G54SOD (Spring 2018)

Workshop 10
Cost-Benefit and Multi-Criteria Decision Analysis

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Cost Benefit Analysis (CBA)

For more details see Damodaran (2007)

Cost Benefit Analysis

- CBA adds up the **total costs** of a programme or activity and compares it against its **total benefits**
  - Assumes that a **monetary value** can be placed on all the costs and benefits of a programme (including tangible and intangible returns)
- Methods (most commonly used)
  - Scenario Analysis
  - Decision Trees
  - Monte Carlo Simulation

Steps in a Scenario Analysis

1. Define possible scenarios and responses
2. Calculate economic costs
3. Calculate total economic costs
4. Calculate net benefits
5. Conduct a sensitivity analysis

Example: Port of Calais

Siebers, PO, Aickelin U and Sherman G (2009) 'Development of a Cargo Screening Process Simulator: A First Approach'. In: Proceedings of the 21st European Modeling and Simulation Symposium (EMSS2009), 23-25 Sep, Tenerife, Spain.

Scenario Analysis

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

Table 2: Two factors with three scenarios each and their probability of occurrence

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% (Cost: £5,000,000)
    - Increasing the search activities by 20% (Cost: £10,000,000)

Scenario Analysis

- Calculating Economic Costs (EC)
  - PLM = Positive Lorries Missed
  - SG = Search Growth

$$PLM(TG,SG)=PLM*(1+TG)/(1+SG) \quad (1)$$

Table 3: PLM for (PLG=0)

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

$$EC(TG,SG,PLG)=PLM(TG,SG)*(1+PLG) \quad (2)$$

Table 4: EC for different SG options

SG 0%	PLG -50%	PLG 0%	PLG 25%
TG 0%	£30,000,000	£60,000,000	£75,000,000
TG 10%	£33,000,000	£66,000,000	£82,500,000
TG 20%	£36,000,000	£72,000,000	£90,000,000
SG 10%	PLG -50%	PLG 0%	PLG 25%
TG 0%	£27,272,727	£54,545,455	£68,181,818
TG 10%	£30,000,000	£60,000,000	£75,000,000
TG 20%	£32,727,273	£65,454,545	£81,818,182
SG 20%	PLG -50%	PLG 0%	PLG 25%
TG 0%	£25,000,000	£50,000,000	£62,500,000
TG 10%	£27,500,000	£55,000,000	£68,750,000
TG 20%	£30,000,000	£60,000,000	£75,000,000

Scenario Analysis

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

$$p(TG,PLG)=p(TG)*p(PLG) \quad (3)$$

Table 5: Combined probabilities

	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

$$TEC(SG)=\sum(EC(SG,TG,PLG)*p(TG,PLG)) \quad (4)$$

$$NB(SG)=TEC(SG=0)-TEC(SG)-C(SG) \quad (5)$$

Table 6: CBA for different SG options

Option	1	2	3
SG	0%	10%	20%
TEC	£60,500,000	£55,000,000	£50,416,667
C	£0	£5,000,000	£10,000,000
NB	£0	£500,000	£83,333

CBA using Scenario Analysis

- Sensitivity Analysis for Positive Lorries Missed (PLM)

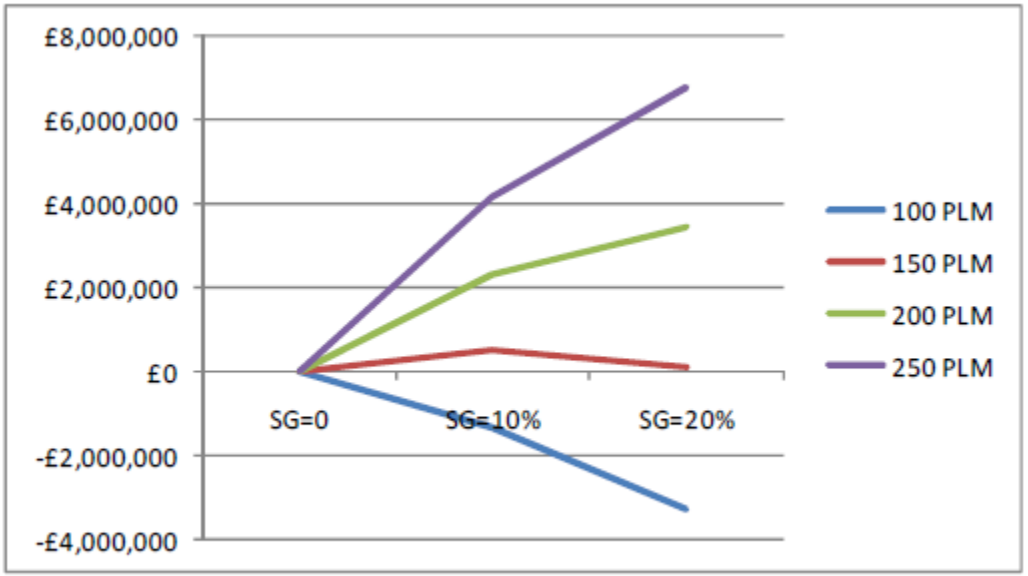


Figure 2: Sensitivity analysis results

Multi Criteria Decision Analysis

For more details see Dodgsonet et al (2009)

What is MCDA

- Provides an overall **ordering of options**; from the most preferred to the least preferred one
- 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 Static 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. Conduct a sensitivity analysis

Example: Port of Dover

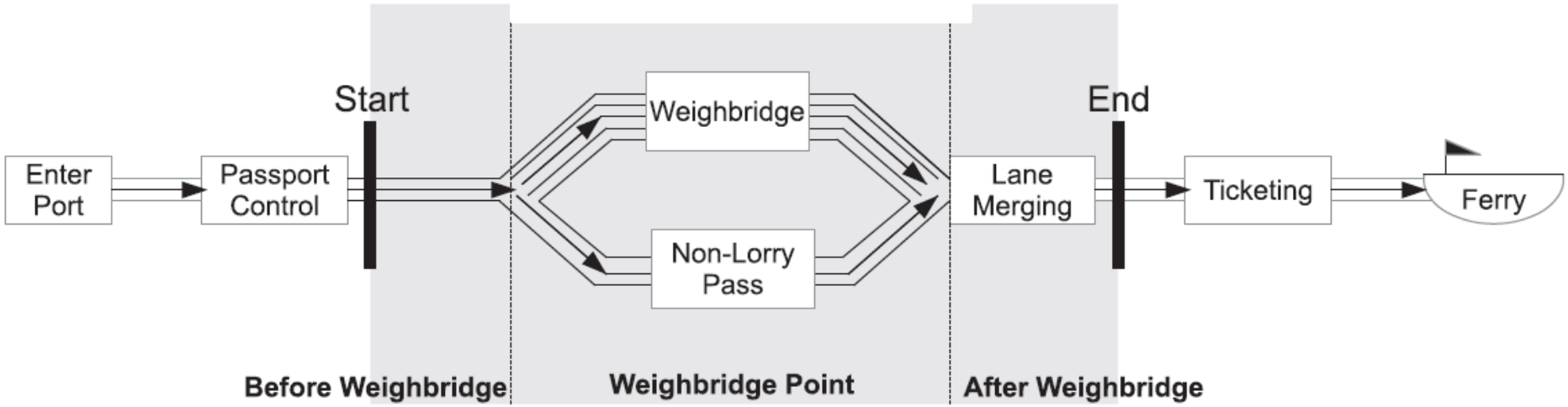
Aickelin U, Reps JM, Siebers PO , Li P (2017). Using Simulation to Incorporate Dynamic Criteria into Multiple Criteria Decision Making. Journal of the Operational Research Society, 0(online)

Example: Port of Dover

- When the customers go through the port, they will pass several important check points where they might have to queue.
  - Passport checking
  - Weighbridge (for lorries only)
  - Ticketing booths

- Dover aims to double the current traffic in twenty years
  - Whether the current system can handle the traffic growth is the problem that worries Dover Harbour

Example: Port of Dover



Example: Port of Dover

- System under study
  - Port of Dover
- Key factors to be considered
  - Traffic growth (space constraints; environmental concerns)
  - Service quality (customer satisfaction)
  - Environmental damage (through traffic growth)
  - Profit
- Specific case we investigate
  - Traffic flow in the port (**weight bridges are the flow bottleneck**)

Example: Port of Dover

From Static to Dynamic MCDA

- We are interested in "Risk Analysis" of a human centric system
  - For this purpose often CBA and MCDA are used together
  - Both are usually static decision support tools

- Agent Oriented Discrete Event Simulation (AO-DES)
  - Allows to simulate the dynamics of a human centric system over time
  - Agent oriented > we can consider different types of people

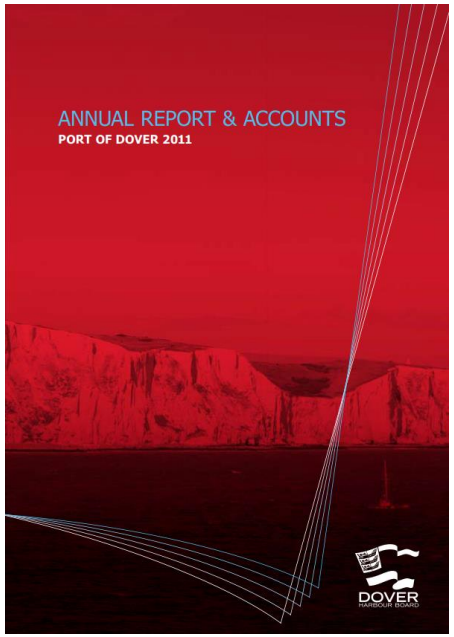
- We use CBA to deal with the monetary factors and AO-DES to deal with the non-monetary factors

Steps in a Dynamic MCDA

1. Collect information
2. Conduct CBA
3. Build a simulation model and run some relevant experiments
4. Conduct **MCDA using the results** from CBA and simulation
5. Conduct **sensitivity analysis** to **minimise risk**
6. Provide suggestions to the client

Data

- The annual report contains information about
  - Financial Result
  - Turnover
  - Costs; Net Finance Costs
  - Employees
  - Safety
  - Stakeholder's Benefit
  - Traffic running through Dover (2006-2011)



- Additional information
  - Budget for the tree planting (including cost of labour, cost for purchasing trees, and cost for maintenance)

Data

- Customers' satisfaction with nearby customers
  - Customers can be dissatisfied with the nearby fellow customers. But if they are coming together with their friends or colleagues, they will be more tolerable.
  - Since the data is quite subjective, four criteria have been used when interviewing people who know Dover's transportation well:
    - Whether they meet queue before entering the weighbridge point
    - Whether it is passive queuing
    - Whether the customer's temper is bad
    - Whether the customer comes alone

System Analysis

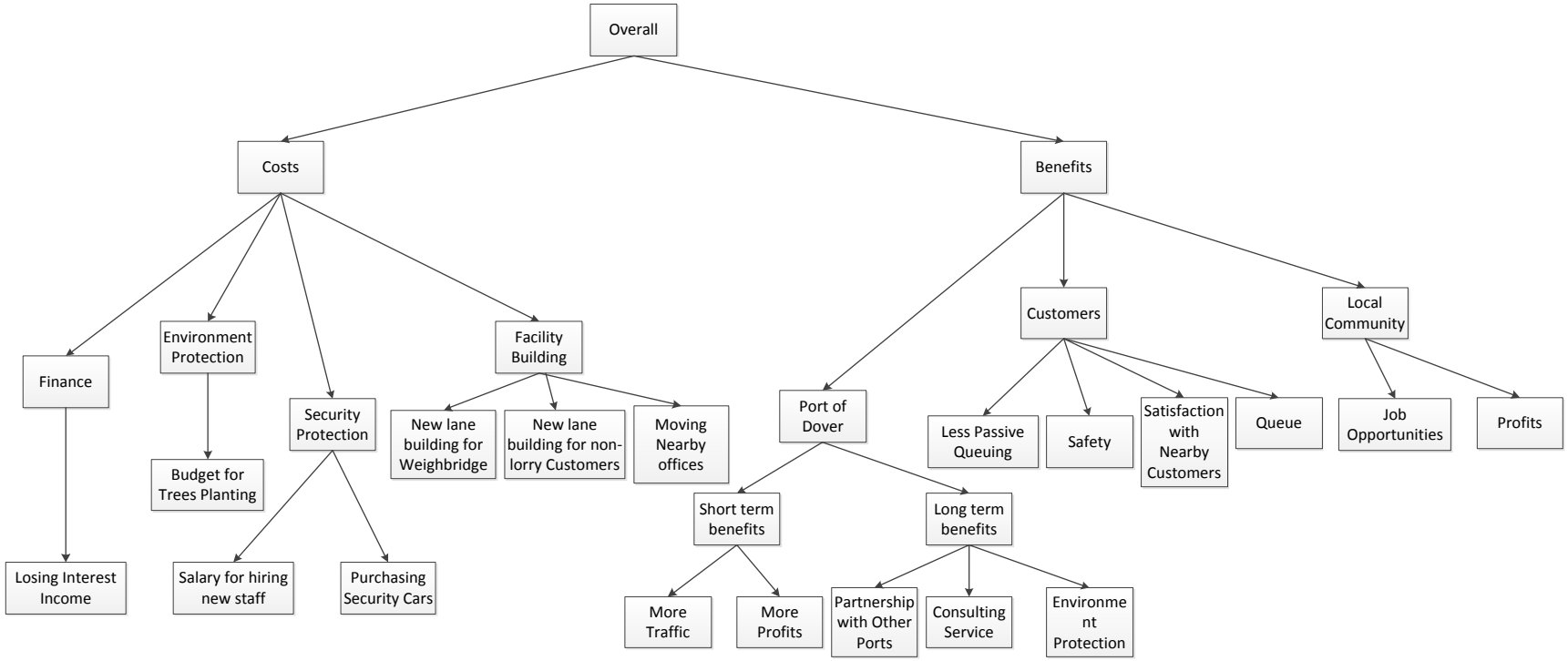
- Constraint
  - Due to space constraints a maximum of 8 lanes is possible in the weight bridge area

- Identified strategies
  - Strategy 1 represents the base case (current situation)

	Number of Weighbridges	Number of non-lorry Lanes
Strategy 1	5	2
Strategy 2	6	2
Strategy 3	5	3

System Analysis

- Criteria Identification
  - Two high level objectives are costs and benefits



Scenario Identification

- Scenarios related to Vehicle Traffic growth

	Vehicle Traffic Growth (VTG)	p(VTG)
Scenario 1	0%	25%
Scenario 2	10%	50%
Scenario 3	20%	25%

- Scenarios related to Lorry Traffic percentage

	Share of lorries (LTP)	p(LTP)
Scenario 1	44.17%	50%
Scenario 2	46.38% (5% increase)	25%
Scenario 3	48.59% (10% increase)	25%

CBA Cost Summary

- Economic costs

	VTG 0%	VTG 10%	VTG 20%
Strategy 1	£ 0	£ 205,146.8	£ 461,487.4
Strategy 2	£ 92,149	£ 297,296	£ 553,636
Strategy 3	£ 92,149	£ 297,296	£ 553,636

- Total economic cost

	Strategy 1	Strategy 2	Strategy 3
Total Economic Cost	£ 217,945.3	£ 310,094.1	£ 310,094.1

CBA Benefit Summary

- Benefit trough profit
  - Linear relationship between traffic growth and profit

	VTG (0%)	VTG (10%)	VTG (20%)
Strategy 1	£ 0	£ 758,800	£ 1,517,600
Strategy 2	£ 0	£ 758,800	£ 1,517,600
Strategy 3	£ 0	£ 758,800	£ 1,517,600

- Total benefit
  - As the total benefit comes from traffic growth and the traffic growth for all strategies is the same the three strategies have the same monetary benefit

	Strategy 1	Strategy 2	Strategy 3
Benefit	£ 758,800	£ 758,800	£ 758,800

AO-DES Conceptual Model

- Objective:
  - Simulate the customers passing the weighbridge point; collect the data at each point and use it to analysis customers' satisfaction
- Constraints
  - A maximum of 8 lanes can be built due to space constraints
- Experimental Factors:
  - Customer arrival rate
  - Number of weighbridges
  - Number of non-lorry lanes
  - Size of the queuing area at the weighbridge
  - Service time at the weighbridge point

AO-DES Conceptual Model

- Experimental Factors (continued):
  - % of lorry among the traffic
  - % of the customers that are driving together with friends or colleagues
  - Percentage of the customers with nice temper

- Responses:
  - Percentage of customers who are angry with their nearby neighbours
  - Percentage of customers who meet passive queuing
  - Percentage of customers who meet a queue before entering the weighbridge point

AO-DES Conceptual Model

- Assumptions:
  - The queue before entering the weighbridge point has unlimited space
  - Probability is used when considering the customers' temper and relation with other customers
  - At the end of the weighbridge time for queues merging is quite short
  - Only the queue behaviour before entering the weighbridge point will affect customer satisfaction

- Simplification:
  - Normal distribution is used for service time at the weighbridge

AO-DES Conceptual Model

- Scope

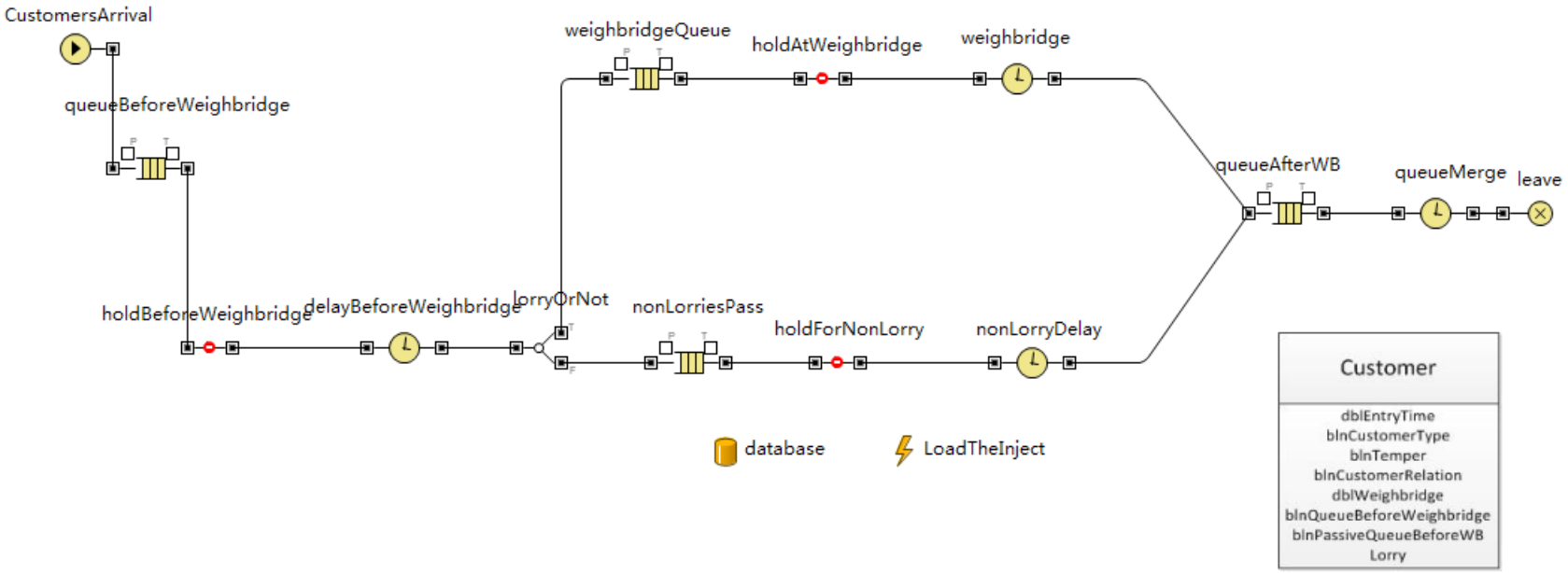
Customers		Include	Main entity (Experimental factor; response)
Staff		Include	Responsible for service time (Experimental factor; response)
Weighbridge		Exclude	Represented by staff
Non-lorry lane		Include	Customers spend less time than the weighbridge
Queues	Before entering the weighbridge point	Include	Record whether the customer meet passive queuing
	At the weighbridge point	Include	Directly related to waiting time
Weight of the lorry		Exclude	Implicit in service time

AO-DES Conceptual Model

- Level of detail

Customer	Arrival time	Include	Using historical data
	Customer Type	Include	Using historical data
	Temper	Include	A small percentage of the customers is not very nice to the others
	Customer Relation	Include	A small percentage of customers is coming with their friends' or colleague's
	Brand of vehicle	Exclude	Not relevant
	Time spending at the weighbridge point	Include	For both the lorry and non-lorry, the waiting time should be considered
	Passive Queuing	Include	If the lorry is queuing because of the non-lorry customer stuck the traffic, they will not be very satisfied and vice versa.
Staff	Service time	Include	Normal distribution
	Absenteeism	Exclude	Rarely occurs
	Age	Exclude	Not relevant
	Training level	Exclude	Reflected in service time
Queues	Queuing	Include	Required for waiting time response
	Capacity	Include Exclude	The size queue before entering the weighbridge is unlimited. But the queue at the weighbridge has limited capacity
	Queuing Behavior	Include	Customer's temper will be considered

AO-DES Conceptual Model



Data Organisation

- Performance for each strategy

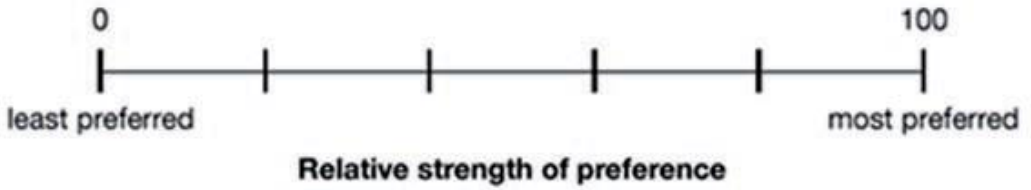
Criteria		Strategy 1	Strategy 2	Strategy 3
Costs		£ 217,945.3	£ 310,094.1	£ 310,094.1
Benefits for Port	profits	£ 758,800	£ 758,800	£ 758,800
Benefits for Customers	Queue	9.16%	0.06%	6.39%
	Passive Queuing	2.64%	0.01%	1.72%
	Safety	√	√	√
	Not Satisfy with nearby	5.28%	0.03%	3.65%
Benefits for local community	Bring more Profits	√	√	√
	More Job opportunities		√	√

Scoring

- Score the options on the criteria

  - Relative preference scales; comparing differences in consequences (people find it easier to make relative judgements) by replacing 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



AO-DES Data Organisation

- Scored options

Criteria		Strategy 1	Strategy 2	Strategy 3
Costs		100	0	0
Benefits for Port	profits	100	100	100
Benefits for Customers	Queue	0	100	30.4
	Passive Queuing	0	100	35.0
	Safety	100	100	100
	Not Satisfy with nearby	0	100	31.0
Benefits for local community	Bring more Profits	100	100	100
	More Job opportunities	0	100	100

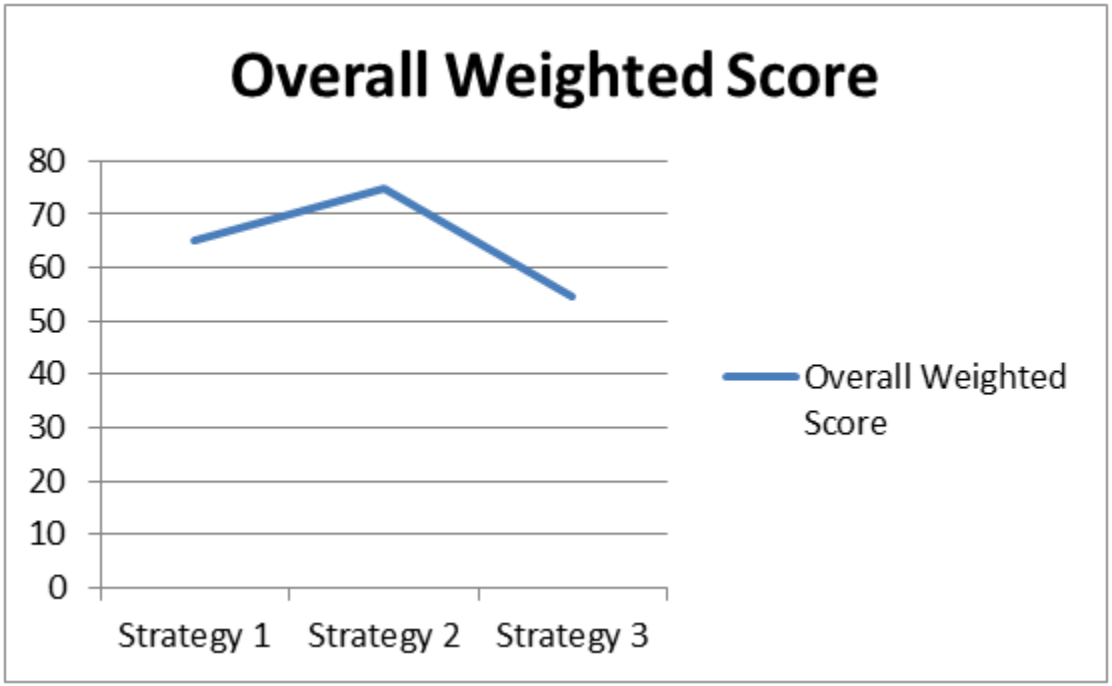
AO-DES Data Organisation

- Weight assignment + overall weighted score calculation

Criteria		Strategy 1	Strategy 2	Strategy 3	Weights
Costs		100	0	0	**25**
Benefit for Port	profits	100	100	100	**25**
Benefits for Customers	Queue	0	100	30.4	**10**
	Passive Queuing	0	100	35.0	**10**
	Safety	100	100	100	**10**
	Not Satisfy with nearby	0	100	31.0	**10**
Benefits for local community	Bring more Profits	100	100	100	**5**
	More Job opportunities	0	100	100	**5**
Total		**65**	**75**	**54.64**	

MCDA: AO-DES Overall Weighted Score

- Strategy 2 shows the best potential



Sensitivity Analysis

- Do other scores or weights affect the overall ordering of the options?
  - Using the model to examine how the scoring or ranking of options might change under different 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: AO-DES Weights Assignments

- Sensitivity analysis setup

Criteria		S 1	S 2	S 3	W 1	W2	W3	W4
Costs		100	0	0	16	13	5	21
Benefits for Port	profits	100	100	100	20	21	19	16
Benefits for Customers	Queue	0	100	30.4	14	11	20	12
	Passive Queuing	0	100	35.0	13	12	10	11
	Safety	100	100	100	14	13	15	12
	Not Satisfy with nearby	0	100	31.0	13	14	19	15
Benefits for local community	Bring more Profits	100	100	100	7	7	7	7
	More Job opportunities	0	100	100	3	9	5	6

MCDA: AO-DES Sensitivity Analysis

- Changes of weights do not affect the final result

Exam

- There is a mock exam on Moodle
  - Go through it to get an idea about timing
- Conceptual modelling
  - Use the announcement template and tips

- Simulation
  - You should be familiar with all simulation methods
- Optimisation
  - Not sure

Questions / Comments

References

- Damodaran, A., 2007. Strategic risk taking: a framework for risk management. Upper Saddle River, New Jersey: Wharton School Publishing.
- Dodgson, J. S., Spackman, M., Pearman, A., & Phillips, L. D. (2009). Multi-Criteria Analysis: A Manual.
- Keeney, R. L., & Raiffa, H. (1976). Decisions with Multiple Objectives: Preferences and Value Tradeoffs, John Wiley, New York, reprinted, Cambridge University Press, 1993.