Decision Analysis: MN50417

Aims and objectives of this unit

Decisions relating to technology and innovation in businesses and other organisations are often difficult because of their complex structure, uncertainty and risk, the desire to achieve several, often conflicting, objectives and the existence of different groups or individuals who all have a stake in the outcome of the decision. This course aims to explore a number of methods that are designed to address these problems. Used correctly, these methods can often yield insights into the nature of the decision so that the decision makers can develop a better understanding of the problems they face. Throughout the course the strengths and limitations of the methods will be highlighted so that you will be able to judge whether it is appropriate to use them in particular contexts.

This is an essentially practical unit. The approaches that you will encounter have been applied in a wide range of organisations ranging from a voluntary organisation in Australia to the US postal service and from UK defence establishments to a leading confectionery company. Though most of the approaches are essentially quantitative, the course will not involve any abstract or complex mathematics or difficult notation.

Specifically, the aims of the unit are:

- ⇨ To investigate how individuals and groups of people make decisions relating to technology and innovation and to evaluate their decision-making abilities;
- ⇨ To explore, in an applied context, a number of methods that are designed to enable complex decision problems relating to technology and innovation to be tackled with insight and confidence;
- ⇨ To evaluate these methods by critically examining their underlying assumptions and rationale

Teaching/Learning Approach

The ten sessions during the week will be used i) to introduce the material in an interactive way; ii) to apply decision analysis to case studies and smaller decision problems, iii) to explore psychological biases that are associated with decision making iv) to use computer software to model decision problems and v) and to discuss and debate controversial issues associated with decision making and decision analysis.

The reading associated with each session will be indicated in the notes.

About the lecture notes

Detailed lecture notes will be provided for the entire week. These lecture notes are designed as a package to supplement the textbook and other course materials. They will contain the lecture plan for the unit, the reading list, the learning objectives and reading for each session, tutorial exercises, case studies, occasional notes to supplement the textbook and copies of lecture slides (where appropriate). A specimen examination paper, together with suggested answers, will be provided in due course.

Moodle

You will find on Moodle:

- All the lecture notes and Powerpoint slides
- Suggested answers to all in-class exercise and case studies
- Quiz questions which should be helpful when you come to revise for the examination (answers are supplied in a separate folder on Moodle)
- Old examination papers with outline answers
- A copy of the coursework

Assessment

The unit is assessed by using one piece of *individually* assessed coursework (which will take the form of a case study problem that is amenable to decision analysis) and a two-hour closed book written examination. Your final mark on the unit will be the calculated as a weighted average of your coursework (40%) and examination marks (60%).

The lecturers

Paul Goodwin and Baris Yalabik will be the lecturers.

Reading

The recommended textbook for the course is:

P. Goodwin and G. Wright, *Decision Analysis for Management Judgment* (4th edition), Wiley, 2009.

Other useful texts are:

S.French, J. Maule and N Papamichail, *Decision Behaviour, Analysis and Support,* Cambridge University Press, 2009.

(Covers both behavioural issues and decision support methods)

G.P Hodgkinson and W.H Starbuck (Eds.) *The Oxford Handbook of Organizational Decision Making,* Oxford University Press, 2008.
(Contains a diverse collection of chapters which look at decision making from multiple perspectives).

S.R. Watson and D.M. Buede, *Decision Synthesis,* Cambridge University Press, 1987
(This book is often demanding mathematically, but it is also particularly strong on practical applications)

D. von Winterfeldt and W Edwards, *Decision Analysis and Behavioral Research,* Cambridge University Press, 1986
(A comprehensive and challenging text, which is strong on theory and practical applications.)

The following journals are also worth consulting:

Interfaces (Contains numerous examples of practical applications of decision analysis)

Journal of Behavioural Decision Making (emphasis is on behavioural aspects)
Organizational Behaviour and Human Decision Processes (emphasis is on behavioural aspects)

Papers relating to decision analysis can also sometimes be found in:

Management Science
Journal of the Operational Research Society
Omega

MSc in Innovation & Technology Management
Decision Analysis: Lecture Plan

Session	Topic	
Monday AM	Introduction. Why decisions can go wrong.	(PG)
Monday PM	Structuring decision problems: decision trees	(BY)
Tuesday AM	Heuristics & biases associated with judgment under uncertainty	(PG)
Tuesday PM	Probability assessment and risk analysis	(BY)
Wednesday AM	Measuring attitudes to risk: utility Revising judgments in the light of new information	(BY)
Wednesday PM	CASE STUDY (No formal session)	
Thursday AM	Decisions involving multiple objectives: SMART	(BY)
Thursday PM	Group decision making.	(PG)
Friday AM	Technological forecasting and planning: growth curves, the Delphi method, prediction markets	(PG)
Friday PM	Scenario planning and Review	(PG)

PG = Paul Goodwin

BY = Baris Yalabik

1 Decision Problems!

Objectives
At the end of this session you should understand the following :

⇨ Why business decisions are often complex

⇨ The relative merits of intuition and analysis when making decisions

⇨ Some common traps that people fall into when making decisions

⇨ The role of decision analysis in decision aiding

Reading: Goodwin and Wright, Chapter 1

Why business decisions are often complex

Business decisions are often complex because they involve:

1. Risk and uncertainty.

   e.g. if we decide to develop a new product we will be uncertain about its technological feasibility, future market conditions, production costs and the lifetime.

2. Multiple objectives –which often conflict.

   e.g. in choosing a new computer system we may want the cheapest, most reliable, most user-friendly, best supported, most easily implemented and most easily updated system; no system meets all of these requirements so we have to make trade-offs between the different objectives.

3. A complex structure

   e.g. if we choose to invest in technology A, we may have to decide later on what to do if the technology fails –there would be at least six options here, each contingent on the cause of the failure and each with different chances of success. Technology B , on the other hand, would need to be updated at some time in the future and we would have to decide how and when to do this. The updating decision would be influenced by market conditions, financial conditions at the time of the updating etc etc…

4. The existence of different individual or groups who all have a stake in the decision.

   E.g. If we decide to develop a new international airport at Filton, near Bristol, this will benefit business commuters and create employment for people in the Bristol travel-to-work area, but it will also course traffic congestion and noise for people living in the approaches to the airport and for people living under the flight path.

Is intuition the best way of making decisions?

There are many examples of where intuition has led to brilliant decisions and insights (see lecture slides).

Intuition (gut feel) works relatively well where:

- The decision is relatively unstructured (e.g. many problems that occur at the strategic level of organisations)

- There is no objective criteria for success (e.g. political, aesthetic or ethical problems)

- The decision maker has experience & expertise in problem domain (e.g. Carly Fiorina's ousting from Hewlett-Packard in 2005 was because "She did not have the right type of experience to succeed at HP"

However, our intuition can also deceive us (see examples on lecture slides). Relying unquestionably on intuition carries several dangers….

Quick decision making quiz

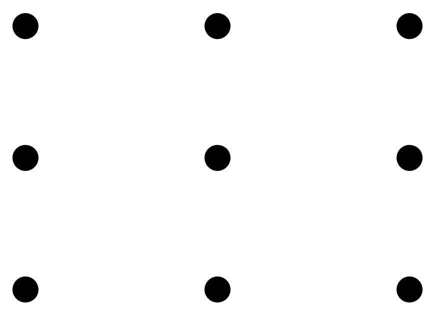
1. Your department has so far invested £12 million over the last three years in the development of a new product, but there are still a large number of technical problems to solve. Recent market research suggests that the product is unlikely to achieve the level of sales that were originally forecast and other technologies are likely to be developed in the near future which will render your product obsolete

   Would you: a) decide to continue with the development otherwise your £12 million will have been wasted.

   b) abandon the development, despite the huge investment that has already been made in it?

2. You are the manager of the division of a company. Your division has the opportunity of engaging in a project with another company that has a 50% chance of bringing gains of £5m and a 50% chance of losing the division £3m. Would you accept the opportunity?

3. On the diagram below, draw four continuous straight lines connecting all of the dots, without lifting your pencil from the paper:



4. Your organisation is experiencing serious financial problems and 3000 jobs are under threat. Two rescue packages are available.

   Package A will lead to the certain loss of 2000 jobs

   Package B has a 1/3 chance of losing no jobs and a 2/3 chance of losing 3000 jobs

   Which rescue package would you choose?

5. You are the manager of the division of a company. Your division has the opportunity of engaging in a package of 30 projects with another company. Each of these that has a 50% chance of bringing gains of £5m and a 50% chance of losing the division £3m. The projects are independent so that, if any one project gains or loses money, it will have no affect on the returns of the other projects. Would you accept the opportunity?

6. Your organisation is experiencing serious financial problems and 3000 jobs are under threat. Two rescue packages are available.

Package X will lead to 1000 jobs being saved
Package B has a 1/3 chance of saving all 3000 jobs and a 2/3 chance of saving no jobs.

Which rescue package would you choose?

Why people have problems coping with complex decisions

The human mind has limited information processing capacity and memory. For example, imagine disposing of your diary and trying to hold all of your appointments and commitments for the next year in your head or carrying out a complex set of a calculations in your head without using a pen and paper or a calculator. To cope with this complexity when facing a difficult decision problem we tend to try to simplify problems or focus on the simplest aspects of the problem. These simplifying mental strategies that we adopt are referred to as heuristics. They have evolved to give us efficient ways of handling decision problems quickly and with the least cognitive effort. However, what evolved to help us to survive in prehistoric times may not be useful when we face decisions in the modern world. As a result, these heuristics can sometimes lead to biases and poor decisions..

Problems with framing decisions

The frame refers to how you structure the decision problem. For example, what must be decided, what are the options and what are the criteria for choosing between the options? Several problems can arise when the decision is inappropriately framed including:

1. Solving the wrong problem

e.g. U.S car manufacturers from 1940 to 1970 used mathematical methods to determine the optimum length of production runs of a particular car model, before changing over to the production of a new model. Changing equipment from the production of one model to another took time –it was assumed between 6 to 8 hours – and hence led to loss of production. Thus frequent changes were undesirable, but production runs that were too long led to high stock levels and hence high stockholding costs.

Japanese manufacturers, particularly Toyota, framed the problem differently. They focused on reducing the changeover time (which US manufacturers assumed was fixed) and eventually got it down to 44 seconds. This saved thousands of dollars of production costs compared to their US rivals and almost led to the demise of the US car industry.

2. Get hooked on complexity –overlooking simple options

E.g. There were a large number of complaints from passengers at an airport terminal about the long waits for luggage to appear on the carousel. Much effort was expended in trying to improve the logistics and develop new designs for the baggage handling system However, the solution was
……………………………………………………………………

E.g. The Red Telephone company in Australia was losing money because telephone regulations mean that local calls cost the same amount, irrespective of the call's duration. This meant that people were often occupying its telephone kiosks for long periods, but generating only small amounts of cash for the company. The company needed a way to discourage long telephone calls, but financial disincentives were not permitted.

The solution to the problem was:
……………………………………………………………………………………..

3. Assuming sunk costs are relevant to the decision –the sunk cost fallacy

A sunk cost is the amount of money or other resources that has already been spent in pursuit of a course of action. These resources cannot be recovered, whatever course of action is chosen in the future. Because of this, sunk costs should not influence the decisions between courses of action that we have to make now. These decisions should be based on *future costs and future benefits*.

However, the desire to justify past costs can encourage people to pursue a strategy that is obviously not working when "cut your losses and abandon the strategy" would be the best advice. This phenomenon is sometimes referred to as <u>non-rational escalation of commitment</u>. Here are some examples:

- <u>The Tennessee-Tombigbee water project</u>. This huge construction project involved building a set of locks designed to connect the Tennessee and Tombigbee rivers so that the US state of Tennessee would be opened up to the Gulf of Mexico. By 1981 the costs incurred had already amounted to over $1 billion. However, new estimates revealed that the cost of completing the project from that point forward would be greater than the potential benefits? The US senators involved with the project argued:

  "To terminate a project in which $1.1 billion has been invested represents an unconscionable mishandling of taxpayers' dollars"

  "Completing (the project) is not waste of taxpayers' dollars. Terminating a project at this late stage of development would, however, represent a serious waste of funds already invested.

  The project was completed in 1985, but will never pay the back the costs incurred in its construction.

- <u>The pursuit of the Vietnam war</u>. On taking office in 1968 Nixon argued that he could not betray the 30,000 troops who had already died in the war. As a result the US continued the war and 15,000 more troops lost their lives. In the end, South Vietnam became communist, anyway.

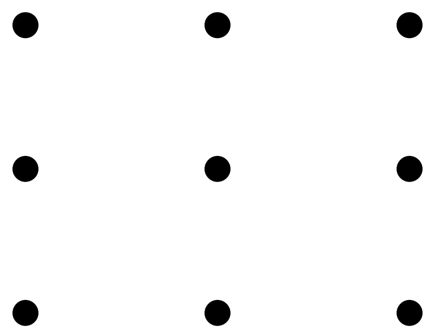
- <u>The Millenium Dome</u>. On 28 May 2000 *The Independent* reported: “So much money has disappeared into the Dome -£897 million at the last count –that it has been compared to a financial black hole, from which nothing, not even light entertainment, can escape… Last week the Millenium Commission doled out a further £29 million to keep the show on the road."

W.C. Fields once said "If at first you don't succeed, try, try again. Then quit. No use being a damn fool about it

4. Imposing imaginary constraints on the range of options

The nine dot problem

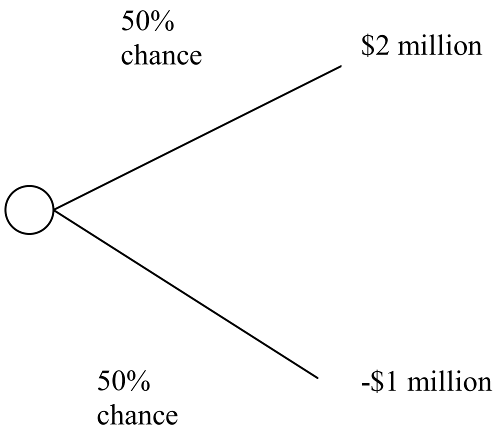
On the diagram below, draw four continuous straight lines, connecting all of the dots, without lifting your pencil from the paper:



5. Narrow bracketing of decisions

The way we mentally bracket groups of decision together often influences how much risk we are prepared to take when making each decision. In companies, when projects are evaluated one at a time, rather than part of an overall portfolio there is usually an extreme unwillingness to take risks. Taking a broader view, i.e. looking at all the projects together can act as an antidote to this excessive risk aversion.

E.g. Richard Thaler, a US professor ,was teaching a group of executives from one firm, each of whom was responsible for managing a separate division. He asked each where s/he would be willing to undertake a project for the division if the payoffs were as follows:



Only three of the 25 executives accepted the gamble. However, when the CEO was asked whether he would like to undertake a portfolio of 25 of these investments he nodded enthusiastically,

6. Being influenced by reference points

The outcomes of a decisions tend to be evaluated in terms of *changes* from a reference point, e,g. gains and losses from your current level of wealth (the reference point). However, simply changing the reference point can lead us to make different decisions for the same problem.

E.g. Tversky and Kahneman posed these problems to people:

A. Imagine that you are about to purchase a jacket for $125 and a calculator for $15. The calculator salesperson informs you that the calculator you wish to buy is on sale for $10 at the other branch of the store, located 20 minutes drive away. Would you be willing to make the trip to the other store?

Most people say they would be willing to travel. The reference point they are using is the £15 price of the calculator –a saving of $5 on $15 seems worth having.

B. Imagine that you are about to purchase a jacket for $15 and a calculator for $125. The calculator salesperson informs you that the calculator you wish to buy is on sale for $120 at the other branch of the store, located 20 minutes drive away. Would you be willing to make the trip to the other store?

Most people say they would not be willing to travel. The reference point they are using is $125 price of the calculator –a saving of $5 on $125 does not seem worth the effort of the 20 minute journey.

Yet in both cases the decision problem is the same: is it worth driving for 20 minutes to save $5?

E.g. Consider the following options, also posed by Tversky and Kahneman

1. Imagine that the country is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed.

Program A will lead to 200 lives being saved

Program B will lead to a 1/3 chance of saving 600 lives and a 2/3 chance of saving no lives.

Which program would you choose?

Most people (72%) chose Program A –presumably because they did not want to risk the 2/3 probability of saving no lives.

2. Imagine that the country is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed.

Program A will lead to 400 deaths

Program B will lead to a 1/3 chance of 0 deaths and a 2/3 chance of 600 deaths

Which program would you choose?

Most people (78%) chose Program B –presumably because 400 deaths seems almost as bad as 600 and because it seemed worth taking a chance that nobody would die at all.

Although the problems are identical they suggest the use of two different reference points. In decision (1) the reference point is the 600 deaths if nothing is done. People see the outcomes as gains from this worst-case scenario. In decision (2) the reference point is the situation where no one dies from the disease. The outcomes are seen as losses from this reference point.

Now Tversky and Kahneman have also shown that people tend to be risk averse when faced with gains and risk seeking when facing decisions involving losses. Hence the change of reference point means that they tended to choose the less risky decision when facing the gains in formulation (1) and the riskier decision when facing the losses in formulation (2).

7. Ignoring or misjudging probabilities

People often make decisions without any reference to the probabilities of different outcomes. As we shall see later in the course, people also have systematic tendencies to misjudge probabilities. This means that:

a) People seeking to avoid a risky course of action, mistakenly opt for an even riskier action in its place.

For example, in the year after 9/11 Americans drove cars to avoid the risk of flying. But flying is much safer than driving –even after taking into account the terrorist threat (A US professor calculated that , even if terrorists were hijacking and crashing one passenger jet a week in the USA, a person who took one flight a month for a year would have a 1/135,000 chance of being killed in a hijacking –a small risk compared to the 1/6000 probability of being killed in a car crash.

An estimated 1595 people died because of the switch from planes to cars (Gigerenzer, 2006)

b) It can also mean that scarce resources are wasted in trying to reduce relatively small risks when the money would have been better spent on reducing much larger risks.

E.g. After an accident on the London tube system on 1 February 2003, the Central line was closed for some considerable time. Arguably, the increased risk of death and injury though road accidents caused by the increased traffic volume far outweighed the risk of another accident had the line been quickly re-opened.

The role of decision analysis

How can decision analysis help to improve decision making?

- Analysis implies 'divide and conquer' -complex problems are broken down into small parts which are more easily handled (a process known as decomposition)
- It yields a defensible rationale for a chosen course of action (i.e. an 'audit trail')
- It raises consciousness about the issues involved in the decision
- It allows participation of different specialists and stakeholders; participation in the decision process often leads to commitment to make the decision work
- It can yield insights, often by challenging the decision maker's intuitive view of the problem, and can lead to creative thinking
- It can provide guidance on information needs and indicate which sources of information are cost effective.

Note that the main purpose of decision analysis is to yield insights and understanding about the decision problem, rather than to impose an 'optimal' solution.

2 Modelling decision problems -Decision Trees

Objectives: At the end of this session you should be familiar with the following topics:

- ⇨ Decision trees
- ⇨ Sensitivity analysis
- ⇨ Limitations of the expected monetary value (EMV) criterion

1. Expected Values

An expected value is a "long run average result". For example, if a fair die is thrown a large number of times the average score should be around 3.5.

To calculate an expected value from a probability distribution simply multiply each outcome by its probability of occurrence and add the results.

Example

The weekly commission earned by a salesperson follows the probability distribution shown below. Determine her expected weekly commission.

Commission	Probability
£80	0.3
£90	0.5
£100	0.2

The expected commission = (80 x 0.3) + (90 x 0.5) + (100 x 0.2) = **£89**

Quick check on your understanding so far

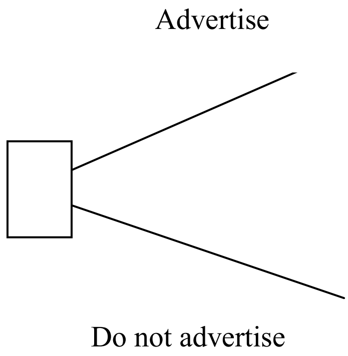
You offered a bet which gives you a 0.1 probability of winning £10,000 and a 0.9 probability of *losing* £2000.

If you accept the bet, what are your expected winnings?

2. Decision Trees

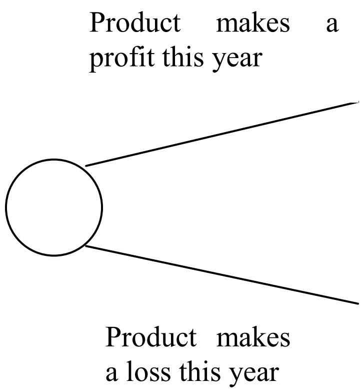
Decision trees are diagrams that are designed to represent and clarify decision problems. They are particularly useful where problems involve sequences of decisions. Two symbols are used in decision trees.

(i) *decision nodes* –these represent the alternative courses of action that are available, for example:



Immediately beyond a decision node, the decision maker can choose which route to follow

(ii) *chance nodes*: -these represent the possible outcomes of a decision, for example:



The outcomes emanating from a chance node are assumed to be beyond the control of the decision maker, once the decision has been made. Hence, immediately beyond a chance node, "chance determines" which route is followed.

Example: The inventor's decision problem

An engineer has invented a new device and has to decide whether to manufacture the device himself or to sell the patent rights to an established company. If he manufactures the device himself and sales are high, he estimates that he will earn £80,000, but, if sales are low, he will lose £5000. Alternatively, if he sells the patent rights, he will earn £40,000 in royalties if sales are high, but only £1000 if sales are low. The engineer estimates that the probability of high sales is 0.4, irrespective of whether he sells the patent rights or manufactures the device himself. Which option should the engineer choose?

Answer:

A decision tree for this problem is shown below:

Space left for diagram, *which will be drawn during lecture*

3. The Maximin Criterion

Decision criteria determine the rules that you should apply in order to make a decision. According to the maximin criterion the decision maker should proceed as follows:

1. For each course of action –identify the worst possible payoffs
2. Select the course of action which has the *best* of these worst possible payoffs

For the inventor's problem the options are listed below together with their worst possible outcomes:

Option	Worst payoff	
Manufacture device himself	-£5000	
Sell patent rights	£1000	← Best of the worst payoffs

Thus according to the maximin criterion the inventor should sell the patent rights.

Note that this criterion is suitable only if the decision maker is *extremely* risk averse. For example, consider the following two options:

Option A: This offers a 0.9999 probability of winning £10 million and a 0.0001 probability of losing £1

Option B: This will give you £1 for certain

According to the maximin criterion you should choose Option B. Obviously, it is very unlikely that this choice would be consistent with most decision makers' preferences.

4. The Expected Monetary Value (EMV) criterion

According to the EMV criterion, the decision maker should choose the option that yields the best *expected* payoff (i.e. the highest expected gain or the lowest expect loss).

For the inventor's problem the expected profits are shown below for the two options:

Option	Expected payoff (£)	
Manufacture device himself	(0.4 x 80000) + (0.6 x –5000) = £29000	← Best
Sell patent rights	(0.4 x 40000) + (0.6 x 1000) = £16600	

This, according to the EMV criterion, the engineer should manufacture the device himself.

5. Limitations of the method applied in the last section

a) Since an expected value represents the average payoff which would accrue if the decision was repeated a large number of times, is it reasonable to apply it to a one-off decision?

b) The EMV criterion assumes the decision maker is *risk neutral*. This means that it does not take into account the decision maker's attitude to risk if he or she is either risk averse or risk seeking. One answer to this problem is to use a criterion called "expected utility" which will be covered later on this course.

This problem can be seen clearly in the famous **St Petersburg paradox**, described by Bernoulli. Imagine that you are offered the following gamble. A fair coin is to be tossed until a head appears for the first time:

If the head appears on the 1st toss you will win £2
If the head appears on the 2nd toss you will win £4
If the head appears on the 3rd toss you will win £8
If the head appears on the 4th toss you will win £16

and so on…….

How much would you be prepared to pay to engage in the gamble ?

…………….

According to the EMV criterion you should be prepared to pay

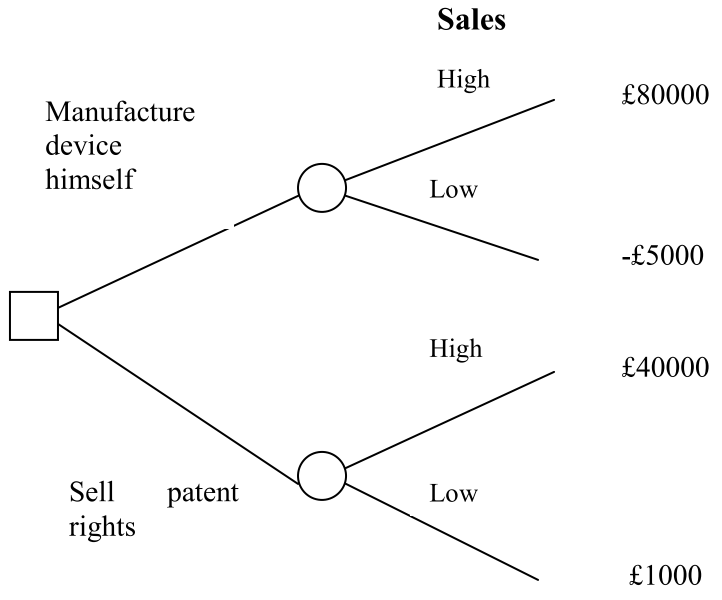
……………….

c) The EMV criterion assumes that the decision involves only one objective, namely maximisation of monetary returns. However, many decisions involve several, often conflicting, objectives many of which cannot be assessed in monetary terms e.g. conservation of the environment, aesthetic and social factors. If a decision does involve multiple objectives, "multiattribute utility" models can be used instead of the EMV criterion.

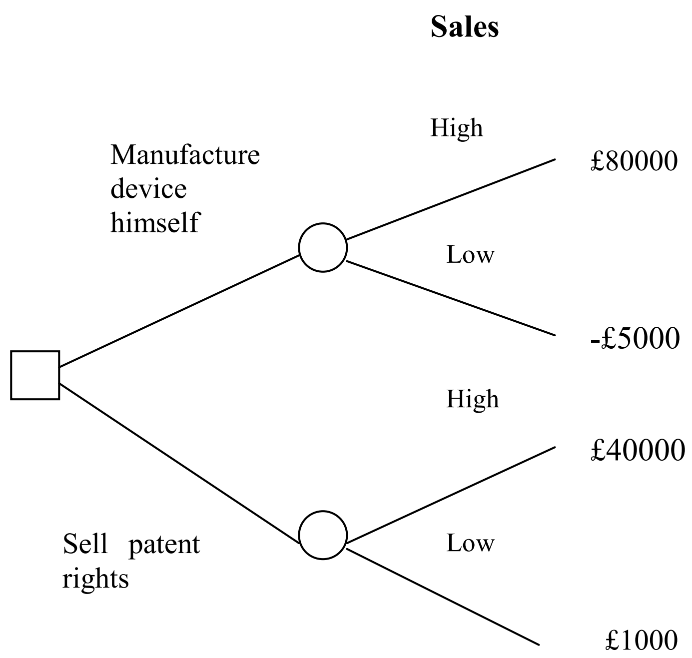
d) The probabilities and payoffs are only guestimates. However, note that sensitivity analysis (see next section) often shows that these guestimates do not need to be exact. It sometimes takes quite large changes in these figures before an alternative option becomes preferable.

6. Sensitivity Analysis

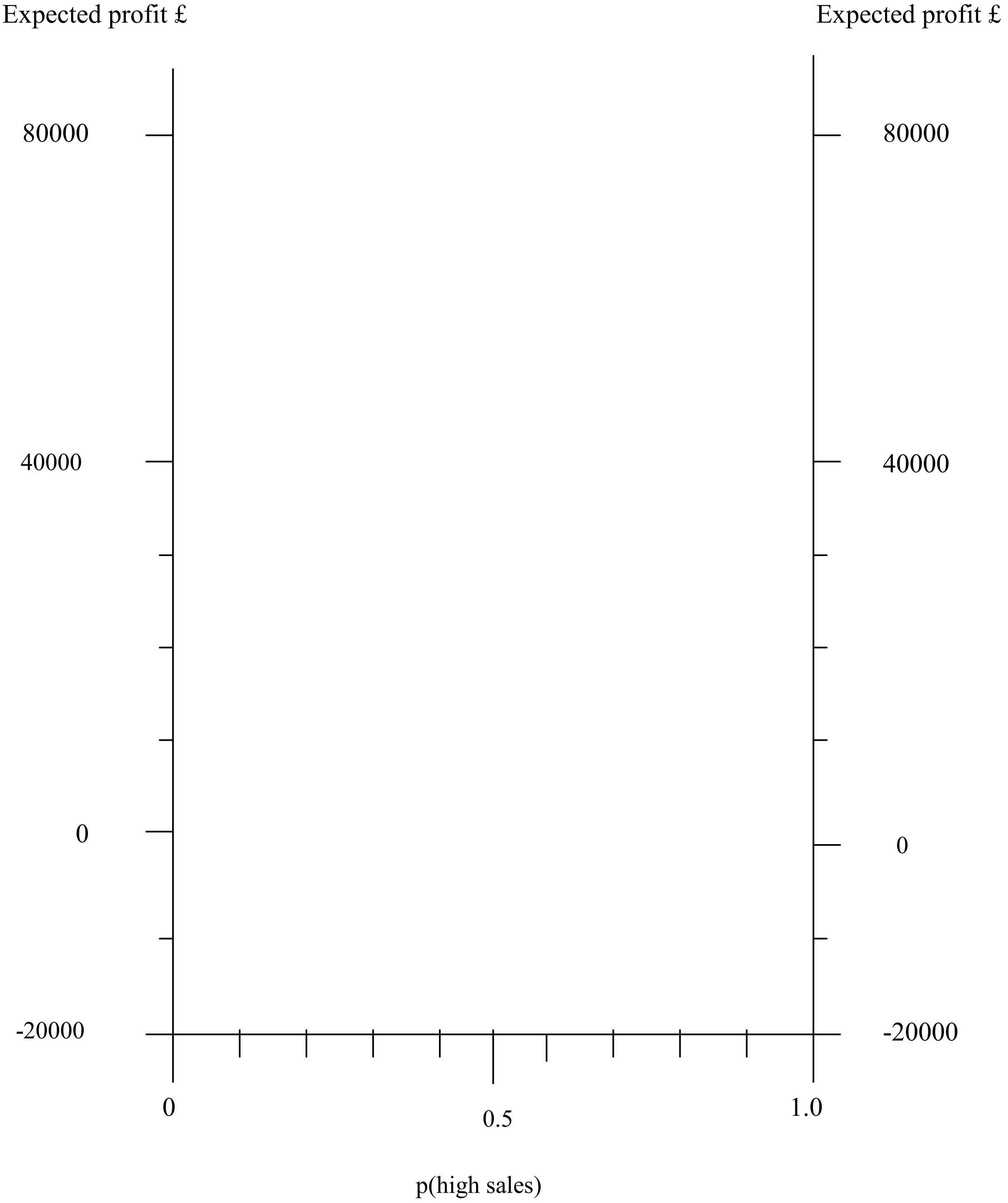
The probabilities in the model may be subjective estimates, or if they have been derived from past data, they may be subject to change. It is therefore useful to examine how large a change in the probabilities is required before an alternative course of action is chosen. This process is known as sensitivity analysis. We first examine which option we would have selected if the probability of high sales was 0:



Then we examine which option we would have selected if the probability of high sales was 1.0.



These results are then plotted on the graph below.



It can be seen that the inventor should decide to manufacture the device himself only if the probability of high sales is at least 0.13. Otherwise, he should sell the patent rights.

7. Decision trees involving sequences of decisions

Hitech Svstems plc

Hitech are planning to manufacture a new state-of-the art product and have to choose between two production methods. If production method I is chosen, there is only a 0.6 probability of it working, in which case the returns from the method will be £6 million. If the method fails, Hitech will have to decide whether or not to modify it or to abandon the entire project at a loss of £5 million. If the method is modified, there is a 0.4 probability that it will work and yield net returns of £1 million. However, if the modification fails, losses of £6 million will be incurred.

If production method II is chosen there is a 0.7 probability that it will work and yield returns of £3 million. However, if it fails losses of £2 million will be incurred and, for technical reasons, the method cannot be modified. Determine the sequence of decisions which maximises expected returns.

Answer:

Space left for diagram, which will be drawn during lecture

Thus, according to the EMV criterion, Hitech should opt for production method I and, if the method fails, they should attempt to modify it.

Mini Case Studies

1) A company has to supply some technical equipment to a customer in Rumania and three alternative modes of transport are being considered: rail, air and sea. Rail transport will cost £3500, air transport will cost £5000 and it will cost £1900 to send the equipment by sea. If the equipment is delivered late, the company will have to pay a penalty of £6000 in addition to the transport cost. The probability that rail transport will lead to late delivery is 0.3 while the probabilities for air and sea are 0.1 and 0.5 respectively.

   a) Which mode of transport will minimise expected total costs?

   b) How low would the probability of late delivery with (i) rail transport and (ii) air transport have to fall before it was worth considering these forms of transport?

2) Westward Magazine Publishers are thinking of launching a new fashion magazine for women in the under 25 years old age group. Their original plans were to launch in April 1989, but information has been received that a rival publisher is planning a similar magazine. Westward now have to decide whether to bring their launch forward to January 1989. This would cost an additional £500,000. If the launch is brought forward, it is estimated that the chances of launching before the rival are about 80%. However, if the launch is not brought forward, it is thought that there is only a 30% chance of launching before the rival.

   For simplicity, the management of Westward have assumed that the circulation of the magazine will be either high or low. If Westward launch before the rival, it is though that there is a 75% chance of a high circulation. However, if the rival launches first, this probability is estimated to be only 50%.

   If the rival does launch before Westward, then they could try to boost sales by advertising on commercial radio. This would cost about £200,000, but it is thought that it would increase the probability of a high circulation to 70%. Commercial radio advertising would not be considered if Westward's magazine was launched first.

   Westward's accountants have estimated that a high circulation would generate a gross profit over the magazine's lifetime of £4 million. A low circulation would bring a gross profit of about £1 million. It is important to note, however, that these gross profits do not take into account additional expenditure caused by bringing the launch forward or by radio advertising.

   a) Assuming that Westward's objective is to maximise expected profit, advise them on their decision. (For simplicity, you should ignore the fact that cash flows have not been discounted cash flows to their present value.)

   b) In reality, Westward have little knowledge about the progress which has been made by the rival. Consequently, the probabilities given above for beating the rival (if the launch is or is not brought forward) are very rough estimates. How sensitive is the decision you recommended in (b) to changes in these probabilities? Explain and comment on your answer.

c) Discuss the limitations of the approach which you adopted to model Westward's decision problem.

Case Study: The Hartland River Authority

The risk of the flooding in land adjacent to the River Nudd has recently increased. This is because of a combination of high spring tides and the development by farmers of more efficient drainage systems in the nearby hills which means that, after heavy rainfall, water enters the river more quickly. A tidal barrier is being constructed at the mouth of the river, but the Hartland River Authority has to decide how to provide flood protection in the two years before the barrier is completed. Flooding is only likely to occur during the spring high tide period and the height of the river at this time cannot be predicted with any certainty. In the event of flooding occurring in any one year the Authority will have to pay out compensation of about £2 million. Currently, the Authority is considering three options.

First, it could do nothing and hope that flooding will not occur in either of the next two years. The river's natural banks will stop flooding as long as the height of the water is less than 9.5 feet. It is estimated that there is a probability of 0.37 that the height of the river will exceed this figure in any one year.

Alternatively, the Authority could erect a cheap temporary barrier to a height of 11 feet. This barrier would cost £0.9 million to erect and it is thought that there is a probability of only 0.09 that the height of the river would exceed this barrier. However, if the water did rise above the barrier in the first year, it is thought that there is a 30% chance that the barrier would be damaged, rendering it totally ineffective for the second year. The Authority would then have to decide whether to effect repairs to the barrier at a cost of £0.7 million or whether to leave the river unprotected for the second year.

The third option would involve erecting a more expensive barrier. The fixed cost of erecting this type of barrier would be £0.4 million and there would be an additional cost of £0.1 million for each foot in the barrier's height. For technical reasons the height of this barrier would be either 11 or 13 feet and it is thought that there would be no chance of the barrier being damaged if flooding did occur. The probability of the river's height exceeding the 13 feet barrier in anyone year is estimated to be only 0.004.

a) Draw a decision tree to represent the River Authority's problem.

b) Determine the optimum policy for the Authority, assuming that their objective is to minimise expected costs. (For simplicity you should ignore time preferences for money).

Further practice questions

1) The table below shows the probabilities of a product achieving particular sales levels on
a given day. Determine the expected level of sales.

Sales (no. of units)	0	1	2	3	4
Probability	0.1	0.3	0.4	0.1	0.1

2) The Casti engineering company manufactures specialized components for agricultural machinery. The moving part of one of these components needs to be protected by applying a waterproof seal to its surface. Recently, two new technologies have become available, which it is thought, could replace the existing sealing method and yield cost savings which would give Casti a significant advantage over competitors. The company now has to decide which technology, if any, it should develop (resource constraints mean that only one technology can be developed at any one time).
The first technology is a patented method called KVG electro-sealing. It is thought that there is a 0.8 probability that this technology could successfully be applied to the sealing process. The cost of developing this technology is estimated to be £8 million and a successful development would lead to *gross* savings (i.e. savings before development costs have been taken into account) of £19m with a probability of 0.1, £12 million with a probability of 0.5 and £9 million with a probability of 0.4. If the process could not be made to work successfully then the company would abandon the project and continue with the existing method of sealing.

The second technology would involve dipping the components in a solution of TCX. Developing this technology would cost an estimated £2 million, but it is thought that there is only a 0.65 probability that the process could be designed to meet EC pollution standards. If pollution standards can be met then the process will lead to *gross* savings estimated to be worth £8 million. If the standards cannot be met then the company would have three options. Either it could abandon the entire project, or it could attempt to modify the method or it could switch its resources in an to attempt to develop the KVG electro-sealing instead. Modifying the TCX dipping procedure would be likely cost a further £2 million and, it is thought that there would be a 50:50 chance that the modification would succeed. In the event of modification failing to meet the pollution standards the entire project would be abandoned.

Assuming that Casti's objective is to maximize expected net savings (i.e. gross savings minus development costs) determine the policy that the company should pursue (for simplicity you should ignore time preferences for money).

Answers to practice questions

1. Expected sales = 1.8 units

2. Casti should choose the TCX dipping procedure and, if it fails, modify it. This gives expected net savings of £3.9 million as opposed to £1.2 million for the KVG electro-sealing technology.

3 Heuristics and biases in probability estimation

Objectives

At the end of this session you should:

- ⇨ Be able to identify biases resulting from the availability, representativeness and anchoring and adjustment heuristics
- ⇨ Be aware of other potential biases, such as optimism bias and conservatism
- ⇨ Be able to discuss criticisms of research that ahs identified these heuristics and biases

Test your judgment

(1) In 2007 approximately what percentage of people in the USA (aged 12 or over) were victims of robbery according to the official statistics?

(2) Consider the chances of a randomly selected US citizen dying as a result of the following causes in the course of a year (as estimated in 2005): i) assault by a sharp object, such as a knife, ii) a fall, iii) firearm discharge, iv) being bitten or struck by a dog, v) being an occupant in a car that is involved in an accident.

Rank these causes of death from the most to least likely.

(3) Eight percent of people interviewed for jobs at a company have a criminal record. Given below are the notes made by the interviewer on one applicant, Jim X. These notes have been randomly selected from the files of interviewed candidates.

> Jim had an unshaven, scruffy appearance. Though his clothes looked expensive they did not fit him well. He never made eye contact during the interview and he had a strange, hard look about him. When I cracked a joke he failed to laugh. His handshake was weak and I noticed a scar on the back of his hand. He said he had no hobbies or family and his general demeanor was unfriendly, and even a little contemptuous.
>
> Estimate the probability, on a 0 to 100 scale, that Jim X has a criminal record.

(4) A box contains 100 light bulbs of which half are defective. A quality control inspector is about to select six bulbs randomly from the box. Which of the following sequences is most likely to occur:

	1st bulb	*2nd bulb*	*3rd bulb*	*4th bulb*	*5th bulb*	*6th bulb*
A	defective	OK	defective	OK	defective	OK
B	defective	defective	defective	OK	OK	OK

C OK OK defective OK defective defective

(5) A man has been driving for 40 years without having a road accident. A friend tells him that the chances of him being involved in an accident in the next five years must be high because the probability of an individual driving for 45 years without an accident is low. Is this thinking correct?

(6) In the British National Lottery people choose six numbers (from 1 to 49) which they hope will be randomly selected in the draw. When the lottery started, a newspaper advised: '... sometimes week after week, a certain number may resolutely refuse to put in an appearance. It becomes ''overdue'', and you could reason that therefore it is bound to turn up soon – the so-called cold number system.'

Would choosing 'cold numbers' increase your chances of winning the lottery?

(7) During the summer, a brewery's sales of canned beer are largely influenced by chance factors, such as the weather and the number of people watching sporting events. In the first week of August exceptional sales of 1.2 million cans were achieved. In the absence of other information, would you judge that it is more likely that sales for the following week will be:

(a) higher;

(b) about the same; or

(c) lower than 1.2 million cans?

(8) David is 28 years old, tall, slim and powerfully built. He is popular with his colleagues at work, who like his ready sense of humor, and he spends his lunch times jogging in the nearby park. While relaxing at home he prefers to wear a track suit and recently he took out a subscription to a cable television channel devoted entirely to sport. He takes little interest in reading or in the arts or current affairs. Which is more likely:

(a) David is a librarian;

(b) David is a librarian who regularly plays basketball

(9) Which of the following scenarios is most likely to occur?

(a) A decline in the share of the global market of the US computer manufacturing industry during the second decade of the twenty-first century.

(b) A decline in the share of the global market of the US computer manufacturing industry during the second decade of the twenty-first century, as a result of competition from Asian countries such as, China, Japan, Malaysia and South Korea.

(10) a) Was the population of Egypt in 2006 (excluding Egyptians living abroad) higher or lower than 15 million?

b) Estimate Egypt's population in 2006 (excluding Egyptians living abroad).

(11) An electronic safety system, which will automatically shut off machinery in the event of an emergency, is being proposed for a factory. It would consist of 150 independent components, each of which must work if the entire system is to be operational. On any day, each component would be designed to have a 99.5% probability of working. Estimate the probability that the entire safety system would be operational on any given day if a decision was made to install it.

(12) Currently, 10 people work in an office and each has a 5% probability of leaving during the next year. Estimate the probability that at least one of these people will leave within the next 12 months. (Assume that the chance of any one person leaving is independent of whether the others stay or leave.)

(13) For each of the 10 quantities listed below (i) write down your best estimate of that quantity and (ii) put a lower and upper bound around your estimate so that you are 90% confident that your range will include the true value of that quantity.

(a) The air distance, in miles or kilometres, from Moscow to Cape Town.

(b) The population of Canada as recorded by the country's 2006 census.

(c) The area of Greenland in square miles or square kilometres.

(d) The year the ball point pen was first patented by Biro.

(e) The year that the H. J. Heinz food manufacturing company was founded.

(f) The distance (in miles or kilometres) between Earth and Mars when Mars is at its closest. to Earth.

(g) The US inflation rate (as measured by the Consumer Price Index) over the twenty year period between December 1988 and December 2008.

(h) The year that Louis Braille, inventor of the Braille communication system, was born.

(i) The average depth of the Pacific ocean in feet or metres (to the nearest thousand).

(j) The length, in miles or kilometres, of the river Danube

Introduction

In a classic paper in the Journal *Science*, two famous psychologists, Amos Tversky and Daniel Kahneman, examined how people make estimates of quantities such as probabilities. Tversky and Kahneman suggested that individuals develop rules of thumb or HEURISTICS to reduce the information processing demands involved in making the estimates.

These heuristics often provide people with efficient ways of dealing with complex estimation problems BUT they can also lead to systematically biased judgements

Three commonly used heuristics have been identified by psychologists:

a) The availability heuristic
b) The representativeness heuristic
c) Anchoring and adjustment

The Availability Heuristic

People assess the probability of events by how easily these events can be brought to mind: e.g. how easily they can be recalled or imagined.

Biases resulting from the availability heuristic

- *When ease of recall is not associated with probability* – probabilities of events that are vivid or recent may be overestimated; probabilities for less-easily recalled events may be underestimated. For example, in the aftermath of 9/11 people grossly over estimated the probability that they would be victims of a terrorist attack.
- *When ease of imagination is not related to probability* -easily imagined events are not necessarily more likely, and vice versa. For example, fairground rides may appear to be dangerous because it easy to imagine accidents occurring. In fact, they are relatively safe.
- *Illusory correlation* – When people have preconceived notion that events, or factors, are associated they will tend to easily recall occasions when these events occur together. They are less likely to recall the number of occasions when the events did not occur together. For example, the preconception may exist that politicians are more dishonest that the rest of the population. Instances of politicians being dishonest will be readily recalled to support the belief, but instances of politicians behaving honestly will not be so easily recalled. Thus the frequency of co-occurrences (of politicians and dishonesty) is overestimated and the false belief that the two factors are correlated persists.

The Representativeness Heuristic

This is used where people have to judge:

1) the probability that an object or person belongs to a particular class (e.g. what is the probability that Fred Bloggs is a farmer?) or,

2) the probability that an event originates from a particular process (e.g. what is the probability that our sales are purely random?).

People judge the required probabilities by the extent to which the object or person appears to be *representative* or typical of the class or process, usually by using stereotypes.

Biases resulting from the representativeness heuristic

⇨ *Expecting short sequences of random events to look random*

-e.g. in the UK lottery six numbers are drawn at random from the numbers 1 to 49. Many people would expect sequence A (below) to be more likely to occur than sequence B because it appears to be more representative of a random pattern. In fact both sequences are equally probable.

A: 2 23 25 39 44 48

B: 2 3 4 5 6 7

⇨ *Expecting chance to be self correcting*

- The gambler's fallacy - e.g. after a run of ten heads on tosses of a fair coin, a tail is judged to be more likely to occur than a head on the next toss.

⇨ *Ignoring regression to the mean*

-Ignoring the fact that extreme events tend to be followed by events which are closer to 'average'. For example, extremely intelligent parents tend to have children who have IQ's closer to average IQ.

⇨ *The conjunction fallacy*

-Where an event can occur in many particular ways, falsely judging that the occurrence of the event in one particular way is more likely than the occurrence of the event in any way.

E.g. judging that "in the next year, heavy rainfall will lead to a dam burst in northern Greece which will kill over 100 people" is more likely than "in the next year a dam burst in northern Greece will kill over 100 people". The second event has to be more probable because it includes a dam burst resulting from *any* cause, not just heavy rain. However, because the first event gives a specific reason for the disaster it is easier to envisage and hence appears to be more probable.

Biases resulting from the anchoring and adjustment heuristic

⇨ *Insufficient adjustment from the anchor*

– In making estimates people often start with an initial value (this is called the anchor). For example, in estimating next month's sales of a product we might start off with this month's sales and then adjust the estimate to take into account next month's market conditions. However, this adjustment is usually insufficient and the initial estimate is set too close to an initial value

⇨ *Overestimating the probability of conjunctive events*

– when estimating the probability of A <u>and</u> B happening people anchor on the probability of one of the *individual* events occurring.

For example, suppose that eight products that are being launched each have an independent probability of 0.7 of succeeding. When asked to estimate the probability that all eight products will succeed managers may anchor on the 0.7 and adjust this down to (say) 0.6. However, the true probability of all eight succeeding is $(0.7)^8$ = only 0.058

⇨ *Underestimating the probability of disjunctive events*

– when estimating the probability of <u>either</u> X <u>or</u> Y happening people anchor on the probability of one of the individual events occurring.

For example, suppose that each of seven machines in a factory has an independent 0.1 probability of breaking down tomorrow. What is the probability that at least one machine will breakdown (at least one means that either 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 machines will breakdown)? In answering this managers might anchor on the 0.1 probability and adjust it to (say) 0.2. However, the true probability is:

$$1 - p(\text{all machines OK}) = 1 - (0.9)^8$$
$$= 0.57$$

⇨ *Overconfidence* - The tendency of people to be overconfident that an event will occur in a particular interval. This often occurs where people are first asked to estimate the most likely value and then to provide upper and lower bound for the possible range of values. The problem is that the most likely value acts as an anchor

E.g. suppose you are asked to estimate the most likely time that it will take to complete a job. Your estimate is 3 hours. You are then asked for optimistic and pessimistic estimates such that there is 90% probability that the true duration will fall between these estimates. Because you anchor on the 3 hours your optimistic and pessimistic estimates are too close to this value. Let's say that you estimate 2 to 4 hours. This range is likely to be too narrow to allow for a 90% probability that the actual job duration will fall within it. You are likely to be surprised when the true job duration falls outside this range

Other biases

⇨ *Optimism bias*

Believing that desirable outcomes are more probable than they really are and undesirable outcomes are less probable than they really are

⇨ *Conservatism*

- not revising your probability estimates sufficiently when you receive new information (Bayes theorem tell you how much revision you should make to your original estimates).

⇨ *Biased assessment of covariation*

-when presented with a table people will tend only to look at the cell representing the co-occurrence of two events. For example, does the table below suggest that cheap computers are more likely to require repair in their first year of use? A glance at the table might suggest that that this is the case since the biggest number in the table relates to cheap computers that required repair.

(no. of computers)	*Cheap*	*Expensive*
Required repair	120	40
Did not require repair	24	8

However, when the probabilities are calculated we find that the chances of cheap and expensive computers requiring repair are the same:

p(cheap computer requires repair) = 120/144 = 5/6

p(expensive computer requires repair) = 40/48 = 5/6

Criticisms of the Psychological Research

Is human judgment really seriously biased? There have been several criticisms of Tversky and Kahneman's work. People who believe that judgment is better than Tversky and Kahneman's work would suggest argue on the basis of the following points:

a) Citation bias - studies showing good performance exist, but they are rarely cited in the research literature.

b) Tasks carried out by research subjects - these are often contrived, not typical of real problems and often not understood by the subjects.

c) Type of subjects participating in experiments - these are often psychology undergraduates who may be untypical of experts/business people who make 'real' decisions.

d) Problem of framing -minor changes in the way a problem is framed can often have a major influence on the way subjects approach the task. Subjects often view (frame) problems differently from experimenters and are therefore actually working on a different task from that assumed by the experimenter.

e) Motivation of subjects - in experiments, subjects rarely receive rewards for good judgement therefore it may be quite rational to adopt a sub-optimal strategy when good judgment is costly in time and effort.

f) Recently, Gerd Gigerenzer has argued that people are happier to think in terms of <u>frequencies</u> rather than probabilities. For example, he has found that the conjunction fallacy is not evident if people are asked questions reflecting the frequency of occurrence of events. In a demonstration of the conjunction fallacy, people thought that it was less likely that Linda was a bank teller, as opposed to a bank teller who was also active in the feminist movement. However, when people were asked, "Are there more bank tellers than bank tellers who are also active in the feminist movement?" the bias disappeared. Gigerenzer's work therefore suggests that human judgment may not be as poor as Tversky and Kahneman's work implies, as long as elicitation of judgments involve notions of frequency, wherever this is practical.

4 Probability assessment and risk analysis

Objectives
At the end of this session you should:

⇨ Be aware of methods designed to aid the assessment of subjective probabilities such as probability wheels and risk analysis;

⇨ Be aware of the special problems of assessing subjective probabilities for rare events and understand methods designed to overcome these problems, such as event and fault trees;

⇨ Be aware of problems which are amenable to risk analysis (including investment appraisal decisions based on net present values);

⇨ Understand the rationale which underpins risk analysis and the stages involved in the process;

⇨ Be able to interpret the results of a risk analysis, and to apply stochastic dominance to compare alternative courses of action.

Introduction

In the light of the biases we met in the previous session, probability elicitation clearly needs to be carried out with care. In this session we will consider a number of techniques that have been developed to aid elicitation. Some of these are based on the principle that the accuracy of probability estimates is likely to be improved if they are inferred from the decision maker's choices, rather than assessed directly. Others are based on the decomposition approach of breaking the estimation task into smaller parts. We will also look at how probability estimates should be revised when new information becomes available.

Probability elicitation methods

Direct assessment

This involves asking the decision maker a direct question such as "What is the probability that a new electronics company will make a profit in the first year?" As we have seen the decision maker may struggle to answer this question accurately. For example:

- Gigerenzer has argued that people think naturally in terms of frequencies rather than probabilities;
- The notion of a probability of (say) 0.86 may be difficult to visualise;
- The event in question may itself be the result of a large series of other events. For example the electronics company's profitability may depend on factors like the activities of competitors, world economic conditions, whether the technology it

employs works successfully and the success of its marketing operations. The information processing limitations of the human brain mean that it will be difficult to think about all of these effects together.

Indirect assessment methods

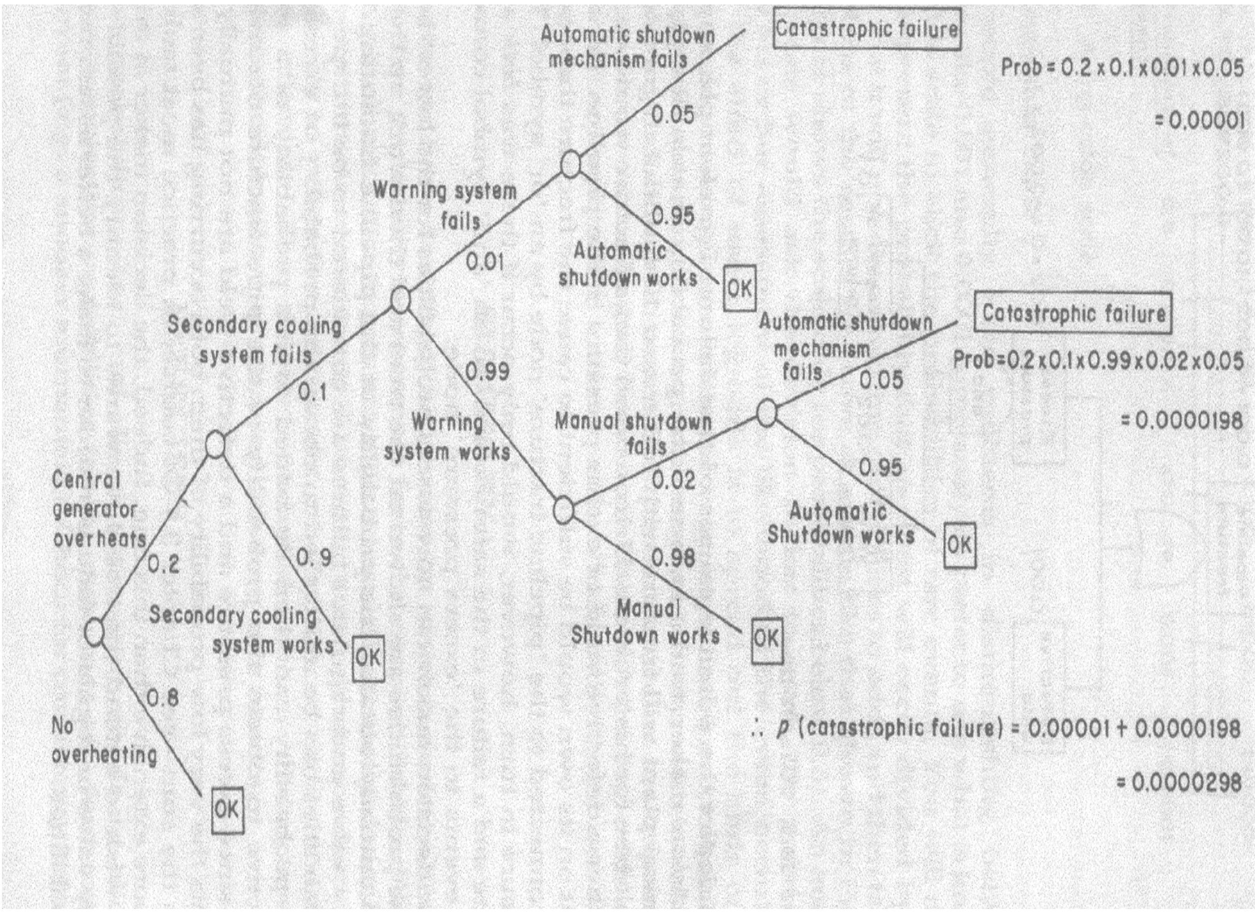
Some of these problems can be overcome by using indirect assessment methods which employ devices like probability wheels or equivalence urns.

A probability wheel is a wheel that has two segments (say white and black). The wheel can be spun and next to it is a pointer which, when the wheel comes to rest, will either be pointing to the black or white segment. The relative size of these segments can be adjusted. When the wheel is used in elicitation, the decision maker is asked to choose which is the more likely: the event in question occurring or the pointer on the probability wheel pointing towards the black segment. The relative size of the segments is adjusted after each judgment until the decision maker cannot choose between the event or the wheel. If this occurs when the black segment makes up 84% of the wheel then it can be inferred that the probability of the event occurring is judged to be 84%. Notice that the probability is inferred indirectly from the decision maker's choices.

Assessing probabilities for rare events: Probability (or event) trees

Probability trees are used by engineers to assess the risks associated with large systems like a chemicals factory. The probabilities of events like catastrophic failure and explosion are difficult to assess directly because the events are so rare and their probabilities are so small. However, the probabilities of the individual events that might combine to lead to the failure are likely to be larger and easier to assess (e.g. some of these events may be fairly common so that past data exists on their frequency enabling their empirical probability to be assessed). By representing the combinations of events that might, or might not, lead to failure on a probability tree, the overall risk can be determined.

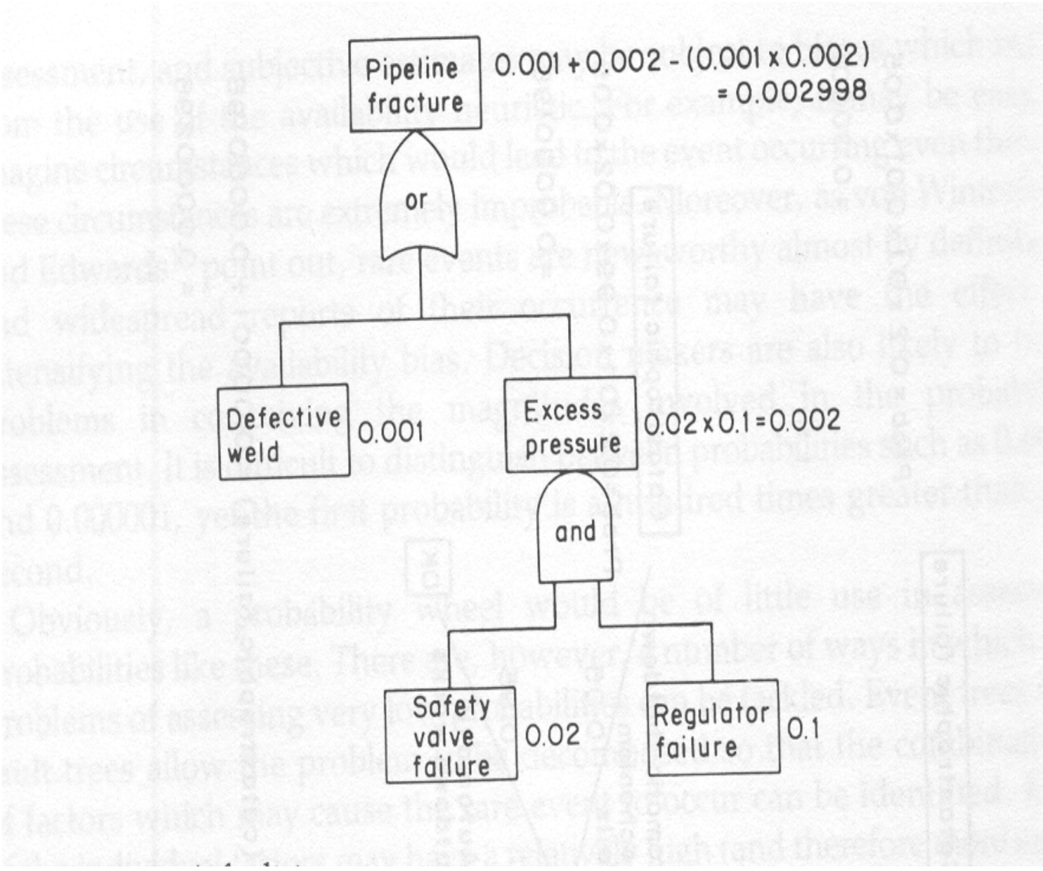
An example is shown below.



Assessing probabilities for rare events: Fault trees.

These enable the risk of faults in systems to be assessed by starting with the fault and then identifying the events needed for the fault to occur. Precursors to these events are then identified, and the process continued until the tree has been broken down to set of events for which it is relatively easy to determine probabilities. The addition and multiplication rules are then used to identify the probability of the fault occurring.

An example is shown on the next page. This shows that how the probability of a pipeline fracturing in a given year was estimated to be 0.002998 (or roughly 3 chances in 1000). Note that the tree has two different symbols that are used to represent “or” and “and” situations respectively. The probability of each event that is not at the bottom of the tree is determined by using either the addition or multiplication rule, as appropriate, to combine the probabilities of the events in the level below.



A fault tree

Eliciting probability distributions.

Often we need to estimate entire probability distributions. A number of methods have been put forward, but the main problem with many methods is that they can lead to anchoring and under adjustment from the first value that is elicited. For example, some of the methods start by asking for the most likely value. They then ask for optimistic and pessimistic values, but because of anchoring, these are likely to be estimated too closely to the most likely value so that the distribution is insufficiently spread out.

The following exercise illustrates a method that is designed to avoid this problem.

Exercise

1. Use the method outlined below to assess a probability distribution for the population of Poland in July 2004 (which it is assumed you do not know).

1. Establish a range of values within which you are certain that the true population lies:

From . . . . to . . . .

2. Are you sure that the true population does not lie outside this range? If you axe not sure extend your range:

From . . . . to . . . .

3. Divide your range into 6 or 7 roughly equal intervals (ignore the ‘Probability’ column for the moment):

		Probability
From . . . . to	(a)	. . . .
From . . . . to	(b)	. . . .
From . . . . to	(c)	. . . .
From . . . . to	(d)	. . . .
From . . . . to	(e)	. . . .
From . . . . to	(f)	. . . .
From . . . . to	(g)	. . . .

4. Write down your estimate of the probability that the population of Poland falls below each of the quantities labelled (a) to (f) above. Use the Probability column (above) to record your subjective probabilities

5. Plot your cumulative probability distribution

6. By subtracting consecutive cumulative probabilities from each other calculate your subjective probability that the population of Poland falls within each interval.

7. Sketch a histogram to approximate your probability density function.

What checks would you perform on your assessed distribution to establish that it accurately represents your views?

Assessing Risks in Investment Appraisal: Net Present Value (NPV)

One area where the assessment of risks is particular important is investment appraisal where a decision has to be made on whether to invest in a particular project such as the development of a new machine or a new product. The problem is that, while money will have to be spent on developing the project now, returns will not accrue until the future. Money to be received in the future is less valuable than money held now. For example, if you have £1000 now, you could invest it and, depending on interest rates, it might be worth £1100 in a year's time. Moreover, the more years you have to wait for a monetary payment then the less attractive that payment will be.

This implies that money which will be earned in the future should be *discounted* so that its value can be compared with sums of money which are being held now. The process involved is referred to as 'discounting to present value'. For example, we might judge that the £1000 due in one year is only equivalent to receiving £909 now, while the £1000 due in 2 years has only the same value as receiving £826 now. The severity with which we discount future sums of money to their present value is reflected in the discount rate. Determining the appropriate discount rate for a company's potential investment projects is, ultimately, a matter of judgment and preference. However, many attempts have been made to make the choice of a discount rate as 'objective' as possible, making this a complex area which is beyond the scope of this text. For many situations, it will be convenient to let the discount rate reflect the opportunity cost of the capital which is being invested (i.e. the rate of return which could be earned on the best alternative investment). Thus if we are only considering two mutually exclusive projects A and B and we could earn a 12% return on project A, then the discount rate for project B would be 12% because, if we invest in B, we will be forgoing the 12% return which A would have generated. Having determined the appropriate discount rate, the process of discounting future sums of money is very straightforward. It simply involves multiplying the sum of money by a *present value factor*, which can be obtained from published tables.

Let us now use a simple example to illustrate the net present value approach to investment appraisal. A company is considering whether to buy an Alpha machine at a cost £30 000. The machine has an expected lifetime of 4 years. Estimates of the annual cash inflows which the machine would generate are given below together with estimates of the cash outflows which would be experienced for each year of the machine's operation. For simplicity, we will assume that all the cash flows occur at the year end.

Alpha machine

Time of cash flow	Year 1	Year 2	Year 3	Year 4
Cash inflows	£14 000	£15 000	£15 000	£14 000
Cash outflows	£2 000	£4 000	£6 000	£7 000

Assuming that a 10% discount rate is appropriate we can calculate the NPV of the machine, as follows.

Time of cash flow	**Cash inflow**	**Cash outflow**	**Net cash flow**	**Present value factor**	**Discounted cash flow**

Net Present Value

If the NPV is positive then the investment is worth considering. If a choice between several investment has to be made then the one with the highest NPV is the most attractive (at least in monetary terms).

Limitations of this approach

While this approach to investment appraisal is widely used, the NPV figures are obviously only as good as the estimates on which the calculations are based. In general, there will be uncertainty about the size of the future cash flows and about the lifetime of the project. Expressing the cash flow estimates as single figures creates an illusion of accuracy, but it also means that we have no idea as to how reliable the resulting NPV is. For example, it may be that the year 1 cash inflow for the Alpha machine could be anywhere between £6000 to £22,000, and we have simply used the mid-range figure, £14000, as our estimate. If the actual flow did turn out to be near £22,000 then our estimated NPV would have been very misleading.

We next consider an approach which is designed to allow us to take into account this uncertainty.

Risk analysis

When an event's probability depends on many other events credence decomposition (or risk analysis) can be used. To illustrate this, suppose that a company's profit this year depends on the size of its market, its market share (%), the price of its product and its fixed and variable costs. The following model can be used to represent this.

Profit = Size of market x Market share x (Price - Variable cost per unit) - Fixed costs

Rather than asking the decision maker to estimate a probability distribution for profit directly, separate probability distributions can be estimated for each of the factors: i) Size of market, ii) Market share iii) Variable costs per unit and iv) Fixed costs. (we will assume that price is determined by the decision maker). Thus the estimation task is broken down into small parts allowing the decision maker to focus on each part separately. Monte Carlo simulation can then be used to simulate the profits obtained from thousands of combinations of these factors. The distribution of these generated profits should provide a reasonable estimate of the probability distribution for profit. Packages like @RISK and CRYSTAL BALL are designed to allow these simulations to be carried out on a spreadsheet, but the following exercise illustrates the basic idea.

Lecture Example

1. An equipment hire company has to decide whether to buy a specialised high-technology piece of earth-digging machinery for £60000. The machine would be sold after two years. The main factors, which it is thought will affect the return on the investment, are:
   - ⇨ The revenue generated by hiring the machine out for a day: it is certain that this will be £400
   - ⇨ The number of days that the machine will be hired out in year 1 and in year 2
   - ⇨ The costs of having the machine available for hire (e.g. maintenance and repair costs) in year 1 and year 2
   - ⇨ The price that will be obtained for the machine when it is sold at the end of year 2.

For each factor the following probability distributions have been estimated:

<table>
<tr><th>Number of days hired out in year 1</th><th>Probability</th><th>Number of days hired out in year 2</th></tr>
<tr><td>Under 100</td><td>30%</td><td rowspan="3">(This is assumed to have the same distribution as year 1)</td></tr>
<tr><td>100 to under 200</td><td>50%</td></tr>
<tr><td>200 to under 360</td><td>20%</td></tr>
</table>

Annual costs	Probability in year 1	Probability in year 2
£10000 to under £20000	50%	30%
£20000 to under £30000	30%	40%
£30000 to under £40000	20%	30%

Se1ling price at end of year 2	Probability
£10000 to under £20000	40%
£20000 to under £30000	60%

Using the worksheet at the end of these notes, carry out one simulation of a possible combination of circumstances and calculate the NPV for your simulation (assume a 10% discount rate).

The results for the entire group can then be entered into the following table:

Net Present Value	Number of simulations resulting in NPV's in this range	Probability
Less than -£100,000	. . . .	
-£100,000 to under -£50,000	. . . .	
-£50000 to under £0	. . . .	
£0 to under £50,000	. . . .	
£50,000 to under £100,000	. . . .	
£100,000 to under £150000	. . . .	
£150,000 or more	. . . .	

Therefore the most likely range for the NPV appears to be . . . .

and the probability of a negative NPV appears to be . . . .

Simulation Worksheet

Number of days hired out in year 1	Midpoint	Probability	Cum. Prob.	Random nos.
Under 100				
100 to under 200				
200 to under 360				
Random no.		No. of days		Year 1 revenue . . . .

Number of days hired out in year 2	Midpoint	Probability	Cum. Prob.	Random nos.
Under 100				
100 to under 200				
200 to under 360				
Random no.		No. of days		Year 2 revenue . . . .

Costs in year 1	Midpoint	Probability	Cum. Prob.	Random nos.
£10000 to under £20000	£1,500	0.5	0.5	00 - 49
£20000 to under £30000	£2,500	0.3	0.8	50 - 79
£30000 to under £40000	£3,500	0.2	1.0	80 - 99
Random number		Year 1 costs		

Costs in year 2	Midpoint	Probability	Cum. Prob.	Random nos.
£10000 to under £20000	£1,500	0.3	0.3	00 - 29
£20000 to under £30000	£2,500	0.4	0.7	30 - 69
£30000 to under £40000	£3,500	0.3	1.0	70 - 99
Random number		Year 2 costs		

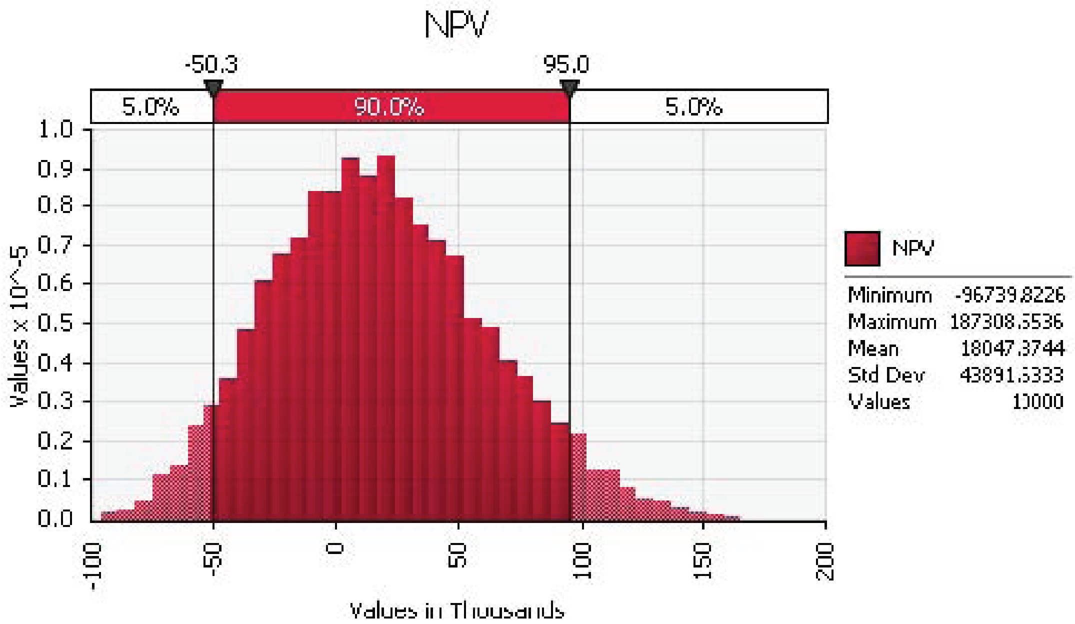
Selling price	Midpoint	Probability	Cum. Prob.	Random nos.
£10000 to under £20000	£1,500	0.4	0.4	00 - 39
£20000 to under £30000	£2,500	0.6	1.0	40 - 99
Random number			Selling price	

Time	Cash inflow	Cash outflow	Net cash flow	Present value factor	Discounted cash flow
Now				1.000	
End of year 1				0.909	
End of year 2				0.826	

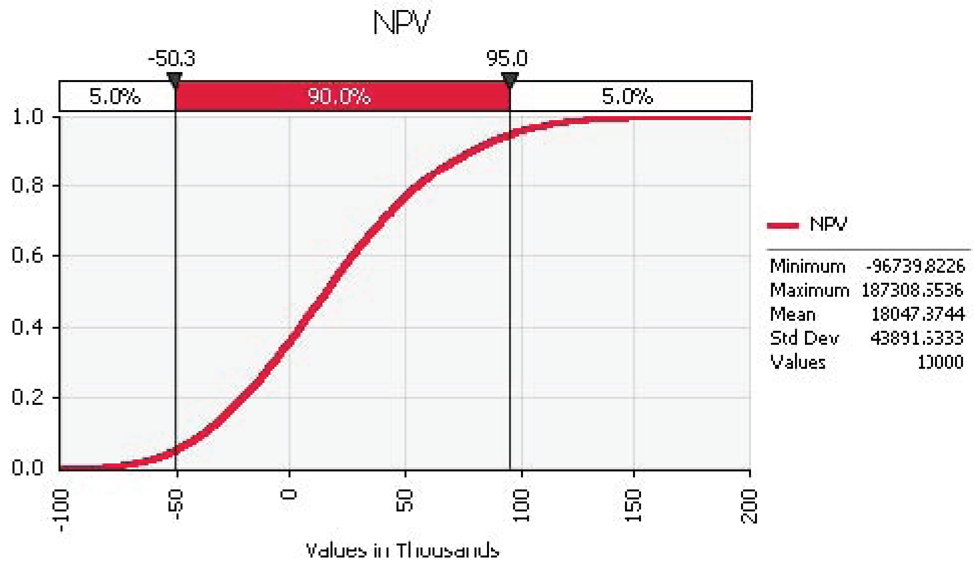
Net present value £ . . . .

Outputs of @RISK

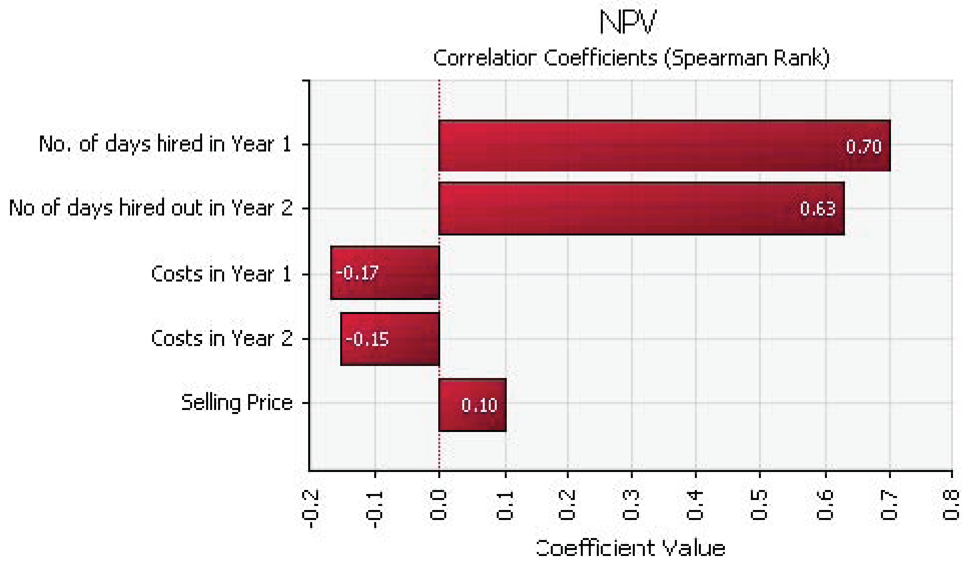
The histogram below shows the most likely NPV is around £20,000 and the risk of a negative NPV is around 35%.



This can also be expressed as a cumulative distribution.



The tornado diagram (below) shows that the number of days that the equipment is hired out are the key sources of variation and uncertainty in the return on the investment. The costs and selling price have relatively little impact on this.



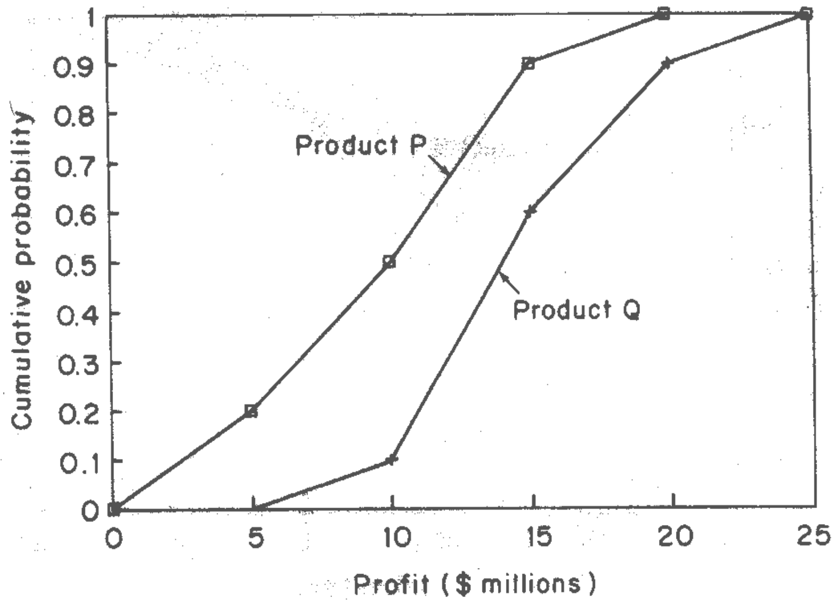
Using the outputs of risk analysis for decision making

Suppose that we carry out risk analyses for two alternative new products that we are thinking of developing (P and Q) and obtain the following probability distributions of their returns (this time measured in terms of profits).

Product P			Product Q		
Profit ($m)	Prob.	Cumulative prob.	Profit ($m)	Prob.	Cumulative prob.
0 to under 5	0.2	0.2	0 to under 5	0	0
5 to under 10	0.3	0.5	5 to under 10	0.1	0.1
10 to under 15	0.4	0.9	10 to under 15	0.5	0.6
15 to under 20	0.1	1.0	15 to under 20	0.3	0.9
			20 to under 25	0.1	1.0

How can we make a decision between the two investments? One approach involves plotting their cumulative probability distributions to see if one alternative exhibits stochastic dominance over the other. If stochastic dominance is apparent it means that, as long as a set of minimal assumptions are appropriate, the best option can be clearly identified without the need to elicit utilities.

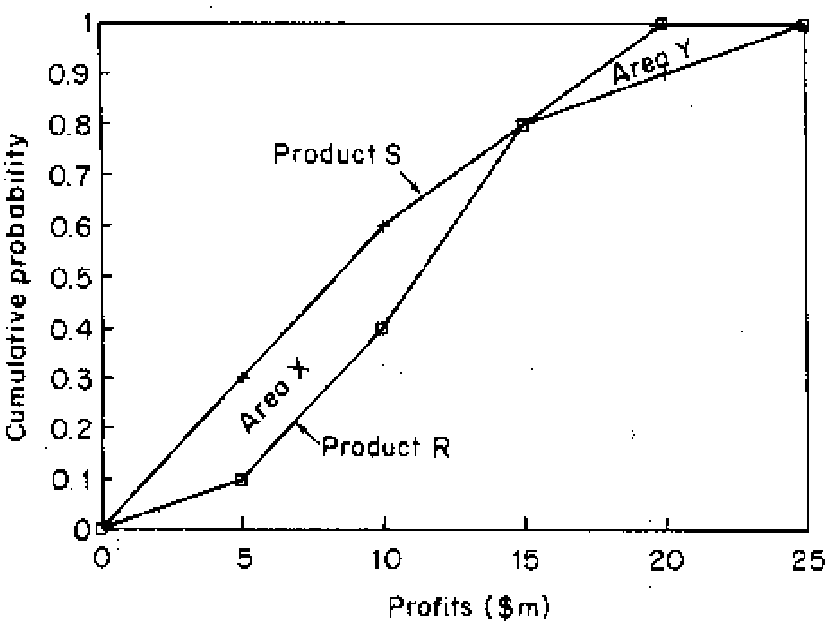
If the cumulative distributions look like those in the diagram below then option P (which has a cumulative distribution which is never to the right of Q) is said to exhibit first-order stochastic dominance over option Q. This means that, as long as we can assume that a higher return is better than a lower return, then P is clearly the best choice.



Suppose that in another decision we have to make a decision between launching two further products (R and S) and risk analysis yields the probability distributions below

Product R			*Product S*		
Profit ($m)	*Prob.*	*Cumulative prob.*	*Profit* ($m)	*Prob.*	*Cumulative prob.*
0 to under 5	0.1	0.1	0 to under 5	0.3	0.3
5 to under 10	0.3	0.4	5 to under 10	0.3	0.6
10 to under 15	0.4	0.8	10 to under 15	0.2	0.8
15 to under 20	0.2	1.0	15 to under 20	0.1	0.9
20 to under 25	0	1.0	20 to under 25	0.1	1.0

When we plot the cumulative distributions it can be seen that they cross. In this case we note that area X, between the curves, is greater than area Y. Thus, in as sense, S tends to be to the left of R more than vice versa. In this case, as long as we can make the assumptions i) than higher returns is preferred and ii) that the decision maker is risk averse then it can be shown that S should be the preferred option


Cumulative probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Product S
Product R
Area X
Area Y
0
5
10
15
20
25
Profits ($m)

Exercise

The managers of a chemical company have to decide whether to extend their existing plant or replace it with completely new equipment. A simulation of the two alternatives gives the following probability distributions of net present value.

NPV (£m)		Probabilities	
From	to under	Extend existing plant	Replace with new equipment
-3	-2	0.05	0.00
-2	-1	0.05	0.05
-1	0	0.15	0.15
0	1	0.29	0.26
1	2	0.22	0.21
2	3	0.14	0.18
3	4	0.10	0.10
4	5	0.00	0.05

a) Compare the two distributions, and stating any necessary assumptions, determine the option that the management should choose.

b) After the above simulations have been carried out a third possible course of action becomes available. This would involve the movement of some of the company's operations to a new site. A simulation of this option generated the following probability distribution. Is this option worth considering?

NPV (£m)		Probability
From	To under	
-2	-1	0.05
-1	0	0.05
0	1	0.40
1	2	0.40
2	3	0.04
3	4	0.03
4	5	0.03

5 Measuring attitudes to risk & Revising risk assessments in the light of new information

Objectives

At the end of this session you should:

- ⇨ Be able to apply methods for measuring the utility of single attributes in decision problems involving risk
- ⇨ Appreciate the problems of applying utility in many practical situations
- ⇨ Be able to interpret the shape of a utility function
- ⇨ Be able to apply Bayes' theorem to revise probability estimates in the light of new information
- ⇨ Be able to calculate the expected value of perfect information for a decision

Lecture Notes

Assessing attitudes to risk

Example: Location of an exhibition

A businesswoman, who is organising a business equipment exhibition in a provincial town, has to choose between two venues: the Luxuria Hotel and the Maxima Centre. To simplify her problem she decided to estimate her potential profit at these locations on the basis of two scenarios: high attendance and low attendance at the exhibition.

If she chooses the Luxuria Hotel, she reckons that she has a 60% chance of achieving a high attendance and hence a profit of £30,000. There is, however, a 40% chance that attendance will be low, in which case her profit will be just £11,000.

If she chooses the Maxima Centre, she reckons that she has a 50% chance of high attendance, leading to a profit of £60,000 and a 50% chance of low attendance, leading to a loss of £10,000.

Tackling the problem

We can represent the businesswoman's problem in the form of a decision tree (a space has been left for this on the next page).

If we apply the EMV criterion to the tree we see that it indicates that she should choose the Maxima centre. But this is the riskiest of the two options –she has a 50% chance of losing £10,000, while she cannot lose money if she chooses the Luxuria hotel. This may be too big a risk to take. For example, if she already has financial problems losing a further £10000 could lead to the demise of her business. Alternatively, she may enjoy taking a risk and prefer the Maxima centre, given that it offers the highest returns if attendance is high.

How can we build the decision maker's attitudes to risk into our decision model? The answer is to assess the decision maker's utility function.

Space for decision tree for location of exhibition problem

Eliciting utility functions

There are several methods of eliciting utility functions. The easiest to understand is the *probability-equivalence* approach. In this method we first list all of the payoffs in the decision tree from best to worst.

Payoff	Utility
£60,000	1.0
£30,000	?
£11,000	?
-£10,000	0

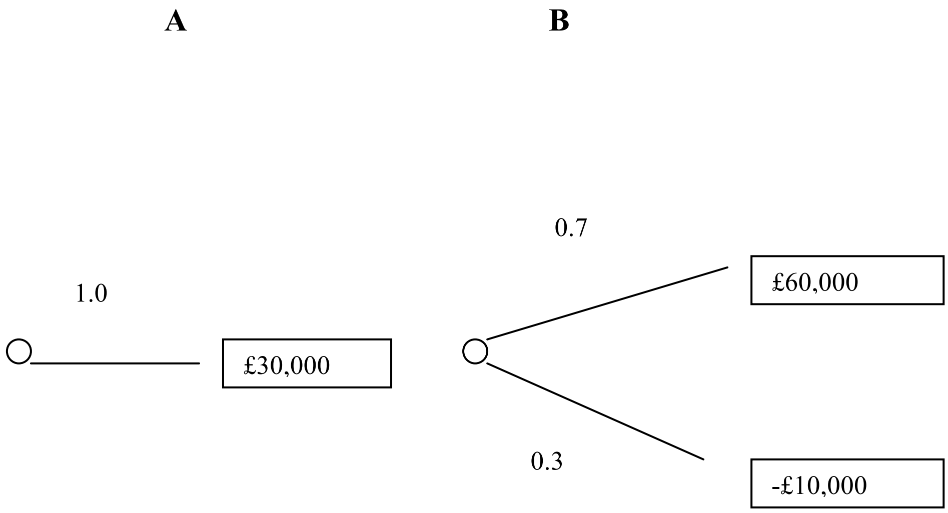
We than assign a utility of 1 to the best payoff and 0 to the worst payoff. (mathematically this is known as interval scale).

Obtaining the businesswoman's utility of £30,000

We offer her a series of options. In each case, she will have the choice of *either* receiving £30,000 for certain *or* entering gamble where she will receive either the best or worst payoff with particular probabilities. Our objective is to find the probabilities that would make her indifferent between the certain money and the gamble.

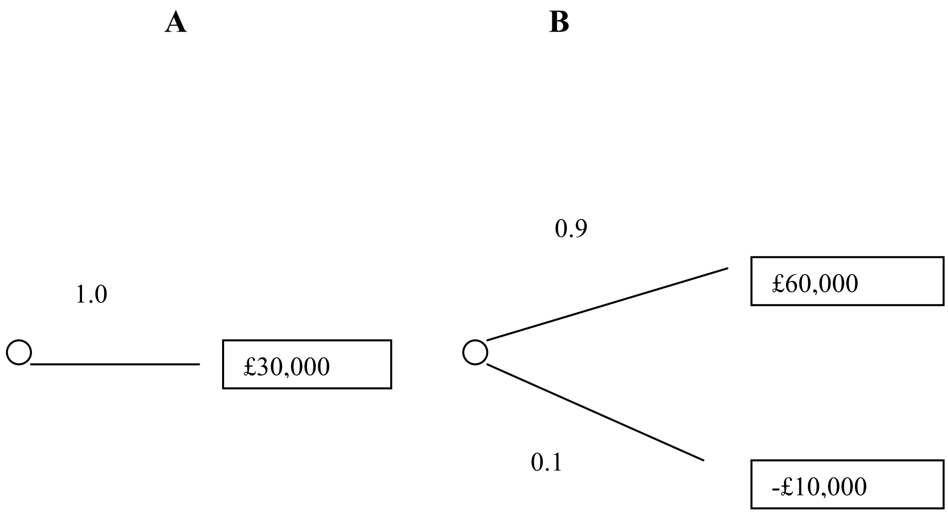
A typical elicitation session might proceed as follows:

Which of these two options would you prefer, if any?



Answer: A 30% chance of losing £10,000 is too risky. I'll go for option A

OK, which of these two options would you prefer, if any?

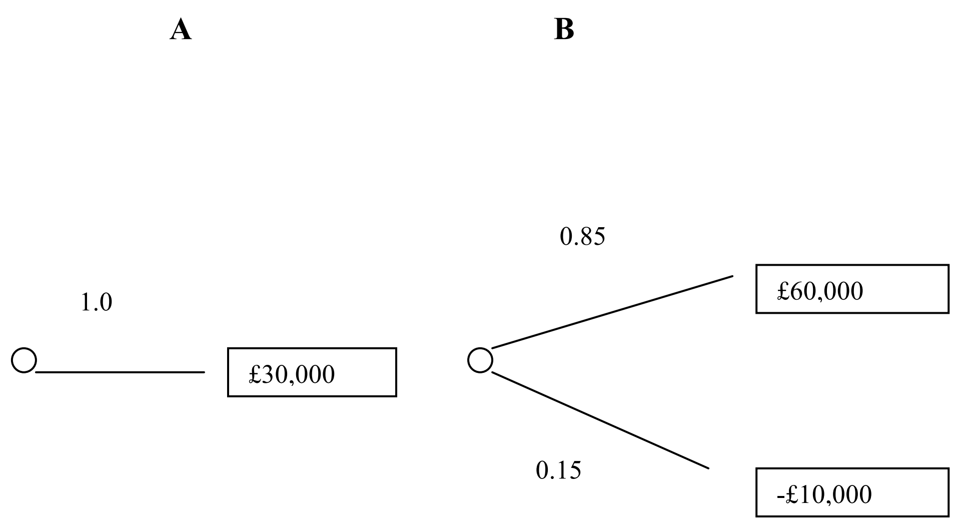


Answer: I now stand such a good chance of winning the gamble that I think I would take the risk. I'll go for option B

The decision maker's point of indifference between the certain money and the gamble should therefore lie somewhere between a 0.7 chance of winning (when the certain money was preferred) and a 0.9 chance of winning (when the gamble was preferred).

Suppose that, after several more questions, we offer the following options

Which of these two options would you prefer, if any?



Answer: I can't choose between these –I would be indifferent between them.

We are now in a position to determine the utility of £30,000. Given that we have identified the point of indifference, it is simply equal to the probability of winning the gamble i.e. 0.85.

Obtaining the businesswoman's utility of £11,000

We would use a similar process to the one above, but for option A we would offer a certain chance of winning £11,000. The payoffs for option B would be the same as above, i.e. they would involve the best and worst possible payoffs on the decision tree. We will assume that the utility of £11,000 turns out to be 0.6.

We have now assessed the utility function for all the payoffs in the decision tree:

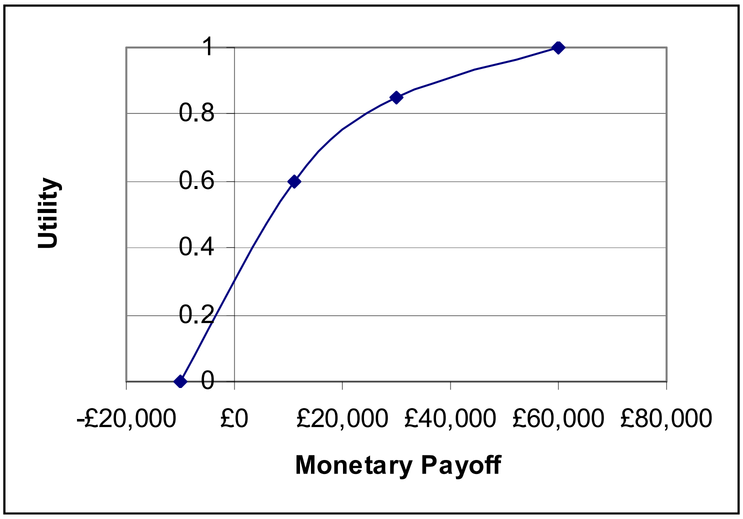
Payoff	Utility
£60,000	1.0
£30,000	0.85
£11,000	0.60
-£10,000	0

Applying the utilities to the decision

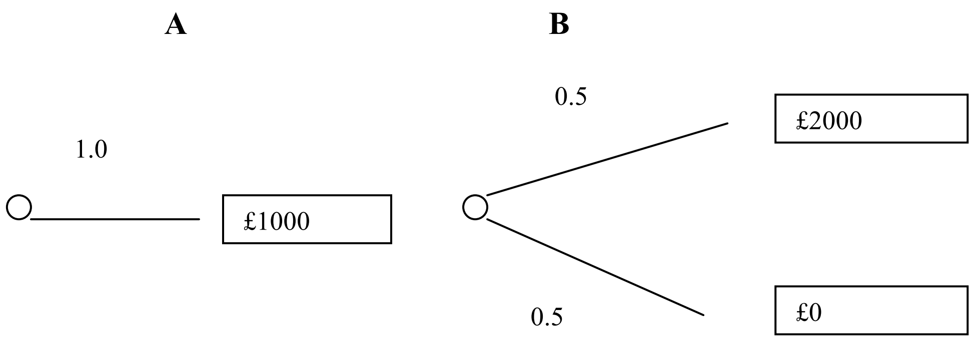
We simply replace the monetary payoffs in the tree with their utilities and find the option yielding the highest *expected utility* (see original decision tree). It can be seen that the businesswoman should now chose the less risky option –the Luxuria hotel. The diagram attached to the *back of the notes* shows the rationale for using utilities in this way.

Interpreting the utility function

The utility function has been plotted below



The curve is concave (i.e. it always lies above a diagonal line drawn between the first and last points). This indicates risk aversion. Why is this? A simpler example will be helpful here. Consider the following options



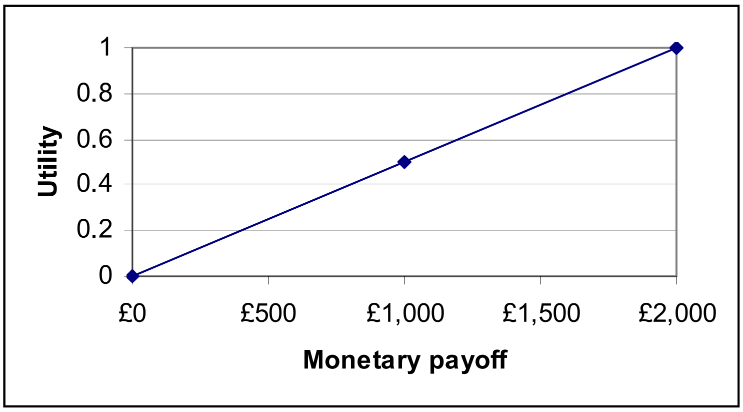
We can assign utilities as follows

Payoff	Utility
£2000	1.0
£1000	?
£0	0

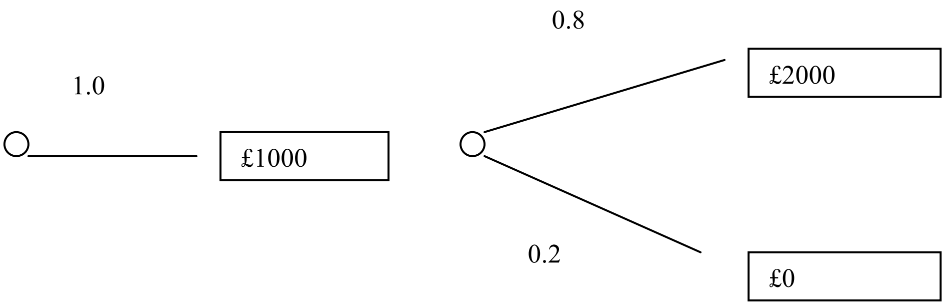
Note that the expected value of the gamble is (0.5 x £2000+ 0.5 x £0) = £1000.

- Now for a risk neutral decision maker the EMV criterion is the appropriate way to compare decision options. They would therefore be indifferent between A and B. This means that their utility of £1000 is 0.5

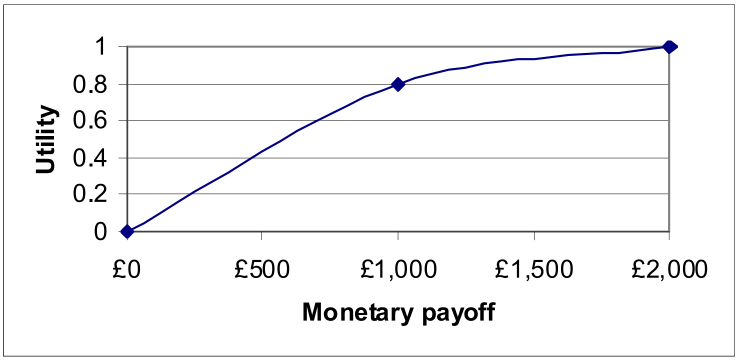
Their utility function is therefore represented by the straight line below:



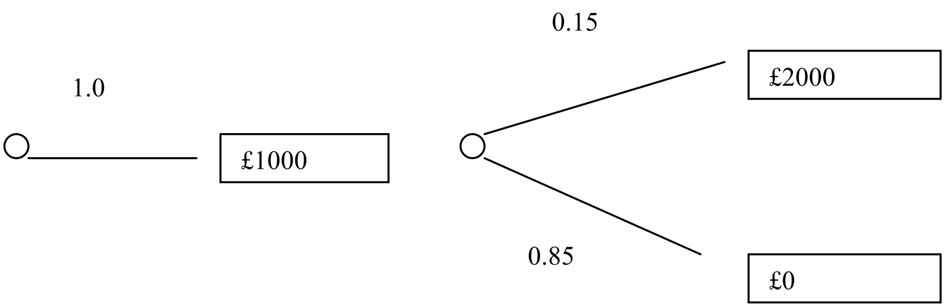
- A risk averse decision maker would require a higher than 0.5 probability of winning the gamble to tempt them away from opting for the certain money. For example, they might be indifferent only if the probability of winning the gamble is 0.8.



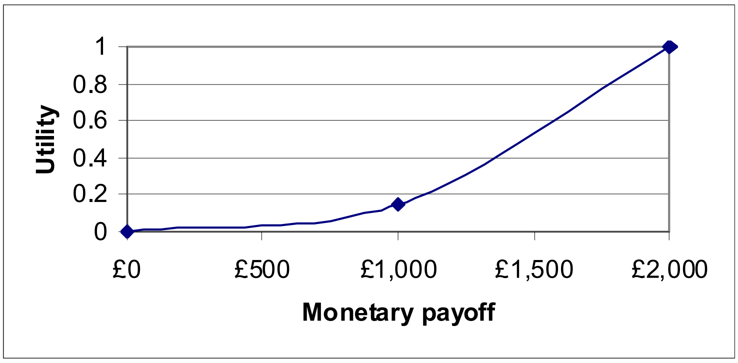
This means that their utility of £1000 is 0.8 –which yields the concave utility function below:



- A risk seeking decision maker would be tempted to consider gambling, even if the chance of winning is below 0.5. For example, if they are very risk-seeking they might be indifferent between A and B if the probability of winning is only 0.15.



This means that their utility of £1000 is only 0.15, yielding the *convex* utility function below:



Utility functions for non-monetary attributes

Utility functions can also be elicited for decisions that do not involve monetary considerations. For example, a pharmaceutical company, which is trying to develop a new anti-cancer drug may have to choose between two possible approaches to the development. Each approach may lead to particular probabilities of the drug being developed within a given numbers of years. By eliciting the utility of each development time it will be possible to establish whether the company should choose a the riskier approach, which might lead to the drug being ready for the market very soon, but which might also lead to the drug taking very many years to develop if things go wrong.

How useful is utility?

Pros

- It allows the decision maker's attitude to risk to be incorporated into the decision model.
- It can be extended to decisions involving several objectives (see session 8)
- It is soundly based on a formal set of testable axioms

Cons

- Utilities are sensitive to the questions involved in their elicitation. For example, questions framed in terms of gains tend to lead to risk averse responses. Questions phrased in terms of losses tend to lead to risk seeking responses. Therefore it is usually good practice to elicit utilities in several different ways and then to reconcile any discrepancies with the decision maker.
- The elicitation process takes the decision maker away from the real decision to a world of hypothetical lotteries. Thus a decision maker's responses to the elicitation questions may not be consistent with what they would choose when faced with the real decision.
- Decision makers from some cultures or with particular religious beliefs may be averse to questions phrased in terms of gambles
- Utilities are specific to particular decision problems. For example, you may be risk averse when faced with some decision problems and risk seeking when faced with others. This means that separate functions should be assessed for each new problem. Nevertheless, there is a problem if decision makers' utility functions are labile (i.e. changeable) –e.g. if they vary at different times of the day.
- Eliciting a utility function can be time consuming and is therefore only worthwhile for important problems
- It is difficult to obtain a utility function for a group of decision makers.

- Unaided decision makers often do not make the same decisions that utilities suggest that they should (e.g. see Allais's paradox) –but our aim is to help decision makers to make rational decisions, not to describe the way they behave if they don't have the benefits of decision analysis to help them

Exercise

1) A building contractor is submitting an estimate to a potential customer for carrying out some construction work at the customer's premises. The builder reckons that if he offers to carry out the work for £150,000 there is a 0.2 probability that the customer will agree to the price, a 0.5 probability that a price of £120,000 would eventually be agreed and a 0.3 probability that the customer will simply refuse the offer and give the work to another builder.

If the builder offers to carry out the work for £100,000 he reckons that there is a 0.3 probability that the customer will accept this price, a 0.6 probability that the customer will bargain so that a price of £80,000 will eventually be agreed and a 0.1 probability that the customer will refuse the offer and take the work elsewhere.

a) Determine which price the builder should quote in order to maximise the expected payment he receives from the customer.

b) Suppose that, after some questioning, the builder is able to make the following statements.

"I am indifferent between receiving £120,000 for certain or entering a lottery that will give me a 0.9 probability of £150,000 and a 0.1 probability of winning £0."

"I am indifferent between receiving £100,000 for certain or entering a lottery that will give me a 0.85 probability of winning £150,000 and a 0.15 probability of winning £0."

"I am indifferent between receiving £80,000 for certain or entering a lottery that will give me a 0.75 probability of winning £150,000 and a 02S probability of winning £0."

i) Sketch the builder's utility function and comment on what it shows.

ii) In the light of the above statements which price should the builder now quote to the customer and why?

iii) Show how utility enables the decision problem to be reduced to a comparison of simple lotteries each offering the best and worst payoffs with different probabilities.

iv) Show how the axioms of utility theory were necessary for your demonstration in part (iii) above.

2) a) Split into groups of two people and use the *probability equivalence method* to assess each other's utility function for the following monetary values (assume that the money will be received immediately):

£0, £1000, £3000, £5000

b) Plot the resulting utility functions and explain what they show.

c) Now re-assess your own utility function using the certainty equivalence method as outlined below:

Use the following questions to assess your own utility function for money values between £0 and £5000. You should assume that all sums of money referred to will be received immediately.

i) You are offered either a sum of money for certain or a lottery ticket that will give you a 50% chance of winning £5000 and a 50% chance of winning £0.

Write down below the certain sum of money, which would make you indifferent between whether you received it or the lottery ticket

£ . . . . (we will now refer to this sum of money as X)

The utility of X is 0.5.

ii) You are now offered a lottery ticket which offers you a 50% chance of £ . . . . (enter X here) and a 50% chance of £0. Alternatively, you will receive a sum of money for certain.

Write down below the certain sum of money, which would make you indifferent between whether you received it or the lottery ticket

£ . . . . The utility of this sum of money is 0.25.

iii) Finally, you are offered a sum of money for certain or a lottery ticket which will give you a 50% chance of £5000 and a 50% chance of £ . . . . . . (enter X here).

Write down below the certain sum of money, which would make you indifferent between whether you received it or the lottery ticket

£ . . . . The utility of this sum of money is 0.75.

Now plot a utility function to represent your responses to the above questions.

d) How consistent are the two utility functions? If they are not consistent, which function do you think most accurately reflects your attitude to risk?

Revising probability estimates in the light of new information

Bayes' Theorem

Bayes' theorem is concerned with how we should modify the strength of our beliefs when new information becomes available. It assumes that our initial beliefs are represented by what is known as a <u>prior</u> probability distribution. Probabilities which have been revised in the light of new information are called <u>posterior</u> probabilities. The diagram below summarises this:

Prior probability	→	New information (which may not be perfectly reliable)	→	Posterior probability

<u>Examples</u>

- You estimate that there is a 0.7 chance of it raining today, you then hear the weather forecast which indicates that it will not rain; how should you revise your original estimate?
- A manager estimates that there is a 0.9 probability that a new product will sell over 1 million units in its first year. However, market research results then become available and these suggest sales will be less than 1 million. How should the manager revise her original estimate?
- Geologists estimate that there is a 0.6 probability that oil is available in commercial quantities in an area of Australia. A test drilling also yields a positive result. To what extent should the geologists increase their estimates of the probability of commercial quantities of oil being available?

Bayes' theorem tells us exactly how we should convert our prior probabilities into posterior probabilities when we receive new information. The following example shows how.

<u>Lecture Example</u>

In 70% of weeks the sales of a magazine are high, while in 30% of weeks they are low.

1) Write down prior probabilities of high and low sales in the coming week.

………………………………………………………………………………

2) You are now given the sales figures for Monday and these show low sales. In the past:

- In weeks when sales turned out to be high, Monday had low sales on only 20% of occasions;
- In weeks when sales turned out to be low, Monday had low sales on 60% of occasions.

Revise your prior probabilities in the light of Monday's sales figure.

Space left for probability tree 1

Space left for probability tree 2

Quick check on your understanding so far

An insurance company estimates that 80% of drivers are good risks and categorises them as Class A drivers, while the remaining 20% are bad risks and classified as Class B. Mr Jones takes out a policy with the company. What is the prior probability that he is a Class A driver?

a) You now receive the following information: *Mr Jones has an accident within a year of taking out the policy.* The probability of a Class A driver having an accident in any year is 0.05, while the equivalent probability of a Class B driver is 0.1.

What is the revised (i.e. posterior) probability that Mr Jones is a Class A driver?

Another quick check on your understanding so far

A manager estimates that there is a 0.8 probability that a production process is running at peak efficiency. However, he is then handed the latest production cost figures and these have exceeded the budget. The probability of the costs exceeding the budget if the process is at peak efficiency is only 0.1, while the probability that they will exceed the budget if the process is not at peak efficiency is 0.7.

What is the posterior probability that the process is running at peak efficiency?

The effect of "strong" and "weak" prior probabilities

Example

A manager estimates that a new product is certain to yield high sales in its first year. However, market research results indicate that sales will only be low. This research has a 90% chance of giving a correct indication.

a) What is the posterior probability of high sales?

b) If the manager estimates, instead, that in the first year of the product's life high and low sales each have a 0.5 probability of occurring, what will be the posterior probability of high sales?

Further Exercise

A sales manager estimates that there is only a “30% chance” that the sales of a product will reach break-even level this year. However, at the end of March she is handed the sales figures for the first quarter of the year. These suggest that sales *are* on target to achieve the break-even level. The probability that the first quarter sales will give this indication when sales will reach break-even level is 0.8. The probability that they will give this indication when sales will not reach break-even level is 0.3. What is the posterior probability that sales will reach break-even level?

The expected value of perfect information (EVPI)

These days information, such as weather forecasts, market research information or the results of geological surveys, can be expensive to obtain. Sometimes the improvements in our decision making resulting from access to the information may not be sufficient to justify its cost, especially if the information is not perfectly reliable. For example weather forecasts, medical tests and market research results usually do not give perfectly accurate indications.

One way to assess the value of information is to assume that it is perfectly reliable and then see what improvements it would bring to the decision. These improvements set an upper limit on the value of the information. They also provide guidance to us on the aspects of our decision problem where acquiring further information would be most valuable.

Lecture Example 1

A company has just received some “state of the art” electronic equipment from an overseas supplier. The packaging has been damaged during delivery and the company must decide whether to accept the equipment. If the equipment itself has not been damaged, it could be sold for a profit of £10,000. However, if it is accepted and turns out to be damaged, a *loss* of £5,000 will be incurred. Rejection of the equipment will lead to no change in the company's profit. After a cursory inspection, the company’s engineer estimates that there is a 60% chance that the equipment has not been damaged.

The company has another option; a local specialist company could test the equipment. Assuming that its tests is perfectly reliable determine how much would it be worth paying for the information from the test (i.e. calculate the expected value of perfect information, EVPI) .

Space left for answer

Exercise

The managers of Red Valley Auto Products are considering the national launch of a new car-cleaning product. For simplicity the potential average sales of the product during its lifetime are classified as being high, medium or low and the net present value of the product under each of these conditions is estimated to be £80 million, £15 million and -£40 million respectively. The company's marketing manager estimates that there is a 0.3 probability that average sales will be high, a 0.4 probability that they will be medium and a 0.3 probability that they will be low. It can be assumed that the company's objective is to maximise expected net present value.

a) On the basis of the marketing manager's prior probabilities, determine whether the product should be launched;

b) The managers have another option. Rather than going immediately for a full national launch they could first test market the product in their Northern sales region. This would obviously delay the national launch and this delay, together with other outlays associated with the test marketing, would lead to costs having a net present value of £3 million. The test marketing would give an indication of whether a national launch will lead to either high, medium or low sales. However its reliability is unknown. Assume that the test marketing is perfectly reliable and hence calculate the expected value of perfect information (EVPI). Interpret your result.

7 Decisions Involving Multiple Objectives: SMART

Objectives
At the end of these sessions you should:

- ⇨ Be able to use value trees to identify the attributes associated with a given decision and be able to assess the usefulness of the tree;
- ⇨ Be able to use value functions and direct rating to measure the attractiveness of the options on each attribute;
- ⇨ Understand the dangers of using importance weights and be able to use swing weights;
- ⇨ Be able to identify the options which lie on the efficient frontier,
- ⇨ Be able to use Edward's and Newman's method to identify the preferred option;
- ⇨ Be able to apply sensitivity analysis to the decision model;
- ⇨ Understand the axioms underpinning the method and concepts such as mutual preference independence and requisite models.

<u>Using SMART to support decisions involving multiple objectives</u>

SMART = Simple Multiattribute Rating Method

Objectives versus attributes

An objective is an indication of the preferred direction of movement of a decision maker. Typically when stating objectives we use terms like maximise or minimise. E.g. minimise pollution, maximise exposure to a TV advertisement or minimise distance travelled.

An attribute measures performance in relation to an objective. For example performance in relation to the objective, 'minimise pollution' may be measured by the attribute 'tonnes of CO_2 emitted' . Similarly performance on the objective 'maximise exposure to a TV advert' may be measured by the attribute 'number of people surveyed who recall seeing the advertisement'. Some companies may measure performance on the objective 'maximise employee job satisfaction' using the attribute 'rate of staff turnover'.

Advantages of SMART

- Breaks the problem down into smaller and (hopefully) easier parts
- Hence allows the decision maker to consider all of the available information and address

all of the objectives –not just a few

- Allows the decision maker to carry out 'what if' analyses. E.g. what if I change the priorities of the objectives
- Guides decision maker on what information needs to be gathered
- Provides a documented and defensible rationale for the decision
- Challenges intuition
- Enables consistent decisions to be made e.g. in the selection of suppliers
- Compared to more complex methods it is quick and transparent.

The stages of SMART

We will apply SMART to the choice of an ultra-portable notebook computer (see table on next page).

The stages of SMART are:

1. *Identify the decision maker or decision makers*
2. *Identify the alternative courses of action*
3. *Identify the objectives/attributes that are relevant to the decision problem*
4. *For each attribute –assign values to measure the performance of the alternatives on that attribute*
5. *Determine a weight to reflect the importance of the attributes in the decision*
6. *For each alternative, take a weighted average of the values assigned to that alternative*
7. *Make a provisional decision*
8. *Perform sensitivity analysis to see how robust the decision is to changes in the figures supplied by the decision maker*

Note that, in practice, these stages are not carried out in a 'linearly'. Usually, decision makers past back and forth between the stages as they learn more about the decision problem

:

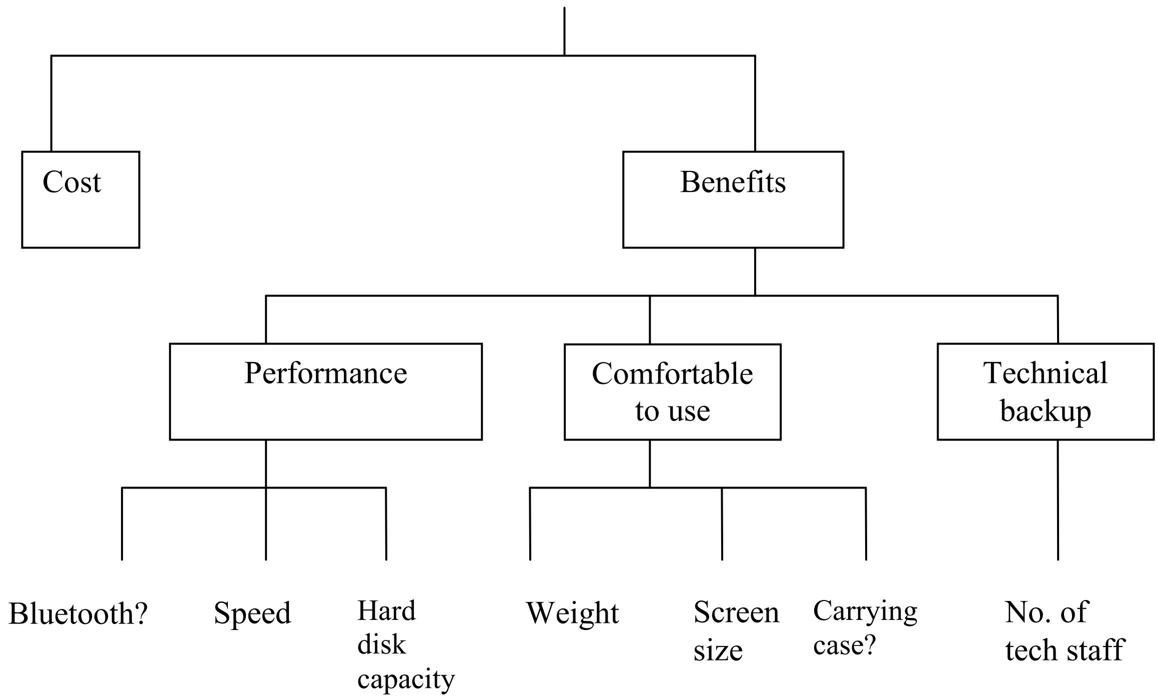
Ultra-Portable Notebooks

Manufacturer/Model	Price £	Speed	Hard disk	Weight	Screen size	Bluetooth?	Carrying case?	No. of technical support staff
Acer TravelMate	790	1.66 GHz	120 GB	1.8 kg	12.1 inches	Yes	No	>150
Evesham Lightbook	731	1.20 GHz	60 GB	1.3 kg	12.1 inches	No	No	9
Fujitsu Siemens Amilo	586	1.83 GHz	100 GB	2.0 kg	12.1 inches	No	No	>150
Hi-Grade Notino	686	2.00 GHz	100 GB	2.0 kg	13.3 inches	No	No	10
HP Compaq	697	1.83 GHz	80 GB	2.3 kg	14.1 inches	Yes	No	40
MSI MegaBook	550	1.66 GHz	60 GB	2.1 kg	12.1 inches	Yes	Yes	82
Toshiba Satellite Pro	654	1.66 GHz	60 GB	1.9 kg	12.1 inches	Yes	No	est >150

(Source Computer Shopper March 2007)

Identifying the objectives of the decision

A <u>value tree</u> is generally used for this purpose:



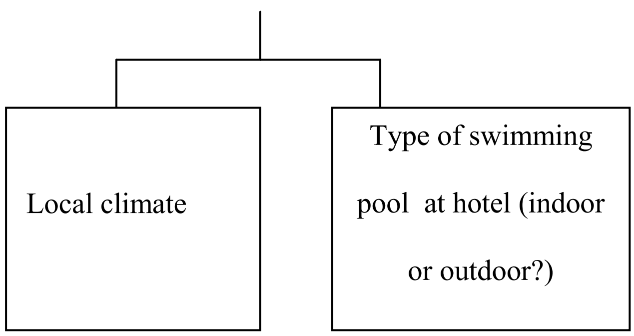
How do we know if the value tree is a valid? Keeney and Raiffa have suggested five criteria that can be used to assess the tree.

1. *Completeness* –have we included all of the attributes that are relevant to the decision?

2. *Operationality* –are the lowest level attributes in the tree specific enough for them to be evaluated and compared across the different options? If they are not they probably need to be decomposed further. E.g. “Level of pollution” might be too vague. Decomposing this into “Tonnes of CO_2 emitted per year” and “Tonnes of sulphur dioxide released per year” would probably allow the performance of options to be measured and compared.

3. *Decomposability* –can we judge the performance of an option on a given attribute, without having to think about its performance on other attributes?

E.g. choice of a holiday hotel: (part of value tree)



If you are asked to state your preference between and indoor or outdoor pool, you will probably say "that depends on the local climate –in a cold climate I prefer an indoor pool, in a hot climate I prefer an outdoor pool". Thus we cannot judge the performance of the hotels on their type of swimming pool without at the same time worrying about their performance on another attribute.

Other examples might be:

- Preference between a 4x4 or a conventional hire car for holiday depends on remoteness of holiday location

- The attraction of having a company car with a job depends on whether or not the job is based in London

Remember that in decision analysis our aim is to simplify decision problems by breaking them into separate parts so that we can focus on each part independently. If we have to think about how an option performs on several attributes at the same time then we have not achieved this separability and we probably need to restructure the tree or redefine attributes.

If relative preferences for options on one attribute are not dependent on how they perform on other attributes, and if this applies to all attributes, then the attributes are said to be mutually preference independent. The calculations we will perform later in SMART assume that mutual preference independence applies.

4. *Absence of redundancy* – do two or more attributes in the tree duplicate each other, perhaps because they represent the same thing but under different names (e.g. "storage capacity of computer" and "hard disk size of computer")? We also have redundancy when attribute is such that all of the options perform equally well on it. For example, a decision maker may consider the "number of bedrooms" in a house to be very important, but if all the houses being considered have 3 bedrooms then this attribute is irrelevant to the choice between them and can be eliminated from the tree.

5. *Minimum size* –our intention is to help the decision maker by making the decision problem simpler and more manageable. Very large trees are unlikely to achieve this. Often the size of a tree can be reduced by eliminating trivial attributes which have very little importance in the decision.

For our choice of notebook problem we will assume that our value tree is valid.

Assigning values (or scores) to the options on each attribute

There are three types of attribute:

i) monetary attributes

ii) non-monetary attributes that do not have a natural, or easily formulated, numeric scale (e.g. comfort of seats on different airlines, quality of image created by different office facades, beauty of alternative holiday destinations).

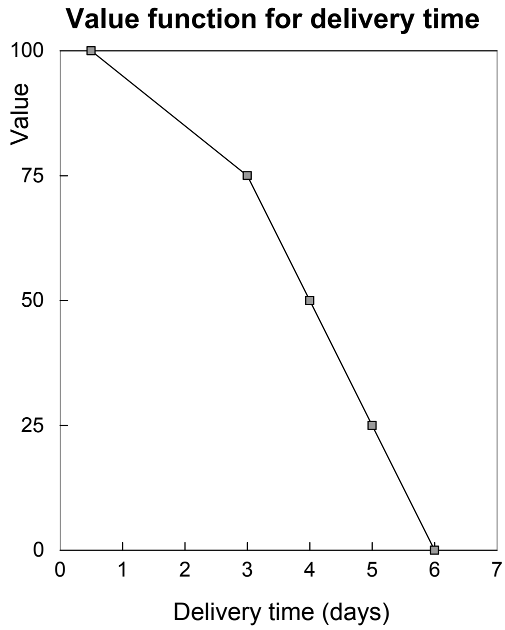
iii) non-monetary attributes that <u>do</u> have a natural numeric scale (e.g. top speed of a car, number of bedrooms of a house, screen size of a computer's monitor).

We deal with these attributes in different ways as we now show.

i) <u>Monetary attributes</u> -. If trading-off money against non-monetary attributes involves difficult judgments, these can be left in their original monetary units. We can then put the monetary attributes 'on one side' until later on in the analysis. We will do this here. However, if this trade-off is not problematical then we can treat them as in (ii) (below).

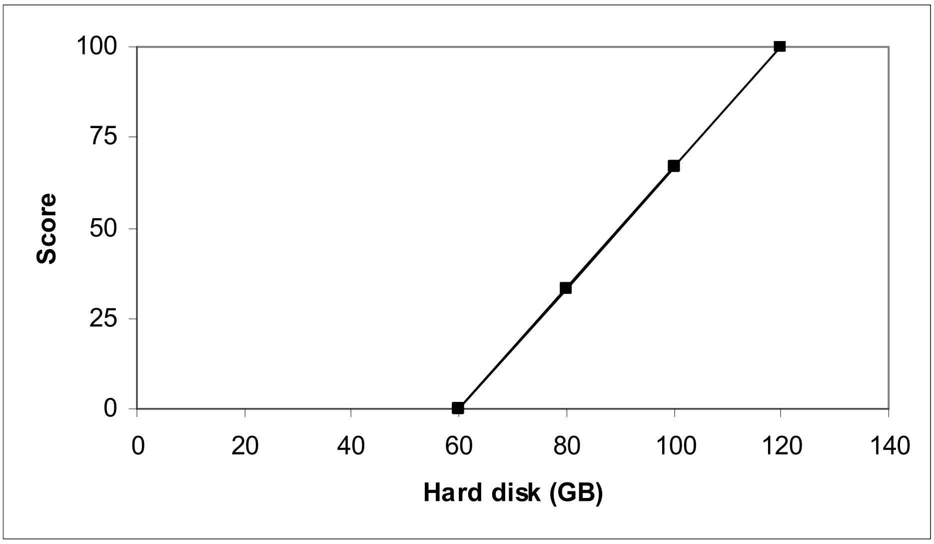
ii) <u>Attributes that have a natural numeric scale</u>

A value function can be used to convert the attribute's numeric values to a 0 to 100 scale (0 = worst and 100= best). This can either be sketched or it can be obtained by using a more formal procedure. An example of a value function for the delivery time of some equipment is shown below:



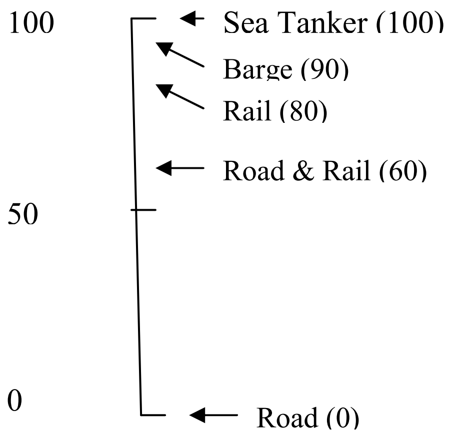
We could now use the value function to read off the values of the different delivery times. For example the 5 days delivery time translates to a score of 25.

Often it is reasonable to approximate the true value function with a linear function. We will assume that's the case here. For example:



ii) Attributes that do not have a natural numeric scale

For each of these we can score how well the different options perform by first ranking them in order from best to worst and then using direct rating on a scale from 0 (the worst) to 100 (the best). The scores in the example below show an assessment of how well different forms of transport perform in terms of their "effect on environment" .



For our choice of notebook decision, assignment of the scores is simple. For example:

Carrying Case?	Score
Yes	100
No	0

All the scores we have obtained are displayed in the table on the next page.

Manufacturer/Model	Price (£)	Speed	Hard disk	Weight	Screen size	Bluetooth?	Carrying case?	Technical support staff
Acer TravelMate	790	57.5	100.0	50.0	0.0	100.0	0.0	100.0
Evesham Lightbook	731	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Fujitsu Siemens Amilo	586	78.8	66.7	30.0	0.0	0.0	0.0	100.0
Hi-Grade Notino	686	100.0	66.7	30.0	60.0	0.0	0.0	0.7
HP Compaq	697	78.8	33.3	0.0	100.0	100.0	0.0	22.0
MSI MegaBook	550	57.5	0.0	20.0	0.0	100.0	100.0	51.8
Toshiba Satellite Pro	654	57.5	0.0	40.0	0.0	100.0	0.0	100.0

Determining weights for the attributes

It is easy to make a serious error at this stage. Consider the following problem. One of two cars (A and B) is to be purchased based on the cars' fuel economy (miles per gallon or mpg) and top speed (miles per hour or mph). Because she lives in a congested urban area the decision maker considers that fuel economy is 9 times more important than top speed. As we will see, we usually ensure that weights sum to 1 (or 100) so this implies weights of 0.9 and 0.1.

Given below are the details of the two cars.

Car	Fuel economy (mpg)	Top speed (mph)
A	43.0	55
B	42.9	85

This implies values of:

Car	Fuel economy (mpg)	Top speed (mph)
A	100	0
B	0	100
Weights	0.9	0.1

This means the weighted average scores of the two cars are:

A: (0.9 x 100) + (0.1 x 0) = 90
B: (0.9 x 0) + (0.1 x 100) = 10

so we should, according to the decision model, choose car A. We have chosen car A because it does best on the most important attribute: fuel economy. However, it is only better than the competing car by 0.1 mpg. To gain this 0.1 mpg we have forgone an extra 30 mph on the top speed. This is not the sort of trade-off that most decision makers would be prepared to accept.

The solution is to avoid the use of importance weights like these, but instead to use swing weights which will reflect ranges between the worst and best performers on each attribute. In this case we would be asked to compare the desirability of an extra 0.1 mpg and an extra 30 mph. The latter is likely to be far more desirable and the swing weights would reflect this.

To determine the swing weights, first list the swings from the worst to the best value for each attribute……

Non-monetary attribute	Swing		
	Worst		Best
Speed	1.2 GHz	→	2 GHz
Hard disk	60 GB	→	120 GB
Weight	2.3 kg	→	1.3 Kg
Screen size	12.1 inches	→	14.1 inches
Bluetooth?	No	→	Yes
Carrying case?	No	→	Yes
Technical support staff	9	→	over 150

Then we can rank these swings (improvements) in terms of their desirability. Say we have:

1. Weight	2.3 kg	→	1.3 Kg
2. Technical support staff	9	→	over 150
3. Screen size	12.1 inches	→	14.1 inches
4. Speed	1.2 GHz	→	2 GHz
5. Hard disk	60 GB	→	120 GB
6. Carrying case?	No	→	Yes
7. Bluetooth?	No	→	Yes

Next we can give the most preferable swing a weight of 100 and then assign weights to the other swings to reflect their relative desirability

				Weight
1. Weight	2.3 kg	→	1.3 Kg	100
2. Technical support staff	9	→	over 150	60
3. Screen size	12.1 inches	→	14.1 inches	40
4. Speed	1.2 GHz	→	2 GHz	35
5. Hard disk	60 GB	→	120 GB	15
6. Carrying case?	No	→	Yes	10
7. Bluetooth?	No	→	Yes	5
			Sum	**265**

It is usual to normalise these weights so that they sum to 1 (or, if preferred, 100). This is simply achieved by dividing each weight by the sum of the weights (265 in this case) to :

Attribute	Raw weight	Normalised weight
Weight	100	0.38
Tech support staff	60	0.23
Screen size	40	0.15
Speed	35	0.13
Hard disk	15	0.06
Carrying case?	10	0.04
Bluetooth?	5	0.02
Sum of weights	**265**	**1.00** *(subject to rounding)*

Obtaining the aggregate scores

We now have the following scores and weights:

Manufacturer/Model	Price (£)	Speed	Hard disk	Weight	Screen size	Bluetooth?	Carrying case?	Technical support staff
Acer TravelMate	790	57.5	100.0	50.0	0.0	100.0	0.0	100.0
Evesham Lightbook	731	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Fujitsu Siemens Amilo	586	78.8	66.7	30.0	0.0	0.0	0.0	100.0
Hi-Grade Notino	686	100.0	66.7	30.0	60.0	0.0	0.0	0.7
HP Compaq	697	78.8	33.3	0.0	100.0	100.0	0.0	22.0
MSI MegaBook	550	57.5	0.0	20.0	0.0	100.0	100.0	51.8
Toshiba Satellite Pro	654	57.5	0.0	40.0	0.0	100.0	0.0	100.0
Normalised weights		0.13	0.06	0.38	0.15	0.02	0.04	0.23

A weighted aggregate score for each computer can be calculated.

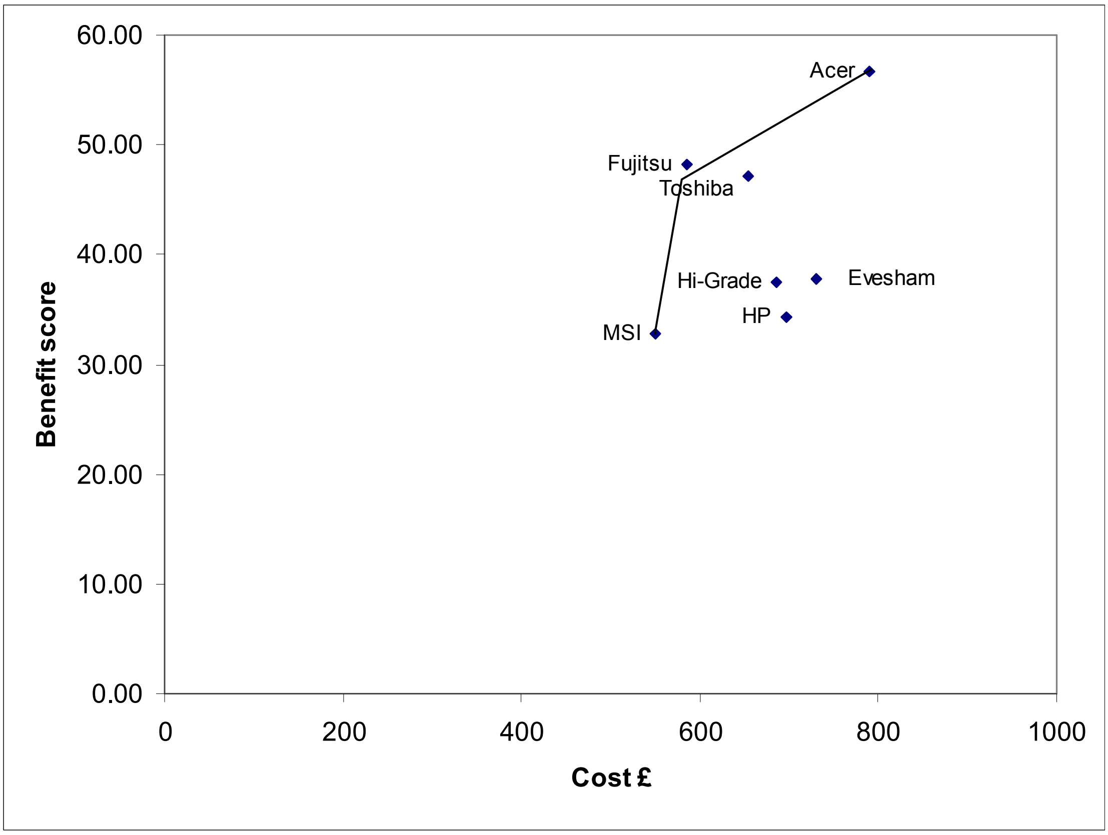
E.g. Acer score = (0.13 x 57.5) + (0.06 x 100) + (0.38 x 50) + (0.15 x 0)
+ (0.02 x 100) + (0.04 x 0) + (0.23 x 100)

= 57.5 *(subject to rounding)*

The complete set of costs and aggregate scores are given below:

Manufacturer/Model	Price (£)	Aggregate Score
Acer TravelMate	790	57.5
Evesham Lightbook	731	38.0
Fujitsu Siemens Amilo	586	48.6
Hi-Grade Notino	686	37.6
HP Compaq	697	34.3
MSI MegaBook	550	33.0
Toshiba Satellite Pro	654	47.7

We can now plot the aggregate scores for the non-monetary attributes against the costs:



Note that all the computers *except* the MSI, Fujitsu and Acer are dominated. In each case another computer offers higher benefits at a lower cost. The only non-dominated computers: the MSI, Fujitsu and Acer are said to lie on the efficient frontier.

Making a provisional decision

In this case SMART has not indicated which computer is best, but it has reduced the list of options that we have to choose between to just three. A method called the Edwards Newman method can be used to help the decision maker to choose from the options on the efficient frontier. We consider the following possible switches along the efficient frontier, starting with the cheapest option:

Switch	Increased cost £	Increased benefit	Cost per extra benefit point
MSI to Fujitsu	35.3	15.6	2.3
Fujitsu to Acer	204.7	8.9	23.0

Now we need to assess how much the decision maker is prepared to pay for each extra 'benefit point'. We can obtain this information implicitly by asking them to tell us how much they would be prepared to pay to improve one of the attributes from its worst to its best value, if all the other attributes are held constant. Suppose that the decision maker would be prepared to pay £12 for a carrying case (i.e. to improve this attribute from its worst position, 'no case', to its best :'being provided with a case'), all else remaining equal.

Now the aggregate benefit score for a computer with no carrying case will be: (0.13 x score for speed) + (0.06 x hard disk score) + (0.38 x weight score) + (0.15 x screen size score) + (0.02 x Bluetooth score) + **(0.04 x 0)** + (0.23 x technical staff score)

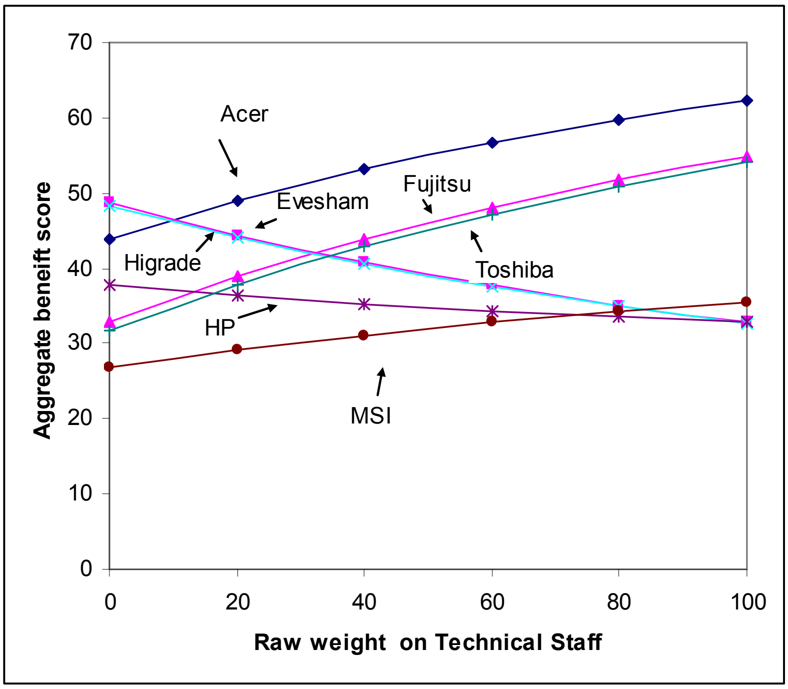
If nothing else changes, apart from the provision of a carrying case then the score will increase to:
(0.13 x score for speed) + (0.06 x hard disk score) + (0.38 x weight score) + (0.15 x screen size score) + (0.02 x Bluetooth score) + **(0.04 x 100)** + (0.23 x technical staff score)

that is an increase of 4 points. So the decision maker is implicitly prepared to pay £12 for 4 points or £3 per point. On this basis the first switch to the Fujitsu is acceptable, but the subsequent switch is not. Thus the provisional decision should be to purchase the Fujitsu.

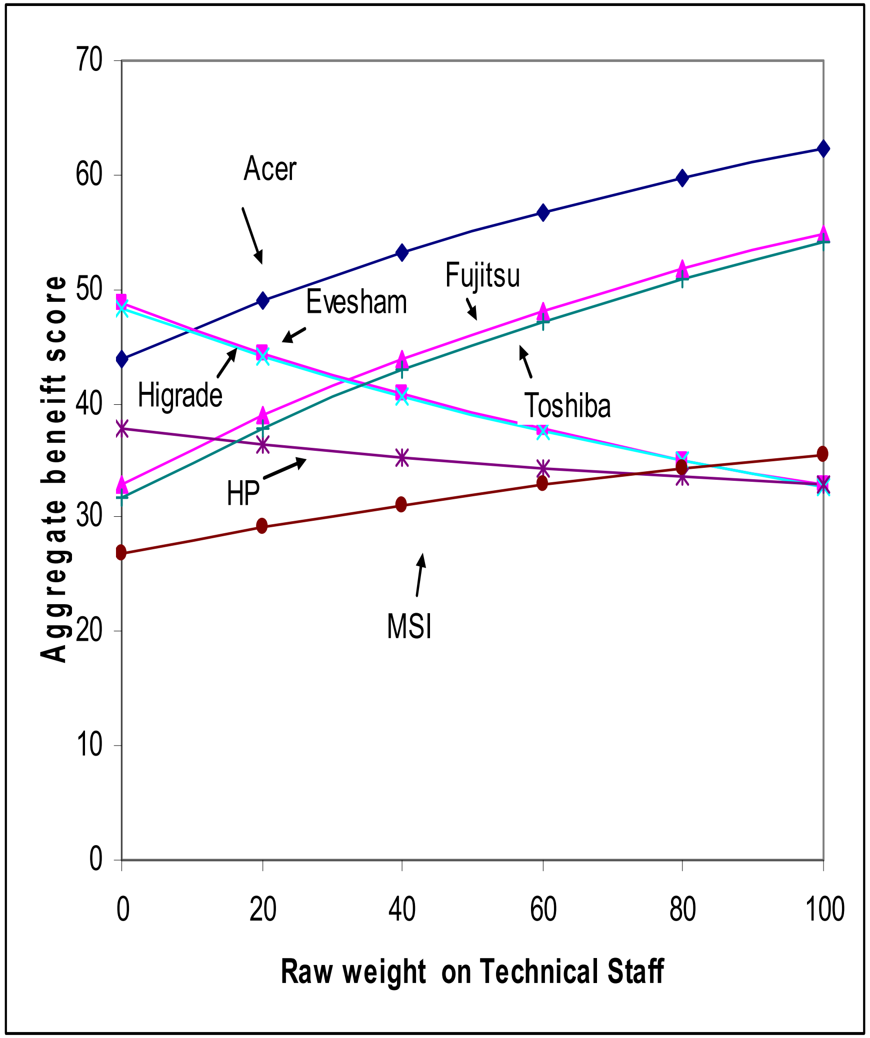
Sensitivity analysis

The weights and scores we have used in the analysis are based on rough judgments and, within decision making teams, there may be disagreements about these values. It is therefore very important to examine how sensitive the decision is to variations in the values. One example of sensitivity analysis involves assessing how robust the membership of the efficient frontier is to changes in the weights assigned to the attributes.

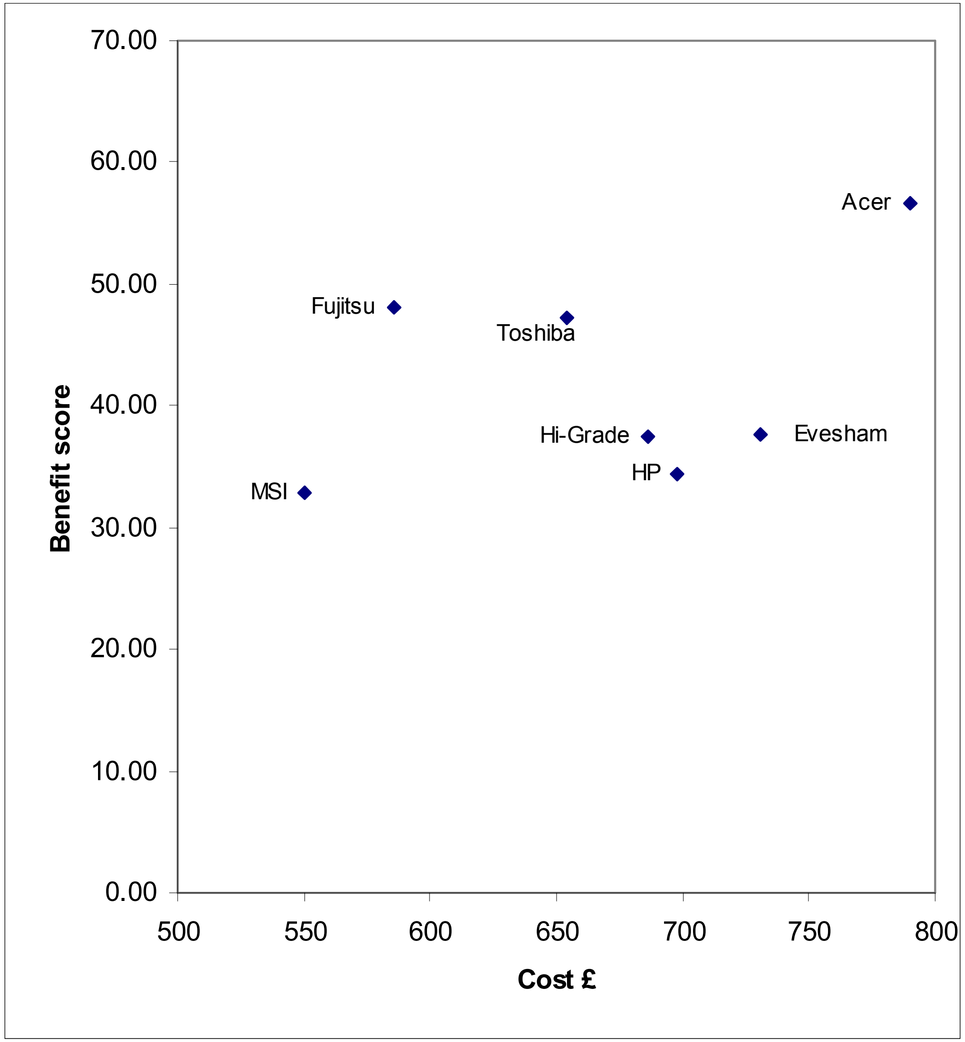
Suppose we are unsure about the raw weight of 60 which we assigned to the number of technical support staff. The graph below shows what happens to the aggregate benefit scores of the computers as this weight changes from 0 to 100 (with all other raw weights held constant).



By aligning this graph with efficient frontier graph we can detect how robust the membership of the efficient frontier is to changes in the raw weight on technical staff.



Aggregate benefit score
70
60
50
40
30
20
10
0
0
20
40
60
80
100
Raw weight on Technical Staff
Acer
Evesham
Fujitsu
Higrade
Toshiba
HP
MSI



Benefit score
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
500
550
600
650
700
750
800
Cost £
Acer
Fujitsu
Toshiba
Hi-Grade
Evesham
HP
MSI

A quick way to obtain approximate swing weights

Recall that we ranked the swings in order of preference as follows:

1. Weight	2.3 kg	→	1.3 Kg
2. Technical support staff	9	→	over 150
3. Screen size	12.1 inches	→	14.1 inches
4. Speed	1.2 GHz	→	2 GHz
5. Hard disk	60 GB	→	120 GB
6. Carrying case?	No	→	Yes
7. Bluetooth?	No	→	Yes

Approximate weights can now be estimated using the rank-sum method:

Attribute	Rank	Reverse Rank	Reverse rank/sum
Weight	1	7	7/28 = 0.25
Tech support staff	2	6	6/28 = 0.21
Screen size	3	5	5/28 = 0.18
Speed	4	4	4/28 = 0.14
Hard disk	5	3	3/28 = 0.11
Carrying case?	6	2	2/28 = 0.07
Bluetooth?	7	1	1/28 = 0.04
Sum of ranks	**28**		**1.00**

Requisite decision models

What happens when your intuitive choice differs from that indicated by the decision model? Consider the possible reasons for this discrepancy.

The model might be wrong

For example:

-an important attribute might have been omitted from the model

-the weights or values put forward by the decision maker do not correctly reflect his or her true preferences.

-the attributes are not mutually preference independent

-Edwards and Newman's method assumes a linear trade-off between costs and benefits (i.e. each extra benefit point is worth the same number of £s to the decision maker) –this may not be the case

The decision maker's intuition might be wrong

-the problem might be too large and complex for the decision maker to take an overall rational view of the problem. For example, he or she might only be able to focus on one or two attributes at a time and therefore may be basing his or her choice on only a sub-set of the important attributes.

Resolving the conflict

Some people argue that this is when decision analysis is at its most valuable –by exploring the discrepancies between your intuition and the model you develop a deeper understanding of the problem and also improve the model. Once the intuitive decision and the model's indication have converged the model is said to be requisite. At this point the model should provide the decision maker with enough guidance and insight to make the decision with confidence.

Tutorial Questions

1. Apply SMART to the Baleston Council case study problem, which is set out below.

2. Apply SMART to the International Components case study problem, which is also set out below.

3 a) Formulate a value tree to identify the attributes which are of concern to you when choosing a career.

   b) To what extent does your tree meet the following criteria?
      (i) Completeness
      (ii) Operationally
      (iii) Decomposability
      (iv) Absence of redundancy
      (v) Minimum size

4. You need a word processing package for the personal computer in your office. Because your employer will pay for the package you are not concerned about the cost, but you would like a package that was as easy to use as possible and which also had a wide range of functions such as a thesaurus, spell checker and graphics. After discussing the matter with a friend, who is something of an expert in this field, you identify seven potential packages and allocate values to them to reflect their ease of use and available facilities. These values are shown below (0 = worst, 100 = best).

Package	Ease of use	Facilities Available
Super Quill	100	30
Easywrite	90	70
Wordright	50	20
Lexico	0	40
Ultraword	20	100
Keywrite	40	0
Fastwrite	85	55

a) Plot each package's value for 'ease of use' and 'facilities available' on a graph and hence determine the packages that lie on the efficient frontier.

b) Suppose that you judge that a switch from a package with the least facilities available to one with the most facilities is only 60% as attractive as a switch from a package that is the least easy to use to one which is the most easy to use. Assuming that mutual preference independence exists between the two attributes, which package should you choose?

c) After some reflection you realise that the extra facilities available on a package will be of little value to you if they are going to be difficult to use. What does this imply about your method of analysis in part (b)?

Case Study Baleston Council

Baleston Council has to decide on the location of a new waste disposal facility and five sites are currently being considered: Inston Common, Jones Wood, Peterton, Red Beach and Treehome Valley. In order to help them to choose between the sites the managers involved in the decision arranged for a decision analyst to attend one of their meetings. He first got the managers to consider the factors which they thought were relevant to the decision and, after some debate, four factors were identified.

1. The visual impact of the site on the local scenery (for example a site at Treehome Valley would be visible from a nearby beauty spot).
2. The ease with which the waste could be transported from the site (for example, Red Beach is only two miles from the main town in the area and is close to a main road, while Inston Common is in a remote spot and its use would lead to a major increase in the volume of transport using the minor roads in the area).
3 The risk that the use of the site would lead to contamination of the local environment (for example, because of leakages of chemicals into watercourses);
4. The cost of developing the site.

The decision analyst then asked the managers to assign scores to the sites to show how well they performed on each of the first three attributes. The scores they eventually agreed are shown below, together with the estimated cost of developing each site. Note that 0 represents the worst and 100 the best score on an attribute. Therefore in the case of risk, a score of 100 means that a site is the least risky.

	Benefits			
Site	Visual Impact	Transport	Risk	Costs (£m)
Inston Common	100	0	60	35
Jones Wood	20	70	100	25
Peterton	80	40	0	17
Red Beach	20	100	30	12
Treehome Valley	0	70	60	20

The decision analyst then asked the managers to imagine a site that had the worst visual impact, the most difficult transport requirements and the highest level of risk. He then asked them, if they had a chance of switching from this site to one which had just one of the benefits at its best value, which would they choose? The managers agreed that they would move to a site offering the least risk of contamination. A move to a site with the best visual impact was considered to be 80% as preferable as this, while a move to one with the most convenient transport facilities was 70% as preferable.

Questions

a) Can we conclude from the values, which were assigned to the different sites for visual impact that, in terms of visual impact, the Inston Common site is five times preferable to Red Beach. If not, what can we infer from the figures?

b) An alternative way of allocating weights to the three benefit attributes would have involved asking the managers to allocate a score reflecting the importance of each attribute. For example, they might have judged that risk was five times more important and visual impact three times more important than ease of transport, so that weight of 5, 3 and 1 would have been attached to the attributes. What are the dangers of this approach?

c) Assuming that the attributes are mutually preference independent, determine the value of aggregate benefits for each site.

d) Plot the costs and the value of aggregate benefits of each site on a graph. Hence identify the sites that lie on the efficient frontier.

e) (*This question should only be attempted if you have access to a spreadsheet package.)*Although a weight of 80 was finally agreed for visual impact, this was only after much debate and some managers still felt that a weight of 65 should have been used, while others thought that 95 would have been more appropriate. Perform a sensitivity analysis on the weight assigned to visual impact to examine its effect on the aggregate benefits of the sites and interpret your result.

f) Assuming that the original weights stand, suppose that the managers agree that it would be worth paying about £20 million to switch from a site with the worst transport facilities to one with the best, determine which site they should choose.

Case Study International Components

A British company has won an important contract to supply components regularly to Poland. Four methods of transport are being considered:

1. Air
2. Sea
3. Road and ferry
4. Rail and ferry

The company's distribution manager has identified four relevant attributes for the decision:

1. Punctuality
2. Safety of cargo
3. Convenience
4. Costs.

She has also allocated weights of 30 to punctuality, 60 to safety of cargo and 10 to convenience.

The manager then rated the performance of each form of transport on the different attributes. The vales she assigned are shown in the following table (0 = worst, 100 = best), together with the estimated annual cost of using each form of transport.

	Benefits			
Form of Transport	Punctuality	Safety	Convenience	Costs (£)
Air	100	70	60	150,000
Sea	0	60	80	90,000
Road/Ferry	60	0	100	40,000
Rail/ferry	70	100	0	70,000

Use a spreadsheet to:

a) Identify the options in the following decision problem that lie on the efficient frontier (assuming that the attributes are mutually preference independent).

b) If you have access to a spreadsheet, examine the sensitivity of the aggregate benefit of the options to changes in the weight placed on 'safety'.

8 Group Decision Making

Objectives
At the end of this session you should:

- ⇨ Be aware of issues relating to group size and the weighting of individual judgements
- ⇨ Be aware of Condorcet's Paradox and Arrow's Impossibility Theorem;
- ⇨ Be able to debate whether it is meaningful to average utilities and values.
- ⇨ Understand the conditions which can lead to groupthink
- ⇨ Be aware of the symptoms of groupthink and its effect on the quality of decisions
- ⇨ Understand the processes involved in decision conferencing and how decision conferences are designed to avoid groupthink

Carter Racing Case Study

This will be handed out in class

Unstructured group processes

Unstructured group processes essentially refers to meetings of decision makers where no methods are used to control the flow of discussion or no use is made of structured decision making methods like decision analysis

One of the main dangers associated with unstructured group processes is referred to as <u>groupthink.</u>

Groupthink refers to the tendency of groups who have been working together for some time to make poor decisions because social pressures to conform and avoid conflict lead to suppression of contradicting opinions.

<u>Conditions leading to groupthink</u>

- ⇨ High group cohesiveness
- ⇨ Insulation of group
- ⇨ Lack of methodological procedures for searching for and appraising options
- ⇨ Directive leadership
- ⇨ High stress with a low degree of hope of finding a solution better than the one favoured by the leader or other influential person.

<u>Symptoms of groupthink</u>

- ⇨ Illusion of invulnerability: - excessive optimism; taking extreme risks
- ⇨ Collective rationalisation
- ⇨ Belief in group's inherent morality

- ⇨ Stereotypes of rivals and enemies as evil, weak and stupid
- ⇨ Direct pressure on dissenters - loyalty is expected
- ⇨ Self-censorship - minimising importance of one's doubts and counter arguments
- ⇨ Shared illusion of unanimity - false assumption that silence implies consent
- ⇨ Self appointed 'mindguards' - who protect group from adverse information that might shatter shared complacency

<u>Some consequences of groupthink</u>

- ⇨ Incomplete survey of alternative courses of action and objectives
- ⇨ Failure to examine risks of preferred choice
- ⇨ Poor information search
- ⇨ Selective bias in processing available information
- ⇨ Failure to work out contingency plans in case things go wrong

Avoiding groupthink: Decision Conferencing

This method uses a socially interactive approach to:

1. Generate a shared understanding of a problem
2. Produce a commitment to action

Decision conferencing:

- Brings together group processes, decision analysis and IT in an intensive 2 or 3 day session
- Involves a small group of decision makers with a decision analyst and assistant who uses IT to model individual and group views
- Simple models (often SMART based) tend to be used so that the model is transparent to all participants and shared understanding of problem is generated
- Participants gain a sense of common purpose and commitment to action
- Sensitivity analysis enables participants to see if individual disagreements affect the preferred course of action.

<u>Why decision conferences should avoid groupthink</u>

Decision conferences are designed to avoid groupthink:

- Participants are not on home ground
- The group is carefully composed of people from all perspectives - adversarial processes operate
- The facilitator is a neutral outsider who is aware of the unhelpful affects of groupthink

- Decision analysis model is used to structure the debate. This should assure that all key issues are addressed; everyone has a chance to influence the importance which is assigned to each issue.

Mathematical aggregation of group judgments

Mathematical aggregation is a way of obtaining decisions from groups without holding meetings. It usually involves either the use of voting systems or the use of decision models based on averages of individuals' probability estimates, utilities or values.

The advantages of mathematical aggregation are:

1. It is relatively easy to implement
2. Individual decision makers need not be in the same location
3. The status, personality and assertiveness of individuals should not affect the decisions that emerge from the group.

The disadvantages are:

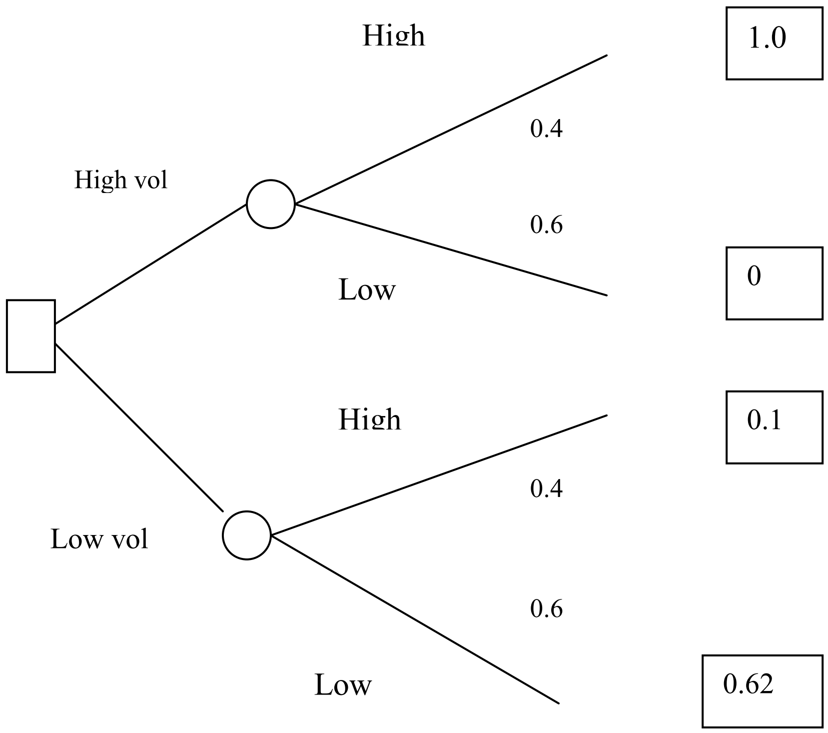
1. Individuals do not have access to the exchange of information, alternative perspectives and arguments of other decision makers to help them to improve their understanding of the decision

2. Mathematical aggregation can lead to paradoxical results as shown below.

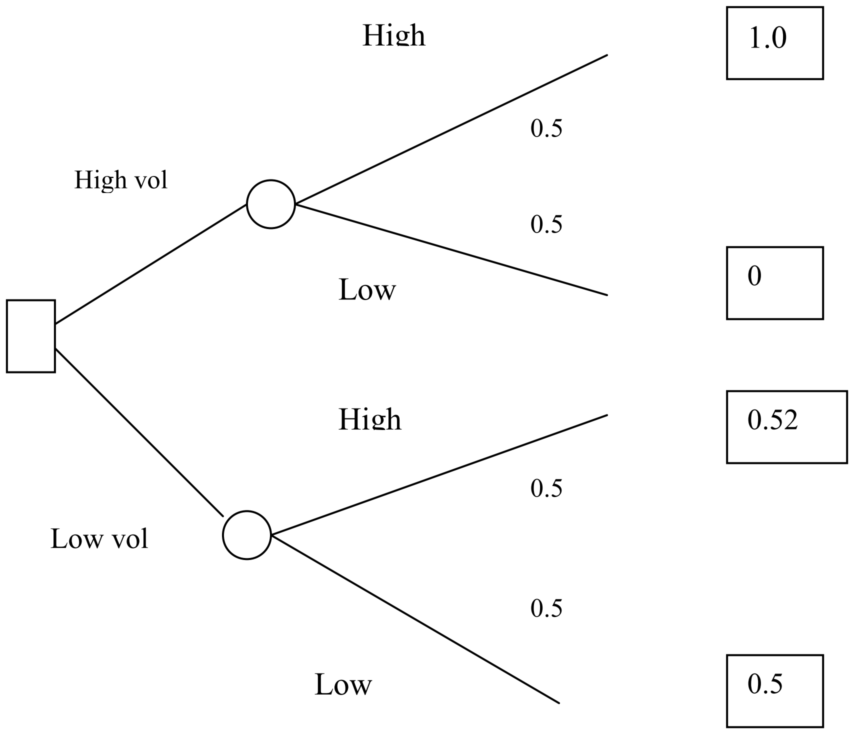
Example

A group of two people –a production manager and an accountant have to agree on whether their company should purchase a high-volume or low-volume processor. Decision trees, which represent their individual views of the relevant probabilities and utilities, are shown below.

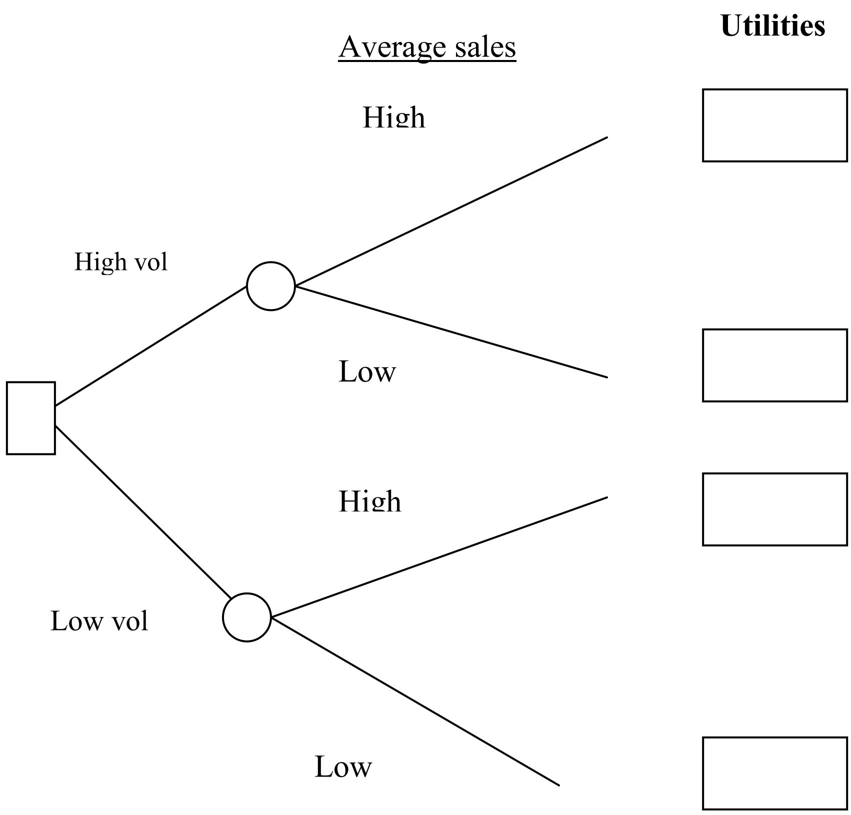
The production manager's decision tree



The accountant's decision tree



The group's decision tree



Although all the members of the group prefer the low volume processor our aggregation method suggests that they should choose the high volume processor! We will consider later whether it is reasonable to average the utilities of individual decision makers.

Aggregating judgments in general

This could be judgments of variables like sales, construction costs or advertising revenue. There are two simple methods that can be employed:

1. *Simple averaging of individuals' judgments.*

This is appropriate where:

each individual estimate = true value + independent random error

and the random errors are not biased i.e., their expected value = 0

The process of averaging individuals' judgments under these conditions can be modelled as follows. Assume that each person's estimate is symmetrically distributed about the true value μ, with a standard deviation of σ and that there are n people in the group. Sampling theory tells us that the mean of the group's estimates will be distributed with a mean of μ, and a standard deviation of $\sigma / \sqrt{n}$. This latter measure, which is also known as the standard error of the mean, gives us an idea of the unreliability of the group's estimate. It can be seen larger groups lead to greater reliability, but a quadrupling of the group size is needed to half unreliability. This means that, as we add individuals to the group, each extra individual brings smaller improvements in reliability.

In most working groups the judgments of individuals are likely to be correlated. This is because they are likely to have access to the same information and be working in the same environment. If this is the case our assumption of independent errors is not valid because, if one individual tends to overestimate then others also likely to overestimate. This means that each individual who joins the group will bring even less improvement in reliability. Therefore limits to accuracy will be reached with quite small groups. Research by Ashton and Ashton at *Time Magazine* supports this conclusion. Thirteen advertising personnel were asked to forecast the number of pages of advertising that would be sold in a given period. It was found that the accuracy of forecasts based on the average of 5 people's estimates was as good as that obtained from all 13. Little was therefore to be gained by using groups of more than 5 people.

Key Point 1: Small groups are usually adequate for obtaining accurate estimates

2. Weighted averages of individuals' judgments

If the estimates of some group members are more likely to be accurate than those of others it seems reasonable to attach a greater weight to estimates from these individuals and to derive the group's estimate from a weighted average. There are three approaches that could be used to determine the weights:

a) self rating –each individual gives an assessment of their own expertise. However research has shown that individuals' confidence in their own judgments are often unrelated to the accuracy of these judgments.

b) rating by the entire group –each member rates all the other members.

c) weights based on past performance -but the current estimation task may differ from previous tasks and also individuals may have improved their accuracy through learning.

Is it worth weighting individual judgments? Most studies suggest that equal weighting performs just as well. This is because i) in many groups people have roughly equal expertise, anyway and ii) members of groups often have access to the same information .

For example, when discussing whether it is worth using weighted averages to obtain groups estimates of probabilities Von Winterfeldt and Edwards argue that the simple average is usually good enough: “The odds seem excellent that if you do anything more complex, you will be wasting your time”

Key Point 2: Simple averages of individual estimates are likely to be the best way of obtaining group estimates

Aggregating preferences

Special problems apply to the process of trying to the determine preferences of a group of people between different options. Members of groups can express their individual preferences in two ways:

1. As orderings or ranks

   e.g. When deciding on a technology for our new product: “I prefer Technology A to Technology B to Technology C”

2. As values (as in SMART) or utilities

   e.g. my values for the three technologies are :

   Technology A: 100, Technology B 20, Technology C: 0.

Aggregating preference orderings

Voting systems are the usual method for identifying a group’s preferred option, when the members’ preferences are expressed as orderings. However, voting systems can lead to paradoxes. One of the most famous of these is *Condorcet’s paradox.*

Suppose that three managers: Edwards, Fletcher and Green have to decide on the location of their company’s new office. Three locations are being considered; A,B and C. Their individual preferences for the locations are shown below (> means “is preferred to”)

Manager	Preference ordering
Edwards	A > B > C
Fletcher	B > C > A
Green	C > A > B

Now suppose that the locations are to be compared in pairs. The preferred option in each pair will be the one that attracts the most votes.

A v B …………………………….

B v C …………………………….

C v A ……………………………

This suggests that the group prefers A > B and B > C but also C > A, which is not a transitive preference ordering.

This voting system can also lead to tactical voting –where individuals' votes do not represent their true preferences because they are trying to avoid their least preferred choice being selected. For example, suppose that the voting will proceed as follows.

A and B are to be compared first. The winner then goes forward to compete with C in the next round.

Edwards sees C, his least preferred choice, winning. He therefore dishonestly states his preferences as B > A > C. This ensures that B wins the first round and goes on to beat C in the second.

Arrow's Impossibility Theorem

Problems like Condorcet's paradox led Kenneth Arrow to ask if any voting system can meet four "eminently reasonable: conditions:

1. it produces a transitive preference ordering

2. if every member of the group prefers an option then so must the group

3. the group choice between A and B must depend only on preferences of members between A and B and not on other options

4. there is no dictator.

Arrow showed mathematically that if there are more than two options it is impossible for any voting system to satisfy all four conditions. This implies that it is impossible to derive a truly democratic system for resolving differences of opinion.

<u>Aggregating values and utilities</u>

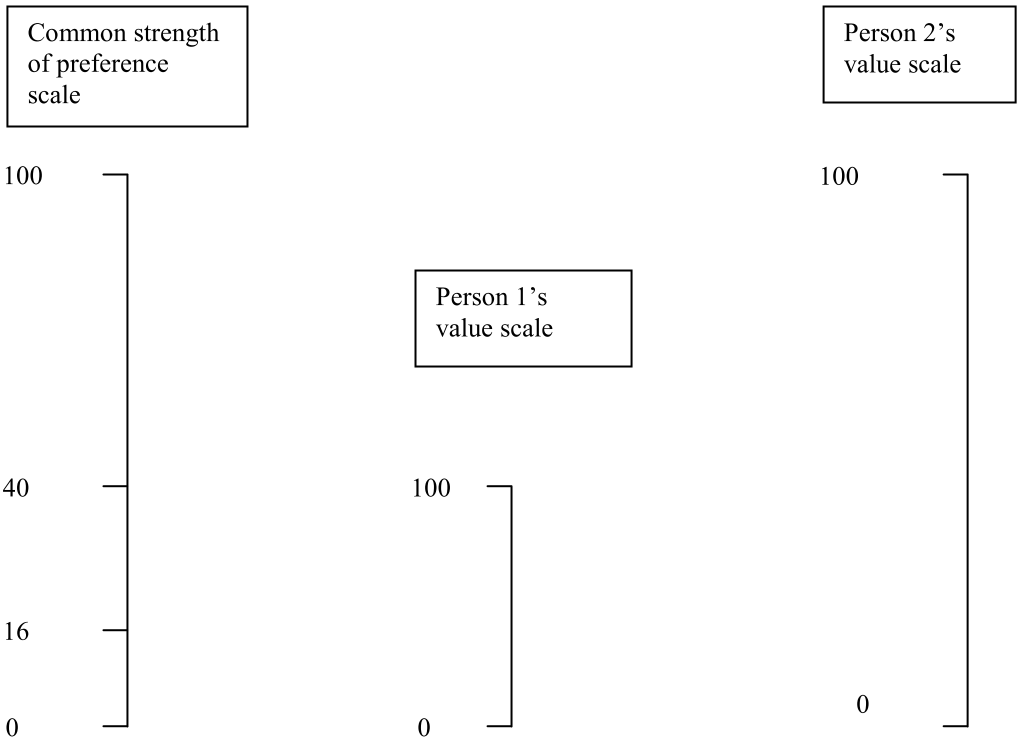
Arrow's theorem only applies when preferences are expressed as orderings. Orderings, or ranks, ignore *intensity of preference,* e.g. A may be strongly preferred to B, but B is only slightly preferred to C. An ordering of preferences would not show this.

The problem with aggregating values or utilities is that we have no way of making interpersonal comparisons of intensity of preference. Consider the following example:

A group of 2 people have to agree on a holiday destination. Three destinations are available. The values they assign to each destination are shown below:

Destination	Person 1	Person 2	Average
Rio de Janeiro	100	50	75
San Francisco	40	100	70
Toronto	0	0	0

The simple average of values suggests that the group should go to Rio, but this makes the strong assumption that a move from 0 to 100 on one person's value scale represents the same increase in preference as from 0 to 100 on the other person's scale. This may not be the case. Suppose that somehow we are able to measure the strength of preference of the group members for one destination over another on common reference scale, as shown on the following diagram:



On the common strength of preference scale the values are:

Destination	Person 1	Person 2	Average
Rio de Janeiro	40	50	45
San Francisco	16	100	58
Toronto	0	0	0

So San Francisco will now be the group's choice.

The problem is how do obtain the common strength of preference scale? All methods fail in practise. For example, we may ask each individual how much they would be prepared to pay to switch from their least preferred to their most preferred option. However, if person 1 is a millionaire and person 2 a pauper these monetary values are unlikely to reflect intensity of preference –we end up trying to make interpersonal comparisons of strength of preference for money instead.

Are individual values and utilities still useful in group decision making?

Despite the problem of interpersonal comparisons of strength of preference values and utilities can still be useful in that:

1. They can help each group member to clarify their individual preferences –as a result they can make a more informed contribution to the group decision process;

2. They can improve communication and lead to an enhanced appreciation of the views of other group members

3. A simple average of individual values and utilities can provide a rough initial model of a problem –sensitivity analysis can then be used to test the effect of using individual values and utilities.

9 Technological forecasting

Objectives
At the end of this session you should:

- ⇨ Understand how to implement the Delphi method and be aware of the rationale of the method
- ⇨ Be able to discuss the role of prediction markets and their advantages and disadvantages relative to the Delphi method
- ⇨ Understand the difference between diffusion and sales
- ⇨ Know when customer intentions surveys are likely to be most reliable
- ⇨ Understand the role of the logistic, Gompertz and Bass curves in forecasting the diffusion of new products and be able to use these curves to generate forecasts

Introduction

In this session we will address two forecasting problems:

1. Forecasting when new technologies will become available
2. Forecasting the demand for new products.

Iterative group estimation: The Delphi Method

The Delphi method is designed to obtain estimates from groups of people without the biasing effect of face-to-face discussion and to ensure the airing of diverse views. It does this by restricting inter-personal interaction between the group members and controlling information flow. Note that group members are referred to as panellists.

Typical uses of the Delphi method include: estimates of the size of the market in ten year's time, dates when new technologies will be available, sales forecasts, forecasts of rates of inflation in national economies and probability and development cost estimates

<u>The phases of Delphi</u>

The Delphi method can take several forms but typically it involves the following phases:

1. Panellists provide forecasts, often as responses to a questionnaire, which they complete individually and without the knowledge of other members of the panel.

2. The results of this polling are tallied and statistics (e.g. medians and ranges) of the whole group's opinions are fed back to individual panellists

3. A re-polling takes place -anonymous written discussion may be allowed (sometimes

panellists whose estimates fall outside the upper or lower quartiles are asked, anonymously, to give reasons why they think their forecasts are superior to those of the rest of the group

4. The process is repeated until a consensus emerges, (or until no further changes of opinion are evident). The median of the group's estimate in the final round is then used as the forecast.

The rationale for Delphi

a) In judgment, two or more heads are probably better than one, particularly where people have different perspectives and access to different information;

b) The method allows input from a larger number of participants than could feasibly be included in a group or committee meeting and from group members who are geographically dispersed;

c) Panellists can make their forecasts on the basis of their true beliefs about the future, free from undue pressures from dominant or dogmatic individuals and free from the influence of potentially irrelevant factors, such as the status of the person proposing a particular forecast.

d) Anonymity means that panellists have the opportunity to change their forecasts between rounds without fear of losing face in the eyes of the other group members.

e) After feedback, improved accuracy is thought to result from opinion changes in the 'swingers', who change less firmly grounded opinions, and opinion stability of the 'holdouts' who are assumed to be more accurate than the swingers (this is sometimes referred to as the Theory of Errors).

Some further points on Delphi

a) Information sharing is small, even if anonymous discussion takes place - this does not help individuals to construct an alternative theory or scenario with which to produce a revised prediction. In a face-to-face meeting there is more opportunity to be persuaded to change one's mind by the quality of other panellists' arguments;

b) Using experts on the panel: how do we define expertise and hence select our experts? Also, beyond a minimum level of expertise there is no evidence of the superior accuracy of experts as forecasters.

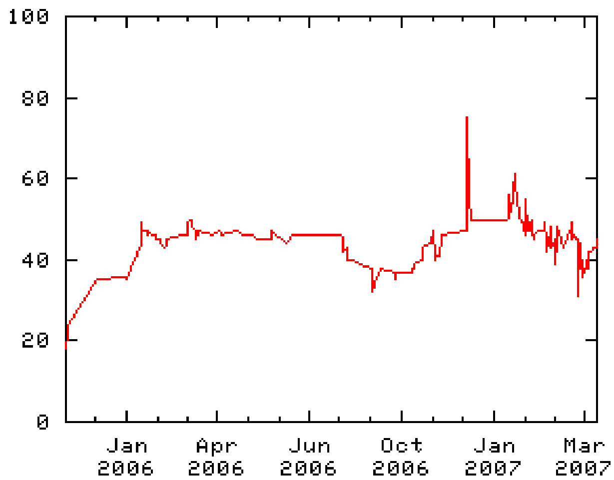
Using prediction markets to forecast when new technologies will be available

In prediction markets assets are created whose final cash value (often this is £1 or £100) is tied to a particular event (e.g., will a given technology be patented by 2012) or parameter (e.g., total sales next quarter). If the event occurs the owner of the asset receives the final cash value. If it does not occur they receive nothing. These assets are bought and exchanged in a market. The current market prices can then be interpreted as predictions of the probability of the event or the expected value of the parameter.

E.g. a price of £0.7 = a probability of 0.7

Or, if the final payout is £100, a price of £30 would indicate a 30% probability

In the example below the probability that Hilary Clinton would be the Democratic candidate in the 2008 US Presidential election was assessed to be about 0.42 by the Foresight Exchange Market in March 2007.



Implementing prediction markets

1. The event being forecast must be clearly defined, otherwise accuracy of predictions & participation in market is diminished

E.g Tradesports.com: People bet that North Korea would launch long-range missiles beyond its airspace. North Korean missiles fell in Sea of Japan on July 4 2006. Tradesport did not recognise this as it had specified that the event must be reported by the US Dept. of Defense and they remained silent. Instead those who bet against the event were rewarded.

2. Number of traders need not be large, but they must be active

3. Incentives must be real

Advantages of prediction markets

1. They provide incentives for accurate forecasts
2. They mitigate bias -the optimist's views are balanced by the pessimist's
3. They release untapped knowledge -there is usually a great body of knowledge within organizations that is never formally observed.
4. They can reduce time spent in meetings
5. They are dynamically updated –it's in people's interests to incorporate new information into updated forecasts.

Disadvantages of prediction markets relative to the Delphi method

1. People may find it hard to translate their expectations into market prices
   - Delphi is easier for them
2. May be morally objectionable to benefit from trading on some events
3. Prediction markets are vulnerable to attacks designed to manipulate results
4. In Delphi reasons for judgments can be circulated –others may learn from these
5. Delphi avoids cascades -an excessive price movement when people think an initial price movement was due to new information and react to this
6. Delphi requires only 5 to 20 participants all of whom have agreed to participate

Forecasting the demand for new products

Diffusion versus sales

Diffusion =number of people, households or companies who have adopted the innovation i.e. who have made *at least one* purchase

Sales: includes the above + second purchases and replacement of original purchases

E.g. A household may buy a second plasma TV, or replace the one they originally bought

Usually it's easier to forecast diffusion rather than sales because:

a) There is normally a saturation point for diffusion (e.g. at most 10 million households will buy product X). Sales may have no upper bound;
a) Modelling decisions on purchasing second or replacement items is difficult.

Main problem

Unlike established products we have no past data on demand to which we can fit a statistical model. This implies that we have to rely on judgment to make forecasts However, if we have demand histories for analogous products, statistical methods may be useful.

Customer intentions surveys

These involve surveying potential customers and asking them to assess the probability that they would purchase the product if it was launched. E.g. Using a scale..

0………………………………...100

Will definitely not purchase	Will certainly purchase

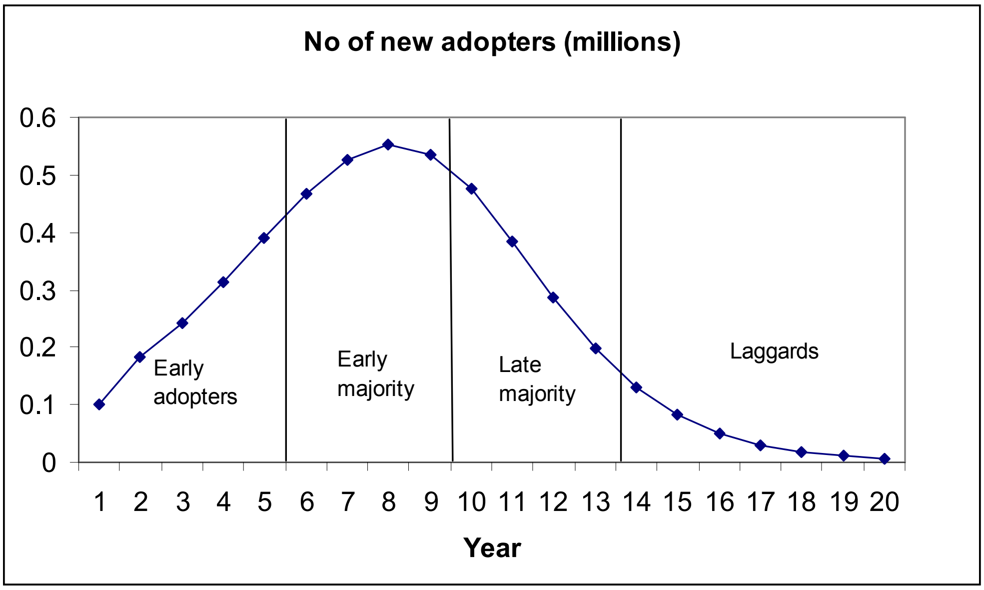
When are customer intentions surveys reliable?

According to research by Morwitz et al (*International Journal of Forecasting*, 23, 347-364, 2007) customer intentions surveys are most reliable when:

1. The real purchase decision will be made very soon after the study
2. The product is durable rather than non-durable
3. Consumers are asked to indicate their intentions relating to specific products types of a product (e.g. flavours of ice cream, rather than ice cream)
4. They are used to predict the % of consumers who will buy the product as opposed to total market sales.
5. (Worryingly) forecasts are made for existing products rather than new ones

Growth curve models

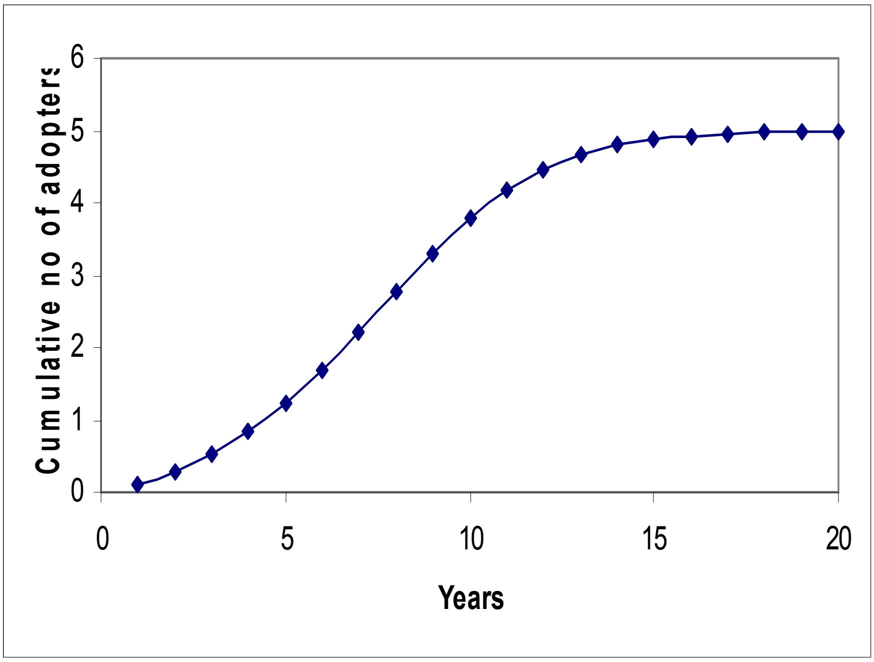
The diffusion of new products often follows the pattern below:



If we cumulate the annual numbers of new adopters we will have the number of people (or households) who have adopted the new product up to the end of each year:

Year	No.of new adopters (m)	Cumulative number of adopters (m)
1	0.10	0.10
2	0.18	0.28
3	0.24	0.53
4	0.31	0.84
5	0.39	1.23
6	0.47	1.70
7	0.53	2.22
8	0.55	2.78
9	0.54	3.31
10	0.48	3.79
11	0.39	4.17
12	0.29	4.46
13	0.20	4.66
14	0.13	4.79
15	0.08	4.87
16	0.05	4.92
17	0.03	4.95
18	0.02	4.97
19	0.01	4.98
20	0.01	4.99

Plotting the cumulative number of adopters for each year usually yields an S-shaped curve like the one below. This is known as a growth curve.



Note that the curve flattens out after several years as it approaches the market saturation level. The point where it changes from increasing to decreasing growth is known as the point of inflection.

Two opposing forces will determine the shape of growth curves.

1. As more people adopt the product the greater will be its exposure to the public and the more likely it is that others will realise that the product exits and imitiate exisiting adopters. This factor means that growth will speed up as more people adopt the product.

2. However, as the market saturation point is approached the more difficult it will be to find new adopters as the remaining people will consist of those who have a low propensity to adopt new products. This factor will cause growth to slow down.

Growth curves are used to obtain:

Medium and long term forecasts of diffusion

Estimates of saturation levels

Estimates of when peak diffusion will occur, and

Estimates of how large peak demand will be.

However, because past data for the new product will not be available, how can we estimare the appropriate growth curve for a new product? If there are existing products or services which are analogous to the one which we are considering launching then we can fit a mathematical curve to the past demand for these products and use it to estimate the demand for the new product. Alternatively we can estimate the equations for these curves if we have good estimates of their parameters, perhaps from industry-wide data.

Three commonly applied growth curve models are:

1. The Simple Logistic (or Pearl) curve
2. The Gompertz curve
3. The Bass curve

The simple logistic curve

The formula for the curve is:

$$y = \frac{m}{1 + ae^{-bt}}$$

Where: y = cumulative no. of adopters

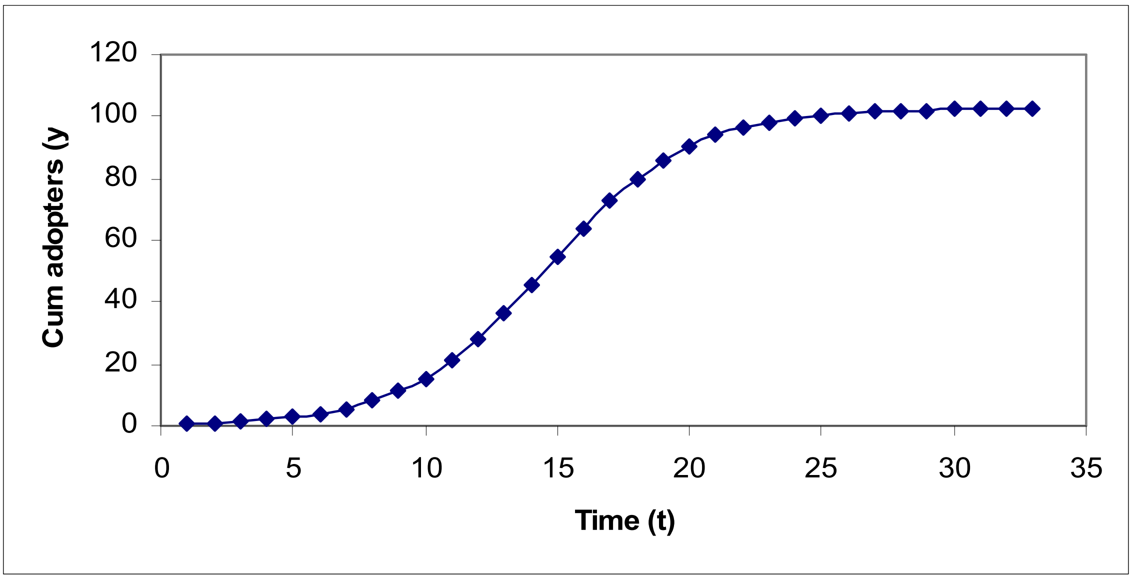
t = time

m = saturation level

a , b = parameters estimated from the data which determine the curve's location and shape

e = 2.71828….

An example of a simple logistic curve is shown below. The curve has the parameters m= 102.5, a = 232, b = 0.37



Notice that the curve is symmetrical about its point of inflection (which is 14.7 years) and apporaches a market saturation levelof 102.5 million adopters.

When might a simple logistic curve apply? The slope of the curve depends on y (the present level of adoption) and m-y (the difference between the present level of adoption and the saturation level). This implies that progress already achieved stimulates further growth (through imitation), but this is inhibited as saturation point is approached.

The Gompertz curve

The formula for the curve is:

$$y = me^{-ae^{-bt}}$$

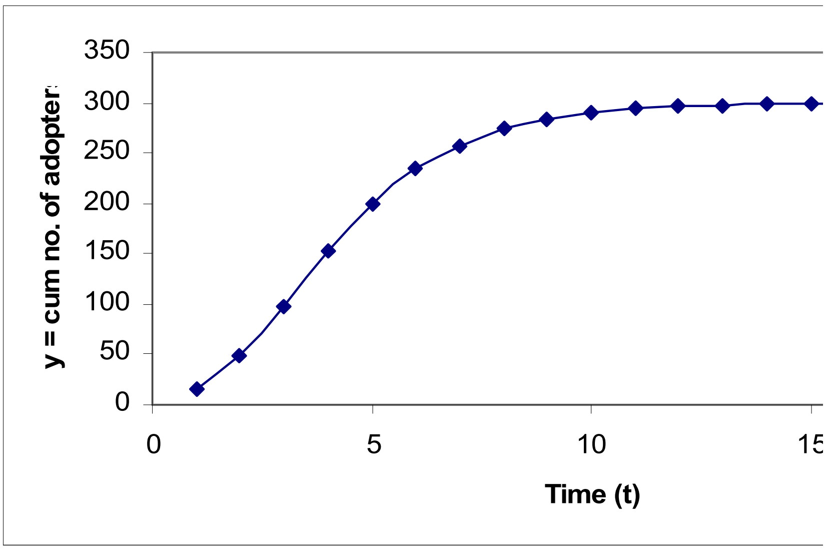
Where: y = cumulative no. of adopters

t = time

m = saturation level

a, b = parameters estimated from data which determine the curve's shape and location.

An example of a Gompertz curve is shown below. The curve has the parameters a = 5, b = 0.5, m = 300.



Note that this curve is not symmetrical about its point of inflection (which occurs after 3.2 years).

When might a Gompertz curve be applicable? Once a large level of adoption is achieved the slope of the curve depends only on m- y (i.e. the gap between the current level of adioption and the saturation level). This implies present levels do <u>not</u> stimulate further growth (e.g. through imitation) and continued progress becomes increasingly more difficult.

<u>The Bass Curve</u>

This assumes that adoption of innovations depends on:

1. <u>The coefficient of innovation</u> (p)
   = the likelihood that a person will start to use the product because of media coverage or other external factors;

2. <u>The coefficient of imitation</u> (q)
   = the likelihood that a person will start to use the product because of "word of mouth" or other influences from those already using product;

3. <u>The total market potential</u> (m)

The formula for a Bass curve is shown below:

Cumulative adoption at time t

No. who have not yet bought product

$$y_t = y_{t-1} + p(m - y_{t-1}) + q\frac{y_{t-1}}{m}(m - y_{t-1})$$

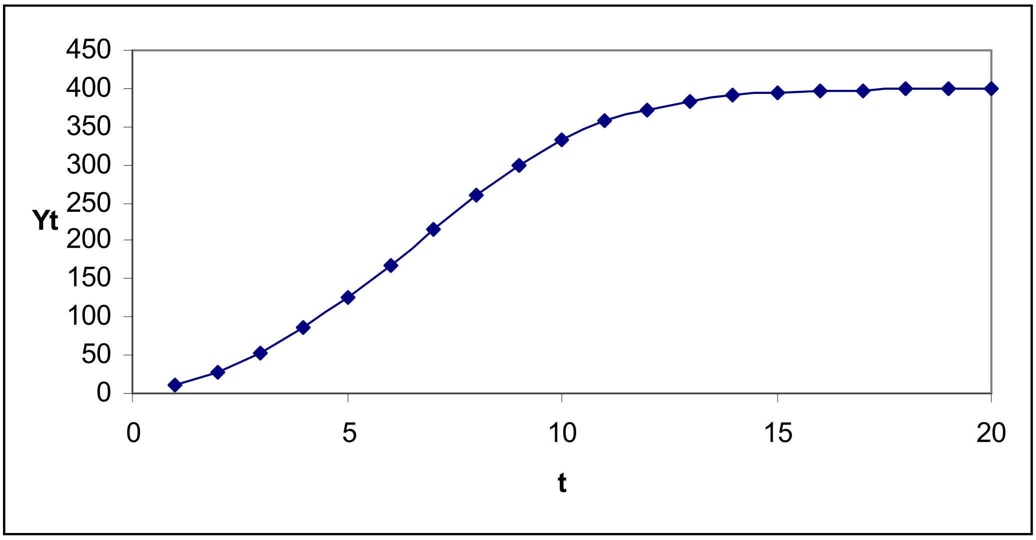
Proportion of those who haven't yet bought product who will buy in this period because of **external influence**

Proportion of those who haven't yet bought product who might buy in this period because of **word of mouth etc**

Proportion of potential market who have already bought product

The larger this is, the greater the influence of 'word of mouth'

An example of a Bass curve is shown below. The curve has the parameters p = 0.04, q = 0.38 and m = 400.



Example of calculations for a Bass Curve.

Given $y_{t-1} = 214$, $m = 400$, $p = 0.04$, $q = 0.38$. Estimate y_t, the number of people who will have become adopters by the end of year t.

No. who have not yet adopted = 400 - 214 = 186

No of these who will adopt through external influence this period

$$= 0.04 \times 186 = 7.44$$

No of these who will adopt through internal influence this period

$$= 0.38 \times \left(\frac{214}{400}\right) \times 186 = 37.81$$

Expected total number of adopters by end of year t = 214 + 7.44 + 37.81 = **259.25**

Exercise on Bass curves

A mobile phone company wants to make forecasts of the number of adopters in a particular country in 2009 for a new type of phone . It decides to use a Bass model to make the forecasts. It is thought that the maximum possible number of adopters in the country is 18 million.

a) By the end of the year 2008 1 million people in the country had bought the new phones. The coefficients of external and internal influence are estimated to be 0.08 and 0.56, respectively. Use the Bass model to forecast the cumulative number of adopters of the product by the end of the year 2009

b) What reservations would you have about forecasts obtained using the company's method?

Some points on applying growth curves

1. Customer intentions surveys can be used to estimate total market (m)
   -but often this is reduced by 50% because people overstate intentions

2. Data-based estimates of saturation levels are normally better than judgmental estimates

3. For Bass curves, analogous products can be used to estimate coefficients of innovation and imitation

4. The coefficient of innovation (p) tends to be stable across applications (often around 0.03)

5. The coefficient of imitation (q) much more variable (but average is around 0.38)

6. Short term forecasts are a good indicator of the appropriateness of a model

10 Scenario Planning

Objectives

At the end of this section you should:

⇨ Be able to apply scenario planning using the extreme world method.

⇨ Be able to discuss the strengths and limitations of scenario planning

Scenario Planning

The practice of scenario planning implicitly assumes

1) that managers are <u>not</u> able to make valid assessments of the likelihood of unique future events;
2) "best guesses" of what the future may hold may be wrong.
3) groupthink can countered by allowing minority opinions about the future to have "airtime", relative to majority opinion.

How does scenario planning work?

1. A scenario is not a forecast of the future. Multiple scenarios are pen-pictures of a range of <u>plausible</u> futures. Each individual scenario has an infinitesimal probability of actual occurrence, but the <u>range</u> of a <u>set</u> of individual scenarios can be constructed in such a way as to <u>bound</u> the uncertainties that are seen to be inherent in the future.

2. Unlike probability judgments, scenarios highlight the reasoning underlying judgments about the future and give explicit attention to sources of uncertainty.

3. A major focus is <u>how</u> the future can evolve from today's point-in-time to the future that has unfolded in the horizon year of the scenario - say 10 years hence.

4. The relationship between the <u>critical</u> uncertainties (as they resolve themselves - one way or the other), important predetermined trends (such as demographics, e.g. the proportion of the US population who are in various age bands in, say, 10 years time) and the behaviour of actors who have a stake in the particular future (and who will tend to act to preserve and enhance their own interests within that future) are thought through in the <u>process</u> of scenario planning such that the resultant pen-pictures are, in fact, seen as plausible to those who have constructed the scenarios.

5. Strategic decisions are then tested for robustness in the 'wind tunnel' created by the set of scenarios.

Scenario construction: the extreme-world method

Before applying scenario planning it is necessary to identify an issue of concern, around which the scenarios will be constructed. Key issues often concern the survival and viability of an organization, or one of its divisions, in an environment that is known to be changing and which might change in a way as to be inhospitable to that organization with its current competencies and core capabilities.

Step 1 Identify current trends that are relevant to the organisation, as perceived by industry experts, managers and knowledgeable outsiders.

Typical trends might be:

Demographic -e.g. population, growth, birth rates
Technological –e.g. growth in production capacity
Political –e.g. shifts in power
Cultural – e.g. changing values, fashions and spending patterns
Economic –e.g. disposable incomes, investment levels
Agricultural –e.g. changes in climate, stocks of food

Step 2 Identify key uncertainties

E.g. Will new technology be successful? Will government regulation of the industry be brought in? Will the UK join adopt the Euro? Will the current demand for our product be sustained? Will we face foreign competition?

Step 3 Identify whether the trends and uncertainties will have a negative of positive impact on the area of concern

Step 4 Create extreme world scenarios by putting all positive elements in one world and all negative elements in the other

The scenarios should be written up as stories and given distinct names.

Step 5 Check for internal consistency

Could the trends and resolved uncertainties coexist in plausible future scenarios?

Check (i) trend consistency
(ii) outcome consistency
(iii) actor consistency.

Step 6 Write Scenarios

The scenarios should be written up as stories and given distinct names. Alternative strategies can then be tested to see how they would perform in each of these extreme worlds and, if necessary, new strategies can be designed that would enable the organisation to prosper, in either of these extreme circumstances.

Example: National Mail Company

This simplified case study concerns a newly privatised national mail company which needs to formulate strategies with a ten year planning horizon. To date, the company has been protected by legislation which allows it to operate as a monopoly on letter deliveries. This protection has engendered a culture of muddling through (i.e., minor adjustments to policies in reaction to events, with no clear sense of overall direction). However, the environment within which the company may operate in the future is likely to fundamentally change. For example, there is a possibility that it will lose its monopoly position, while technological developments pose long term threats to the volume of letter mail.

Step 1 and 3 Identify current trends and certainties that are relevant to the organisation, as perceived by industry experts, managers and knowledgeable outsiders.

	Impact
• Growth in email and text messaging	-ve
• Increasing number of people working at home	+ve
• Increasing use of direct marketing by companies	+ve
• Increasing number of bill payments by direct debit	-ve
• Increasing number of purchases made on the Internet	+ve

Step 2 and 3 Identify key uncertainties		Impact
• Monopoly on letter delivery	Continues	+ve
	Removed	-ve
• Increased competition on non-letter business	Yes	-ve
	No	+ve
• Economic conditions	Growth	+ve
	Recession	-ve
• Taxes on email introduced?	Yes	+ve
	No	-ve

Step 3 Identify whether the trends and uncertainties will have a negative of positive impact on the area of concern

See above

Step 4 Create extreme world scenarios by putting all positive elements in one world and all negative elements in the other

All negative elements

Growth in email and text messaging
Increasing number of bill payments by direct debit
Monopoly on letter delivery removed
Increased competition on non-letter business
Economic recession
No tax on emails

All positive elements

Increasing number of people working at home
Increasing use of direct marketing by companies
Increasing number of purchases made on the Internet
Monopoly on letter delivery continues
Absence of increased competition on non-letter business
Economic growth
Tax on emails introduced

Step 5 Check for internal consistency

E.g. Would a tax on emails be compatible with increasing number of purchases made on the Internet?
Would increasing number of purchases made on the Internet be compatible with an absence of increased competition in the non-letter market?

For simplicity we will assume that these events are compatible.

Step 6 Write Scenarios

Scenario 1: (DOG FIGHT) The company loses its monopoly on letter deliveries. Rival companies take several years to develop their own delivery systems, but within five years there is keen competition on price, delivery times and reliability. These rivals also compete strongly for non-letter business. Growth in the use of electronic communications, particularly by direct marketing organisations and growth in the number of bill payments by direct debit leads to a large reduction in the total volume of paper mail which needs to be delivered. This reduction is exacerbated by poor economic conditions.

Scenario 2: (MAIL MOUNTAIN) The company retains its monopoly on letter delivery. Despite, increases in the use of electronic communications, taxes levied on e-mail messages mean that paper mail remains popular. Buoyant economic conditions lead to increases in the volume of mail generated by direct marketing organisations. Increased ‘home working’ also leads to increases in the number of paper documents which need to be delivered by mail. A huge increase in Internet purchasing leads to substantial increases in the volume of parcel deliveries. These increases are even greater because of weak competition from rival parcel delivery companies,

The mail company can now use these two scenarios to test how well different strategies it is considering strategies would fair in these alternative futures. The strategies it is considering are:

A Continue with the current strategy of specialising in letter delivery, continuing to take advantage of increased mechanisation where appropriate, by buying the technology from foreign suppliers (STATUS QUO).

B Continue specialising in letter delivery, but allocate very large amounts of investment to R & D with the objective of becoming a world leader in letter sorting technology (R & D).

C As A, but also diversify into electronic communications by becoming an Internet service provider and by seeking to merge with a telecommunications company (DIVERSIFY).

Other approaches to scenario planning

Note that the Extreme World method is the quickest and simplest approach to scenario planning. However, some practitioners of scenario planning caution against presenting the decision maker with such extreme worlds since their very extremeness may cause doubts amongst managers about their plausibility. Because of this, several other methods have been developed (See Goodwin and Wright, 2009 chapter 16 for more details). We will not consider these here since the intention is merely to introduce the concept of scenarios as an alternative to conventional methods of addressing future uncertainties.

When should a company use scenario planning?

1. When uncertainty is high (relative to one’s ability to predict).
2. When too many costly surprises have occurred in the past?
3. When insufficient new opportunities are being perceived and generated by a company’s managers
4. When an industry, to which the company belongs, has experienced significant change, or is about to.
5. When strong differences opinion exist between managers about future plans –and each opinion has its merits.

Typical outcomes of scenario planning

- “This is what we have to do” (developing new business opportunities)
- “We had better think again” (understanding outcomes of plans better)
- “We better watch those dots on the horizon” (perceiving weak signals of new developments)
- “We are on the right track” (moving forward with more confidence)

Some Pros and Cons of scenario planning

- It allows a variety of viewpoints about the future to the reflected, minority opinions are not ignored.
- Once a scenario has been read it may sensitise managers that a particular future is beginning to unfold:

  - early contingency plans can then be laid to cope with an unfavourable future;
  - new business opportunities can be grasped as soon as favourable scenarios begin to unfold.

- Scenario thinking emphasises the construction of causal “storylines” that describe how the future will unfold. Willem Wagenaar, in a study of how judges reach decisions in courtrooms has found, analogously, that judges and juries do not weigh probabilities that a defendant is guilty “beyond reasonable doubt”. Instead, such decision makers evaluate scenarios that describe why and how the accused committed the crime. One such scenario is, in principle, contained in the prosecutions indictment. The prosecution tells the story of what happened and the court decides whether that is a true story or not. “Good” stories provide a context that gives an easy and natural explanation of why the ‘actors’ behaved in the way they did. So, storytelling via scenario planning may be a natural way of making sense of the world
- However, scenario planning is a practitioner-derived approach to dealing with future uncertainty. It is not based on a formal set of theories - and so different practitioners tend to promote different methodologies to construct scenarios. Moreover there is an absence of empirical evidence on the benefits that result from using the approach.

Group Exercise on scenario planning

You are a Director of a company which manufactures passenger jet aircraft which are used by airlines for both intercontinental and short-haul flights.

Produce scenarios that can be used to guide the company's strategic plans for the next ten years.

Review

You are a 'fly-on-the-wall' at a meeting of the Senior Managers of a hi-tech company who are meeting to make a major strategic decision.

List the criteria that you would use to assess the quality of their decision process.