Capturing the Impact of Critical Criteria in MCDA

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Royal Holloway, 18 July 2018

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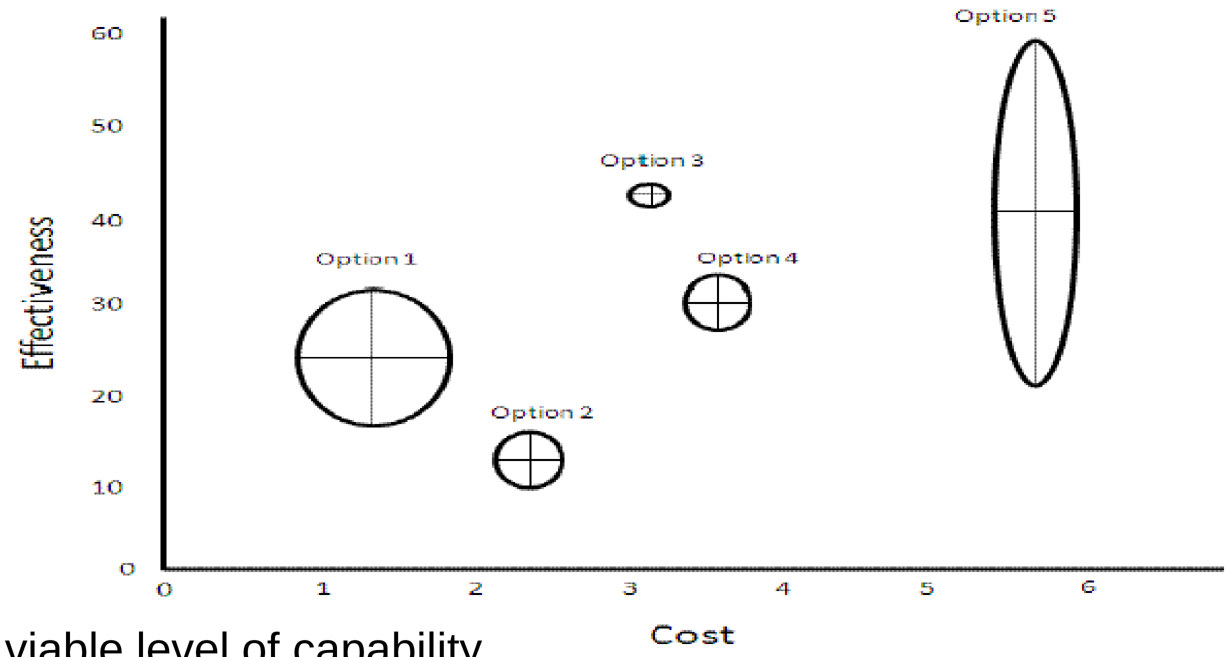
Background – Making the Case for Defence Acquisitions

- "*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

Solution - Overview

1. Identify problem and solution space - what sort of option could represent a possible solution?
2. Identify cost metric(s) and benefit criteria
3. Develop metric (quantitative or qualitative) for each benefit criterion
4. Assign a standard scoring function to each metric
5. Define an objective function which assigns an overall score to each possible combination of criterion scores

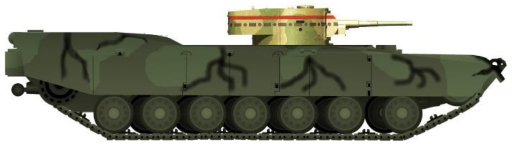
Solution - Decision Criterion Taxonomy

- The criteria for complex decisions are normally structured as a **hierarchy**
  - Breaks problem up into decision areas, within which the criteria are related
  - Within each area, only need to compare criteria within that area
  - Allows assessments to be conducted independently by domain experts
  - Trade-offs between high-level criteria to be decided by policy-makers

Objective:	Level 1 Criteria:	Level 2 Sub-Criteria:	Level 3 Sub-Criteria:
Cost-Benefit	Affordability	Acquisition Cost	
		Lifecycle Cost	
	Benefits and Risks	Operational Effectiveness	Scenario 01
			Scenario 02
			Scenario 03
			Scenario 04
			Scenario 05
		DLOD Impact	Training
			Equipment & Technology
			Personnel
			Information
			Doctrine & Concepts
			Organisation
			Infrastructure
			Logistics
		Risk	Technical Risk
			Supply Chain Risk
			Other Risks
		Compliance	Environmental Compliance
			Health & Safety
			Employment Law
			ITAR

Solution – Quantifying “Criticality”

Firepower = 100
Mobility = 100
Protection = 100
Overall = 100



Firepower = 0
Mobility = 100
Protection = 100
Overall = 10
Crit[Firepower] = 90

Firepower = 100
Mobility = 0
Protection = 100
Overall = 20
Crit[Mobility] = 80

Firepower = 100
Mobility = 100
Protection = 0
Overall = 40
Crit[Mobility] = 60

Firepower = 0
Mobility = 0
Protection = 0
Overall = 0

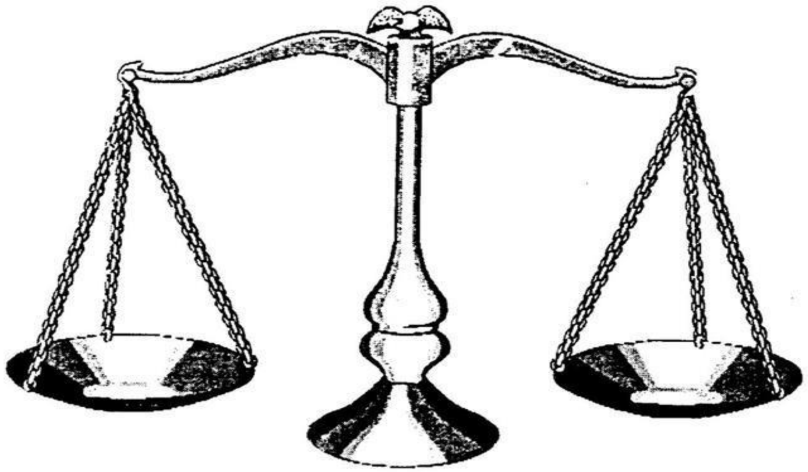
0 = Threshold score
100 = Objective score

Criticality of criterion j is the **reduction in overall score** when j is at threshold value and all other criteria are at objective value

0 is just a score; it does **not** mean “no capability”

NB: There is **no** combination of linear weightings for the three criteria that could even approximate these response properties

Solution – Criticality v Weighting



- Low criticalities imply ‘OR’ logic
  - Success against **any** criterion ensures a reasonable outcome overall
- High criticalities imply ‘AND’ logic
  - Failure against **any** criterion ensures a poor outcome overall
  - Conventional MCDA techniques cannot capture either logic
- The criticality of each criterion is independent of the criticalities assigned to competing criteria
  - In the real world, there is no constraint on the number of high-criticality criteria …
  - … but in conventional MCDA the number of criteria that exhibit criticality > C must be strictly less than 1/C (e.g. no more than 4 criteria can exhibit criticality >20%)

Solution – Parameterisation by Criticality

Question: if we are agreed on the criticalities that we want to assign to each of our criteria, is there an objective function which satisfies them?

Answer: Yes!

Solution – the Multiplicative Objective Function

U[X] = $$\frac{1+h - \prod_{j=1}^{n} \max[0,1+hC_j(1-X_j)]}{h}$$

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

1 + h = $\prod_{j=1}^{n} 1 + hC_j$

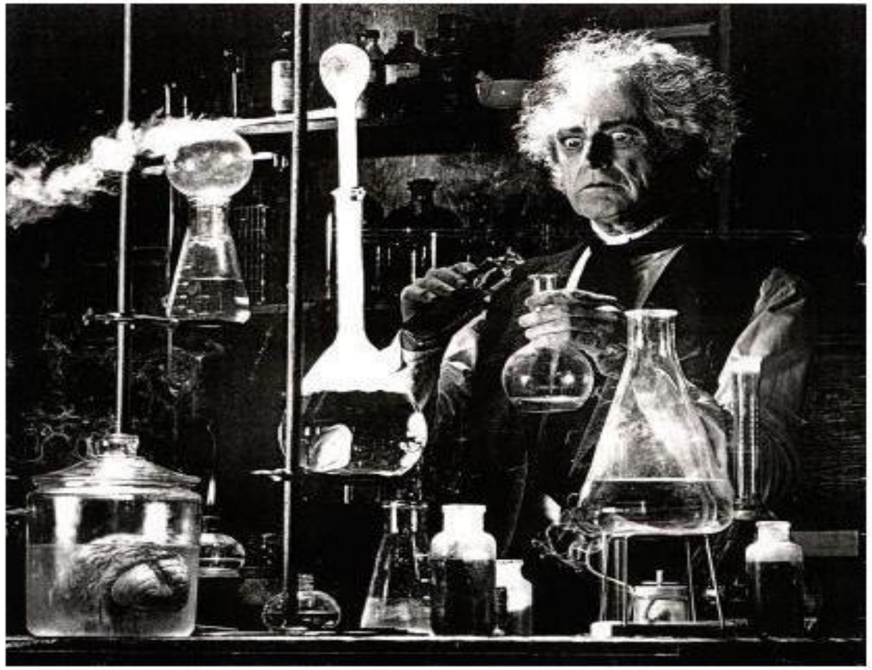
Check:

U[0, 0, …0] = $\frac{1+h - \prod_{j=1}^{n} 1+hC_j}{h}$ = 0

U[1, 1, …1] = $\frac{1+h-1}{h}$ = 1

U[1, 1, … 0…1] = $\frac{1+h-(1+hC_j)}{h}$ = 1- Cj

j'th criterion



X_j = 0 at threshold value
X_j = 1 at objective value

Solution - Worked 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

Solution - Decision Criterion Metrics

Decision Criterion	Metric	Threshold Value	Objective Value
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

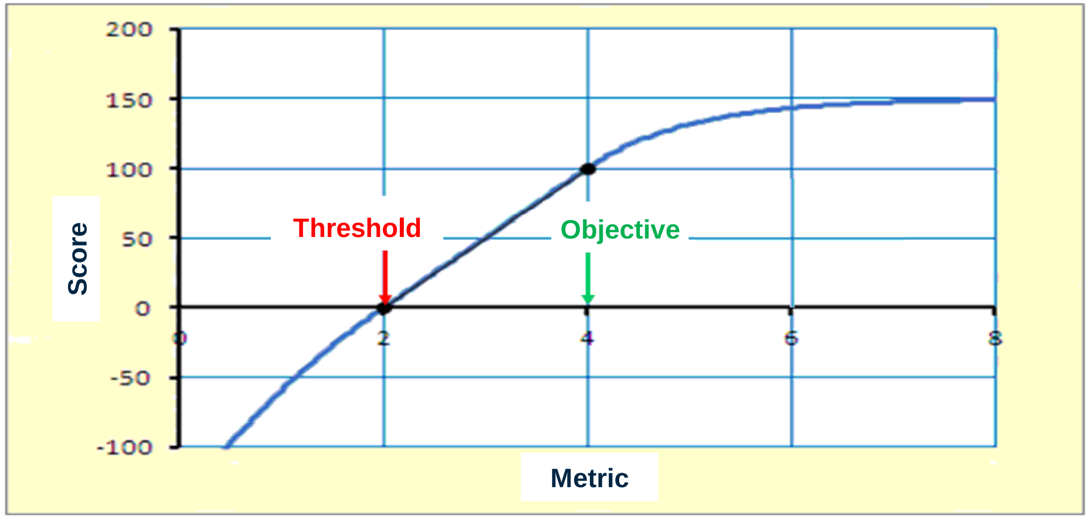
Qualitative Scoring (0-5)

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

Solution - Criterion Scoring

To ensure option independence, the scale against which each criterion is score must be fixed independently of the outcomes which are being assessed against it

1) Define a suitable real-world metric for each criterion
   – If necessary, split the criterion into two or more sub-criteria
2) Assign Threshold and Objective values to each metric
3) Assign a scoring rule such that the Threshold and Objective values score 0 and 1 (or 100) respectively
4) The score should be normally be bounded above
   – overachievement against one criteria will usually incur diminishing returns, and should not overwhelm serious shortfalls against other criteria
5) Add a tail which penalises options that fail to achieve the Threshold value.



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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 - Criticalities

Objective:	Level 1 Criteria:	Criticality	Level 2 Sub-Criteria:	Criticality	Level 3 Sub-Criteria:	Criticality	Level 4 Sub-Criteria:
Cost-Benefit	Affordability	70	Affordability		Cost per garment		Cost per garment
	Benefits	80	Standard of product	70	Product quality	70	Product quality
					Product range	30	Product range
			Standard of service	80	Capacity	60	Capacity
					Reliability	20	Reliability
					Ethical standards	80	Ethical standards
					Supplier risk	40	Supplier risk
					Lead time	20	Lead time

- 0 < Cj < 100 (converted to 0-1 scale for processing)

Worked example – Option Scoring

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

Worked example - Overall Benefit (original calculation)

Objective:	Level 1 Criteria:	Level 2 Sub-Criteria:	Level 3 Sub-Criteria:	Option 1				Option 2				Option 3				Option 4				Option 5			
				Purple Dragon				Red Admiral				White Nites				Greenwear				Blue Horizon			
Cost-Benefit	Affordability	Affordability	Cost per garment	32.2	100.0	100.0	100.0	20.2	33.3	33.3	33.3	37.7	66.7	66.7	66.7	-3.8	-37.3	-37.3	-37.3	12.4	0.0	0.0	0.0
	Benefits	Standard of product	Product quality		15.3	92.1	131.6		29.0	65.0	50.0		38.4	109.5	100.0		32.7	107.1	131.6		41.4	50.0	50.0
			Product range				0.0				100.0				131.6				50.0				50.0
		Standard of service	Capacity			-4.1	150.0			25.6	148.0			19.5	20.0			13.5	-12.5			57.2	127.5
			Reliability				111.1				75.0				-27.2				12.5				111.1
			Ethical				-142.2				0.0				100.0				131.6				50.0
			Supplier risk				131.6				131.6				0.0				0.0				50.0
			Lead time				25.0				50.0				50.0				-27.2				100.0

- In the original form of the method, the score at each level is calculated from the scores at the next level down, using the user-defined criticalities and converted to 1-100 scale ("chained" calculation)

Original Proposal – The snag

- Since 2013, we have discovered that the chained calculation can fail if we obtain a very poor outcome against a high-criticality criterion.
- This is because it allows a product term to become zero, which “freezes” the objective function
- This occurs when X_j reaches the criterion score bound CSB[j] = $(1 + hC_j)/hC_j$
- We term this behaviour “bottoming out”

$$U[\underline{X}] = \frac{1+h - \prod_{j=1}^{n} \max[0, 1+hC_j(1-X_j)]}{h}$$

If $h < 0$, $X_j < 0$ and C_j is large, the j’th project term can become 0

Original Proposal – Bottoming-out Example (1)

Option	Level 5 Sub-Criteria:	Metric	Units	Critical Value	Target Value	Bottoming-out Option A	Bottoming-out Option B
Affordability	Cost per garment	Cost per garment	£	9	6	6	5.9
Benefits	Product quality	0-5	n/a	2	4	4	4
	Product range	0-5	n/a	2	4	4	4
	Capacity	Garments/wk	n/a	150	400	400	150
	Reliability	% of timely deliveries	%	90	98	98	90
	Ethical standards	0-5	n/a	2	4	1	1
	Supplier risk	0-5	n/a	2	4	4	2
	Lead time	Lead time	wk	5	1	1	5

- Option A is greatly superior to Option B in Capacity, Reliability, Supplier Risk, and Lead Time, and marginally inferior to Option B only in Cost per Garment…
- … so of course it will be assigned a higher overall score?

Original Proposal – Bottoming-out Example (2)

Objective:	Level 1 Criteria:	Level 2 Sub-Criteria:	Level 3 Sub-Criteria:	Option 6 Bottoming-out Option A				Option 7 Bottoming-out Option B			
Cost-Benefit	Affordability	Affordability	Cost per garment	33.4	100.0	100.0	100.0	34.3	103.2	103.2	103.2
	Benefits	Standard of product	Product quality		16.7	100.0	100.0		16.7	100.0	100.0
			Product range				100.0				100.0
		Standard of service	Capacity			-4.1	100.0			-4.1	0.0
			Reliability				100.0				0.0
			Ethical				-59.3				-59.3
			Supplier risk				100.0				0.0
			Lead time				100.0				0.0

- Due to the bottoming out of the Standard of Service criterion, the higher-scoring contributors to that criterion are wiped out, so B prevails over A by virtue of its marginally lower cost

Preventing Bottoming-out

- To avoid bottoming-out, we must calculate the scores at each level directly from the bottom-level scores, rather than from the next level down
- Experimentation has resulted in a general solution, in which it is necessary to introduce a new set of internally-generated fitting parameters, termed q-values, to ensure that the response properties of the method at each level of the hierarchy are correct.
- The new formula requires no new inputs and is virtually immune to bottoming-out
- The new formula is complicated, (see next slide), but can easily be automated so that its complexity is invisible to the user

Objective:	Level 1 Criteria:	Level 2 Sub-Criteria:	Level 3 Sub-Criteria:	Option A				Option B			
				Objective score	Level 1 scores	Level 2 scores	Level 3 scores	Objective score	Level 1 scores	Level 2 scores	Level 3 scores
Cost-Benefit	Affordability	Affordability	Cost per garment	52.5	100.0	100.0	100.0	27.8	103.2	103.2	103.2
	Benefits	Standard of product	Product quality		57.8	100.0	100.0		28.9	100.0	100.0
			Product range				100.0				100.0
		Standard of service	Capacity			-4.1	100.0			-4.1	0.0
			Reliability				100.0				0.0
			Ethical standards				-59.3				-59.3
			Supplier risk				100.0				0.0
			Lead time				100.0				0.0

New method – The Generalised Multiplicative Objective Function

$$UJ_0[\underline{u}] = \frac{1+h - \prod_{n=1}^{NC} max\{0,(1+h\, q[n]\, CP[n]\, (1-u_n))\}}{h}$$

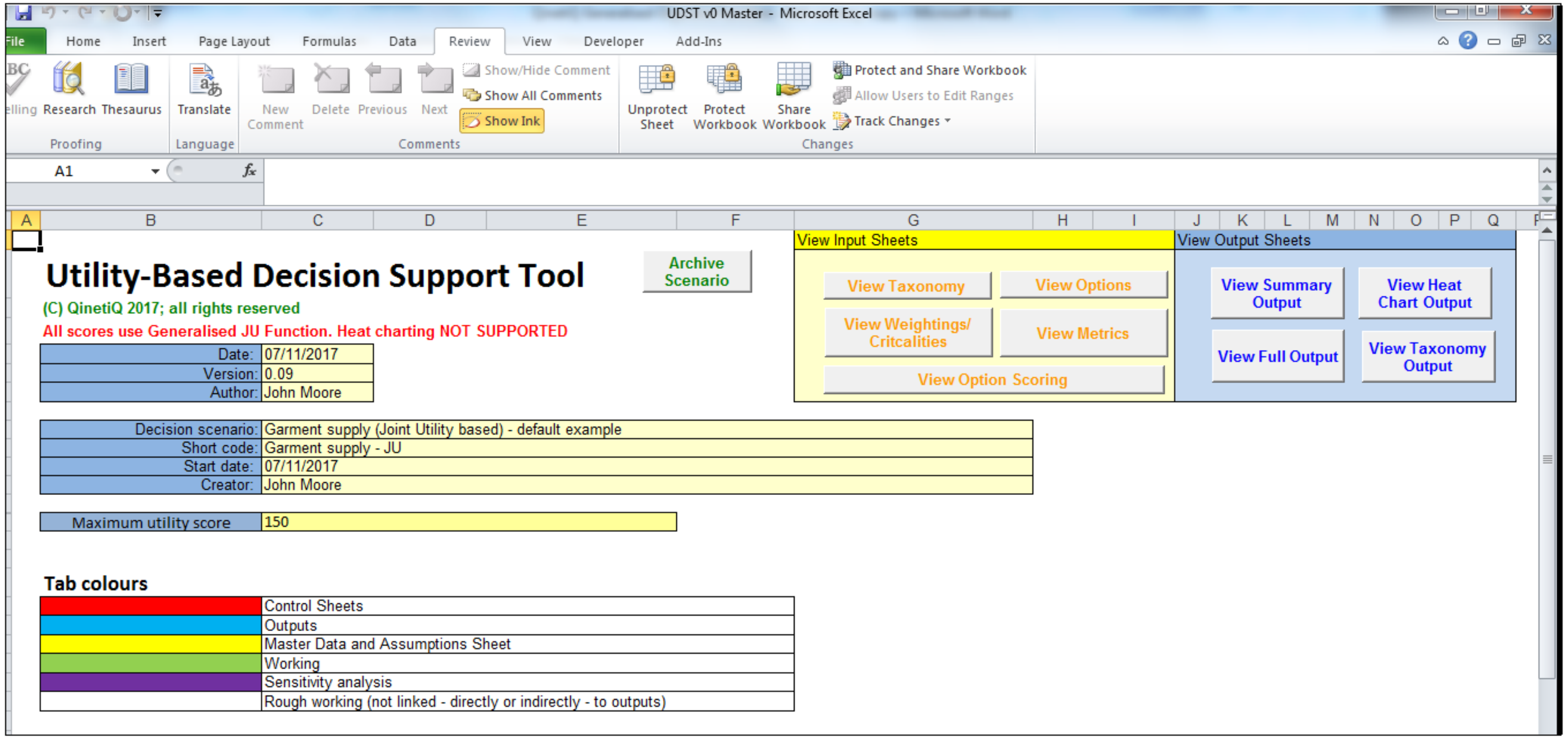
where

- *NC* = Number of low-level criteria
- *CP[n]* is the product of all criticalities to which low-level criterion *n* is subject
- *h* is the same as in the original formula, and
- the *q*-terms satisfy the condition that, for any Level 1 criterion *X*, (that is, the level immediately below the Overall Score), when all low-level criteria feeding into that Level 1 criterion score 0, and all other low-level criteria score 1, the Overall Score is 1 – C_X, where C_X is the criticality of *X* with respect to the Overall Score.

Like *h*, the *q*-terms can be calculated automatically by iteration

Implementation

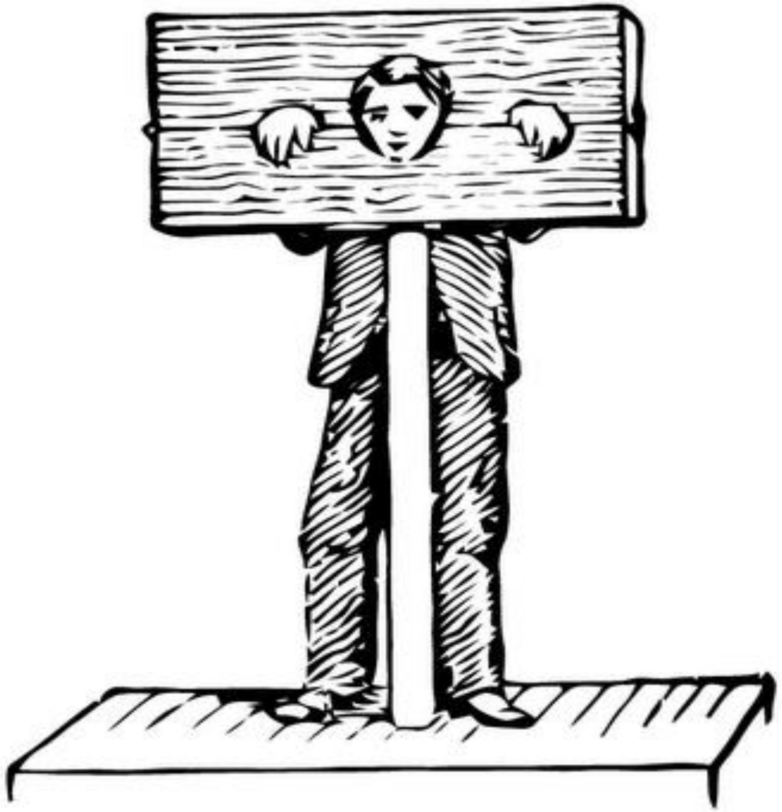
- QinetiQ has developed versions of a prototype tool using the original chained calculation and the new Generalised Multiplicative Objective Function throughout
- We will be happy to provide demonstrations on request.



Summary & Conclusions

- The multiplicative objective function provides a means of evaluating tradeoffs across multiple decision criteria without being forced into the straitjacket of MCDA
- The Generalised Multiplicative Objective Function is more robust against the risk of bottoming out, but is less transparent
- Both methods are more powerful and flexible than conventional MCDA, particularly when there are numerous highly critical parameters across which tradeoffs must be made

Questions?



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