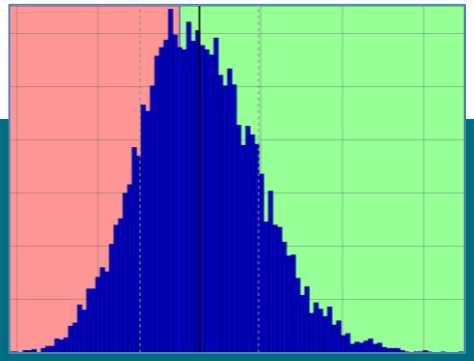

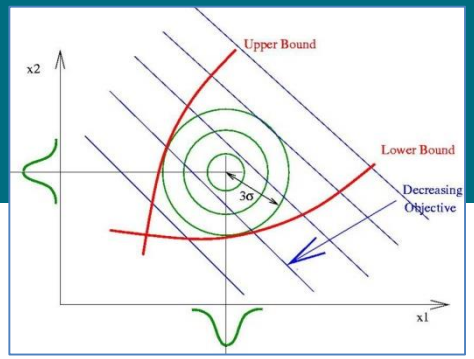

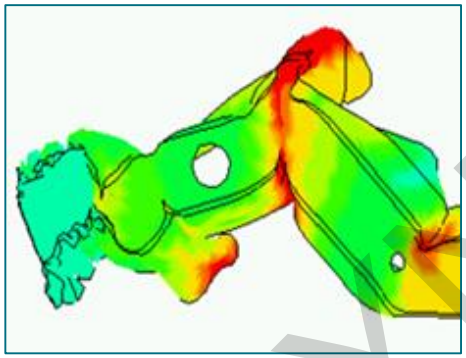

Robustness Analysis with LS-OPT®

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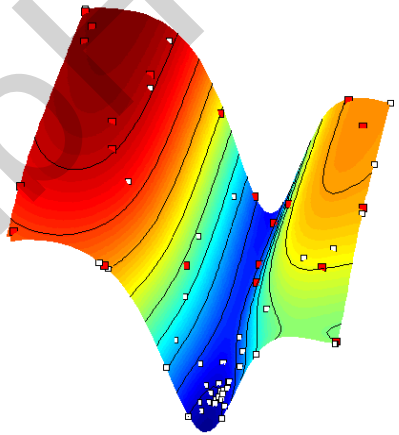
DYNAmore GmbH, Stuttgart
www.dynamore.de

Bamberg, 12.10.2016

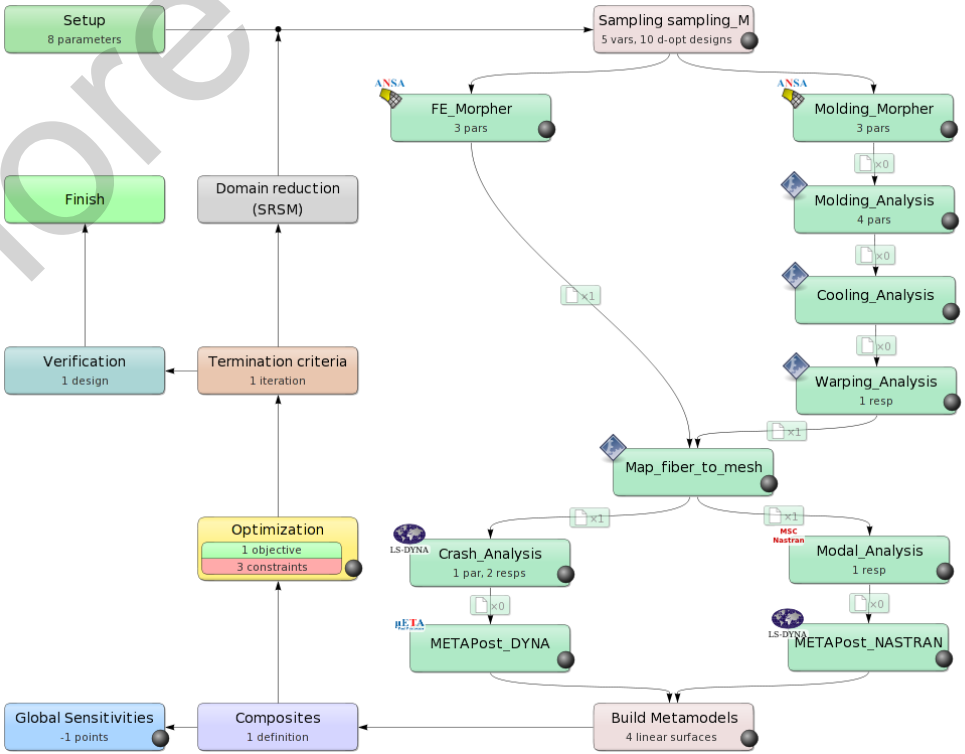
Outline

- About LS-OPT
- Motivation
- Robustness Analysis
  - Direct and metamodel-based Monte Carlo Analysis
- Example Robustness Analysis
  - Live demonstration
- Optimization
  - RBDO/RDO
  - Tolerance Optimization
- Summary
- Outlook

About LS-OPT

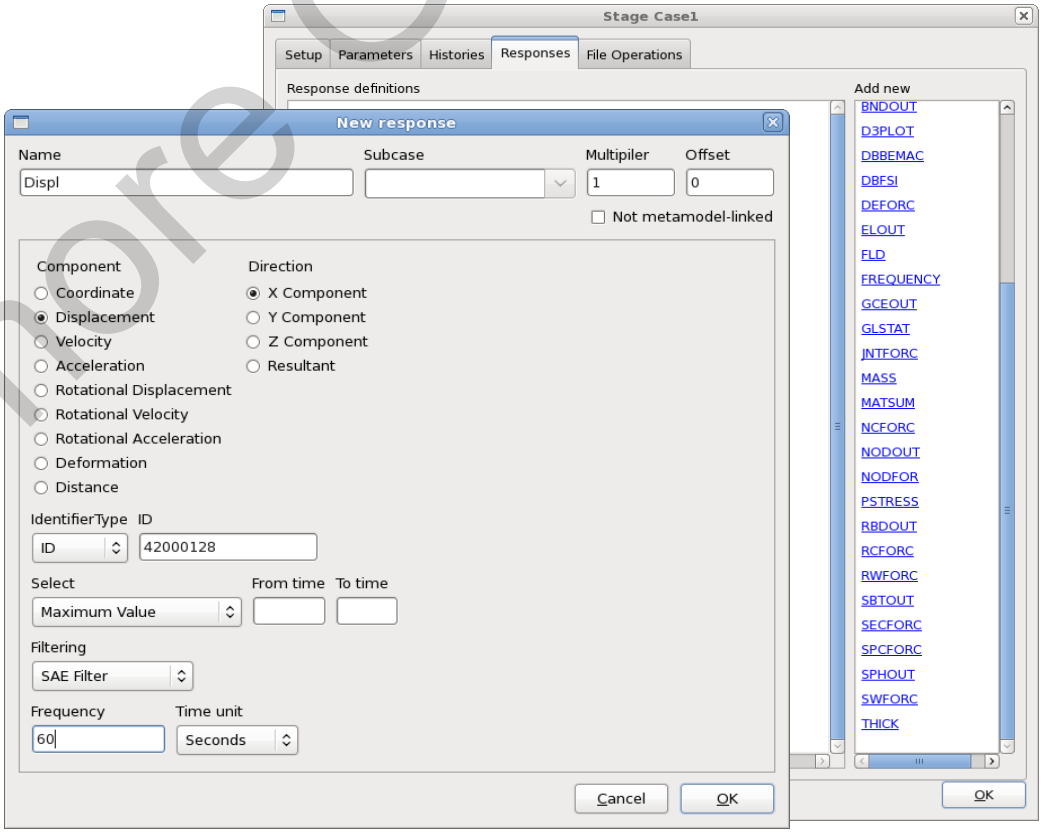


- LS-OPT is a standalone optimization software
  - → can be linked to any simulation code
  - Interface to LS-DYNA, MSC-Nastran, Excel, Matlab
  - User-defined interface
  - Interfaces to preprocessors, e.g. for shape optimization
    - Interface to LS-PrePost, ANSA, Hypermorph, …
    - User-defined interface to any preprocessor
  - Result extraction
    - Interface to META Post
    - User-defined interface



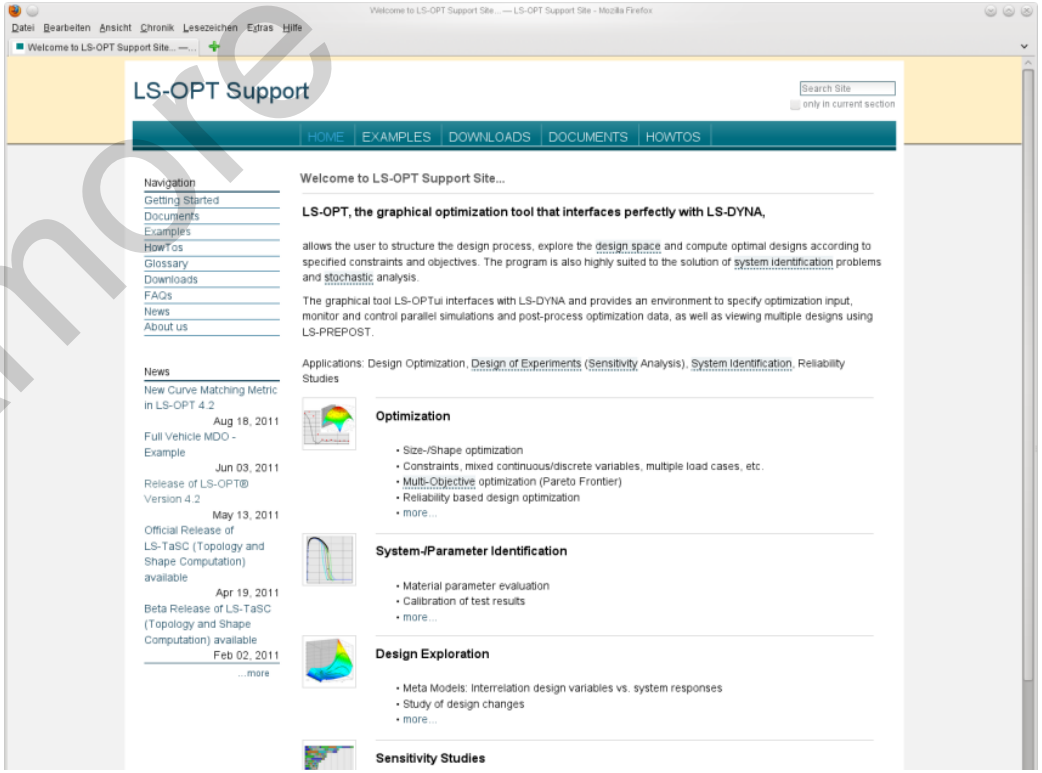
About LS-OPT

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



About LS-OPT

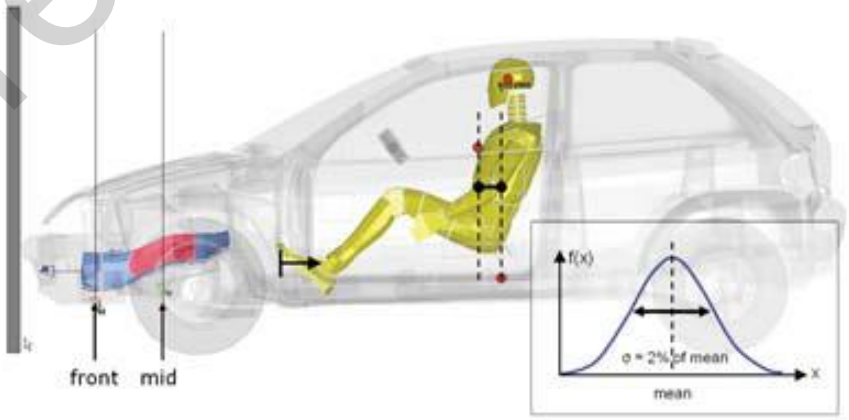
- Current production version is LS-OPT 5.2
- LS-OPT Support web page
  → www.lsoptsupport.com
  - Download of Executables
  - Tutorials
  - HowTos / FAQs
  - Documents
  - ….



Robustness Analysis with LS-OPT

Motivation

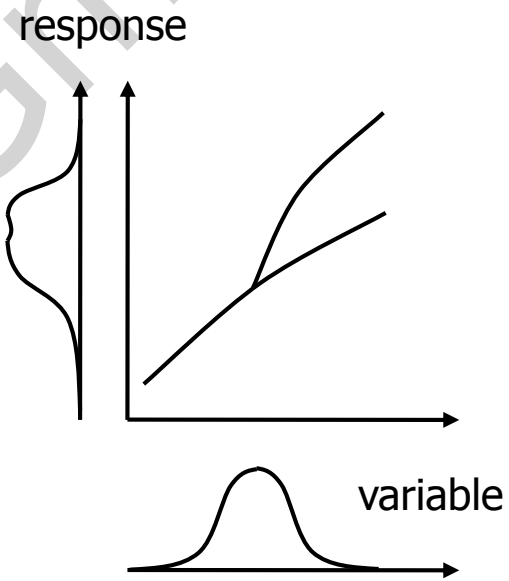
- Simulation
  - Design parameters (sheet thicknesses, material properties, …) fully controllable
- Reality
  - Design parameters are associated with uncertainties
- Sources of uncertainties
  - Manufacturing imperfections
  - Load variations
  - Environment variations
  - …

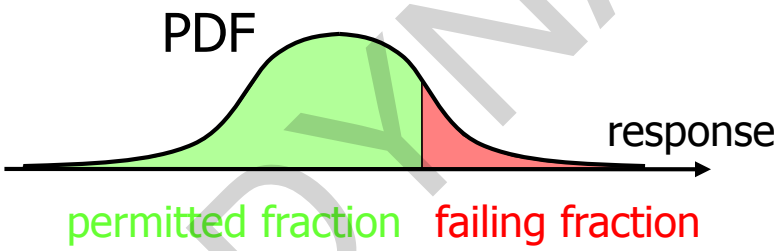


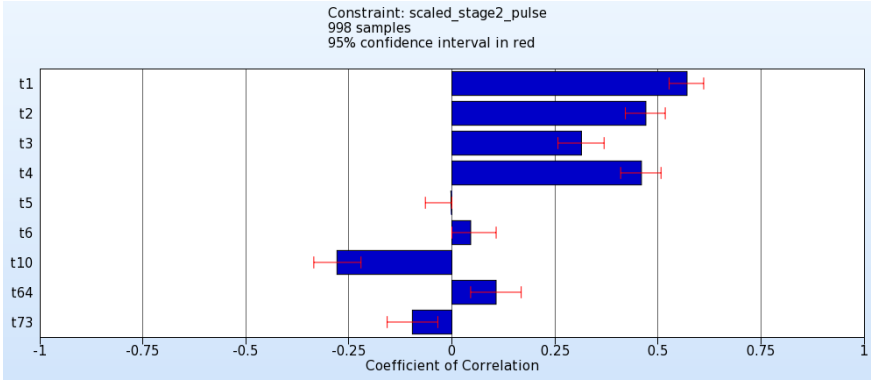
→ Variation of design parameters (uncertainties) should be considered in design process simulation

Robustness Analysis

- Estimation of probability quantities of variables and responses
  - mean
  - standard deviation
  - distribution function
- Analysis of relationship (sensitivities)
  variables ←→ responses
  - correlation analysis
  - stochastic contributions
- Reliability of a system
  - evaluation of probability of failure



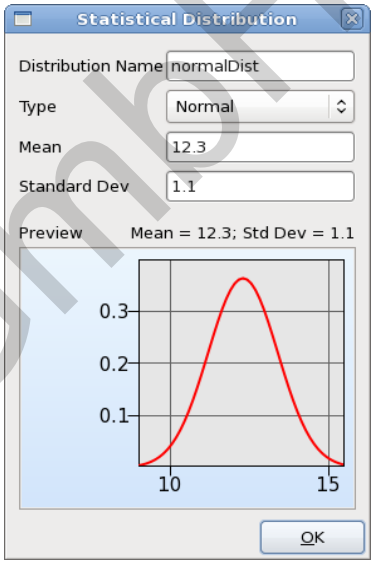


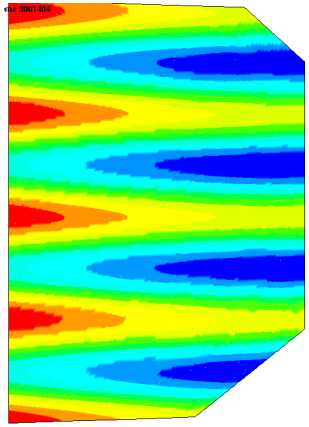


Robustness Analysis

- Uncertainties of variables
  (sheet thicknesses, material properties, …)
  - Probability density function
    - Uniform distribution
    - Normal distribution
    - …
  - *PERTURBATION (LS-DYNA keyword)
    - Geometric imperfections
    - Material imperfections

    → Buckling analysis





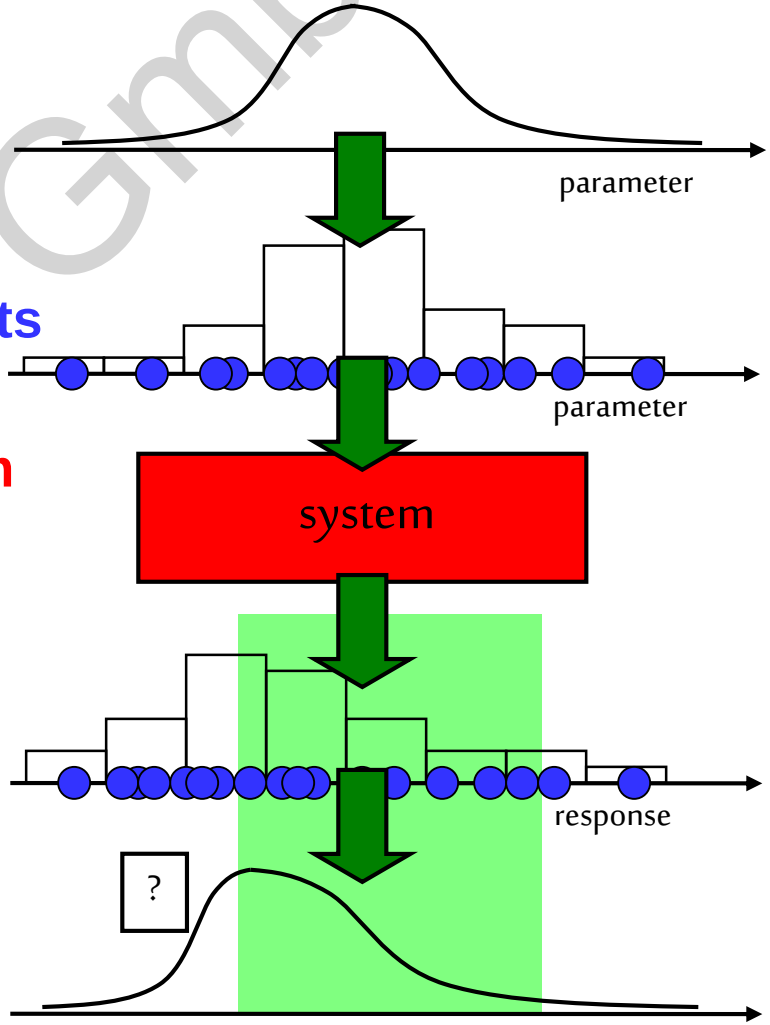
sheet thickness variation by a harmonic random field, amplitude: m=0,s=0.005mm in both directions

LS-DYNA Keyword

*PERTURBATION

Robustness Analysis

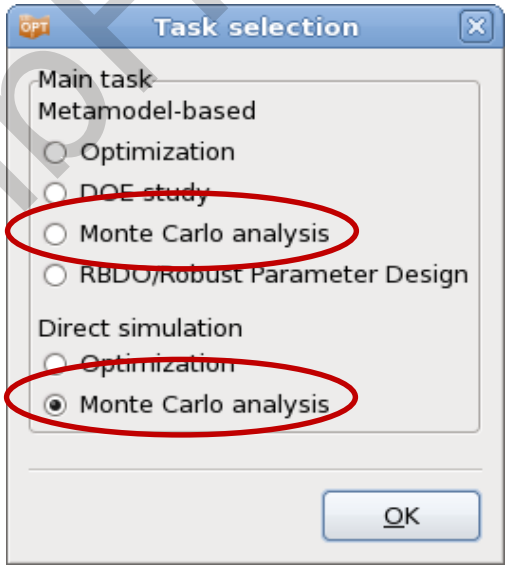
- Scatter of parameters constituted by means of probability distributions
- Approximation of probability distributions using appropriate *samples* = **experiments**
- Investigation of the *FEA-model* = **system** using experiments
- Distribution of the system **responses**
  → Approximation to *exact* distribution
- **Permitted area**

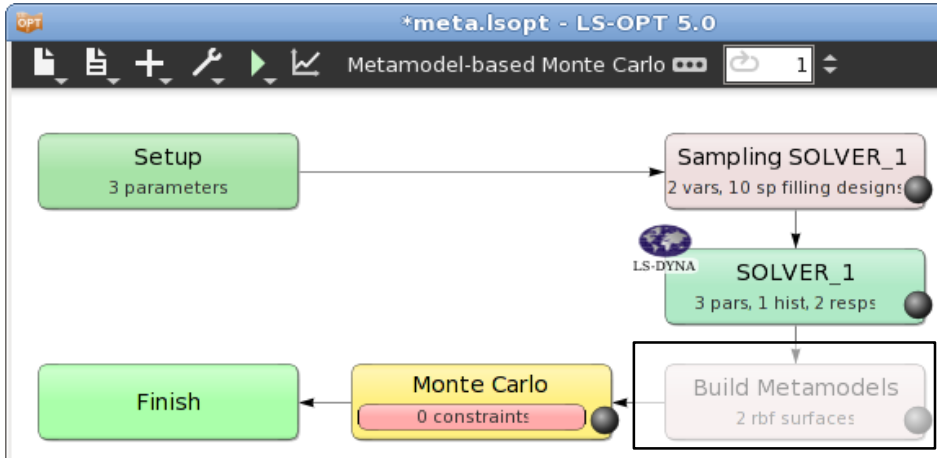


Robustness Analysis

- Monte Carlo Analysis using direct simulations
  - Random process
  - Large number of simulation runs (100+)

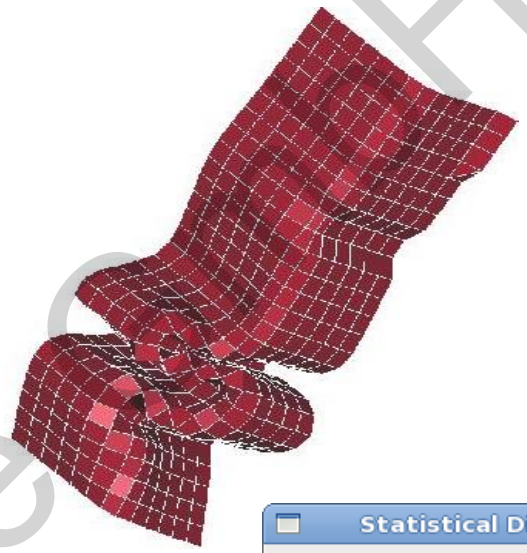
- Monte Carlo Analysis using metamodels
  - Construction of a metamodel (Polynomials, Radial Basis Functions, Feedforward Neural Networks, …)
  - Number of simulations depends on number of variables
  - Reliability, Robustness Analysis through functional evaluation of sampling points (10^6) on the metamodel

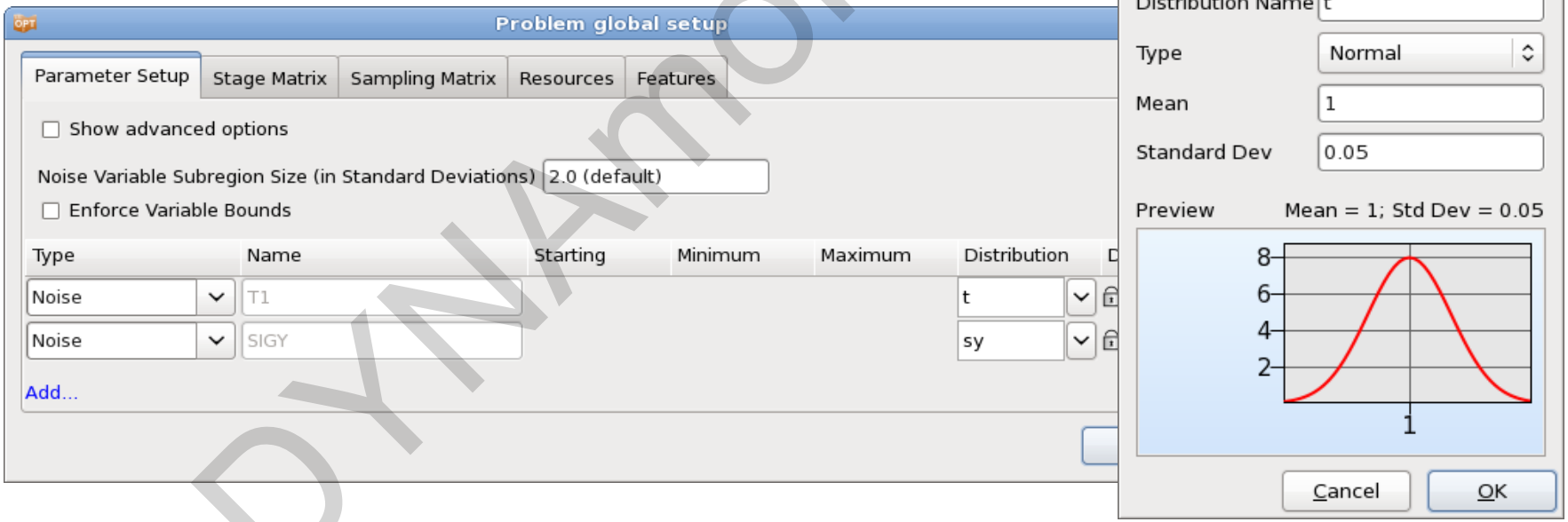




Example

- Tube impact
- Variables (Noise variables)
  - Thickness
  - Scale factor of stress-strain curve
- Response
  - Intrusion



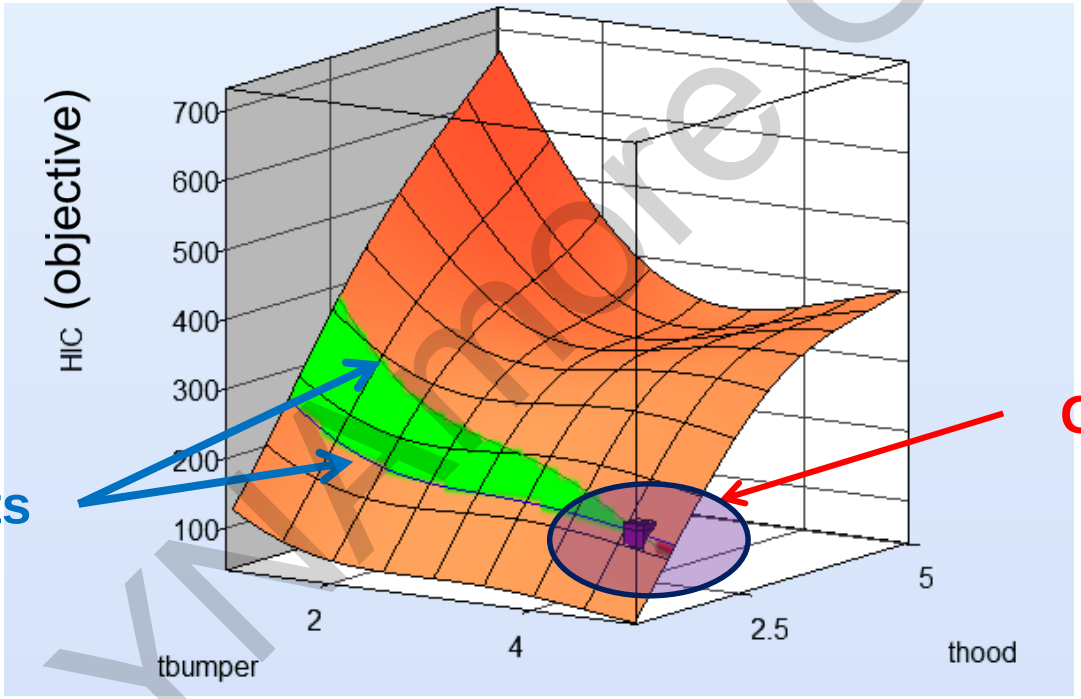


Live demonstration

Optimization considering uncertainties

Optimization

- Deterministic optimization
  - Minimize Objective Function subject to Constraints
  - Optimum very often lies on the constraint boundary



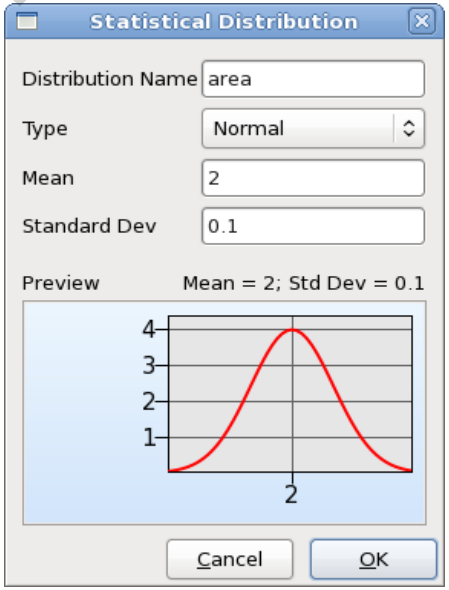
Constraints

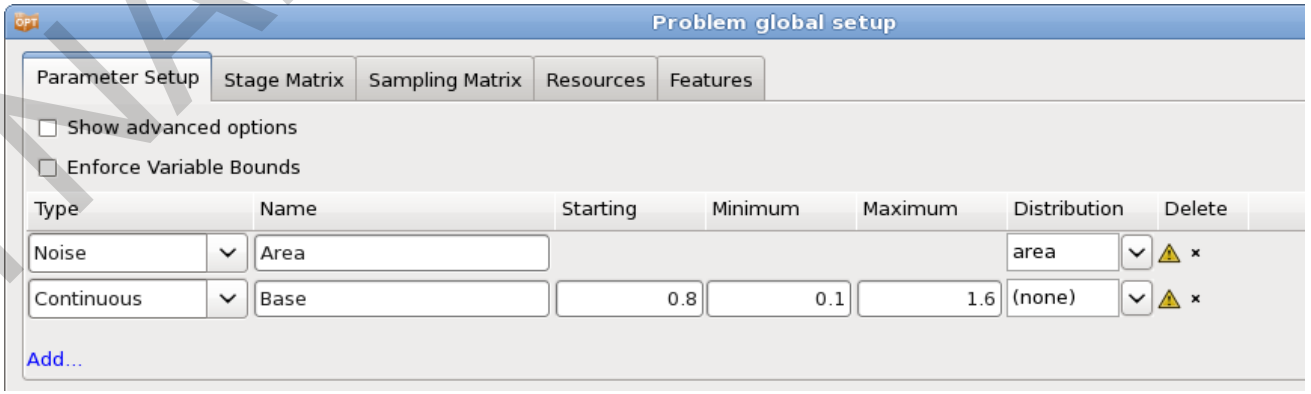
Optimum

Not Robust!

RBDO/Robust Parameter Design

- Includes uncertainty of variables and responses into optimization
- Requires statistical distribution of variables
- **Control Variables (Design Parameters)**
  - Nominal value controlled by designer
    - Gauge
    - Shape
- **Noise Variables (Environment)**
  - Values not controlled by designer but can vary
    - Load
    - Yield stress
    - Friction

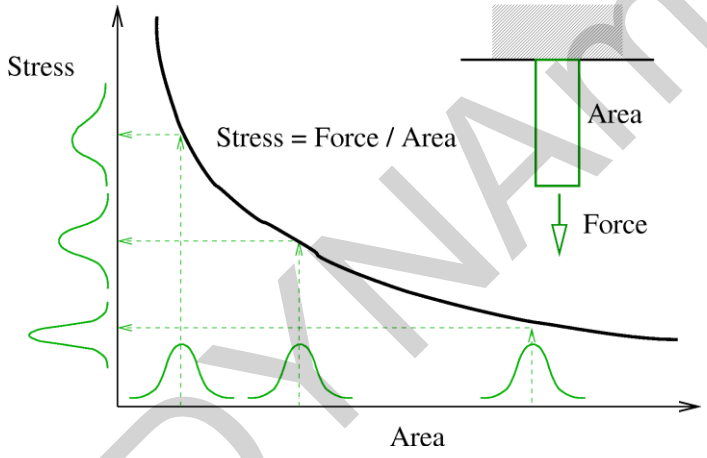




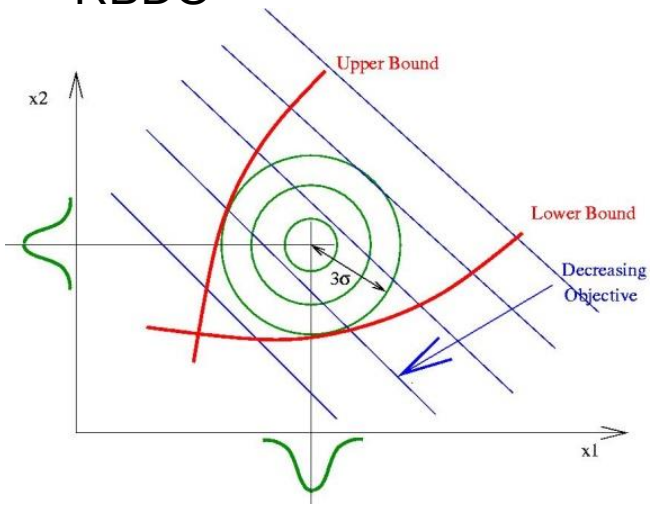
RBDO/Robust Parameter Design

- Robust Parameter Design (RDO)
  - Improve/Maximize the robustness of the optimum
- Reliability Based Design Optimization (RBDO)
  - Improve failure probability of optimum

RDO



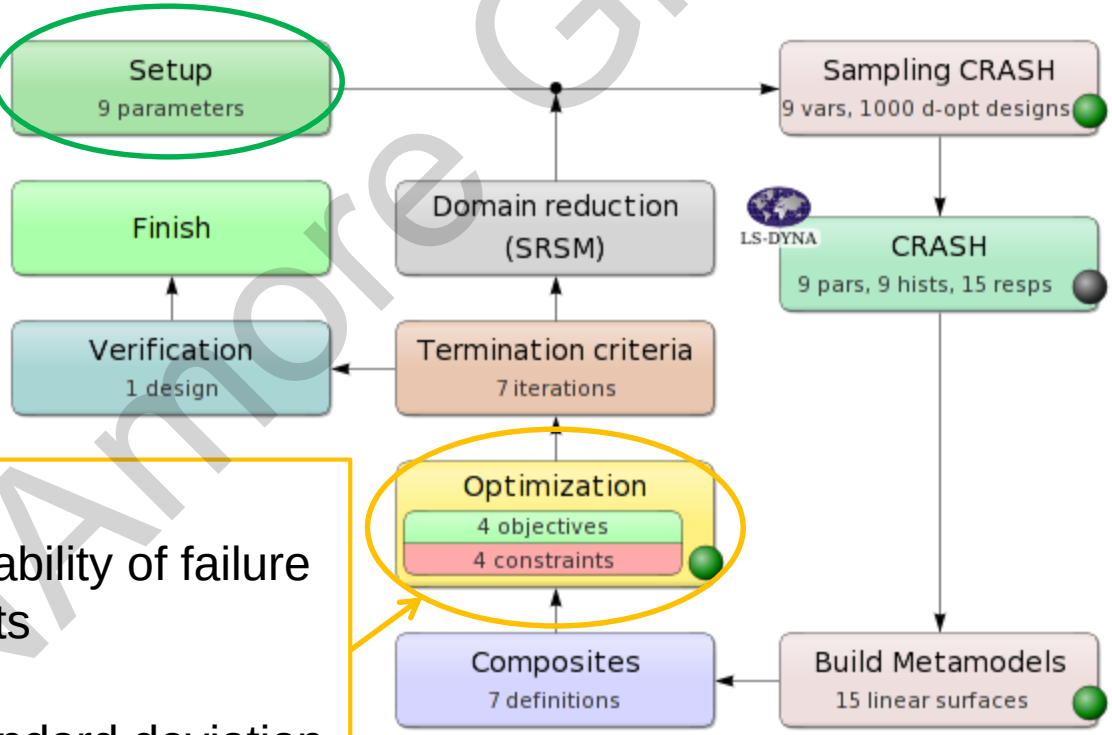
RBDO



RBDO/Robust Parameter Design

- Method to solve RBDO/RDO
  - Metamodel-based optimization

Statistical distribution of variables



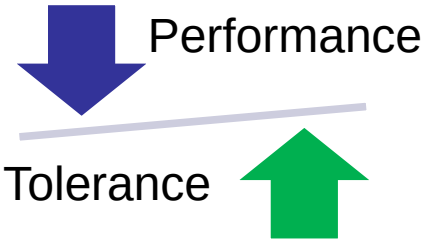
RBDO:
limit on probability of failure for constraints
RDO:
objective standard deviation of response/composite

Tolerance Optimization

- RBDO/RDO
  - Variables associated with distribution
  - Mean variable values (distribution means) are optimized

- Tolerance Optimization
  - Variables associated with tolerance values
    → Optimize nominal design variables **and tolerances**
  - Maximize tolerance
  - No failure within tolerance

→ incorporate uncertainties into optimization
if variable distributions are not available



Summary

- Monte Carlo Analysis (Robustness Analysis)
  - Direct or metamodel based
  - Estimation of PDF, mean, standard deviation, … of responses
  - Significance of parameters
    - Correlation coefficients
    - Stochastic contribution (only metamodel based MC Analysis)
  - Reliability of system
  - Confidence intervals
  - Buckling Analysis
    - DYNAStats: fringe of statistics on the FE model

Summary

- Reliability Based Design Optimization (RBDO)
  - Probabilistic bounds on constraints
- Robust Parameter Design
  - Minimize Standard Deviation of response
- Tolerance Optimization
  - Incorporate uncertainties into optimization if no distribution information of the variables is available
  - Maximize tolerance
  - no failure within tolerance

Thank you!