Mathematical Evaluation of Conceptual Design Methods

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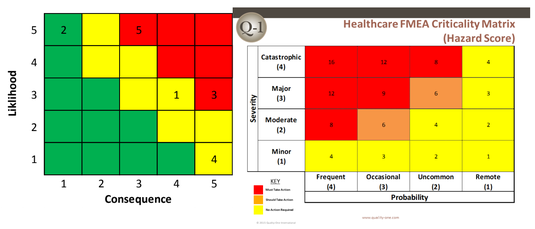
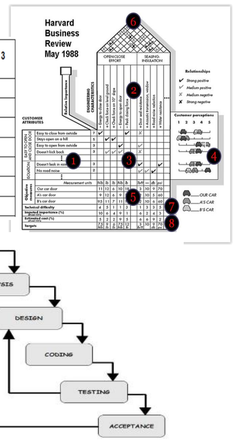
Research Task / Overview

- Many Systems Engineering methods are based on heuristics
- Research focused on applying rigor and theory to Systems Engineering methods
- Normative theory examines how a design engineer should act when performing system design [2]
- Motivation is to develop normative theory to evaluate effectiveness of systems engineering methods



Criterion	Monitor 1 (Datum)	Monitor 2	Monitor 3
No distortion of lines	0	0	+
Text crisp across display	0	0	+
1600 x 1200 resolution @ 85 Hz	0	+	+
Cost under $600	0	-	-
3-year warranty	0	+	0
24-7 Phone support	0	+	+
Total	0	+2	+3



Goals & Objectives

- During conceptual design activities, we often use heuristics rather than rigorous methods
- Use of heuristics can lead to a loss in value or profit [00]
  - How often does this happen?
  - When if does happen, how bad is it?

Research Questions

1. Under what conditions does the Pugh Method lead to the best design?
2. When the Pugh method does not lead to the best design, how much worse is the selected design?
3. Under what conditions does the Quality Function Deployment lead to the best design?
4. When the Quality Function Deployment method does not lead to the best design, how much worse is the selected design?

- This poster focuses on Questions 1 and 2

Data & Analysis

Methodological Inconsistencies

- Two primary inconsistencies to evaluate in Pugh that lead to a selection other than the best design
  - Masking attribute differences
  - Intransitive ordering of designs after aggregation of attribute ordering

Example 1 – Intransitive Outcome

- Select the best microwave
- 3 Attributes
  - Power (more is preferred)
  - Cost (less is preferred)
  - Volume (more is preferred)

	Design A	Design B	Design C
Power (W)	1100	1200	1000
Cost ($)	106.99	139.99	121.53
Volume (ft³)	1.2	1.3	1.4

	Design A	Design B	Design C
Power (W)		+	-
Cost ($)	DATUM	-	-
Volume (ft³)		+	+

B is best

	Design A	Design B	Design C
Power (W)	-		-
Cost ($)	+	DATUM	+
Volume (ft³)	-		+

C is best

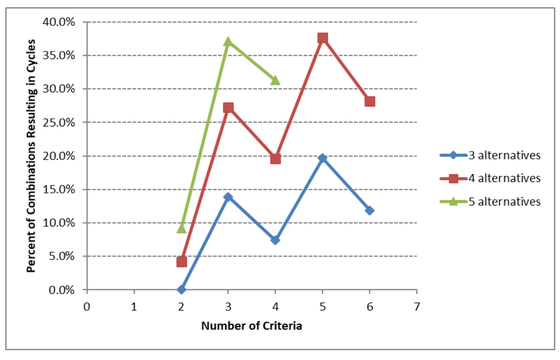
	Design A	Design B	Design C
Power (W)	+	+	
Cost ($)	+	-	DATUM
Volume (ft³)	-	-	

A is best

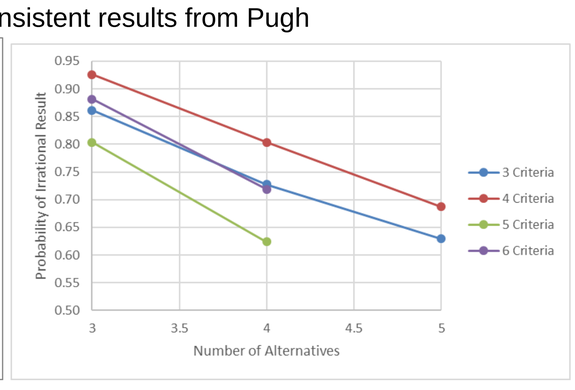
Choice of datum determines outcome, not the attributes
NO WAY TO DETERMINE THE BEST DESIGN

How Likely are these Inconsistencies?

Using analytical and exhaustive search, determine the likelihood of inconsistent results from Pugh



- Inconsistencies become more likely as the number of attributes (criteria) increases
- Even number of attributes are less likely to exhibit behavior then odd number of attributes
  - Cyclic behavior is due to "Condorcet triples" [4]

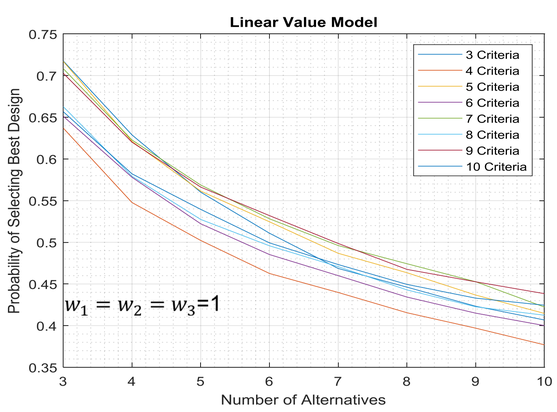


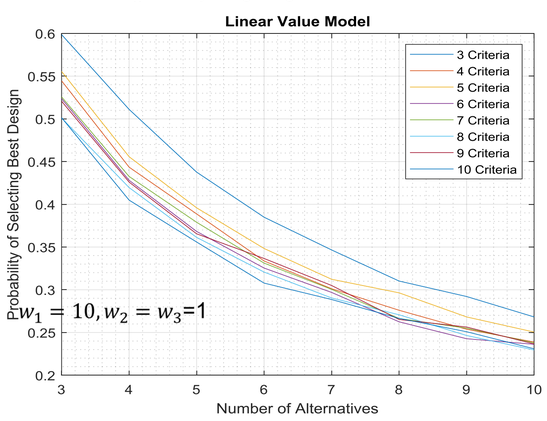
- Inconsistencies become more likely as the number of design alternatives (criteria) increases

What's the probability of selecting the best design?

Monte Carlo simulation using linear value model and all designs equally probable

$$U_{system} = w_1U_1 + w_2U_2 + w_3U_3 \quad where: U_n = \text{utility of attribute n}, \; w_n = \text{utility weighting of attribute n}$$





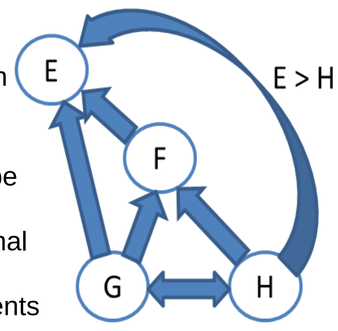
Methodology

The Concept of the " Best Design"

- Pugh and QFD are a class of design/selection methods that [3]:
  - Ordinally rank designs from "best" to "worst"
  - Decompose design into a set of important attributes (cost, performance, etc)
  - Assume deterministic attribute values
- For these methods, finding the best design is a two step process [2]
  - Order the candidate design concepts from worst to best
  - Choose the best design concept

Minimal Assumptions

- Evaluate Pugh method using minimal necessary set of assumptions
  - Best case conditions for method
  - Determine if all basic assumptions are true, does Pugh reliably select the best design
- Assumptions
  - Reflexivity of attribute ordering
  - Transitivity of attribute ordering
  - Completeness of attribute ordering
- Example (right) shows a complete, transitive, reflexive ordering
  - Under these assumptions, with this ordering, E is the best design



Value Modeling

- Using minimal assumptions for Pugh, the true best design cannot be determined
  - Degree of attribute differences cannot be determined using ordinal scale
  - All combinations of orderings can be analyzed, but each represents and infinite set of attribute values
- Value modeling used to generate designs with a total utility (cardinal ranking)
  - Each design transformed into ordinal attribute orderings
  - Evaluate each using Pugh method
  - Determine if best design was selected
  - If best design was not selected, determine difference in utility of selected design compared to utility of best design

Future Research

Non-Linear Value Modeling

- Most real value models of systems are non-linear [6]
- Linear value model is best case scenario for Pugh method
- Assess performance of Pugh method with non-linear/realistic value model to infer performance of method for real design scenarios

Extend Method to QFD and AHP

- Using theoretical framework, use minimal assumptions for QFD and evaluate effective of QFD for conceptual design purposes (part of dissertation)
- Evaluate AHP in same framework as Pugh to determine effectiveness

Contacts/References

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