Multi Criteria Decision Analysis: A Primer

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IMA Tutorial

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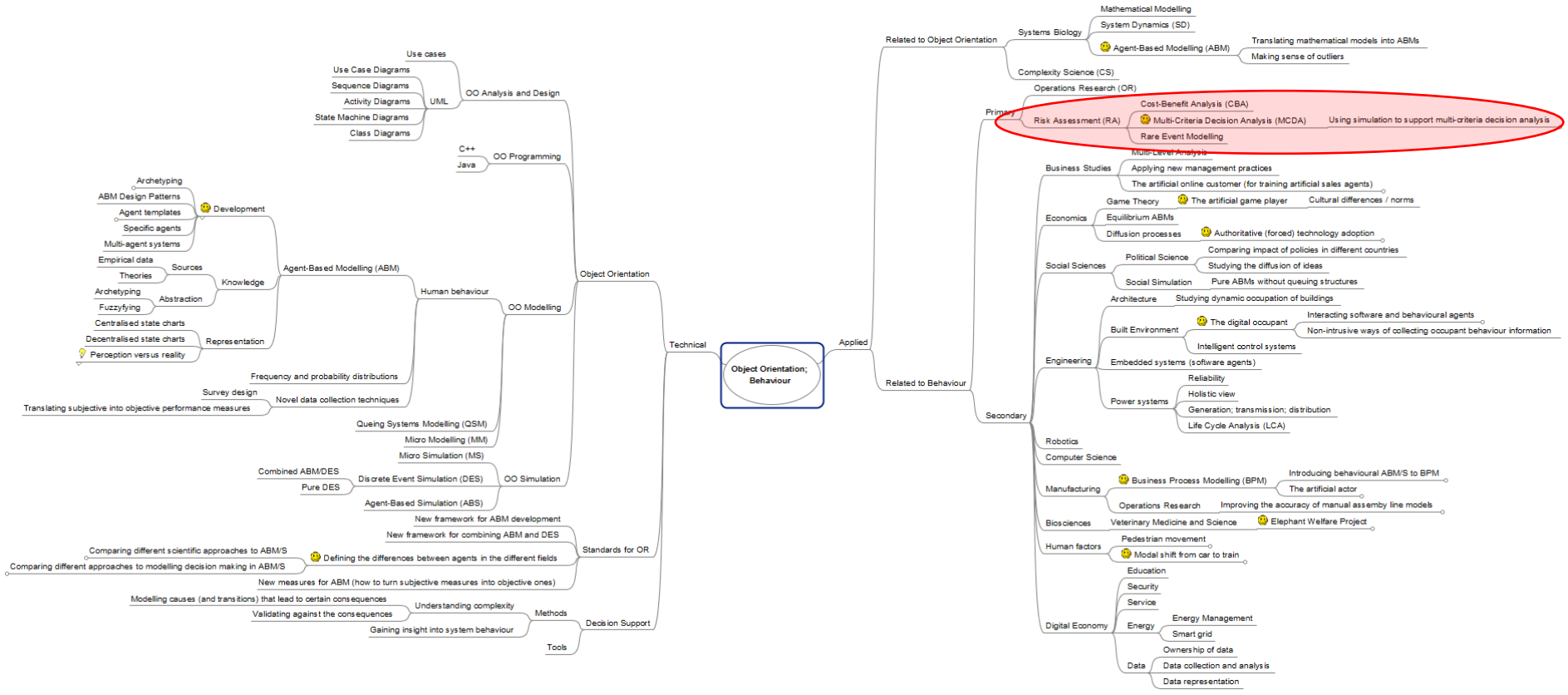
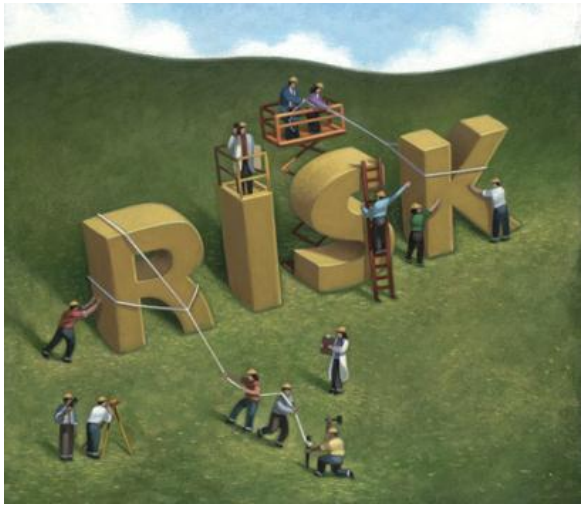
My academic interests



My academic interests

- Risk Assessment (RA)
  - Cost-Benefit Analysis (CBA)
  - Multi-Criteria Decision Analysis (MCDA)
    - Using MCDA together with Simulation
  - Rare Event Modelling



Introduction to
Multi-Criteria Decision Analysis (MCDA)

Introduction

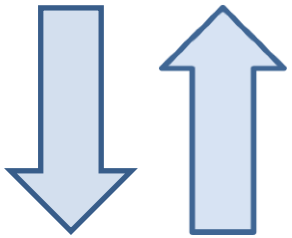
- This part of the presentation based on DCLG (2009)

What is MCDA

- Provides an overall **ordering** of options; from the most **preferred** to the least preferred one
- Options may differ in the extent to which they achieve objectives and no one option will be obviously best in achieving all objectives
- Looking at complex problems that are characterised by any mixture of **monetary** and **non-monetary** objectives
- An extension to **decision theory**; developed by Keeney and Raiffa (1976) to accommodate **multi attributed consequences**

Steps in a MCDA

1. Establish the decision context
2. Identify the options to be appraised
3. Identify objectives and criteria
4. Scoring. Assess the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion
5. Weighting. Assign weights for each of the criterion to reflect their relative importance to the decision
6. Combine the weights and scores for each option to derive an overall value (preference level of option)
7. Examine the results
8. Sensitivity analysis



1. Establish the decision context

- Establish aims of the MCDA and identify decision makers and other key players
  - A statement of initial aims is crucial
  - Decision makers (stakeholders): Anyone who has an investment (financial or otherwise) in the consequences of any decisions taken
  - Key player: Anyone who can make a useful and significant contribution

- Design the socio-technical system for conducting the MCDA
  - When and how will the stakeholders and key players contribute?
  - What form of MCDA is to be used?
    - Facilitated workshops most common

1. Establish the decision context

- Consider the context of the appraisal
  - Describing the **current situation** and then being clear about the **goals to be achieved** establishes the discrepancy between now and the vision for the future
    - SWOT analysis

MCDA Toaster Case Study

- The Jones

MCDA Toaster Case Study

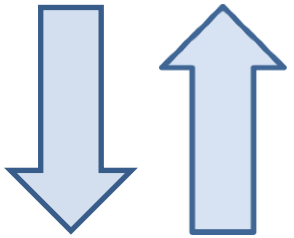
1. Establish the decision context
   - Initial aim of MCDA
     - To make the best use of the data available to inform the choice of a new toaster
   - Stakeholders and key players:
     - Members of family (Fred, Jane, Tom, Caroline)
     - Jane: Neighbour who recently purchased a toaster; Which? Magazine
     - Fred: Local store salesperson he trusts
   - Design the system (stakeholder contribution – when and how?)
     - Fred neglects this and visits his local store on the way home to buy the toaster recommended by his trusted shopkeeper. When he comes home with the new toaster his wife is not happy as some features are missing that she would have liked. He realises that it is important to consider the opinion of all stakeholders. The next day he returns the toaster.

MCDA Toaster Case Study

- Context (current situation; goals to be achieved)
  - Fred and his family give some thought to what they really want. The whole family of two adults and two children often eat breakfast together; perhaps they should consider two-slot four-slice toasters in addition to the two-slot two-slice models. On Sunday morning, Fred picks up fresh bagels for Sunday brunch, so an adjustable slot width might be handy. As the family discusses what they might like, Fred suddenly remembers seeing a toaster-oven in the home of an American friend on a recent visit to the United States. Perhaps they should consider that function too, for then the oven could also be used to cook single frozen meals, which would be handy for the occasions when someone comes home late and wants a hot meal.

2. Identify the options to be appraised

- A common error is to attempt to analyse just one option, under the assumption that there is no alternative. But there is always the alternative of continuing as at present
- Those conducting the MCDA should be open to the possibility of modifying or adding to the options as the analysis progresses



MCDA Toaster Case Study

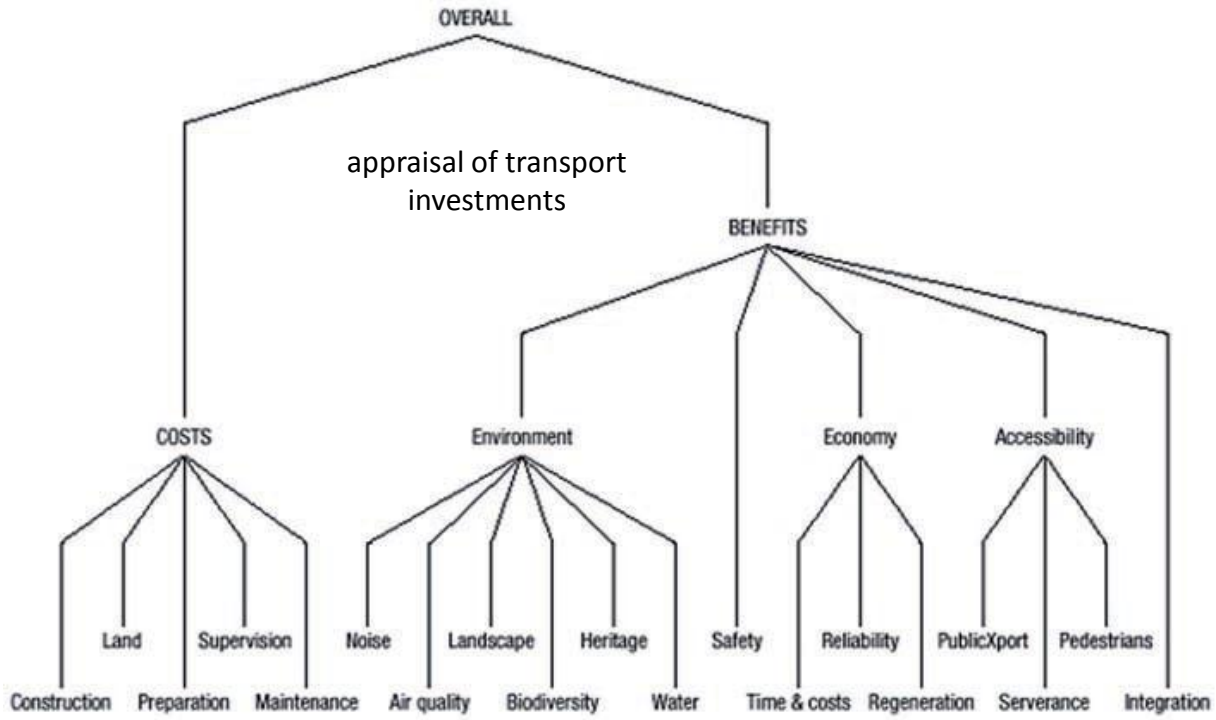
2. Identify the options to be appraised
   - Six recommended in the Which? guide
   - Toaster oven is more than they need
   - One toaster missing in the Which? guide recommendation due to drawbacks but has the best rating in toasting evenness

3. Identify objectives and criteria

- Identify criteria (specific measurable objectives) for assessing the consequences of each option
  - Consequences are being assessed - not the options themselves
  - Distinguish between means and end objectives (ask: why do you care about this? When there is no more to be said you reached the end objective); means objectives are usually easy to measure but end objectives are the important ones to assess
  - Measures
    - Numerical (including monetary valuation)
    - Rating
    - Qualitative descriptions

3. Identify objectives and criteria

- Organise the criteria by clustering them under higher-level and lower-level objectives in a hierarchy
  - Create value tree (only necessary for complex problems)



MCDA Toaster Case Study

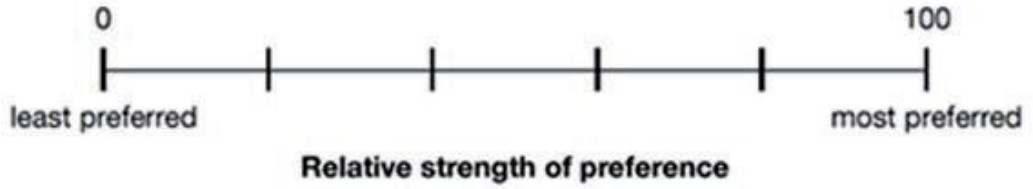
3. Identify objectives and criteria
   - Identify criteria:
     - Key: Evenness of toasting and protection from burned fingers
     - Which? guide has a long list of features and advantages; after a brief discussion list is reduces to six criteria: price, reheat setting, warming rack, adjustable slot width, evenness of toasting, and number of disadvantages.
   - Organise criteria:
     - The **benefits** associated with the toasters do **not** appear to be **related to their costs** - at least not for the seven toasters on the short list; so they do not bother with this step.

4. "Scoring"

- Assess the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion.
  - Describe the consequences of the options.
    - For simpler problems create a performance matrix; for complex problems (that involve a value tree) construct a separate consequence table for each option.
  - Score the options on the criteria.
    - Different types of measures cannot be directly combined
    - Construct scales representing preferences for the consequences

4. "Scoring"

- Score the options on the criteria (cont.)
  - Relative preference scales; comparing differences in consequences (people find it easier to make relative judgements) by replace consequences (values) with scores (strength of preference indicators)
  - This only works if we compare several options at the same time; if we compare options serially we need to compare them to a standard
- Check the consistency of the scores on each criterion
  - Method depends on style of scale used



MCDA Toaster Case Study

4. "Scoring"
   - Describe the consequences of the options
     - Stars represent best scorers only

Options	Price	Reheat setting	Warming rack	Adjustable slot width	Evenness of toasting	Number of drawbacks
Boots 2-slice	£18				☆	3
Kenwood TT350	£27	✓	✓	✓	☆	3
Marks & Spencer 2235	£25	✓	✓		★	3
Morphy Richards Coolstyle	£22				☆	2
Philips HD4807	£22	✓			★	2
Kenwood TT825	£30				☆	2
Tefal Thick'n'Thin 8780	£20	✓		✓	★	5

A tick indicates the presence of a feature. Evenness of toasting is shown in *Which?* on a five-point scale, with a solid star representing the best toaster, and an open star the next best. The family eliminated from consideration all the toasters that scored less than best or next best.

MCDA Toaster Case Study

- Score the options on the criteria
- Check consistency
  - Evenness of toasting: Seems unfair to only give 0 and 100 but later weighting makes it fair
  - Drawbacks: Not well represented by number - also need to consider seriousness; now considered in the scoring

Options	Price	Reheat setting	Warming rack	Adjustable slot width	Evenness of toasting	Drawbacks
Boots 2-slice	100	0	0	0	0	50
Kenwood TT350	25	100	100	100	0	80
Marks & Spencer 2235	42	100	100	0	100	50
Morphy Richards Coolstyle	67	0	0	0	0	100
Philips HD4807	67	100	0	0	100	90
Kenwood TT825	0	0	0	0	0	90
Tefal Thick'n'Thin 8780	84	100	0	100	100	0

5. "Weighting"

- Assign weights for each of the criterion to reflect their relative importance to the decision.
  - Preference scales cannot be combined as unit of preference on one does not necessarily equal a unit of preference on another
  - Weighting preference scales
    - Swing weighting is based comparing differences: if the overall difference between highest and lowest score is very small you might not care too much about this criterion and give it a low weight

MCDA Toaster Case Study

5. Weighting
   - 100 points against the criteria as weights
     - Price difference matters most to them
     - Small difference in toasting evenness is about half as important as price
     - Presence of a warming rack is about equal to toasting evenness
     - The adjustable slot seems a little less important than the price difference

Options	Price	Reheat setting	Warming rack	Adjustable slot width	Evenness of toasting	Drawbacks
Boots 2-slice	100	0	0	0	0	50
Kenwood TT350	25	100	100	100	0	80
Marks & Spencer 2235	42	100	100	0	100	50
Morphy Richards Coolstyle	67	0	0	0	0	100
Philips HD4807	67	100	0	0	100	90
Kenwood TT825	0	0	0	0	0	90
Tefal Thick'n'Thin 8780	84	100	0	100	100	0
Weights	**30**	**5**	**15**	**25**	**15**	**10**

6. Combine the weights and scores for each option to derive an overall value

- The overall preference score for each option is simply the weighted average of its scores on all the criteria.

$$S_i = w_1 s_{i1} + w_2 s_{i2} + \ldots + w_n s_{in} = \sum_{j=1}^{n} w_j s_{ij}$$

i = option; j = criterion; s = preference score; w=weight

- Check for mutually preference independence
  - Important: All the criteria must be mutually preference independent
  - If this cannot be avoided slightly more complex mathematics are required

MCDA Toaster Case Study

6. Combine the weights

Table 6.4 Calculating overall scores

Options	Price	Reheat setting	Warming rack	Adjustable slot width	Evenness of toasting	Drawbacks	Total
Boots 2-slice	100	0	0	0	0	50	**35**
Kenwood TT350	25	100	100	100	0	80	**61**
Marks & Spencer 2235	42	100	100	0	100	50	**53**
Morphy Richards Coolstyle	67	0	0	0	0	100	**30**
Philips HD4807	67	100	0	0	100	90	**49**
Kenwood TT825	0	0	0	0	0	90	**9**
Tefal Thick'n'Thin 8780	84	100	0	100	100	0	**70**
Weights	**30**	**5**	**15**	**25**	**15**	**10**	

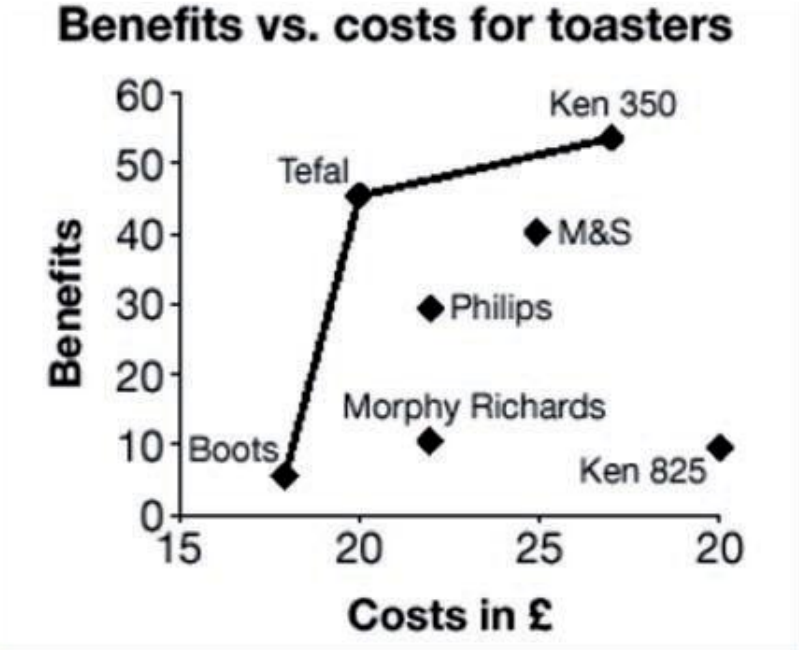
7. Examine the results

- The top-level ordering of options is given by the weighted average of all the preference scores
  - These total scores also give an indication of how much better one option is over another

- Another way of looking at the results is to display the options in a two dimensional plot to show the main trade-offs
  - The outer surface of the plot gives the most cost-effective options

MCDA Toaster Case Study

7. Examine the results
   - According to the diagram which toaster is the best choice?



8. Sensitivity analysis

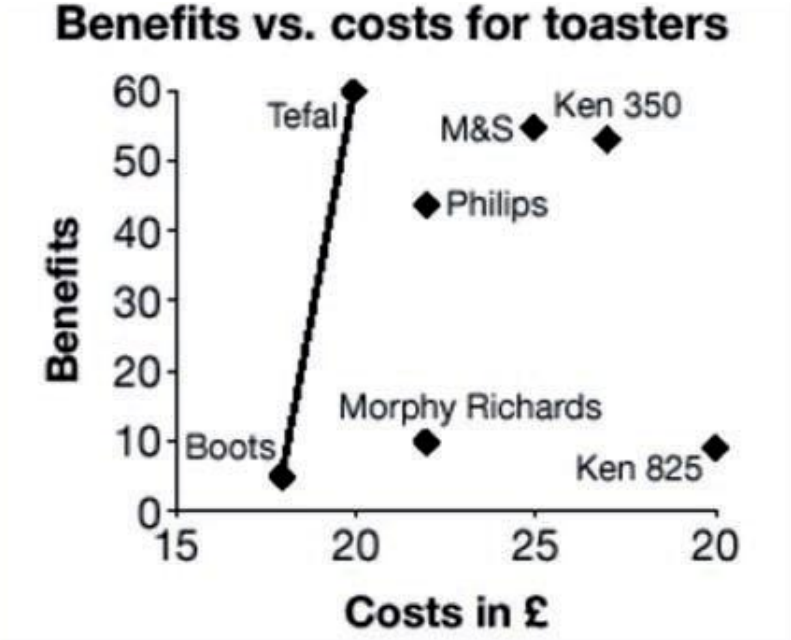
- Do other preferences or weights affect the overall ordering of the options?
  - Using the model to examine how the ranking of options might change under different scoring or weighting systems

- There is a potentially useful role for sensitivity analysis in helping to resolve disagreements between interest groups.

- An important characteristic of MCDA models is that they are often remarkably insensitive to many scores and weights but people often find it difficult to live with rough-and-ready inputs.

MCDA Toaster Case Study

8. Sensitivity analysis
   - Fred thinks if more weight had been given to evenness of toasting, his original purchase, the Philips, would look better overall because it received a best rating for evenness in Which?



MCDA Toaster Case Study

- What happened in the end?
  - Fred and Jane decided to take a look at the Tefal and Kenwood 350 toasters. The length of the Tefal worried Jane when she saw it; Which? magazine hadn't given dimensions, only small photographs of the toasters. She had not realised how long a longslot toaster is, and she thought that the Tefal was rather bulky. In the end, they decided to buy the Kenwood. The MCDA had helped them in many ways, but the final decision was theirs to take.

Break

- Time for a break ;-)

Application of Multi-Criteria Decision Analysis

Case Study: Port of Calais

Context

- Two key stake holders with different interests involved in the decision processes concerning the port operation
  - Port Operators
    - Service providers and as such interested in a smooth flow of port operations as they have to provide certain service standards
  - Border Agencies
    - Represent national security interests that need to be considered; checks have to be conducted to detect threats such as weapons, smuggling and sometimes even stowaways

- Cost is another important factor
  - Security checks require expensive equipment and well trained staff

Context

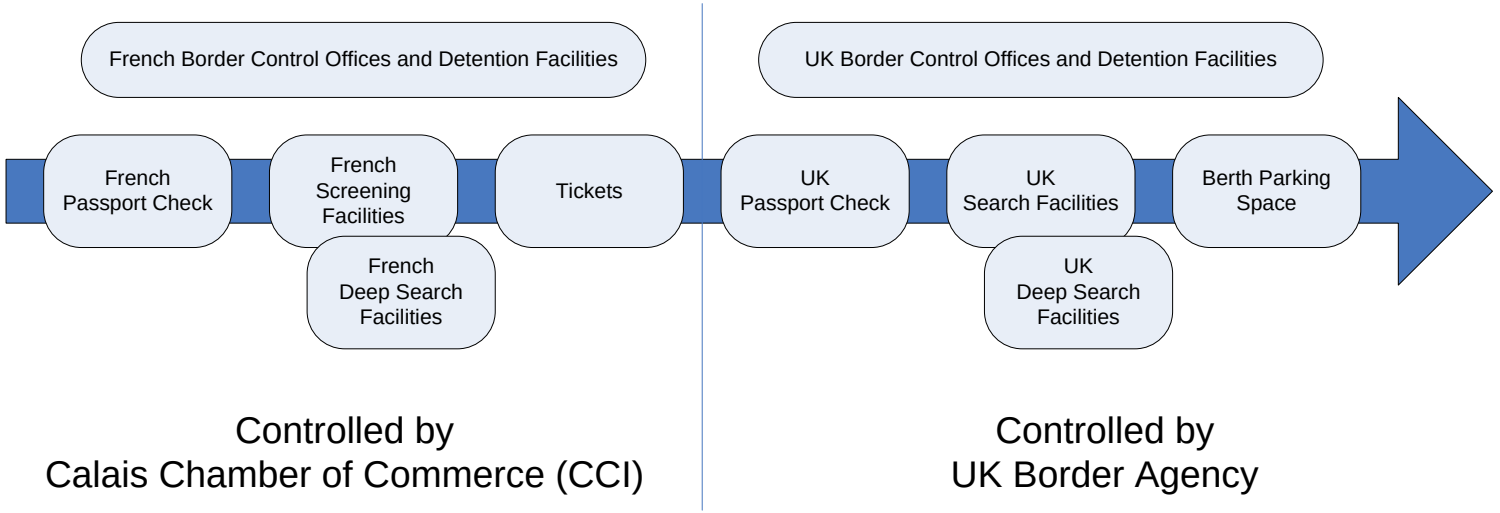
- How can we find the right balance between service, security, and costs?
  - Decide the level of security required to guarantee a certain threshold of detection of threats while still being economically viable and not severely disrupting the process flow

Context

- Cost Benefit Analysis (CBA) used in Economics
  - Scenario Analysis (SA) [deterministic, static]
- Alternatives from Operations Research and Social Sciences
  - Discrete Event Simulation (DES) [stochastic, dynamic]
  - Agent-Based Simulation (ABS) [stochastic, dynamic]
- A step forward: Using CBA and Simulation together
  - CBA allows to assess costs
  - Simulation allows to assess service quality
  - Both feed into **Multi Criteria Analysis (MCA)** to study trade-offs

Case Study System

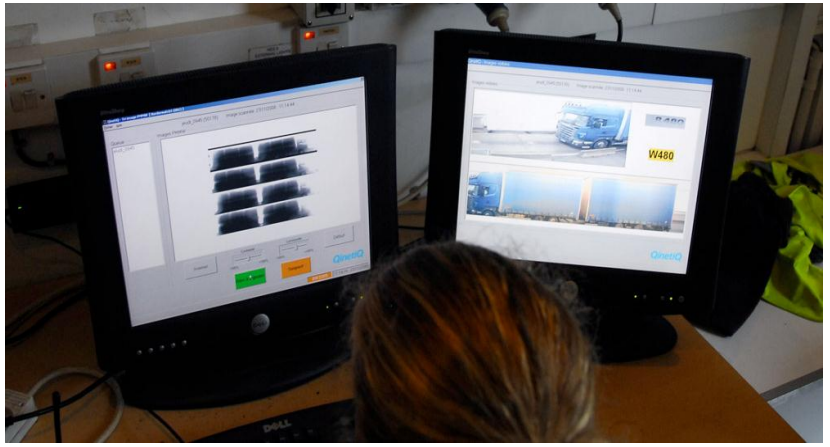
- Location: Calais Ferry Port (France)
- Problem: Illegal immigration (people hiding in lorries)
- 900,000 lorries per year; 3500 positive lorries found (0.4%)
- Cost per positive lorry missed: £5,000*4*5=£100,000



Case Study System

Case Study System

- Inspection Sheds
  - Heartbeat Detector
  - CO_2 Probe
  - Visual Inspection
  - Canine Sniffers
- Drive Through
  - Passive Millimetre Wave Scanner



Data

- Data collection on a rainy day in Calais

- Data from 2008/2009

Statistic	Value
Total number of lorries entering Calais harbour	900,000
Total number of positive lorries found	3474
Total number of positive lorries found on French site	1,800
Total number of positive lorries found on UK site	1,674
… In UK Sheds	890
… In UK Berth	784

Cost Benefit Analysis

CBA using Scenario Analysis
Experimental Setup

- Possible Scenarios
  - TG=Traffic Growth
  - PLG=Positive Lorry Growth

Factor 1	TG	p(TG)
Scenario 1	0%	0.25
Scenario 2	10%	0.50
Scenario 3	20%	0.25
Factor 2	PLG	p(PLG)
Scenario 1	-50%	0.33
Scenario 2	0%	0.33
Scenario 3	25%	0.33

- How should UKBA respond to these scenarios?
  - Possible responses
    - Not changing the search activities
    - Increasing the search activities by 10%
    - Increasing the search activities by 20%

CBA using Scenario Analysis Results

- Calculating Net Benefits (assuming that currently 150 lorries are missed)

PLG 0%	SG 0%	SG +10%	SG +20%
TG 0%	150.00	136.36	125.00
TG 10%	165.00	150.00	137.50
TG 20%	180.00	163.64	150.00

	PLG -50%	PLG 0%	PLG 25%
TG 0%	0.0833	0.0833	0.0833
TG 10%	0.1667	0.1667	0.1667
TG 20%	0.0833	0.0833	0.0833

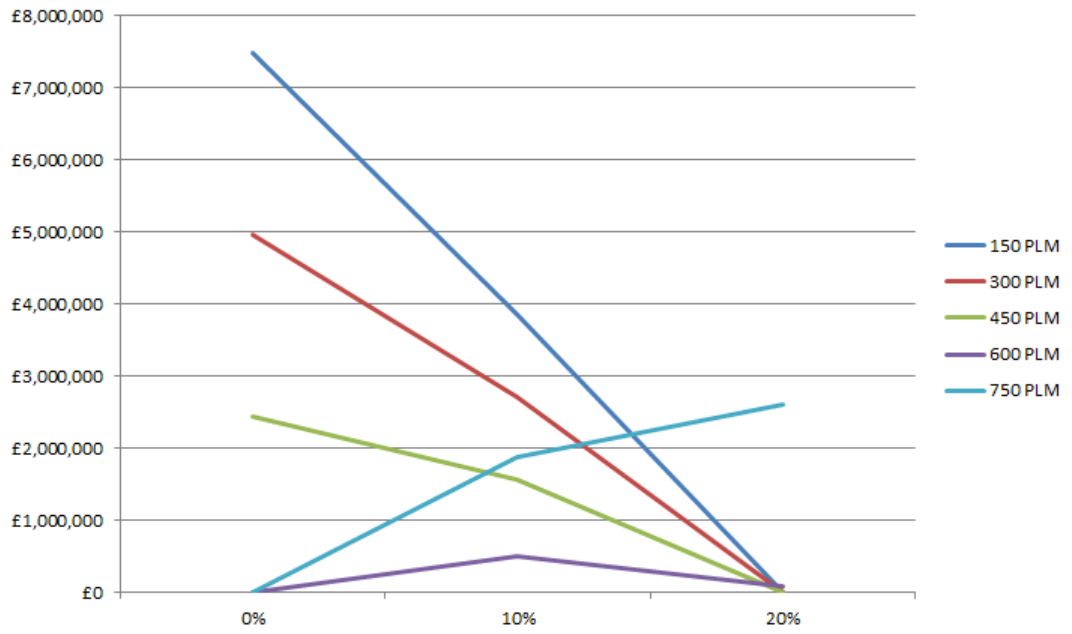
TG vc PLG	PLG -50%	PLG 0%	PLG 25%
TG 0%	£7,500,000	£15,000,000	£18,750,000
TG 10%	£8,250,000	£16,500,000	£20,625,000
TG 20%	£9,000,000	£18,000,000	£22,500,000
TG vc PLG	PLG -50%	PLG 0%	PLG 25%
TG 0%	£6,818,182	£13,636,364	£17,045,455
TG 10%	£7,500,000	£15,000,000	£18,750,000
TG 20%	£8,181,818	£16,363,636	£20,454,545
TG vc PLG	PLG -50%	PLG 0%	PLG 25%
TG 0%	£6,250,000	£12,500,000	£15,625,000
TG 10%	£6,875,000	£13,750,000	£17,187,500
TG 20%	£7,500,000	£15,000,000	£18,750,000

- Results

SG	EC	TEC	NB
0%	£15,125,000	£15,125,000	£7,479,167
10%	£13,750,000	£18,750,000	£3,854,167
20%	£12,604,167	£22,604,167	£0

CBA using Scenario Analysis Results

- Sensitivity Analysis for Positive Lorries Missed (PLM)



Object Oriented Discrete Event Simulation

Discrete Event Simulation

- In DES time and space can be taken into account which allows us, amongst others, to:
  - Assess service quality (in terms of waiting time)
  - Consider real world boundaries (e.g. space limitations for queues)

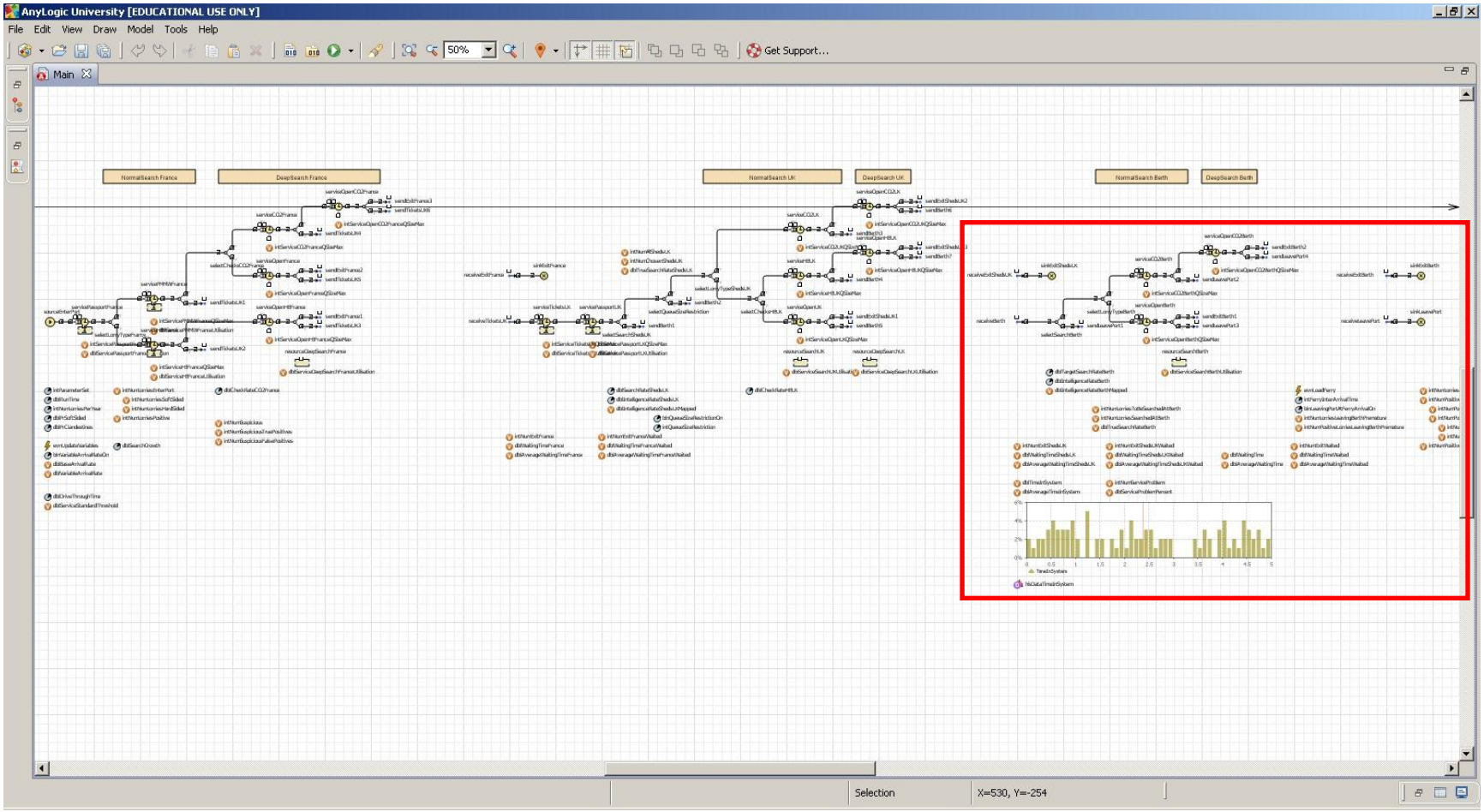
- Simulation model implementation
  - Object oriented (we transfer all the intelligence from the process definition into the object definition)
  - Reproduced base scenario through calibration (matching number of positive lorries found at different stages)
    - Number of positive lorries entering the port
    - Sensor detection rates
    - Berth search rate

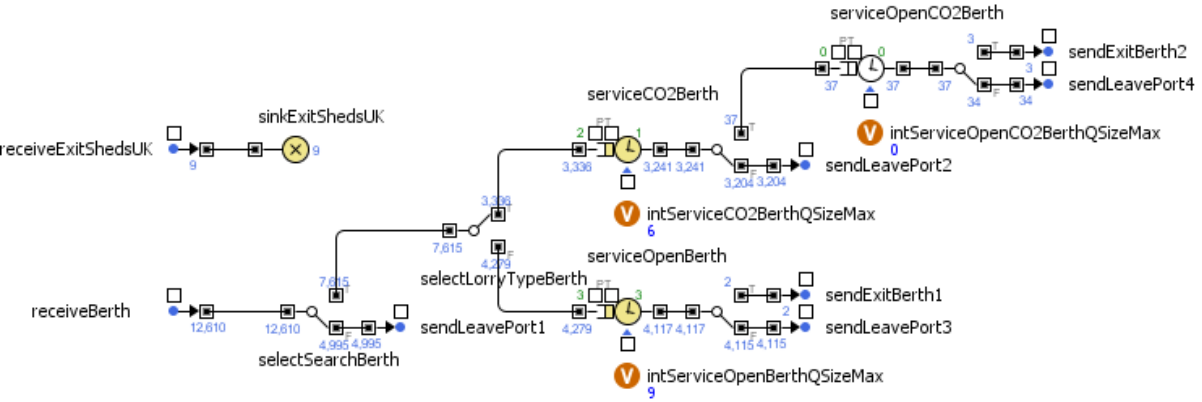
Discrete Event Simulation Experimentation

- Objectives (service standards)
  - Less than 5% of lorries should spend more than 27.01 minutes in the system
  - The base detection rates should not be compromised

- Possible intervention
  - Allow lorries to pass without inspection when queues in front of the UK sheds are getting too long

The Simulation Model

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intServiceCO2BerthQSizeMax
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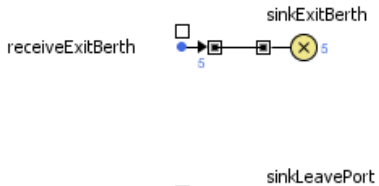
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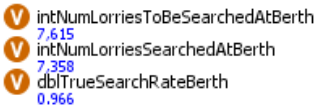
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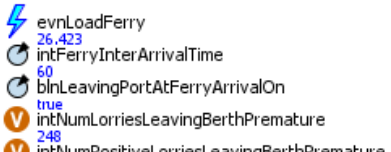
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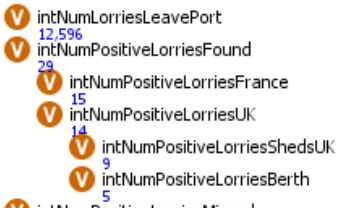
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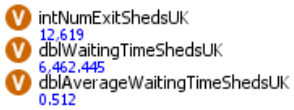
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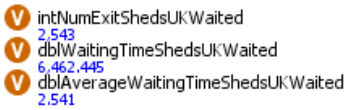
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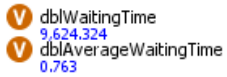
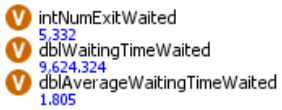
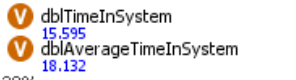
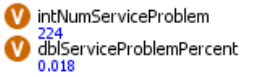
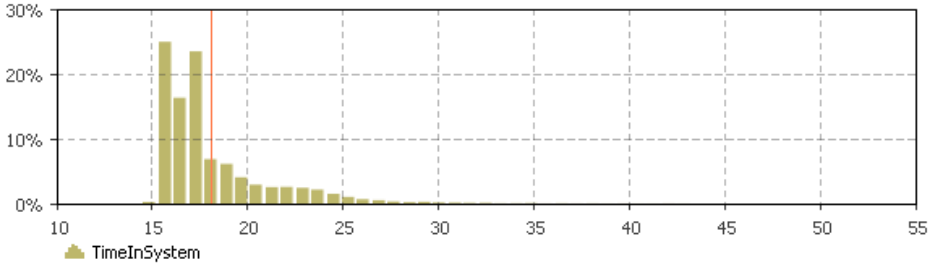
dblAverageWaitingTimeShedsUKWaited
2.541

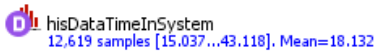

dblWaitingTime
9,624.324
dblAverageWaitingTime
0.763


intNumExitWaited
5,332
dblWaitingTimeWaited
9,624.324
dblAverageWaitingTimeWaited
1.805


dblTimeInSystem
15,595
dblAverageTimeInSystem
18.132


intNumServiceProblem
224
dblServiceProblemPercent
0.018


30%
20%
10%
0%
10
15
20
25
30
35
40
45
50
55
TimeInSystem


hisDataTimeInSystem
12,619 samples [15.037...43.118], Mean=18.132

Scenarios		1	2	3	4	5	6	7
Traffic Growth (TG)		0%	10%	20%	0%			
Search Growth (SG)		0%			10%	20%		
Lorries	Arrivals	900000	990000	1080000	900000			
	Soft-sided	0.44						
	Positive	0.00550	0.00500	0.00458	0.00550			
Search rate	UK Sheds	0.330	0.300	0.275	0.363	0.396		
	UK Berth	0.600	0.545	0.500	0.660	0.720		
Detection Rates	France	0.41						
	UK Sheds	0.80						
	UK Berth	0.95						
Queue size restriction	UK Sheds	off					10	9
Results		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Waiting times (avg)[*1)]	France	0.858	1.019	1.268	0.863	0.859	0.860	0.863
	UK Sheds	2.612	2.474	2.321	3.452	5.046	3.940	3.763
	Overall	1.831	1.783	1.856	2.439	3.620	2.901	2.788
Time in system (avg)		18.099	18.085	18.155	18.517	19.274	18.893	18.834
Service problem		0.019	0.019	0.020	0.036	0.068	0.052	0.049
Resource utilisation	UK Sheds	0.676	0.676	0.677	0.744	0.812	0.803	0.801
	UK Berth	0.808	0.808	0.809	0.868	0.915	0.914	0.914
Positive lorries	France	1774.9	1765.5	1745.9	1780.5	1774.3	1757.5	1769.7
	UK Sheds	900.8	814.0	733.8	981.2	1078.0	1061.2	1042.8
	UK Berth	699.9	658.4	630.7	715.9	743.0	746.5	746.8
	Missed	1590.1	1697.2	1797.0	1480.7	1365.7	1361.7	1358.1

Multi Criteria Decision Analysis

1. Establish the decision context

- Identifying aim(s) and key stakeholders
  - Aim: Decide about the search growth (security) while keeping costs and service quality in mind
  - Decision makers (stakeholders): UK border agency; border agency staff (both sides); port operators; tax payers; ferry operators
  - Key players: Travellers (pedestrians; car; lorry); (academic) experts; literature

2. Identify options to be appraised

- Developing options
  - Generate options that will build on strengths, fix weaknesses, seize opportunities and minimise threats

2. Identify options to be appraised

- Developing options
  - Generate options that will build on strengths, fix weaknesses, seize opportunities and minimise threats: We use search growth in combination with passing x lorries (the impact of this is something that you get only from simulation through PLM)

3. Identify objectives and criteria

- Identify criteria for assessing the consequences of each option

3. Identify objectives and criteria

- Identify criteria for assessing the consequences of each option
  - Criteria are specific measurable objectives (lowest level)
  - High level objectives:
    - Minimise costs, maximise benefits (service, security)
  - Low level objectives:
    - Cost: TEC, staff utilisation
    - Service: Service time, fulfil standard
    - Security: Number of lorries not caught; intervention "lorries to pass unchecked"

3. Identify objectives and criteria

- Description of consequences
  - Performance matrix

		TEC	% queue time exceeded	Service standard met	Allows lorries to pass unchecked
Strategy1	SG0	£155,214,583	1.76%	Y	N
Strategy2	SG10	£150,452,083	3.14%	Y	N
Strategy3	SG20	£150,731,250	5.89%	N	N
Strategy4	SG0+QS	£157,185,417	1.71%	Y	Y
Strategy5	SG10+QS	£149,352,083	2.87%	Y	Y
Strategy6	SG20+QS	£146,354,167	4.76%	Y	Y

4. Scoring ... 5. Weighting ... 6. Combine both

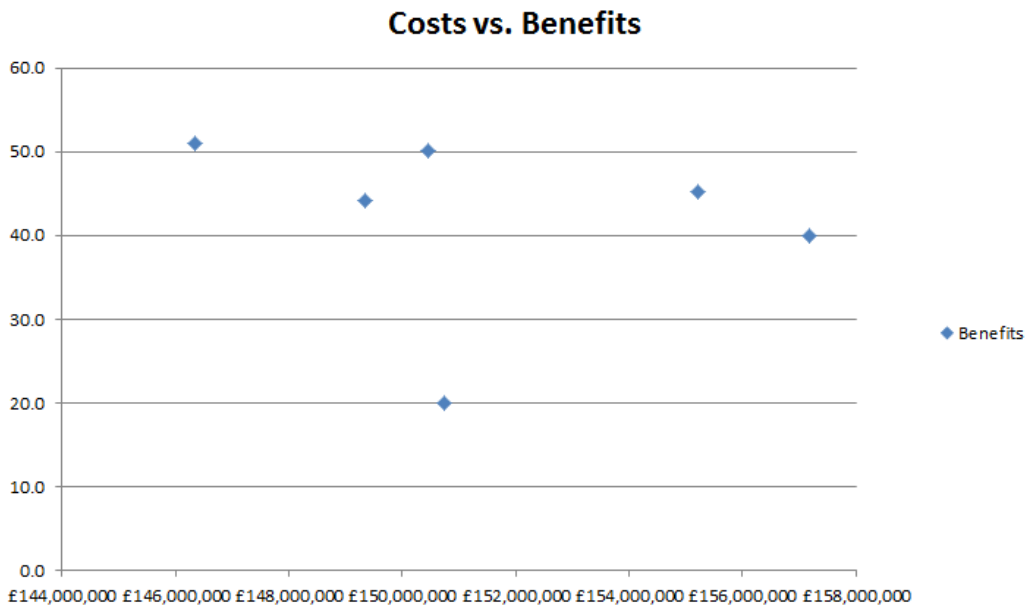
- Score options on the criteria
  - Construct scales representing preferences for the consequences
  - Weight the scales for their relative importance
  - Calculate weighted averages across the preference scales
- Assess weights for each of the criteria to reflect its relative importance to decision; calculate simple weighted averages

		TEC	% queue time exceeded	Service standard met	Allows lorries to pass unchecked	Overall weighted scores
Strategy1	SG0	18	1	100	100	52.5
Strategy2	SG10	62	34	100	100	75.0
Strategy3	SG20	60	100	0	100	43.8
Strategy4	SG0+QS	0	0	100	0	40.0
Strategy5	SG10+QS	72	28	100	0	73.1
Strategy6	SG20+QS	100	73	100	0	91.0
Weight		0.4	0.15	0.4	0.05	

7. Examine results

- Plot benefits vs. costs (to show the main trade-offs)
- The outer surface of the plot gives the most cost effective options
- Compare the options by checking the relationships btw. costs and benefits

TEC	Benefits
£155,214,583	45.2
£150,452,083	50.1
£150,731,250	20.0
£157,185,417	40.0
£149,352,083	44.2
£146,354,167	51.0

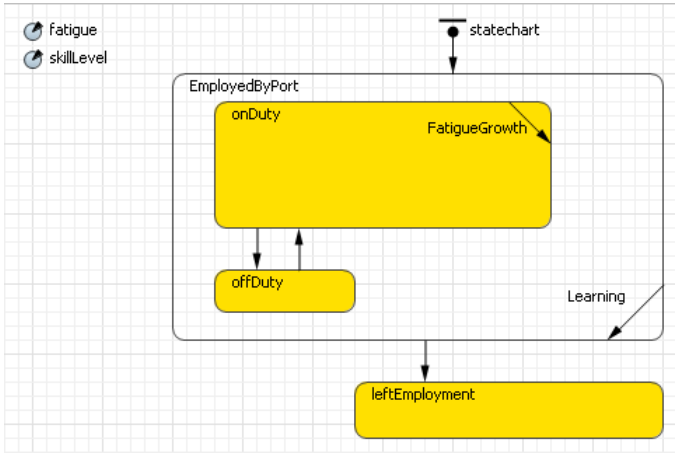


8. Sensitivity Analysis

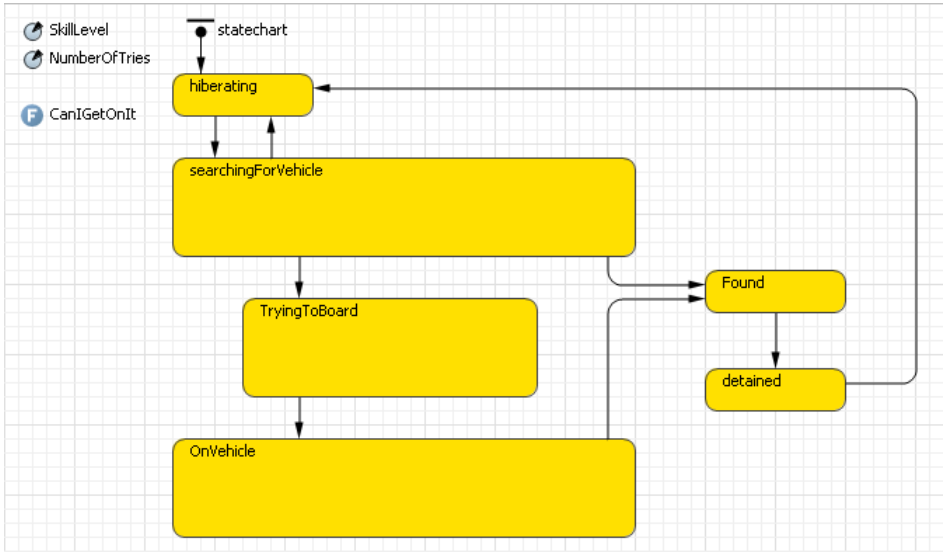
- Not done yet …

Next Steps

- Continue our investigation into MCDA
- Develop a combined DES/ABS version of the model



Officer agent state chart



Clandestine agent state chart

Summary

- CBA + DES can provide different kind of data for MCDA
- In addition DES allows you to gain insight into the system
- MCDA can help to study the trade-offs between multiple objectives using monetary and non-monetary criteria
- MCDA requires frequent collaboration with key stakeholders

MCDA can help in many ways but the final decision is yours!

Questions / Comments

References

- Keeney, R. L., & Raiffa, H. (1976). Decisions with Multiple Objectives: Preferences and Value Tradeoffs, John Wiley, New York, reprinted, Cambridge University Press, 1993.

- Dodgson, J. S., Spackman, M., Pearman, A., & Phillips, L. D. (2009). Multi-Criteria Analysis: A Manual.