East Midlands Simulation SIG

Using Simulation to Support Multi-Criteria Decision Analysis

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EM SIM SIG Presentation

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- My Academic Life

Part 2

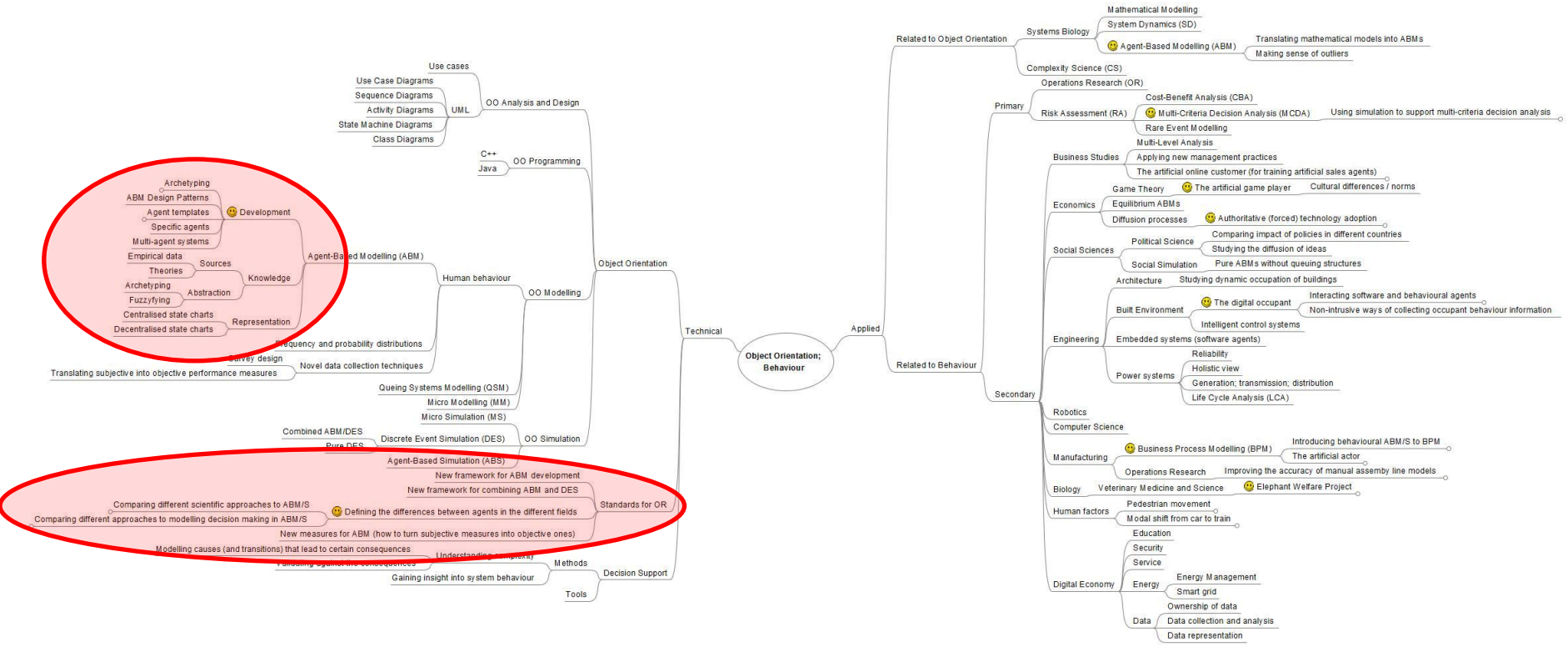
- Using Simulation to Support Multi-Criteria Decision Analysis
  - Case Study: Port of Calais

My Academic Life

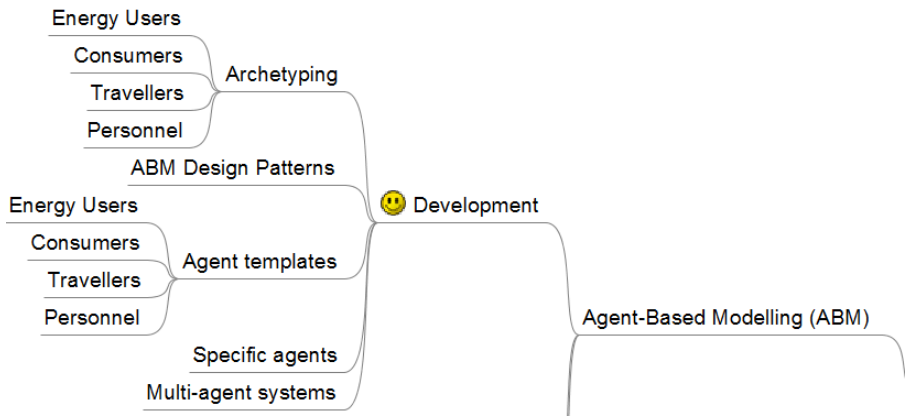
My Academic Life …

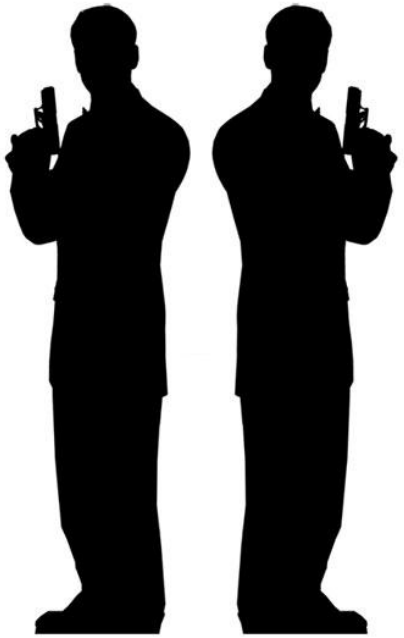
- My Mission
  - Development of human behaviour models which can be used to better represent people and their behaviours in OR models
  - Combining ideas from OR (DES) and Social Simulation (ABM/S)
    - More interested in developing frameworks and testing them for different application areas
    - Less interested in solving/investigating specific cases

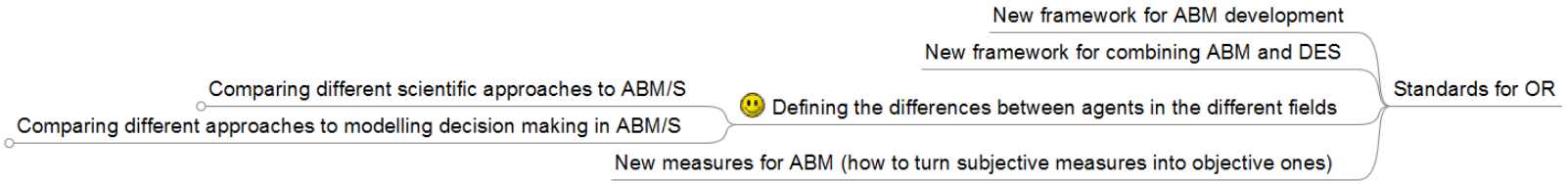
My Academic Life ...



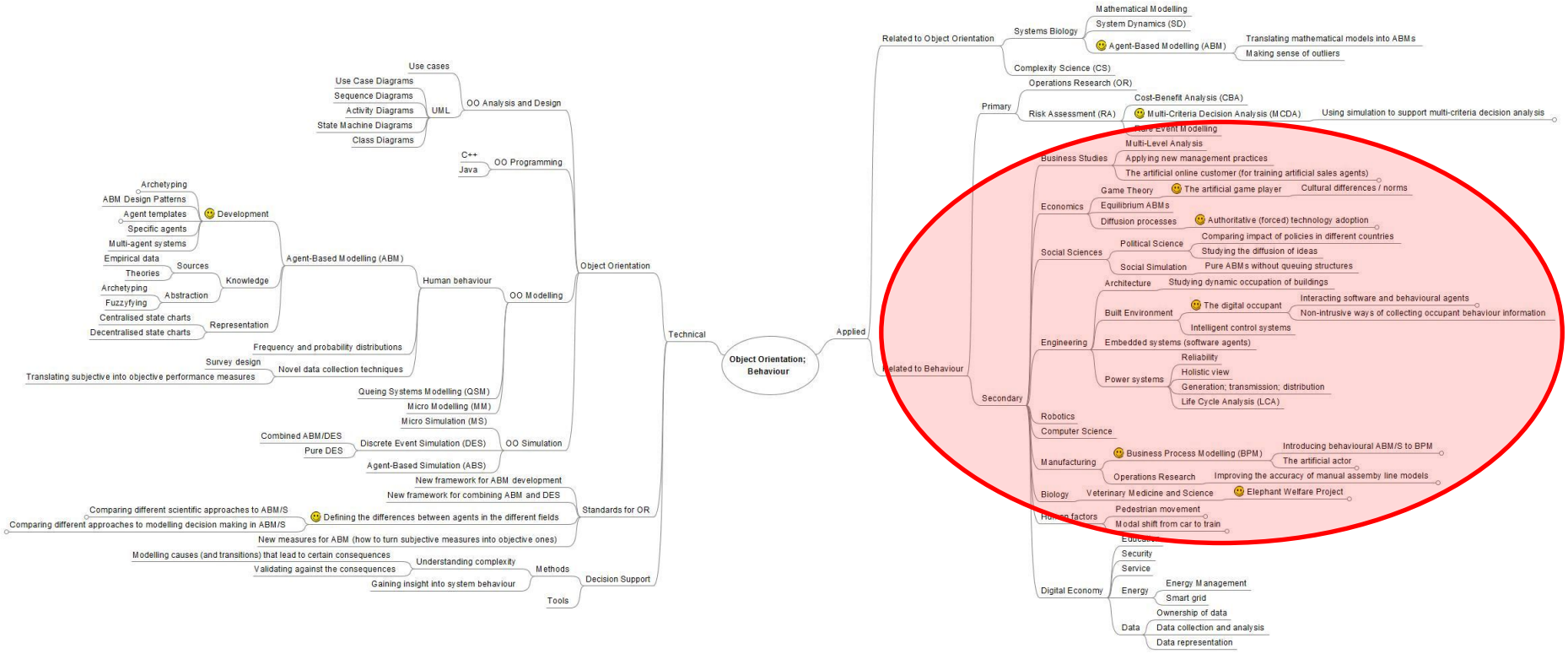
Technical Aspects



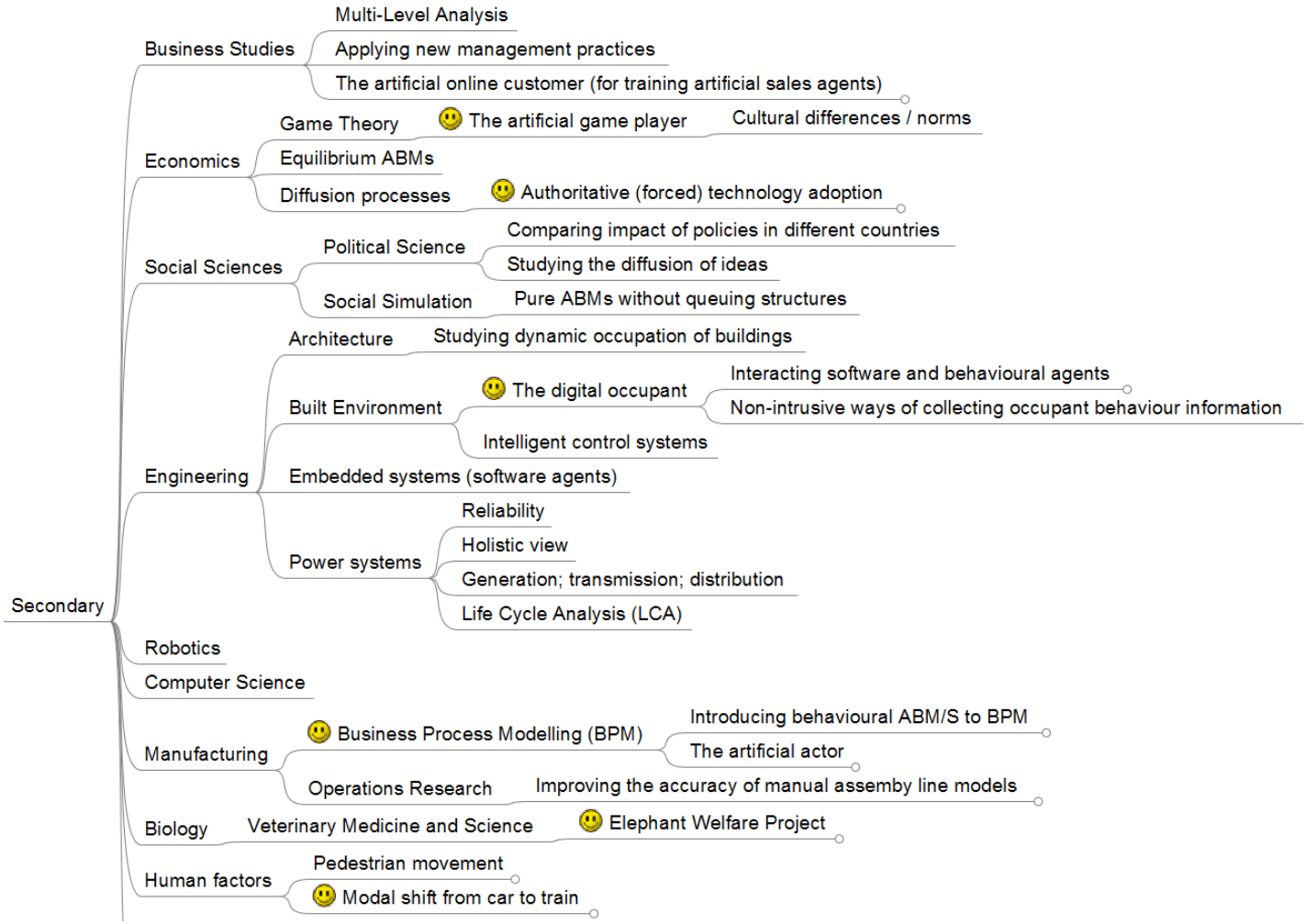




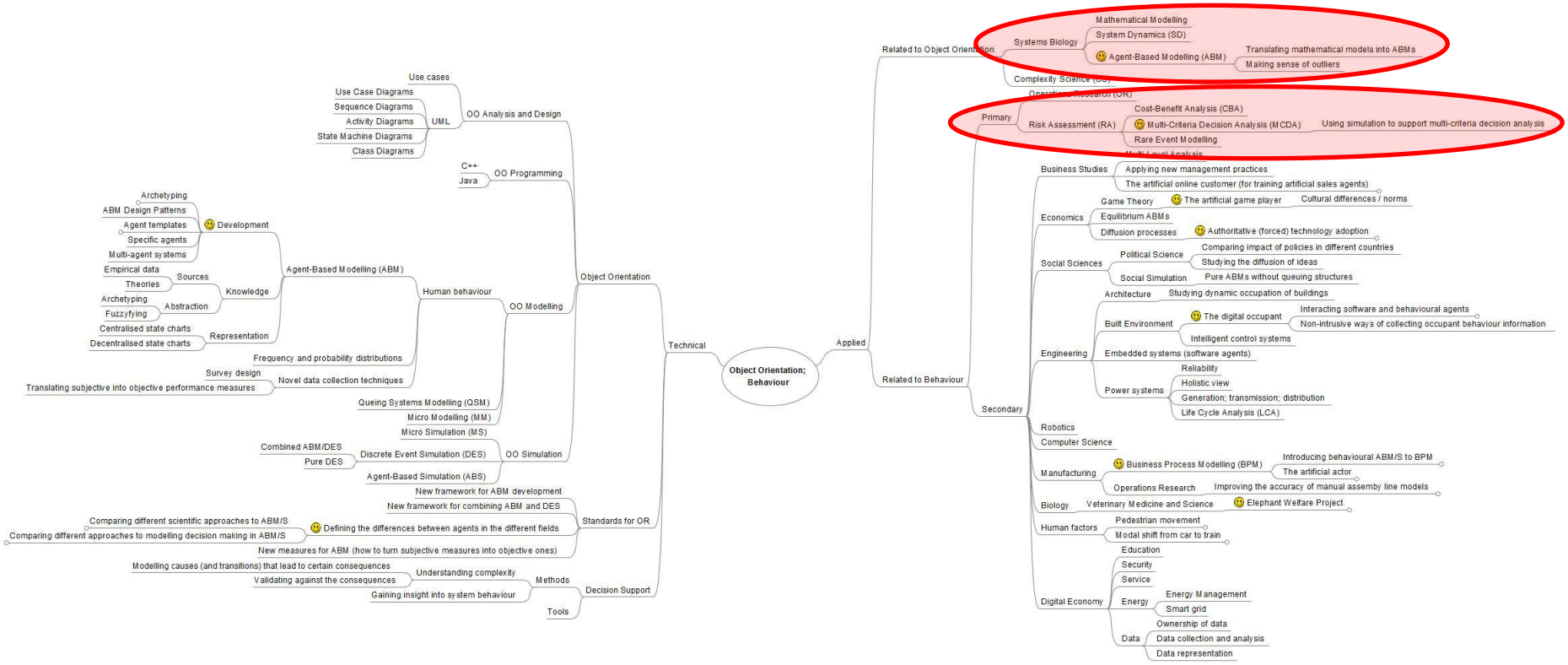
My Academic Life ...



Applications

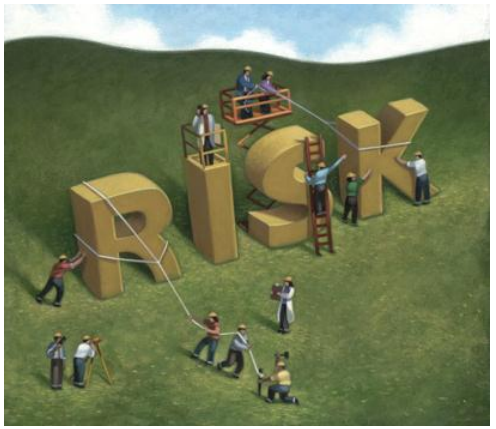


My Academic Life …



Other Activities Related to Simulation

- Systems Biology
  - Mathematical Modelling
  - System Dynamics (SD)
  - Agent-Based Modelling (ABM)
    - Translating mathematical models into ABMs
    - Making sense of outliers



- Risk Assessment (RA)
  - Cost-Benefit Analysis (CBA)
  - Multi-Criteria Decision Analysis (MCDA)
    - Using simulation to support multi-criteria decision analysis
  - Rare Event Modelling

Using Simulation to Support 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

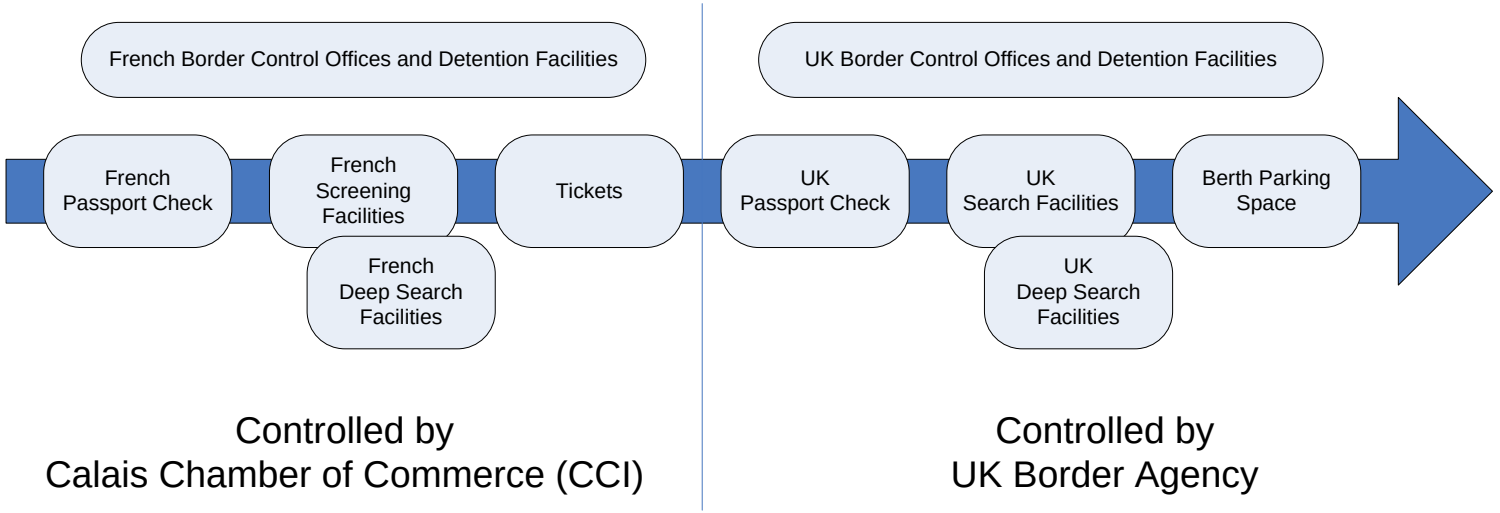
- How can we find the right balance between service, security, and costs?
  - Decide the level of security required to guarantee a certain threshold of detection of threats while still being economically viable and not severely disrupting the process flow

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

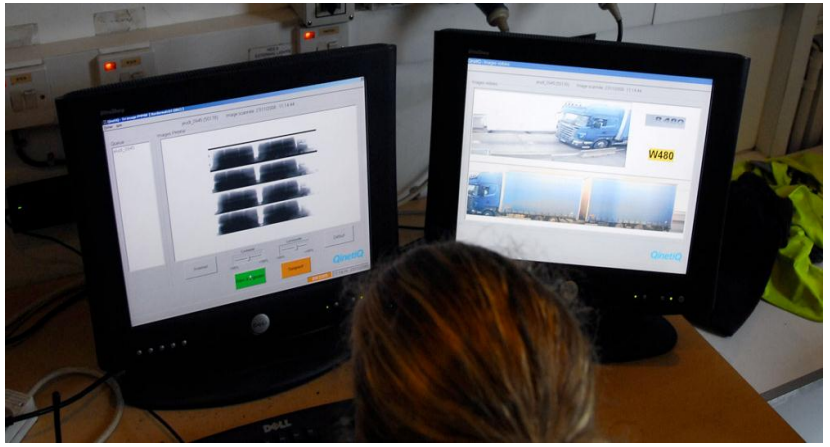
- Location: Calais Ferry Port (France)
- Problem: Illegal immigration (people hiding in lorries)
- 900,000 lorries per year; 3500 positive lorries found (0.4%)
- Cost per positive lorry missed: £5,000*4*5=£100,000



Case Study System

Case Study System

- Inspection Sheds
  - Heartbeat Detector
  - CO2 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

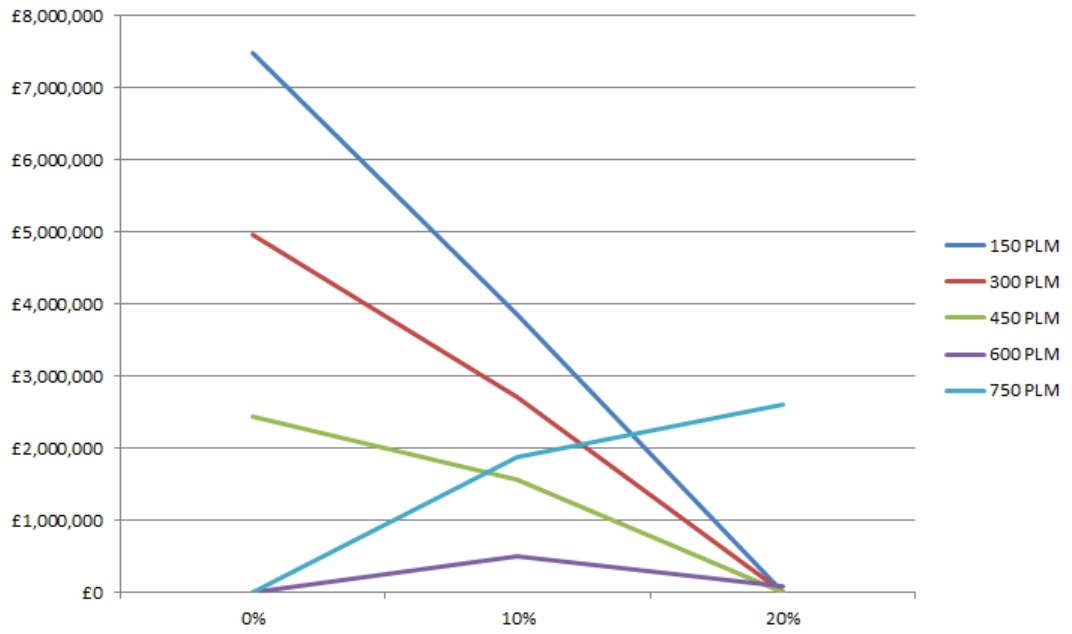
TG vc PLG	PLG -50%	PLG 0%	PLG 25%
TG 0%	£7,500,000	£15,000,000	£18,750,000
TG 10%	£8,250,000	£16,500,000	£20,625,000
TG 20%	£9,000,000	£18,000,000	£22,500,000
TG vc PLG	PLG -50%	PLG 0%	PLG 25%
TG 0%	£6,818,182	£13,636,364	£17,045,455
TG 10%	£7,500,000	£15,000,000	£18,750,000
TG 20%	£8,181,818	£16,363,636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

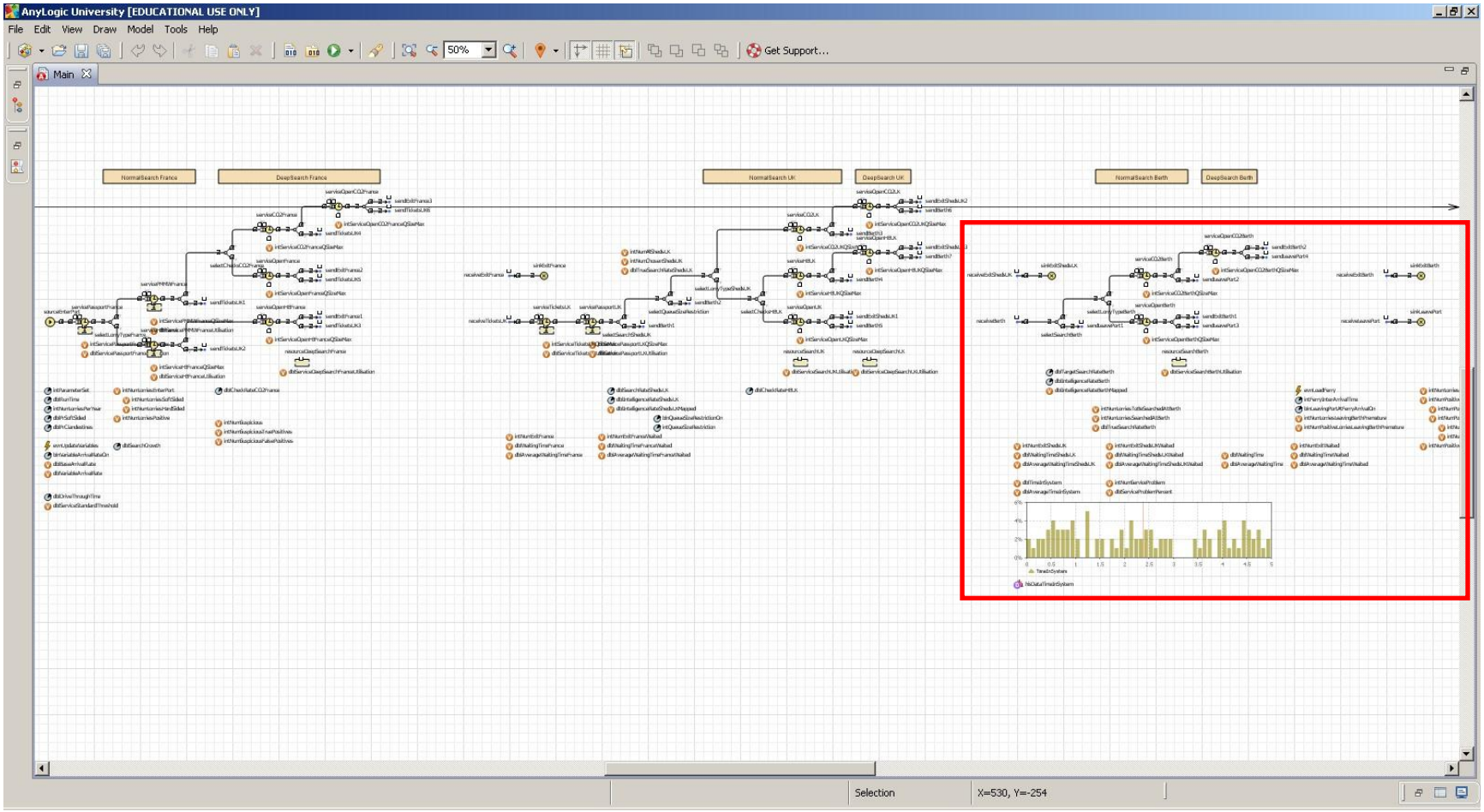
- Simulation model implementation
  - Object oriented (we transfer all the intelligence from the process definition into the object definition)
  - Reproduced base scenario through calibration (matching number of positive lorries found at different stages)
    - Number of positive lorries entering the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

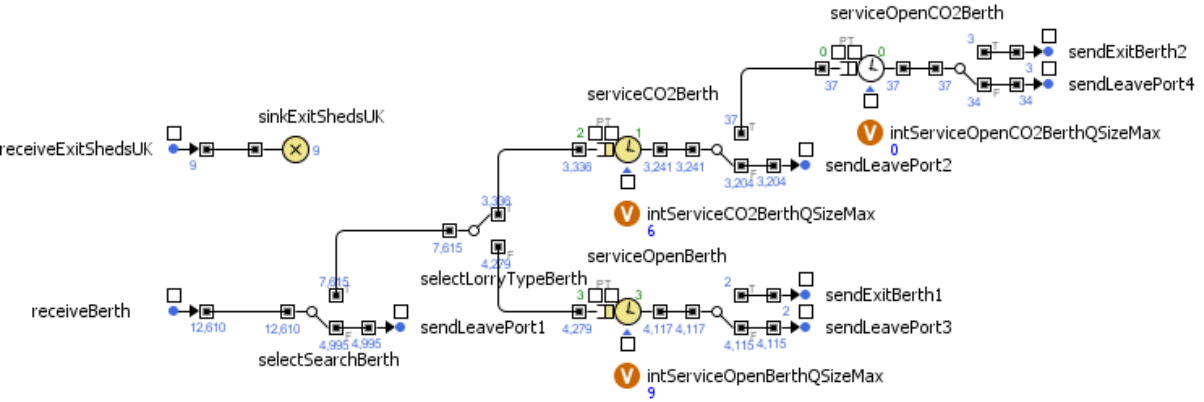
Discrete Event Simulation Experimentation

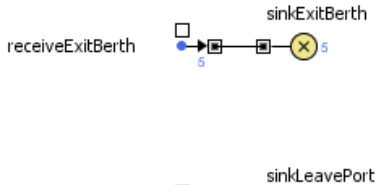
- Objectives (service standards)
  - Less than 5% of lorries should spend more than 27.01 minutes in the system
  - The base detection rates should not be compromised

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

The Simulation Model







intNumLorriesToBeSearchedAtBerth
7,615
intNumLorriesSearchedAtBerth
7,358
dblTrueSearchRateBerth
0.966

evnLoadFerry
26.423
intFerryInterArrivalTime
60
blnLeavingPortAtFerryArrivalOn
true
intNumLorriesLeavingBerthPremature
248
intNumPositiveLorriesLeavingBerthPremature
0

intNumLorriesLeavePort
12,596
intNumPositiveLorriesFound
29
intNumPositiveLorriesFrance
15
intNumPositiveLorriesUK
14
intNumPositiveLorriesShedsUK
9
intNumPositiveLorriesBerth
5
intNumPositiveLorriesMissed
17

intNumExitShedsUK
12,619
dblWaitingTimeShedsUK
6,462.445
dblAverageWaitingTimeShedsUK
0.512

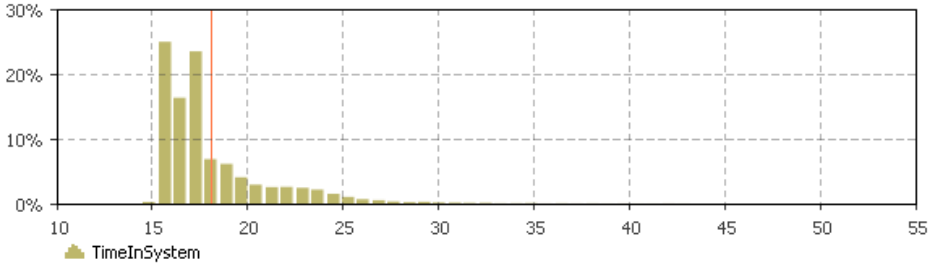
intNumExitShedsUKWaited
2,543
dblWaitingTimeShedsUKWaited
6,462.445
dblAverageWaitingTimeShedsUKWaited
2.541

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



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

Multi Criteria Analysis

- Multi-Criteria Analysis (MCA)
  - MCA allows taking a mixture of monetary and non monetary inputs into account. It can use the results of a CBA as monetary input and service quality estimators as non monetary input and produce some tables and graphs to show the relation between cost/benefits of different options

- Multi Criteria Decision Analysis (MCDA)
  - A form of MCA
  - Based on decision theory

Multi Criteria Decision Analysis

- Department for Communities and Local Government (2009) proposes an eight-step process:
  - Establish decision context
  - Identify options to be appraised
  - Identify objectives and criteria
  - Scoring
  - Weighting
  - Combine weights and scores to derive an overall value
  - Examine the results
  - Sensitivity analysis

Multi Criteria Decision Analysis Procedure

- Identifying aim(s) and key stakeholders
  - Aim: Decide about the search growth (security) while keeping costs and service quality in mind
  - Key stakeholders: UK border agency; border agency staff (both sides); other (academic) experts + literature
- Developing options
  - SWOT analysis (strengths, weaknesses, opportunities and threats) for 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)

Multi Criteria Decision Analysis Procedure

- 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"

Multi Criteria Decision Analysis Procedure

- 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

Multi Criteria Decision Analysis Procedure

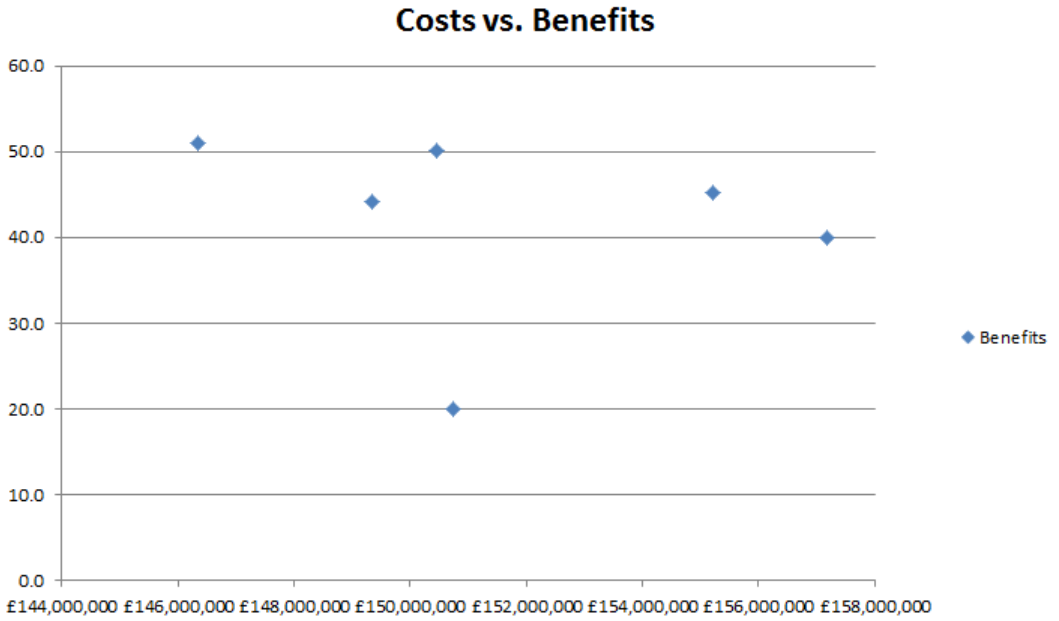
- Score options on the criteria
  - Construct scales representing preferences for the consequences
  - Weight the scales for their relative importance
  - Calculate weighted averages across the preference scales
- Assess weights for each of the criteria to reflect its relative importance to decision;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

Multi Criteria Decision Analysis Procedure

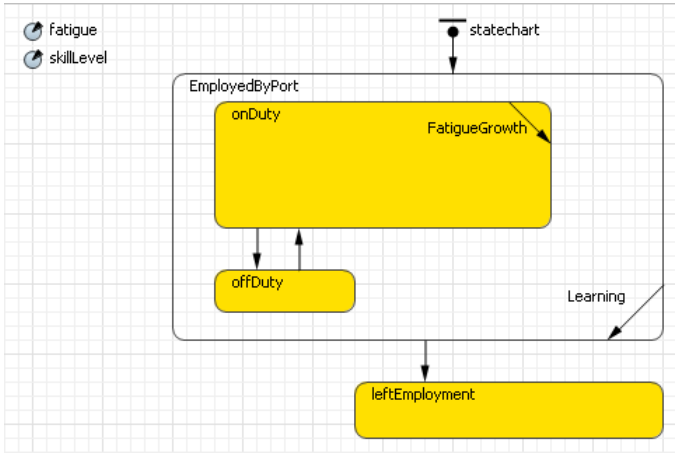
- Examine results
  - Plot benefits vs. costs (to show the main trade-offs)
  - The outer surface of the plot gives the most cost effective options
  - Compare the options by checking the relationships btw. costs and benefits

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

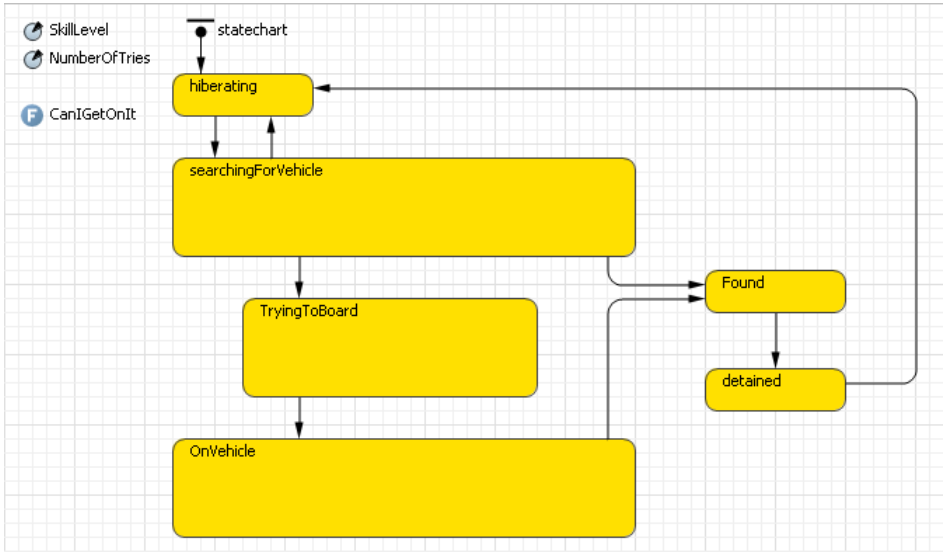


Next Steps

- 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