The University of Manchester
Manchester
Business School

Multiple Criteria Decision Analysis

— *Problems, Models, Methods and Applications*

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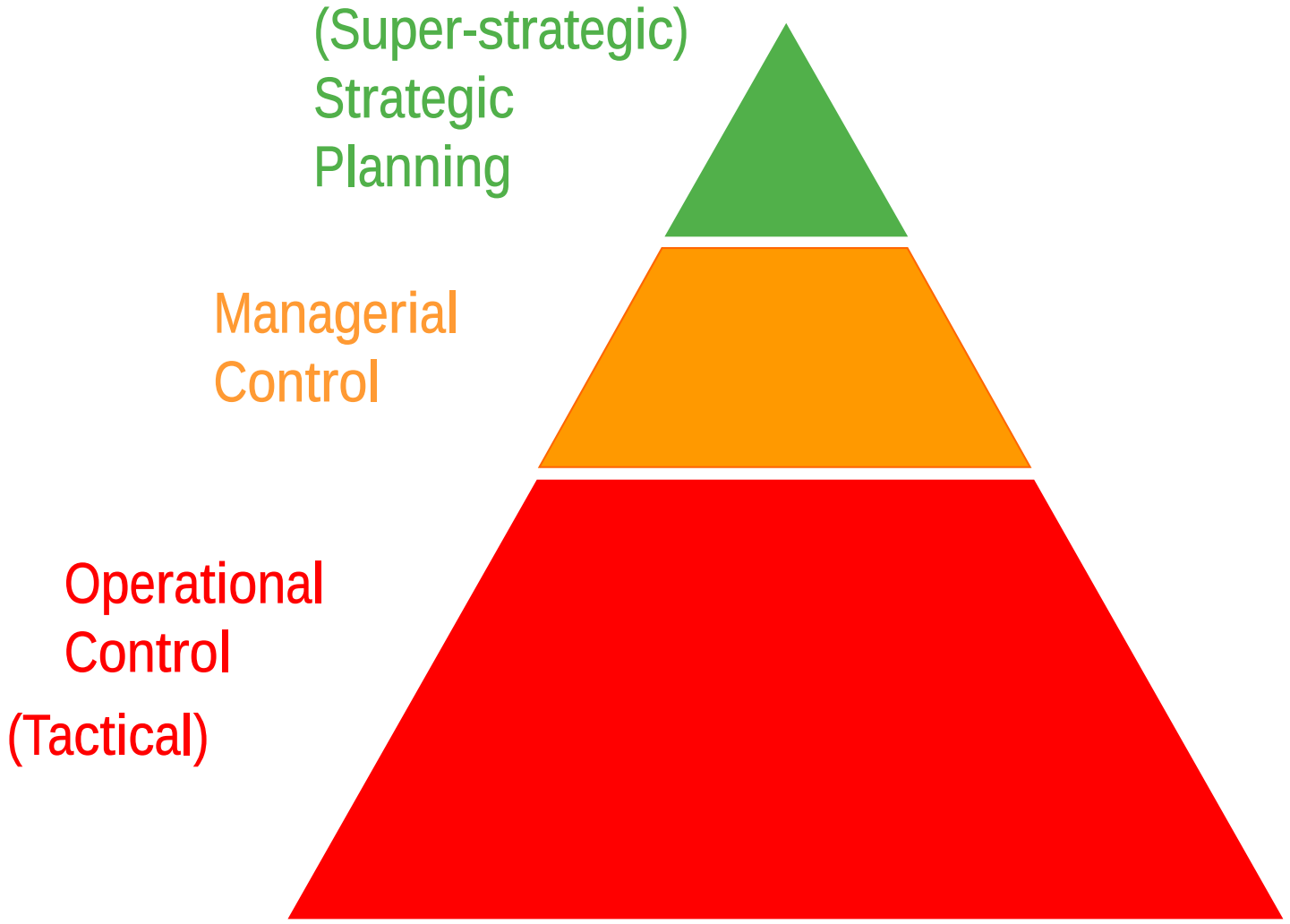
Main Topics of the Session

- Multiple criteria decision analysis – an introduction
- Multiple objective optimization problems in real world
- Multiple criteria assessment and decision analysis problems in real world
- Decision matrix and MCDA explained in graph
- Additive value function approach in MCDA
- Deal with uncertainties in MCDA
- Evidential reasoning MCDA – concept, model, process and tool
- A snapshot of real world MCDA applications

Decision Making at Different Levels

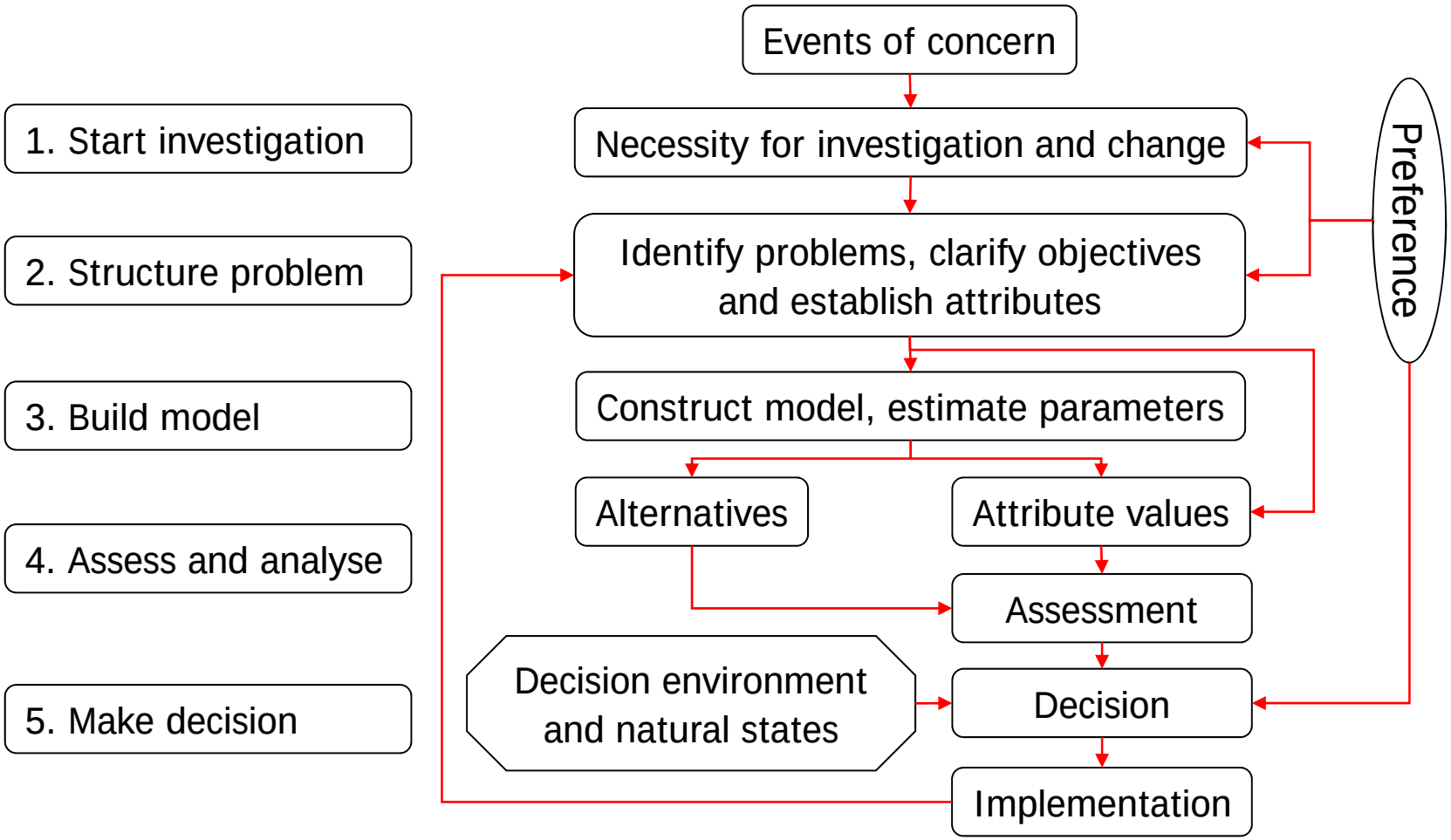
(Anthony's Model, 1965)



Decision Issues at Different Levels

- **Strategic planning**
  - New business opportunities
  - Competition strategies
  - Technology adoption
  - Strategic partnership
- **Managerial control**
  - Financial control
  - Project control
  - Quality control
  - Risk control
  - HR control
- **Operational control**
  - Task scheduling
  - Production optimization
  - Coordination
  - Skill development

Multiple Criteria Decision Making – Typical solution procedure



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Multi-objective optimization in real world
– *Production planning and scheduling*

- Multiple objective optimisation for production planning in oil refinery
- Large scale optimisation methods and software
- Multiple criteria decision analysis
- Automatic model update
- Decision support systems

http://www.astreetjournalist.com/2010/01/11/country%E2%80%99s-biggest-project-under-the-shadow-of-heavy-strike/

Multi-objective optimization in real world
– *Made-to-order engineering product design*

- **Offshore structures**
  - **Construction cost**
  - **Layout optimisation**

http://www.offshore-technology.com/contractors/pipes/project-materials/project-materials1.html

Multi-objective optimization in real world
– *Made-to-order engineering product design*

- **Offshore structures**
  - **Construction cost**
  - **Layout optimisation**
- **Optimal ship design**
  - **Transportation cost**
  - **Light ship mass**
  - **Annual cargo**

http://www.istockphoto.com/stock-photo-6151204-cargo-container-ship-entering-the-harbor.php

Multi-objective optimization in real world
– *Made-to-order engineering product design*

- **Offshore structures**
  - Construction cost
  - Layout optimisation
- **Optimal ship design**
  - Transportation cost
  - Light ship mass
  - Annual cargo
- **Optimal ferry design**
  - Safety measures

http://blogs.seattleweekly.com/dailyweekly/2007/09/

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Multi-objective optimization in real world

– *Project portfolio analysis and management*

Automotive

Mercedes S Class
MCU's
Night Vision

BMW X5
MCU's
Dynamic Drive

Honda Stepwagon
MCU & Sensor
-Airbag

Ford Fusion
i.MX31 (MPU)
Sync

Aston Martin DB9
Sensors
Airbag

Ducati 696
S12 & Pressure Sensor
ECU

Networking

Wireless and Metro
MPU, DSP, RF

Routers & Switches
MPU

Factory & Aerospace
MPU, DSP

Surveillance & Conferencing
MPU, DSP

Printers
MPU

Industrial

Insulin Pump
MCU's

Blood Pressure Meter
Pressure Sensors

Washer
MCU's
Sensors

Toaster
MCU's

Power Meter
MCU's
802.15.4 (Zigbee)

Consumer

HP Photosmart eStation
and 7" detachable wireless
Android tablet with i.MX51

OZing
tablet
with
i.MX51

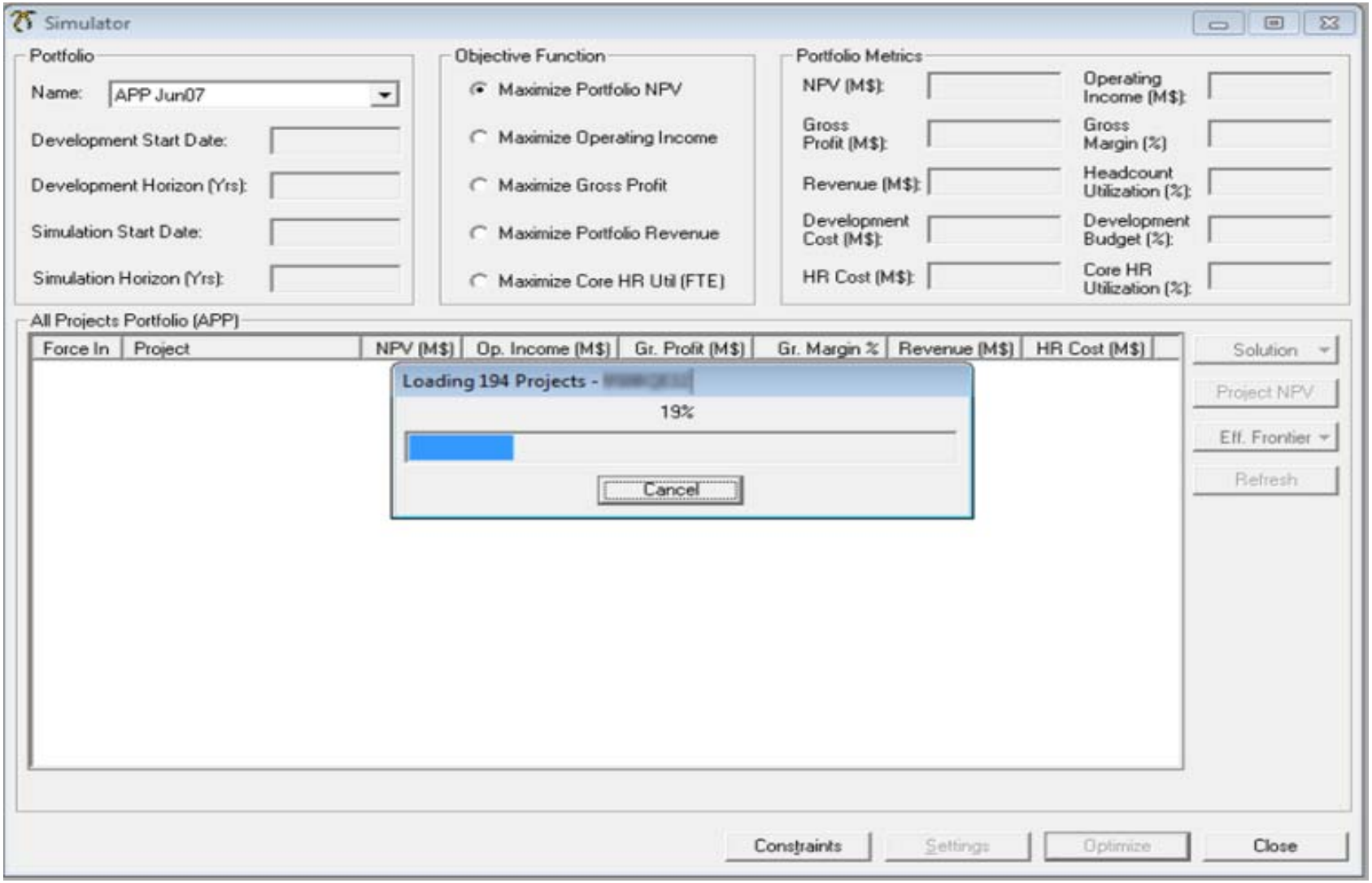
Kindle with i.MX35, Sensors & PMIC

Philips Gogear Connect
Tablet, i.MX51

DBA thesis of MBS by Alex Koh in 2011

Multi-objective optimization in real world

– *Project portfolio analysis and management*



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Multi-Criteria Decision Analysis in real world

– *Design selection of engineering products*

- Offshore structures
- Container ship
- Cargo ship
- Roll-on roll-off ferry
- Aircraft
- Car
- Computer
- Motorcycle
- house
- …

http://www.lodic.no/?side=1016

http://rmspkonline.com/

http://www.freefoto.com/preview/806-30-8702?ffid=806-30-8702

http://www.freefoto.com/preview/2026-05-1?ffid=2026-05-1

http://www.dicts.info/picture-dictionary.php?w=aircraft

http://www.sustainabilitymatters.net.au/news/43589-ABB-and-GM-to-collaborate-on-electric-car-battery-research

Multi-Criteria Decision Analysis in real world

– *Risk & safety analysis of products and systems*

- Offshore structures
- Cargo ship
- Container ship
- Roll-on roll-off ferry
- Nuclear plant
- Food and drink
- Sea port
- Air port
- Hospital
- …

http://science.howstuffworks.com/environmental/energy/offshore-drilling.htm

http://www.guardian.co.uk/uk/2008/jan/15/1

http://xmb.stuffucanuse.com/xmb/viewthread.php?tid=4175

http://www.nypost.com/p/news/international/item_U8RbcKY6QO72rVYlKFhABM

http://www.alternavox.net/the-fukushima-nuclear-plant-accident-reaches-category-4

Multi-Criteria Decision Analysis in real world

– *Prioritise voices of customer via surveys (GM)*

http://www.carbuyersnotebook.com/2011-chevy-cruze-pictured/

http://news.discovery.com/tech/gm-urban-car-china.html

Multi-Criteria Decision Analysis in real world

– *Prioritise voices of customer using surveys*

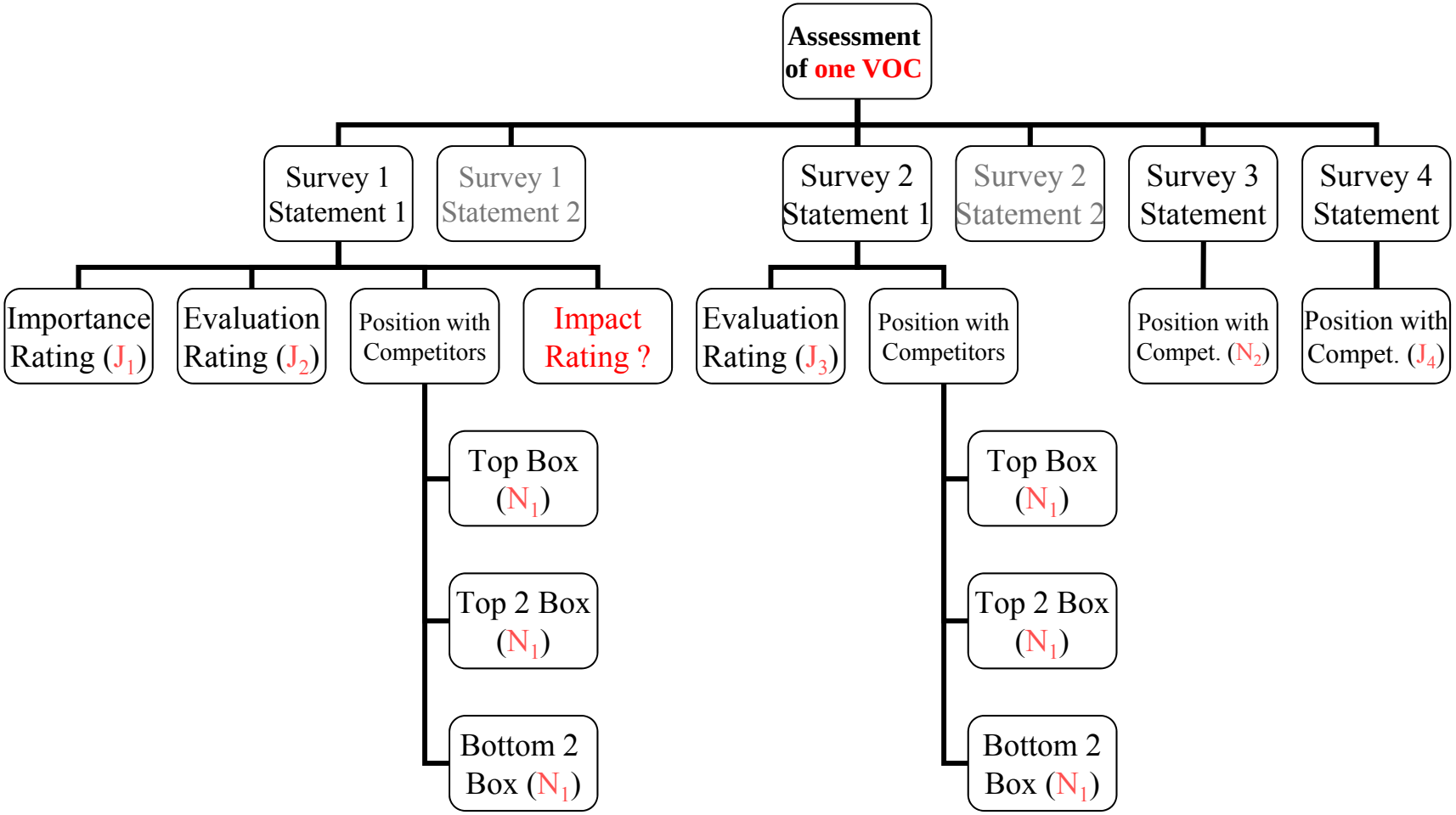
SCALE INCOMPATIBILITY IN SURVEYS

Survey 1	Survey 2	Survey 3
1: Disagree Strongly	1: Not Good	1: Unacceptable
2: Disagree	2: Good	3: Below Average
3: Neutral	3: Very Good	5: Average
4: Agree	4: Excellent	7: Good
5: Agree Strongly	5: Truly Outstanding	10: Outstanding

- **Surveys use different rating scales: Limited control if not in-house**
- **Handling incompatibility of rating scales**
  - **Define common scale and create transformation functions**
  - **Define criteria that are independent of scales**

Multi-Criteria Decision Analysis in real world

– *Prioritise voices of customer using surveys*



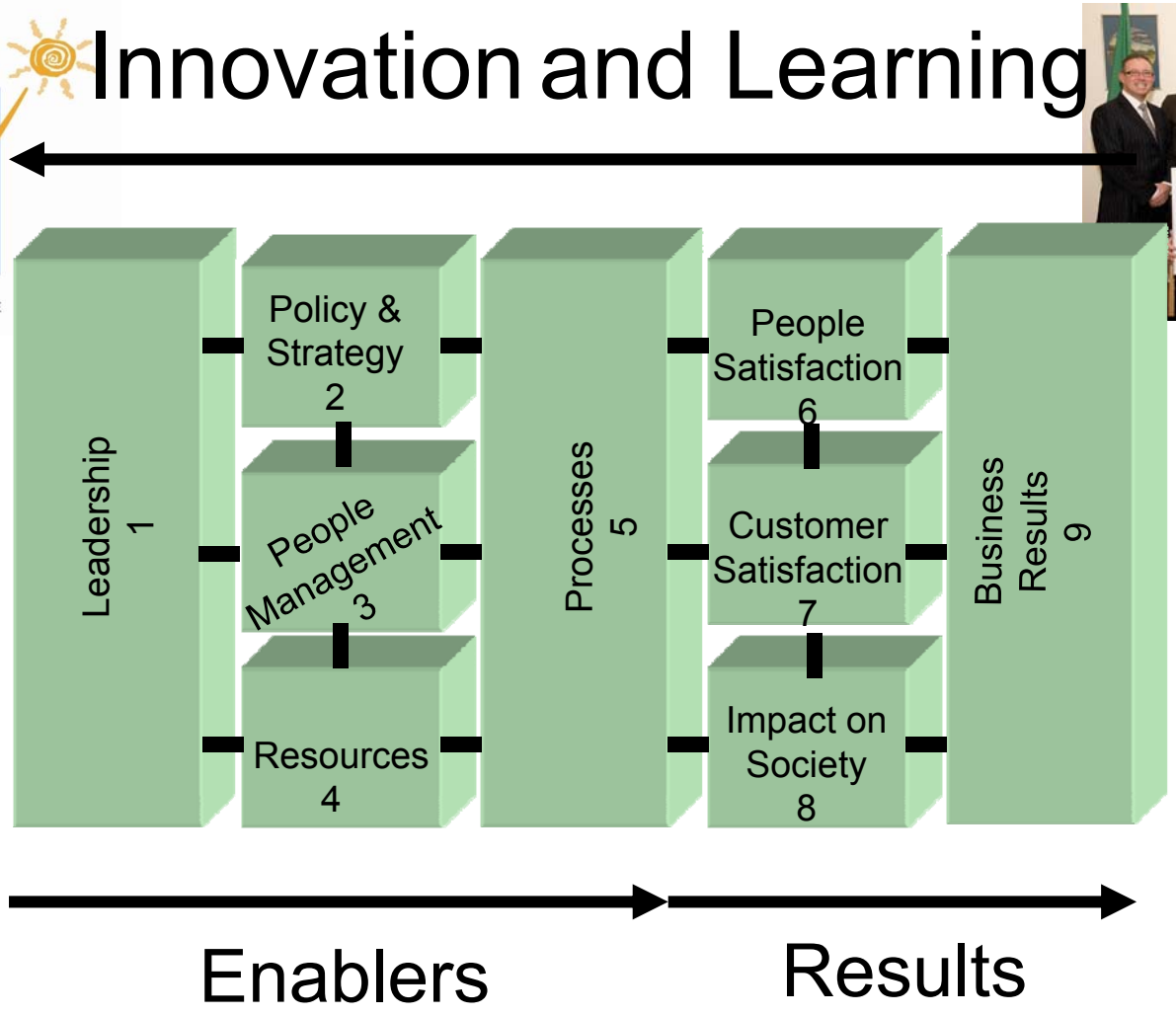
Multi-Criteria Decision Analysis in real world

– *Business excellence self-assessment: EFQM*

BEST PRACTICE FORUM
BUSINESS EXCELLENCE AWARDS 2011
TOURISM ■ HOSPITALITY ■ LEISURE

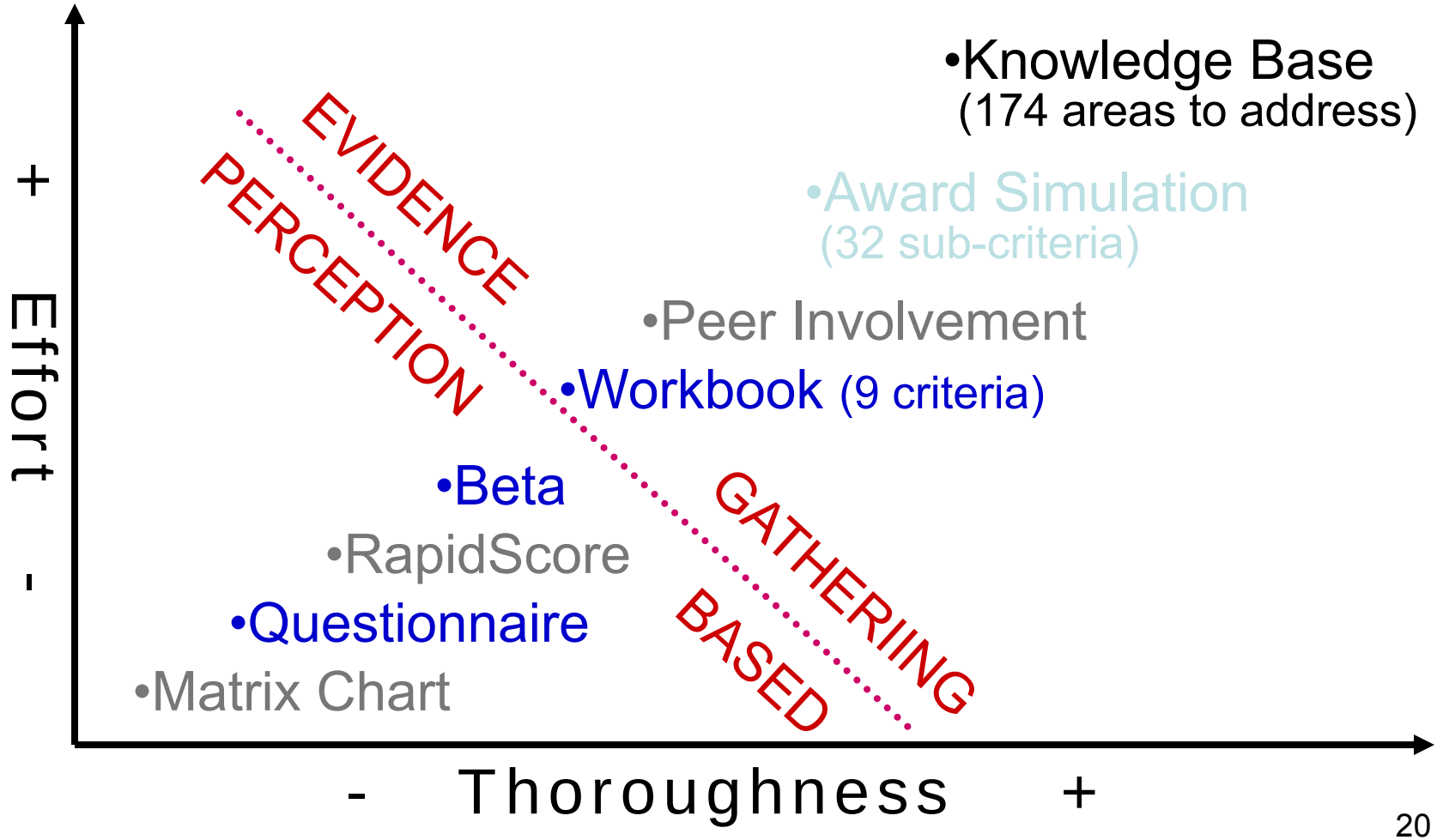
http://www.bestpracticeforum.org/business-excellence-awards.aspx

http://newsweaver.ie/failte_ireland/e_article000969204.cfm?x=bbL71MH,b3TtMJrq,w



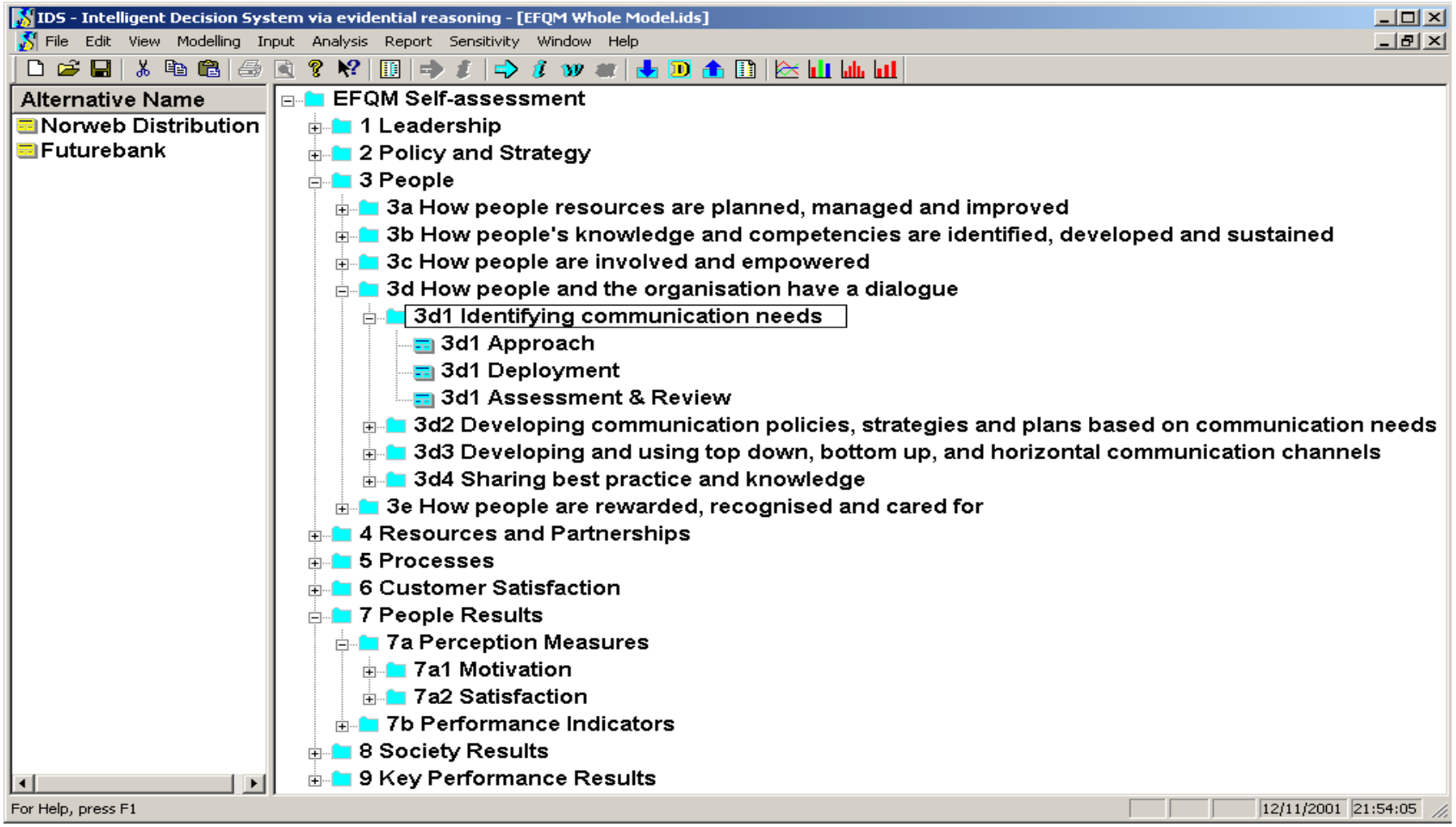
Multi-Criteria Decision Analysis in real world

– *Business excellence self-assessment: EFQM*

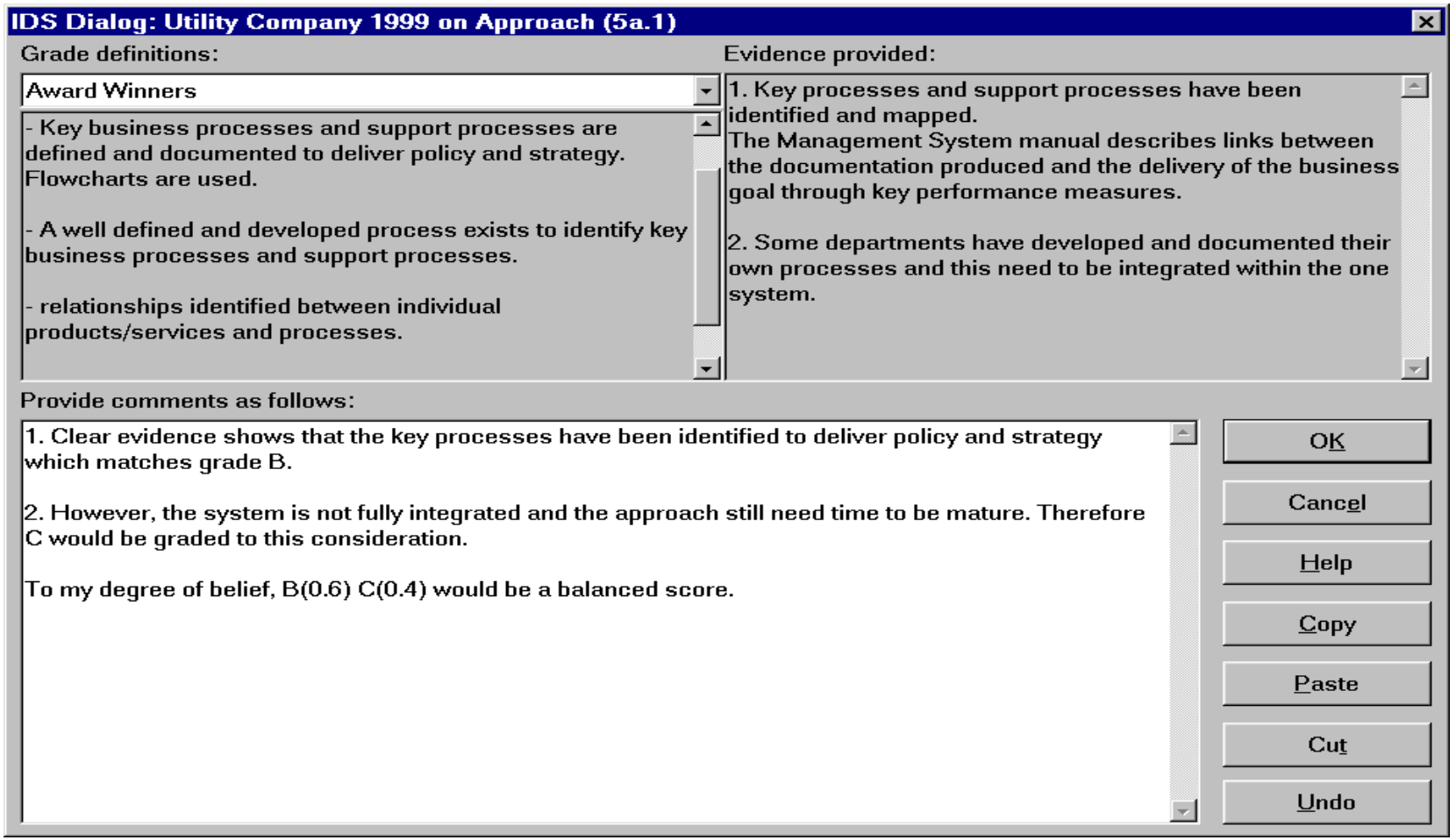


EFQM Self-Assessment Model:

For total quality management in an organisation



Intelligent Decision System (IDS): Evidence Mapping Window



Multi-Criteria Decision Analysis in real world

– *Supplier assessment and selection*

- Supplier Assessment
  - Quality
  - Supply Chain Evaluation
  - Technical Competence evaluation
  - Total Cost Evaluation
  - General Factors Evaluation
  - After Sales Evaluation
  - Enviroethical
  - Leadership and Strategy
  - Project Management
  - Customer Needs
  - E - Readiness

http://www.electricalequipment.co/siemens-process-instrumentation/

http://www.franke-gmbh.com/en/news/detail.php?id=12

Supplier Assessment Model (Siemens UK)

Question & quantitative answers

6. After Sales Evaluation

6.1 Product Support

6.1.6 What is your response time?

Answers:

1> 1 – 2 hours
2> 3 – 4 hours
3> 5 – 6 hours
4> 7 – 8 hours

Supplier Assessment Model (Siemens UK)

Question & multiple choice answers

1. Quality

1.5 Quality Performance of Supplier

1.5.4 Are quality costs measured, monitored and published?

Answers:

1> No
2> Yes, occasionally
3> Yes, with improvement plans prioritised
4> Yes, with management review done regularly

Supplier Assessment Model (Siemens UK)

Question & Yes / No answers

2. Supply Chain Evaluation

2.1 Performance Measures

2.1.27 Which of the following criteria are used to measure the performance?

Answers: (Yes / No)

2.1.27.1 Purchase savings
2.1.27.2 Availability of stocks
2.1.27.3 Number of purchase orders outstanding
2.1.27.4 Level of inventory
2.1.27.5 Stock turnover
2.1.27.6 Standard cost variance

Supplier Assessment Model (Siemens UK)

Overall assessment grade (TQM Concept)

Supplier Classification

World Class	(ideal)
Award winners	(reliable)
Improvers	(potential)
Drifters	(unfavourable)
Uncommitted	(unqualified)

Supplier Assessment Model (Siemens UK)

Propagation of quantitative assessment

Response time	⇔	After Sales Evaluation
1 hour or less	⇔	(World Class)
3 hours	⇔	(Award winners)
5 hours	⇔	(Improvers)
7 hours	⇔	(Drifters)
8 or above	⇔	(Uncommitted)

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Multi-Criteria Decision Analysis

Traditional problem modelling method

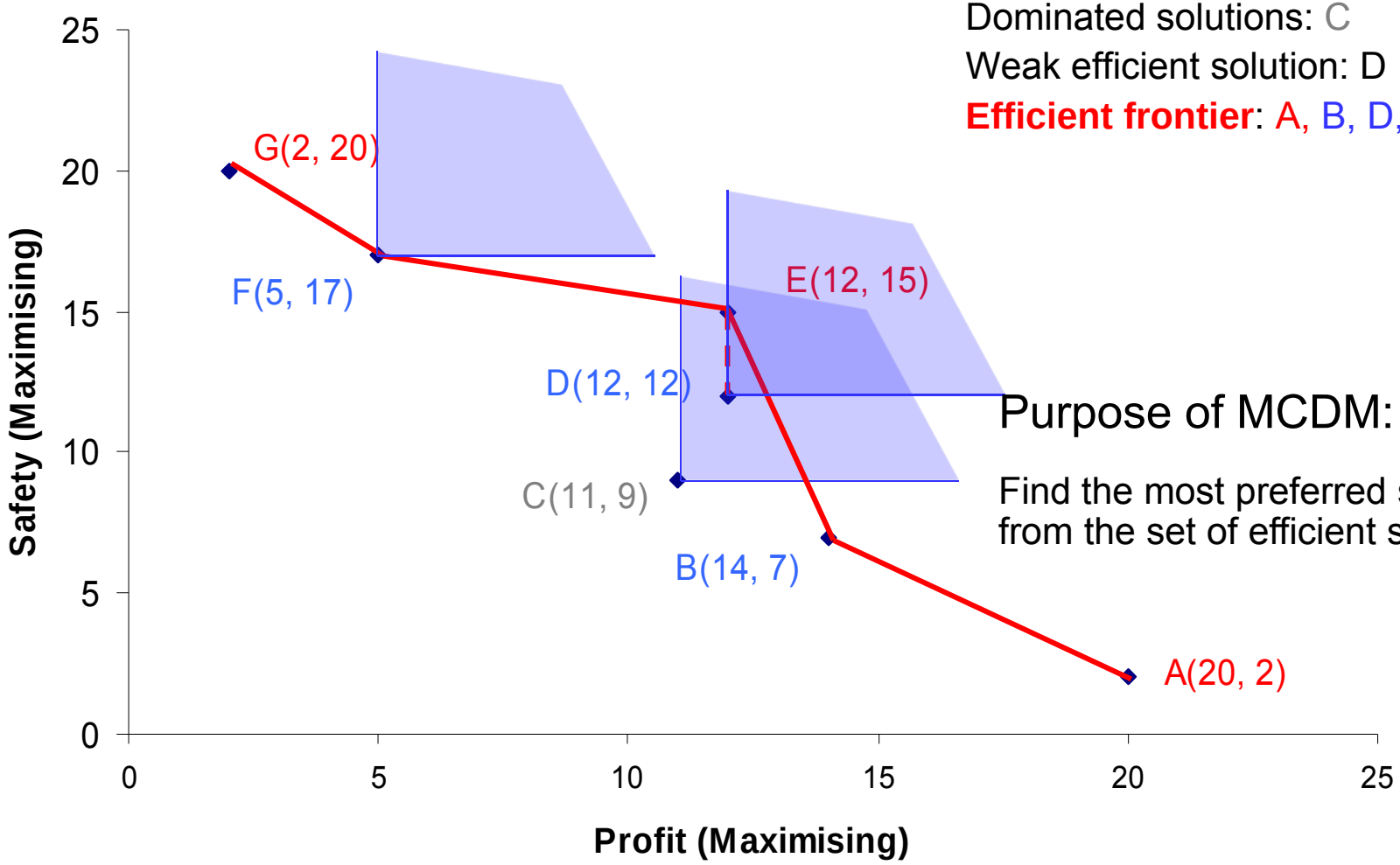
- **Traditional Decision Matrix – Average Point Assessment**

	Attribute 1	Attribute 2	……	Attribute n
Alternative 1	A_{11}	A_{12}		A_{1n}
Alternative 2	A_{21}	A_{22}		A_{2n}
……				
Alternative m	A_{m1}	A_{m2}		A_{mn}

It uses average numbers to assess each alternative on all criteria

MCDM – Graphic Interpretation for

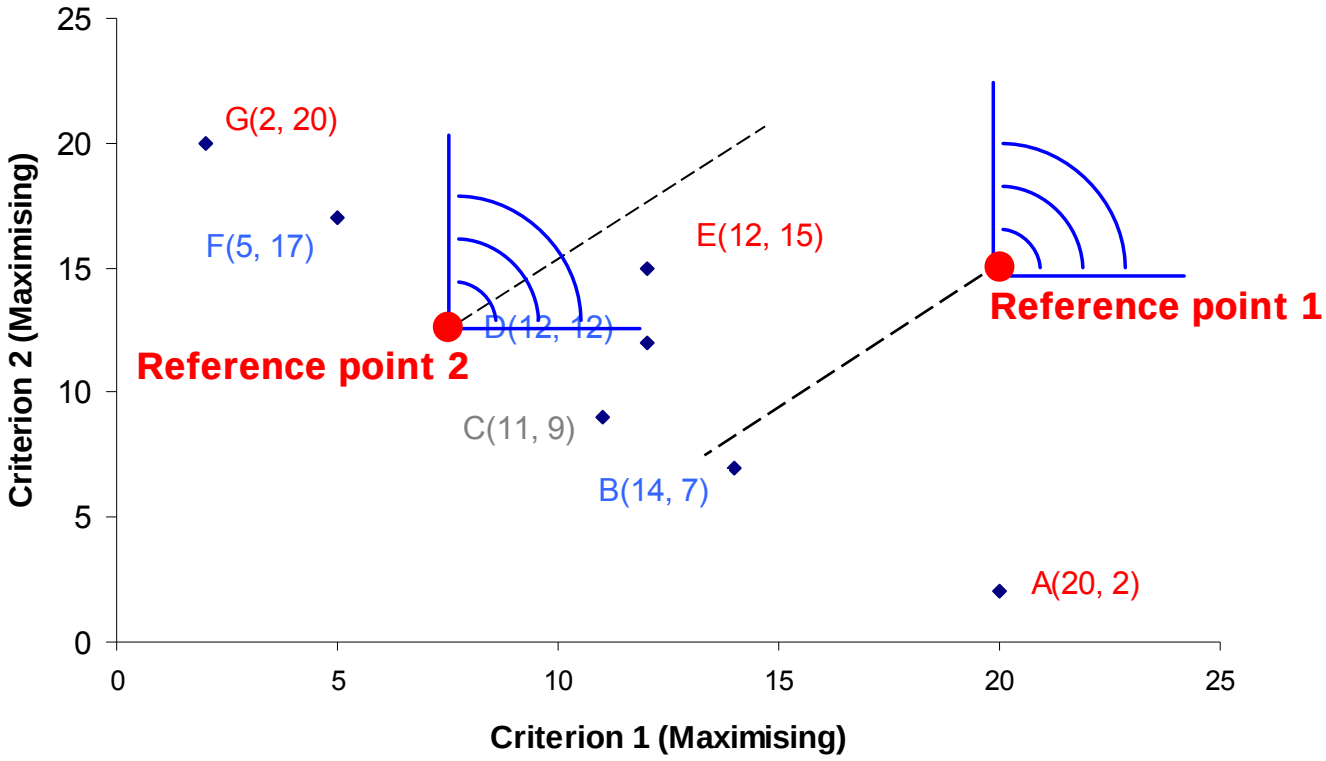
Dominated solutions, efficient solution, efficient frontier



Distance-based Preference Modelling

Aspiration level models (minimax distance)

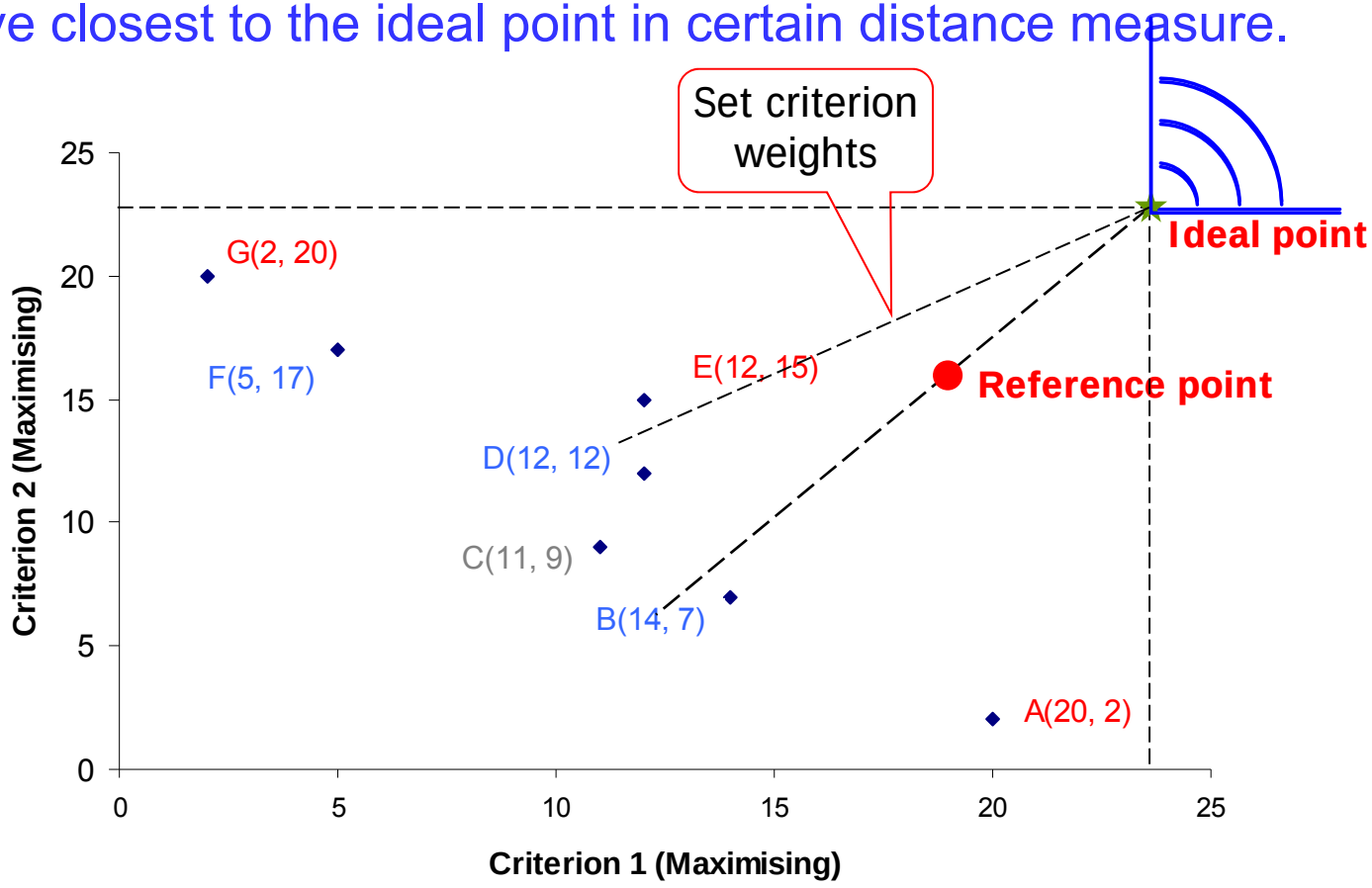
Reference point models: Set a reference point and find an alternative closest to the reference point in certain distance measure.



Distance-based Preference Modelling

Ideal point models (minimax distance)

Ideal point models: Set an ideal reference point and find an alternative closest to the ideal point in certain distance measure.



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Additive Value Function Approach

Assessment of postgraduate schools – example 1

Original Decision Matrix

	Average book (y_1, *number*)	*Student / staff* (y_2, *ratio*)	Research grant (y_3, \$,000)	*Graduation delayed* (y_4, %)
School 1	0.1	5	5,000	4.7
School 2	0.2	7	4,000	2.2
School 3	0.6	10	1,260	3.0
School 4	0.3	4	3,000	3.9
School 5	2.8	2	284	1.2

Assign Importance Weights by Comparisons

School performance assessment example

Comparisons: Suppose the most important criterion of the four criteria for school performance assessment is "research grant".

1. Compare its importance with each of the other criteria:
   "Research grant" is twice as important as "books", $\omega_3/\omega_1 = 2$
   "Research grant" is 1.5 times as important as "ratio", $\omega_3/\omega_2 = 1.5$
   "Research grant" is 3 times as important as "graduation", $\omega_3/\omega_4 = 3$

   Solve the four linear equations:

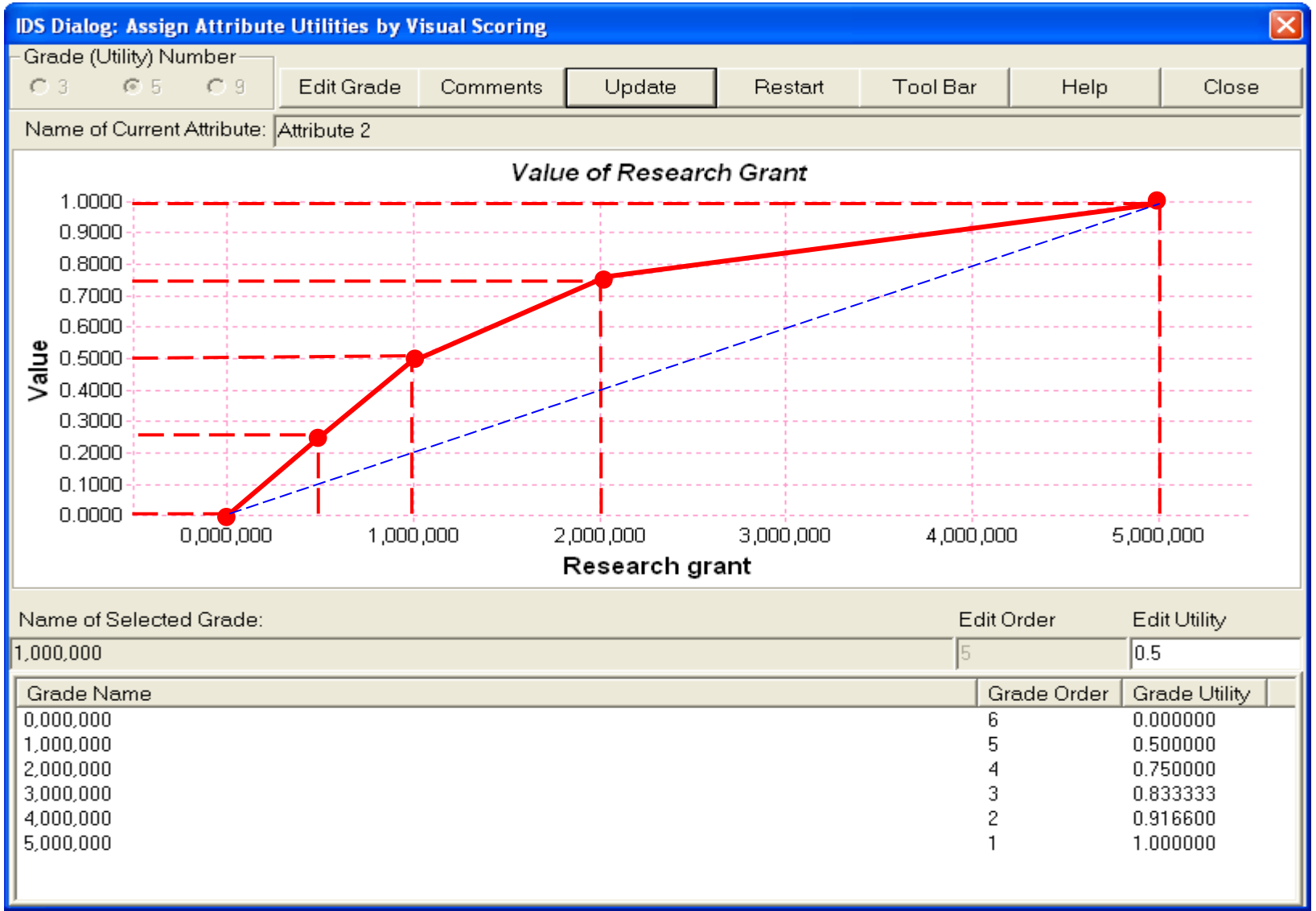
   $$\omega_3 - 2\omega_1 = 0,\ \omega_3 - 1.5\omega_2 = 0,\ \omega_3 - 3\omega_4 = 0,\ \omega_1+\omega_2+\omega_3+\omega_4 = 1$$

   So, the weights of the four criteria are given by

   $$\omega_1 = 0.2,\ \omega_2 = 0.2667,\ \omega_3 = 0.4,\ \omega_4 = 0.1333$$

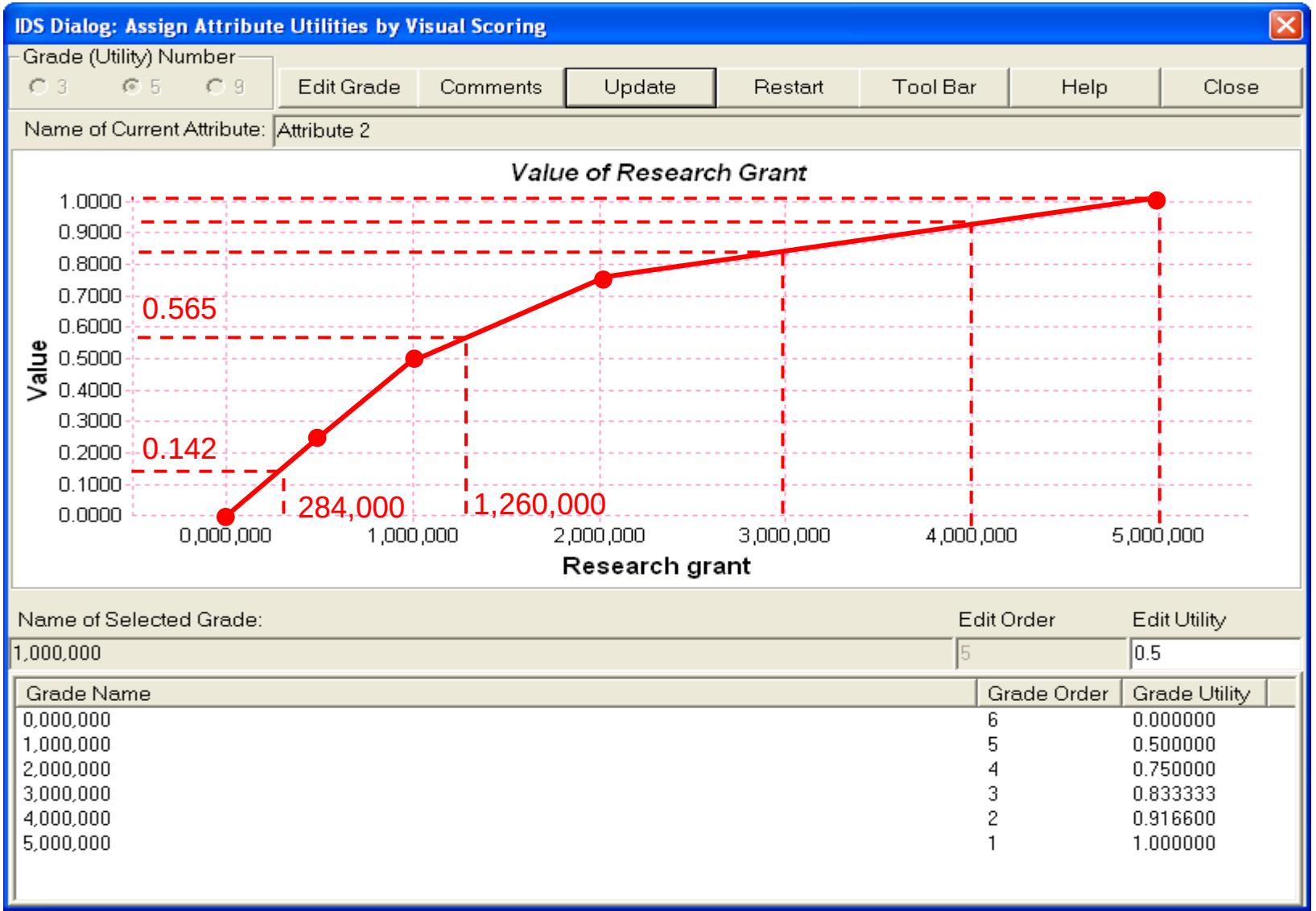
Definition of A Partial Value Function

Direct assessment via visual aid – v_3



Look up Partial Value Function

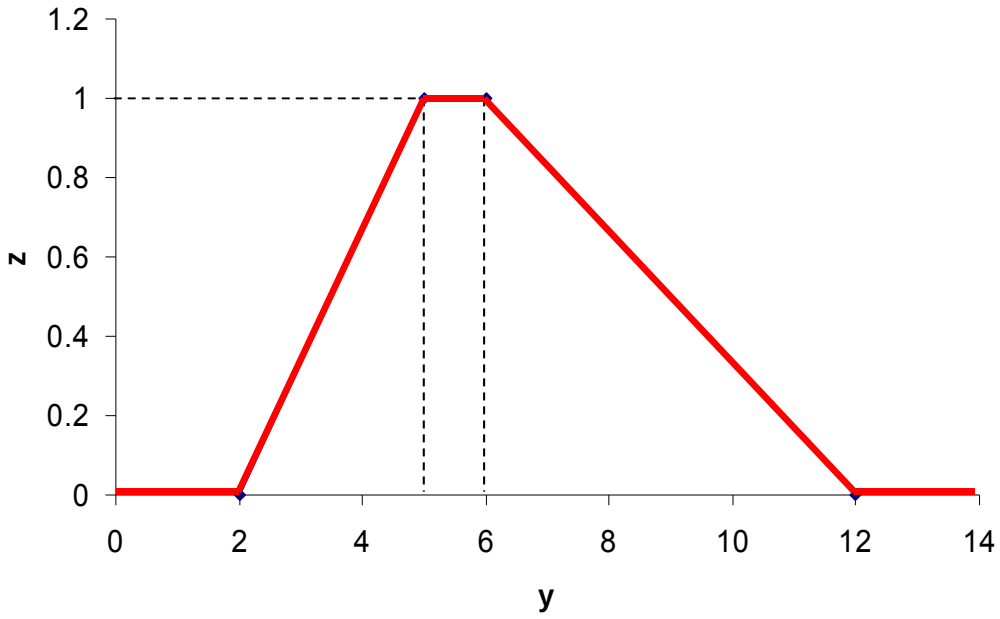
To get values for research grant – v_3



Pre-processing Data Collected

Transformation of data with optimal interval

Concept: For some criteria neither larger nor smaller is desirable, such as student and staff ratio. A high ratio may lead to the compromise of quality, but a low ratio means low workload for staff. A desirable ratio may be shown in the following diagram



Additive Value Function Approach

Performance assessment for postgraduate schools

Variously-Transformed Decision Matrix with Weights

	Average book (ω_1=0.2)	*Student / staff* (ω_2=0.2667)	Research grant (ω_3=0.4)	*Graduation delayed* (ω_4=0.1333)
School 1	0.5950	1.0000	1.0000	0.0000
School 2	0.6100	0.8333	0.9166	0.7142
School 3	0.6700	0.3333	0.5650	0.4857
School 4	0.6250	0.6666	0.8333	0.2286
School 5	1.0000	0.0000	0.1420	1.0000

Multiple Attribute Value Theory

Additive value function and conditions required

General form of an additive value function is given by:

$$v = \sum_{i=1}^{m} \omega_i v_i(y_i) = \omega_1 v_1(y_1) + \omega_2 v_2(y_2) + \cdots + \omega_m v_m(y_m)$$

Conditions for use of Additive MAVF:

1. Satisfaction of *preferential independence* among any groups of attributes. This is only a necessary condition.
2. Satisfaction of the *corresponding trade-off*, or *Thomsen* condition.
3. *Interval scale property* for constructing marginal value function.
4. Weights of attributes need to be assessed as scaling constants (trade-offs), or swing weights, not necessarily relative importance.
5. Linear & complete compensation among criteria without any limit.

Additive Value Function Approach

Performance assessment for postgraduate schools

Ranking Using Variously-Transformed Decision Matrix

	$z^h{}_1$ (ω_1=0.2)	$z^f{}_2$ (ω_2=0.2667)	v_3 (ω_3=0.4)	$z^e{}_4$ (ω_4=0.1333)	$\sum \omega_i v_i$	Ranking
School 1	0.5950	1.0000	1.0000	0.0000	**0.7857**	**2**
School 2	0.6100	0.8333	0.9166	0.7142	**0.8061**	**1**
School 3	0.6700	0.3333	0.5650	0.4857	**0.5136**	**4**
School 4	0.6250	0.6666	0.8333	0.2286	**0.6666**	**3**
School 5	1.0000	0.0000	0.1420	1.0000	**0.3901**	**5**

It is useful to conduct **sensitivity analysis** by changing weights, using different normalisation methods or changing value functions.

MCDA – Value Measurement Theory

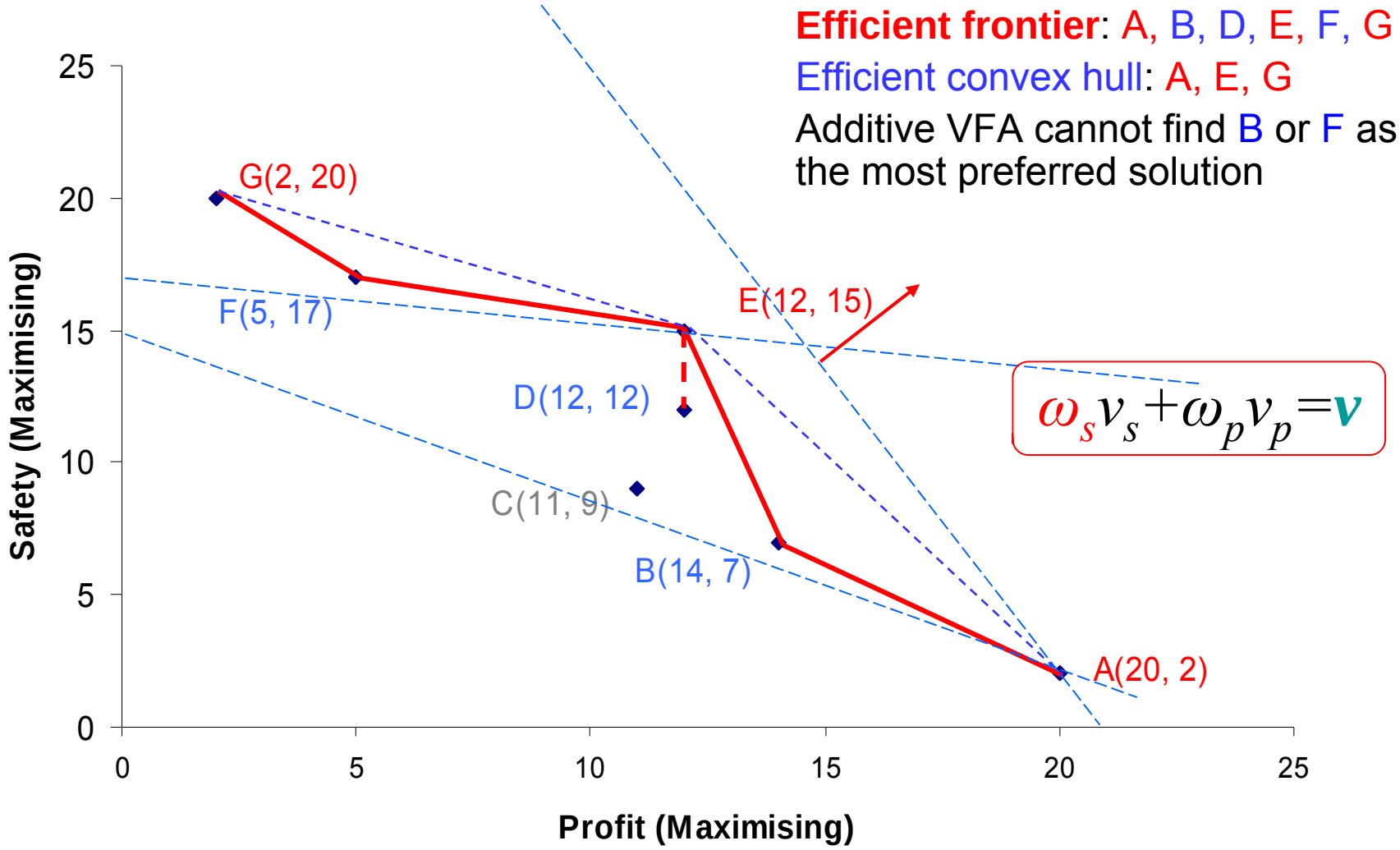
Preferential independence – Violation example

For purchase of MP3 players, suppose three attributes are taken into account: *price*, *memory*, and *sound quality*

MP3-A	High price + Large memory	High sound quality
MP3-B	Low price + Small memory	High sound quality
Suppose MP3-A is preferred to MP3-B		

MP3-C	High price + Large memory	Low sound quality
MP3-D	Low price + Small memory	Low sound quality
Would MP3-C still be preferred to MP3-D ?		

Limitation or Bias of Additive VFA



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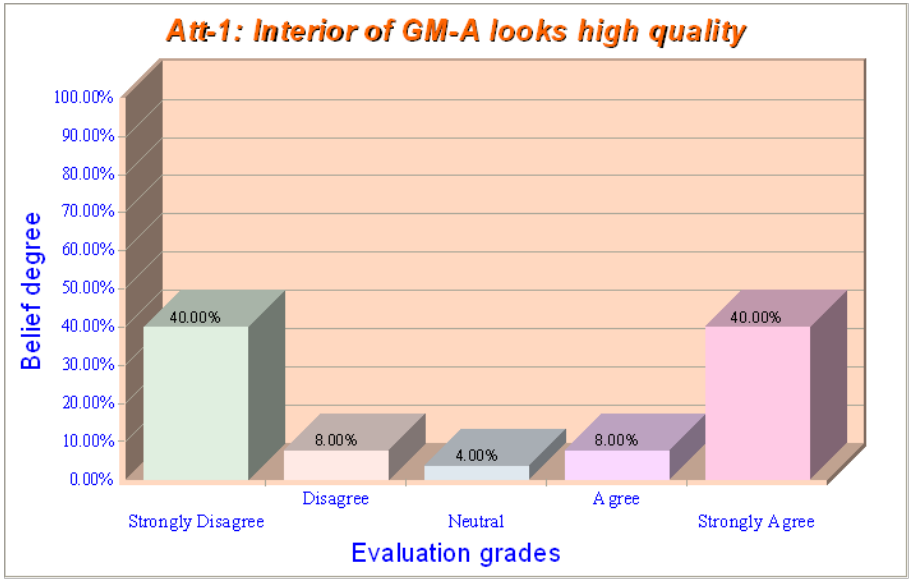
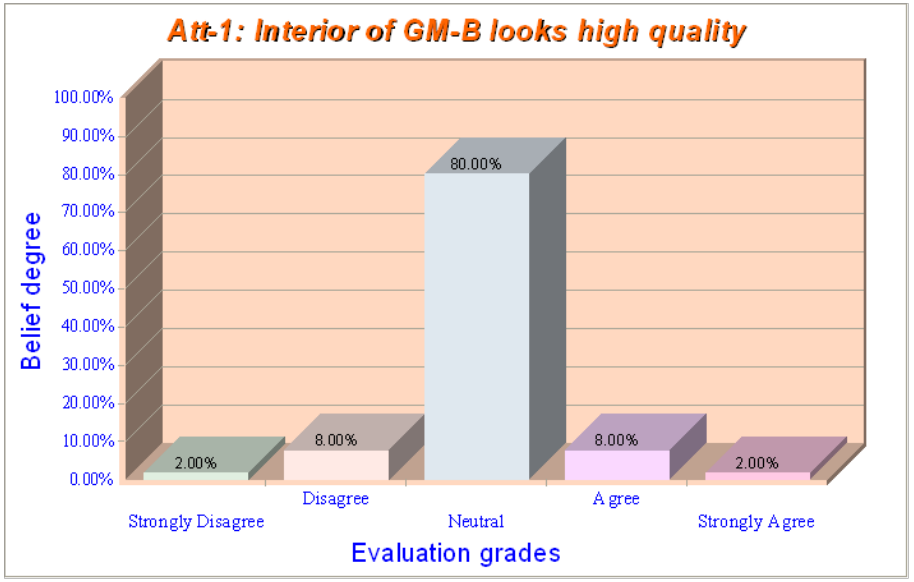
Multi-Criteria Decision Analysis

Belief distribution versus average assessment

- Frequencies of customer responses from external surveys





- The average score of GM-B is about the same as that of GM-A
- Is GM-B of the same priority to GM as GM-A in future design?

Multi-Criteria Decision Analysis

Belief decision matrix for problem modelling

- **Belief Decision Matrix – Distribution Assessment**

	Attribute 1	Attribute 2	.....	Attribute n
Alternative 1	A_{11}	A_{12}		A_{1n}
Alternative 2	A_{21}	A_{22}		A_{2n}
.....				
Alternative m	A_{m1}	A_{m2}		$A_{mn} = \{(H_1, \beta_1), (H_2, \beta_2), ..., (H_N, \beta_N)\}$

1. It can represent precise numbers for all criteria on each alternative
2. It can represent subjective judgements
3. It can represent ignorance explicitly

Multi-Criteria Decision Analysis

Belief decision matrix for problem modelling

House / Criteria	House 1 in Altrincham	House 2 in Heaton	House 3 in Mercy	House 4 in Didsbury
Location	$\{(G, 0.5), (E, 0.5)\}$	$\{(G, 0.5)\}$	$\{(A, 0.2), (G, 0.8)\}$	$\{(G, 0.2), (E, 0.8)\}$
Distance (mile)	7	5	6	5.5
Asking Price (£)	113,000	110,000	118,000	150,000
Attractive-ness	$\{(P, 0.05), (G, 0.35), (E, 0.60)\}$	$\{(A, 0.4), (G, 0.6)\}$	$\{(G, 0.3), (E, 0.7)\}$	$\{(G, 0.6), (E, 0.4)\}$

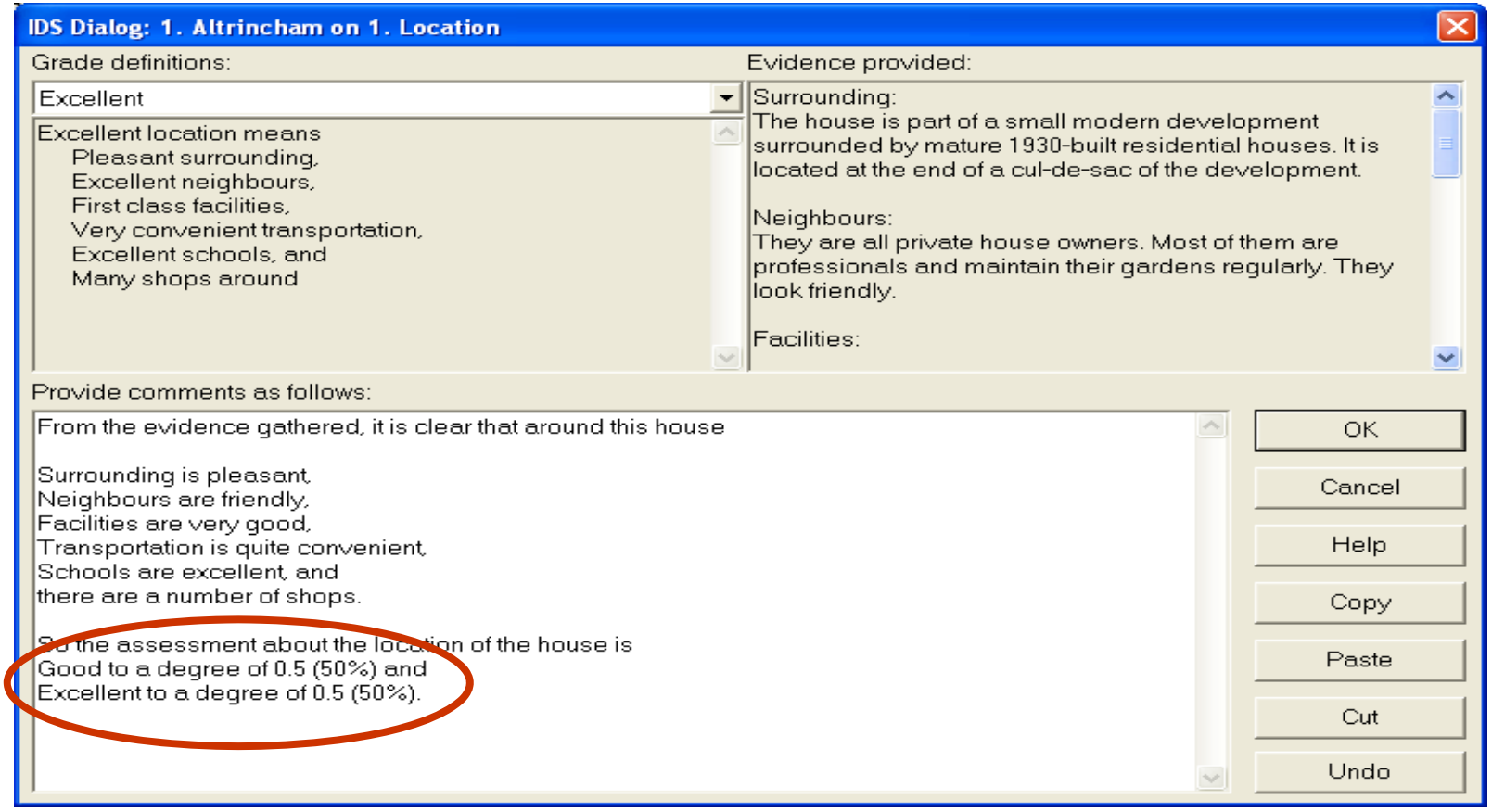
Construct Qualitative Value Function

Assess the location of houses in south Manchester

Grade	**Definition** (list of indicators for collecting evidence)
excellent	Pleasant surrounding, Excellent neighbours, First class facilities, Very convenient transportation, Excellent schools, and Many shops around
Good	Good surrounding, Friendly neighbours, Good facilities, Convenient transportation, Good schools, and A number of shops around
Average	Normal surrounding, Ordinary neighbours, Some facilities, Some transportation, Average schools, and A few shops around
Poor	Noisy surrounding, Unfriendly neighbours, Poor facilities, Inconvenient transportation, Poor schools, and Few shops around
Bad	Unbearable surrounding, Terrible neighbours, No facilities, No transportation, No schools, and No shops around

Belief Decision Matrix

Assessment based on evidence collected



Assessing the Location of House 1 in Altrincham using the collected evidence against the agreed assessment standards

Belief Decision Matrix

Examples for uncertainty modelling

- **From comparing evidence to grading standards**

  Supplier 1's performance on Technical Competence

  {(Excellent, 50%), (Good, 40%), (Poor,10%)}

- **Group opinion distribution**

  Deep repository on health risk

  {(High, 30%), (Medium, 30%), (Low, 40%)}

- **Random data**

  Car fuel consumption in mpg (miles/gallon):

  {(20mpg, 30%), (22mpg, 30%), (25mpg, 40%)}

Belief Decision Matrix

Examples for uncertainty modelling

- **Judgments from Experience -** Personality Test:

  Do you always try to avoid the gaps on pavement?

  {(Yes, 20%), (No, 80%)}

- **From converting numerical data to grades**

  If Excellent=100, Good=75,

  then 90={(Excellent, 60%),(Good, 40%)}

Belief Decision Matrix

Examples for uncertainty modelling

- **Data with ignorance (partial or complete)**

Car engine quality assessment:

{(Excellent, 30%), (Good, 50%)}

with unknown 20% — Partial ignorance

{(Excellent, 0%), …,(Poor, 0%)}

with unknown 100% — Complete ignorance

Belief Decision Matrix

Examples for uncertainty modelling

- **Data with interval uncertainties**

  Belief assigned to an interval of grades:

  {(Excellent-Good), 60%), (Good, 40%)}

- **Interval belief assessed to individual grades:**

  {(Moderately Negative, 20-30%),

  (Neutral, 30-40%), (Positive, 40-50%)}

Main Topics of the Session

- Multiple criteria decision analysis – what is it?
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- Decision matrix and MCDA explained in graph
- Additive value function approach in MCDA
- Deal with uncertainties in MCDA
- **Evidential reasoning MCDA – concept, model, process and tool**
- A snapshot of real world MCDA applications

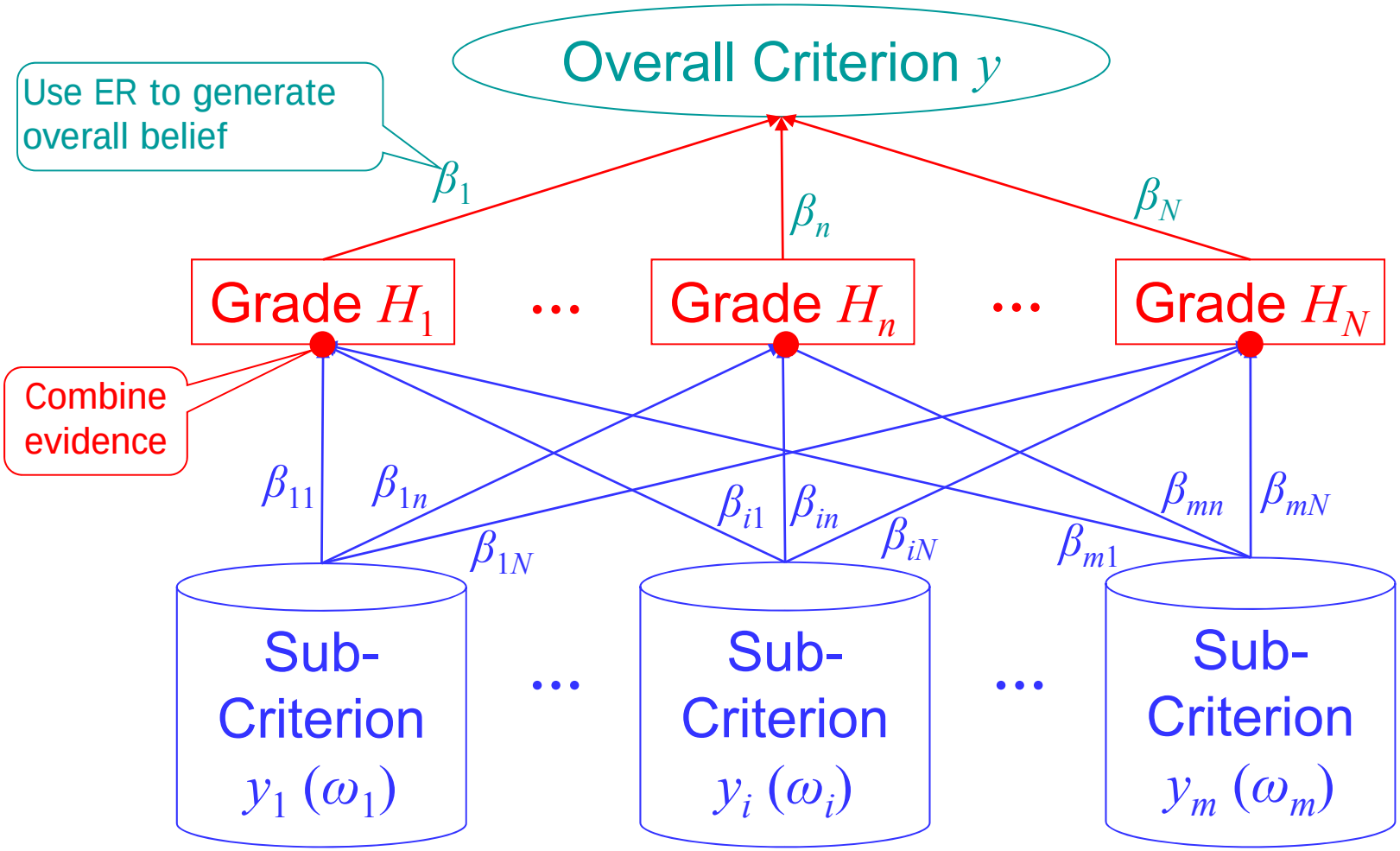
Multi-Criteria Decision Analysis

Belief decision matrix for problem modelling

House / Criteria	House 1 in Altrincham	House 2 in Heaton	House 3 in Mercy	House 4 in Didsbury
Location	$\{(G, 0.5), (E, 0.5)\}$	$\{(G, 0.5)\}$	$\{(A, 0.2), (G, 0.8)\}$	$\{(G, 0.2), (E, 0.8)\}$
Distance (mile)	7	5	6	5.5
Asking Price (£)	113,000	110,000	118,000	150,000
Attractive-ness	$\{(P, 0.05), (G, 0.35), (E, 0.60)\}$	$\{(A, 0.4), (G, 0.6)\}$	$\{(G, 0.3), (E, 0.7)\}$	$\{(G, 0.6), (E, 0.4)\}$

Evidential Reasoning MCDA

Modelling structure and graphic interpretation



Evidential Reasoning Approach

Framework and algorithm

Step 1: Construct a belief decision matrix

Step 2: Weight assignment and normalised

Step 3: Convert belief to basic probability mass

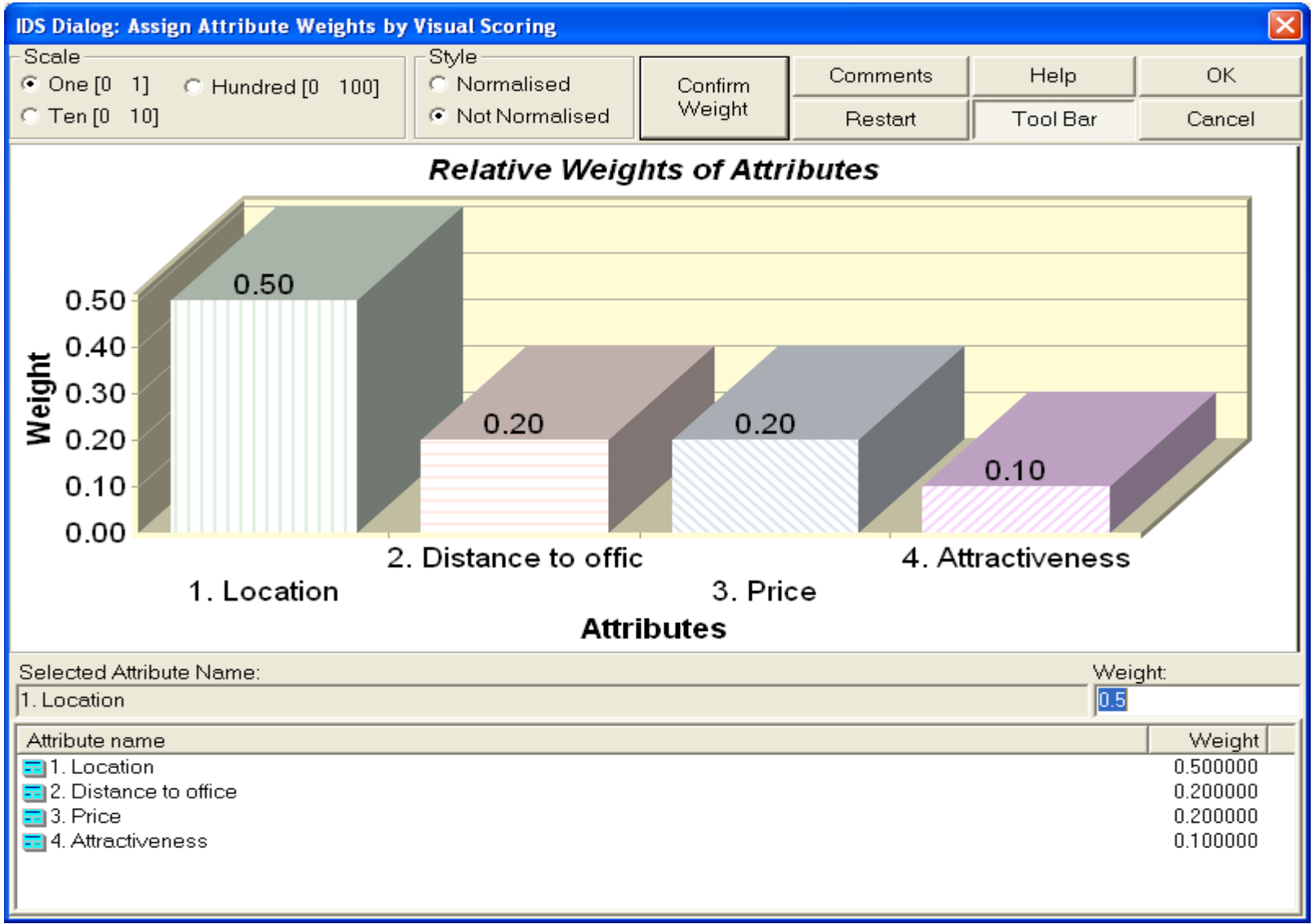
Step 4: Combine basic probability mass

Step 5: Generate combined distribution assessment

Step 6: Utility function based alternative ranking

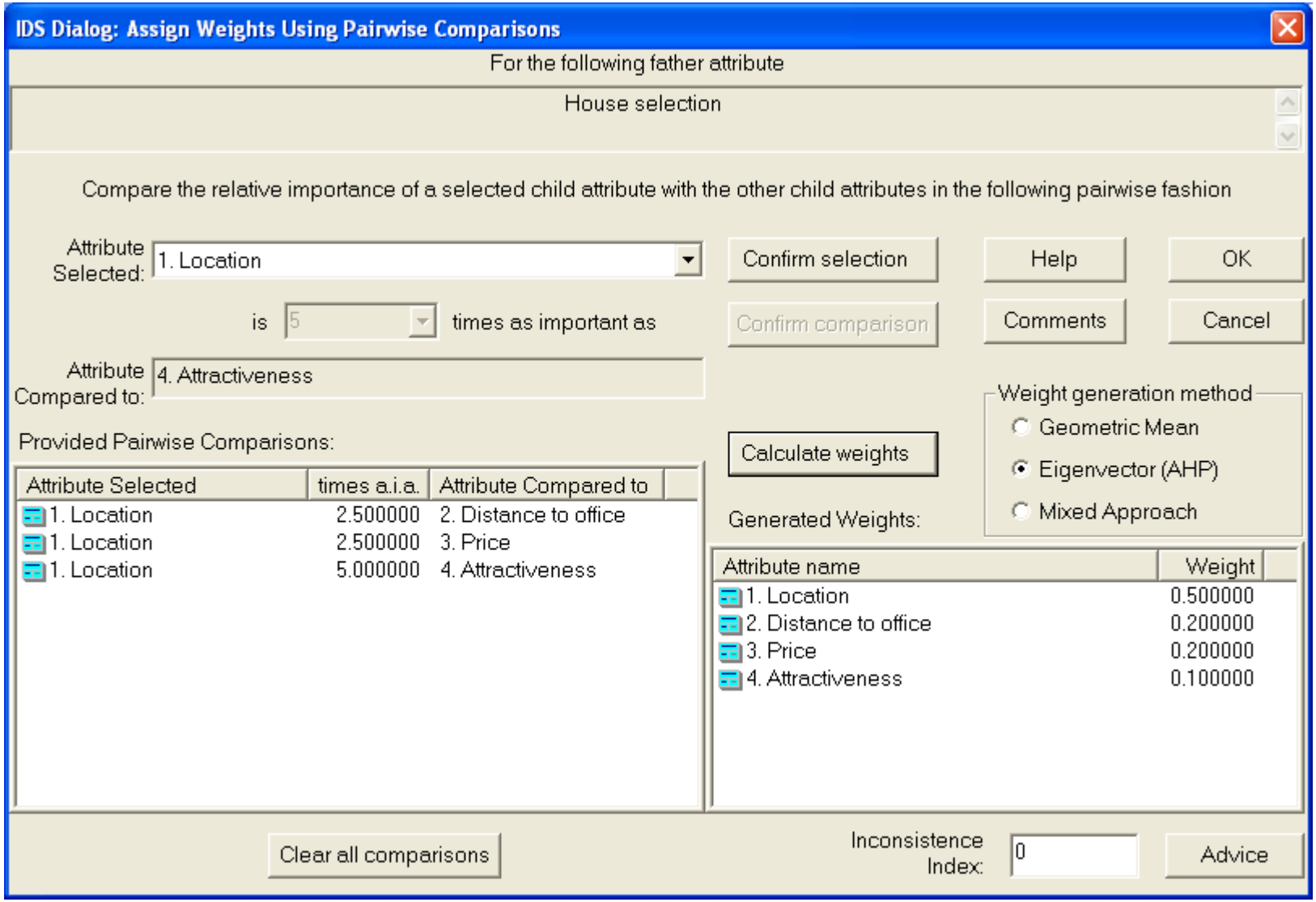
Directly assigning criterion weights

The house purchase example



Assigning weights by Comparisons

The house purchase example



Evidential Reasoning MCDA

The evidential reasoning algorithm

Generation of overall belief:

β_n can be generated by using the following nonlinear evidential reasoning algorithm:

$$\beta_n = k\left[\prod_{i=1}^{m}(\omega_i\beta_{i,n} + 1 - \omega_i) - \prod_{i=1}^{m}(1-\omega_i)\right]$$

$$k = \left[\sum_{n=1}^{N}\prod_{i=1}^{m}(\omega_i\beta_{i,n} + 1 - \omega_i) - N\prod_{i=1}^{m}(1-\omega_i)\right]^{-1}$$

$$S = \{(H_n, \beta_n),\ n = 1, \ldots, 5\}$$

ER-MCDA and Condition to Use

Judgmental independence

An attribute is judgementally independent of other attributes if the assessment of the former does not depend on the assessment of the latter as long as they are fixed.

For example, for purchase of MP3 players, suppose only two attributes *price* and *sound quality* are taken into account. It is then commonly accepted that

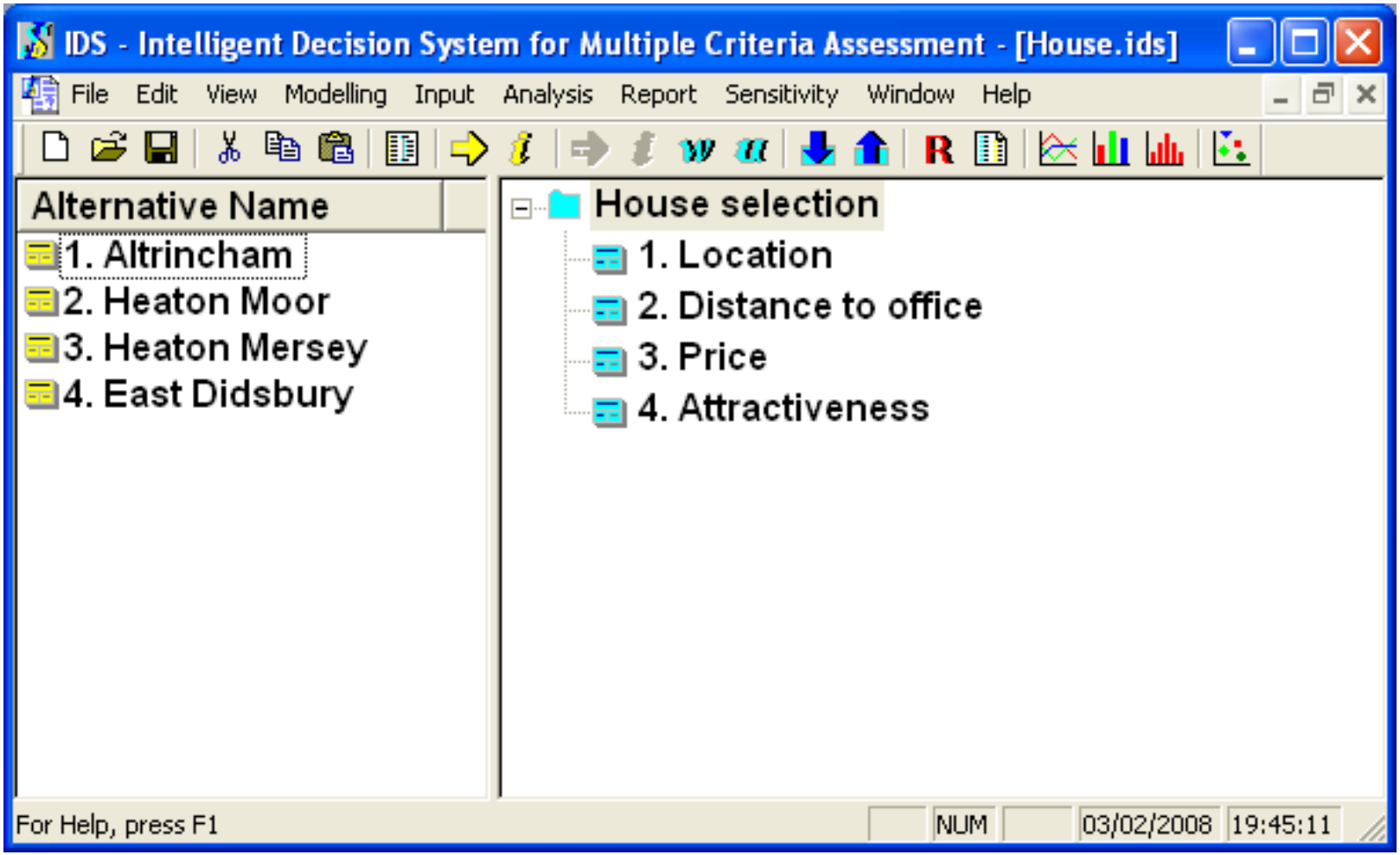
1 – For any fixed price, high sound quality MP3 is judged to be better

2 – For any fixed sound quality, low price MP3 is judged to be better

So, the two attributes *price* and *sound quality* are mutually judgementally independent, though they may be correlated.

Buy house – IDS Main Interface

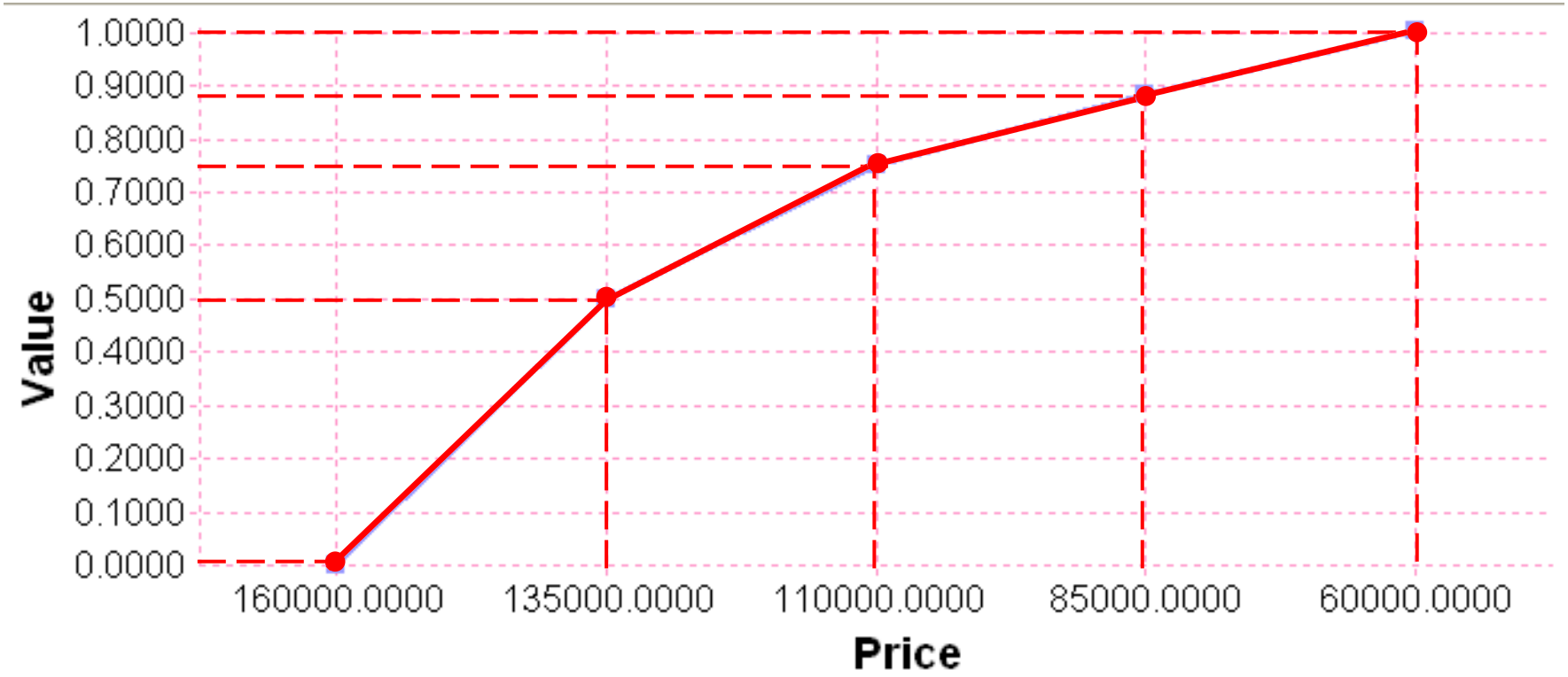
Assessment hierarchy and alternative houses



Assess a partial value function

Direct assessment method

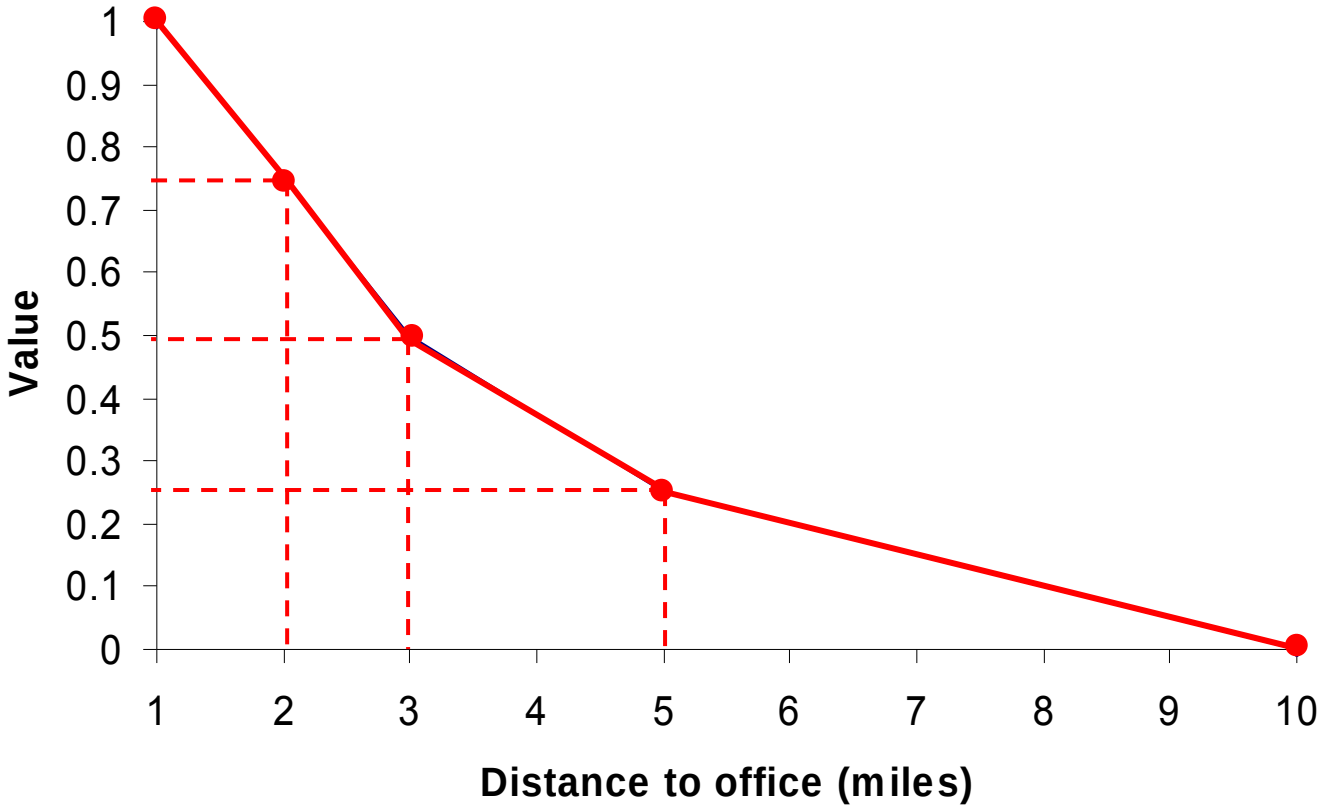
The marginal value function of the price



Assess a partial value function

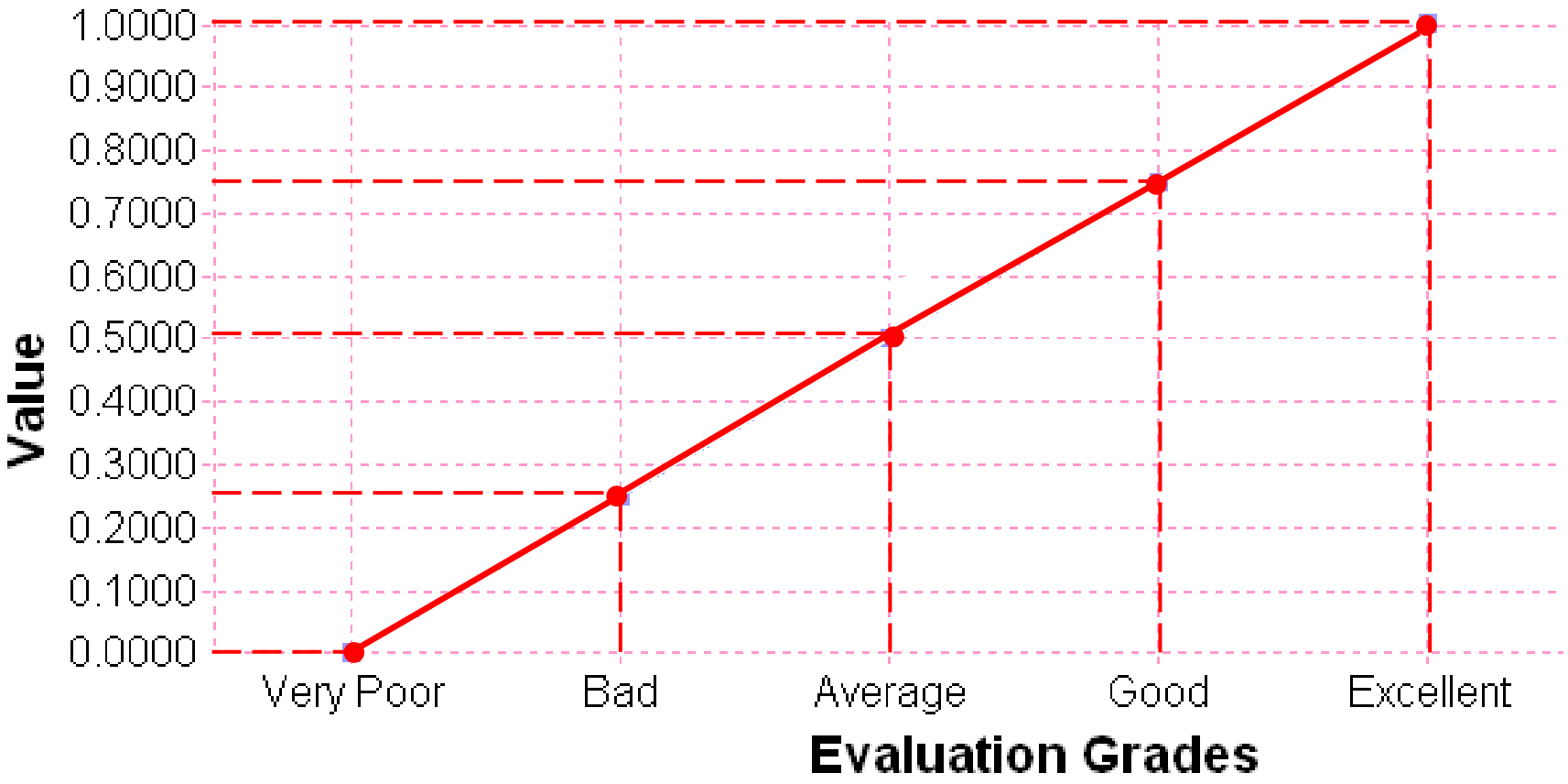
Bisection assessment method

The marginal value function of the distance to office

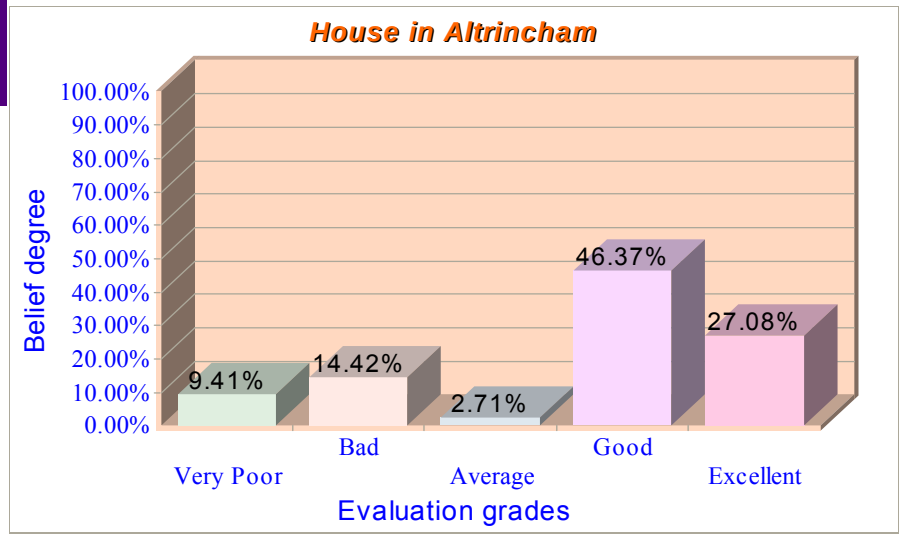


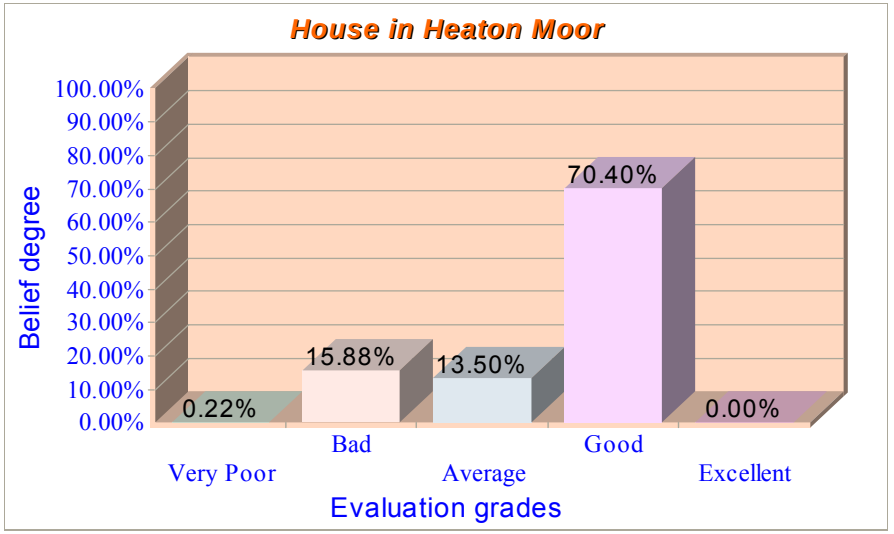
Example 2: Buy house

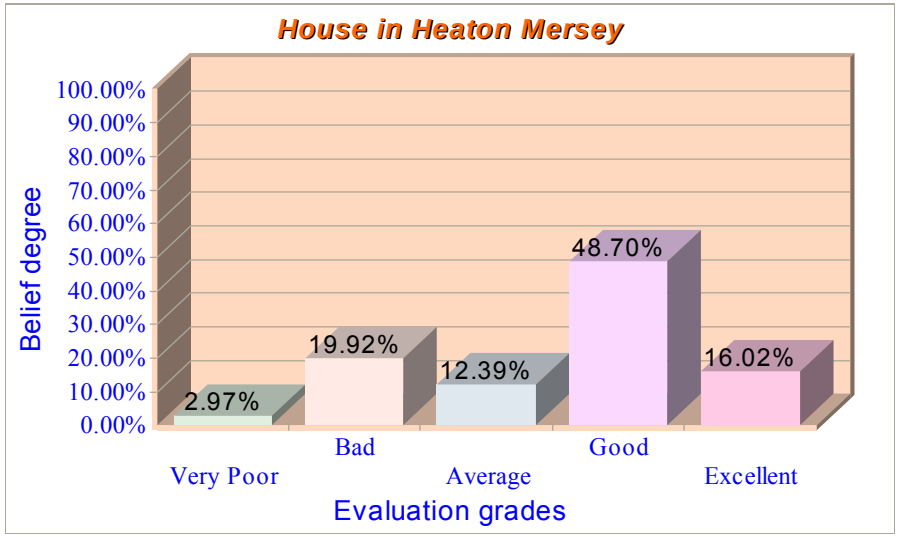
Assess value functions for other attributes

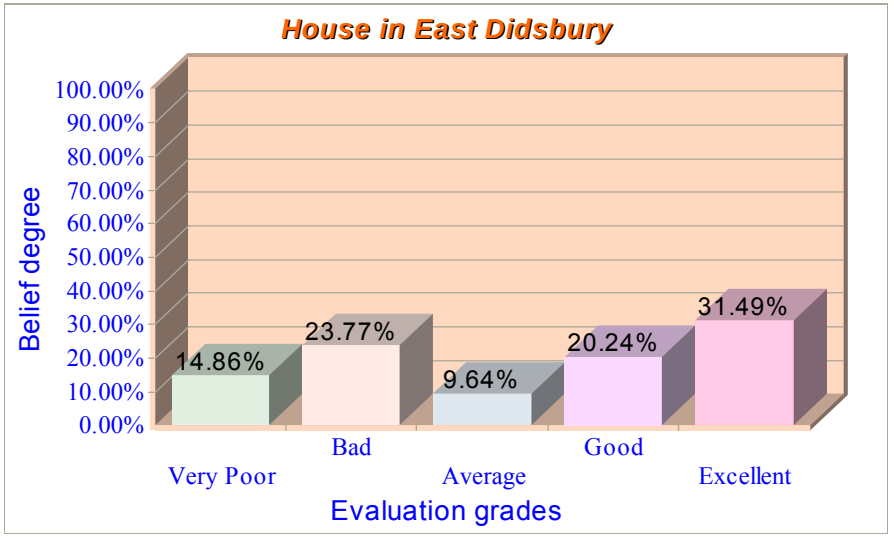


Distributed Assessments of Four Houses

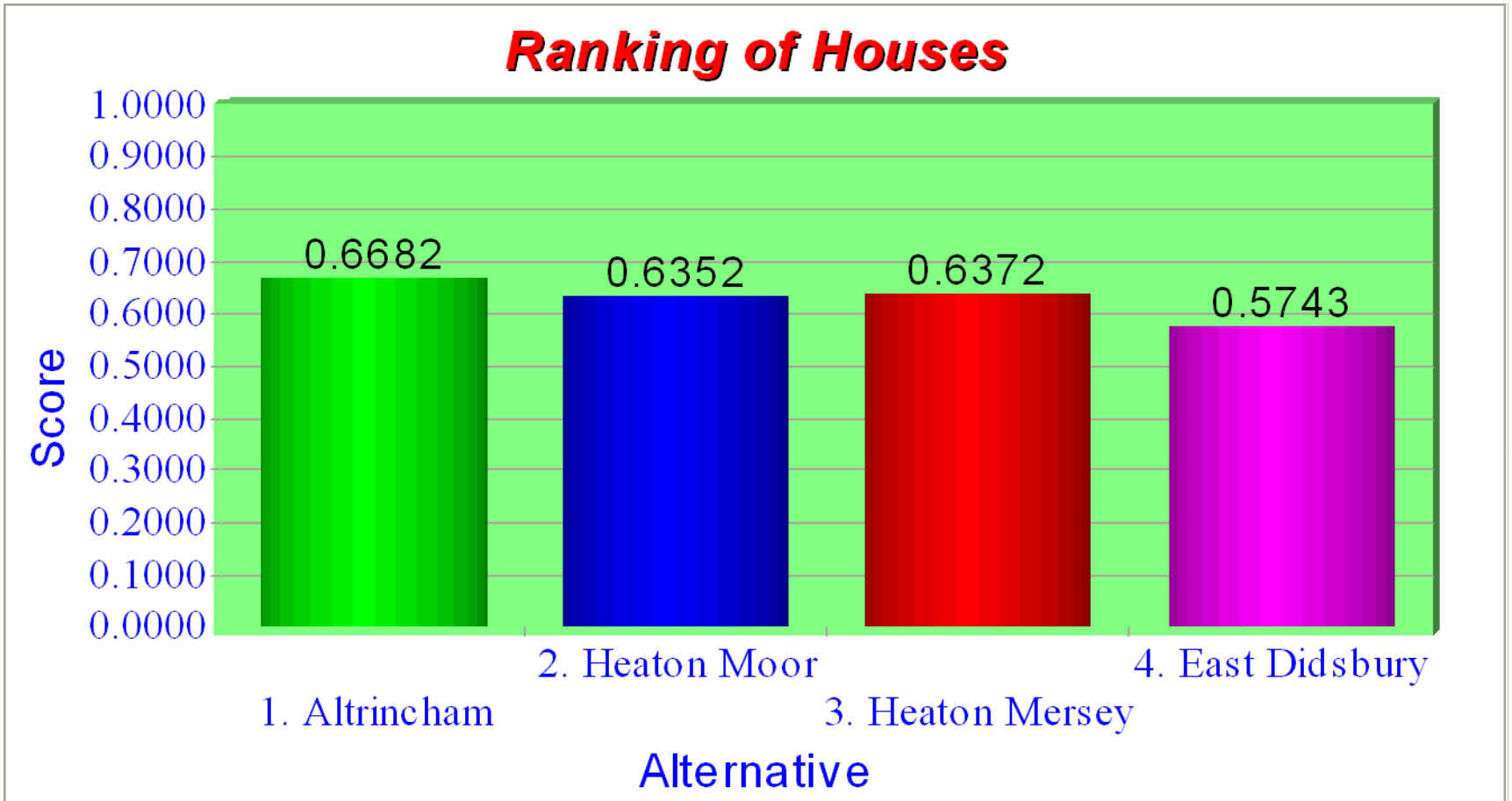






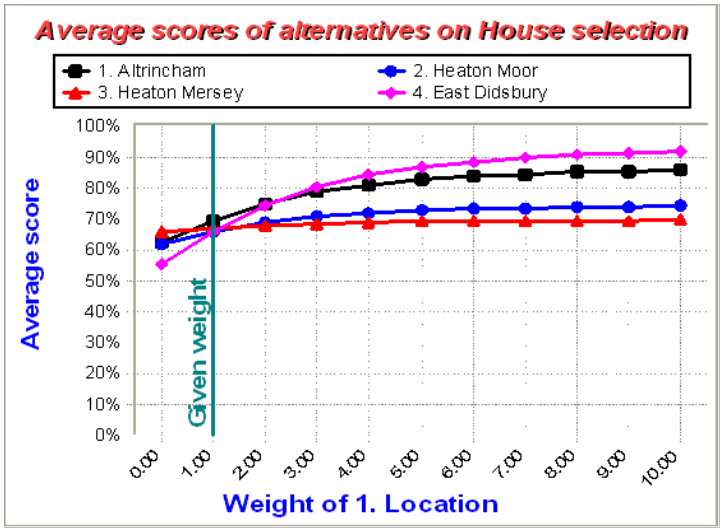


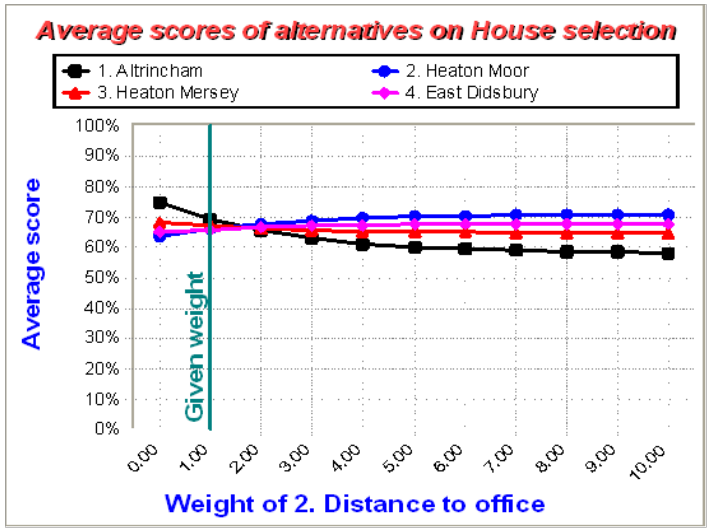
Rank Order of the Four Houses

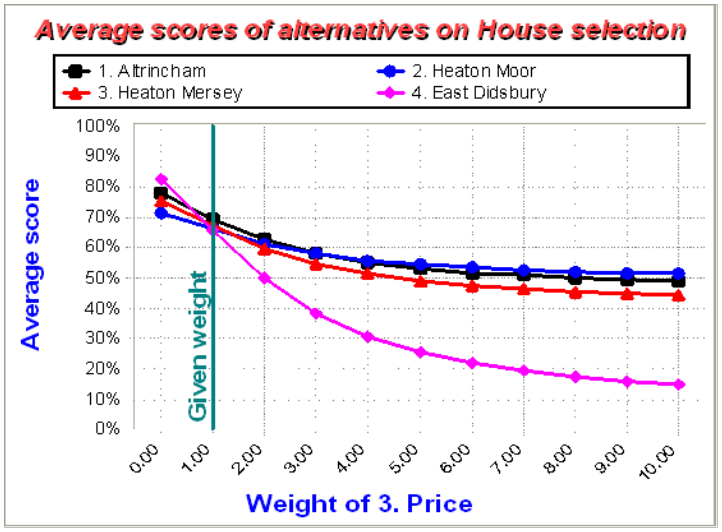


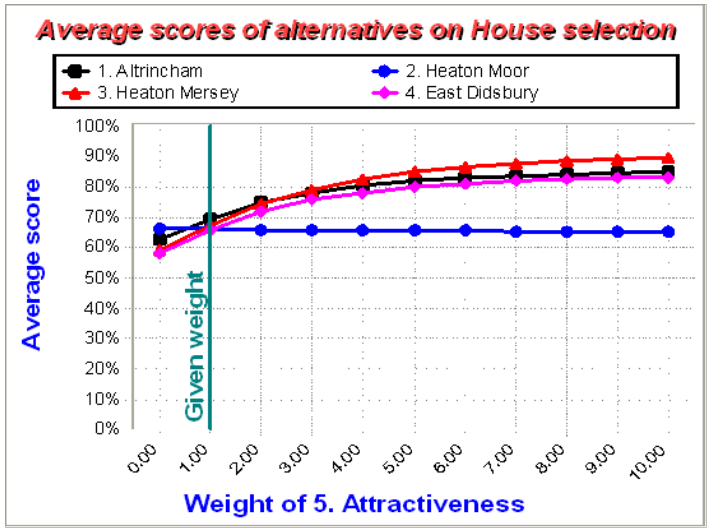
	1. Altrincham	2. Heaton Moor	3. Heaton Mersey	4. East Didsbury
Average score	0.6682	0.6352	0.6372	0.5743

Sensitivity of the Ranking of Houses









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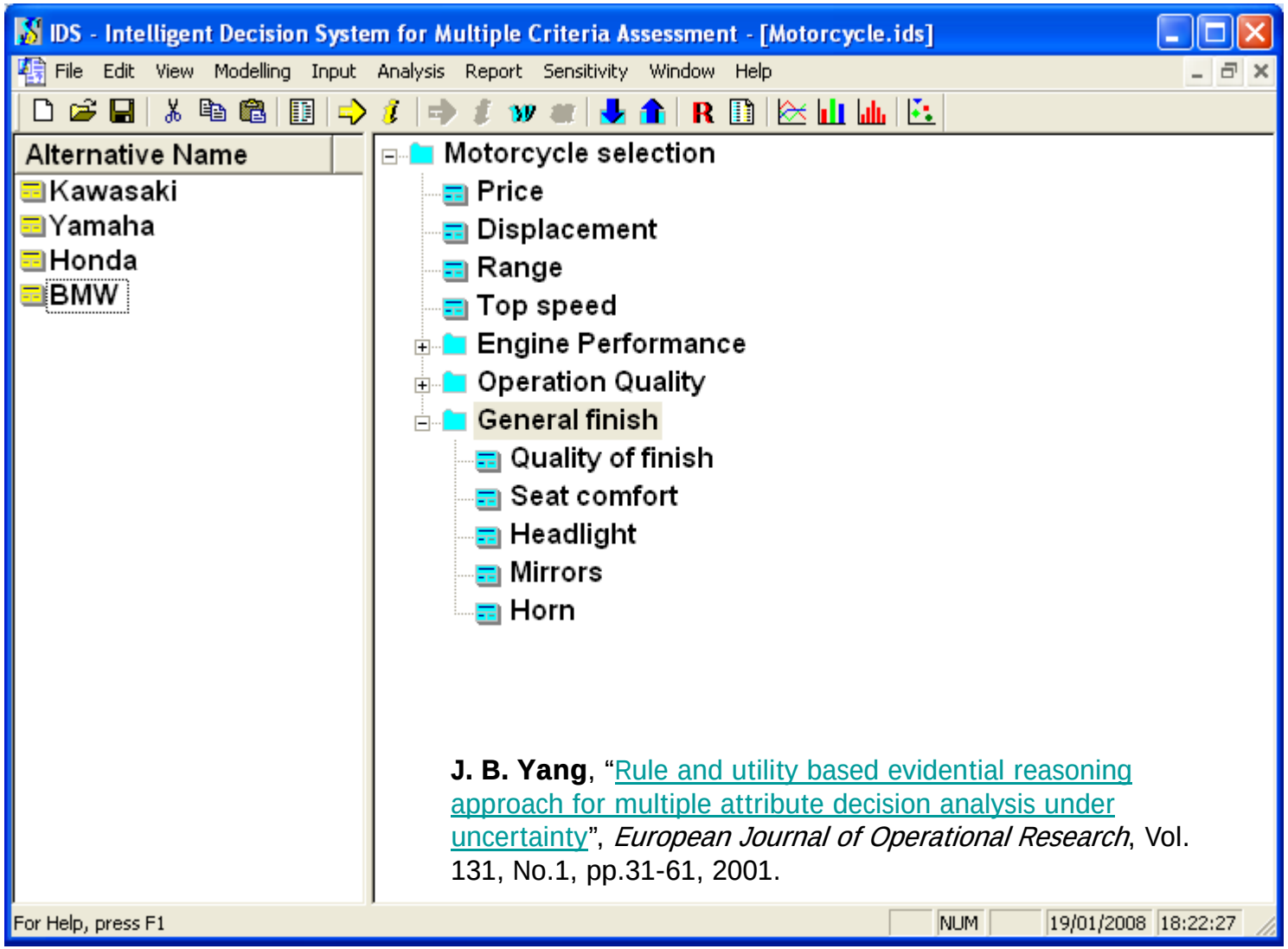
MCDA Applications in Real World

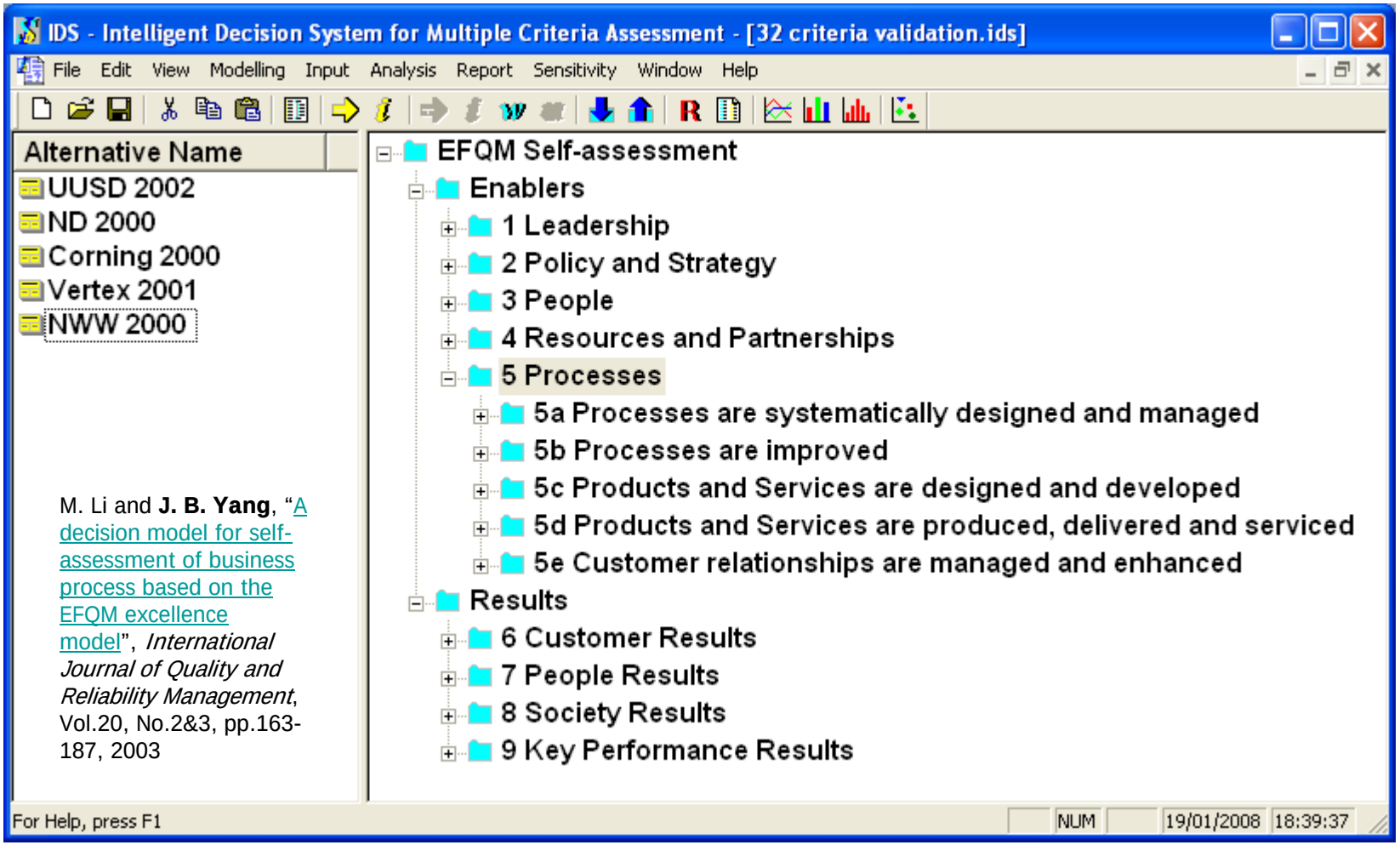
Example 3: Motorbike performance assessment hierarchy



J. B. Yang, "Rule and utility based evidential reasoning approach for multiple attribute decision analysis under uncertainty", *European Journal of Operational Research*, Vol. 131, No.1, pp.31-61, 2001.

MCDA Applications in Real World

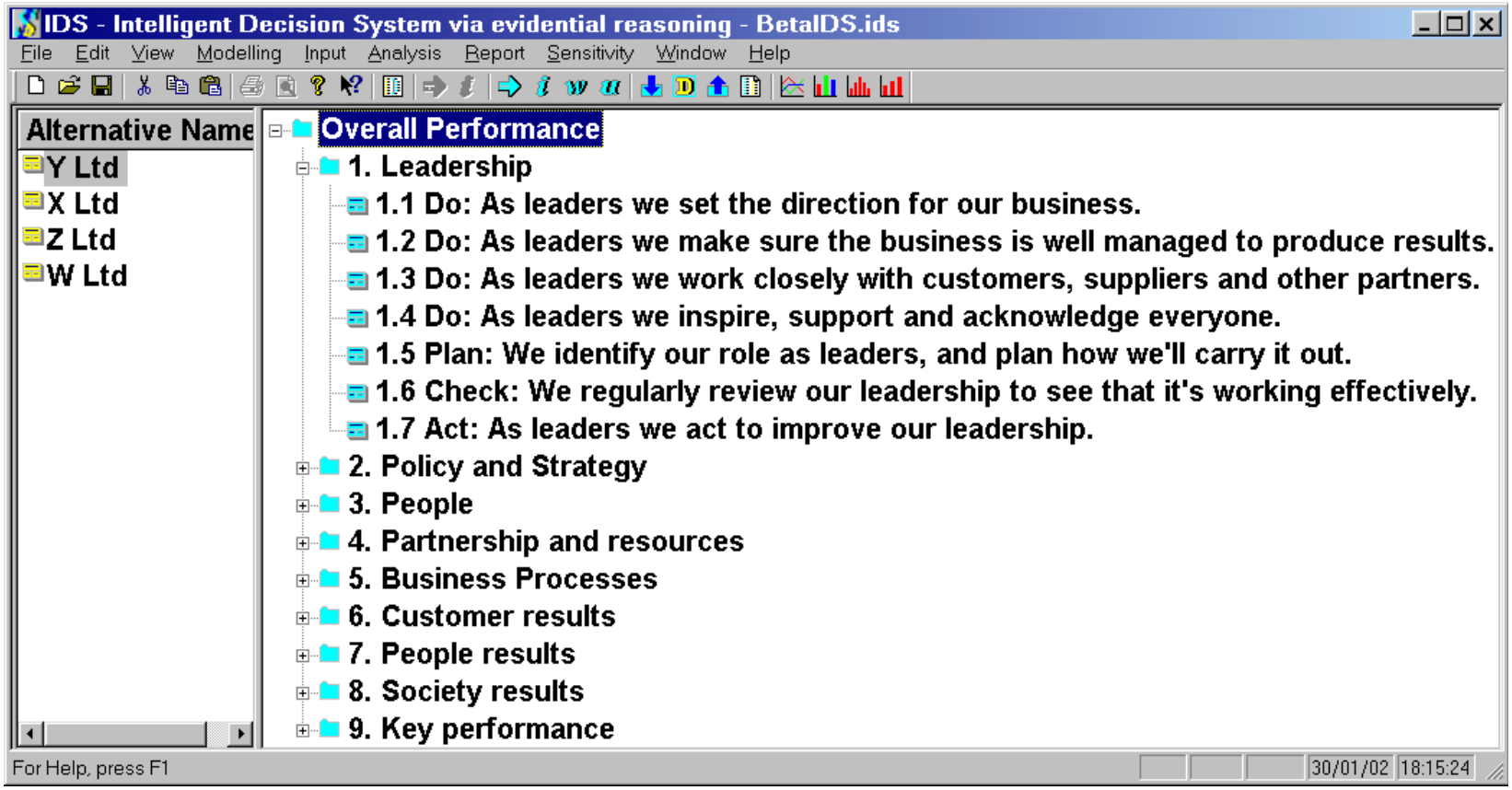
Example 4: Organisational quality self-assessment



M. Li and **J. B. Yang**, "A decision model for self-assessment of business process based on the EFQM excellence model", *International Journal of Quality and Reliability Management*, Vol.20, No.2&3, pp.163-187, 2003

MCDA Applications in Real World

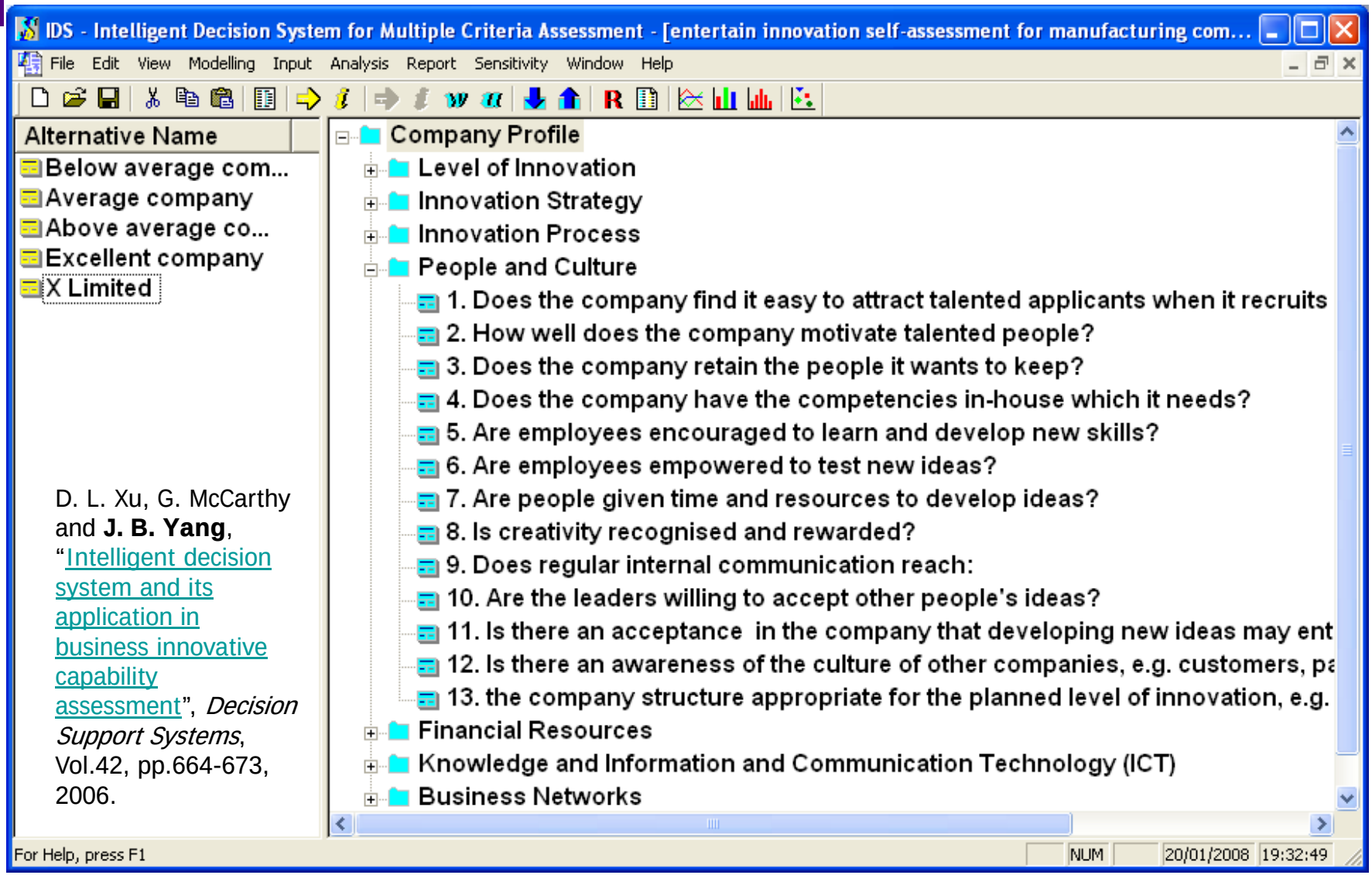
Example 5: Performance assessment for SME



D. L. Xu and **J. B. Yang**, "Intelligent decision system for self-assessment", *Journal of Multiple Criteria Decision Analysis*, Vol.12, 43-60, 2003.

MCDA Applications in Real World

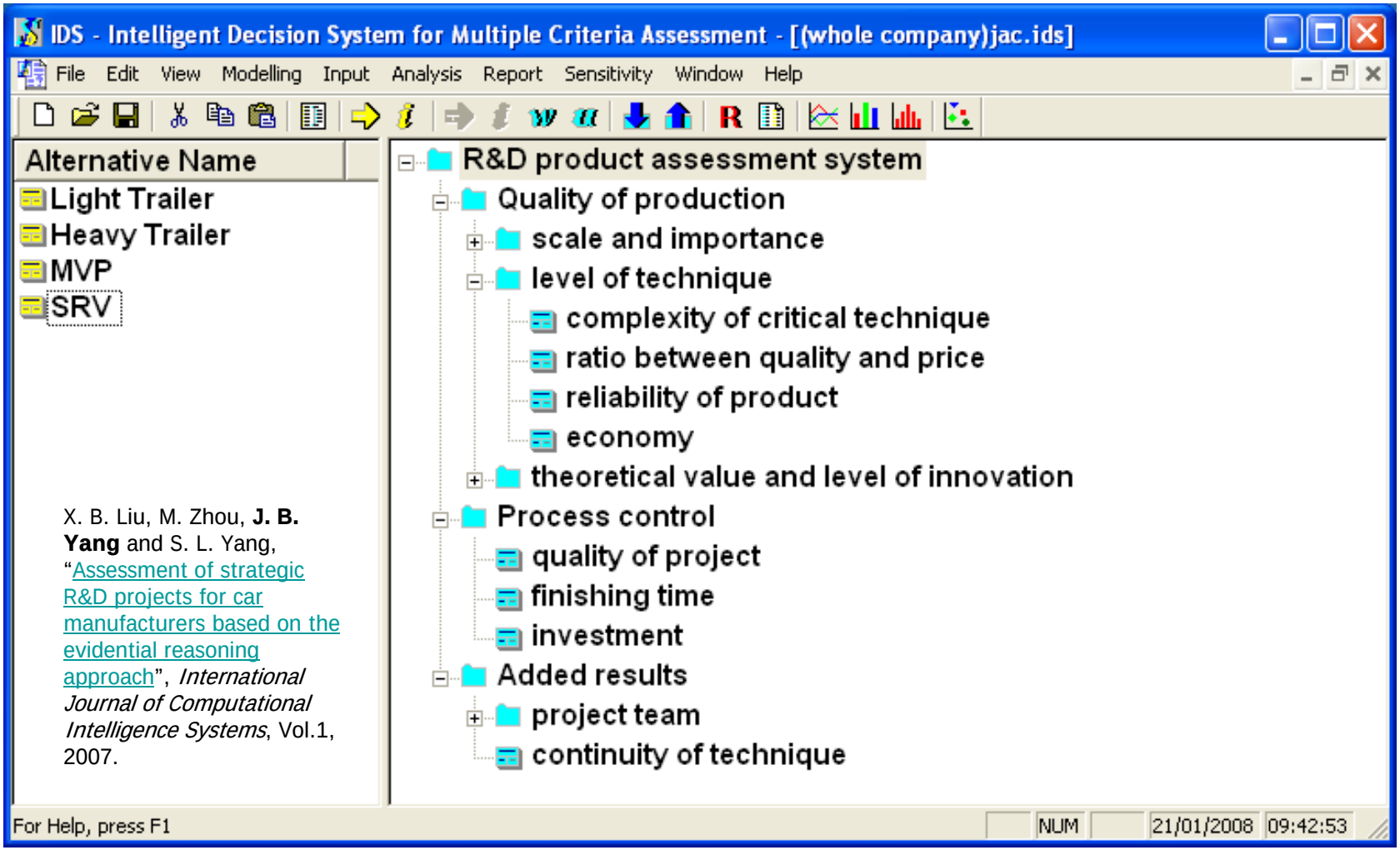
Example 6: Company innovation capability assessment



D. L. Xu, G. McCarthy and **J. B. Yang**, "Intelligent decision system and its application in business innovative capability assessment", *Decision Support Systems*, Vol.42, pp.664-673, 2006.

MCDA Applications in Real World

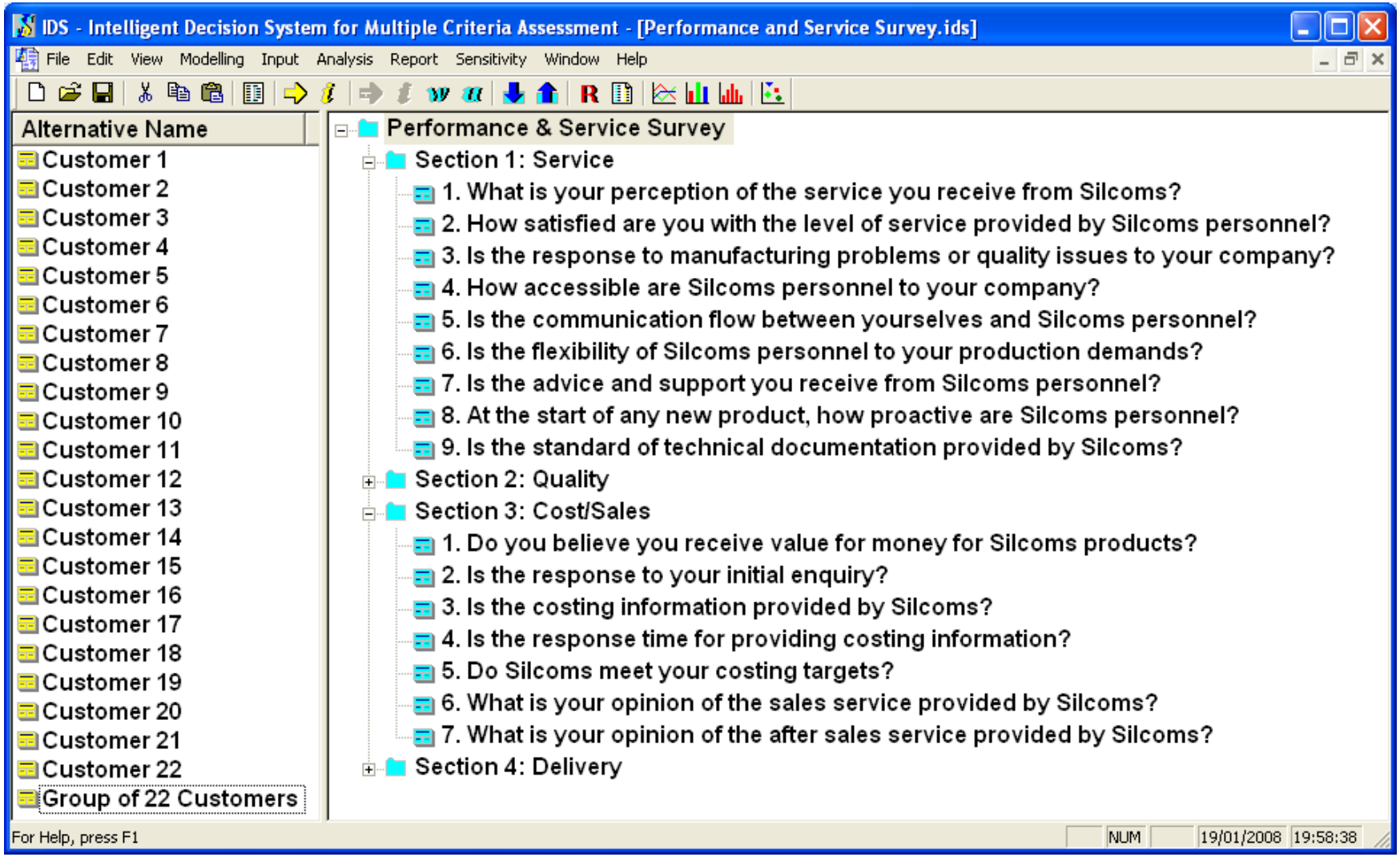
Example 7: R&D project performance assessment



X. B. Liu, M. Zhou, **J. B. Yang** and S. L. Yang, "Assessment of strategic R&D projects for car manufacturers based on the evidential reasoning approach", *International Journal of Computational Intelligence Systems*, Vol.1, 2007.

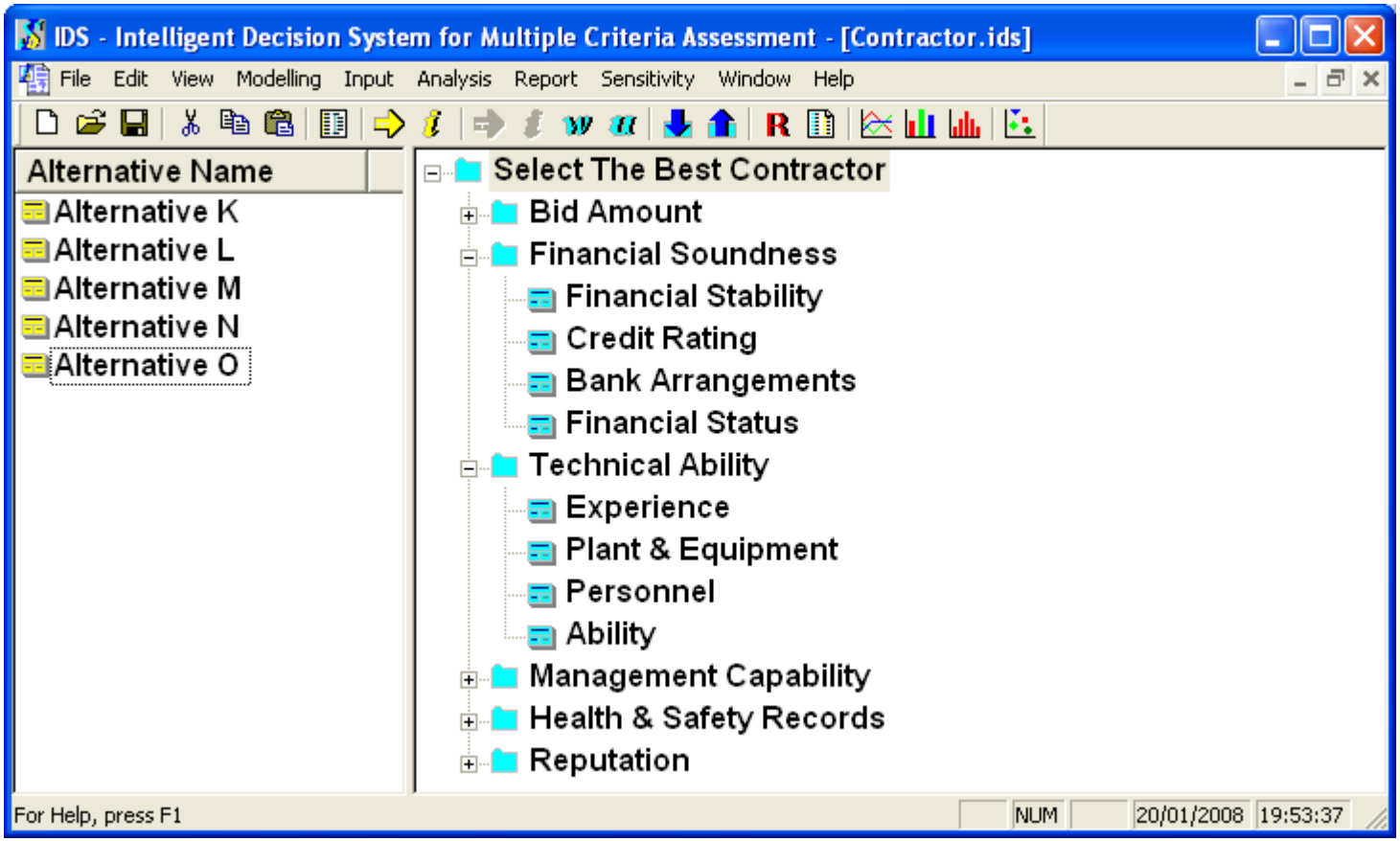
MCDA Applications in Real World

Example 8: Customer satisfaction survey & assessment



MCDA Applications in Real World

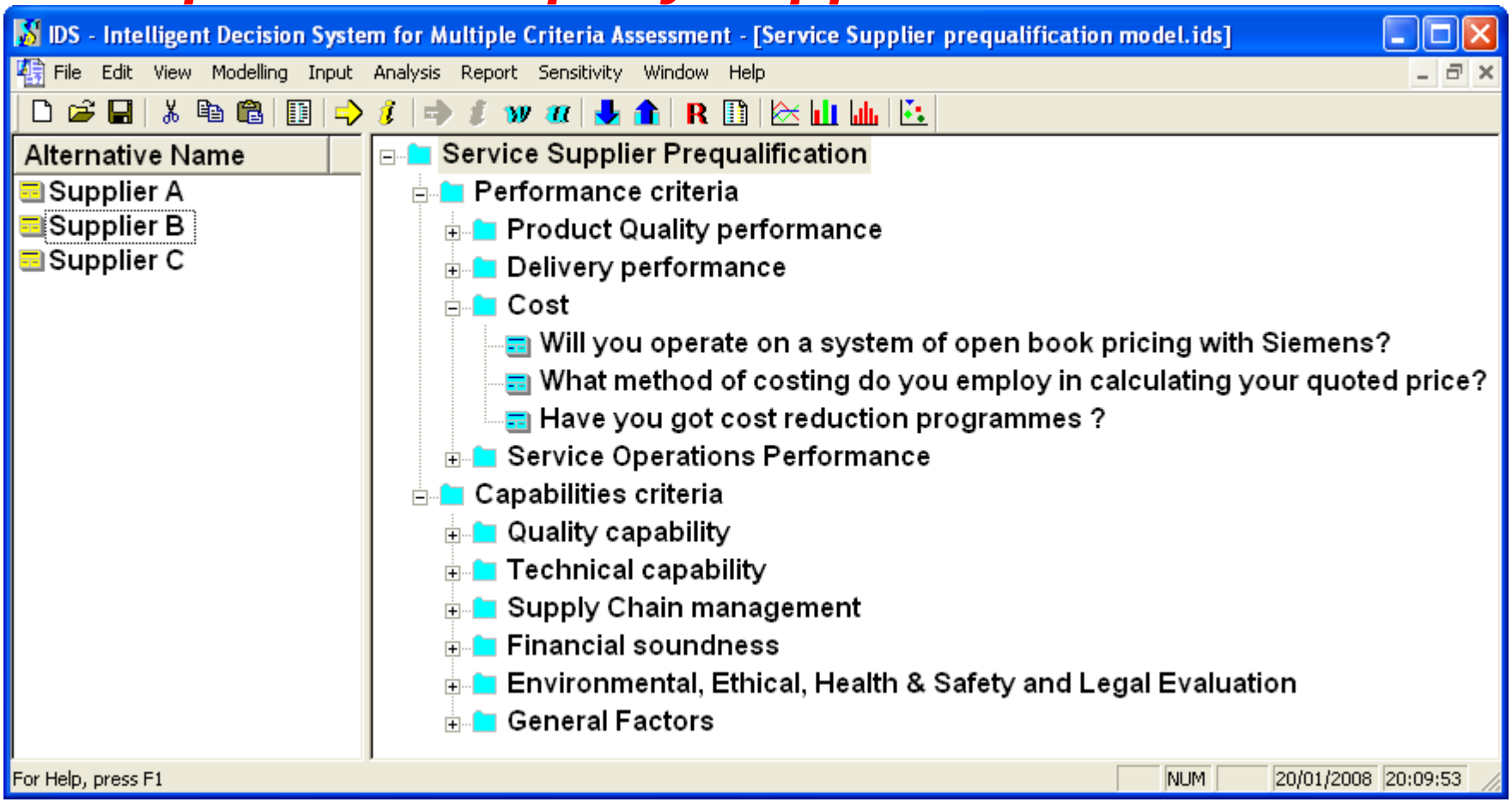
Example 9: Selection of construction contractors



M Sonmez, G. Graham and **J. B. Yang** and G D Holt, "Applying evidential reasoning to pre-qualifying construction contractors", *Journal of Management in Engineering*, Vol.18, No.3, pp.111-119, 2002.

MCDA Applications in Real World

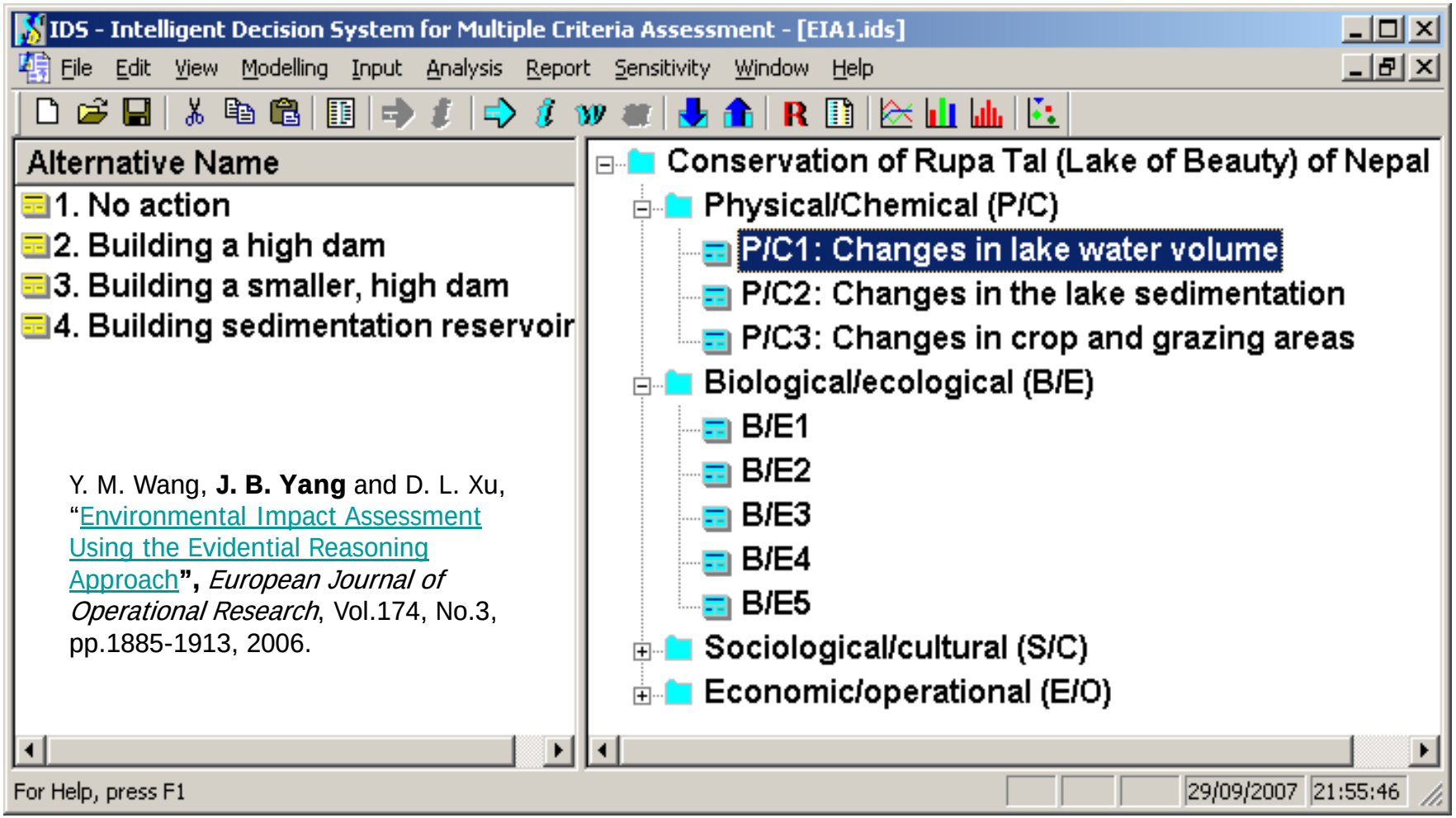
Example 10: Company supplier selection



Joanna Teng "Development of a supplier prequalification model for Siemens UK", *MSc Dissertation, Manchester School of Management, UMIST*, 2002

MCDA Applications in Real World

Example 11: Environmental impact assessment



Y. M. Wang, **J. B. Yang** and D. L. Xu, "Environmental Impact Assessment Using the Evidential Reasoning Approach", *European Journal of Operational Research*, Vol.174, No.3, pp.1885-1913, 2006.