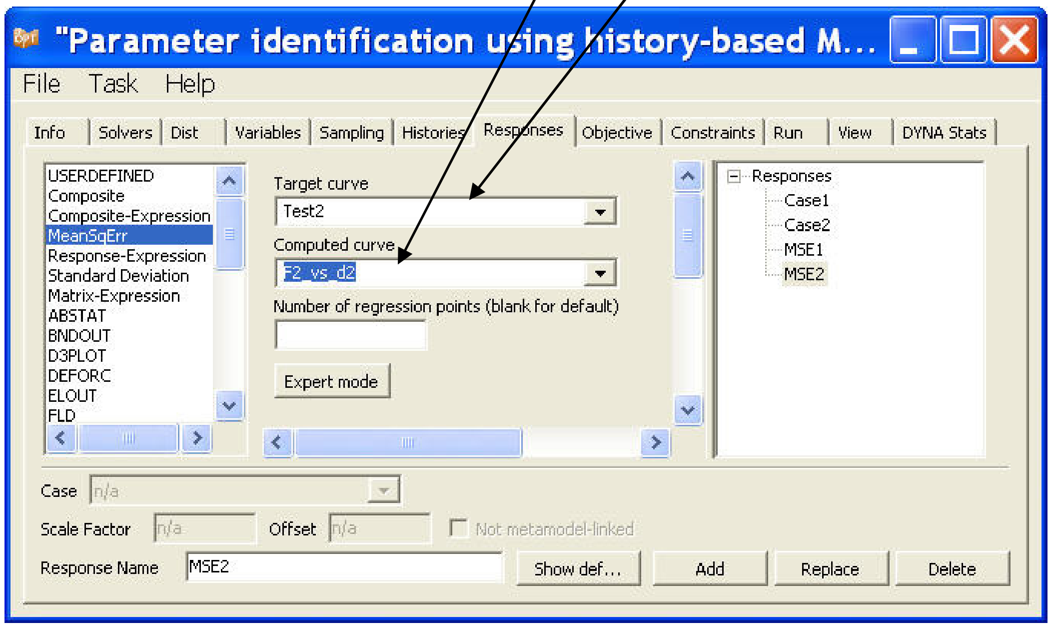




About LS-OPT

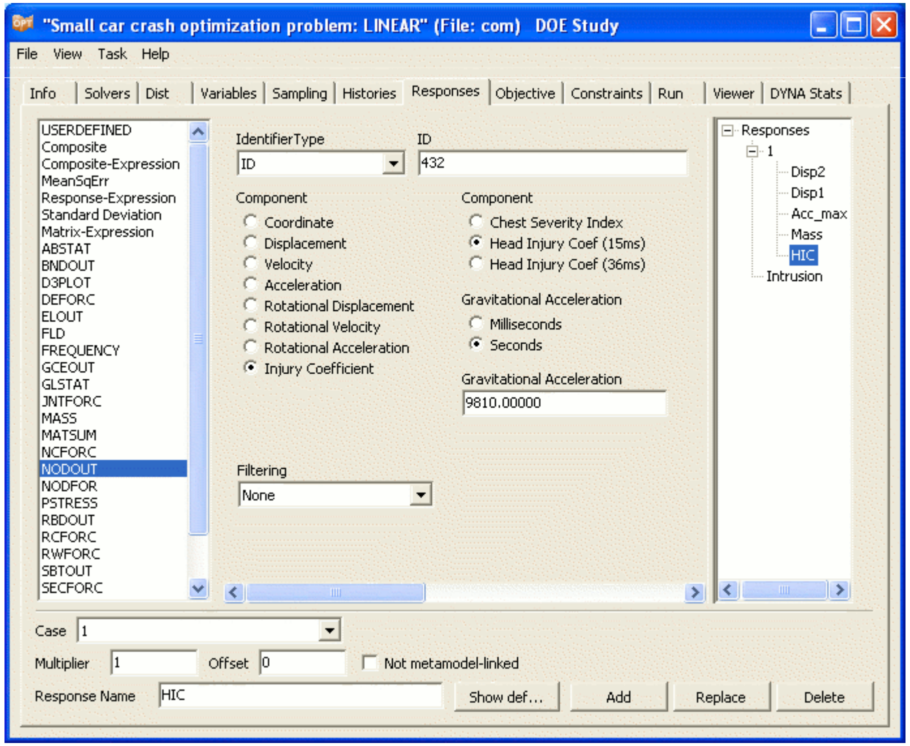
- Parameter Identification Module
  - *Handles "continuous" test curves*
  - *Automated use of test results to calibrate materials/systems*
  - *Simplify input for system identification applications*
  - *Visualization of test and simulation curve to compare*
  - *Confidence intervals for individual parameters in parameter identification*

$$\frac{1}{P}\sum_{p=1}^{P} W_i \left(\frac{F_i(\mathbf{x})-G_i}{s_i}\right)^2$$



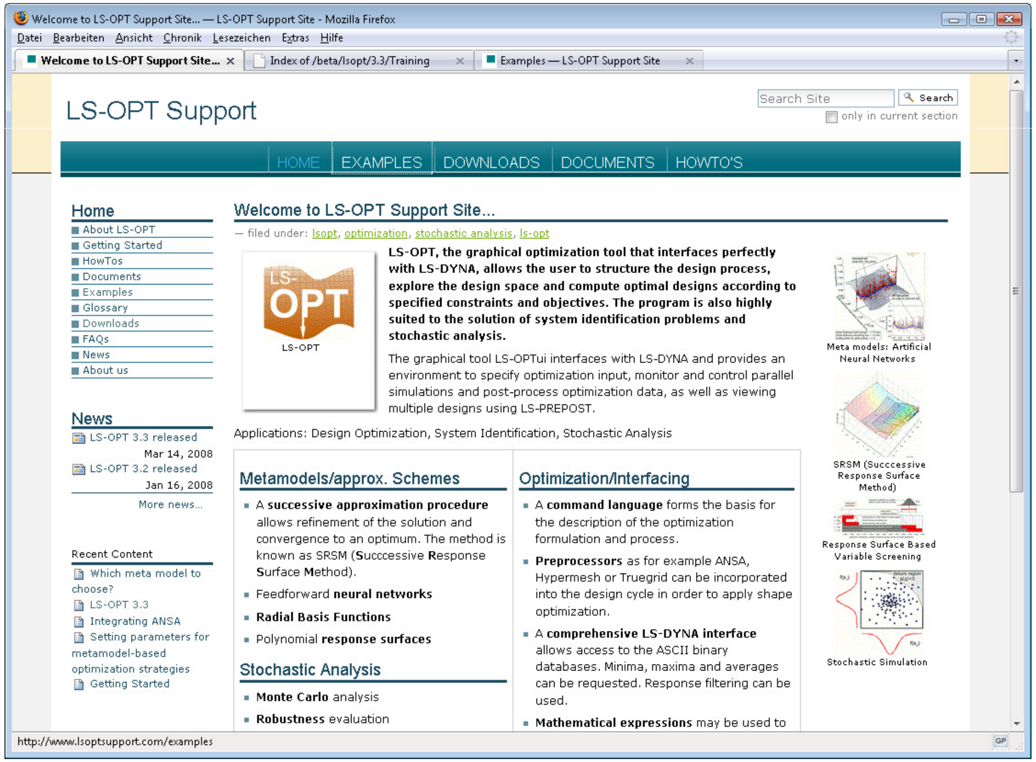
About LS-OPT

- LS-DYNA Integration
  - *Checking of Dyna keyword files (*DATABASE_)*
  - *Importation of design parameters from Dyna keyword files (*PARAMETER_)*
  - *Monitoring of LS-DYNA progress*
  - *Result extraction of most LS-DYNA response types*
  - *D3plot compression (node and part selection)*

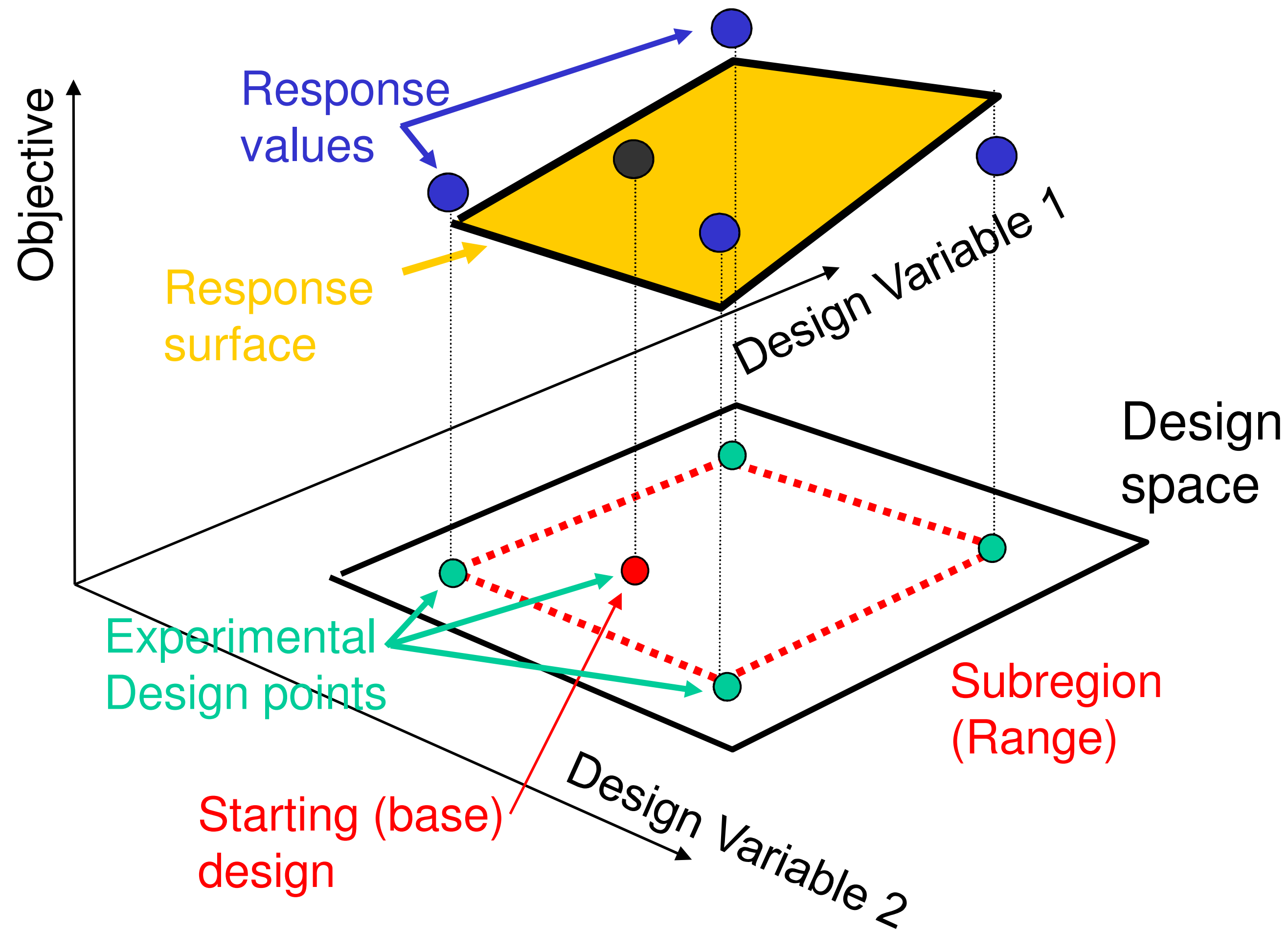


About LS-OPT

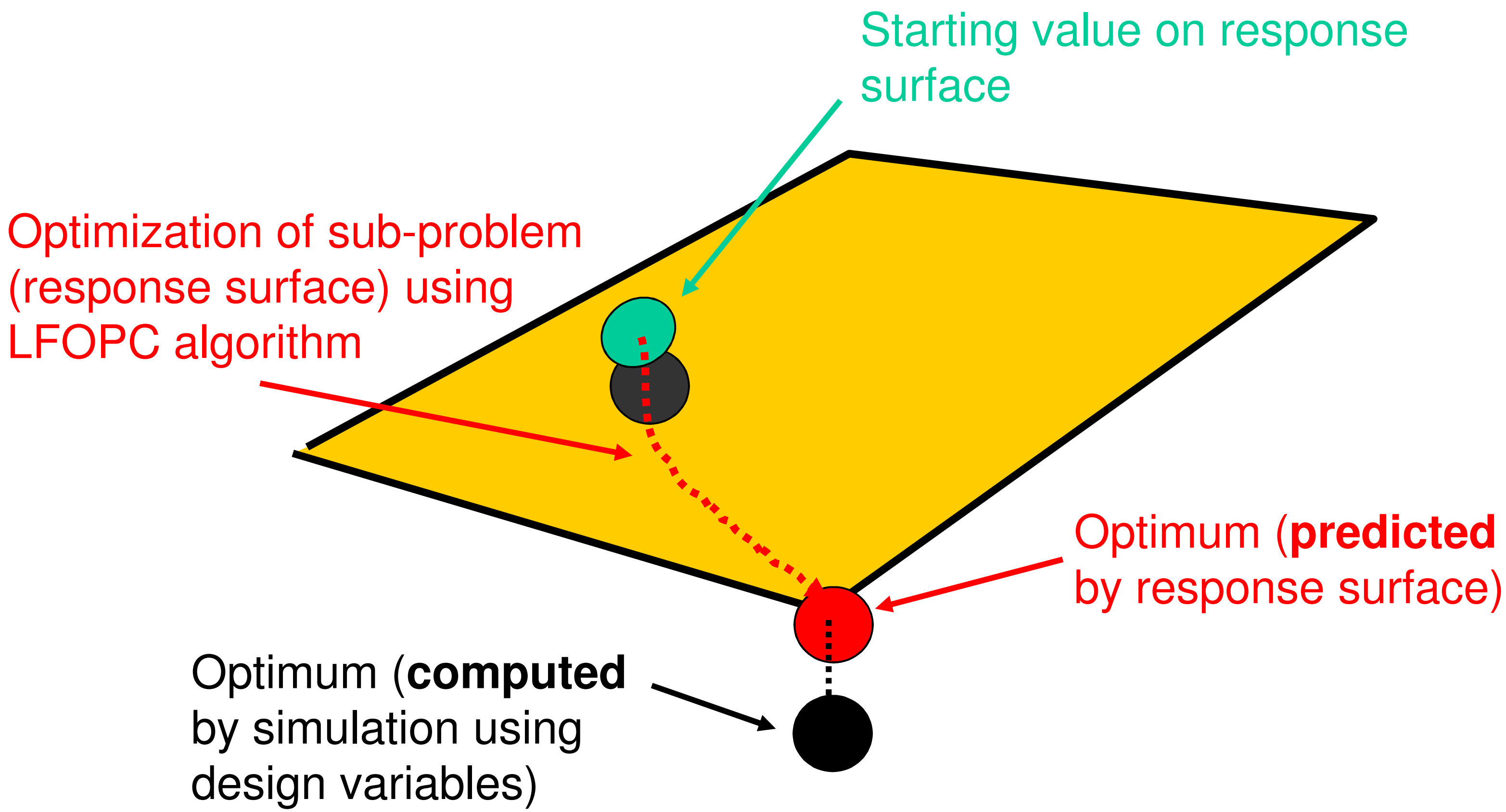
- LS-OPT Supportwebpage -> www.lsoptsupport.com
  - *Many examples, tutorials, FAQs, HowTos…*



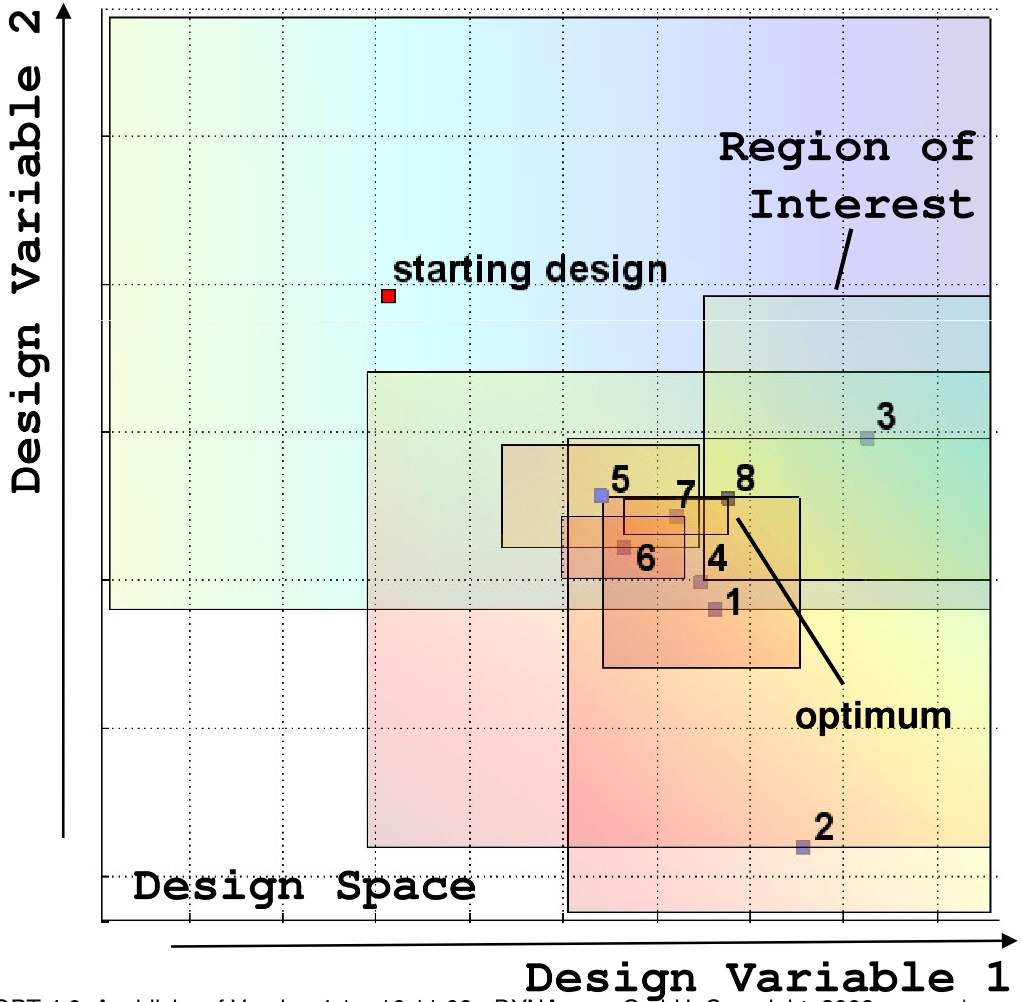
Response Surface Methodology - Optimization Process



Find an Optimum on the Response Surface (one iteration)



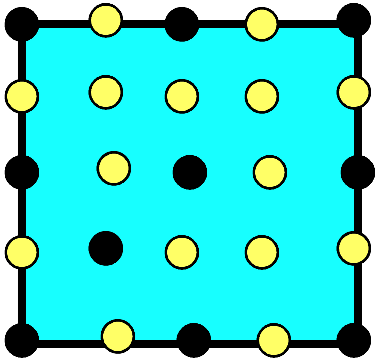
Successive Response Surface Methodology



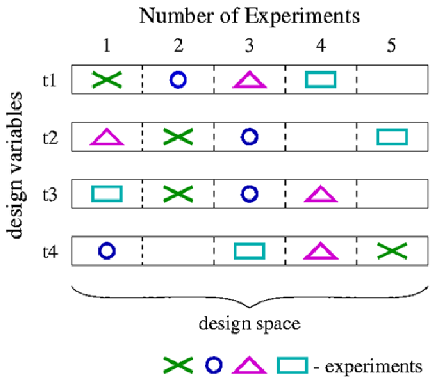
Design of Experiments (DOE) - Sampling Point Selection

- Koshal, Central Composite, Full Factorial
- D-Optimality Criterion - Gives maximal confidence in the model

$$\max \left| X^T X \right|$$

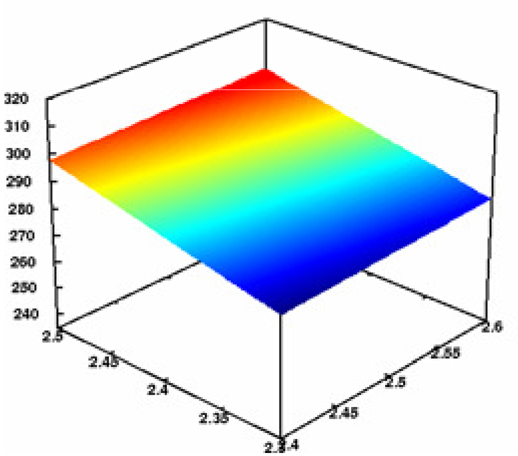


- Monte Carlo Sampling
- Latin Hypercube Sampling (stratified Monte Carlo)
- Space Filling Designs
- User Defined Experiments

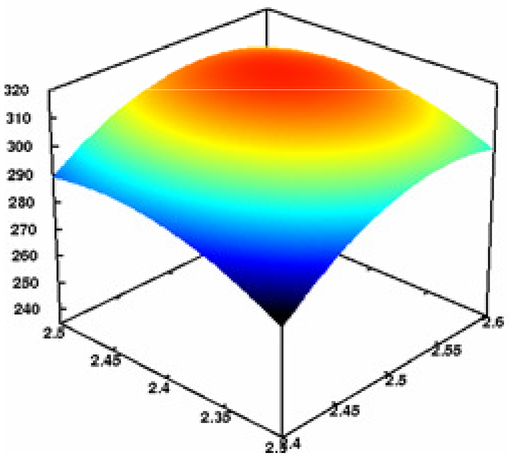


Response Surfaces (Meta Models)

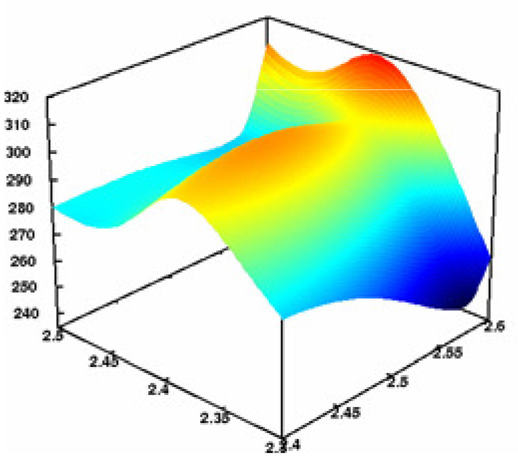
- Linear, Quadratic and Mixed polynomial based
- Radial Basis Functions, Feed Forward Neural Networks and Kriging for global approximations



linear polynomial



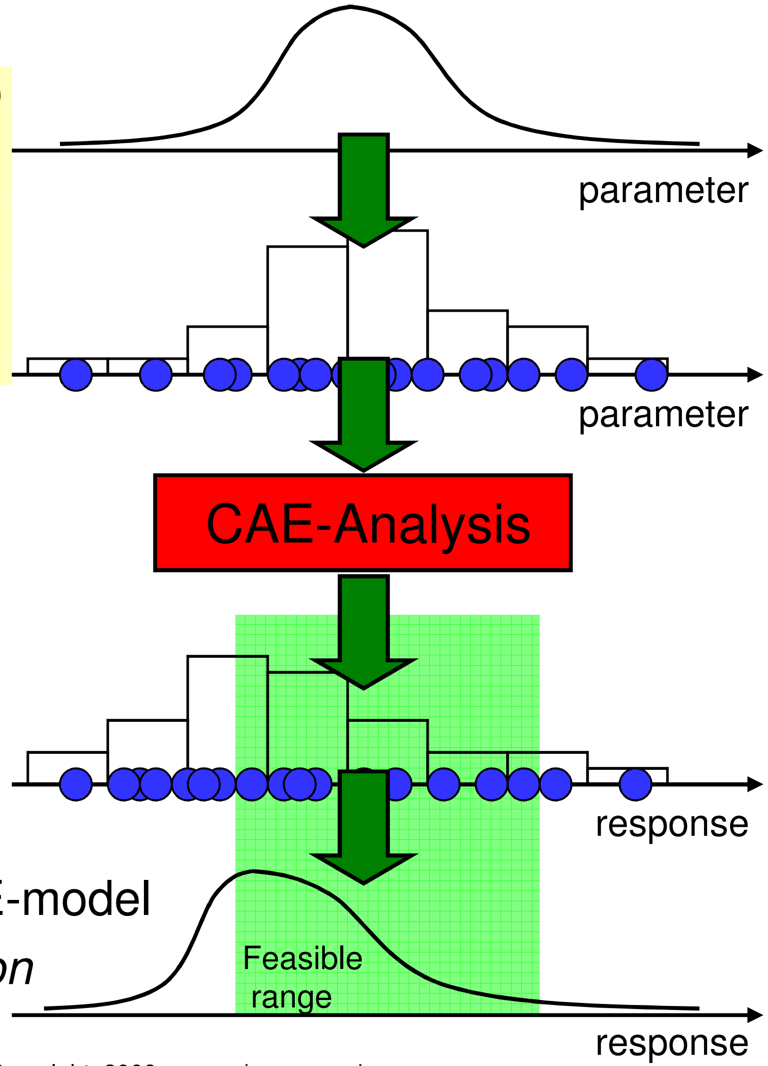
quadratic polynomial



neural network

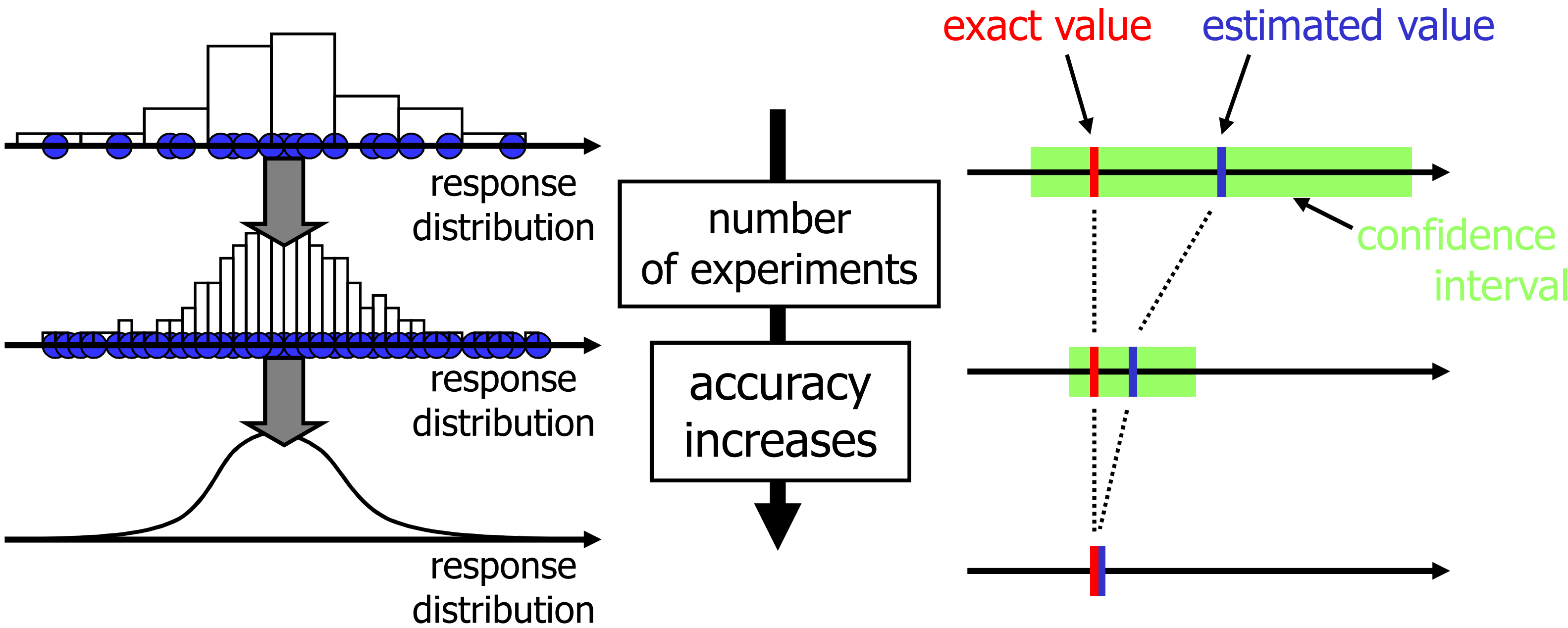
Stochastic Analysis - Goals

- Statistical Quantities of Output (Response) due to Variation of Input (Parameter)
  - *Mean*
  - *Standard deviation*
  - *Distribution function*
- Significance of Parameter with respect to Responses
  - *Correlation analysis*
  - *Stochastic contributions*
  - *ANOVA – analysis of variance*
- Reliability Issues
  - *Probability of failure*
- Visualization of statistical quantities on FE-model
  - *Spatial detection of variation/correlation*



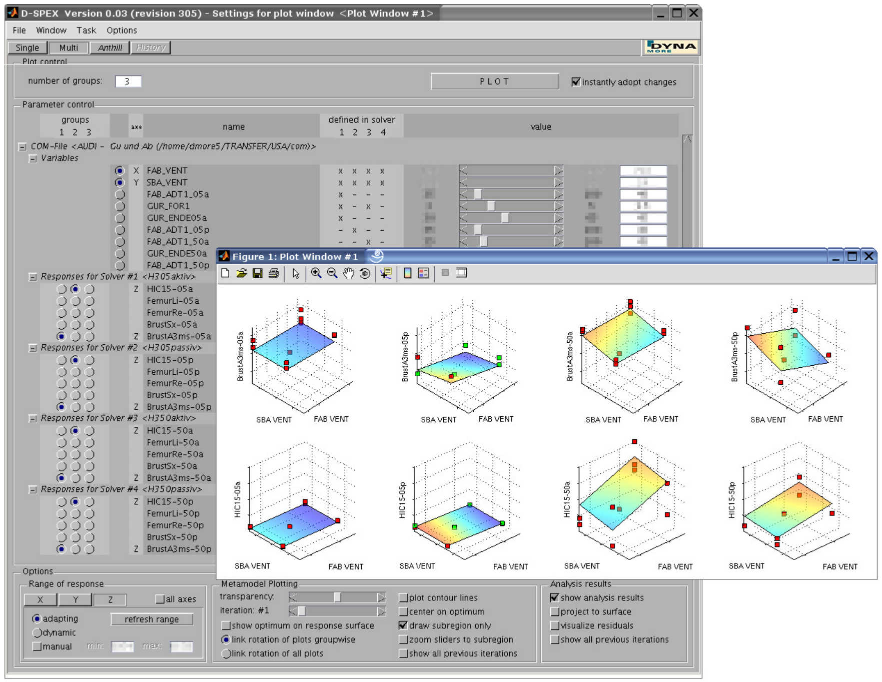
Statistical Quantities of Output due to Variation of Input

- Direct Monte Carlo Sampling
  - *Latin Hypercube sampling*
  - *Large number of FE runs (100+)*
  - *Consideration of confidence intervals for mean, std. dev., correlation coeff.*



Statistical Quantities of Output due to Variation of Input

- Monte Carlo using Meta-Models
  - *Response Surface / Neural Network*
  - *Medium number of FE runs (10 – 30+)*
  - *Number of runs depend on the dimension of the problem (number of variables) and the type of the response surface*
  - *Identify design variable contributions clearly*
  - *Exploration of parameter space ->D-SPEX*



Multi Meta-Model exploration with D-SPEX

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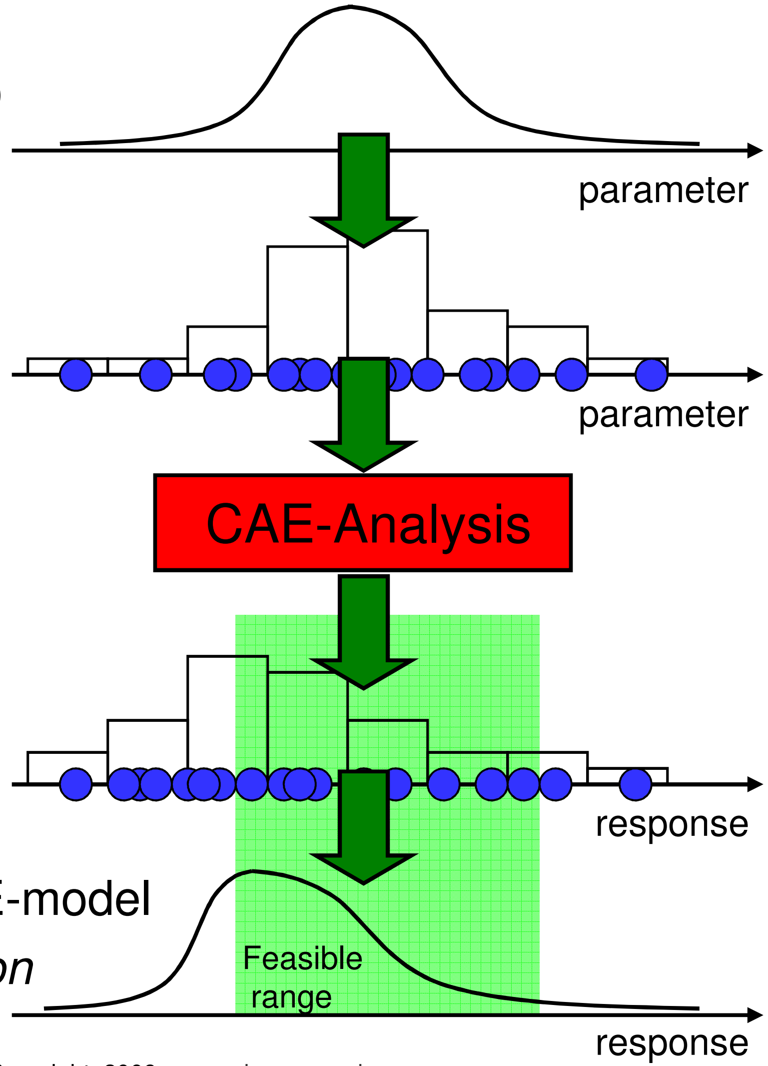
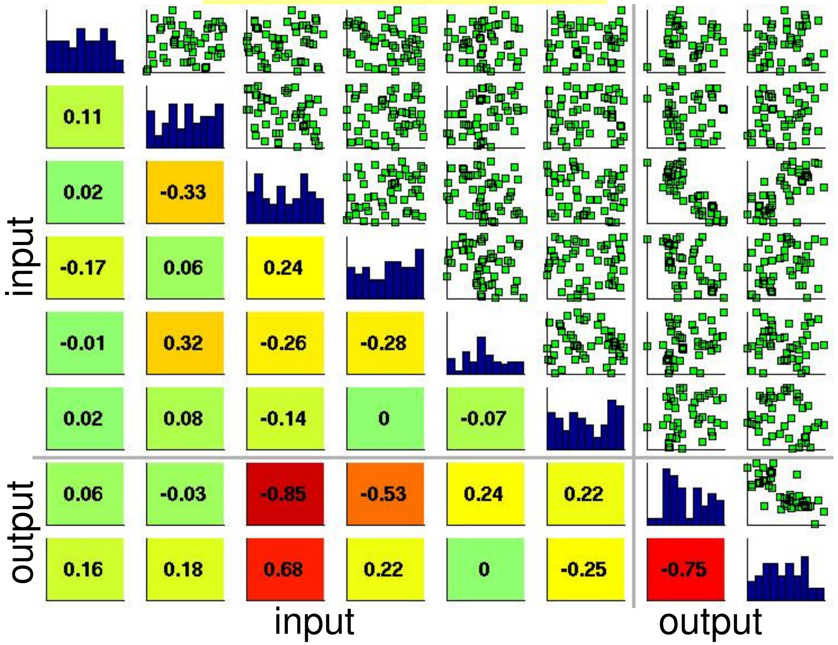
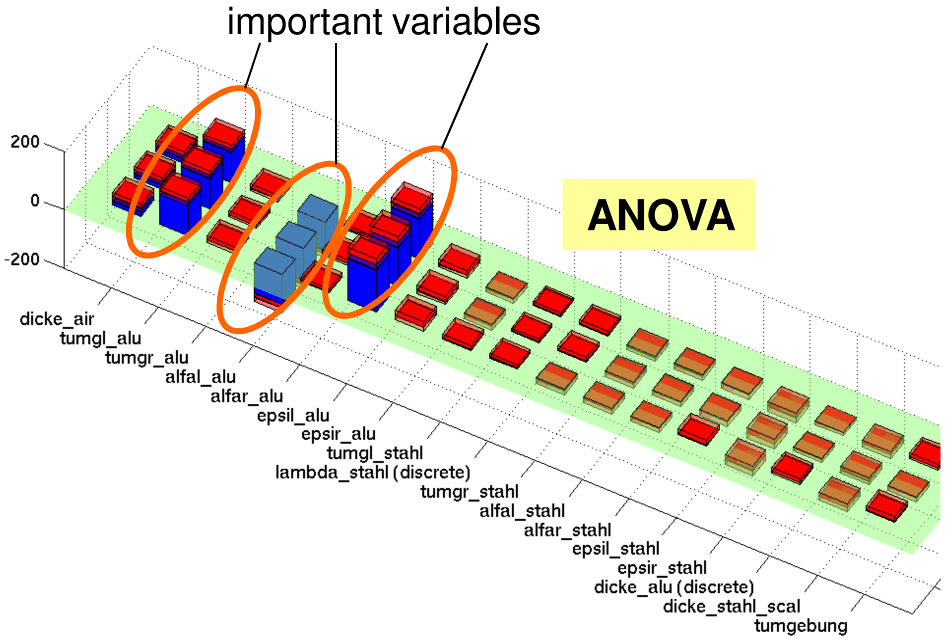


Significance of Variables

- Correlation Analysis
- ANOVA - Meta-Model based
- Stochastic Contributions – Meta-Model based

Correlation Matrix





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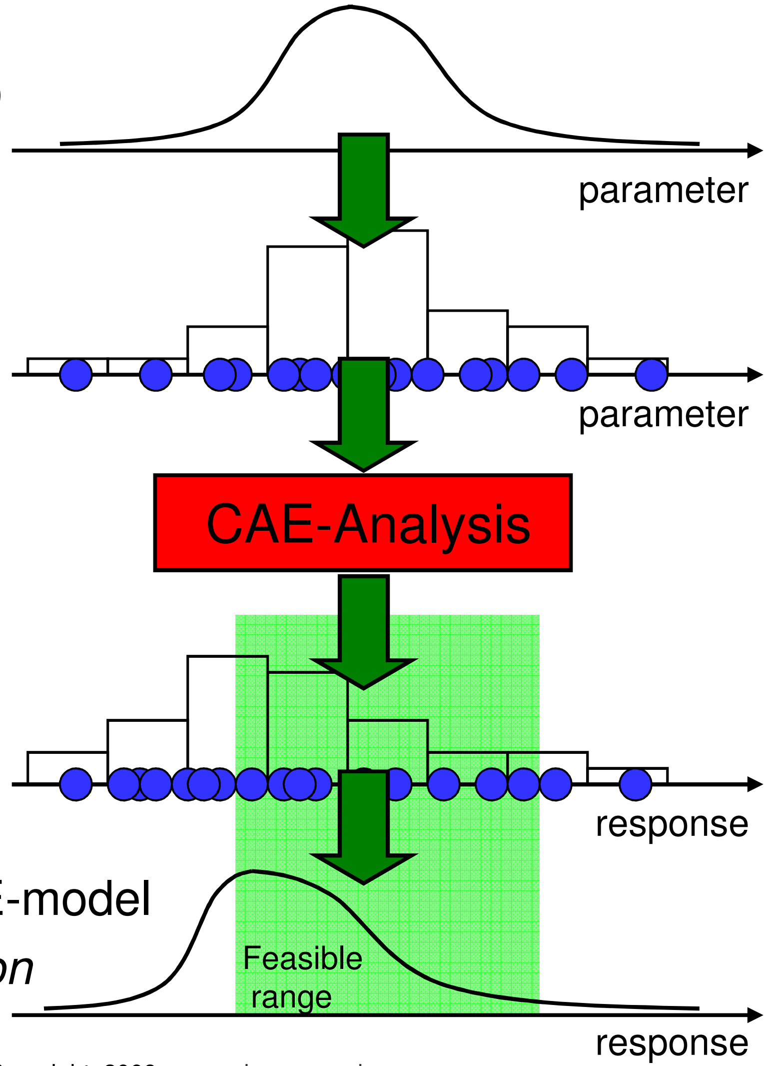
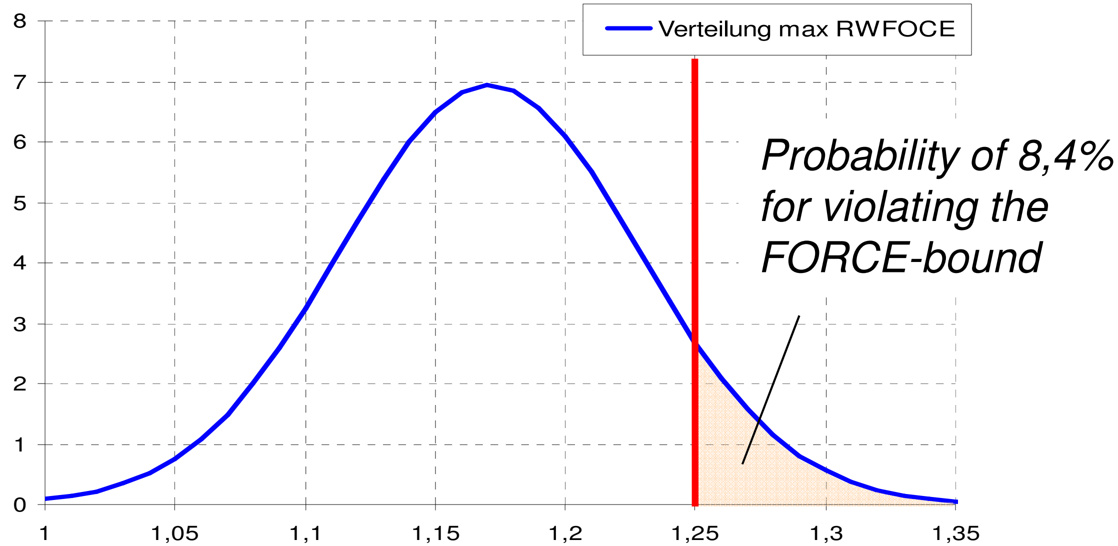


Reliability Analysis

- Probability of failure
- Evaluation of confidence interval
- Prediction error (confidence interval) depends
  - *on the number of runs*
  - *on the probability of event*
  - *not on the dimension of the problem (number of design variables)*



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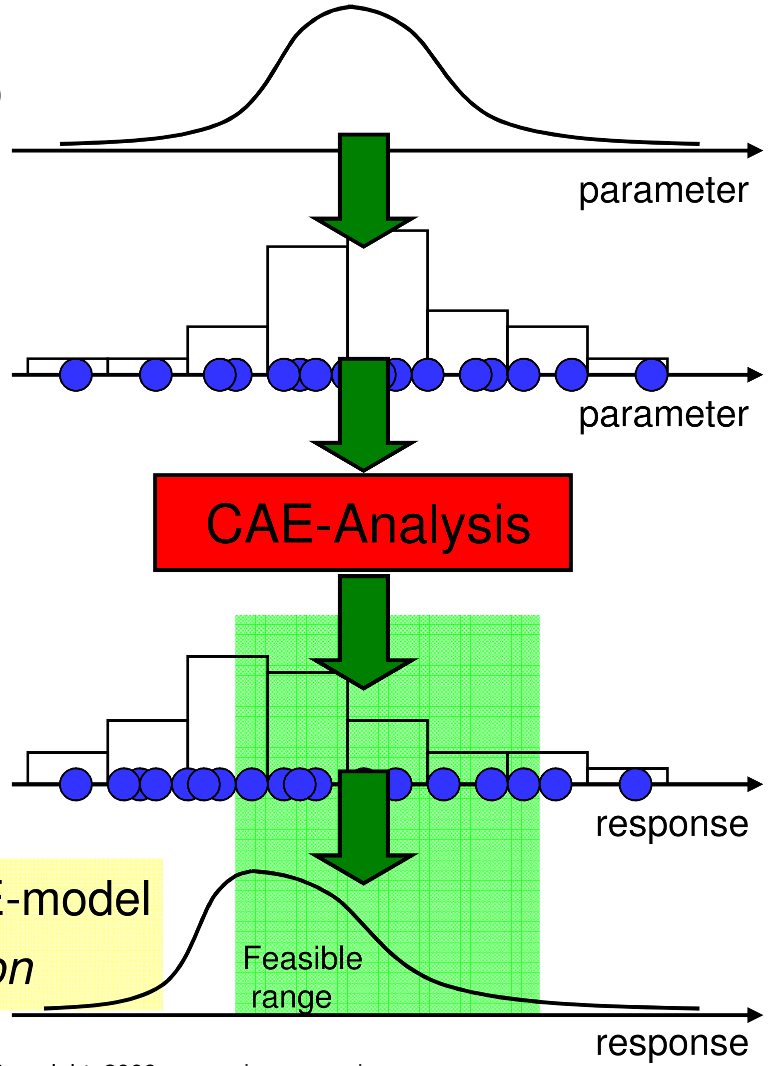
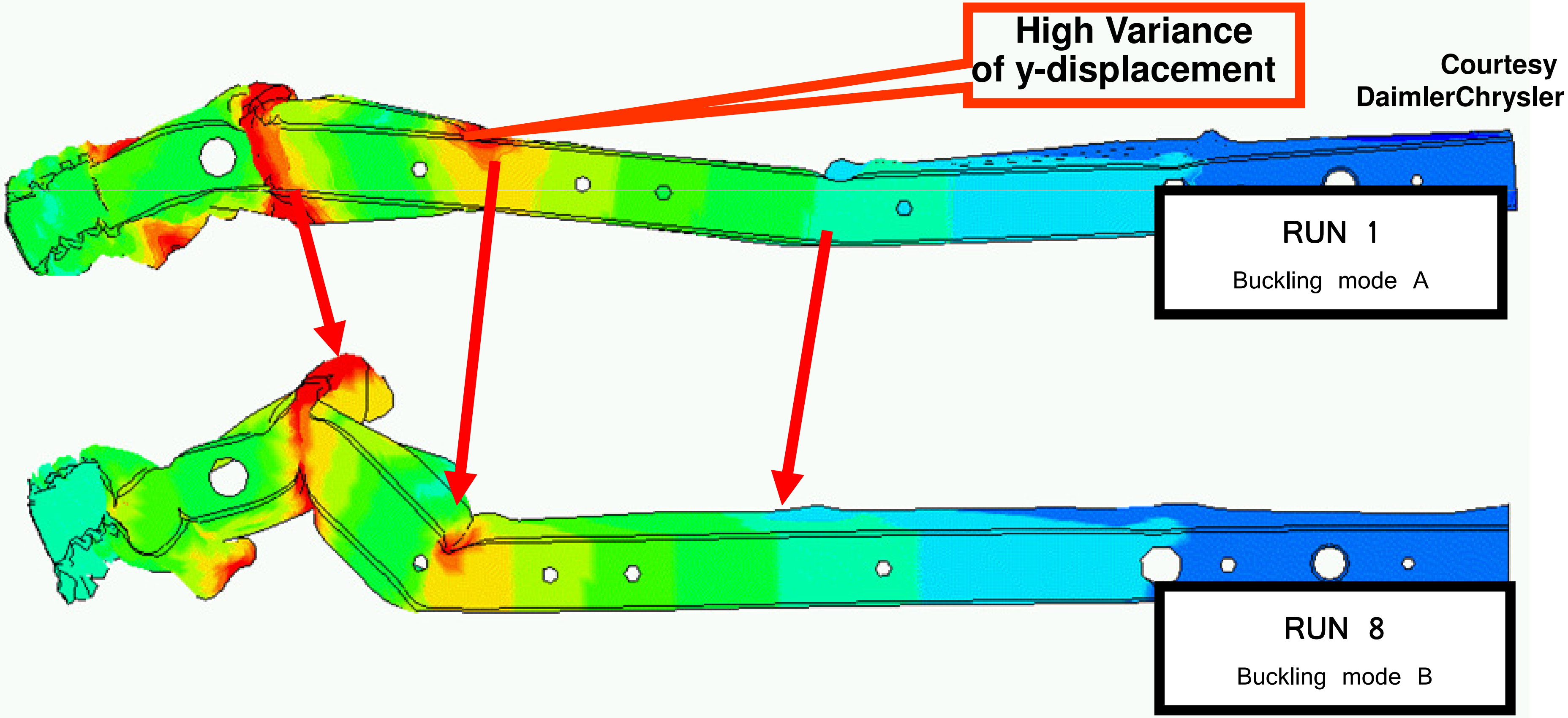


Visualization of Statistical Quantities on FE-model

- Standard deviation of y-displacements of each node (40 runs)

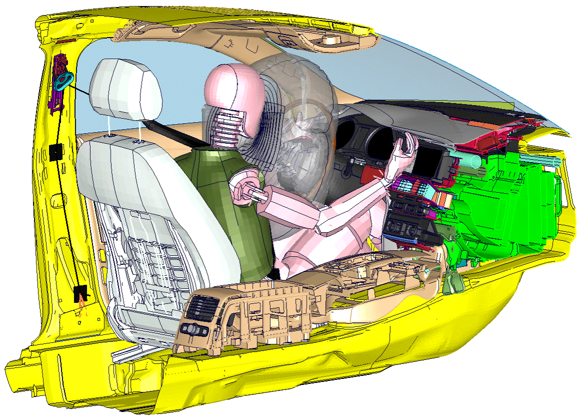


Optimization of an Adaptive Restraint System

- Four Different Front-Crash Load Cases (FMVSS 208)

Dummy	56 km/h – belted	40 km/h – not belted
Hybrid III 5th Female	**H305a**(ktiv)	**H305p**(assiv)
Hybrid III 50th Male	**H350a**(ktiv)	**H350p**(assiv)

- PAM-Crash Model
  - *about 500000 elements*
  - *wall clock simulation time ~19 h, 4 cpus, distributed memory*



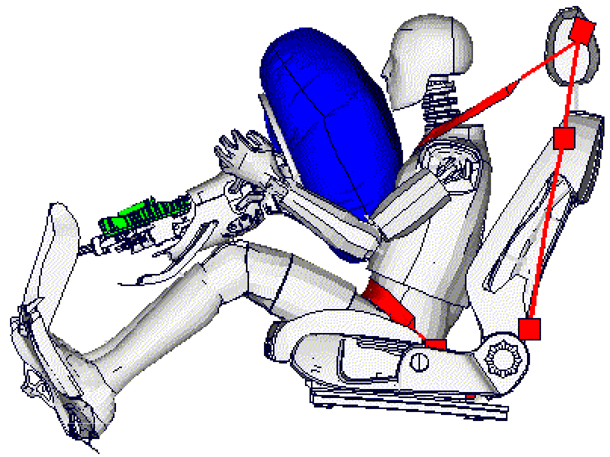
- Load Case Detection available
  - *Differentiation of the loadcases **belted** / **not belted** and **"Hybrid III 5th Female"** / **„Hybrid III 50th Male"** possible*
  - *Trigger time for seatbelt, airbag and steering column might be different*

Example I - Optimization

Optimization Problem

- Objective
  - *Minimize Thorax Acceleration*

```
-> min BrustA3ms-05a
-> min BrustA3ms-50a
-> min BrustA3ms-05p
-> min BrustA3ms-50p
```



- Constraints < 80% of regulation requirements
  - *Head Injury Coefficient (15ms)*

```
-> HIC15-05a
-> HIC15-50a
-> HIC15-05p
-> HIC15-50p
```

  - *Thorax Intrusion*

```
-> BrustSx-05a
-> BrustSx-50a
-> BrustSx-05p
-> BrustSx-50p
```

  - *Femur Forces (left/right)*

```
-> FemurLi-05a
-> FemurLi-50a
-> FemurLi-05p
-> FemurLi-50p
```

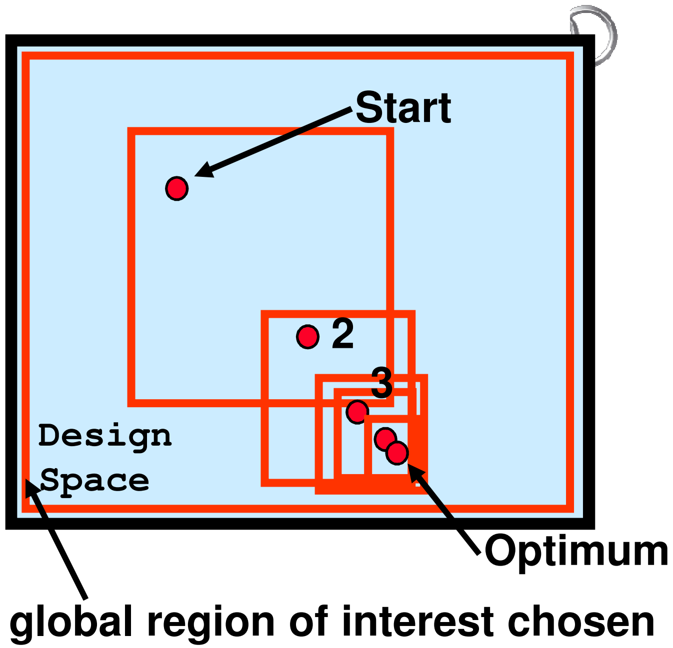
  - *Thorax Acceleration*

```
-> BrustA3ms-05a
-> BrustA3ms-50a
-> BrustA3ms-05p
-> BrustA3ms-50p
```

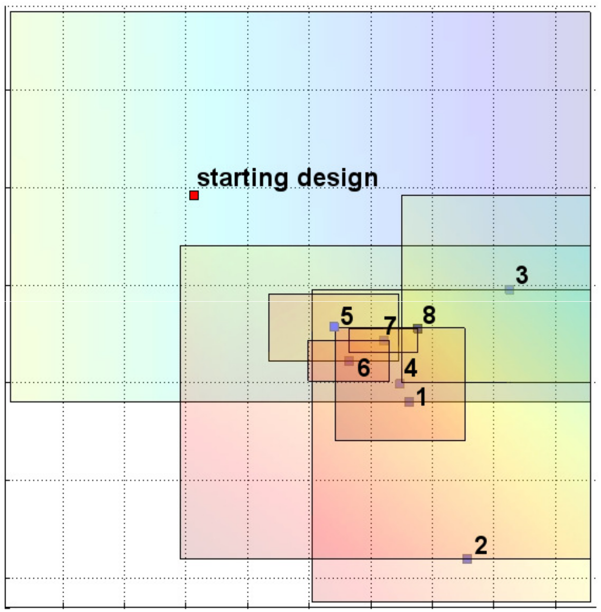
Example I - Optimization

Application of Optimization

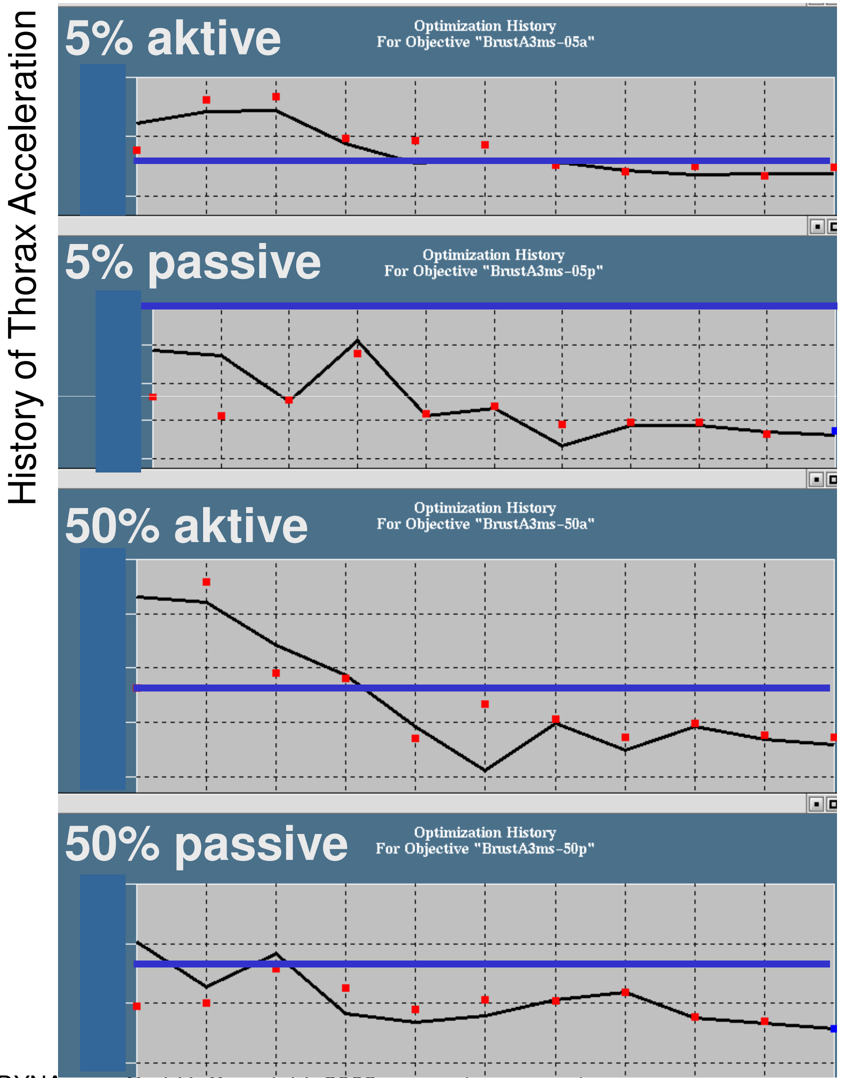
- Preferred Configuration at AUDI
  - *Adaptive Restraint System only for Airbag and Seatbelt*
  - *Reduction to 9 Variables in total (active=6, passive=3)*
- LS-OPT Approach: Successive Response Surface Methodology (SRSM) using linear polynomial approximations
  - *34 runs per iteration*
  - *D-optimal Design of Experiments (DOE)*
- Results
  - *8 iterations - total runs: 276*
  - *all constraints are fulfilled*
  - *minimization of multi-objective (second step) not applied*



Optimization Progress

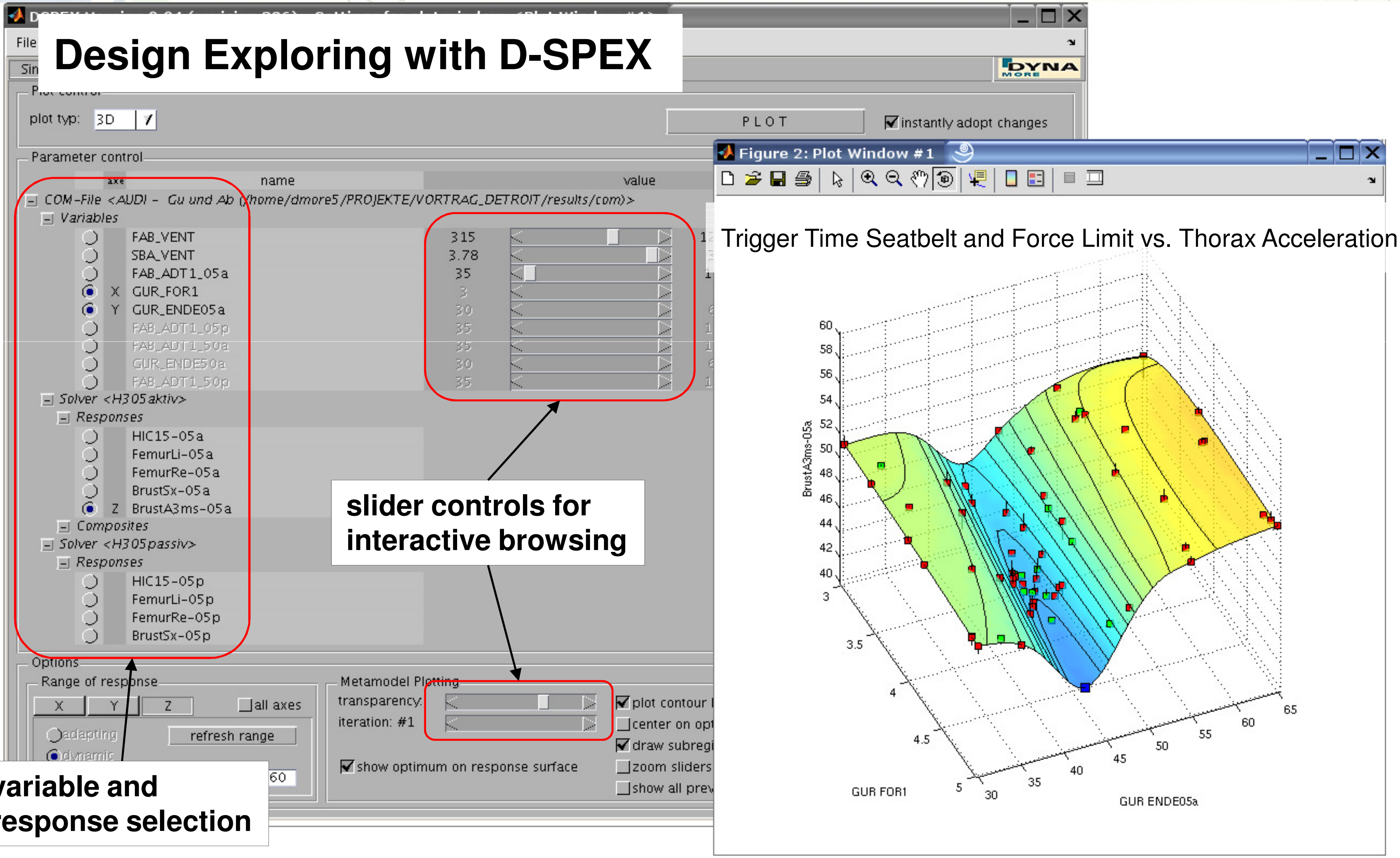


a result which meets all requirements is gained in 8 iterations, each with 34 shots



Example I - Optimization

Design Exploring with D-SPEX



Parameter Identification of Plastic Material

- Material properties: nonlinear visco-elastic behaviour
- LS-DYNA hyperelastic/viscoelastic formulation - *MAT_OGDEN_RUBBER (#77)
- Hyperelasticity

$$W = \sum_{i=1}^{3} \sum_{j=1}^{n} \frac{\mu_j}{\alpha_j}\left(\lambda_i^{\alpha_j} - 1\right) + \frac{1}{2} K (J-1)^2$$

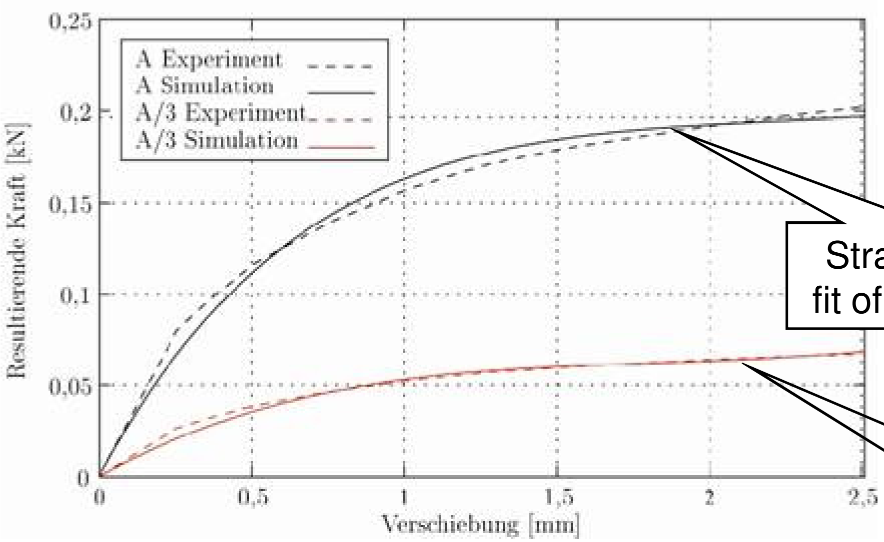
- Prony series representing the viscos-elastic part (Maxwell elements):

$$g(t) = \sum_{m=1}^{N} G_m e^{-\beta_m t} \quad ; \; \text{N=1, 2, 3, 4, 5, 6} \quad ; \; \sigma_{ij} = \int_0^t g_{ijkl}(t-\tau) \frac{\partial \varepsilon_{kl}}{\partial \tau} d\tau$$

Parameter Identification of Plastic Material

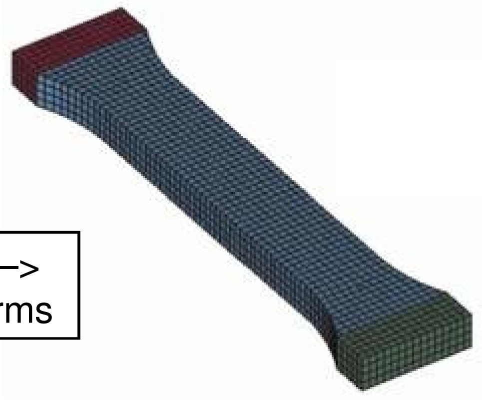
- Minimize the distance between experimental curve and simulation curve
- Least-Squares Objective Function

$$F(\mathbf{x}) = \sum_{p=1}^{P} \{[y(\mathbf{x}) - f(\mathbf{x})]^2\} \rightarrow \min F(\mathbf{x})$$



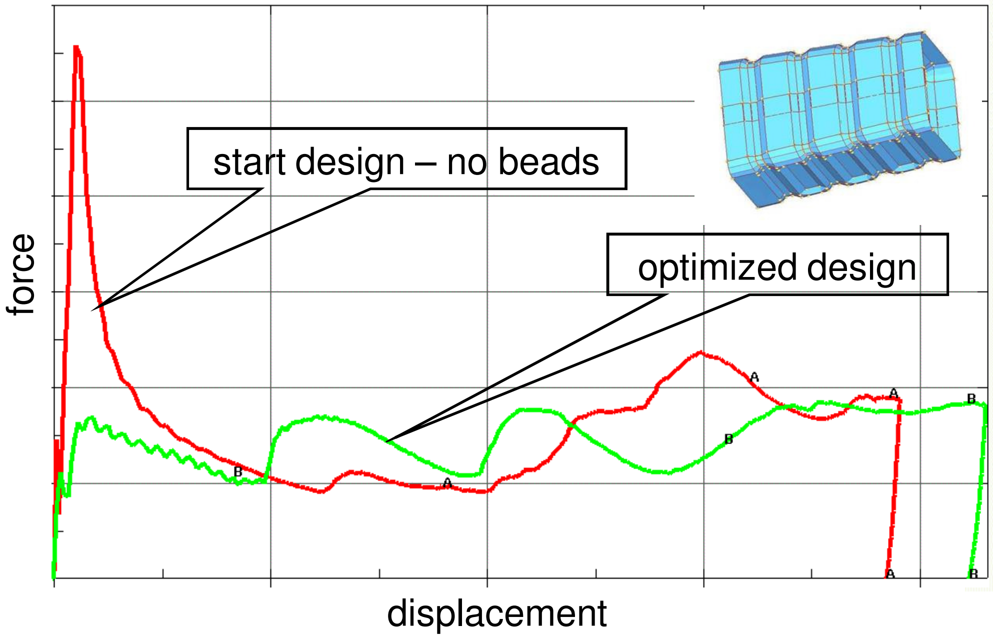
Strain rate A –> fit of Prony terms

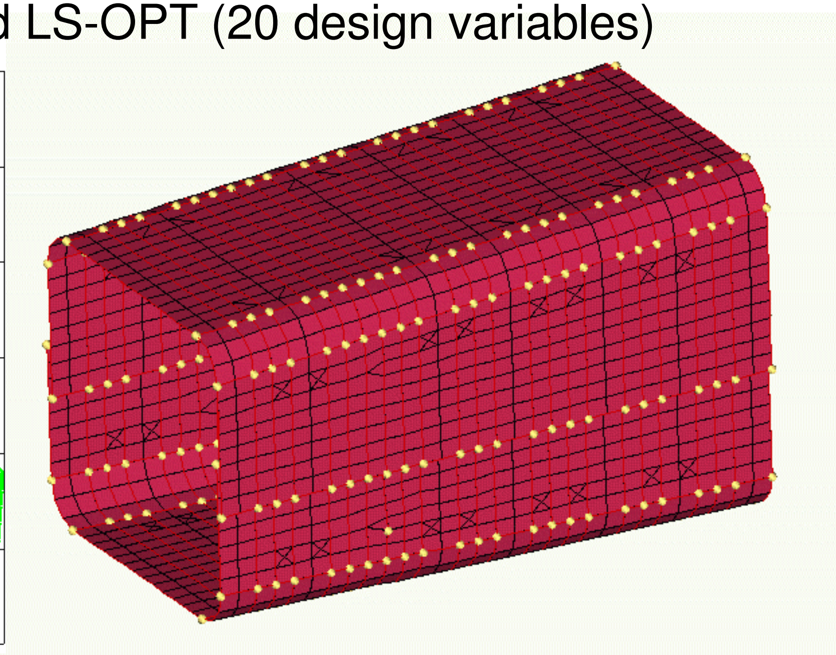
quasi-static curve – > Ogden fit



Shape Optimization of a Crash Box

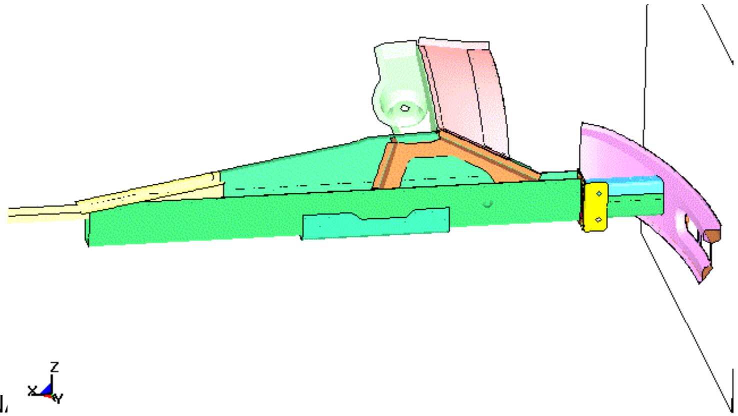
- Scope of optimization:
  - *minimize the maximum crash force*
  - *steady-going force progression*
- Shape variation by using Hypermorph and LS-OPT (20 design variables)





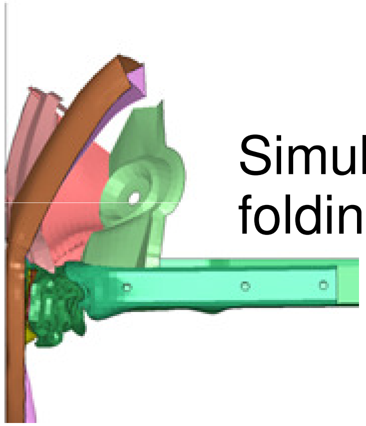
Robustness Investigations – Monte Carlo Analysis

- Variation of sheet thicknesses and yield stress of significant parts in order to consider uncertainties
- Normal distribution is assumed
  - *T_1134 (Longitudinal Member)* *mean = 2.5mm;* *σ = 0.05mm*
  - *T_1139 (Closing Panel)* *mean = 2.4mm;* *σ = 0.05mm*
  - *T_1210 (Absorbing Box)* *mean = 0.8mm;* *σ = 0.05mm*
  - *T_1221 (Absorbing Box)* *mean = 1.0mm;* *σ = 0.05mm*
  - *SF_1134 (Longitudinal Member)* *mean = 1.0 ;* *σ = 0.05*
- Monte Carlo analysis using 182 points (Latin Hypercube)

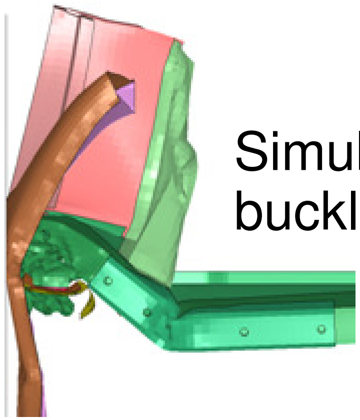


Tradeoff Plot

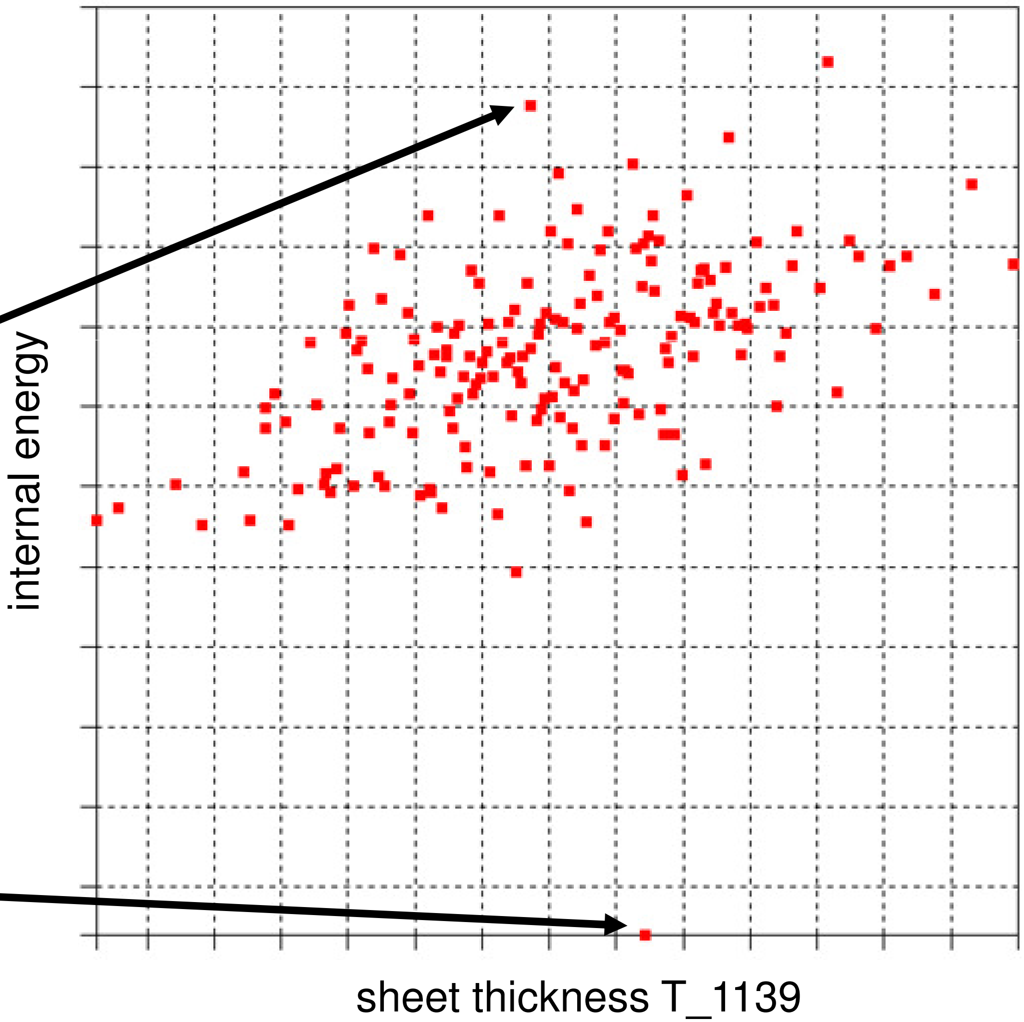
- Monte Carlo Simulation
- Identification of Clustering



Simulation 185
folding

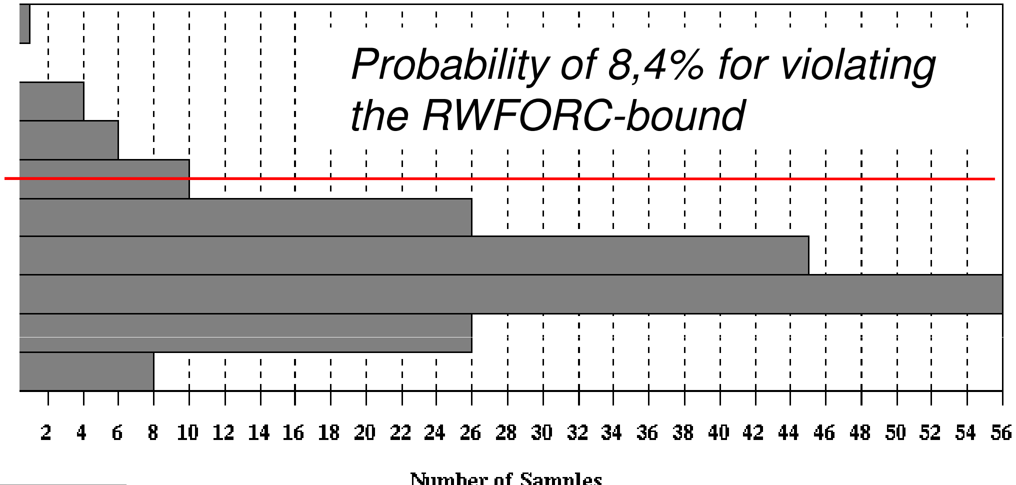


Simulation 47
buckling



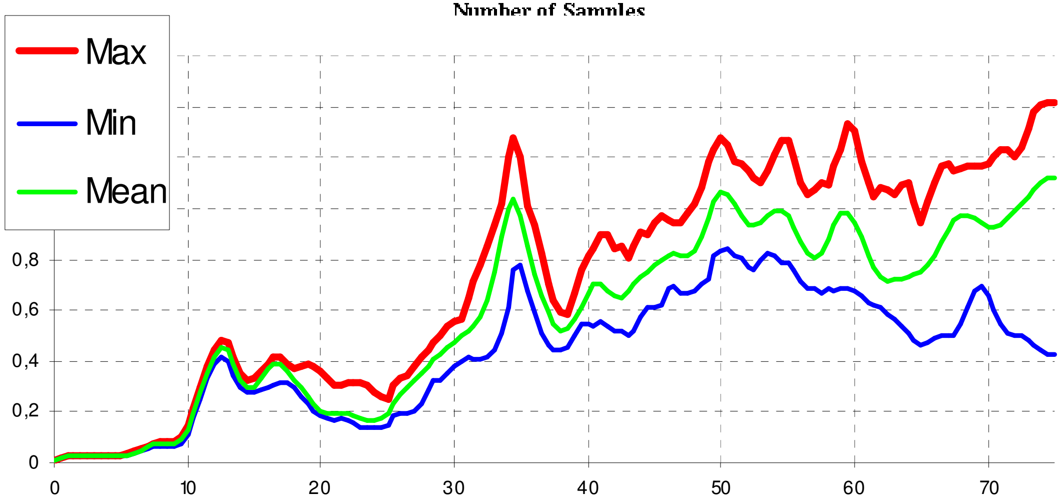
Reliability Analysis

- Histogram of distribution
- Probability of exceeding a constraint-bound

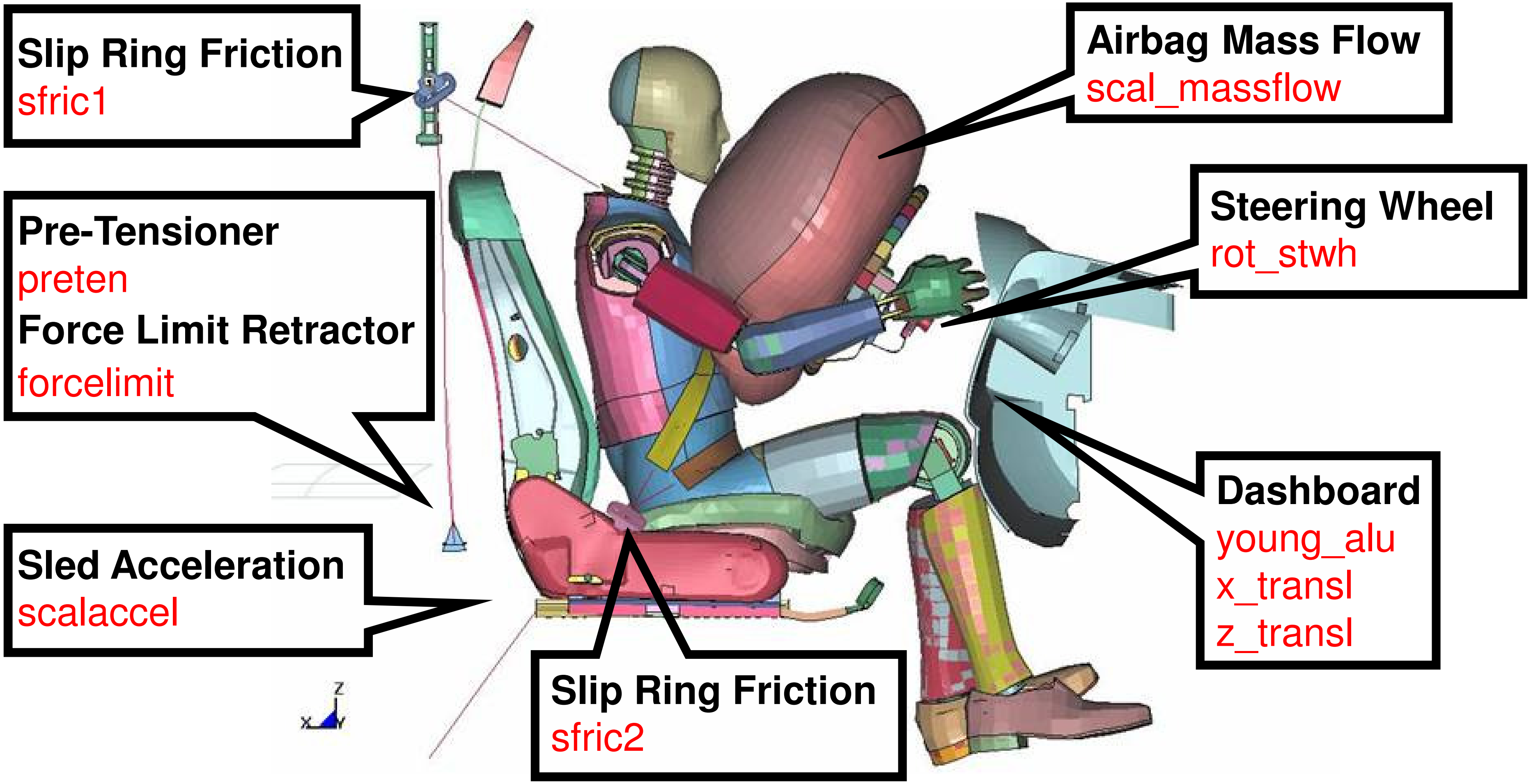


Min-Max Curves

- Plot of minimum, maximum and mean history values
- Gives a confidence interval of history values



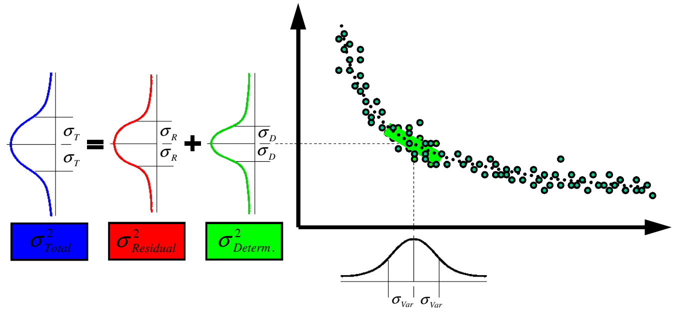
Design Variables - Uncertainties in Test Set-Up



Example II – Robustness

Stochastic Contribution - Results of 30 Experiments

Design Variable	Standard Deviation of Design Variable	Standard Deviation Contribution: HIC36	max_chest_intru	max_b_f_shoulder	max_bf_pelvis	max_chest	max_pelvis
scalaccel	2,5%	3,1%	1,5%	0,1%	2,3%	1,9%	2,9%
sfric1	25,0%	1,3%	0,6%	4,1%	1,8%	0,7%	0,7%
sfric2	25,0%	0,5%	0,6%	0,1%	3,7%	0,1%	0,1%
preten	4,4%	0,0%	0,5%	0,0%	1,1%	0,3%	0,2%
forcelimit	5,6%	1,3%	0,4%	4,4%	0,6%	1,4%	0,2%
rot_stwh	4,8%	0,5%	0,1%	0,1%	0,0%	0,1%	0,1%
transl_x	50,0%	0,1%	0,1%	0,7%	4,5%	0,5%	0,8%
transl_z	50,0%	1,2%	1,0%	0,3%	1,6%	0,2%	0,9%
scalmassflow	5,0%	1,8%	1,8%	0,6%	2,2%	0,6%	0,9%
young_alu	5,0%	0,3%	0,3%	0,0%	0,5%	0,1%	0,1%
all variables		4,3%	2,8%	6,1%	7,2%	2,6%	3,4%
residuals		4,7%	1,9%	1,8%	6,0%	3,5%	2,3%
Total		**6,4%**	**3,4%**	**6,3%**	**9,4%**	**4,3%**	**4,1%**



Contribution of variation of design variables to variation of results

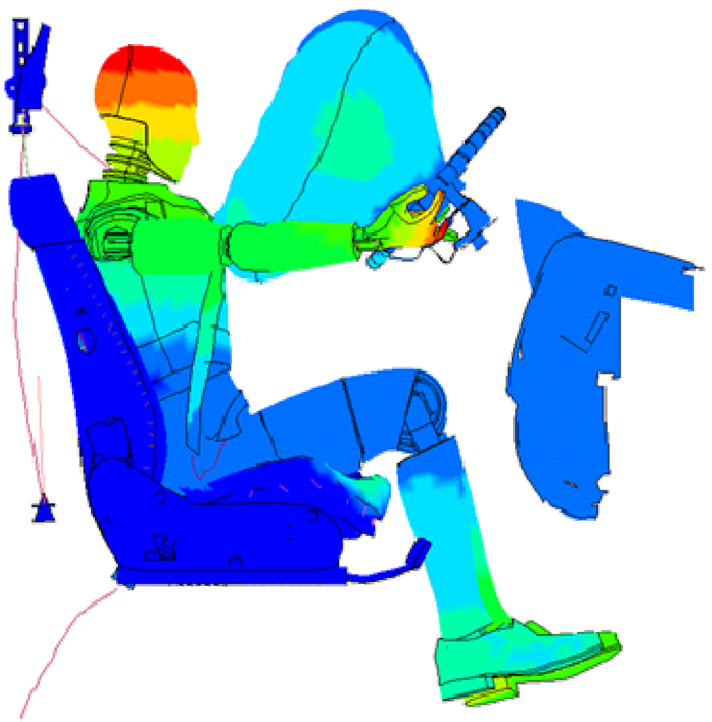
Meta-model space

Residual space

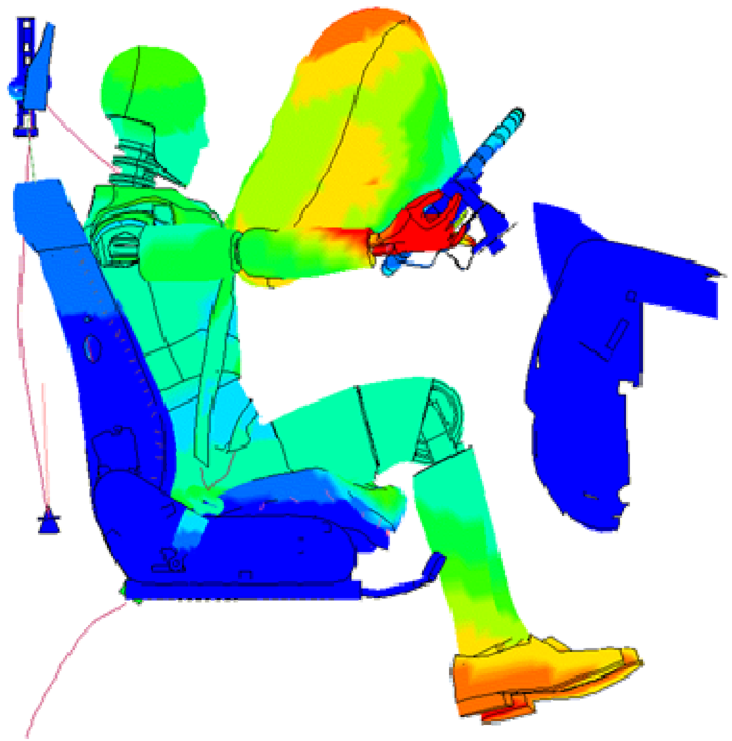
Total Variation

Standard deviation of x-displacements of each node (120 runs)

（a） Deterministic （Meta−Model）



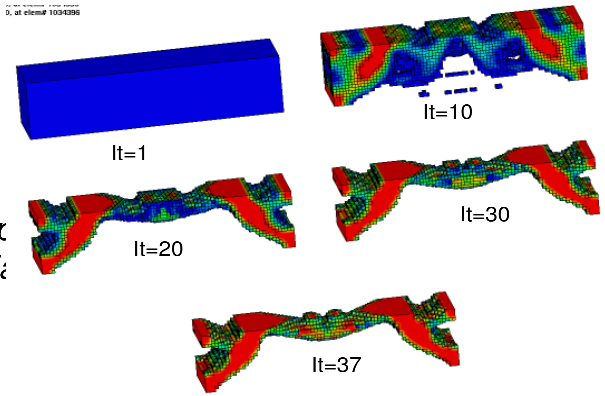
（b） Residual （Outliers）



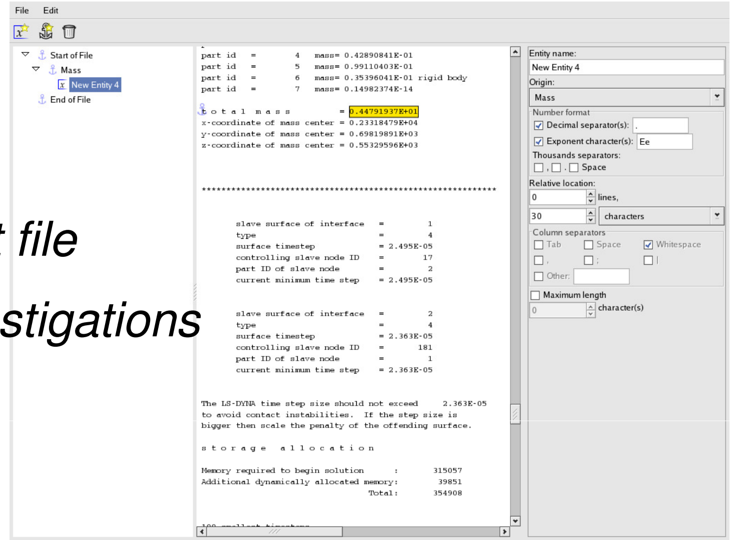
➔ Outlook – Version 4.1

- LS-OPT/Topology (available end 2009)
  - *Nonlinear topology optimization*
  - *LS-DYNA based*
  - *Multiple load cases*
  - *Linear as well as non-linear*
  - *Design part selection*
  - *Methodology: Hybrid Cellular Automata*

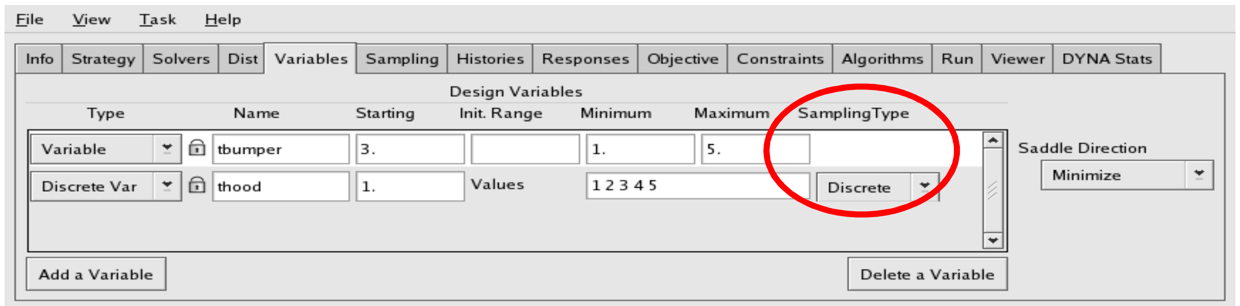
    Ref.: Hybrid cellullar automata with local control rules: a new ap
    Quevedo W., Patel N., Renaud J. (University Notre-Dame, India
    Structural and Multidisciplinary Optimization, 2005, Brazil



➔ Outlook – Version 4.1



- Generic File extractor
  - *Extraction of values from any ASCII input file*
- *Correlated Input Variables for Stochastic Investigations*
- Additional injury criteria (DYNA extraction)
  - *IIHS, neck/tibia indices,…*
- Full Factorial Discrete
  - *Schedule all combinations of discrete variables*
- Discrete sampling on a variable basis



→ Outlook – Version 4.1

- Improved Space Filling algorithm
  - *Greater accuracy: more boundary points*
- Frequency/Mode Tracking
  - Available for NASTRAN
  - MAC and orthogonality criterion

$$\boxed{\max_{i} \left[\left(\boldsymbol{\varphi}_r^T \mathbf{M}_r \right) \boldsymbol{\varphi}_i \right]}$$

- Global Sensitivity Analysis with Sobol Indices (GSA)
- Pareto Optimal Solutions
  - *Self-Organizing Maps (Ver. 4.1)*
- Many new Features within the "viewer"
  - *e.g. history curves visualization*