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# A Possibilistic Approach to Set Achievable and Feasible Goals while Designing Complex Systems

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**Abstract:** How to make, early in the development cycle of complex products, the most promising design choices as regards the customer's requirements and being at the limit of what is technically feasible by the manufacturer? To contribute to solve such a difficult problematic, we propose an original approach based on possibility theory that aims finding the best alternative according to the preferences of the stakeholders and being feasible by the designer team. Customer's and manufacturer's preferences are captured in a multi attribute utility theory (MAUT) framework that is extended to uncertain and imprecise evaluation of the alternatives' characteristics since available knowledge about the future system is mostly qualitative in preliminary design stages.

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*Keywords:* design of complex system, imprecise assessment, multiple-criteria decision analysis, possibility theory.

## 1. INTRODUCTION

The survival of a company is heavily dependent on its capacity to identify new customer needs and develop new products Shen *et al*. (2000). Industries must always search for sustainable advantages, improving their performance. However, designing new products or improving existing ones in today's highly competitive market presents significant risks. Many system requirements must be taken into account when designing or improving a product Baykasoglu *et al*. (2002); Ng (2006). Decisional strategies are required to define, compare and select potential design alternatives with respect to the relationships existing between performance expressions Bititci *et al*. (1995). These relationships may be of a different nature, *e.g*. operational, physical or preferential. Operational relationships between two variables refer to the existence of improvement actions that allow or prevent the conjoint improvement of a subset of criteria (*e.g*., there does not exist improvement actions that both allow working better and more quickly). Physical relationships express influences, constraints or balances between variables related to performance expressions (*e.g*., it is difficult to reduce the friction force while increasing the speed of a vehicle because the friction force varies as the speed or the square of speed). Finally, preferential relationships refer to subjective interactions among performance expressions (*e.g*., "I would like my new car to be both roomy and fuel-friendly" refers to a conjunctive interaction whereas "I would like my new car to be either comfortable or sportive" is a disjunctive interaction). Whereas the customers' preferences regarding the system to be designed are considered to be expressed in their needs, the manufacturers' preferences are rather related to the effort the system achievement will necessitate: the more complex the system, the more uncertain the achievement and the more time the project risks to consume and finally the less worthwhile the cost/benefit ratio for the manufacturer.

So, design decisions require large analysis and forecasting capacities especially during the preliminary design stage when system requirements, product models and performances' interactions are merely based on unprecise information. Therefore, identifying new solutions to satisfy customers in such a context appears as a complicated task Moulianitis (2004), Couturier *et al*. (2014). The industrial manufacturers must design new products/systems from past experience according to customers' needs at the limit of what is technically feasible as they are aware of their available enterprise-level skills. Defining achievable targets is a matter of situation awareness to relevantly manage the balance between strategic ambition and manufacturing realism Sow *et al*. (2016), Montmain *et al*. (2015). Thus, design alternatives to be retained as a priority are those which allow both significant positive impacts on product/system performance but also correspond to actions that are derived from the expertise of the manufacturer. This will help the designer to avoid focusing on the implementation of alternatives that would be too far from the genuine ability and know-how of the manufacturer.

Despite their interest in design decision making, few works address the modeling of technical feasibility. In Bause *et al*. (2014), the authors clarify the concept of « technical feasibility study» often used in the context of product development process and explain how such concept concerns usually the activities: "idea detection", "modeling of principle and embodiment", "detection of alternative solutions" and "analysis of consequences". However the

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authors do not deepen methods and tools required to evaluate. Clivillé *et al*. (2015) are interested with this duality between expected and feasible performances. They do not limit the decision making process to the satisfaction of alternatives but introduce a feasibility function such as "a configuration *a* is more feasible than a configuration *b*" if one can pass from *a* to *b*. For each configuration, they then seek to maximize the satisfaction that can be expected starting from this configuration under feasibility constraints. However the work does not consider relationships existing between performance expressions and all information about feasibility is supposed to be given by experts. In Chinkatham *et al*. (2015) is proposed the 'Inventive Design Method' to prevent the surrender of good solution concepts and to reject unfeasible ones as early as possible when designing a product. The approach is based on finding first doubts or uncertain conditions of any solution after reaction of designers or experts. The estimated feasibility is then found by considering one or more behavior model(s), but also design objectives and constraints. However no preference model is discussed.

Also, this paper proposes selecting the most relevant design alternative for the product/system to meet the customer's requirements subject to the enterprise-level skills in taking into account the uncertain environment and the operational, physical or preferential relationships between performance expressions. At this aim, a fuzzy model of the expected performances and of the ability to achieve is defined. The paper will be organized as follows. Section 2 introduces the problematic and the necessary notations to the problem formalization in the context of design/improvement of complex system. Section 3 presents the possibilistic model of preference required to select a design alternative. Section 4 considers an experimented application. Further prospects for this work are considered in the conclusion.

## 2. PROBLEMATIC AND CHARACTERIZATION

### *2.1 Problematic: Evaluation in System Engineering*

Designing a system generally imposes to solve an ill-posed problem admitting multiple solutions and whose definition becomes more and more accurate as the choices for developing a satisfying solution are made. The most critical stage in the design process is the preliminary stage where most of the system development costs are committed Phillips *et al*. (1993). Therefore it is crucial to evaluate concepts and design alternatives against technical and economic criteria very early in the preliminary design stage (i.e. the conceptual and embodiment stages) even if, at this design stages, the available knowledge and descriptions of the system are incomplete, imprecise and subject to change. To respond to this problematic, we assume that some experts can provide advices, as regards design choice performances and feasibility, which can be formulated in form of possibility distributions and we propose an approach that aims at identifying among the possible design solution alternatives, the ones that better satisfy the customer's criteria and that are achievable by the designer team. This is done by estimating an overall satisfaction of design alternatives on several criteria with respect to the preference of the stakeholders' respectively to its feasibility on these criteria. Some definitions and results will be recalled about multi attribute utility theory that manages multiple criteria context and possibility theory before formalizing the proposed approach.

### *2.2 Characterization and Notations*

In order to design a complex system, we characterize it by a set of parameters $(\gamma_1, \gamma_2, ..., \gamma_n)$ whose values have to be fixed by the designers. Let $\Gamma$ be the set of all possible values of the vector $(\gamma_1, \gamma_2, ..., \gamma_n)$. A system is then defined by a design solution or configuration $\gamma \in \Gamma$. Improving a system is to make it evolve from a configuration $\gamma \in \Gamma$ to a configuration $\gamma' \in \Gamma$ which gives better satisfaction regarding the objectives that have been fixed for the system by the customer's and taking into account cost constraints of the manufacturer (effort, money, risk, time etc.). The satisfaction of the objectives will be evaluated in a multi-criteria decision analysis (MCDA) framework using multi attribute utility theory.

### *2.3 Multi Attribute Utility Theory (MAUT)*

Let us denote by $N = \{1, 2, ..., n\}$ a set of attributes where the $i^{th}$ attribute takes its values in a set denoted $X_i$. The MAUT allows establishing an analytical model of the decision maker's preference relationships over $X = \prod_i X_i$. Let $\preceq$ be a preferential relation over $X$. The MAUT proposes to model it through a utility function $U : X \to [0,1]$ such that:

$$\forall (x, x') \in X^2, x \preceq x' \Leftrightarrow U(x) \leq U(x') \quad (1)$$

The function $U$ of the equation (1) can take several forms; the most often used is the additive model:

$$\forall x \in X, U(x) = \sum_{i=1}^{N} w_i u_i(x_i) \text{ where } \sum_{i=1}^{N} w_i = 1, \ \forall i \in N, w_i > 0,$$

and each $u_i : X_i \to \mathbb{R}$ is an elementary utility function that synthetizes the preference of the decision maker regarding the $i^{th}$ attribute (it translates the value $x_i$ into a utility value $u_i(x_i)$, here a performance with regard to $i^{th}$ criterion).

The additive aggregation intrinsically tolerates compensation between criteria and required independence between them Keeney & Raiffa (1976). This additive form is the most widespread because of its simplicity and its intuitive interpretation. It is generally, a very simplifying assumption because in reality attributes interact between them. To solve this problem, a more general model of the overall utility $U$ in equation (1) has been proposed in Krantz et al. (1971) where $U$ is written under certain conditions of separability and independence:

$$\forall x \in X, U(x) = F(u_1(x_1), u_2(x_2), ..., u_n(x_n)) \quad (2)$$

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