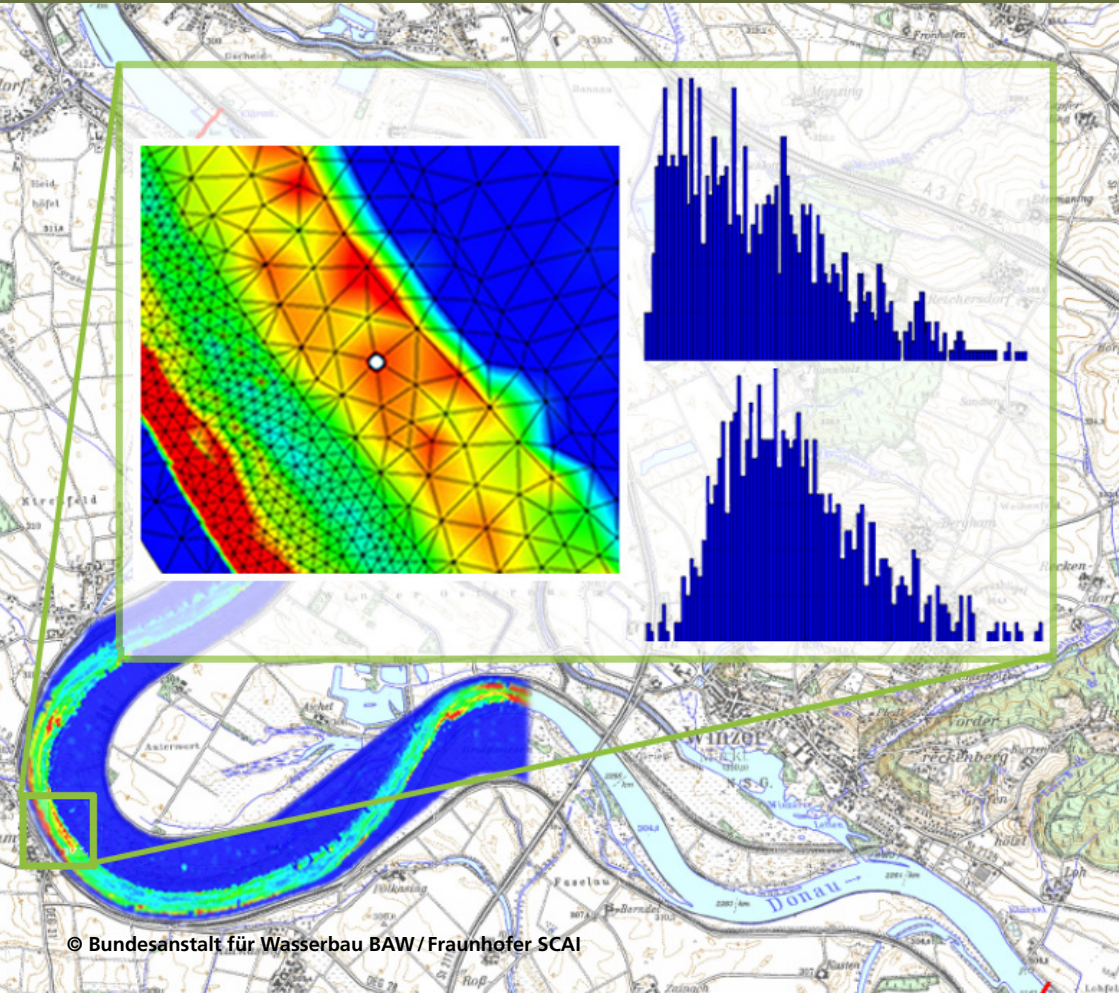


COMPUTER-AIDED ROBUST DESIGN



UNDERSTANDING ROBUST DESIGN

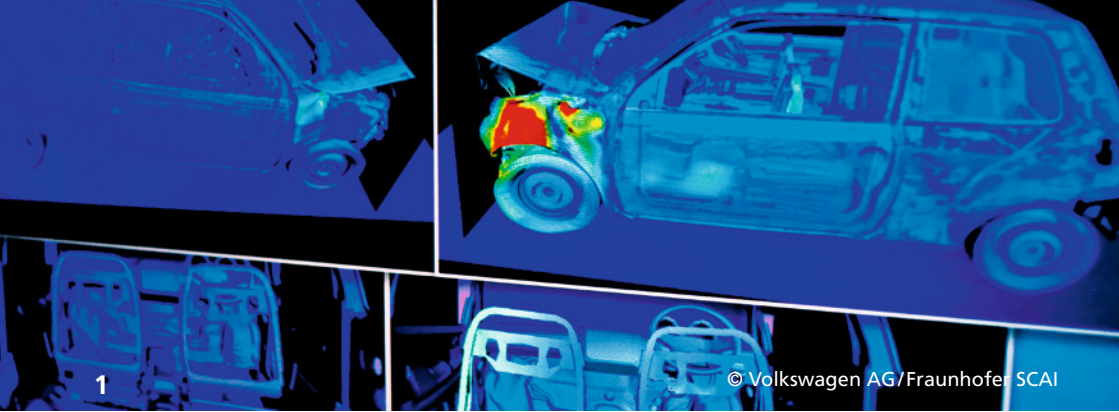
We call a design **robust** if small changes in the initial conditions will only have minimal impact on the results. The robustness and quality of production processes and products suffer from variations occurring in a range of parameters relating to defining features such as material properties, process parameters, variations in geometry. **Analyzing and controlling** the effects of these variations **helps in the identification of robust and optimal settings** under realistic conditions.

Applications arise from a variety of fields that include the automotive industry (e.g., crash simulation, metal forming, casting), microelectronics and semiconductor physics, oil and gas reservoir management, chemistry, fluid mechanics, and molecular dynamics.

Computer-aided robust design and the intuitive exploration of design spaces and simulation results belong to the most challenging research and development tasks with a high relevance for industry.

METHODS

Our methods for robust design include **global or local sensitivity and robustness analysis** with an efficient reduction of the parameter space, **multi-objective, robust parameter optimization, metamodeling** and advanced design-of-experiments methods (see DesParO), and a methodology for the **analysis of process chains** (see PRO-CHAIN).



YOUR BENEFITS

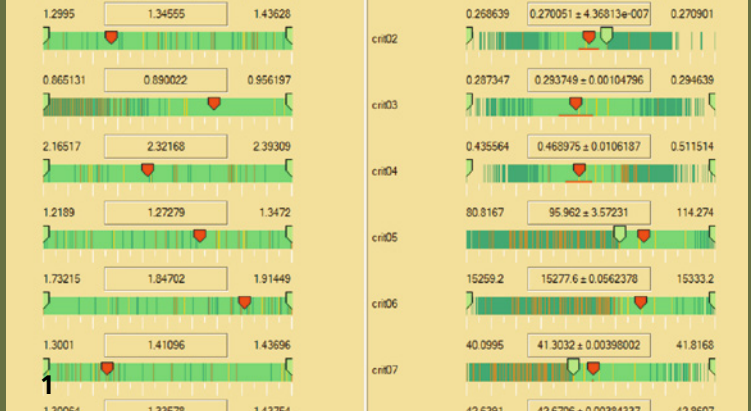
- save time consuming simulation runs or costly experiments
- achieve a device optimization or best possible product configuration by taking parameter variations and tolerances into account
- understand important dependencies and achieve robust optimization of parameter-dependent process steps and of entire process chains dealing with high dimensional simulation results
- calibration of material models and the (history-) matching of simulation models under uncertain parameters
- interpolation, compression, visualization and statistical analysis methods of parameterized problems from a single source

1 *Distribution of uncertainties: robust design (left), high-scatter design (right).*

WHAT WE OFFER

Employing the methods described, we offer:

- the software **DesParO** for interactive, multi-objective robust design-parameter studies, statistical analysis, and optimization
- the methodology **PRO-CHAIN** for efficient statistical analysis and robust design of process chains
- consulting
- customer-tailored software solutions



INTERACTIVE, MULTI-OBJECTIVE ROBUST DESIGN-PARAMETER STUDIES AND OPTIMIZATION

Benefits for Developing Processes and for Developing Products

DesParO is an intuitive, interactive exploration tool which identifies a full set of **alternative solutions**. Moreover, it facilitates a global view of the whole space of design variables of a production process, product configuration, material model or simulation model. The software offers the possibility to obtain **almost optimal configurations** with a low number of simulation runs or physical experiments, which is a particular **time- and resource-saving** benefit. Our methods are especially suited for computationally expensive simulation codes as well as for the purely experimental analysis of costly processes and products.

Features

- efficient, easy-to-use, reliable meta-modeling (response surface) technique
- iterative refinement and fully local tolerance prediction of the metamodel

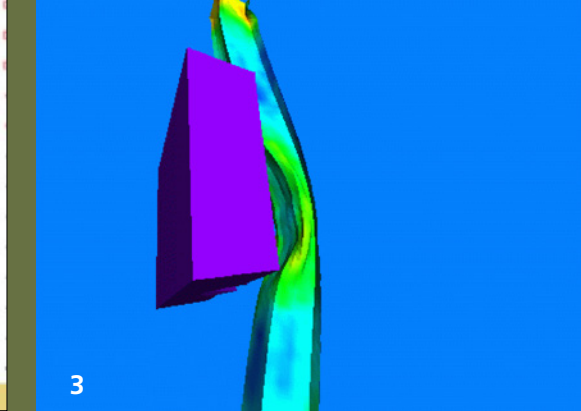
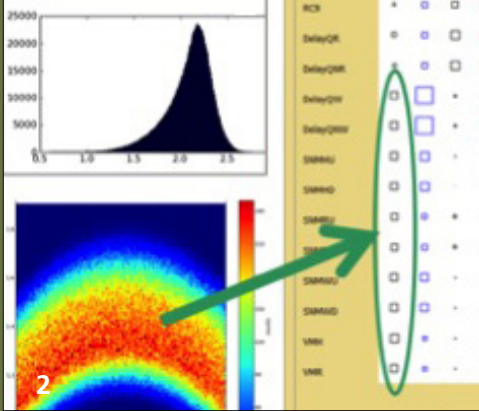
- parameter sensitivity analysis, even for simulation results on highly resolved meshes
- reduction of the design space, extraction of main tendencies, compression of data bases
- wide set of statistical analysis methods for considering different parameter distributions with one single metamodel.
- fast interpolation and visualization of simulation results on highly resolved meshes

Technical Specifications

DesParO is available for Linux and Windows systems in the following versions:

- stand-alone application (Graphical User Interface and batch compute option)
- documented Software Development Kit (SDK) for the integration into a customer's own software

DesParO offers Python scripts for user defined workflows tailoring the process steps needed or for the integration into standard workflow tools or other optimization software.



FAST INTERPOLATION AND VISUALIZATION

As an additional core competence, we offer fast interpolation and visualization of simulation data and their scatter information on fine meshes. In particular, this allows fast previews of optimal designs which have been found by means of DesParO.

- 1 DesParO's Explorer
- 2 histogram and correlation plot, correlation matrix
- 3 DesParO's Geometry Viewer

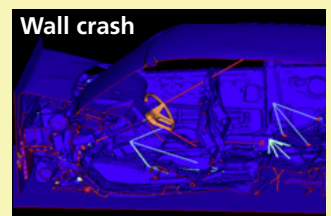
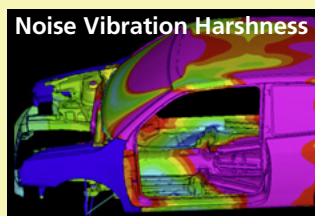
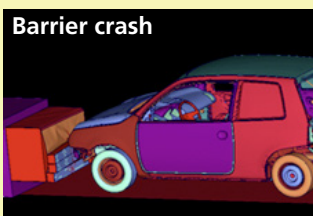
EXAMPLE

Multi-Disciplinary Optimization of a Volkswagen Lupo Model

The optimization task considers the maximum intrusions in different critical points as well as the maximum acceleration, first eigen-frequencies and torsional stiffness. The **main objective** was a reduction of total mass taking the thicknesses of 15 parts as design parameters into account.

Result of Optimization with DesParO

We achieve a mass reduction of 1.5 kg with all 11 constraints satisfied robustly. For comparison, the analysis of an unconstrained problem shows that in the same region of design variables the maximal possible mass reduction is 2 kg.



PRO-CHAIN

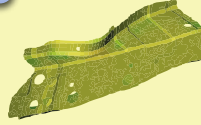


Input: material and process parameters etc. along with their scatter

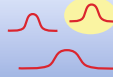
Metal Sheet

Forming Simulations

(•) DesParO



MpCCI MetalMapper:
mapping of thicknesses,
strains, damages etc.



Output: distributions of thicknesses, strains, damages etc. along with their scatter on grid used for forming simulation

STATISTICAL ANALYSIS AND ROBUST DESIGN OF PROCESS CHAINS

Products are often manufactured by means of a sequential chain of processing steps. As a minimum, the most important process steps and corresponding variations should be analyzed in order to obtain realistic information about relevant parameter dependencies and properties of the overall process and resulting products.

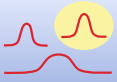
The PRO-CHAIN methodology helps to

- quantify influences of scatter from the entire history of a process up to the ultimate result, giving **valuable insight** into local behavior,
- considerably **improve the forecasting quality** of simulations and, with a subsequent robust optimization, the quality of the resulting product,
- answer and visualize “what-if” scenarios, without additional time-consuming simulation runs.

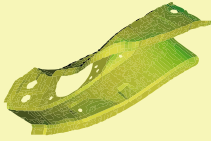
Special Features

PRO-CHAIN includes an efficient **local analysis of variations** on highly resolved meshes allowing a design-parameter space reduction for each process step. It comes with a fast and nevertheless accurate **prediction of new designs**, incorporating distributions of, for example, thicknesses, strains, or damages by means of a metamodel.

In addition, PRO-CHAIN enables an accurate **transformation of local scatter** from one step to the next one, minimizing the necessary number of simulation runs. It offers a fast **visualization of new designs** including their statistical information. Altogether, it leads to an **intensive reduction** of required **memory** and **computational time** compared with standard Monte Carlo methods.

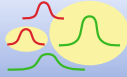
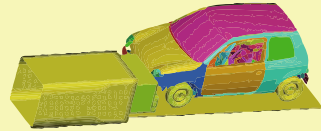


Input: distributions of thicknesses, strains, damages etc. along with their scatter on grid used for crash simulation



Crash Simulations

(•) DesParO



Output: local displacements etc. and optimization criteria (e.g. intrusion, total mass, robustness etc.) along with their scatter

PRO-CHAIN WORKFLOW AND EXAMPLE

We provide efficient methods and software tools for the analysis of process chains, for instance:

- from metal forming/casting to component tests/crash analysis
- from semiconductor process over device simulation to circuit simulation

Exemplified by the forming to crash analysis process chain, the strategy consists of the following **main steps** and **software tools**:

1. Analysis of the first process step (forming):

- ensemble of forming simulation runs based on a design-of-experiments with a minimal number of simulation runs
- parameter sensitivity analysis and iterative construction of the data base (DesParO)
- optional application of a multi-objective robust design-parameter optimization (DesParO)

2. **Transformation** of the data base, including distributions of functionals on the simulation mesh and their local variations, so that the output of forming serves as an input for crash analysis:

- compression of the data base
- mapping of the ensemble of relevant functionals to the next processing step (with SCAI's MpCCI MetalMapper) and setup of a new data base

3. Analysis of the second process step (crash):

- ensemble of crash simulation runs based on an extended design-of-experiments
- sensitivity analysis and iterative construction of the data base (DesParO)
- multi-objective robust optimization of the whole process chain (DesParO)

DEVELOPED BY

Network Evaluation Technologies
Fraunhofer Institute for Algorithms
and Scientific Computing SCAI

Prof. Dr. Tanja Clees
Schloss Birlinghoven 1
53757 Sankt Augustin
Germany

robust-design@scai.fraunhofer.de
www.scai.fraunhofer.de/robust-design

DISTRIBUTED BY

scapos AG

Schloss Birlinghoven 1
53757 Sankt Augustin
Germany

phone +49 2241 14-4400
fax +49 2241 14-4405
info@scapos.com
www.scapos.com

Cover: Example of a robust design study for river bed simulation including uncertain parameters. The figure shows the river Danube model area with a 270° bend of Mühlham. Quantile estimators indicate the asymmetry of the resulting distribution for the river bottom changes over time.