

An integration of a Multi-Objective Optimization Design framework with Design Science Research Process for engineering problems

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ABSTRACT

This work investigates how multi-objective optimization techniques can effectively solve complex engineering problems. We propose integrating the Multi-objective Optimization Design (MOOD) framework with the Design Science Research Method (DSRM) to support iterative problem-solving and knowledge acquisition. Unlike traditional approaches, this integration enables continuous refinement of models, cost functions, optimization algorithms, visualization strategies, and decision-making processes. A case focused on controller tuning for refrigeration systems, proposed by the Spanish Committee of Automation, is presented. Results highlight the flexibility of the framework and its potential to produce feasible, high-quality solutions through iterative learning. Future work will assess the real-world performance of the proposed solutions and further refine the framework for broader engineering applications.

KEYWORDS. Multiobjective Optimization. Design Science Research. Iterative process.

Multi-objective Optimization

1. Introduction

Multi-objective optimization techniques have demonstrated significant value across a wide range of knowledge domains [Sharma and Kumar, 2022]. This relevance stems from their ability to simultaneously handle conflicting objectives, enabling decision-makers to explore and balance trade-offs effectively. Such techniques offer a higher level of involvement in the decision-making process, allowing for more informed and strategically aligned solutions.

Within this context, the *Multi-Objective Optimization Design* (MOOD) procedure has been proposed as a structured framework to support the successful application of multi-objective optimization in engineering projects [Reynoso Meza et al., 2017]. However, the assumption that these steps can be correctly defined and successfully executed in a single attempt often does not reflect the realities of engineering practice. In real-world scenarios, the problem-solving process is inherently iterative, requiring the analysis of preliminary solutions and the subsequent refinement of problem definitions, objectives, and model parameters.

To address this need for iteration and continuous refinement, we propose the integration of the MOOD framework with the *Design Science Research Method* (DSRM) [Peffer et al., 2007]. By integrating DSRM with the MOOD framework, we aim to formalize the iterative cycles necessary for refining problem formulations, optimization strategies, and decision-making criteria in complex engineering contexts.

The remainder of this paper is organized as follows: Section 2 presents the theoretical background of the proposed approach. Section 3 describes the integration methodology between MOOD and DSRM. Section 4 illustrates the application of the proposed approach through a representative case study. Finally, Section 5 summarizes the main findings and outlines future research directions.

2. Background

Multi-objective optimization can be defined, roughly speaking, as the simultaneous optimization of more than one objective function, searching for a better solution to a mathematical problem. In general, a multi-objective problem, without loss of generality, can be defined as follows:

$$\min_{\mathbf{x}} \mathbf{F}(\mathbf{x}) = [f_1(\mathbf{x}), \dots, f_m(\mathbf{x})] \quad (1)$$

subject to:

$$\begin{aligned} g(\mathbf{x}) &\leq 0 \\ h(\mathbf{x}) &= 0 \\ \underline{x}_i &\leq x_i \leq \overline{x}_i, i = [1, \dots, n] \end{aligned} \quad (2)$$

where $\mathbf{x} \in \mathbb{R}$ is the decision vector, $\mathbf{F}(\mathbf{x})$ is the objective vector, $g(\mathbf{x})$ and $h(\mathbf{x})$ are, respectively, the inequality and equality constraints and $\underline{x}_i, \overline{x}_i$ are the boundaries of the decision space for the variable $\mathbf{x}$ [Miettinen, 1999].

On the one hand, in order to have success employing such ideas in engineering design, at least three fundamental steps [Reynoso Meza et al., 2017] must be carried out: the Multi-objective Optimization Problem (MOP) statement; the Multi-objective Optimization (MOO) process; and the Multi-criteria decision making/analysis (MCDM/A).

On the other hand, the Design Science Research Process (DSRP), proposed by Peffer et al. [2007], provides a structured methodology for conducting research in information systems through the creation and evaluation of innovative artifacts. The process is characterized by its flexibility,

allowing both forward (from problem to solution) and backward (from solution to problem) initiation. It consists of six nominal stages: Problem Identification and Motivation; Define Objectives of a Solution; Design and Development; Demonstration; Evaluation; Communication.

3. Integration proposal

The proposed DSRM with the MOOD framework is illustrated in Figure 1. In this integration, a direct link is established between the *Multi-Objective Problem Statement* and the *Definition of Solution Objectives*. Similarly, the *Development* phase is directly connected to the *Multi-Objective Optimization Process*, while the *Demonstration and Evaluation* phase aligns with the *Multi-Criteria Decision-Making Analysis*.

Throughout this process, the iterative refinement cycles play a fundamental role, particularly through the continuous analysis of the Pareto front obtained at each iteration. This analysis is crucial for validating the type and quality of solutions produced, ensuring that they accurately reflect the underlying realities of the problem domain.

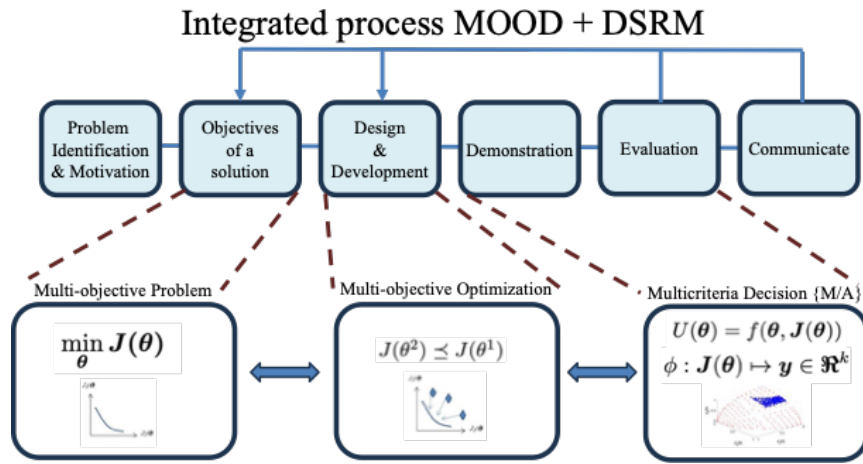


Figure 1: Integration proposal of MOOD and DSRM.

4. Case study

The proposed scenario, established by the *Comité Español de Automática* (CEA), involves implementing a controller for a solar absorption cooling machine using a simulated model based on the Yazaki WFC10 system. In this configuration, solar collectors heat water stored in a buffer tank, which is then directed through a three-way valve to the generator. This process regulates the temperature of a lithium bromide-water solution, producing a refrigeration effect at the evaporator and rejecting extracted heat at the cooling tower. The primary control objective is to maintain the temperature of the water exiting the evaporator (T_{eva}^s) at a desired reference by manipulating the bypass valve position.

Decision variables are $x_i \in \{kp, T_i\}$, corresponding to a PI controller of the form:

$$C(s) = kp \left(1 + \frac{1}{T_i s} + \right) E(s) \quad (3)$$

The multi-objective problem stated is as follows:

$$\min_{\mathbf{x}} \mathbf{J}(\mathbf{x}) = [J_{performance}(\mathbf{x}), J_{robustness}(\mathbf{x})] \quad (4)$$

subject to:

$$J_{gap}(\mathbf{x}) = GAP(\mathbf{x}, \mathbf{S}) \leq \overline{GAP} \quad (5)$$

$$\underline{x}_i \leq x_i \leq \overline{x}_i, i = [1, \dots, n] \quad (6)$$

Design objectives $J_{performance}(\mathbf{x})$, $J_{robustness}(\mathbf{x})$ are design objectives for performance and robustness respectively. The MOP statement of (4) Was used as starting point into the iterative process. From there, the following iterations after the MCDM/A step were carried out:

1. It was approximated a Pareto front with 100 solutions which dominated the baseline solution. Nevertheless, the selected solution from the approximation was not consistent with this behavior with the Benchmark. A new MOP with a third objective $J_3(\mathbf{x}) = -k_i = kp/Ti$ to optimize regulatory response was included.
2. A new Pareto front approximation was calculated. In this case, dominance relations were consistent with the performance in the Simulink Model. From here, in order to improve the performance of the controller, a clamping saturation was included.

5. Conclusions

In this work, we addressed the central research question: *How can multi-objective optimization techniques be effectively applied to solve engineering problems?* To this end, we proposed an integration of the *Multi-Objective Optimization Design* (MOOD) framework with the *Design Science Research Method* (DSRM). The proposed approach differs from other methodologies in the literature by providing a more flexible and comprehensive framework, allowing for the identification and refinement of multiple aspects throughout the optimization process. This includes potential modifications to the parametric models, cost functions, optimization algorithms, visualization strategies, and decision-making methods.

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