Motivation for Multi-Attribute Modeling

So far we have considered single-objective models, but most of real-life decisions are multiple-objective: e.g., price + performance (conflicting)

Influence diagrams facilitate multi-objective modeling to some degree. However, more is needed in terms of model development and analysis of decisions. Thus, specialised models and software.

Multi-attribute modeling is very useful and practical.

Questions

1. Have you ever encountered a:
   - multi-objective decision problem?
   - multi-attribute model?

   When, where, for what kind of problems?

2. Compare multi-attribute models with:
   - decision trees
   - influence diagrams

3. Suggest types of decision problems suitable for the application of multi-attribute models
Multi-Attribute Models

- **cars**: buying, maint, safety, doors, comp, lug

Multi-Attribute Modelling: *Why?*
- Systematic, structured approach (to difficult real-life problems)
- Model development:
  - problem decomposition into smaller, less-complex subproblems
  - requires understanding and careful elaboration of the problem
  - facilitates and motivates communication and knowledge interchange
- Evaluation:
  - selection of a single alternative
  - ranking of alternatives
  - “what-if” analysis
  - sensitivity analysis
  - explanation:
    - how? (evaluation procedure)
    - why? (selective explanation of advantages/disadvantages)
  - option generation
- Contributes to better decisions:
  - understanding, justification, explanation, documentation

Multi-Attribute Model for Car Selection

- **F(X, X₂, X₃)**

Multi-Attribute Model Structure

- **Y**: F(X₁, X₂, X₃)
- **Attributes**: X₁, X₂, X₃
- **Alternatives**: a₁, a₂, a₃

Quantitative Multi-Attribute Model for Car Selection

- **F(X, X₂, X₃)**
- **Aggregation Function**: 50 × P₁ + 20 × P₂ + 30 × P₃
- **Marginal Value Functions**
- **Alternatives**: 1. 22.000 8 6 2. 26.000 6 9 3. 19.000 7 8
- **Value**: 63, 72, 88
Marko Bohanec: DS Multi Attribute

1. Problem identification

1. Tree of Attributes

2. Utility Functions (Aggregation)

3. Evaluation and Analysis

Hierarchical Multi-Attribute Model

Qualitative Multi-Attribute Model for Car Selection

Multi-Attribute Modelling: How?

- 0. Problem identification
- 1. Tree (or hierarchy) of attributes
- 2. Utility functions
- 3. Evaluation and analysis of alternatives
- 4+. Implementation

1. Tree of Attributes

Decomposition of the problem to to sub-problems ("Divide and Conquer")

The most difficult stage!

2. Utility Functions (Aggregation)

Aggregation: bottom-up aggregation of attributes’ values

3. Evaluation and Analysis

- direction: bottom-up (terminal ⇒ root attributes)
- result: each alternative evaluated
- inaccurate/uncertain data?
3. Evaluation and Analysis

- interactive inspection
- "what-if" analysis
- sensitivity analysis
- explanation

MDM Tools

1. "Paper and Pencil" (Abacon)
2. Spreadsheets and mathematical modelling software (MS Excel)
3. Specialized MADM software

Spreadsheet Modelling

Specialized Software (1/5)

- Logical Decisions
  - http://www.logicaldecisions.com/
- Criterium DecisionPlus
  - http://www.winpre.com/

Specialized Software (2/5)

- DECERNS
- HiView
  - http://www.catalyze.co.uk/index.php/software/hiview

Specialized Software (3/5)

- Web-HIPRE
  - http://www.catalyze.co.uk/index.php software/hiview
Exercise

You would like to buy a new laptop computer for your own purposes (study, internet, fun, ...).

Suggest a suitable set of attributes and create a tree of attributes.

Consider the guidelines presented on the next two slides.

Developing Attribute Structure

Desirable features of attributes and their structure:

- Completeness: Do not overlook important attributes
- Relevance (non-redundancy): Use only relevant attributes, omit redundant attributes
- Minimality: Use a minimal number of attributes
- Orthogonality: Basic attributes should be independent of each other
- Operativity: Basic attributes should be easy to assess or measure
- Comprehensibility: Create meaningful sub-trees of inter-related attributes

Developing Attribute Structure

Three basic strategies:

- Top-Down: Start with the overall evaluation (target objective), decompose it to sub-goals.
- Bottom-Up: Start with desirable characteristics, sub-goals. Group them into connected, meaningful sub-trees.
- Middle-Out: Combining the two above. Iteratively decompose (refine) and group (generalise) attributes.

Working Example

One Thursday morning, Charles, instead of attending his Management Science Techniques for Consultants class, was mulling over his four job offers. His offers came from: Acme Manufacturing, Bankers Bank, Creative Consulting, and Dynamic Decision Making. He knew that factors such as location, salary, amount of management science (which he loved), and long term prospects were important to him, but he wanted some way to formalize the relative importance, and some way to evaluate each job offer.

Kepner-Tregoe


**Characteristics:**
- List of attributes
- Importance of attributes is expressed by weights \( w \in [0, 10] \)
- Alternatives are described by vectors of values \( v \in [0, 10] \)
- Evaluation (aggregation) principle: weighted sum
- Supported analyses: what-if, sensitivity

Kepner-Tregoe Model

<table>
<thead>
<tr>
<th>Attribute</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Salary</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Management Science</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term Prospects</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
</tr>
</tbody>
</table>

Job Offers: What-If Analysis

<table>
<thead>
<tr>
<th>Attribute</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Salary</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Management Science</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term Prospects</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
</tr>
</tbody>
</table>

Kepner-Tregoe: Sensitivity Analysis

```
Sensitivity analysis

<table>
<thead>
<tr>
<th>Value</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>135</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>130</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>125</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>115</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>110</td>
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<tr>
<td>95</td>
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<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

```

AHP

**AHP: Analytic Hierarchy Process** (Thomas Saaty, 1980)

**Characteristics:**
- Based on multiple attribute hierarchies
- Assessing weights by a pairwise comparison of attributes
- Assessing preferences by a pairwise comparison of alternatives
- Consistency analysis
Marko Bohanec
Jožef Stefan International Postgraduate School
Ljubljana, Slovenia

Hierarchy of Attributes

<table>
<thead>
<tr>
<th>VALUE</th>
<th>WEIGHTS</th>
<th>PREFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Salary</td>
<td>MS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Salary</th>
<th>MS</th>
<th>Long</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>1/5</td>
<td>1/3</td>
<td>1/2</td>
<td></td>
</tr>
<tr>
<td>Salary</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>MS</td>
<td>3</td>
<td>1/2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Long</td>
<td>2</td>
<td>1/4</td>
<td>1/3</td>
<td>1</td>
</tr>
</tbody>
</table>

Assessing Weights

1. Normalize the columns so that the sum equals 1
2. Take the average of rows.

<table>
<thead>
<tr>
<th>Location</th>
<th>Salary</th>
<th>MS</th>
<th>Long</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>0.495</td>
<td>0.513</td>
<td>0.546</td>
<td>0.478</td>
</tr>
<tr>
<td>Salary</td>
<td>0.273</td>
<td>0.256</td>
<td>0.273</td>
<td>0.353</td>
</tr>
<tr>
<td>MS</td>
<td>0.182</td>
<td>0.128</td>
<td>0.091</td>
<td>0.118</td>
</tr>
<tr>
<td>Long</td>
<td></td>
<td></td>
<td></td>
<td>0.130</td>
</tr>
</tbody>
</table>

Pairwise Comparison Values

1. Items i and j are of equal importance (preference)
2. Item i is weakly more important (better) than j
3. Item i is strongly more important (better) than j
4. Item i is very strongly more important (better) than j
5. Item i is absolutely more important (better) than j

2, 4, 6, 8 are intermediate values

Assessing Preferences (Scores)

For each attribute, e.g., Location, compare alternatives:

1. Normalize the columns so that the sum equals 1
2. Take the average of rows.

<table>
<thead>
<tr>
<th>Location</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Preferences</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.161</td>
<td>0.137</td>
<td>0.171</td>
<td>0.227</td>
<td>0.174</td>
</tr>
<tr>
<td>B</td>
<td>0.323</td>
<td>0.275</td>
<td>0.257</td>
<td>0.318</td>
<td>0.293</td>
</tr>
<tr>
<td>C</td>
<td>0.484</td>
<td>0.549</td>
<td>0.514</td>
<td>0.490</td>
<td>0.489</td>
</tr>
<tr>
<td>D</td>
<td>0.032</td>
<td>0.099</td>
<td>0.057</td>
<td>0.045</td>
<td>0.046</td>
</tr>
</tbody>
</table>

Assessing Preferences (Scores)

Scores for all the attributes:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>0.174</td>
<td>0.210</td>
<td>0.210</td>
</tr>
<tr>
<td>Salary</td>
<td>0.050</td>
<td>0.038</td>
<td>0.038</td>
</tr>
<tr>
<td>MS</td>
<td>0.444</td>
<td>0.312</td>
<td>0.312</td>
</tr>
<tr>
<td>Long</td>
<td>0.293</td>
<td>0.293</td>
<td>0.293</td>
</tr>
</tbody>
</table>

Evaluation: \[ WSM \cdot v(\alpha) = \sum_{i=1}^{n} w_i v_i(\alpha) \]

Acme: \( (0.086)(0.174) + (0.496)(0.050) + (0.289)(0.210) + (0.130)(0.210) = 0.164 \)
Bankers: \( = 0.256 \)
Creative: \( = 0.335 \)
Dyanmic: \( = 0.238 \)

AHP Software

<table>
<thead>
<tr>
<th>Criterion DecisionPlus</th>
<th>DECRNS</th>
<th>WinPre</th>
</tr>
</thead>
</table>
Web-HIPRE Software

Web-HIPRE [http://www.hipre.hut.fi/]

Homework

1. Run Web-HIPRE
2. Load one of the existing models (e.g., Cellular Phone)
3. Look at all Web-HIPRE’s features for
   • describing alternatives
   • assessing alternatives’ preferences and scores
   • assessing attributes’ weights
4. Do the following:
   • evaluation of alternatives
   • sensitivity analysis
5. Try to make some changes to the model:
   structure, preferences, weights (but no need to save)

DEX: Expert System Shell for Multi-Attribute Decision Making

1987−1995, DOS

DEX: 

“DEX for Education”

Computer Program for Multi-Attribute Decision Making

1999 → Windows

What is DEX?

Originates in 1980’s

Multi-Criteria Decision Analysis
   • modeling using criteria and utility functions
   • problem decomposition and structuring
   • evaluation and analysis of decision alternatives

Artificial Intelligence
   Expert Systems
   • qualitative (symbolic) variables
   • “if-then” rules
   • decision model = knowledge base
   • handling imprecision and uncertainty
   • transparent models, explanation

Machine Learning

Fuzzy sets
   • verbal measures
   • fuzzy operators
**DEX**

**Method for qualitative multi-attribute modeling**

DEX is different from other multi-attribute methods:

1. Attributes are discrete, symbolic, qualitative

 Numerical (quantitative): $87/\text{BUYING} = 12.232$ €
 Symbolic (qualitative): BUYING = medium scale: (high, medium, low)

**DEX Methodology**

- Initial development
- DECMAK
- "toolbag"
- First applications
- HW and SW selection
- Personnel management
- Nursery schools
- Related + MINT
- Further improvement
- Education
- International applications
- Soil EuNet
- Agriculture, food, GMO
- Project evaluation
- Finance
- Related

**DEXi Model**

A simple computer program for MADM that facilitates:

- Creation and editing of
  - model structure (tree of attributes)
  - value scales of attributes
  - decision rules (incl. using weights)
  - alternatives and their descriptions (data)
- Evaluation of alternatives (can handle missing values)
- Presentation of evaluation results with:
  - tables
  - charts
- Analyses: "what-if", "±1", selective explanation, comparison
- Preparing reports and charts
Stages of MADM with DEXi

1. Identification of Attributes
   a. unstructured list of attributes
   b. hierarchy (tree) of attributes
   c. measurement scales
2. Definition of Utility Functions (Decision Rules)
3. Evaluation and Analysis of Alternatives
   a. description of alternatives (data acquisition)
   b. evaluation of alternatives
   c. analysis
4. Implementation

1.a: Unstructured List of Attributes

Problem in Personnel Management:
Select a Candidate for a Job (e.g., a project manager)
- education
- age
- experience
- references
- knowledge
- work approach
- ability to work in a group
- health
- ... (Do not overlook important attributes!)

1.b: Tree of Attributes

Create meaningful, related groups
Avoid aggregate attributes having more than three descendants
1.b: Tree of Attributes

1.c: Scales

Scales are discrete, typically ordered from bad to good. Values should distinguish between importantly different characteristics. Their number should gradually increase from bottom to the root.

2: Decision rules

Utility Functions, Bottom-Up Aggregation

3.a: Description of Alternatives
3.a: Description of Alternatives

3.bc: Evaluation/Analysis of Alternatives

1. Evaluation
   - proceeds from bottom (basic attributes) to the root
   - result: qualitative evaluation of each alternative
   - handles missing (DEXi) or imprecise (DEX) alternative values

2. Analysis
   - interactive inspection of results
   - what-if analysis
   - analyses:
     - compare alternatives
     - "±1" analysis
     - selective explanation
     - reports
     - charts

3.b: Evaluation of an Alternative

<table>
<thead>
<tr>
<th>Candidate A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Employ</strong></td>
</tr>
<tr>
<td><strong>Educat</strong></td>
</tr>
<tr>
<td><strong>ForLang</strong></td>
</tr>
<tr>
<td><strong>Exper</strong></td>
</tr>
<tr>
<td><strong>Age</strong></td>
</tr>
<tr>
<td><strong>Abilit</strong></td>
</tr>
<tr>
<td><strong>Comm</strong></td>
</tr>
<tr>
<td><strong>Leader</strong></td>
</tr>
</tbody>
</table>

3.c: What-If Analysis

<table>
<thead>
<tr>
<th>Candidate A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Employ</strong></td>
</tr>
<tr>
<td><strong>Educat</strong></td>
</tr>
<tr>
<td><strong>ForLang</strong></td>
</tr>
<tr>
<td><strong>Exper</strong></td>
</tr>
<tr>
<td><strong>Age</strong></td>
</tr>
<tr>
<td><strong>Abilit</strong></td>
</tr>
<tr>
<td><strong>Comm</strong></td>
</tr>
<tr>
<td><strong>Leader</strong></td>
</tr>
</tbody>
</table>
3.c: *What-If Analysis*

![What-If Analysis Diagram]

3.c: *“±1” Analysis*

![“±1” Analysis Diagram]

3.c: *Compare Alternatives*

![Compare Alternatives Diagram]

3.c: *Selective Explanation*

![Selective Explanation Diagram A]

3.c: *Selective Explanation*

![Selective Explanation Diagram B]

3.c: *Selective Explanation*

![Selective Explanation Diagram C]

Charts and Reports

![Charts and Reports Diagram]
DEX and DEXi: Experience

- Wide applicability to various application areas
- Usually, solutions are specific (non-general)

1. Model development time
   - heavily problem-dependent: from hours to months
   - typical: 2 to 15 days

2. The most difficult stage
   - designing the tree of attributes

3. Appropriate decision problems
   - many attributes (> 15)
   - many alternatives (> 10)
   - prevailing qualitative decision-making, judgment
   - inaccurate or missing data
   - group decision making (communication and explanation)
   - sufficient resources available (expertise, time)

DEX in DEXi: Future Plans

- Combined qualitative and quantitative models

- Extensions:
  - Data Mining (e.g. machine learning of models by HINT)
  - Data Bases, Data Warehouses, OLAP

- Software:
  - “Dex Machine”: Low-level OO library for QQ models
  - Various types and levels of GUI

DEX and DEXi: Summary

1. Combination of
   - multi-attribute decision making and expert systems

2. Characteristics:
   - qualitative (symbolic) decision making
   - explanation and analysis
   - active support in the acquisition of decision rules

3. Applicability:
   - for complex real-world problems
   - hundreds of real-life applications

Exercise

1. Take one of the already defined “empty” models shown on the next slide
2. Define all utility functions (decision rules) in that model
3. Define and describe a few (about 4) alternatives
4. Evaluate and analyse the alternatives
5. Extend the model:
   - add and/or refine a few attributes (including their scales and rules)
   - repeat the steps 2, 3, and 4.
6. Prepare and print out (or save) a report

Models

- Portable Computer
- Car Selection
- Performance Evaluation of Companies
- Programmer’s Performance

Also available: Employ