Research on Imprecision Methods for Quality Engineering Design at Caltech

Kevin N. Otto
Graduate Research Assistant

Erik K. Antonsson
Associate Professor of Mechanical Engineering

Engineering Design Research Laboratory
Division of Engineering and Applied Science
Mail Code 104-44, California Institute of Technology
Pasadena, CA 91125

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The mathematics of uncertainty in engineering design is being investigated at the Engineering Design Research Laboratory of the Division of Engineering and Applied Science at the California Institute of Technology, supervised by Professor Erik Antonsson. Work has focused on the development of methods for manipulating preliminary engineering design models, when parameter values are imprecise. A *semi-automated* design method has been developed, termed the *method of imprecision*, to aid the designer in evaluating preliminary design models, even before the model has been completely designed. The reader is referred to [7, 8, 9].

In addition to designer's uncertainty in choosing a particular value for a design parameter, probabilistic uncertainty is also present in engineering design. Manufacturing errors and measuring limitations all require the use of probability. Combining these effects within preliminary models is discussed in [10].

The appropriateness of fuzzy sets to model design imprecision, and a comparison with that of probability mathematics for the same modeling, are presented in [11]. This paper quantitatively demonstrates the superiority of fuzzy sets to model design imprecision, over probability methods.

Comprehensive discussions of the method of imprecision are available in [6, 12, 13].

Current research has focused on extending the method of imprecision to the parametric stage of engineering design, where actual values of model parameters need to be determined. We have shown that utility theory, fuzzy sets, and probability all fail to provide all of the required features of this calculation [3]. Instead, the properties of general goal resolving operators are presented, similar to the properties of a T-norm. We then introduce specific operators (such as *min* or a product of power weightings) based on a specified *design trade-off strategy.* The reader is referred to [3, 4].

Reference [4] also discusses level α-cut calculations, and generalizes results on their applicability to beyond simple fuzzy sets. It should be noted that level cut calculations (meaning an entire interval is represented by the end points) can be performed on any operator which is idempotent, including, but not limited to, the *min* operation.

Current research has focused on the concepts of possibility and necessity in engineering design [2]. Possibility methods appropriately model variables that are adjusted (or tuned) during the manufacturing process in response to earlier manufacturing variabilities. We believe that this specific example of the applicability of possibility theory illustrates the theory's appropriateness. The theory of necessity that we are developing is different from that of Dubois and Prade [1]. They view necessity as the possibility of the negation of an event occurring. We view necessity as the degree to which a value of a parameter must be satisfied.

Current research has also focused on the propagation of imprecision through operator equations, such as differentiation, integration, and ordinary differential equations. Fuzzy theory is extended to operator equations over sets which have a general manifold structure. The reader is referred to [5].

Current research is also now focusing on the conceptual engineering design stage, when models are developed. The aim is to provide imprecise rankings of candidate models based entirely on a conceptual description, with no parameterizations at all. Since preliminary decisions have been shown to be the most important (and potentially the most costly, if in error) our approach has the potential to dramatically impact engineering design decision making.

References

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