Utility-Based Methods for Acquisition Decisions

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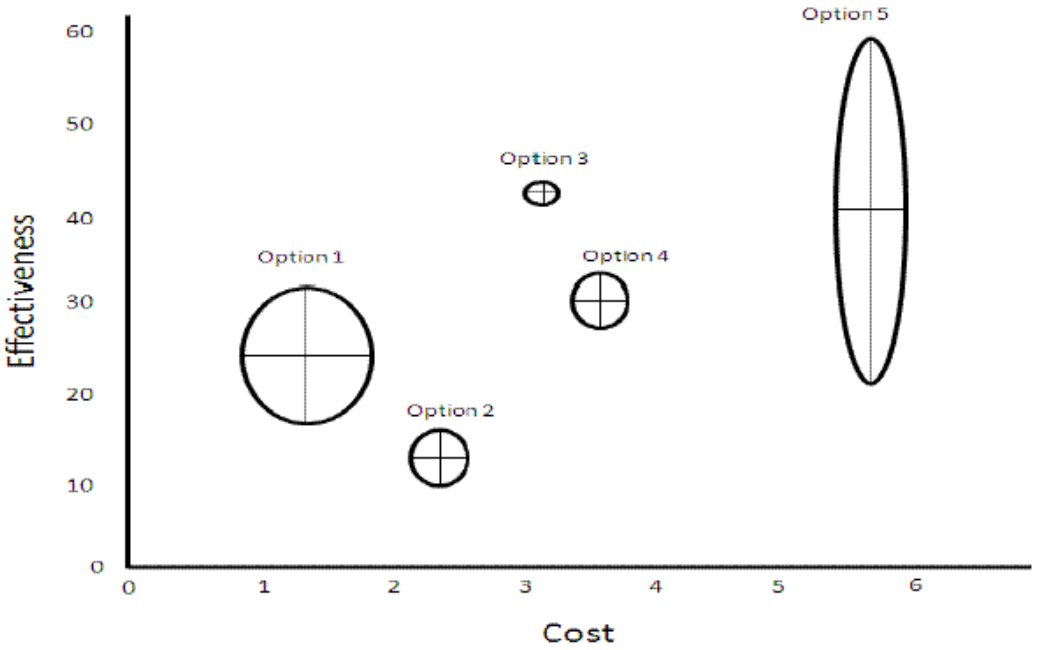
Background – Statutory Requirements for Public Contract Award

- Newham Ruling (High Court 2008):
  - *"The authority must state the award criteria … in the contract documents [and] cannot apply weightings or sub-criteria … which it has not previously brought to the tenderers' attention."*
- Defence and Security Public Contract Regulations (DSPCR 2011):
  - *"You must award the contract based on the most economically advantageous tender."*
  - *"You must disclose the evaluation criteria [and their] relative weightings [and] the [assessment] methods you will use."*
  - *"Recent case law has indicated a need for total transparency in respect of evaluation criteria."*

Background – Making the Case for Defence Acquisitions

- *"Business case submissions must be supported by…*
  - *Need & Numbers Study ("N&N")*
  - *"Combined Operational Effectiveness and Investment Appraisal" (COEIA)"*

- N&N
  - Provides compelling case to "Do Something"
  - Defines force levels for consideration by COEIA



- COEIA
  - Verifies existence of affordable solution with viable level of capability
  - Identifies most cost-effective solutions(s)

Source: Joint Service Publication JSP 507

Background – Need for Change

- Issues with current MOD guidance:
  - How to trade off operational effectiveness with other benefit/risk criteria (environmental impact, safety of operation, delivery timescale, etc.).
  - How to trade off effectiveness/benefit/risk with cost.
  - How to generate tradeoff criteria which can be published before the options are identified.
- Need approach to these issues which is:
  - Open to scrutiny at every stage
  - Communicable (practitioners' guide)
  - Acceptable to HMG, MoD and suppliers

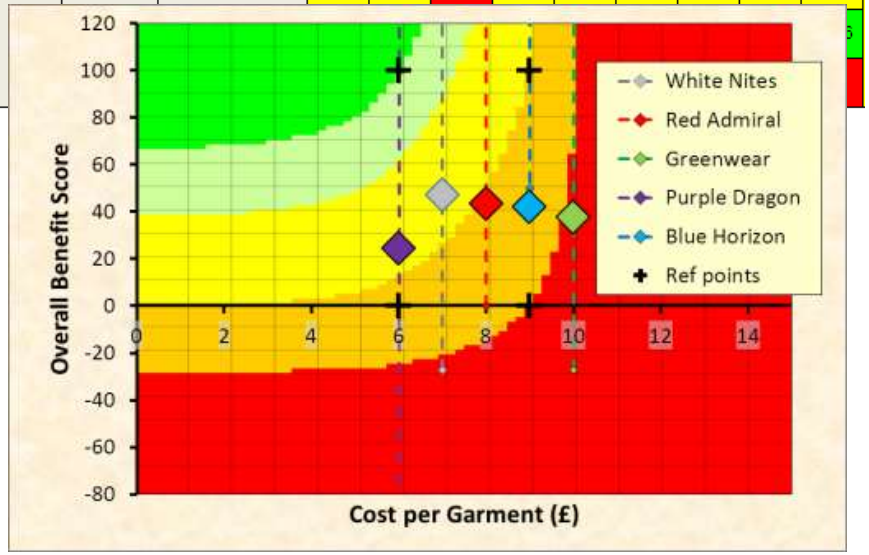
Background – the COEIA Transparency Pilot Study

- QinetiQ tasked by Dstl PCS to investigate three “textbook” approaches:
  - Multiple-Criteria Decision Analysis (MCDA)
  - Indifference Curves
  - Multivariate Utility
- Proposed solutions tested against an actual COEIA
  - In this presentation, a hypothetical example is substituted

Proposed Solution - Overview

- Identify problem and solution space - what sort of option could represent a possible solution?
- Identify cost metric(s) and benefit criteria
- Develop metric (quantitative or qualitative) for each benefit criterion
- Develop a utility function for each metric
- Assign an overall benefit score to each possible combination of criterion benefit scores
- Assign a cost-benefit score to each possible combination of cost and overall benefit
- Publish the resulting decision criteria as:
  a) A specification of the aggregate benefit calculation
  b) A 2-D “heat map” visualisation of the indifference curves for cost-benefit tradeoffs

Level 1 Sub-Criteria:	Level 2 Sub-Criteria:	Level 3 Sub-Criteria:	Option 1			Option 2			Option 3		
			White Nites			Red Admiral			Greenwear		
Benefits	Standard of product	Product quality	33.6	73.3	66.7	31.8	33.3	33.3	3.1	-2.4	-37.3
		Product range			100.0			50.0			131.6
	Standard of service	Capacity		20.5	131.6		59.5	100.0		20.4	50.0
		Reliability			20.0			148.0			-12.5
		Ethical standards			-27.2			75.0			12.5



Proposed Solution - Generic Example

- Problem:
  - Clara is the proprietor of a small independent clothing shop. Her nightwear supplier has unexpectedly gone into liquidation. She needs to choose a new supplier quickly, before her remaining stock is exhausted.
- Solution space:
  - Possible suppliers range from high-volume SE Asian manufacturers to small local companies.
  - Aim to sell at least 150 garments per week and to pay about £6 per garment.
  - Other priorities:
    - Product quality and range
    - Ethically sourced
    - Reliability and assurance of supply

Proposed Solution - Decision Criterion Taxonomy

Objective:	Level 1 Sub-Criteria:	Level 2 Sub-Criteria:	Level 3 Sub-Criteria:
Cost-Benefit	Cost	Cost per garment	Cost per garment
	Benefits	Standard of product	Product quality
			Product range
		Standard of service	Capacity
			Reliability
			Ethical standards
			Supplier risk
			Lead time

Proposed Solution - Decision Criterion Metrics

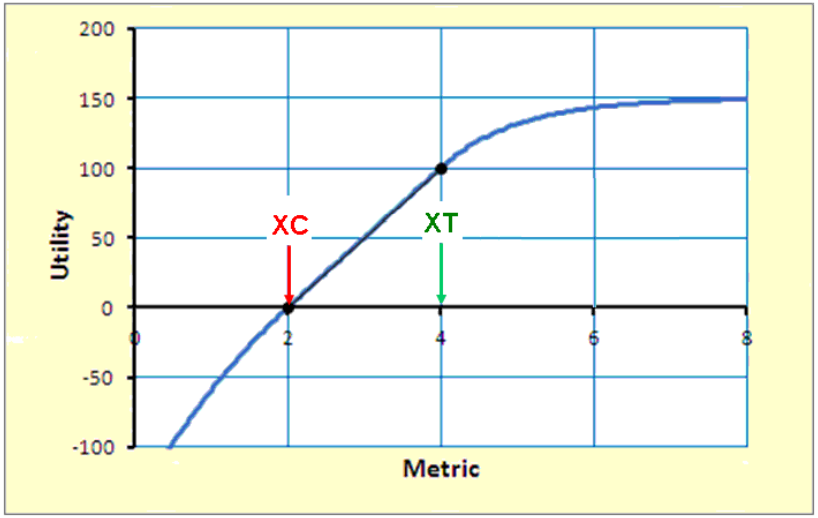
Decision Criterion	Metric	Critical Value (XC)	Target Value (XT)
Cost	£/Garment	9	6
Capacity	Garments/wk	150	400
Reliability	% of timely deliveries	90%	98%
Product Quality	0-5	2 (Poor)	4 (Good)
Product Range	0-5	2 (Poor)	4 (Good)
Ethical Standards	0-5	2 (Poor)	4 (Good)
Supplier Risk	0-5	2 (Poor)	4 (Good)
Lead Time	Weeks	5	1

Qualitative Scoring (0-5)

Description	Score
Unacceptable	0
Very Poor	1
Poor	2
Moderate	3
Good	4
Excellent	5

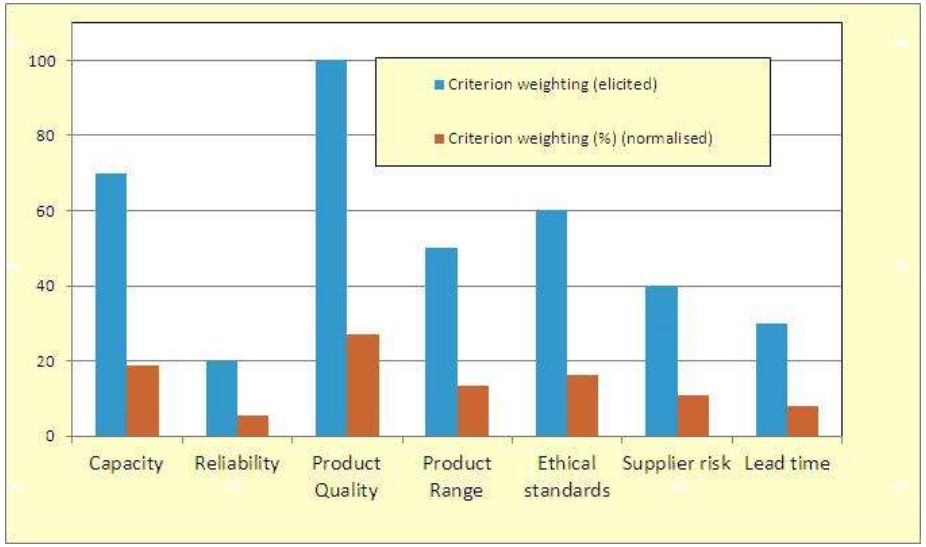
Proposed Solution - Utility

- Utility is an **interval scale** of **strength of preference**
- For any metric, u[x] is a utility function for x if, whenever the outcome x= c is preferred to x = b, and x = b is preferred to x = a:
  a) u[a] < u[b] < u[c]
  b) The amount by which stakeholders prefer c to a, compared to the amount by which they prefer b to a, is expressed by the ratio (u[c] – u[a])/(u[b] – u[a])
- The critical value "XC" always scores 0
- The target value "XT" always scores 100



Proposed Solution - Calculating Overall Benefit by MCDA

- Multiple-Criteria Decision Analysis:
  - Criteria assigned weighting according to:
    - Perceived importance of criterion to decision.
    - Significance of a “swing” from XC to XT for that criterion (“Swing Weighting”)
  - Weightings normalised so that they sum to 1
  - Criterion scores expressed as normalised metrics or utilities
  - Overall benefit = weighted sum of criterion scores
    - Criterion scores may be normalised metrics or utilities



Proposed Solution – Impact and Criticality

- Definitions
  - The **critical option** is the hypothetical option with $x_j = XC_j$ for all j
  - The **target option** is the hypothetical option with $x_j = XT_j$ for all j …
  - The **impact** of criterion j, M_j, is the gain from the critical option when we improve the outcome against criterion j (only) from XC to XT, given that the gain from improving **every** criterion would be 100
  - The **criticality** of criterion j, C_j, is the loss from the target option when we reduce the outcome against criterion j (only) from XT to XC, given that the loss from reducing **every** criterion would be 100
- We can generate a joint utility function **either** by eliciting the impact of every criterion **or** by eliciting the criticality of every criterion.

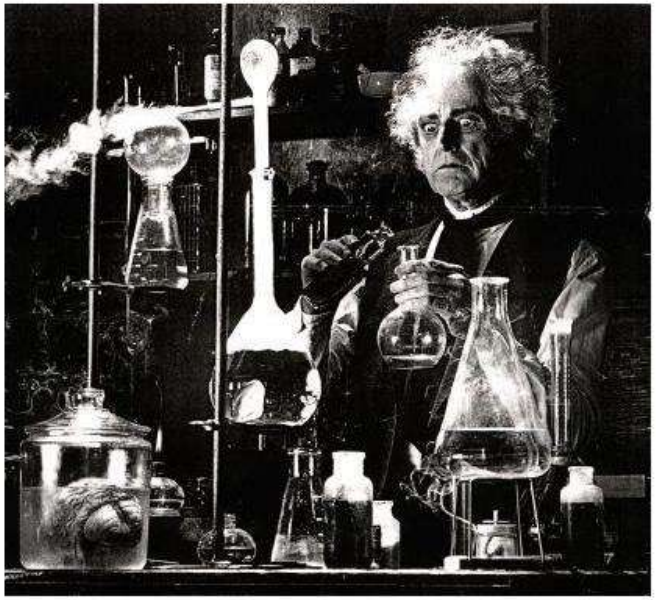
Proposed Solution - Joint Utility Formulas

- If **impacts** (Mj) have been elicited:

  $UJ[\underline{x}] = (100/k)*(\pi\{1+k* M_j*u[x_j]/10000\}-1)$,

  where k is the unique non-zero solution to the equation

  $1+k = \pi\{1+k* M_j/100\}$.



- If **criticalities** (Cj) have been elicited:

  $UJ[\underline{x}] = (100/h)*(1+h-(\pi\{1+h*(1-C_j/100)*(1-u[x_j]/100)\})$

  where h is the unique non-zero solution to the equation

  $1+h = \pi\{1+h* (1-C_j/100)\}$.

Proposed Solution - Cost-Benefit Tradeoff

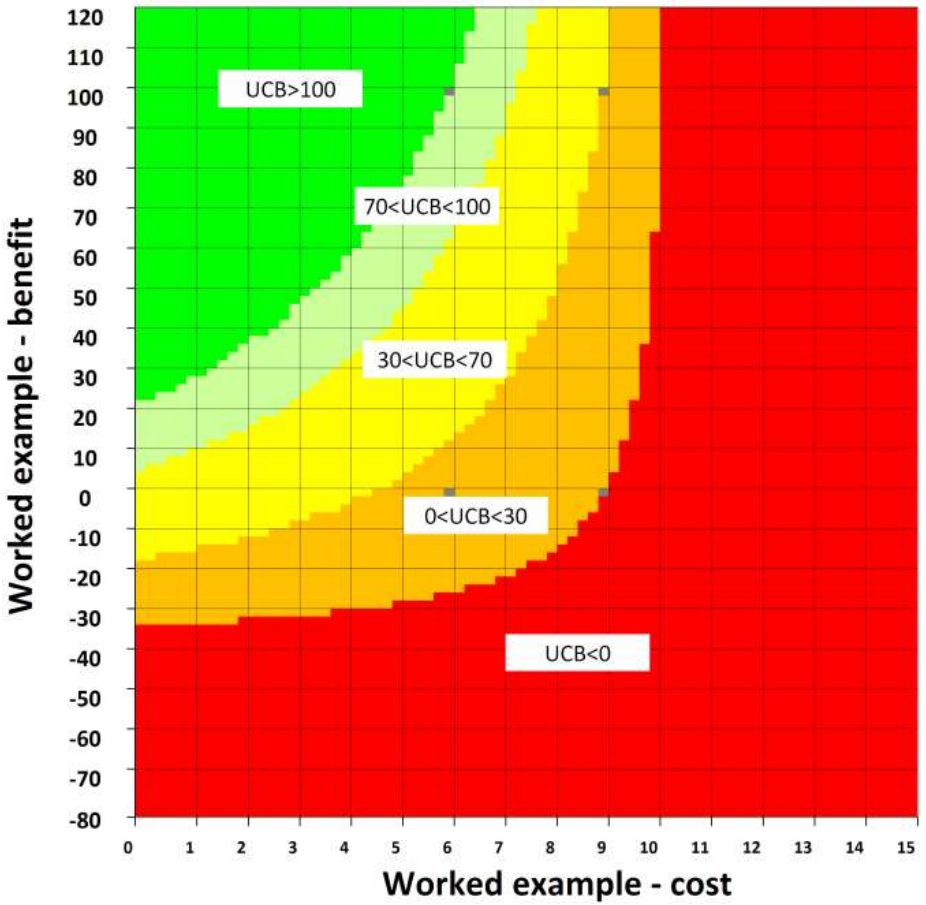
- Derive the cost utility function UC[c]
- Let UB[$\underline{x}$] be the joint utility of the benefit criterion score vector $\underline{x}$
- Then the joint utility of cost and overall benefit is of the form

$$UCB[c, \underline{x}] = \phi * UC[c] + \psi * UB[\underline{x}] + (\phi + \psi - 100) * UC[c] * UB[\underline{x}]/10000$$

- "Tuning" parameters ϕ and ψ are adjusted to capture stakeholder preferences for cost-benefit tradeoffs

Proposed Solution - Plotting the Cost-Benefit Tradeoff Curves

- Create 2D matrix of cost-benefit function
- Use conditional formatting to create “heat map”
- Boundaries between the coloured regions are “indifference curves”
  - these can be used to calibrate cost-benefit joint utility function (parameters ϕ and ψ)



Worked example - Options

Supplier	Description
White Nites	New UK firm with "hi-tech" production facilities
Red Admiral	International consortium with multinational supplier base. Supplies major supermarket chain. Secretive.
Greenwear	UK-based, founder 5 years ago. UK-based. Billed as eco-friendly.
Purple Dragon	SE-Asia based. High volume, large export business.
Blue Horizon	Long-established local firm. Recently downsized.

Worked example – MCDA Weights

Level 1 Sub-Criteria:	Level 2 Sub-Criteria:	Weighting	Level 3 Sub-Criteria:	Weighting
Benefits	Standard of product	100	Product quality	100
			Product range	50
	Standard of service	88	Capacity	100
			Reliability	33
			Ethical standards	100
			Supplier risk	67
			Lead time	33

Worked example - Criticalities

Level 1 Sub-Criteria:	Level 2 Sub-Criteria:	Criticality	Level 3 Sub-Criteria:	Criticality
Benefits	Standard of product	80	Product quality	80
			Product range	40
	Standard of service	70	Capacity	60
			Reliability	20
			Ethical standards	60
			Supplier risk	40
			Lead time	20

- **C_j is a measure of the relative importance of a criterion, though not a weighting in the MCDA sense**

Worked example – Option Scoring

				Option Index:	1	2	3	4	5
Low-Level Criterion	Metric	Units	Critical Value	Target Value	White Nites	Red Admiral	Greenwear	Purple Dragon	Blue Horizon
Cost per garment	Cost per garment	£	9	6	7	8	10	6	9
Product quality	0-5	n/a	2	4	4	3	5	5	3
Product range	0-5	n/a	2	4	5	4	3	2	3
Capacity	Garments/wk	n/a	150	400	200	800	120	10000	500
Reliability	% of timely deliveries	%	90	98	88	96	91	99	99
Ethical standards	0-5	n/a	2	4	4	2	5	0	3
Supplier risk	0-5	n/a	2	4	2	5	2	5	3
Lead time	Lead time	wk	5	1	3	3	6	4	1

Worked example – Benefit Scores (MCDA method)

Objective:	Level 1 Sub-Criteria:	Level 2 Sub-Criteria:	Option 1			Option 2			Option 3			Option 4			Option 5		
			White Nites			Red Admiral			Greenwear			Purple Dragon			Blue Horizon		
Benefits	Standard of product	Product quality	76.7	110.5	100.0	74.5	66.7	50.0	71.6	104.4	131.6	66.5	87.7	131.6	66.1	50.0	50.0
		Product range			131.6			100.0			50.0			0.0			50.0
	Standard of service	Capacity		38.3	20.0		83.3	148.0		34.3	-12.5		42.3	150.0		84.3	127.5
		Reliability			-27.2			75.0			12.5			111.1			111.1
		Ethical standards			100.0			0.0			131.6			-142.2			50.0
		Supplier risk			0.0			131.6			0.0			131.6			50.0
		Lead time			50.0			50.0			-27.2			25.0			100.0

- Overall score = SUMPRODUCT(Normalised weights, Utility scores)

Worked example - Overall Benefit (Joint Utility Method)

Objective:	Level 1 Sub-Criteria:	Level 2 Sub-Criteria:	Option 1			Option 2			Option 3			Option 4			Option 5		
			White Nites			Red Admiral			Greenwear			Purple Dragon			Blue Horizon		
Benefits	Standard of product	Product quality	47.0	112.6	100.0	43.5	60.0	50.0	37.7	102.1	131.6	24.3	79.0	131.6	41.9	45.0	50.0
		Product range			131.6			100.0			50.0			0.0			50.0
	Standard of service	Capacity		17.4	20.0		51.0	148.0		10.0	-12.5		1.0	150.0		66.8	127.5
		Reliability			-27.2			75.0			12.5			111.1			111.1
		Ethical standards			100.0			0.0			131.6			-142.2			50.0
		Supplier risk			0.0			131.6			0.0			131.6			50.0
		Lead time			50.0			50.0			-27.2			25.0			100.0

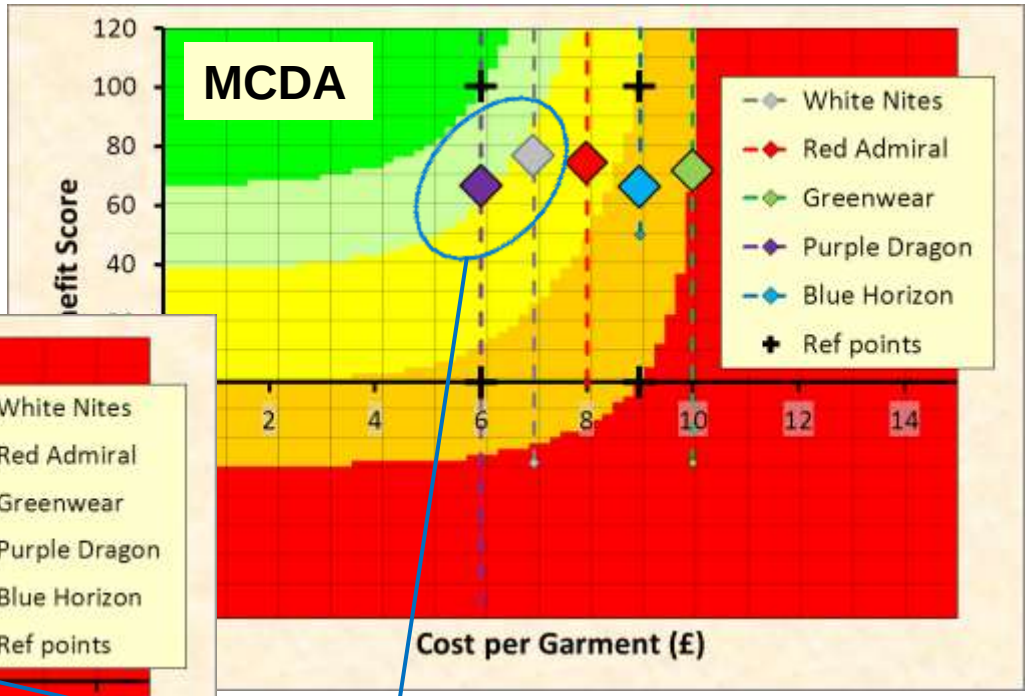
- C_j is a measure of the relative importance of a criterion, though not a weighting in the MCDA sense

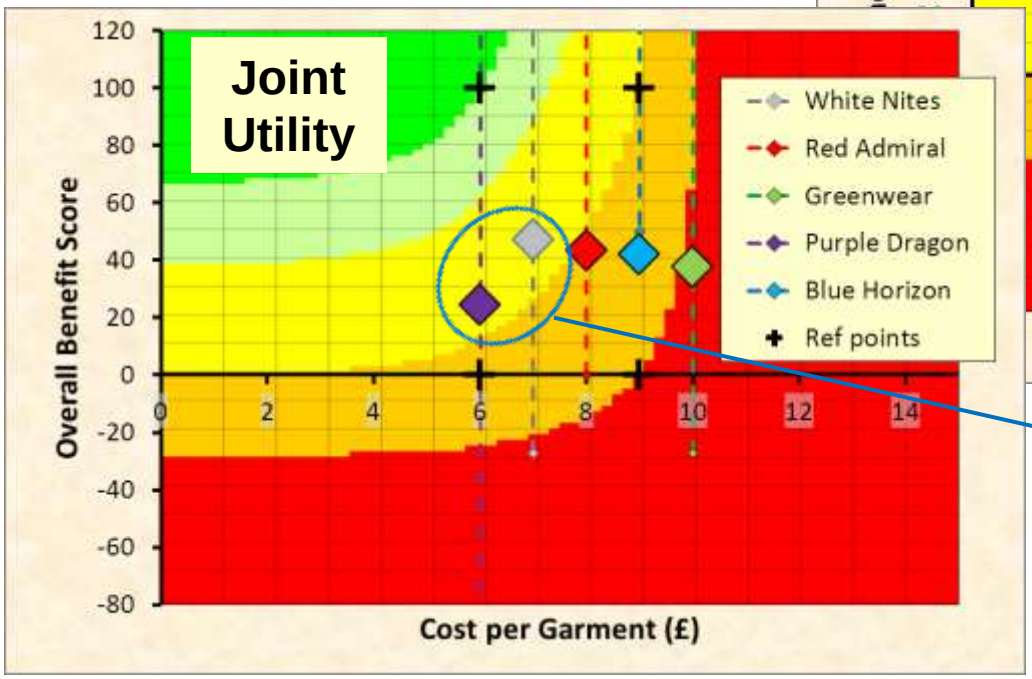
Worked example – Benefit scoring: MCDA v Joint Utility

- Joint utility scores lower and more varied than MCDA scores
- Joint utility more sensitive to major or multiple shortfalls (Greenwear, Purple Dragon)
  - This is due to multiplicative terms in the joint utility formula

Worked example - Cost-benefit outcomes: MCDA v Joint Utility

- Cost-benefit contours are “near-rectilinear”
  - penalise both “cheap-and-cheerful” and “good-but-pricey” outcomes
- Main difference is in valuation of Purple Dragon



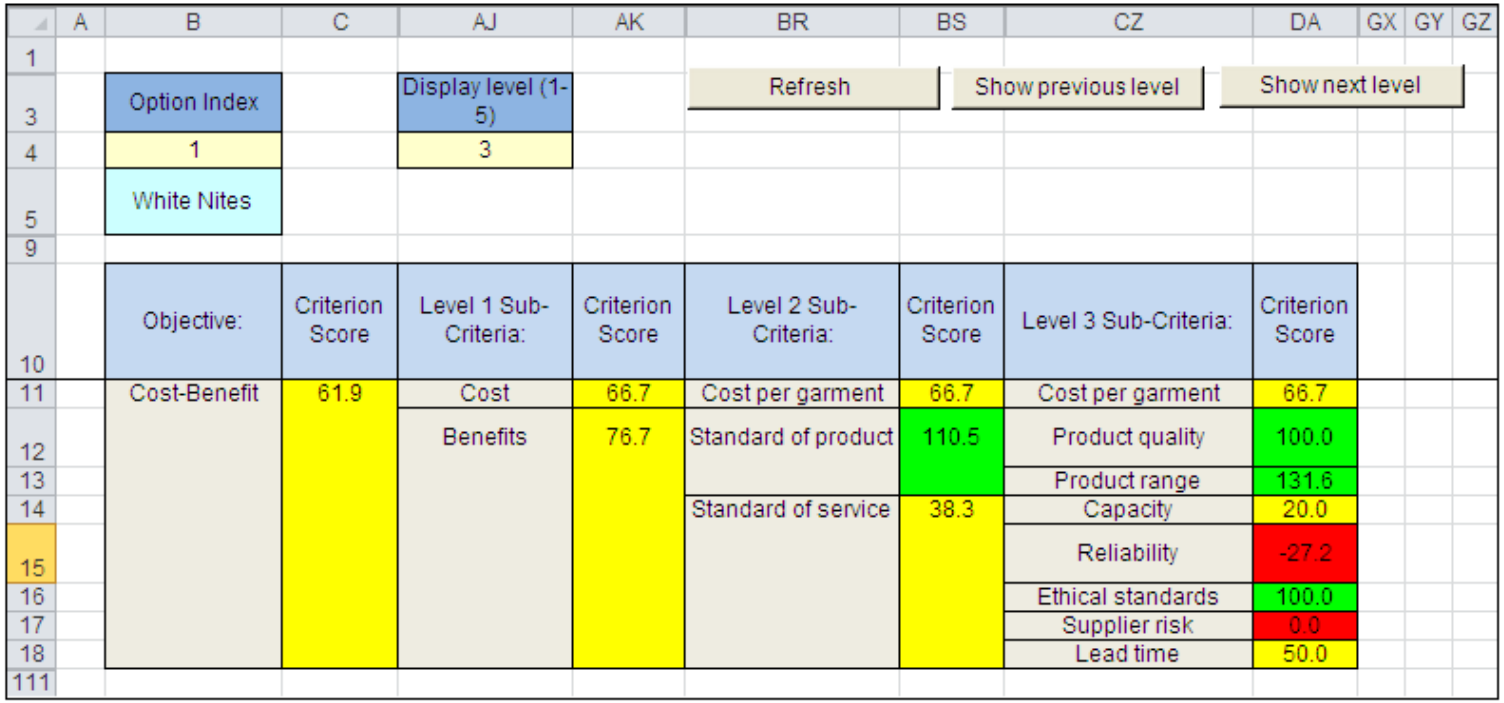


Efficient Set

Dotted lines indicate range of scores against the individual benefit criteria

Reference points are (£6 [target cost], 0); (£9 [critical cost], 0); (£6, 100); and (£9, 100)

Implementation



	A	B	C	AJ	AK	BR	BS	CZ	DA	GX	GY	GZ
1												
3		Option Index		Display level (1-5)		Refresh		Show previous level	Show next level			
4		1		3								
5		White Nites										
9												
10		Objective:	Criterion Score	Level 1 Sub-Criteria:	Criterion Score	Level 2 Sub-Criteria:	Criterion Score	Level 3 Sub-Criteria:	Criterion Score			
11		Cost-Benefit	61.9	Cost	66.7	Cost per garment	66.7	Cost per garment	66.7			
12				Benefits	76.7	Standard of product	110.5	Product quality	100.0			
13								Product range	131.6			
14						Standard of service	38.3	Capacity	20.0			
15								Reliability	-27.2			
16								Ethical standards	100.0			
17								Supplier risk	0.0			
18								Lead time	50.0			
111												

- Prototype implementation has been developed by QinetiQ as Private Venture
- Excel-based solution supports both MCDA and Joint Utility methods
- Currently up to 100 criteria & 20 options

MCDA versus Joint Utility – Which to choose?

- MCDA is a (restrictive) special case of joint utility:
  - So joint utility is either as good as or better than MCDA in capturing actual stakeholder preferences
- In MCDA, only one criterion can be “all-important”;
  - With joint utility, any number of criteria can be “all-important” (in that a score of 0 against that attribute implies a score of 0 overall)
- MCDA cannot discriminate between consistent and inconsistent outcomes:
  - Joint utility can discriminate either in favour of inconsistent outcomes (“boldness”) or against them (“conservatism”), according to the elicited reference utilities
- MCDA is simple to understand and gives an unambiguous weighting to each decision criterion
- MCDA is recommended in the Green Book and (implicitly) in DSPCR 2011

Summary & Conclusions

- The joint utility formulation provides a means of evaluating tradeoffs across multiple decision criteria without being forced into the straitjacket of MCDA
- The workload to generate a joint utility function is similar to that required for MCDA
  - Most activities are common to both methods

- Joint utility may be perceived a “black box” - too complex to satisfy the transparency requirement
- The “heat map” is a very effective way of identifying and communicating cost-benefit tradeoffs preferences

Questions?