Uncertainty Analysis and Robustness Evaluation for Crashworthiness Problems

Name: **Sebastian Thelemann**
E-Mail: **Sebastian.Thelemann@tum.de**
Supervisor: **Prof. Dr.-Ing. habil. Fabian Duddeck**
Associate Professorship of Computational Mechanics
Started: **02/2017**
☒ **ongoing** ☐ **finished: MM/20YY**

Introduction
Crashworthiness aims to reduce the number of fatalities and serious injuries in traffic by focusing on occupant protection via new and improved vehicle design and safety countermeasures. Optimization techniques tend to design structures and systems near their corresponding material and design limits leading to a higher sensitivity against unavoidable variability and incertitude. In general, due to uncertainties, there is often a trade-off between improvement of the performance under nominal conditions and robustness. Thus, new comprehensive, robust and efficient numerical approaches considering stochastic methods, sensitivity analysis, robustness, and optimization techniques need to be developed. This research area is known as Robust Design Optimization (RDO). Aspects of reliability (i.e. probability of failure) can be integrated here as well.

Uncertainty Categorization
Uncertainties can be categorized into two groups: aleatoric and epistemic uncertainties. Aleatoric uncertainties, i.e. variability, describe random variations of physical properties of a system, e.g. manufacturing-based tolerances of material and geometry parameters, randomness in the material microstructure, etc. The other group describes incertitude arising due to lack of knowledge, vagueness or incomplete and limited valid information, e.g. higher degrees of freedom in the concept phase of products, missing constraints, measurement uncertainty, simplification and ignorance about the details of physical models and processes, etc. Consequently, uncertainty quantification (UQ) is an important part in modeling and simulation to handle non-deterministic system behavior and incomplete or inadequate models.

Sebastian Thelemann
Associate Professorship of Computational Mechanics

Uncertainty quantification methodology

For crashworthiness problems, different sources of uncertainty are often inseparable. Quantifying their individual contribution to the system behavior is even more challenging. Therefore, there is a need for a robust and comprehensive procedure addressing mixed types of uncertainty, i.e. total uncertainty.

In literature, several methods and frameworks have been introduced and presented for uncertainty representation (quantification) and propagation of aleatoric, epistemic or combined sources of uncertainties. Uncertainty representation aims to represent both aleatoric and epistemic uncertainty in the input variables using belief or probability density functions. Uncertainty propagation addresses the question how to set up belief or probability functions for the model's output variables (and their statistics) given the belief or probability functions of uncertain input variables [1].

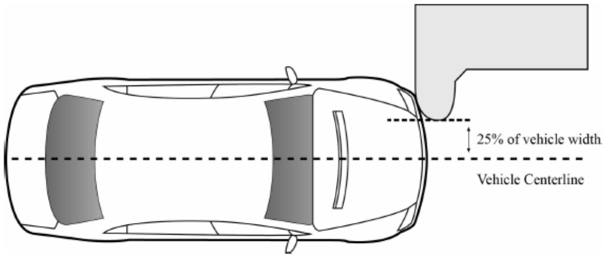

Fig. 1: Frontal crash with Small Overlap Barrier [4]

A well-known and quite general UQ methodology is the evidence theory, a non-additive-measure theory, developed since the 1980s. This method provides a common framework for probabilistic (aleatoric) and possibilistic (epistemic) uncertainty. The theory allows to include predictions of several models, e.g. different material models and fitting parameters (model constants), expert opinions and conflicting information for the same quantity of interest using combination rules. Lack of knowledge and ignorance can be handled adequately, demonstrating the theory's ability to deal effectively with both parametric and model uncertainties. [2]

In general, robustness is a measure of system insensitivity to inputs variation and thus should be integrated in an optimization process. Therefore, sensitivity analysis in conjunction with evidence theory is considered to study the influence of uncertain input parameters on the variation of the model output quantities. To reduce test and analysis time it is crucial to evaluate different sensitivity analysis (SA) methods in terms of effectiveness and efficiency. Effectiveness describes the ability to identify and separate sensitive and insensitive parameters adequately and correctly. While efficiency concerns about the minimum number of samples for a given sampling technique [3]. A suitable methodical approach will be presented to evaluate sensitivities and therefore robustness and derive a basis for describing robust system behavior. The described approaches to quantify total uncertainty are applied in simple examples and crashworthiness problems.

References

[1] He, Y. (2013): Uncertainty Quantification and Data Fusion Based on Dempster-Shafer Theory. *PhD Thesis*. Florida State University, USA.

[2] Salehghaffari, S.; Rais-Rohani, M. (2012): Material model uncertainty quantification using evidence theory. In: *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 227 (10): 2165–2181.

[3] Gan, Yanjun et al. (2014): A comprehensive evaluation of various sensitivity analysis methods. A case study with a hydrological model. In: *Environmental Modelling & Software* 51: 269–285.

[4] IIHS (2017). Small Overlap Frontal Crashworthiness Evaluation. Crash Test Protocol. Version VI. *Insurance Institute for Highway Safety.* USA.

Stand: 31.01.2018