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Fuzzy fitness functions applied to engineering design problems

Erik K. Antonsson [a,*], Hans-Jürgen Sebastian [b]

[a] Engineering Design Research Laboratory, Division of Engineering & Applied Science, California Institute of Technology, 1200 East California Boulevard, Pasadena, CA 91125-4400, USA
[b] Faculty of Economics & Business Administration, RWTH Aachen University, Templergraben 64, 52062 Aachen, Germany

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Abstract

Engineering design is concerned with the creation of devices and systems, and encompasses many activities, including the creative activity of conceiving or synthesizing new devices and systems, as well as the analysis, refinement and testing of those concepts. If all information available to an engineer were precise and deterministic, design would be straightforward. However, uncertainty of many forms is present throughout the design process. The uncertainty theories that are most relevant for engineering design are those that deal with a mixture of numerical, set or interval-valued and linguistic information.

Populations of design alternatives can be generated using evolutionary methods [Antonsson and Cagan, Formal Engineering Design Synthesis, Cambridge University Press, Cambridge, 2001]. It has been shown that incorporating uncertainty, such as variations in the operating environment, simulated by variations in the evaluation of the fitness function, can synthesize designs that are robust to the variations. In this paper a class of fuzzy fitness functions (F^3) and hybrid uncertainty fitness functions are introduced, which combine fuzzy and probabilistic types of uncertainties.

Keywords: Decision support; Engineering design; Fuzzy sets; Genetic algorithms; Multiple criteria analysis; Robustness; Uncertainty modeling

1. Introduction: Uncertainty in engineering design

Engineering design is concerned with the creation of devices and systems. Design encompasses many activities, including the creative activity of conceiving new devices and systems, as well as the analysis, refinement and testing of those concepts. Synthesis is the creative step itself; the conception and postulation of possibly new solutions to solve a problem. An overview of the engineering design process, distinguishing analysis from synthesis [1], is shown in the flow chart in Fig. 1.

* Corresponding author.
E-mail addresses: erik@design.caltech.edu (E.K. Antonsson), sebasti@or.rwth-aachen.de (H.-J. Sebastian).

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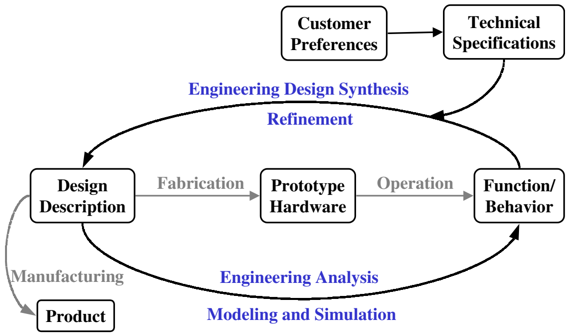

Fig. 1. Flow chart of the engineering design process, distinguishing analysis from synthesis [1].

In engineering analysis, the procedure begins with a physical device or system, and a model (usually computable) of the system is built by decomposing, abstracting and approximating the system and its components. The objective of engineering analysis is to produce a useful description of the performance or behavior of an existing system. Design *synthesis* is the reverse of the analytical process (also shown in Fig. 1). Design begins with the description of the desired function or behavior (in general, not yet available from existing system). The objective is to generate a description of a system which exhibits the desired function and behavior. "Synthesis" in a more narrow sense means combining existing elements into a new configuration; however in connection with design, synthesis is used in a broader sense, that includes the creation of new things in general, and not necessarily only by means of combination of existing parts.

In the following, the term engineering design is used in order to cover both the engineering analysis and the engineering design synthesis view of the process. This paper focuses on formal, meaning computable, methods of solving design problems, where "computable" is used in a very broad sense described below.

Zimmermann [20] considers uncertainty to be a situational property of phenomena which has various causes and which is influenced by available information. He provides a rough taxonomy of uncertainty models, shown in Table 1, including the causes of uncertainty and the nature of the information.

Each uncertainty theory can be characterized by the uncertainty properties shown in Table 1. Some of the most well-established uncertainty theories include various probability theories (e.g., Kolmogoroff's probability theory), evidence theory (Dempster, Shafer), possibility theory (Zadeh), fuzzy set theory (Zadeh), rough set theory (Pawlak), and interval arithmetics. Additionally, combinations such as fuzzy-probability theory are widely investigated.

The most important causes of uncertainty in engineering design are lack of information, abundance of information, and ambiguity (Table 1). The process of engineering design synthesis starts with lack of information. In the early phases of design, customer preferences and technical specifications are only partly available. The available information is mainly linguistic and only partly set-or-interval valued or even numerical.

Design synthesis can be considered to be a process where incomplete or imprecise information is serially replaced by more precise information, or in other words, it is a process that reduces uncertainty and imprecision, and terminates with a precise description of the resulting design. Because of the linguistic character of available information and of requested information (requested information is of course mainly numerical but also linguistic in order to reduce the problem of abundance of information) ambiguity is present in engineering design synthesis. In engineering analysis, the restrictions that exist in modeling and simulation of design artifacts and lack of information require the use of uncertainty methods. Frequency based uncertainty methods (stochastics) are particularly useful when taking into account uncertainties caused by imprecise measurement and uncontrolled variations (e.g., in manufacturing processes or material properties).

The uncertainty theories that are most relevant for engineering design are those that deal with a mixture of numerical, set or interval-valued and linguistic information. Fuzzy set theory, possibility theory and combinations of fuzzy set theory with probability theories appear to be best adapted to the needs of dealing explicitly with uncertainty in engineering design. The use of probability theories (objective and subjective probabilities) also useful