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

ID’s and Multiple Objectives

Venture succeeds or fails
Return on investment
Computer Industry Growth

Maximize Overall Satisfaction
Return on Investment
Invest in Computer Industry

Evaluation Models

options
EVALUATION
MODEL
ANALYSIS

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Institut Jožef Stefan, Department of Knowledge Technologies, Ljubljana
and
University of Nova Gorica
Multi-Attribute Models

**Cars**
- Buying
- Maintenance
- Safety
- Doors
- Price
- Design
- Comp.

**Car Problem Decomposition**

**Multi-Attribute Models**

**Digital Photo Camera**
- 1: war
- 2: weight
- 3: sensor
- 4: body
- 5: lens

**Evaluation of Cameras**

**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**

**Quantitative Multi-Attribute Model for Car Selection**

**Value Function**

\[ Y = f(X_1, X_2, \ldots, X_n) \]

**Multi-Attribute Model for Car Selection**

**Value Function**

\[ f(X_1, X_2, \ldots, X_n) \]

**Attributes**
- Price
- Fuel
- Safety

**Options**
- \( a_1 \)
- \( a_2 \)
- \( a_3 \)
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 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")

2. Utility Functions (Aggregation)
Aggregation: bottom-up aggregation of attributes’ values
3. Evaluation and Analysis

- Direction: bottom-up
  - (terminal ⇒ root attributes)
- Result: each option evaluated
- Inaccurate/uncertain data?

EVALUATION

ANALYSIS

MADM 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.infoharvest.com/
- WinPre

Specialized Software (2/5)

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

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.

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
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 Model

<table>
<thead>
<tr>
<th>Attribute</th>
<th>alternative</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>9</td>
<td>12</td>
<td>34</td>
</tr>
<tr>
<td>Salary</td>
<td>10</td>
<td>6</td>
<td>90</td>
<td>60</td>
<td>40</td>
<td>150</td>
</tr>
<tr>
<td>Management Science</td>
<td>5</td>
<td>20</td>
<td>5</td>
<td>7</td>
<td>35</td>
<td>63</td>
</tr>
<tr>
<td>Long-term prospects</td>
<td>3</td>
<td>30</td>
<td>1</td>
<td>6</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>98</td>
<td>110</td>
<td>131</td>
<td>84</td>
<td>443</td>
</tr>
</tbody>
</table>

### Kepner-Tregoe: What-If Analysis

<table>
<thead>
<tr>
<th>Attribute</th>
<th>alternative</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>2</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>Salary</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>Management Science</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>Long-term prospects</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>131</td>
<td>106</td>
<td>129</td>
<td>84</td>
<td>350</td>
</tr>
</tbody>
</table>

### Kepner-Tregoe Model: Charts

### Kepner-Tregoe: Sensitivity Analysis

Sensitivity analysis
AHP


Characteristics:
• based on multiple attribute hierarchies
• assessing weights by a pairwise comparison of attributes
• assessing preferences by a pairwise comparison of alternatives
• consistency analysis

Hierarchy of Attributes

Pairwise Comparison Values

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

2, 4, 6, 8 are intermediate values

Assessing Weights

<table>
<thead>
<tr>
<th></th>
<th>Location</th>
<th>Salary</th>
<th>MS</th>
<th>Long</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>.191</td>
<td>.102</td>
<td>.091</td>
<td>.059</td>
<td>.096</td>
</tr>
<tr>
<td>Salary</td>
<td>.455</td>
<td>.513</td>
<td>.545</td>
<td>.471</td>
<td>.486</td>
</tr>
<tr>
<td>MS</td>
<td>.273</td>
<td>.256</td>
<td>.273</td>
<td>.353</td>
<td>.289</td>
</tr>
<tr>
<td>Long</td>
<td>.182</td>
<td>.128</td>
<td>.061</td>
<td>.118</td>
<td>.130</td>
</tr>
</tbody>
</table>

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

Assessing Preferences (Scores)

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

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/2</td>
<td>1/3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1/2</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1/5</td>
<td>1/5</td>
</tr>
</tbody>
</table>

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

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>.174</td>
<td>.280</td>
<td>.469</td>
</tr>
<tr>
<td>Salary:</td>
<td>.050</td>
<td>.444</td>
<td>.312</td>
</tr>
<tr>
<td>MS:</td>
<td>.210</td>
<td>.038</td>
<td>.354</td>
</tr>
<tr>
<td>Long:</td>
<td>.510</td>
<td>.012</td>
<td>.290</td>
</tr>
</tbody>
</table>

Evaluation:

Acme: (.174)(.086) + (.050)(-.469) + (.210)(.289) + (.310)(.364) = .164
Banks: (.280)(.086) + (.444)(.469) + (.038)(.289) + (.812)(.364) = .256
Creative: .355
Dynamic: .238
AHP Software

- Criterium DecisionPlus
  - http://www.infoharvest.com/
- Expert Choice
  - http://www.expertchoice.com/
- WinPre
  - http://www.hut.fi/Units/SAL/
  - Downloadable/winpre.htm
- Expert Choice
  - http://www.expertchoice.com/
- Web-HIPRE
  - http://www.hipre.hut.fi/

Multicriteria Modeling Software

<table>
<thead>
<tr>
<th>Software</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000Minds PAPRIKA</td>
<td><a href="http://www.1000minds.com">http://www.1000minds.com</a></td>
</tr>
<tr>
<td>Criterium DecisionPlus</td>
<td><a href="http://www.infoharvest.com/">http://www.infoharvest.com/</a></td>
</tr>
<tr>
<td>Decision Deck MCDA</td>
<td><a href="http://www.decision-deck.org">http://www.decision-deck.org</a></td>
</tr>
<tr>
<td>Decision Lab PROMETHEE &amp; GAIA</td>
<td><a href="http://homepages.ulb.ac.be/~bmaresc/decision_lab.htm">http://homepages.ulb.ac.be/~bmaresc/decision_lab.htm</a></td>
</tr>
<tr>
<td>DecisionPad MCDA</td>
<td><a href="http://decisionpad.com/">http://decisionpad.com/</a></td>
</tr>
<tr>
<td>D-SIGHT PROMETHEE</td>
<td><a href="http://www.d-sight.com/">http://www.d-sight.com/</a></td>
</tr>
<tr>
<td>Expert Choice AHP</td>
<td><a href="http://www.expertchoice.com">http://www.expertchoice.com</a></td>
</tr>
<tr>
<td>GMAA MCDA</td>
<td><a href="http://www.dia.fi.upm.es/~ajimenez/GMAA">http://www.dia.fi.upm.es/~ajimenez/GMAA</a></td>
</tr>
<tr>
<td>HIPRE AHP, SMART</td>
<td><a href="http://sal.aalto.fi/en/resources/downloadables/hipre3">http://sal.aalto.fi/en/resources/downloadables/hipre3</a></td>
</tr>
<tr>
<td>Hiview MAUT</td>
<td><a href="http://www.catalyze.co.uk/index.php/software/hiview3/">http://www.catalyze.co.uk/index.php/software/hiview3/</a></td>
</tr>
<tr>
<td>Logical Decisions MCDA</td>
<td><a href="http://www.logicaldecisions.com/">http://www.logicaldecisions.com/</a></td>
</tr>
<tr>
<td>MakeItRational AHP</td>
<td><a href="http://makeitrational.com/analytic-hierarchy-process/ahp-software">http://makeitrational.com/analytic-hierarchy-process/ahp-software</a></td>
</tr>
<tr>
<td>M-MACBETH MACBETH</td>
<td><a href="http://www.m-macbeth.com">http://www.m-macbeth.com</a></td>
</tr>
<tr>
<td>V.I.S.A MCDA</td>
<td><a href="http://www.visadecisions.com">http://www.visadecisions.com</a></td>
</tr>
<tr>
<td>Visual PROMETHEE</td>
<td>PROMETHEE &amp; GAIA <a href="http://www.promethee-gaia.net/software.html">http://www.promethee-gaia.net/software.html</a></td>
</tr>
<tr>
<td>Web-HIPRE SMART..AHP</td>
<td><a href="http://www.hipre.hut.fi/">http://www.hipre.hut.fi/</a></td>
</tr>
<tr>
<td>WinPre</td>
<td><a href="http://sal.aalto.fi/en/resources/downloadables/winpre">http://sal.aalto.fi/en/resources/downloadables/winpre</a></td>
</tr>
</tbody>
</table>

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?

- 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

DEXi: “DEX for Education”
**DEX**

Method for qualitative multi-attribute modeling

DEX is different from other multi-attribute methods:
1. Attributes are discrete, symbolic, qualitative
2. Evaluation of alternatives (aggregation) is defined by decision rules

**DEX History**

Methodology
- initial development
- DECMAK
- DEC
- DECMAK

Software
- DECMAK
- DEC
- DECMAK

First applications
- HPI and SW selection
- personnel mgmt
- nursery schools

Related
- HINT

1980 1990 2000 2010

**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

**Methodology**
- integration
- software
- DEC
- DECMAK

**Software**
- DECMAK
- DEC
- DECMAK

**First Applications**
- Housing Fund
- Ministry Soc-Tech
- Talent System
- Industry
- Medicine
- Related
- HINT

**Related**
- model revision, proDEX

**DEXi**

Numeric (quantitative): BUYING = 12,233 €
numeric scale, e.g. R

Symbolic (qualitative): BUYING = medium
scale: [high, medium, low]
1. Problem Identification
   a. problem formulation
   b. formation of a decision-making group
   c. selection of decision-support methodology

2. Identification of Attributes
   a. unstructured list of attributes
   b. hierarchy (tree) of attributes
   c. measurement scales

3. Definition of Utility Functions (Decision Rules)

4. Evaluation and Analysis of Options
   a. description of options (data acquisition)
   b. evaluation of options
   c. analysis

5. 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
- leadership
- organizational abilities
- loyalty
- intelligence
- communicativity
- character
- health
- ...
1.b: Tree of Attributes

Create meaningful, related groups
Avoid aggregate attributes having more than three descendants

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

- **Employ**: Educat, Years, Personal
  - Educat: Formal, For.Lang
  - Years: Exp, Age
  - Personal: Abilit, Comm, Leader, Test

<table>
<thead>
<tr>
<th>Candidate</th>
<th>Formal</th>
<th>For.Lang</th>
<th>Exp</th>
<th>Age</th>
<th>Comm</th>
<th>Leader</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>MSc</td>
<td>pas</td>
<td>1-2</td>
<td>21-25</td>
<td>good</td>
<td>more</td>
<td>B</td>
</tr>
<tr>
<td>B</td>
<td>PhD</td>
<td>act</td>
<td>more</td>
<td>26-40</td>
<td>aver</td>
<td>less</td>
<td>B</td>
</tr>
</tbody>
</table>

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

Candidate A

- **Employ**: good
- **Educat**: MSc, PhD, PhD, PhD
- **Years**: pas, to1year, 21-25, 21-25
- **Personal**: good, good, good, good, good, more

Candidate B

- **Employ**: good
- **Educat**: MSc, PhD, PhD, PhD
- **Years**: pas, to1year, 21-25, 21-25
- **Personal**: good, good, good, good, good, more
### 3.c: What-If Analysis

**Candidate A**
- **Employ:** good
- **Educ:**
  - **Formal:** good
  - **Exp Lang:** good
- **Years:**
  - **Formal:** more
  - **Exp Lang:** 20-25
- **Personal:**
  - **Age:** 21-25
  - **Abit:** good
  - **Text:** B
- **Comm:**
  - **Leader:** more

**Candidate B**
- **Employ:** unacc
- **Educ:**
  - **Formal:** act
  - **Exp Lang:** B
- **Years:**
  - **Formal:** less
  - **Exp Lang:** more
- **Personal:**
  - **Age:** 26-40
  - **Abit:** unacc
  - **Text:** B
- **Comm:**
  - **Leader:** less

### 3.c: “±1” Analysis

### 3.c: Compare options

### 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

- Portable Computer
- Programmer’s Performance

Car Selection

Performance Evaluation of Companies

Also available: Employ