Solution spaces for vehicle crash design considering polymorphic uncertainties

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Motivation  
This project aims new methods of uncertainty consideration in early phase design of vehicle crash using non-deterministic solution spaces. Via this approach, it is possible to go beyond standard modeling of probabilistic uncertainties based on probability density functions and even possibilistic uncertainties based on interval arithmetic or fuzzy sets. Both together plus an additional approach for non-reducible lack-of-knowledge problems (the later stages of development are unknown for early phase design) serve here as an overall hybrid approach for polymorphic uncertainty modeling.

Solution spaces  
Solution spaces have been introduced as a method to increase efficiency of the development process in early design stages (Zimmermann et al. 2013). They enable virtual development and optimization of complex structures consisting of a high number of components. Complexity is reduced by breaking down the total structure into components, which can then be developed independently. This complexity reduction modeling is necessary because:

- In early development phases, full and detailed information of the structural concept is not available (non-reducible lack-of-knowledge situation)
- Iterative designing shall be avoided. Fast assessments are needed to enable principle design decisions.
- The components of a complete system are developed by different groups or even companies with a different pace. A decoupled approach is essential to allow efficient development.
- Additionally to the lack-of-knowledge problem, uncertainties have to be considered which concern material data, system parameters, and modeling assumptions.
However, aspects of robustness, reliability and other considerations of uncertainties are not sufficiently integrated into the method of solution spaces. This is addressed by this research project. Probabilistic, possibilistic, and non-reducible lack-of-knowledge modeling will be integrated into an overall polymorphic uncertainty methodology for improved solution space approaches. This is done for vehicle crash design here but can be transferred to other fields.

Vehicle Crash design
To illustrate the idea of vehicle crash design with solution spaces, a simple structural system is regarded, which consists of two sections and is subjected to an axial impact load (Fig. 1). The approach can be transferred to real complex systems, compare (Fender, 2013), where the system problem is a structural design for crash to achieve 5 stars in EuroNCAP rating.

![Vehicle front structure with two sections](image1.png)

**Fig. 1**: Vehicle front structure with two sections (left) and corresponding box-shaped solution space (right), (Zimmermann et al. 2013).

The performance of a vehicle front structure in a full overlap impact against a rigid wall can be represented by two sections having two different constant force levels and two deformation lengths. Instead of optimizing the full system, a solution space is derived first to enable component optimization in a later step. The rest of the car is approximated as a rigid body. The solution space is now obtained by regarding the overall requirements for the system to absorb crash energy, avoid high accelerations and assure a progressive deformation. The complete solution space (good region) is shown in Fig. 1 as white triangle. System optimization would modify now the components such that the average force levels are in this white area. Hence, the algorithm to derive an appropriate solution space must identify a maximum volume subset of the permissible set of designs, which allows decoupling of the components. This means that the solution space must be an axis-parallel box, see Fig. 1.. Taking this solution space, independent constraints for each component are defined. The component optimization problem is now to modify each component separately such that its force levels lie in the range (corridor) of the solution space.

Uncertainties in vehicle crash design that are disregarded in this method include

- Variations in the approximated rigid body mass or the deformation lengths,
- Model uncertainties of the system, and
- Future changes in design criteria or crash load case definitions.

In the new non-deterministic approach for solution spaces such uncertainties are integrated.

References