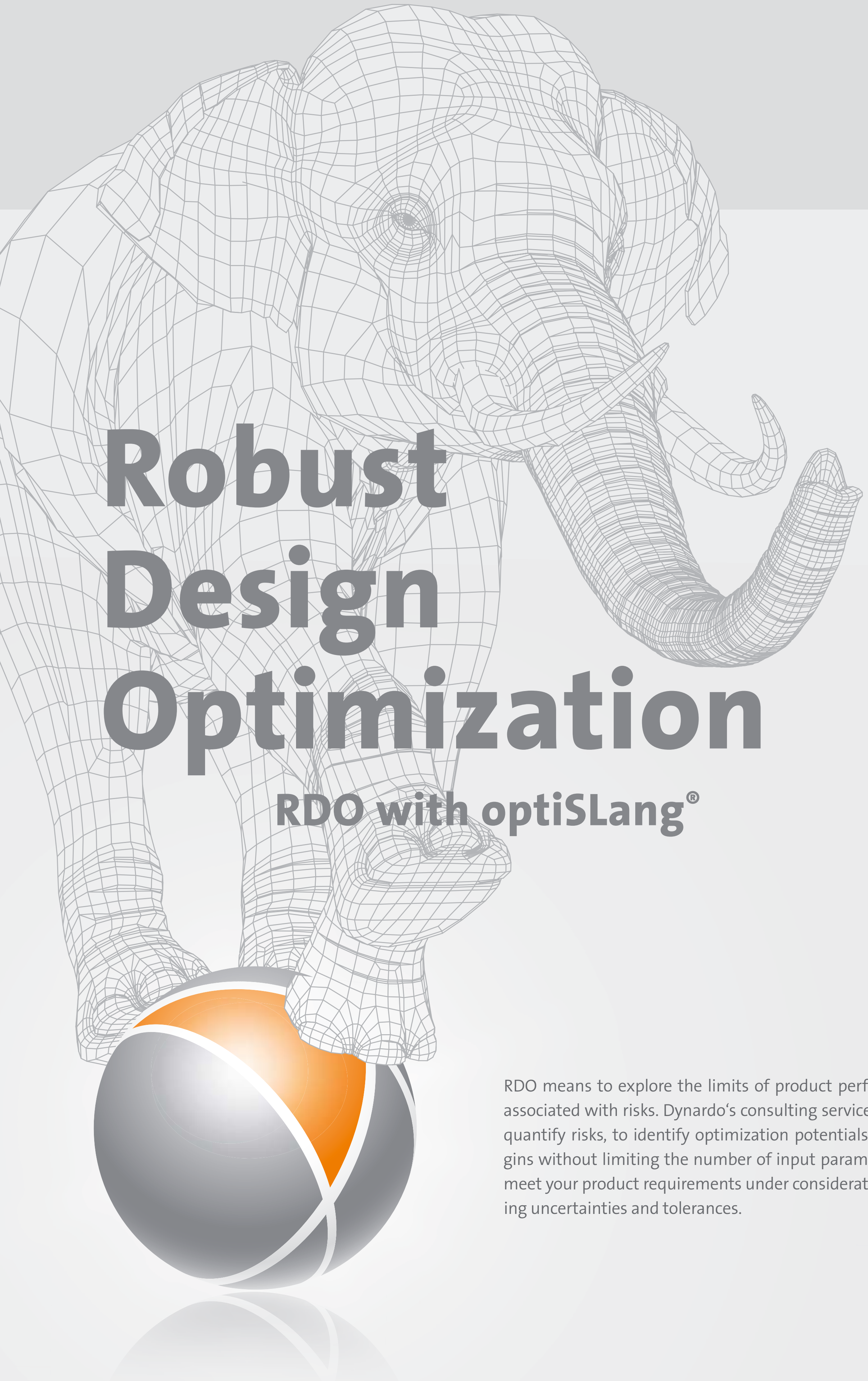
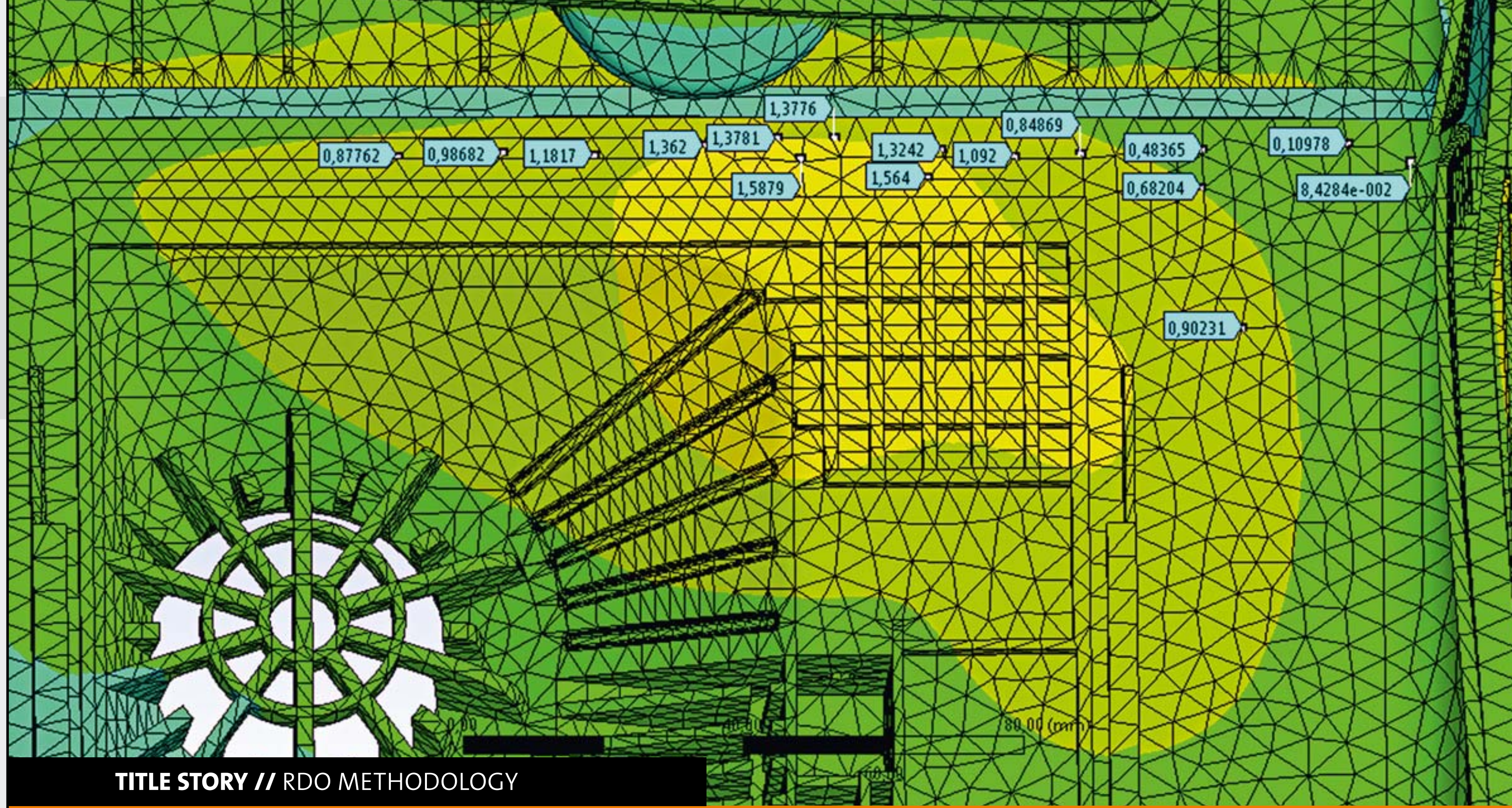


Robust Design Optimization

RDO with optiSLang®

RDO means to explore the limits of product performance, which might be associated with risks. Dynardo's consulting service and software help you to quantify risks, to identify optimization potentials and to adjust safety margins without limiting the number of input parameters. Thus, you can safely meet your product requirements under consideration of all potentially affecting uncertainties and tolerances.



CAE-BASED ROBUST DESIGN OPTIMIZATION IN THE VIRTUAL PRODUCT DEVELOPMENT

CAE-based optimization and stochastic analysis are key technologies to improve resource-efficient product development, to enhance product performance and to secure the quality requirements of reliability and robustness.

The speed of development and introduction of technical innovations, as well as the requirements for the optimization of products, demand more than ever a virtual product development. A distinction has to be made between the construction of designs (Computer Aided Design-CAD) and the calculation or the detection of functionality by simulation methods (Computer Aided Engineering-CAE). Here, CAE-based optimization and stochastic analysis are key technologies to improve product performance while proving the quality requirements of reliability and robustness. At the same time, efficient strategies of Robust Design Optimization (RDO) are required to secure the optimization results and robustness evaluations.

Variant studies, parametrics, and process automation

For 20 years, CAE-based optimization strategies, ranging from manually generated variant studies of DOE techniques, topology and design optimization to multi-disciplinary optimization of parameters, have been gradually integrated into the product development and the production process. In addition to stand-alone solutions for the optimization of individual disciplines and product requirements, there is now a trend using parametric modeling environments that open up the potential to combine CAD and CAE parametric calculation. Thus, several disciplines and product requirements are connected to each other. Products can be optimized automatically by intelligent variant calculations of multiple disciplines and simulations considering CAD and CAE constraints. As a prerequisite, consistent parameterization as well as integration and automation of simulation processes are a necessity of modern RDO processes. This leads to an increased number of parameters which have to be considered. Tasks with a dozen up to a few hundred parameters become normal and represent both parameters to be optimized and scatters to be considered.

Optimization and robustness in conflict?

Optimization goals, such as weight reduction and performance optimization are frequently in conflict with robustness and reliability of products. This is nothing new. Of course, at all times, engineers have been concerned about the balance between optimization and reliability. This is illustrated in the example of the Dombauhütten during the

Fields of Application

- Consumer Goods Industry
- Mechanical and Process Engineering
- Energy Industry
- Civil Engineering and Geomechanics
- Automotive Industry
- Aerospace industry
- Bioengineering

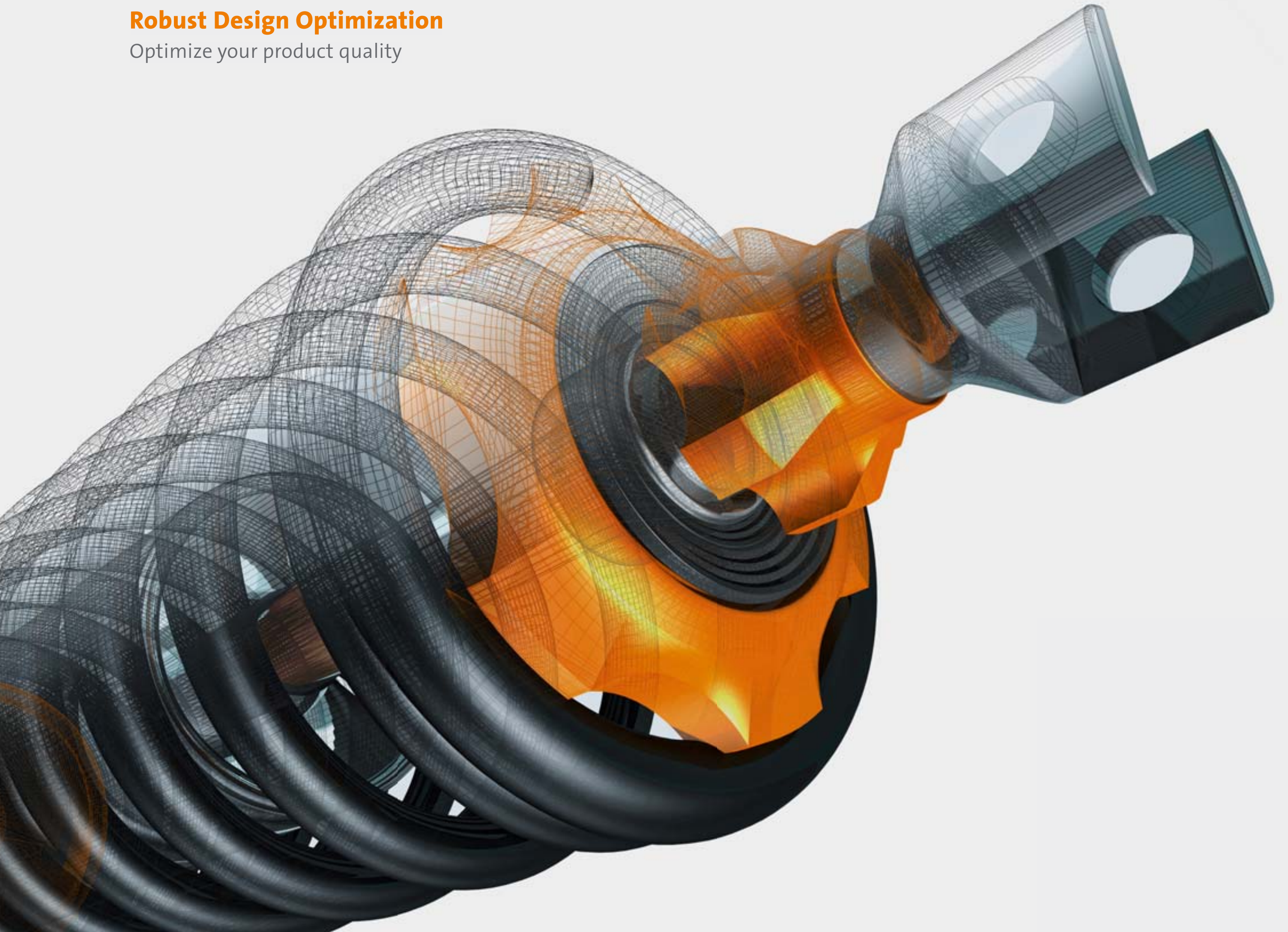
RDO Methodology

Sensitivity analysis
Identify the most important input variables

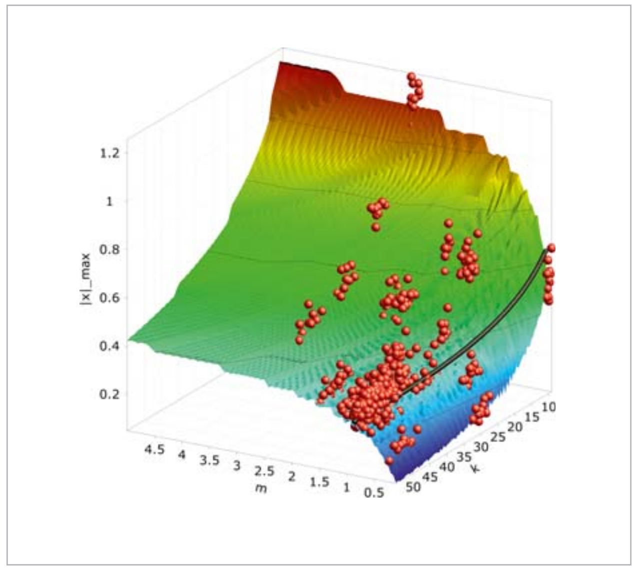
Multiobjective & multidisciplinary optimization
Choose the best design for production

Robustness evaluation & reliability analysis
Quantify your product quality

Robust Design Optimization
Optimize your product quality



Middle Ages. In the Romanesque time, window openings were narrow and arched in a semi-circular shape. From a static point of view, this was very safe. Later, facades became more and more sophisticated and the arcs more risky from a robust point of view. Step by step, the master builder exceeded the known limits of feasible static structures and many churches remained unfinished or simply collapsed. Design rules for masonry structures were derived from these experiences, some of which are still popular today. These safety margins have been established to construct the most sophisticated church buildings. They contain sufficient safety margins considering subsoil uncertainties, geometrical tolerances of the church buildings or material scatters. The implementation of CAE-based optimization follows, in many aspects, these operation methods of engineering to compare different design variants.



Evolutionary Algorithm solving constraint optimization problem with noisy objective function

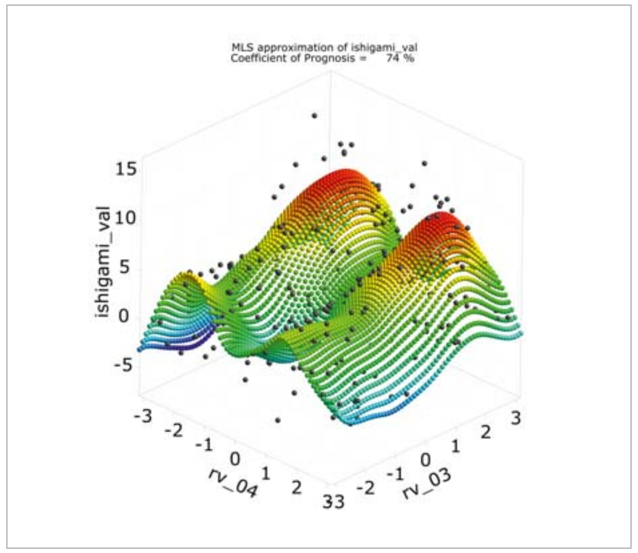
What are the challenges of integrating RDO in the virtual product development?

Of course, the definition of the optimization task (transferring design requirements into objective functions and constraints), the variation space (parameterization of the design space) and the optimization strategy (optimization methods) strongly affect the optimization potential. The introduction of CAE-based stochastic optimization methods requires a significant extension of previous "deterministic" calculation processes. The challenge is to maintain the balance between the definition of the input scatter, the method of stochastic analysis, the estimation of variation and the correlation measures for the evaluation of robustness and reliability.

In order to obtain reliable estimations of outcome variations as a basis of any evaluation of robustness and reliability, all relevant input scatters have to be considered in an appropriate manner. This is an issue concerning the implementation of RDO strategies. It is understood that a detailed knowledge of all potentially affecting variables and an adequate parametric determination of all input scatters appear to be an almost insurmountable obstacle in stochastic analysis. But, waiting for a perfect knowledge will probably lead to no development at all. Therefore, a pragmatic approach is to start with conservative assumptions about all potentially relevant scattering input variables. Thus, for important scattering input variables, the knowledge and the discretization of the definition of scattering input variables can be gradually increased.

Another obstacle for the introduction of stochastic analysis is the fact that a standard deviation or a probability can only be estimated and not (deterministically) calculated. Therefore, the outcome for the user will be an estimation, not a real numerical result. In order to obtain a trustworthy and, thus, a firm estimation which can be used to evaluate product features, often more than one stochastic calculation is necessary. Basically, it must be accepted that the introduction of stochastic analysis for firm evaluation of robustness and reliability within an RDO process demands a significantly large number of nodes (samples of a stochastic analysis) in the region of several hundred or several thousand. Since a single design evaluation already requires a high amount of CPU capacity, it represents a significant challenge to the hardware, and if necessary, to the licenses conducting parallel calculation of designs. Therefore, the challenge in choosing a robust design optimization methodology is to keep a balance between the number of solver calls and the trustworthiness of the robustness and reliability measures. In all RDO methods, for an estimation of robustness measures, it is worthwhile to reduce the amount of real design nodes to a minimum. After a robust design optimization, a final evaluation of the presumptive optimal and robust design with appropriate methods of a reliability analysis is mandatory.

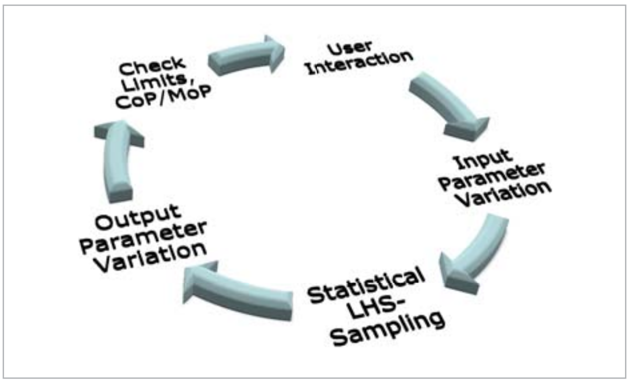
Due to the large number of sampling nodes in a stochastic analysis, RDO algorithms primarily use meta-models (response surface models) to estimate value variation. The



3D visualization of the Metamodel of Optimal Prognosis (MOP) usability of meta-models for robustness evaluation and reliability analysis is discussed controversially in literature. The amount of effort to generate appropriate meta-models depends strongly on the number of important scattering input variables, the non-linearity of the result spaces and the probability level of a robust design. In any case, there must be a final reliability analysis using real design nodes proving the robust design which was generated by meta-models.

Integration status of Robust Design Optimization (RDO) in the virtual product development

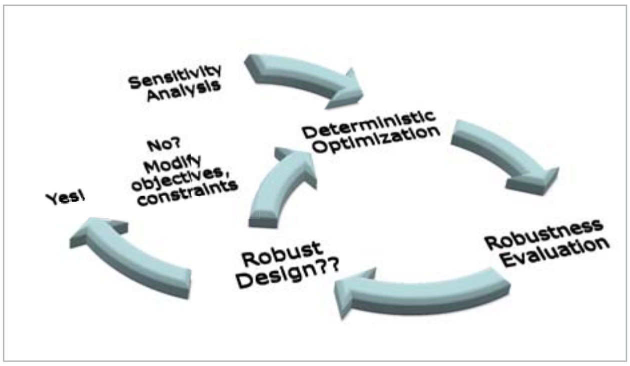
The first important step is to implement a trustworthy robustness evaluation of the most important result values regarding the influence of uncertainties and scatters. By this sensitivity analysis of the uncertainties and tolerances which potentially affect all important result values, a first estimation of variation and variable importance can be conducted.



Process chart robustness evaluation

In order to reduce the number of scattering variables to those being important for the result value variation and to prove the reliability of the estimation of variation values, an iterating approach is often necessary.

In the next step, safety margins are estimated to be considered in the implementation of a deterministic optimization. The generation of an optimized design using preset safety margins is followed by a stochastic analysis proving robustness or reliability. If the safety margins were not sufficient, optimization and robustness steps have to be repeated. This procedure (iterative RDO) is effective if the necessary safety margins are fairly constant in the optimization space. If the safety margins for proving a robust design vary greatly in different areas of the optimization space, it might be necessary to determine the variation of each design in the optimization space. These variation values are used to set constraints and objective functions of a robust design optimization. After that, methods of optimization and stochastic analysis can be automated and combined (automatic RDO). Usually, the effort of an automatic RDO compared to an iterative RDO increases significantly in the course of an analysis.



Process chart Robust Design Optimization

Dynardo's optiSLang

In Dynardo's software optiSLang, the most efficient methods of optimization and stochastic analysis are integrated for the solution of RDO tasks. With the development of the CoP (Coefficient of Prognosis) and the automatic identification of the MOP (Metamodel of Optimal Prognosis) we provide outstanding algorithms for automatic detection of the most important parameters, automatic detection of the best possible meta model and verification of forecast quality of the MOP. Customers have successfully implemented RDO in their virtual product development. This is also confirmed by the lectures at Dynardo's RDO Conference - the Weimar Optimization and Stochastic Days. In order to implement even more RDO applications as an integrated part of product development and to provide this methodology also for customers without expertise in optimization and stochastic analysis, we have currently developed our "best practice" modular system. In the new software version "optiSLang inside ANSYS Workbench" and "optiSLang v4.0", necessary user input was minimized and automated defaults for variable reduction and the automatic generation of the best possible meta-model were implemented.

Minimizing application obstacles

A successful integration of RDO methods in the virtual product development make high demands on the user. Parts of the application obstacles can be minimized in commercial software solutions by easy and safe to use RDO modules. However, if the assumptions on the input scattering for a chosen method of stochastic analysis and the reliability of the estimated variation are not in balance, the results of the RDO calculations are unusable. Therefore, it is recommended to introduce CAE-based RDO methods step by step in the virtual product development and to establish the verification of a trustworthy robustness evaluation as the basis of a reliable estimation of the variation of important output variables. The adjustment of the variation values with measurements and experience, as well as the verification of assumptions about scatters, should be permanently reviewed, verified and refined.

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