Lecture 02
Selection Without Reflection is a Risky Business

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ME 597: Decision Making for Engineering Systems Design

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August 28, 2014
Lecture Outline

1. Selection in Engineering Design

2. Methods for Selection
   - 1: Voice of the Customer
   - 2: Quality Function Deployment (QFD)
   - 3: Pugh Selection
   - 4: Scoring and Weighting Methods
   - 5: Analytical Hierarchy Process

3. Favorable Properties of a Selection Method

Recall: Elements of a Decision

Decision

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Outcomes</th>
<th>Preferences</th>
<th>Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>$O_{11}$</td>
<td>$U(O_{11})$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$O_{12}$</td>
<td>$U(O_{12})$</td>
<td></td>
</tr>
<tr>
<td>$A_2$</td>
<td>$O_{21}$</td>
<td>$U(O_{21})$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$O_{22}$</td>
<td>$U(O_{22})$</td>
<td></td>
</tr>
<tr>
<td>$A_n$</td>
<td>$O_{n1}$</td>
<td>$U(O_{n1})$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$O_{n2}$</td>
<td>$U(O_{n2})$</td>
<td></td>
</tr>
</tbody>
</table>

Select $A_i$
# The Need for Selection Methods

**Goals:**
- Minimum cost
- Maximum quality
- Minimum environmental impact

**Constraints:**
- Limited time
- Imperfect, incomplete data

**Decision-Support Tools:**
- Analysis Tools
- MCDM (Selection) Methods
  etc...

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*Complex Products*

*Designers*

*Need to make decisions involving tradeoffs*
Many selection methods exist. Even methods to select selection methods exist!

Various selection methods have been shown to provide different results for the same problem.

Hazelrigg has shown that ALL selection methods that do not conform to vonNeumann–Morgenstern axioms and Arrow’s axioms are mathematically flawed.

Let us look at some examples...
Example 1: Voice of the Customer

Consider a case of five mutually exclusive design alternatives: $A, B, C, D, E$

Examples: Different colors, shapes, etc.

100 customers are surveyed

- $A =$ Black
- $B =$ Blue
- $C =$ White
- $D =$ Red
- $E =$ Pink

Survey Results:
- 45 prefer $A$
- 25 prefer $B$
- 17 prefer $C$
- 13 prefer $D$
- No one prefers $E$

**Inference from the Survey:** $A > B > C > D > E$
Preference Ordering

If designer considers preference ordering instead of just the top alternative, the following results are seen:

- 45 customers: $A > E > D > C > B$
- 25 customers: $B > E > D > C > A$
- 17 customers: $C > E > D > B > A$
- 13 customers: $D > E > C > B > A$

In fact, there are 120 such preference orderings that will give same survey results.

**Verify** that this preference structure will give the same results as seen on previous slide.
Preference Ordering (contd.)

1. Count the number of customers that prefer A to E...
   \[ = ??? \]

2. Count the number of customers that prefer E to A...
   \[ = ??? \]

Perform similar pair wise comparisons for each pair.

What is the customers’ **ACTUAL** preference?
Preference Ordering (contd.)

1. Number of customers that prefer A to E... = 45
2. Number of customers that prefer E to A... = 55

By performing similar pair wise comparisons, it can be seen that the customers’ actual preference is: \( E > D > C > B > A \), which is exactly opposite of the survey results!!!

Conclusion

The survey is not reliable!!!
Arrow’s Properties of a Valid Survey

1. **Transitivity**: If the group prefers $x$ to $y$ and $y$ to $z$, then the survey should yield the preference that $x$ is preferred to $z$.

2. **Unanimity**: If every member prefers $x$ to $y$, then the survey should obtain the result that $x$ is preferred to $y$.

3. **Independence of Irrelevant Attributes**: The preference of $x$ over $y$ or of $y$ over $x$ should not be influenced by other alternatives.

4. **Dictatorship**: The survey result should not be such that whenever individual $n$ in the group prefers $x$ over $y$, the result is always $x$, regardless of the preference of other individuals.
2: Quality Function Deployment (QFD)

1. Collect customer preference data on individual product attributes
2. Select the preferred attribute instantiations
3. Aggregate these to preferred product specifications

<table>
<thead>
<tr>
<th>Customer</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁</td>
<td>A₂</td>
<td>B₁</td>
<td>B₂</td>
</tr>
<tr>
<td>Customer I</td>
<td>Hate</td>
<td>Great</td>
<td>Great</td>
</tr>
<tr>
<td>Customer II</td>
<td>Great</td>
<td>OK</td>
<td>Hate</td>
</tr>
<tr>
<td>Customer III</td>
<td>Great</td>
<td>OK</td>
<td>Great</td>
</tr>
</tbody>
</table>

Group Preference: []
2: Quality Function Deployment (QFD)

1. Collect customer preference data on individual product attributes
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<tr>
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<th>Attribute</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A&lt;sub&gt;1&lt;/sub&gt;</td>
<td>A&lt;sub&gt;2&lt;/sub&gt;</td>
<td>B&lt;sub&gt;1&lt;/sub&gt;</td>
<td>B&lt;sub&gt;2&lt;/sub&gt;</td>
<td>C&lt;sub&gt;1&lt;/sub&gt;</td>
</tr>
<tr>
<td>Customer I</td>
<td></td>
<td>Great</td>
<td>Great</td>
<td>OK</td>
</tr>
<tr>
<td>Customer II</td>
<td>Great</td>
<td>OK</td>
<td>Hate</td>
<td>Great</td>
</tr>
<tr>
<td>Customer III</td>
<td>Great</td>
<td>OK</td>
<td>Great</td>
<td>OK</td>
</tr>
<tr>
<td>Group Preference</td>
<td>A&lt;sub&gt;1&lt;/sub&gt;</td>
<td>(2 customers prefer A&lt;sub&gt;1&lt;/sub&gt;)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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2: Quality Function Deployment (QFD)

1. Collect customer preference data on individual product attributes
2. Select the preferred attribute instantiations
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<td>A₂</td>
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<td>Customer I</td>
<td>Hate</td>
</tr>
<tr>
<td>Customer II</td>
<td>Great</td>
</tr>
<tr>
<td>Customer III</td>
<td>Great</td>
</tr>
<tr>
<td>Group Preference</td>
<td>A₁</td>
</tr>
<tr>
<td>(2 customers prefer A₁)</td>
<td>(2 customers prefer B₁)</td>
</tr>
</tbody>
</table>
Based on the QFD, an alternative with $A_1$, $B_1$, and $C_1$ would be the best.

However, customers hate certain attributes

- Customer I hates $A_1$
- Customer II hates $B_1$
- Customer III hates $C_1$

Notice that all customers would like the product with attributes $A_2$, $B_2$, and $C_2$, which is least recommended by QFD.

**Conclusion**

QFD can incorrectly rank order design alternatives!!! So, QFD is not reliable.
3: Pugh Selection

One of the alternatives to be compared is selected as the reference design.

Other alternatives are compared against the reference attribute-by-attribute:
- Alternative that is better is assigned ‘+’
- Alternative that is worse scores a ‘-’

Determine total score for each alternative.
3: Pugh Selection

1. Instead of rating the attributes individually, evaluate the combination of alternatives.
2. Each customer is assigned a utility function across candidate products that represents their preferences.
3. Market: How many customers prefer the alternative over the reference?

S = Same, -- = Worse

<table>
<thead>
<tr>
<th>Attribute</th>
<th>A1,B1,C1</th>
<th>A1,B1,C2</th>
<th>A1,B2,C1</th>
<th>A1,B2,C2</th>
<th>A2,B1,C1</th>
<th>A2,B1,C2</th>
<th>A2,B2,C1</th>
<th>A2,B2,C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ref.</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Ref.</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Ref.</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility I</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility II</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility III</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 3: Pugh Selection

The Pugh matrix alludes to $A_1B_1C_1$ as the recommended design, but it is clearly the worst design because no one wants it.
Assume a design problem involving the selection of materials from the following options: A, B, C, D
The designer performs five experiments to rank order the materials based on the experiments
The experimental results are as follows:

- Test 1: A > C > B > D
- Test 2: A > C > B > D
- Test 3: B > A > C > D
- Test 4: B > A > C > D
- Test 5: B > A > C > D

Designers use a scoring method (Borda count) to select the material

- Winning material → 3 points
- Material at second place → 2 points and so on...
- Sum all the scores achieved by a material
Scoring and Weighting Methods (contd.)

- Test 1: $A > C > B > D$
- Test 2: $A > C > B > D$
- Test 3: $B > A > C > D$
- Test 4: $B > A > C > D$
- Test 5: $B > A > C > D$

Material $A$: $3 + 3 + 2 + 2 + 2 = 12$ points
Material $B$:
Material $C$:
Material $D$:
Selection in Engineering Design
Methods for Selection
Favorable Properties of a Selection Method

Scoring and Weighting Methods (contd.)

- Test 1: \( A > C > B > D \)
- Test 2: \( A > C > B > D \)
- Test 3: \( B > A > C > D \)
- Test 4: \( B > A > C > D \)
- Test 5: \( B > A > C > D \)

Material \( A \): \( 3 + 3 + 2 + 2 + 2 = 12 \) points
Material \( B \): \( 1 + 1 + 3 + 3 + 3 = 11 \) points
Material \( C \): \( 2 + 2 + 1 + 1 + 1 = 7 \) points
Material \( D \): \( 0 + 0 + 0 + 0 + 0 = 0 \) points

**Decision**

Select Material \( A \).
Assume that the designer eliminates $C$ from the selection

- Test 1: $A > B > D$
- Test 2: $A > B > D$
- Test 3: $B > A > D$
- Test 4: $B > A > D$
- Test 5: $B > A > D$

Material $A$: $3 + 3 + 2 + 2 + 2 = 12$ points
Material $B$: $2 + 2 + 3 + 3 + 3 = 13$ points
Material $D$: $0 + 0 + 0 + 0 + 0 = 0$ points

Problem of irrelevant alternative!!!

The elimination of alternative $C$ changed the designer’s decision.

The problem can occur whenever the alternatives are used to establish the rating scale. This is a big problem... Designers seldom consider ALL POSSIBLE alternatives.
### Example 5: Analytical Hierarchy Process (AHP)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Airplane A</th>
<th>Airplane B</th>
<th>Airplane C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>1500</td>
<td>2000</td>
<td>3000</td>
</tr>
<tr>
<td>Speed</td>
<td>550</td>
<td>450</td>
<td>600</td>
</tr>
<tr>
<td>Payload</td>
<td>30,000</td>
<td>25,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Cost</td>
<td>15M</td>
<td>20M</td>
<td>10M</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.97</td>
<td>0.98</td>
<td>0.999</td>
</tr>
<tr>
<td>Safety</td>
<td>0.99999</td>
<td>0.99999</td>
<td>0</td>
</tr>
</tbody>
</table>

AHP procedure: Normalize the units on a linear 0 to 1 scale,
- 0 represents the worst
- 1 represents the best

Note: Normalization is based on the alternatives considered
### Example 5: Analytical Hierarchy Process (AHP)

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<td>0</td>
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</tr>
<tr>
<td>Speed</td>
<td>550</td>
<td>450</td>
<td>600</td>
</tr>
<tr>
<td>Payload</td>
<td>30,000</td>
<td>25,000</td>
<td>50,000</td>
</tr>
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<td>0.999</td>
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<td>Safety</td>
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<tr>
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<td>30,000</td>
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</tr>
<tr>
<td>Safety</td>
<td>0.99999</td>
<td>0.99999</td>
<td>0</td>
</tr>
</tbody>
</table>

Total Score: 2.36, 1.68, 5.00

Decision: Select Airplane C

But...

No designer in his/her right mind would select Airplane C!!!
Analytical Hierarchy Process: Limitations

1. Since the rating is based on the alternatives, addition or removal of alternatives will change the results
2. Addition or removal of attributes also affects the evaluation process
3. AHP works best when there is only one attribute (when selection is not required)
4. Attribute weights can be used to assign preferences, further creating problems

Conclusion

AHP is not reliable!!!
Favorable Properties of a Selection Method

1. The method should provide a rank ordering of candidate designs.
2. The method should not impose preferences on the designer, that is, the alternatives should be ranked in accordance with the preferences of the designer.
3. The method should permit the comparison of design alternatives under conditions of uncertainty and with risky outcomes, including variability in manufacture, materials, etc., which pervade all of engineering design.
4. The method should be independent of the discipline of engineering and manufacture for the product or system in question.
5. If the method recommends design alternative $A$ when compared to the set of alternatives $S\{B, C, D, \ldots\}$, then it should also recommend $A$ when compared to any reduced set $S_R$, such as $\{C, D, \ldots\}$ or $\{B, D, \ldots\}$ or $\{D, \ldots\}$, etc.

6. The method should make the same recommendation \textit{regardless of the order} in which the design alternatives are considered.

7. The method itself should \textit{not impose constraints} on the design or the design process.

8. The method should be such that the addition of a new design alternative should not make existing alternatives appear less favorable.

9. The method should be such that obtaining clairvoyance on any uncertainty with respect to any alternative must not make the decision situation less attractive (information is always beneficial).

10. The method should be \textit{self-consistent and logical}, that is, it should not contradict itself and it should make maximum use of available information for design alternative selection.

It is clear that NONE of the design alternative selection methods examined have all the desired properties, even though they would seem intuitively necessary. This alone should give one concern over the use of the methods in question. Still, certain methods might find advantageous use under restrictive circumstances.

(Hazelrigg, 2003)
So what should we do???
THANK YOU!