Robust Design Strategies for CAE-based Virtual Prototyping in the Automotive Industry.

Due to a highly competitive market, the development cycles in the automotive industry have to be constantly reduced while the demand regarding performance, cost and safety is rising. CAE-based virtual prototyping and robustness evaluation helps to meet these market requirements. A CAE-based robustness evaluation creates a set of possible design variations regarding the naturally given input scatter. A stochastic analysis methodology is used to generate the sample set. Depending on the criteria, variance-based or probability based robustness evaluation have to be utilized. In variance-based procedures, a medium sized number (100 to 150) of input variables are generated by Latin Hypercube Sampling (LHS). The primary goal of robustness evaluations is the determination of a variation range of significant response variables and their assessment by using definitions of system robustness like limit value violations. By running a sample set of around 100 Latin Hypercube samples, reliable estimation of event probabilities up to 1 out of 1000 (2 to 3 Sigma range) is possible. For rare event probability estimations like 1 out of 1000000 (4 to 6 Sigma range), probability-based robustness evaluation is necessary. The secondary goal is the identification of correlations between input and response scatter as well as a quantification of "physical" and "numerical" scatter of result variables.

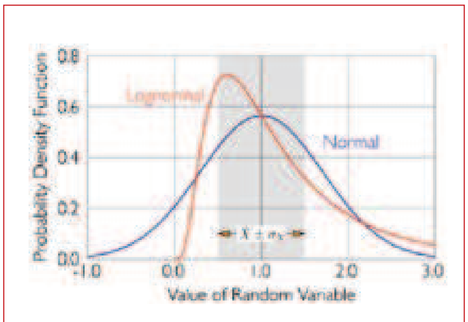

Figure 1: Normal versus Lognormal distribution, the figure visualizes that both distributions may have the same mean and standard variation but very different probability in the tails

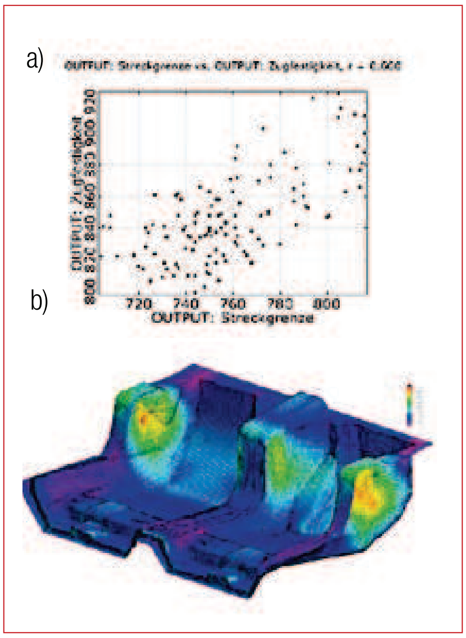

Figure 2:
a) correlation of scattering material parameter/

b) random field of initial stresses after forming process

The definition of the uncertainties forms the base for the stochastic generation of the sampling set. Because robustness evaluation requires knowledge of input scatter influence, the best available know-how needs to be transformed in the definition of input scatter including type of distribution function, correlation of single parameter or spatial correlations (random fields).

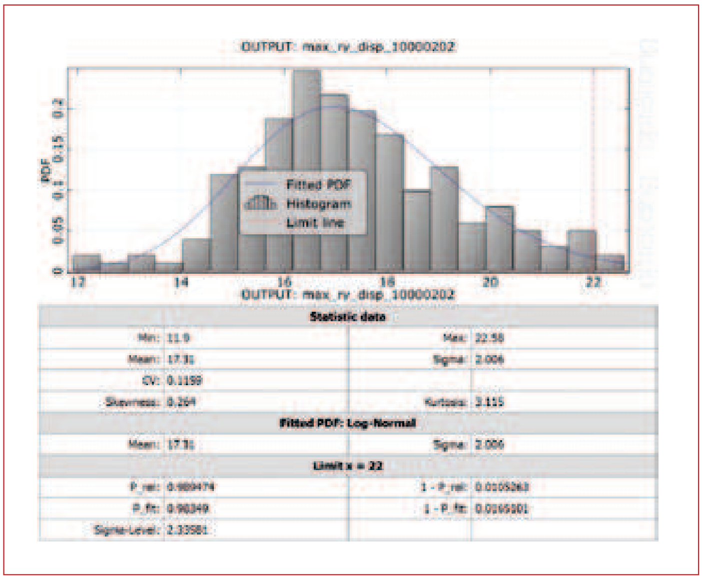

Figure 3: Histogram for Robustness evaluation; the violation probability of the limit 22 is estimated at 1 to 2%

The Metamodel of Optimal Prognosis (MOP) algorithms and the measurement of forecast quality (Coefficient of Prognosis-CoP) of the correlation model were developed to provide automatic reduction of dimensionality to the most important parameter. This is combined with automatic identification of the metamodel which shows the best forecast quality of variation for every important response value. At the same time, the amount of CAE solver calls necessary to reach a certain forecast quality can be minimized. This technology allows successful application of CAE-based robustness evaluation as a standard process to CPU intensive applications in the automotive industry.

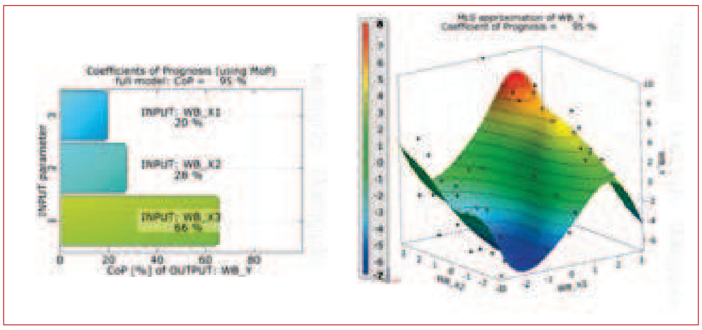

Figure 4: Coefficient of Prognosis (CoP) using the Metamodel of Optimal Prognosis (MoP) to quantify the input variable contribution to the response variable variation

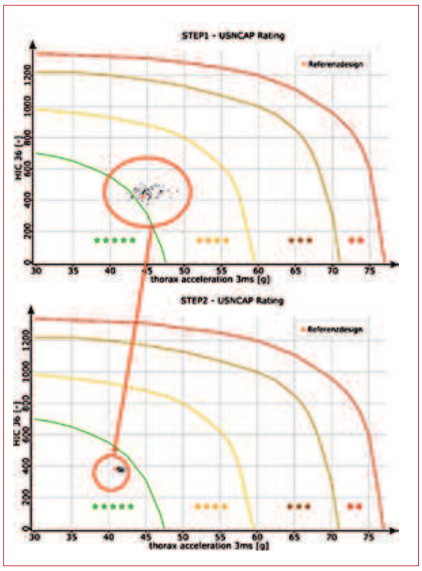

Figure 5: Visualization of robustness improvement of passive safety performance: upper diagram shows the scatter at milestone 1; lower diagram shows the scatter at final milestone of the virtual product development process

The goal of robustness evaluations for passive car safety applications is to investigate and improve the robustness of the restraint systems to fulfill consumer ratings and legal regulations of crash tests. Figure 5 shows an example how a restraint system was improved by FE-modeling and physical modifications to move the mean value and to reduce the response scatter.

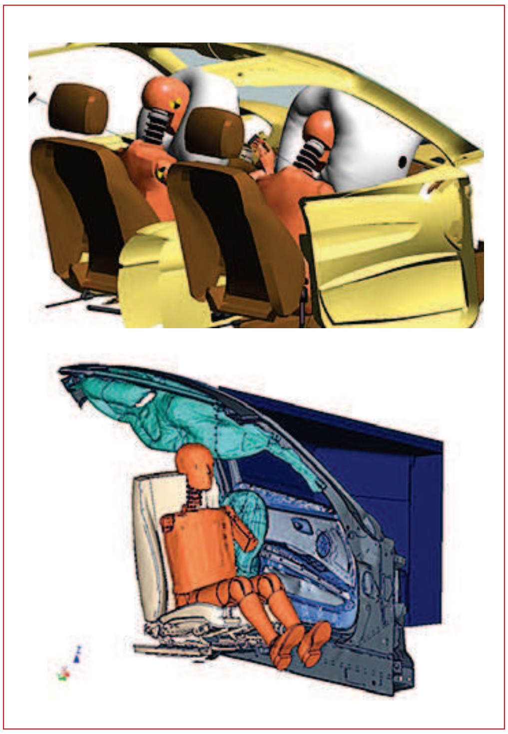

Figure 6: For passive safety applications multi body as well finite element models are used in robustness evaluation

In passive safety applications, using MKS or FE-models, the quantification of numerical noise has become an important part of robustness evaluation. In other words, by investigating the quantity of numerical noise, an assessment of model quality is possible. Nowadays, by developing a reliable quantitative estimation of numerical noise robustness, the evaluation of passive safety applications is applied to regular procedures in virtual prototyping. It is necessary to provide state-of-the-art technology for the consideration of test setup (dummy positioning, crash pulse), airbag (mass flow, venting, permeability), sensors, belt system, door/interior stiffness and scatter of friction (fig. 6). Besides the influencing dummy scatter, also the consideration of geometric body scatter in white car is a topic of interest. Automation of post processing is a key feature for productive serial use. Starting from response variation overview, the engineer can identify the critical response values regarding to variation (fig. 7).

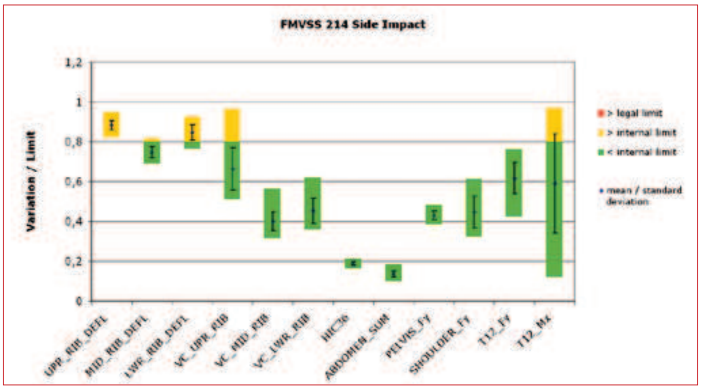

Figure 7: Summary of variation of all important responses for load case FMVSS 214

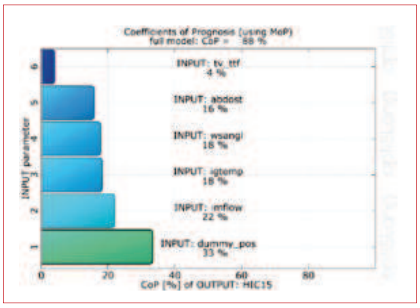

Figure 8: Coefficient of Prognosis for Variation of HIC15 values

In the serial use, the following added value can be expected concerning the dimensioning and increase of the restraint systems robustness:

1. Those scattering input parameters are identified that have significant contribution to important response scatter.
2. Model weaknesses are detected and numerical noise of significant vehicle performance variables is reduced.
3. The model robustness/stability and the quality of prognosis of crash-test computations are increased.
4. Robustness problems of the restraint systems are recognized and in cases of high violation of limits solved or improved by re-design of components.

CAE Wissen by courtesy of Johannes Will, Managing Director Dynardo GmbH, www.dynardo.de