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

Evaluation Models
Multi-Attribute Models

Multi-Attribute Models

Multi-Attribute Models

Multi-Attribute Models

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 option
  - option ranking
- Analysis:
  - "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 Structure

Multi-Attribute Model Structure

Quantitative Multi-Attribute Model for Car Selection

Quantitative Multi-Attribute Model for Car Selection
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- Systematic, structured approach (to difficult real-life problems)
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  - what-if analysis
  - sensitivity analysis
  - explanation:
    - how? (evaluation procedure)
    - why? (selective explanation of advantages/disadvantages)
  - option generation
- Contributes to better decisions:
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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 sub-problems ("Divide and Conquer")

The most difficult stage!

2. Utility Functions (Aggregation)

Aggregation: bottom-up aggregation of attributes' values
3. Evaluation and Analysis

- **EVALUATION**
  - direction: bottom-up
  - result: each option evaluated
  - inaccurate/uncertain data?

- **ANALYSIS**
  - interactive inspection
  - 'what-if' analysis
  - sensitivity analysis
  - explanation

MADM Tools

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

Spreadsheet Modelling

- winPre
  - http://www.hut.fi/Units/SAL/
  - http://www.logicaldecisions.com/

Specialized Software (1/4)

- Logical Decisions
  - http://www.logicaldecisions.com/
- Criterium DecisionPlus
  - http://www.criterium.com/
- HiView
  - http://www.diatel.co.uk/products/hiview

Specialized Software (2/4)

- Expert Choice
  - http://www.expertchoice.com/

- WinPre
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 interrelated attributes

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 \( \in [0,10] \)
• alternatives are described by vectors of values \( \in [0,10] \)
• evaluation (aggregation) principle: weighted sum
• supported analyses: what-if, sensitivity

Kepner-Tregoe: What-If Analysis

Job Offers
Method: Kepner-Tregoe

<table>
<thead>
<tr>
<th>attribute</th>
<th>alternative</th>
<th>weight</th>
<th>salary</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>location</td>
<td>A</td>
<td>10</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>location</td>
<td>B</td>
<td>20</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>location</td>
<td>C</td>
<td>30</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>location</td>
<td>D</td>
<td>40</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Kepner-Tregoe: Sensitivity Analysis

AHP: Analytic Hierarchy Process (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

Kepner-Tregoe Model

Job Offers
Method: Kepner-Tregoe

<table>
<thead>
<tr>
<th>attribute</th>
<th>alternative</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td></td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Salary</td>
<td></td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

Characteristics:

- supported analyses: what-if, sensitivity
- consistency analysis

Kepner-Tregoe Model: Charts

AHP

- Analytic Hierarchy Process (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
Comparison Values

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

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>.164</td>
<td>.137</td>
<td>.172</td>
<td>.387</td>
<td>.274</td>
</tr>
<tr>
<td>B</td>
<td>.268</td>
<td>.370</td>
<td>.337</td>
<td>.319</td>
<td>.308</td>
</tr>
<tr>
<td>C</td>
<td>.464</td>
<td>.940</td>
<td>.836</td>
<td>.164</td>
<td>.480</td>
</tr>
<tr>
<td>D</td>
<td>.294</td>
<td>.940</td>
<td>.836</td>
<td>.164</td>
<td>.494</td>
</tr>
</tbody>
</table>

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

Assessing Preferences (Scores)

Scores for all the attributes:

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>.396</td>
<td>.598</td>
<td>.698</td>
<td>.944</td>
</tr>
<tr>
<td>Salary</td>
<td>.416</td>
<td>.416</td>
<td>.519</td>
<td>.164</td>
</tr>
<tr>
<td>MS</td>
<td>.218</td>
<td>.088</td>
<td>.804</td>
<td>.898</td>
</tr>
<tr>
<td>Long</td>
<td>.518</td>
<td>.218</td>
<td>.196</td>
<td>.196</td>
</tr>
</tbody>
</table>

Evaluation:

- Acme: \(0.396(0.416) + 0.598(0.416) + 0.698(0.519) + 0.944(0.164) = 0.864\)
- Banks: \(0.396(0.416) + 0.598(0.416) + 0.698(0.519) + 0.944(0.164) = 0.888\)
- Creative: 0.396
- Dynamic: 238
**Web-HIPRE Software**


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**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)

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**DEX: Expert System Shell for Multi-Attribute Decision Making**

1987–1995, DOS

**DEXi: “DEX for Education”**

Computer Program for Multi-Attribute Decision Making

1999–, Windows

---

**DEX and DEXi: Background**

1. Multi-Attribute Decision Making
   - modelling using criteria and utility functions
   - problem decomposition and structuring
   - option evaluation and analysis

2. Expert Systems
   - qualitative (symbolic) variables
   - “if-then” decision rules
   - decision model = knowledge base
   - emphasis on the explanation of results (DEX)

---

**DEXi Model**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>location</td>
<td>unacc; ecc; good; exc</td>
</tr>
<tr>
<td>salary</td>
<td>unacc; ecc; good</td>
</tr>
<tr>
<td>satisfaction</td>
<td>unacc; ecc; good</td>
</tr>
<tr>
<td>MS</td>
<td>unacc; ecc; good</td>
</tr>
<tr>
<td>long satisfaction</td>
<td>unacc; ecc; good</td>
</tr>
</tbody>
</table>

---

**DEXi**

Computer Program for Multi-Attribute Decision Making

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)
  - options and their descriptions (data)
- Evaluation of options (can handle missing values)
- Presentation of evaluation results with:
  - tables
  - charts
- Analyses: “what-if”, “±1”, selective explanation, comparison
- Preparing reports and charts

---

**Tables**

<table>
<thead>
<tr>
<th>location</th>
<th>salary</th>
<th>satisfaction</th>
<th>Job</th>
</tr>
</thead>
<tbody>
<tr>
<td>unacc</td>
<td>ecc</td>
<td>good</td>
<td>exc</td>
</tr>
<tr>
<td>exc</td>
<td>ecc</td>
<td>good</td>
<td>unacc</td>
</tr>
<tr>
<td>ecc</td>
<td>unacc</td>
<td>good</td>
<td>acc</td>
</tr>
<tr>
<td>unacc</td>
<td>ecc</td>
<td>good</td>
<td>acc</td>
</tr>
<tr>
<td>ecc</td>
<td>unacc</td>
<td>good</td>
<td>acc</td>
</tr>
<tr>
<td>acc</td>
<td>exc</td>
<td>good</td>
<td>acc</td>
</tr>
<tr>
<td>good</td>
<td>good</td>
<td>exc</td>
<td>acc</td>
</tr>
<tr>
<td>good</td>
<td>good</td>
<td>ecc</td>
<td>acc</td>
</tr>
<tr>
<td>good</td>
<td>good</td>
<td>acc</td>
<td>exc</td>
</tr>
</tbody>
</table>

---

**Marko Bohanec**
Stages of MADM with DEXi

0. Problem Identification
   a. problem formulation
   b. formation of a decision-making group
   c. selection of decision-support methodology

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 Options
   a. description of options (data acquisition)
   b. evaluation of options
   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
- leadership
- organizational abilities
- loyalty
- intelligence
- communicativity
- character
- ...  

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 Options
3.a: Description of Options

3.bc: Evaluation and Analysis of Options

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

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

3.b: Evaluation of an Option

3.b: Evaluation of Options

3.c: What-If Analysis
3.c: What-If Analysis

3.c: "±1" Analysis

3.c: Compare options

3.c: Selective Explanation

3.c: Selective Explanation

Charts and Reports
### 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 options (>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

- 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
   - over 50 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) options
4. Evaluate and analyse the options
5. Extend the model:
   - add and/or refine a few attributes (including their scales and rules)
   - repeat the steps 2, and 4.
6. Prepare and print out (or save) a report

### Models

<table>
<thead>
<tr>
<th>Portable Computer</th>
<th>Programmer’s Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute</td>
<td>Description</td>
</tr>
<tr>
<td>Hardware</td>
<td>Performance of the Programmer</td>
</tr>
<tr>
<td>Memory</td>
<td>Quality of Programmer's Work</td>
</tr>
<tr>
<td>Processor</td>
<td>Technical Characteristics</td>
</tr>
<tr>
<td>Software</td>
<td>Additional Services</td>
</tr>
<tr>
<td>Car Selection</td>
<td>Performance Evaluation of Companies</td>
</tr>
<tr>
<td>Attribute</td>
<td>Description</td>
</tr>
<tr>
<td>Space</td>
<td>Efficiency of the Programmer</td>
</tr>
<tr>
<td>Weight</td>
<td>Quality of Programmer's Work</td>
</tr>
<tr>
<td>Size</td>
<td>Technical Characteristics</td>
</tr>
<tr>
<td>Color</td>
<td>Additional Services</td>
</tr>
<tr>
<td>Also available: Employ</td>
<td></td>
</tr>
</tbody>
</table>