# Chapter 3

## Analysis of Alternatives

### Learning objectives

1. Define and provide the rationale for analysis of alternatives in problem solving
2. Understand decision making in engineering problem solving
3. Applying tools for analyzing alternatives

### INTRODUCTION

#### Nine dot puzzle

Connect the dots by drawing four straight, continuous lines that pass through each of the nine dots, and never lifting the pencil from the paper.

![Nine dot puzzle](image)

The puzzle is easily solved, but only if you draw the lines outside of the confines of the square area defined by the nine dots themselves. Thus, the phrase “thinking outside the box/square”.

### Different view points

Is this a painting of a young girl or an old woman?

The answer is both. The moral of the story is look at a specific aspect of a situation and ask:

- “Is this true?”
- “How else could I explain things?”
- “What is the hidden gift here?”
- “How might (the other person) see this situation?”
- “What can I learn from this?”

Objective 1

Rationale for Analysis of Alternatives

Main highlights

An analysis of alternatives (AoA) is an analytical comparison of the operational effectiveness, cost, and risks of proposed materiel solutions to gaps and shortfalls in operational capability. AoAs document the rationale for identifying and recommending a preferred solution or solutions to the identified shortfall(s). A short definition is “evaluation of different choices available for achieving an objective”.

What is analysis of alternatives?

An analysis of alternatives (AoA) is an analytical comparison of the operational effectiveness, cost, and risks of proposed materiel solutions to gaps and shortfalls in operational capability. AoAs document the rationale for identifying and recommending a preferred solution or solutions to the identified shortfall(s). A short definition is “evaluation of different choices available for achieving an objective”.

The promise of analysis of alternatives

The ultimate goal of alternative analyses is to support making robust resource allocation decisions. This involves the following constituent parts

- a decision process approach
- multidimensional qualitative and quantitative comparisons
- an integration of estimation uncertainty
- the ability to choose evaluation to give you guidance to the process
- making robust decisions
- Application of Analysis of alternatives in engineering

An environmental and Biosystems engineer is involved in solving problems in diverse fields which include:

- soil and water conservation
- irrigation and drainage
- rural water supply
- farm power
- farm machinery
- renewable energy
- harvesting technologies
- storage
- processing
- Google structures
- watershed management
- liquid and solid waste management
environmental impact assessment

In dealing with this issue, he or she has to make certain decisions which involves the evaluation of alternatives. The evaluation of alternatives may be and act questions such as:

- what should we do
- where should we do it
- when should we do it
- which target group should we focus on
- how should we do it
- who should do it

For example, within a given watershed we may need to find out which are the environmental hotspots which would help us answer the question where should we refocusing our interventions. We would also want to know which is a most effective technology to address the problem and since there are several technological alternatives we need a comparison of alternatives to be able to decide on which is the best technological choice. We may also want to ask ourselves the question, which is the best time of the year to actually do this kind of work, in some cases it may be most appropriate to undertake the work during the dry season, while in other cases it is best to undertake the work during the rainy season. The challenge is deciding which is the most appropriate timing for the exercise. This presents a set of issues that say require the use of the an analysis of alternatives techniques.

Evaluation criteria

Evaluation criteria is a benchmark, standard, or yardstick against which accomplishment, conformance, performance, and suitability of an individual, alternative, activity, product, or plan, as well as of risk-reward ratio is measured.
Objective 2
Decision Making Process

Main highlights

Decisions are made to achieve goals through suitable follow-up actions. Means and ends are linked together through decision-making. To decide means to come to some definite conclusion for follow-up action. Decision is a choice from among a set of alternatives.

This clearly suggests that decision-making is necessary in all aspects of engineering – analysis, planning, designing, construction, operation and maintenance organizing, directing, controlling and staffing.

---

What is Decision Making?

Decision-making is an essential aspect of modern management.

A decision may be defined as "a course of action which is consciously chosen from among a set of alternatives to achieve a desired result." It represents a well-balanced judgment and a commitment to action.

It is rightly said that the first important function of management is to take decisions on problems and situations.

Decisions are made to achieve goals through suitable follow-up actions. Means and ends are linked together through decision-making. To decide means to come to some definite conclusion for follow-up action. Decision is a choice from among a set of alternatives.

This clearly suggests that decision-making is necessary in all aspects of engineering – analysis, planning, designing, construction, operation and maintenance organizing, directing, controlling and staffing.

Robust decision making

Robust decision-making is an approach that aims to produce decisions that stakeholders will not regret, the matter how the future turns out. Some of the benefits of this approach include:

- It can be applied to plans, policies and projects already in place or being developed.
- It accepts the future uncertainty is a fact, but instead of attempting predicting an estimation of probabilities, uses a different logic. It asks what future conditions would render the investments vulnerable, and seeks to bolster the investment agonist this eventualities.
- It reaches decisions that perform well over a range of plausible futures, even though they may not be the best for any specific future state.
- It can be applied to both infrastructure investments or management investments.

Robust decision-making means following a strategy that eliminates all possible noises within the resource availability, then making a decision that is as insensitive as possible to the remaining noise conditions.

The four main questions asked every time a decision is being made are:

- what is the best alternative?
- Do we know enough to make a good decision yet?
- What do we need to do next to feel confident about our decisions?
- Is there team consensus about the decisions?
The main steps in robust decision-making process are:

1. Maximize personal decision-making effectiveness
2. Insured team and organization effectiveness
3. States the issue
4. Identify the customers
5. Itemize solution features
6. Define targets for the features
7. Measure feature importance
8. Generate alternative solutions
9. Measure decision-makers knowledge
10. Determined beliefs in alternatives ability to meet targets
11. Determine overall satisfaction in alternatives
12. Decide what to do next

Characteristics of Decision Making
The main characteristics of decision making are:

1. Decision making implies choice: Decision making is choosing from among two or more alternative courses of action. Thus, it is the process of selection of one solution out of many available. Every engineering problem can be solved by different methods. These are the alternatives and a decision-maker has to select one alternative which he considers as most appropriate. The benefits of correct decision-making will be available only when the best alternative is selected for actual use.

2. Continuous activity/process: Decision-making is a continuous and dynamic process. It pervades all engineering activity. Engineers have to take decisions on various technical and non-technical matters.

3. Mental/intellectual activity: Decision-making is a mental as well as intellectual activity/process and requires knowledge, skills, experience and maturity on the part of decision-maker.

4. Based on reliable information/feedback: Good decisions are always based on reliable information. The quality of decision-making at all levels of an engineering organisation can be improved with the support of an effective and efficient engineering and management information system.

5. Goal oriented process: Decision-making aims at providing a solution to a given problem/difficulty before a business enterprise. It is a goal-oriented process and provides solutions to problems faced by an engineering unit.

6. Means and not the end: Decision-making is a means for solving a problem or for achieving a target/objective and not the end in itself.

7. Relates to specific problem: Decision-making is not identical with problem solving but it has its roots in a problem itself.

8. Time-consuming activity: Decision-making is a time-consuming activity as various aspects need careful consideration before taking final decision.

9. Needs effective communication: Decision-taken needs to be communicated to all concerned parties for suitable follow-up actions. Decisions taken will remain on paper if they are not communicated to concerned persons.

10. Pervasive process: Decision-making process is all pervasive. This means engineers working at all levels have to take decisions on matters within their jurisdiction.

11. Responsible job: Decision-making is a responsible job as wrong decisions prove to be too costly to the organisation. Decision-makers should be matured, experienced, knowledgeable and rational in their approach. Decision-making need not be treated as routing and casual activity. It is a delicate and responsible job.
Objective 3
Tools for generating decision support information

Main highlights

- A decision tree is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility.
- Pareto Analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect.
- Critical Path Analysis (CPA) can be defined as the logical sequencing of a series of events necessary for a successful engineering project in such a manner that the most efficient route to some culmination point can be calculated.

Structuring and prioritizing

Decision tree

A decision tree is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. Decision trees provide an alternative and more convenient way of viewing and managing large sets of rules, especially when these rules are not symmetric.

Decision trees are easy to use once you understand that:

- A condition is declared in its diamond-shaped node.
- The possible values for the condition are represented by branches.
- The actions are declared at the end of each branch.

To help you better understand the basic concepts and how they are applied, this section is divided into the following sub-sections:

- Decision tree notation (nodes and branches)
- Payoff values
- Outcome probability
- Expected value
- Decision tree analysis

1. Decision tree notation (nodes and branches)

Any decision includes two or more decision alternatives. Any decision alternative might lead to multiple possible outcomes. One outcome may depend on another, a situation called dependent uncertainty. Decisions may also be linked in a sequence, a condition called sequential decisions. Use decision tree notation to keep these myriad paths and possibilities easy to understand and compare.
**Example:** In the above figure, a company is evaluating whether to invest $1M in a project immediately or wait for a marketing report that may affect project development. Two other alternatives are also possible: invest $1M in a fixed yield bond or do nothing. A fixed-yield investment and doing nothing are examples of baseline alternatives: choices that can be used to compare the overall merits of the decision alternatives.

**Decision nodes and the root node:** Small squares identify decision nodes. A decision tree typically begins with a given “first decision.” This first decision is called the root node. For example, the root node in a medical situation might represent a choice to perform an operation immediately, try a chemical treatment, or wait for another opinion.

Draw the root node at the left side of the decision tree.

**Chance nodes:** Small circles identify chance nodes; they represent an event that can result in two or more outcomes. In this illustration, two of the decision alternatives connect to chance nodes. Chance nodes may lead to two or more decision or chance nodes.

**Endpoints:** An endpoint, or termination node, indicates a final outcome for that branch. Small triangles identify endpoints. Show an endpoint by touching one point of the triangle to the branch it terminates.

**Branches:** Lines that connect nodes are called branches. Branches that emanate from a decision node (and towards the right) are called decision branches. Similarly, branches that emanate from a chance node (and towards the right) are called chance branches. In other words, the node that precedes a branch identifies the branch type. A branch can lead to any of the three node types: decision node, chance node, or endpoint.

**Tip:** Draw branches from the root node with a generous amount of space between the branches. As branches extend outwards, they may spawn any number of additional nodes and branches. Start with enough room between branches to easily accommodate the alternatives and outcomes that may result.

**2. Payoff values**

The payoff value is equivalent to the net profit (or net loss) expected at the end of any outcome. Write payoff values at their respective branch endpoints. Although you can express payoff in various ways, it is common to use monetary units in most business applications. Payoff is the difference between investment cost and gross revenue. This primer adopts the convention of indicating investment costs as negative values to simplify calculating payoff values. Payoff values can be positive or negative. Negative payoff values indicate a net loss.

**Example** Figure shows the expected payoffs at two endpoints. The fixed-yield investment results in $1,050,000 revenue, and therefore a $50,000 payoff. The payoff for doing nothing is $0. The other branches lead to chance nodes at this stage of the decision tree. You can assign payoff values only after these chance nodes lead to endpoints.

**3. Outcome probability**

A chance node leads to two or more outcomes, each outcome represented by a new branch. As with a game of chance, an outcome has a particular probability of happening. The total of all outcomes for a given chance node must equal 100% (or 1.0). A standard decision tree convention expresses probabilities as decimal fractions in parentheses at the chance branches.

**Example:** In the figure, the decision alternative to develop a project immediately can lead to one of three outcomes. The company has determined that there is a 20% chance that the project can meet all the criteria for success in international and domestic markets, but a
50% chance that the project will only meet the criteria for the domestic market. In addition, is a 30% chance that the project will not meet enough criteria for either market as a result of insufficient information. The company can also wait for a marketing study before developing the project. The marketing information may help the company create a successful project. But the information may also suggest unfavorable conditions that the company probably cannot overcome. The company uses its best judgment and guess, with a 50% favorable and a 50% unfavorable outcome.

The decision tree shows these probabilities as decimal fractions in parentheses on their respective chance branches.

### 4. Expected value

Expected value (EV) is a way to measure the relative merits of decision alternatives. The expected value term is a mathematical combination of payoffs and probabilities. You calculate the expected values after all probabilities and payoff values are identified. The goal of the calculations is to find the EV for each decision alternative emerging from the root node. For the purposes of this primer, the decision alternative with the highest EV is the best choice.

Although you can apply the formal definition of expected value, in practice you can calculate EV calculations by applying the following rules. To calculate EV, start from the endpoints and work back towards the root. An easy way to find expected values is to calculate an EV for each terminated branch, then each chance node and each decision node.

- For a terminated decision branch, EV is equal to the payoff.
- For a terminated chance branch, EV is the product of its payoff and probability.
- For a chance node, EV is the sum of each chance branch payoff multiplied by the probability for that payoff.
- For a decision node, EV is the greater EV value of any decision branch. Mark the lower value EV branches with double-hatch marks to disregard these branch paths. Since the root node is also the first decision node, the decision alternative with the greater EV is the overall best decision.
- As the calculations are carried from right to left, use a “resolved” EV at any node type as the payoff “input” at the node closer to the root.
Tip: Start an EV calculation from the endpoint and then proceed from right to left. The EV for a node becomes the payoff “input” for the subsequent EV calculation to the left. For example, use the EV for the topmost decision node (types of markets to enter) as an input to calculate the chance node (criteria outcomes).

Example: Calculate the EV for the decision alternative to develop the project by following the given EV rules:

- Decision node (“international and domestic marketing” vs. “domestic marketing only”). The EV is the greatest value given by all the decision branches, $3,000,000. This value then becomes the payoff “input” for the next node to the left.
- Chance node (“all criteria” vs. “domestic criteria only” vs. “not enough criteria”). \([3,000,000 \times 0.2] + [500,000 \times 0.5] + [(-1,000,000) \times 0.3] = EV = \$550,000\). This value becomes the payoff “input” for this alternative when considering the root node.
- By a similar calculation, the EV for the alternative to wait for the report before deciding whether or not to develop the project is \(EV = \$750,000\). This value becomes the payoff “input” for this alternative when considering the root node.
- The EV for the alternative to invest the capital in a fixed-yield investment is just the payoff value, \(EV = \$50,000\).
- The EV for doing nothing is \(EV = \$0\).

5. Decision tree analysis

The EV at the root node shows that the decision to wait for the marketing report is the best decision. This result may come as a surprise. You can better understand the result after calculating expected values.

Example: Before the decision tree is analyzed you may be tempted to assume that the decision to develop the project immediately is the better choice. After all, the project will only cost $1,000,000 instead of a rushed cost of $1,500,000. Furthermore, there are fewer complications to consider, like waiting to determine the potential for international distribution. The EV for the decision alternative to wait for the report is complicated by two major chance factors. One factor is that the company knows that waiting makes finding an international distributor more difficult than if the project begins immediately. The company has determined that the likelihood of finding an international distributor is less certain (by 50%) if they wait for the report.

The other chance factor is the information in the marketing report. The company estimates that the marketing report has a 50% chance of delivering favorable
data which will help project development. Two or more chance nodes directly connected in this way indicate a dependent uncertainty, a condition that can readily be evaluated through decision tree analysis. Another complication is that rushing development raises development costs by a third, to ($1,500,000), and this alone reduces the payoff for the international and domestic marketing by $500,000.

The decision tree method requires probabilities for all chance outcomes. In this example, the successive chance outcomes of waiting for report results and then securing an international distributor reduce the EV along the branch path.

But a similar analysis of the competing decision alternative reveals important information. Without the benefit of the marketing report the chances of “getting it right” for the international market are fairly low, at 20%. This factor significantly weakens the value of that branch. This alternative is also risky; there is a 30% chance that the company will lose all investment costs. The absence of reliable market information means that the project may not meet criteria for success in any market.

The analyst can sum up the decision tree analysis with the following major presentation points and with the decision tree.

- The international market potential is $3,000,000 in revenue, while the domestic market is only $500,000.
- Immediate project development costs only $1,000,000.
- Waiting to develop the project results in rush costs, pushing the total to $1,500,000.
- Marketing information plays the most important role in the potential success of this project. In the absence of valid marketing data, the chance for success in the international market is poor (20%) and the chance for complete failure is significant (30%). These risk factors significantly reduce the potential for product success.
- Waiting for the marketing report can complicate project development. There is a 50% chance that the report will be favorable enough to proceed. Waiting also reduces the chance (by 50%) for recruiting a distributor in time to capture the international market. However, these risk factors of waiting do not affect the chance of success as much as the absence of marketing data.
- Therefore the best decision, given the known assumptions, uncertainties, and information, is to wait for the results of the marketing report before deciding to develop the project.
Pareto Analysis

Pareto Analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect. It uses the Pareto Principle (also known as the 80/20 rule) the idea that by doing 20% of the work you can generate 80% of the benefit of doing the whole job. Or in terms of quality improvement, a large majority of problems (80%) are produced by a few key causes (20%). This is also known as the vital few and the trivial many.

The 80/20 rule can be applied to almost anything:

- 80% of customer complaints arise from 20% of your products or services.
- 80% of delays in schedule arise from 20% of the possible causes of the delays.
- 20% of your products or services account for 80% of your profit.
- 20% of your sales-force produces 80% of your company revenues.
- 20% of a systems defects cause 80% of its problems.

Steps in Pareto Analysis

Seven steps to identifying the important causes using Pareto Analysis:

1. Form a table listing the causes and their frequency as a percentage.
2. Arrange the rows in the decreasing order of importance of the causes, i.e. the most important cause first.
3. Add a cumulative percentage column to the table.
4. Plot with causes on x-axis and cumulative percentage on y-axis.
5. Join the above points to form a curve.
6. Plot (on the same graph) a bar graph with causes on x-axis and percent frequency on y-axis.

Draw a line at 80% on y-axis parallel to x-axis. Then drop the line at the point of intersection with the curve on x-axis. This point on the x-axis separates the important causes on the left and less important causes on the right.

This is a simple example of a Pareto diagram using sample data showing the relative frequency of causes for errors on websites. It enables you to see what 20% of cases are causing 80% of the problems and where efforts should be focussed to achieve the greatest improvement.

The value of the Pareto Principle for a project manager is that it reminds you to focus on the 20% of things that matter. Of the things you do during your project, only 20% are really important. Those 20% produce 80% of your results. Identify and focus on those things first, but don’t totally ignore the remaining 80% of causes.
**Critical path analysis**

**What is Critical Path Analysis?**

Critical Path Analysis (CPA) can be defined as the logical sequencing of a series of events necessary for a successful engineering project in such a manner that the most efficient route to some culmination point can be calculated. Consequently, the critical path technique has a multitude of uses: (a) As an aid in time management, (b) as a provider of ongoing data for assessing progress, and (c) to give the researcher or program planner considerable information for decision-making.

CPA is a useful planning and management tool for several reasons:

1. A thorough identification of all major activities requiring time and resources must be made during the planning process.
2. Logical sequencing of these activities must be made.
3. The time required for each activity must be estimated or determined.
4. The overall research or planning project is scheduled according to the estimated times, resulting in a determination of the most efficient plan for carrying out the various activities.

Continuous evaluation of the planning and implementation progress according to a predetermined schedule is required so necessary decision-making for maintaining a schedule can be made.

CPA also provides you with a visual picture through the development of a model network displaying how all research or planning functions tie together.

### How CPA is Utilized

Learning how to utilize CPA means understanding a few basic principles, procedures, and definitions. The terminology and process to be described in the following narration and visuals are somewhat unique to the CPA technique. Once these procedures are mastered, you will find them applicable to any type of planning or time management need.

**Step One: List the Major Activities**

The procedure begins by listing all the known or expected major activities to be undertaken in planning and managing a research or other type of project. The level of detail or finiteness of the activities will depend on your determination of their importance or "criticalness" to completing your project planning and management according to various time constraints.

Listing the major activities requires a thorough analysis of the steps involved in initiating, implementing, and bringing to culmination a successful research or planning endeavor. Several activities are described below. The examples used relate to planning a conference or meeting to provide a common reference point for those not yet familiar with necessary research steps.

**A construction example**

Tom Kibunja owns Lightner Construction, a general contracting company specializing in the construction of single-family residences and small office buildings. Tom frequently has numerous construction projects going on at the same time and needs a formal procedure for plan-

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Time Required</th>
<th>Immediate Predecessor Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Excavate</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td>B</td>
<td>Lay foundation</td>
<td>4</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>Rough plumbing</td>
<td>3</td>
<td>B</td>
</tr>
<tr>
<td>D</td>
<td>Frame</td>
<td>10</td>
<td>B</td>
</tr>
<tr>
<td>E</td>
<td>Finish exterior</td>
<td>8</td>
<td>D</td>
</tr>
<tr>
<td>F</td>
<td>Install HVAC</td>
<td>4</td>
<td>D</td>
</tr>
<tr>
<td>G</td>
<td>Rough electric</td>
<td>6</td>
<td>D</td>
</tr>
<tr>
<td>H</td>
<td>Sheet rock</td>
<td>8</td>
<td>C, E, F, G</td>
</tr>
<tr>
<td>I</td>
<td>Install cabinets</td>
<td>5</td>
<td>H</td>
</tr>
<tr>
<td>J</td>
<td>Paint</td>
<td>5</td>
<td>H</td>
</tr>
<tr>
<td>K</td>
<td>Final plumbing</td>
<td>4</td>
<td>I</td>
</tr>
<tr>
<td>L</td>
<td>Final electric</td>
<td>2</td>
<td>J</td>
</tr>
<tr>
<td>M</td>
<td>Install flooring</td>
<td>4</td>
<td>K, L</td>
</tr>
</tbody>
</table>
ning, monitoring, and controlling each project. He is aware of various project scheduling techniques but has never used them. He wants to see how he might apply such techniques to one of the home-building projects he will be undertaking in the near future.

Step Two: Sequence the Major Activities

The next step is to sequence each activity into a logical order based on when it must or is most likely to occur. The sequence you select will be peculiar to your research or planning project, but certain activities logically precede others (for example, in planning some type of meeting formulating objectives almost always takes place before you obtain the meeting speakers). This step usually requires some reshuffling of activities before the final sequence is determined. Experience with planning and the CPA technique will facilitate this sequencing step.

Step Three: Construct an Activity Flow Diagram

In the third step you construct a schematic or flow diagram detailing the sequence of activities determined for an overall planning effort or research project. This step requires an understanding of three basic definitions:

- **Event** - the start or completion point of a meeting task or activity. Events do not consume time or resources but are used as notations in constructing a CPA network.
- **Activity** - the performance of an actual meeting task or activity. Activities do consume time and/or resources.
- **Network** - the flow diagram constructed by connecting events; this details the sequence of activities for a particular meeting.

Step Four: Estimating the Time for an Activity

The next step involves estimating the time required to perform each activity. Time is usually represented on most networks in days or in weeks. In the CPA process it is recommended you estimate the time required for each activity utilizing as guides such criteria as experience, suggested time requirements made by colleagues or planning authorities, and known limitations of staff, resources, and money. A thoroughly constructed network might even have defined how many people and who will be working on a given calendar day, although there will be occasions when approximations will be just as useful.

Step Five: Computing the Expected Times to Complete
All Activities

Following an estimation or determination of the time required for each activity, the planner needs to calculate totals or the earliest possible time that each event can be reached. Symbolized on Figure 3 by the letter "T," this total is derived by summing the estimated times of all activity paths leading to any particular event.

Determining the critical path

The process

- A Forward Pass through the network determines the earliest times each activity can start and finish.
- A Backward Pass through the network determines the latest times each activity can start and finish without delaying completion of the project.
- The longest path through the network is the “critical path”.

Forward pass

- The earliest start time (EST) for the initial activity in a project is “time zero”.
- The EST of an activity is equal to the latest (or maximum) early finish time of the activities directly preceding it.
- The EFT of an activity is equal to its EST plus the time required to perform the activity.

Backward pass

- The latest finish time (LFT) for the final activity in a project is equal to its EFT as determined by the forward pass.
- The LFT for any other activity is equal to the earliest (or minimum) LST of the activities directly following (or succeeding) it.
- The LST of an activity is equal to its LFT minus the time required to perform the activity.

Step Six: Determining the Critical Path

A critical path, or that path of activities that must be completed within the times shown if the entire plan is to stay on schedule, can now be determined.

Critical activities have zero slack and cannot be delayed without delaying the completion of the project.

The slack for non-critical activities represents the amount of time by which the start of these activities can be delayed without delaying the completion of the entire project (assuming that all predecessor activities start at their earliest start times).
Step Seven: Constructing a Gantt Chart

Once all of the totals have been reached, the planner can make the first application of the CPA process. Simply by starting at the first event with some selected or mandatory calendar date, completion dates at each event based on the corresponding totals can be established.

Note:
Slack = LST\_i - EST\_i or LFT\_i - EFT\_i
**Economic tools**

**Time value of money**

The essential idea behind engineering economics is that money generates money. You cannot compare Ksh10.00 today to Ksh10.00 a year from now without adjusting for the investment potential. A simple example would be to take the Ksh10.00 and put it in a savings account at 2% interests. After a year you have Ksh10.20 instead of Ksh10.00.

You might be presented with three options for being paid.

- A single payment right now.
- A single payment at some time in the future.
- A uniform annual payment over several years.

For example, consider a lottery that is held in Nairobi. In this particular lottery, the winner is given three different payment options. The first is a lump sum payment immediately of Ksh1,000,000. The second is a series of 21 annual payments of Ksh50,000. The third is a whopping Ksh2,000,000 to be paid ten years from now. How does the winner choose which option to take? Of course, that will depend on the winners personal needs, but beyond that, how does one compare the three options? The annual payment method provides Ksh50,000 more than the immediate payment, and the deferred payment provides a cool million more. For argument sake, let’s say that the person who won the lottery knows that he can make 5% interest on the money in some safe investment.

The notation is provided in Table 1. We will call the immediate payment the “Present Value” of the winnings. The Ksh50,000 annual payments will be called “Annual Value,” and the Ksh2,000,000 will be the “Final Value.” The interest that we presume we can get on the money in some investment is designated as “i”.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Amount (in example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Present Value (What the money is worth right now)</td>
<td>Ksh1,000,000</td>
</tr>
<tr>
<td>A</td>
<td>Annual Value (What the money is worth in annual payments)</td>
<td>Ksh50,000</td>
</tr>
<tr>
<td>F</td>
<td>Final Value (What the money will be worth at some future date)</td>
<td>Ksh2,000,000</td>
</tr>
<tr>
<td>I</td>
<td>Interest (an estimate of how fast the money can grow in some relatively safe investment).</td>
<td>5%</td>
</tr>
<tr>
<td>N</td>
<td>Number of years (Duration over which an investment is made).</td>
<td>5 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Find</th>
<th>From</th>
<th>Discrete Payments, Discrete Compounding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Payment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F$</td>
<td>$P$</td>
<td>$F = P(1+i)^n$</td>
</tr>
<tr>
<td>$P$</td>
<td>$F$</td>
<td>$P = F/(1+i)^n$</td>
</tr>
<tr>
<td>Equal-Payment Series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F$</td>
<td>$A$</td>
<td>$F = A \frac{1-(1+i)^{-n}}{i}$</td>
</tr>
<tr>
<td>$A$</td>
<td>$F$</td>
<td>$A = F \frac{i}{(1+i)^n-1}$</td>
</tr>
<tr>
<td>$P$</td>
<td>$A$</td>
<td>$P = A \frac{1-(1+i)^{-n}}{i(1+i)^n}$</td>
</tr>
<tr>
<td>$A$</td>
<td>$P$</td>
<td>$A = P \frac{i}{(1+i)^n-1}$</td>
</tr>
</tbody>
</table>
Table 2: Summary of relationships between the different amounts used in engineering economics problems (Adapted from Ertas and Jones).

Table 2 tells us how to convert from one form of payment to another. Consider the column under “Discrete Payments, Discrete Compounding.” The equations are designed to answer the following questions:

\[ F = P(1 + i)^n \]

“If I know what the present value is, what is the future value at a time \( n \) years from now given an interest of \( i \)? In our example, if we want to know the value of the Ksh1,000,000 in 10 years, it would be

\[ F = 1,000,000(1 + 0.05)^{10} = 1,628,894 \]

Given this, the delayed payment option doesn’t appear too bad!

\[ P = F / (1 + i)^n \]

“If I know what the value of the funds will be in \( n \) years, what are they worth now? In our example, if we want to know what Ksh2,000,000 is worth in today’s dollars, it would be

\[ P = 2,000,000 / (1 + 0.05)^{10} = 1,227,826 \]

This just confirms what the previous calculation told us, i.e. that the value of the delayed payment is greater than that of the immediate payment.

\[ F = A \left[ (1 + i)^n - 1 \right] / i \]

“If I know the annual payments, what is the money worth \( n \) years from now?” In our case, after 21 years the Ksh50,000 per year will come out to be

\[ F = 50,000 \left[ (1 + 0.05)^{21} - 1 \right] / 0.05 = 1,785,962 \]

This seems to be a lot of money, but remember that this is in terms of the value of dollars 21 years from now. To compare that to the immediate Ksh1,000,000 we have to convert the Ksh1,000,000 to 21 year old dollars via

\[ F = P(1 + i)^n \]

Previously we used 10 for \( n \), but now we need to use 21. The answer is:

\[ F = 1,000,000(1 + 0.05)^{21} = 2,785,962 \]

This is about a million dollars more, which would argue for the immediate payment.

\[ A = F \left[ \frac{i}{(1 + i)^n - 1} \right] \]

“If I know the future value of the money, what is that equivalent to in annual payments?” So let’s say that we would like to convert the Ksh2,000,000 at ten years to annual payments over 10 years. We then obtain:

\[ A = 2,000,000 \left[ \frac{0.05}{(1 + 0.05)^{10} - 1} \right] = 159,009 \]

\[ P = A \left[ \frac{(1 + i)^n - 1}{i(1 + i)^n} \right] \]

“If I am paid in annual payments of \( A \) over \( n \) years (with the first payment starting at the end of the first year), what does that correspond to in current dollars?” In our case, 21 payments of Ksh50,000 is equivalent to only

\[ P = 50,000 \left[ \frac{(1 + 0.05)^{21} - 1}{0.05(1 + 0.05)^{21}} \right] = 641,058 \]

which is kind of a rip-off.

\[ A = P \left[ \frac{i(1 + i)^n}{(1 + i)^n - 1} \right] \]

“If I could be paid in a lump sum today, what must my annual payment be for me to recover the same amount of money over \( n \) years?” A logical question to ask in our case is, “How much money should I get if I am paid my winnings over 21 years?” The answer is:
Exercise 1: The above analysis does not take into account that the Ksh1,000,000 will be taxed at a different rate from the Ksh50,000 annual payments. Assume that the tax on Ksh1,000,000 in one year is 50% and the tax on Ksh50,000 per year is only 25%. This means that the present value of the Ksh1,000,000 is only Ksh500,000, and that the annual payment of the Ksh50,000 is only Ksh37,500. Calculate the equivalent annual payment for the Ksh500,000 and compare it to the Ksh37,500. Also calculate the present value of the Ksh37,500 payment option.

Recap:

Assume you want to know whether Option 1 or Option 2 is better. The approach is as follows:

1. Decide what common time frame to use. For example, you can convert everything to its value in current dollars (present worth), convert everything to its value in future dollars (future worth), or convert everything to an annual payment. For now we will assume that we are using the present worth method, so we want to convert everything to present worth.

2. Anything that is already expressed in your time frame does not need to be modified. For example, if you are using the present worth method, there is no need to convert the down payment or the initial investment to anything.

For the present worth method, convert annual payments to present dollars with

\[ P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right] \]

4. For the present worth method, convert single payments for any given year to present dollars with .

Now that everything is in terms of the same time frame, you can just add and subtract dollars.

Solution to Exercise 2 using the Present Worth method:

Exercise 2: Your engineering firm needs a rapid prototyping machine. The company gives you two options. In Option 1 you purchase the machine outright for Ksh50,000, pay a maintenance contract of Ksh1,000 per year, and expect to be able to resell the machine after 10 years at a salvage value of Ksh10,000. In Option 2, you lease the machine at Ksh7,000 per year and pay no maintenance, but receive no salvage. Assume that you will be able to take in Ksh8,000 per year in income from this machine. Also assume that an additional option is not to buy the machine at all, but to put the money in the bank at 5% interest. Which option will be best for the firm?

Option 1:
The present worth of the initial 50,000 is just 50,000.

The present worth of the maintenance contract (remembering that it must be paid at the beginning of the year) is:

\[ P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right] = 1000 \left[ \frac{1.05^{10} - 1}{0.05 \times 1.05^{10}} \right] = \$8,107 \]

The present worth of the income (8,000/year), remembering that income comes at the end of the year, is:

\[ P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right] = 8000 \left[ \frac{1.05^{10} - 1}{0.05 \times 1.05^{10}} \right] = \$61,774 \]

The present worth of the salvage (Ksh10,000) is:

\[ P = \frac{F}{(1+i)^n} = \frac{10000}{1.05^{10}} = 6,139 \]

Thus, the profit is Income – Outlay = 61,774 – (50,000 + 8,107 + 6,139) = -Ksh2,473.

Because your profit is negative, you would be better off to put the money in the bank at 5% interest, rather than going for Option 1.

Option 2:
The present worth of the 7,000/year lease is:
We already figured out that the present worth of the Ksh8,000/year profit is Ksh61,774, thus the total profit by this option would be Ksh61,774 - Ksh56,754, or Ksh5,019. This may not sound like much, but it's better than having the money just sit in the bank at 5% interest.

Thus, the correct choice is Option 2.

The benefit-cost analysis model

Benefit-cost analysis is simply rational decision-making. These techniques constitute a model for doing benefit-cost analysis. They include a variety of methods:

- identifying alternatives;
- defining alternatives in a way that allows fair comparison;
- adjusting for occurrence of costs and benefits at different times;
- calculating dollar values for things that are not usually expressed in dollars;
- coping with uncertainty in the data; and
- summing up a complex pattern of costs and benefits to guide decision-making.

It is important to keep in mind that techniques are only tools. They are not the essence. The essence is the clarity of the analyst’s understanding of the options.

The benefit-cost analysis framework

Even when the measurements of costs and benefits are complete, they might not speak for themselves until they are put in a framework. Benefit-cost analysis provides that framework. It can be used wherever a decision is needed and is not limited to any particular academic discipline, such as economics or sociology, or to any particular field of public or private endeavour. It is a hybrid of several techniques from the management, financial and social sciences fields.

As far as possible, benefit-cost analysis puts both costs and benefits into standard units (usually monetary values (ksh or USD) so that they can be compared directly. In some cases, it is difficult to put the benefits into monetary units, so we use cost-effectiveness analysis, which is a cost-minimization technique. For example, there might be two highway-crossing upgrade options that will result in the same saving of lives. In this case, we choose between the options on the basis of minimum cost.

The steps in benefit-cost analysis

A set of standard steps is listed below. Each step is explained in the chapter indicated.

1. Examine needs, consider constraints, and formulate objectives and targets. State the point of view from which costs and benefits will be assessed. (See this chapter.)
2. Define options in a way that enables the analyst to compare them fairly. If one option is being assessed against a base case, ensure that the base case is optimised.
3. Analyze incremental effects and gather data about costs and benefits. Set out the costs and benefits over time in a spreadsheet.
4. Express the cost and benefit data in a valid standard unit of measurement (for example, Kenya shillings, and use accurate, undistorted prices).
5. Run the deterministic model (using single-value costs and benefits as though the values were certain).
6. Conduct a sensitivity analysis to determine which variables appear to have the most influence on the NPV. Consider whether better information about the values of these variables could be obtained to limit the uncertainty, or whether action can limit the uncertainty (negotiating a labour rate, for example). Would the cost of this improvement be low enough to make its acquisition worthwhile? If so, act.
7. Analyse risk by using what is known about the ranges and probabilities of the costs and benefits values and by simulating expected outcomes of the investment. What is the expected net present value (ENPV)? Apply the standard decision rules.
8. Identify the option, which gives the desirable distribution of income (by income class, gender or region - whatever categorisation is appropriate).
9. Considering all of the quantitative analysis, as well as the qualitative analysis of factors that cannot be expressed in dollars, make a reasoned recommendation.
The first component of this investment model is the parameter table, which is a list of variables used to calculate the costs and benefits. For example, both costs and benefits of a project might be influenced over time by the population growth rate of the community. Rather than retype the population growth rate every time it appears in a formula within the table of costs and benefits, it is better to list it in the parameter table and refer...
to it in other parts of the spreadsheet as it is needed. Although not absolutely essential, the use of a parameter table also facilitates all kinds of ‘what if’ analyses, including sensitivity analysis and risk analysis. It simplifies the analyst’s task when changing the value of the parameter, a key requirement of risk analysis. Instead of searching through the whole model for all the places where the population growth rate was used (and perhaps missing some!), the analyst can change the value in the parameter table, and all its uses in the benefit-cost model will change automatically and simultaneously.

The second component is the incremental-effects model. In business or industrial contexts, this is sometimes called the production model. It sets out the expected events and consequences over time. The nature of the events will depend on the project - from illnesses (an immunization project), to sales (an export-incentive project), to letters sorted (a post office capital-investment project). These events are often subject to uncertainty, so we tie them in with the parameter table in the same way that we tie in the table of costs and benefits later.

The third component of the model is the table of costs and benefits over time. This is a list of all costs and benefits, with the values for each noted for every period within the investment horizon. These values are best-expressed in nominal dollars so that adjustments normally calculated in nominal dollars can be made (adjustments for taxes, for example). Nominal dollars cannot be added or subtracted across periods, however, so they must at some stage be converted to constant dollars, and then to present values, before they can be summed up. (For details on constructing a table of costs and benefits, see Section 2.6.) There are two ways of doing this. The first way is to calculate the full table of costs and benefits in nominal dollars, then another table in constant dollars, and then in present values. The second way is a little easier and more concise: the analyst adds all benefits and subtracts all costs within each period to obtain a single nominal-dollar net for each period and then converts this nominal-dollar net cash flow to constant dollars and present values (by convention, the analyst is allowed to add and subtract nominal dollars within a single period, although this is an approximation of true value because the worth of a dollar might change if the period is lengthy).

The final component of the model is the investment results table. Each time the benefit-cost model is run, it estimates an NPV of the investment. If it is a deterministic model, in which all the inputs have fixed values, then the result of each run will always be the same NPV. If it is a risk-analysis model, in which the parameters’ values vary within a stated range according to probabilities, the estimated NPV will also vary. The result of many runs of the model will be a list of possible NPVs, and this list itself will have to be analyzed statistically to determine the probable true NPV. This statistical analysis will show the maximum and minimum values of the NPV and the probabilities that the NPV is within various ranges. With this information, the analyst can apply decision rules to ascertain whether the project is a good one and whether it is the best alternative.

The report
In general, reports should contain at least the following:

1. a description of the need, problem or opportunity;
2. a description of the options with an explanation of why they were chosen and why it is fair to compare them;
3. a statement of the point of view of the analysis;
4. a statement of assumptions and scenarios;
5. a deterministic analysis;
6. a cost-benefit analysis and a risk analysis;
7. a discussion of equity effects and other non-economic effects; and
8. a ranking of the options.

Some cost benefit analysis methods:
In the examples below, figures are presented without reference to net or gross amounts. In reality you should always state both net and gross.

1. Payback:
This is literally the amount of time required for the cash inflows from a capital investment project to equal the cash outflows.

Payback period = Initial payment / Annual cash inflow

So, if Ksh4 million is invested with the aim of earning Ksh 500 000 per year (net cash earnings), the payback period is calculated thus:
P = Ksh 4,000,000 / Ksh 500,000 = 8 years

Payback with uneven cash flows:
In the real world, investment projects by business organisations don’t yield even cash flows. For example (with an initial investment in year 0 of Ksh 4,000,000):
The payback period is precisely 5 years.

The shorter the payback period, the better the investment, under the payback method. The main issue with this is that, even for a short period, there is a sacrifice to be made: an up front investment with the hope that it will be “paid back” in the future (also called opportunity cost).

Another problem is when you are comparing several proposals, for example:

<table>
<thead>
<tr>
<th>Year</th>
<th>Cash flow (Ksh 000)</th>
<th>Cumulative cash flow (Ksh 000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(4000)</td>
<td>(4000)</td>
</tr>
<tr>
<td>1</td>
<td>750</td>
<td>(3250)</td>
</tr>
<tr>
<td>2</td>
<td>750</td>
<td>(2500)</td>
</tr>
<tr>
<td>3</td>
<td>900</td>
<td>(1600)</td>
</tr>
<tr>
<td>4</td>
<td>1000</td>
<td>(600)</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>Zero</td>
</tr>
<tr>
<td>6</td>
<td>400</td>
<td>400</td>
</tr>
</tbody>
</table>

2 Average Rate of Return:

The average rate of return expresses the profits arising from a project as a percentage of the initial capital cost. However, the definition of profit and capital cost vary. For instance, the profits may be taken to include depreciation, or they may not. One of the most common approaches is as follows:

\[ \text{ARR} = \left( \frac{\text{Average annual revenue}}{\text{Initial capital costs}} \right) \times 100 \]

For example, a new system will cost Ksh 240,000 and is expected to generate a total savings of Ksh 45,000 over the project’s five year life.

\[ \text{ARR} = \left( \frac{\text{Ksh 45,000}}{5} \right) / 240,000 \times 100 = 3.75\% \]

Arguments in favour of ARR

- As with the Payback method, the main advantage with ARR is its simplicity.
- There is also a link with some accounting measures that are commonly used. ARR is similar to the Return on Capital.
- The ARR is expressed in percentage terms and this, again, may make it easier for managers to use.

Arguments against ARR

- ARR doesn’t take account of the project duration or the timing of cash flows over the course of the project.
- The concept of savings (or profit) can be very subjective, varying with specific accounting practice and the capitalisation of project costs. As a result, the ARR calculation for identical projects could result in different outcomes from business to business.
- Thirdly, there is no definitive signal given by the ARR to help managers decide whether or not to invest. This lack of a guide for decision making means that investment decisions remain subjective.

3 Net Present Value:

The Net Present Value (NPV) is a Discounted Cash Flow (DCF) technique. It relies on the concept of opportunity cost to place a value on cash inflows arising from capital investment.

Opportunity cost is the calculation of what is sacrificed or foregone as a result of a particular decision. It is also referred to as the ‘real’ cost of taking some action.

Present value is the cash equivalent now of a sum receivable at a later date. If we didn’t spend that money and banked it instead, the opportunity cost includes both the initial sum and the interest earned.

NPV is a technique where cash inflows expected in future years are discounted back to their present value. This is calculated by using a discount rate equivalent to the interest that would have been received on the sums, had the inflows been saved.

Net Present Value Tables

Net Present Value tables provide a value for a range of years and discount rates:

The present value for 0 years is always 1, and this is not included in the present value table.

\[
\begin{array}{cccccc}
\text{If} & 0 & 1 & 2 & 3 & \ldots & n \\
\text{Now} & \text{from now} & \text{from now} & \text{from now} & \text{from now} & \text{from now} \\
\end{array}
\]

you are looking to find the present value of Ksh 150,000 which you expect to receive in 5 years time, at a rate of interest of 3%, the following steps are taken:

Step 1 Use a NVP lookup table (see separate spread-
<table>
<thead>
<tr>
<th>Year</th>
<th>Cash Flow (Ksh)</th>
<th>3% Discount Rate</th>
<th>Present Value (Ksh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>150,000</td>
<td>1.000</td>
<td>150,000</td>
</tr>
<tr>
<td>1</td>
<td>12,000</td>
<td>0.971</td>
<td>11,652</td>
</tr>
<tr>
<td>2</td>
<td>25,000</td>
<td>0.943</td>
<td>23,575</td>
</tr>
<tr>
<td>3</td>
<td>25,000</td>
<td>0.915</td>
<td>22,875</td>
</tr>
<tr>
<td>4</td>
<td>35,000</td>
<td>0.888</td>
<td>31,080</td>
</tr>
<tr>
<td>5</td>
<td>40,000</td>
<td>0.863</td>
<td>34,520</td>
</tr>
<tr>
<td></td>
<td>Net Present Value</td>
<td>26,298</td>
<td></td>
</tr>
</tbody>
</table>

A positive NPV means that the project is worthwhile because the cost of tying up capital is compensated for by the cash inflows that result. When more than one project is being appraised, you choose the one that produces the highest NPV.

4 Internal Rate of Return (IRR):

Sometimes we will want to know how well a project will perform under a range of interest rate scenarios. The aim with IRR is to answer the question: “What level of interest will this project be able to withstand?” Once we know this, the risk of changing interest rate conditions can effectively be minimised (especially in the current climate!).

The IRR is the annual percentage return achieved by a project, at which the sum of the discounted cash inflows over the life of the project is equal to the sum of the capital invested.

Another way of looking at this is that the IRR is the rate of interest that reduces the NPV to zero. Imagine a scenario where we are considering whether to accept or reject an investment project, on the basis of their acquiring the funds necessary at a known rate of interest.

- The NPV approach asks if the present value of cash inflows less the initial investment is positive, at the current borrowing rate.
- The IRR approach asks if the IRR on the project is greater than the borrowing rate.

Illustration of NPV & IRR

For example, using the above NPV illustration of a Ksh 150,000 project yielding a NVP of Ksh 26,298 we know that the project seems worthwhile (positive result) Now, using IRR, we assume the 3% discount rate might well increase in the future so here’s the same project using a 5% rate:

<table>
<thead>
<tr>
<th>Year</th>
<th>Cash Flow (Ksh)</th>
<th>5% Discount Rate</th>
<th>Present Value (Ksh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-150,000</td>
<td>1.000</td>
<td>-150,000</td>
</tr>
<tr>
<td>1</td>
<td>12,000</td>
<td>0.952</td>
<td>11,429</td>
</tr>
<tr>
<td>2</td>
<td>25,000</td>
<td>0.907</td>
<td>22,676</td>
</tr>
<tr>
<td>3</td>
<td>25,000</td>
<td>0.864</td>
<td>21,596</td>
</tr>
<tr>
<td>4</td>
<td>35,000</td>
<td>0.823</td>
<td>28,795</td>
</tr>
<tr>
<td>5</td>
<td>40,000</td>
<td>0.784</td>
<td>31,341</td>
</tr>
<tr>
<td></td>
<td>Net Present Value</td>
<td>-34,164</td>
<td></td>
</tr>
</tbody>
</table>

The negative result shows that 5% will be too high a rate, and the IRR will be somewhere between 3% and 5%.

\[
\text{IRR} = 3\% + \text{Difference between the two discount rates} \\
\times \text{Positive NPV Range of /ve to /ve NPVs}
\]

\[
\text{IRR} = 3\% + (2\% \times 26298) \\
60462
\]

\[
\text{IRR} = 3.87\%
\]

IRR Summary

The value to a business of calculating the IRR is that its decision-makers are able to see the level of interest that a project can withstand. In the case where a number of projects are competing for selection, the one that is most resilient can be chosen.

IRR should not be used to compare mutually exclusive projects, however. For example a project with a lower IRR may in fact have a higher NPV so the potential income (or saving) could be higher.

Also IRR should not be used to compare project of different durations because it doesn’t consider cost of capital (expected return on capital).

Another problem with IRR appears with projects that have irregular cash flows alternating between positive and negative values several times. Numerous IRRs can be identified for such projects potentially leading to confusion and the wrong investment decisions being made.

5 Modified Internal Rate of Return (MIRR)

This is usually used to rank various choices. As the name implies, MIRR is a modification of the Internal Rate of Return (IRR). MIRR adds up the negative cash flows after discounting them to time zero, adds up the positive cash flows after factoring in the proceeds of reinvestment at the final time period, then works out what
To determine if the criteria hierarchy tree is appropriate, Keeny and Raiffa have suggested five attributes which the tree should possess (refer to Goodwin and Wright for descriptions):

- Complete
- Operational
- Decomposable
- Absence of redundancy
- Minimum size

Using these five attributes, determine if the following tree structures are appropriate:

Example 1: Choosing between cars
Identifying Alternatives

Through identifying the problem at hand it will often become clear what alternatives are available. However, having identified these alternatives it is necessary to investigate whether any alternatives have not been recognised or are ‘hidden’ to the decision-maker(s). Often further research or group discussion will elicit further alternatives.

The aim of the decision-maker(s) should be to develop a set of alternatives that is representative of all the options available. To reduce a larger set, the decision-maker(s) can use a screening process. The final set of alternatives should be appropriate, representative and manageable while covering all the possibilities.

Within this screening process, it is important to ensure that there exist no overlapping or joint alternatives. The best set usually incorporate alternatives which are independent (mutually exclusive) of each other, or ones which are loosely dependant but not entirely dependent. Later, when we start scoring the alternatives, it may become apparent that an alternative is dominated by another alternative (in that the alternative is not preferred to the second alternative on any criteria), in which case the dominated alternative can be dropped from consideration.

Focusing Questions:

- Can alternatives be readily recognised? What are they?
- Do they suit the decision problem, i.e. will they help the decision maker(s) achieve their goal?
- Will comparing these alternatives elicit the right answers for the problem or dilemma?
- Do other significant alternatives possibly exist that are unknown? Can these be found? How?
- Do any alternatives overlap with others or are they joint alternatives? If so, how can they be grouped or redefined so that all alternatives are mutually exclusive?
- Can alternatives be excluded because they are dominated by other alternatives?

Example: Apartments

After deciding that their problem warranted the use of MCDA, the four graduates sat down and analysed their situation. They decided that the situation at hand required them to use a number of pre-emptive criteria to screen out alternatives. These were:

- That the apartment should not exceed $250,000 in price.
- That the apartment had to be in the inner-city area and no further than 10 minutes walking distance from the furthest place of work.
- After individually brainstorming for criteria, the four graduates arranged to meet together and decide on an initial set of criteria that would enable them to look for alternatives that met these initial criteria. The group considered the following factors were desirable in an apartment:
  - Had a balcony to enjoy Wellington’s beautiful weather and so the wide doors leading out to the balcony would allow fresh air to circulate more quickly through the apartment. This was important especially when the apartment went unused for long periods of time.
  - Had one or two bedrooms.
  - Was fully or semi-furnished as the apartment needed to be used straight away. Also provided ease of use.
  - Had morning and/or afternoon sun both for intrinsic reasons (mood) and for the welcoming nature of the apartment. Afternoon sun was seen as more important as the graduates would be at work more often in the morning.
  - Had amenities close by.
  - Had a small number of tenants (preferably no greater than five) so that the apartment building remained quiet especially when they wanted to relax.
  - Had parking as it adds value to the apartment and two of the four graduates drive. A car parking building that was within two minutes’ walk was felt to be another option to consider.
  - Should have elevator access
  - Be of solid construction and provide reasonable levels of security

What criteria should be used in the criteria tree? How should the criteria tree be structured? Use the focusing questions to determine a suitable criteria tree.

Do criteria exist which can be used to evaluate the differences in alternatives? What are they? Think of all the factors that influence your decision, including subjective factors.

Are some of these criteria pre-emptive? Can they be used to screen out alternatives? What are they?

Will all the criteria help to assess the alternatives? Are some of the criteria non-differentiating? If so, should they be excluded?

- Does the situation or problem suit an Input/Output analysis, or Cost/Benefit analysis, or a more general tree structure analysis (with more than 2 first-level criteria)? For the appropriate tree structure, group your criteria
under the appropriate first-level criteria.

Do the selected criteria fall into a logical hierarchical sequence? Draw it. Keep in mind the goal or objective of the decision – and use this to keep your tree as small and focused as possible. For an Input/Output or Cost/Benefit model, use these two top headings as the two top-level criteria in your tree. (Refer back to the School IT example, or the House purchase example for examples of cost/benefit models.)

Answer: Apartments

Through applying a screening process, two parent criteria and seven child criteria were selected for analysis. Ideally, the four graduates saw the problem as a cost/benefit analysis. Subsequently the parent criteria were Cost and Benefit. The sub-criteria, or child criteria, under the Cost criterion were selected as:

- The Purchase price of the apartment (Purchase $)
- The Fee incurred through using an agency (Body Corp. fee).

The sub-criteria under the Benefit criterion were selected as:

- The Size of the apartment (square meters).
- Furnishing – how well the apartment is furnished: eg fully furnished, semi furnished or unfurnished.
- The Location of the apartment relative to each graduate’s place of work.
- Added features – balcony, sun, number of tenants, amenities close by.
- Parking – Access and convenience of parking, ranging from on-site parking, car parking building nearby (2 minutes walk) to no parking.