Toward a Method for Achieving Synergy between Heuristic Rules of Thumb and Quantitative Methods in Engineering Design

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ASSESSING FORMULATION GUIDELINES

A design optimization problem formulation is a model of an engineering design problem.
• Optimization formulation guidelines have been developed over the last several decades (theory + experience)
• Applying different sets of formulation guidelines can result in different formulations

Questions:
• How can we ensure a problem formulation captures design intent accurately?
• How can we assess formulation guidelines rigorously?
• What is the tradeoff between solution quality and overall solution effort?

Strategy: quantitative assessment of formulation guidelines
• Enumerate unique formulation guideline sets
• Generate problem formulation for each set
• Solve problems, compare results quantitatively

Challenges:
• Obtaining approximate substantive rationality solution
• Automated solution of different formulations
• Identifying a case study with different levels of representation, comparison metric, and model fidelity

Case Study: Non-linear Vibration Absorber

Multiple Levels of:
• Representation fidelity (SIF vs geometry)
• Comparison metric (norm of a(t) vs surface finish)
• Model Fidelity (simple ODE, detailed FEA)

Nonlinear spring:
• Provides additional design degrees of freedom
• Known strategy for enhancing robustness to disturbance frequency
• Application: precision machining

DESIGN FORMULATION SPACE FRAMEWORK

Three important dimensions of a design optimization problem are:
1. Design Representation (parameterization)
2. Comparison Metrics (quantitative ranking, objectives/constraints)
3. Predictive Model (maps design representation to metrics)

• All three dimensions can be varied in sophistication/accuracy
• When assessing alternative formulations it can be useful to compare them within this framework (e.g., GDA-based topology optimization uses a fundamentally different strategy than SIMP)
• Effective formulation choice: depend on search strategy, other factors

RETRORSPECT DESIGN PROJECT ANALYSIS AND HYPOTHESIS TESTING

Heuristic “rules of thumb” can save time, money and cognitive effort, but can sometimes lead to:
• Inferior solutions, Systematic cognitive biases, Error when applied to new materials/technology/processes

A set of 30 industrially sponsored capstone project reports was analyzed to test hypotheses on the effect of design heuristics.

Hypothesis Testing:
Evaluate effects of heuristics on:
• Tradeoffs
• Demand functions
• Cognitive biases
• Design process
• Product performance

HYBRID DESIGN SOLUTION STRATEGIES: DESIGN RULES + DESIGN OPTIMIZATION

Given an engineering design problem, two primary solution strategies include:
• Established design rules (flowcharts, etc.)
• Normative methods (e.g., design optimization)

A third alternative is a hybrid strategy:
• Make some design decisions using design rules
• Make the remainder using design optimization

Hybrid Solution Method Tradeoff:
• More heuristic: faster solution, reduced development effort, but potential for reduced solution quality
• More optimization-based: increased development effort, but potential for improved solution quality

Questions:
• How can we generate and validate guidelines for composing hybrid solution strategies?

Case Study: Gearset Design

• Sophisticated design guidelines/rules available
• Rules based on extensive empirical evidence
• Design optimization also possible
• Can we refine design rules from optimization results?

Problem:
• Given ratio, speeds, load
• Specify detailed geometry
• Satisfy failure constraints

What decisions are best made using design rules, and which should be made using optimization?