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Draft Report

Life Cycle Costing (LCC) as a contribution to sustainable construction: a common methodology

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0 Introduction

0.1 Background

In 2006 the European Commission appointed Davis Langdon from the UK to undertake a project(1) to develop a common European methodology for Life Cycle Costing (LCC) in construction.

The origins of the project lay in the Commission's Communication '*The Competitiveness of the Construction Industry*' and, more specifically, in the recommendations of the Sustainable Construction Working Group established to help take forward key elements of the Competitiveness study. These recommendations proposed that a Task Group (TG4) be established to prepare a paper on how Life Cycle Costing could be integrated into European policy making. The Task Group's paper(2) recommended the development of a common LCC methodology at European level, incorporating the overall sustainability performance of building and construction.

The project was undertaken in recognition that a common methodology for LCC in construction is required across Europe in order to:

- Improve the competitiveness of the construction industry
- Improve the industry's awareness of the influence of environmental goals on LCC
- Improve the performance of the supply chain, the value offered to clients, and clients' confidence to invest through a robust and appropriate LCC approach
- Improve long-term cost optimisation and forecast certainties
- Improve the reliability of project information, predictive methods, risk assessment and innovation in decision-making for procurement involving the whole supply chain
- Generate comparable information without creating national barriers and also considering the most applicable international developments.

0.2 Purpose of this methodology

This methodology provides a basis for the common and consistent application of LCC across the EU without replacing country-specific decision models and approaches. It is aimed primarily at public sector construction clients and their project advisors, but can also be used by private sector clients and their advisors, and by contractors.

0.3 Using this methodology

LCC may be applied in a wide range of circumstances in construction, for example in a project to invest in:

- A single complete constructed facility such as a building or civil engineering structure
- An individual component or assembly within a facility
- A portfolio comprising a number of facilities.

LCC may be employed to inform decisions throughout the life cycle of a constructed asset or only for a selected limited period within it. However, the core process of LCC comprises the same series of key steps in all circumstances, summarised in figure 1 below.

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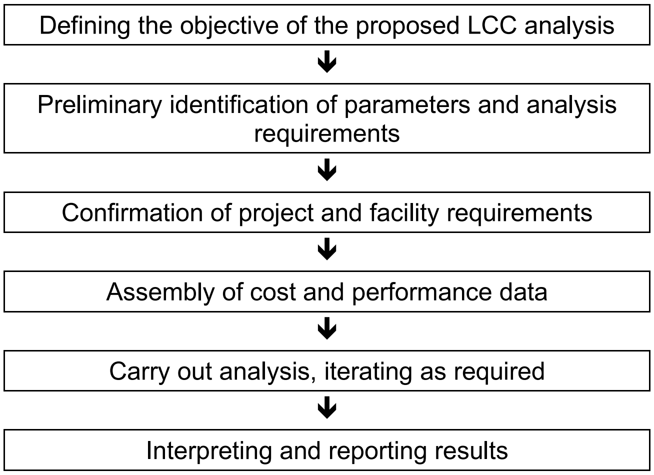
(1): Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology' No. 30-CE-0043513/00-47.

(2): *Task Group 4: Life Cycle Costs in Construction; Version 29 October 2003*, Enterprise Publications, European Commission. Endorsed during 3rd Tripartite Meeting Group (Member States/Industry/Commission) on the Competitiveness of the Construction Industry.

Figure 1: Core process of LCC



The purpose of the analysis as defined in the first step will determine the scope and detail of subsequent steps. To be effective, the process should be undertaken collaboratively between all key stakeholders in the project.

As noted, the process is essentially iterative, in the context of both assessing options for a decision at a specific point and repeating the analysis at successive points in the life cycle of a project in the light of increasingly detailed information. The methodology does not seek to represent these potential iterations, rather takes the user through a series of numbered steps that follow a logical train of thought, shown on the flow diagram included as figure 2 below.

The steps in this methodology therefore do not reflect the actual chronology of a project to invest in a constructed asset. The accompanying guidance document assists the user to apply the methodology in the time line of an actual project by presenting how the steps are followed though in a series of example situations. Section 0.4 below provides an overview of the outcomes for the user as a result of taking each step. The sections following in this methodology are numbered to match the steps.

A number of steps are optional and shown to be taken ‘if required’ because their application depends on early decisions:

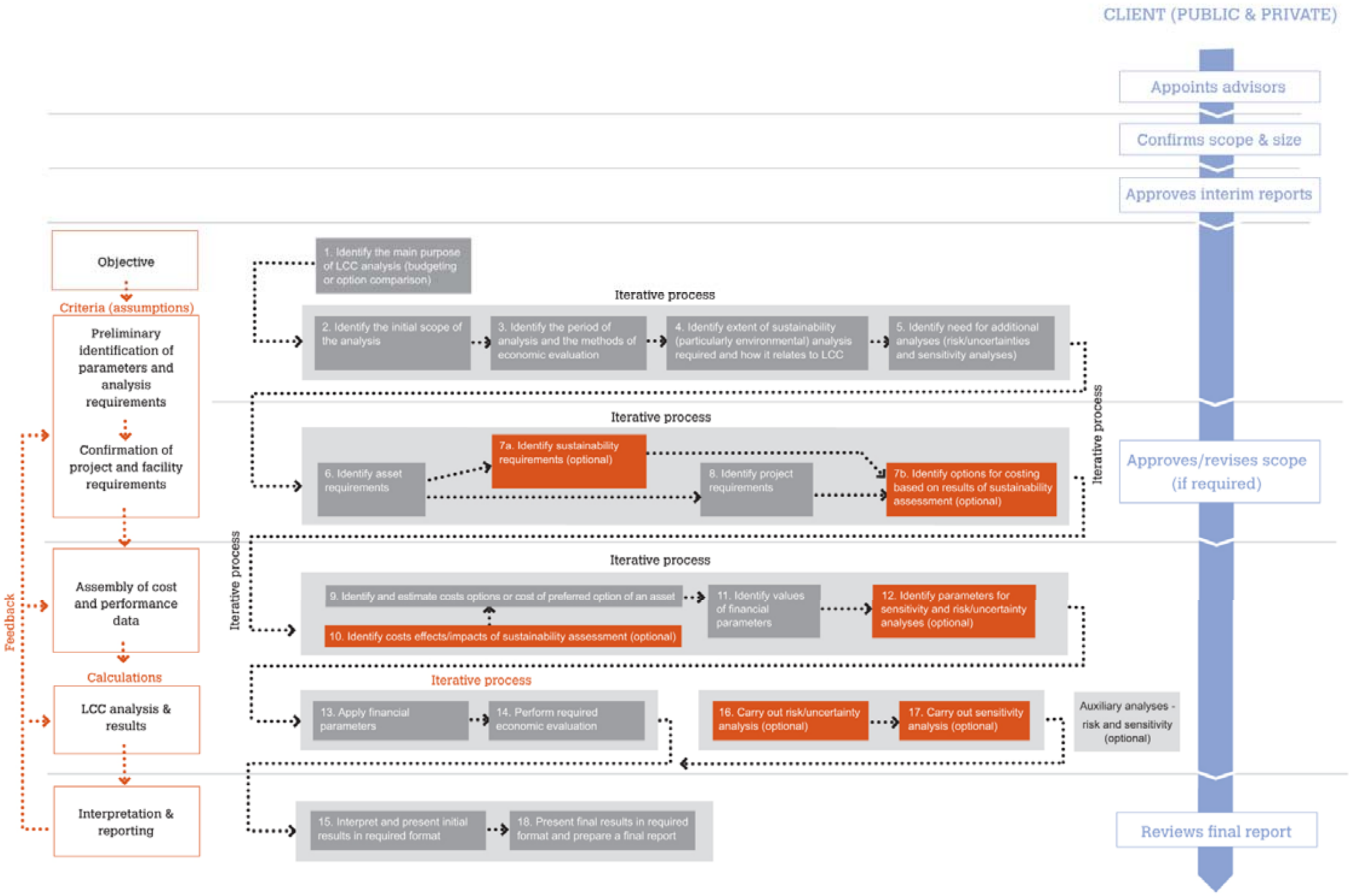
- at step 4, regarding the extent to which sustainability will be taken into account
- at step5, regarding the extent to LCC analysis will be supported by risk/uncertainty analyses.

The steps generally use a vocabulary appropriate to a project to construct a facility but the essential principles set out are entirely applicable to any constructed asset.

The methodology assumes that the user comes to it with a project in view for which the purpose, scale and initial capital cost have been broadly defined.

Definitions in this methodology are as in ISO15686 Part 5.

Figure 2: Methodology flow diagram



0.4 Overview of outcomes

Table 1 below summarises the steps described in this methodology and the outcomes that can be expected as a result of each.

Table 1: Summary and overview

	STEP	**OUTCOME / ACHIEVEMENT**
1	Define the main purpose of the LCC analysis	• Statement of purpose of analysis • Understanding of appropriate application of LCC and related outcomes
2	Identify the initial scope of the analysis	Understanding of: • Scale of application of LCC • Stages over which it will be applied • Issues and information likely to be relevant
3	Consider the period of analysis and the methods of economic evaluation	Understanding of: • Significance of period of analysis and what governs its choice • Use of discounting in analysing future costs/revenues • Use of other economic evaluation methods
4	Identify the extent of sustainability – and specifically environmental – analysis required and how it relates to LCC	Understanding of: • The value and application of sustainability assessments • Their value and use in conjunction with LCC • How sustainability will be further taken into account in later steps
5	Identify the need for additional analyses (risk/uncertainty and sensitivity analyses)	Understanding of: • Approaches to risk and uncertainty analysis • Their potential application on this project • Their relationship to LCC
6	Identify asset requirements - *the key features of the facility*	• Description of intended functions of the facility • Description of its key physical characteristics and performance requirements • Understanding of assumptions made and information still required
7	Identify sustainability requirements / options for costing based on results of sustainability assessment (if required)	• All relevant legislation / guidelines identified • Key environmental objectives defined • Method of assessment identified • Confirmed how assessment will be incorporated into LCC
8	Identify project requirements - *confirm key parameters*	• Definition of the scope of the project • Statement of project constraints • Definitions of relevant quality requirements • A robust and detailed budget • A comprehensive project programme

9	Identify and estimate costs options or cost of preferred option of an asset – *assemble time and cost data to be considered in LCC analysis*	• Cost Breakdown Structure established including all costs relevant to the LCC analysis • Best estimate made of the value of each cost • Time profile of each cost identified
10	Identify costs effects/impacts of sustainability assessment (if required) *ensure implications of environmental assessment are taken into account, including costs*	• All environmental impacts and related costs identified and taken into account (in the course of step 9)
11	Identify values of financial parameters – *also define analysis, fiscal strategy*	• Period of analysis confirmed • Methods of economic evaluation selected • Appropriate values for the financial parameters identified and justified
12	Identify parameters for sensitivity and risk/uncertainty analyses (if required) – *carry out qualitative risk analysis*	• Qualitative risk analysis undertaken – risk register updated • Scope and extent of quantitative risk assessment confirmed • Key parameters selected
13	Apply financial parameters	• Decision matrix drawn up for application of financial parameters • Fiscal strategy confirmed • Relevant justifications and supporting evidence recorded
14	Perform required economic evaluation	• Appropriate measures identified and applied • Results recorded for use at step 15
15	Interpret and present initial results in requires format	• Initial results reviewed and interpreted • Results presented using appropriate formats
16	Carry out risk/uncertainty analysis (if required)	• Quantitative risk assessments undertaken • Results interpreted
17	Carry out sensitivity analyses (if required)	• Sensitivity analyses undertaken • Results interpreted
18	Present final results in required format and prepare a final report	• Final report to agreed scope and format • Complete set of records to ISO 15686:2005 Part 3

1 STEP 1: Identify the main purpose of the LCC analysis

1.1 Purposes for which LCC may be employed

LCC is a versatile technique capable of being applied for a range of purposes, in two broad categories:

- To support the processes of planning, **budgeting** and contracting for investment in constructed assets
- To undertake robust financial **option appraisals**, for example in relation to potential acquisition of assets, design approaches or alternative technologies.

More specifically, LCC can be used to support decision-making in a number of ways:

- In assessing the total cost commitment of investing in and owning an asset, either over its complete life cycle ("cradle to grave") or over a selected intermediate period
- By improving understanding of the total cost of an asset, particularly by construction clients, and improving the transparency of the structure of these costs
- By facilitating effective choices between different means of achieving desired objectives, for example reducing energy use or lengthening a maintenance cycle
- By helping to achieve an appropriate balance between initial capital costs and future revenues costs
- In helping to identify opportunities for greater cost-effectiveness, for example in operation and maintenance costs, or better environmental performance, for example by selecting an alternative to an HVAC system
- Overall, by instilling greater confidence in decision-making in a project.

LCC can be employed throughout or at different stages of the life cycle of a project to invest in construction; this is considered in detail at step 2.

Some examples of common applications of LCC follow below in this section to further illustrate these points.

1.2 Typical applications of LCC

Table 2 below illustrates how LCC can be applied in a variety of circumstances, with examples drawn from a building development. The same principles apply in an infrastructure or engineering context. The successive stages in the whole life cycle of a scheme and the related need for decisions are considered in more detail in section 2 following. More detailed examples are provided in the Guide that accompanies this methodology.

Table 2: Typical applications of LCC

Context and need	Typical application of LCC
During investment planning, clients will need to understand the full cost implications of operating as well as building the scheme, to establish its essential viability.	The analysis will be based on approximate data, typically historical information from similar projects, but sufficient for budgeting and option ranking to allow a decision on whether to go ahead, to reduce the scheme or stop.
During the early stages of scheme design, decisions will be required on the fundamental elements – structure, envelope, services, finishes	The analysis can draw on feasibility studies and pre-project professional advice, as well historical information, to support decisions on the key features of the scheme – its size, scope, method of construction and operation.
By detail design stage, the essential cost parameters of the scheme will be fixed but decisions will still be required on details and whether, finally, to commit to construction.	Cost information can now be fed into the analysis based on a clear view of all primary elements of the scheme and access to related cost data from manufacturers' specifications, as well as similar projects and national price books. This allows a detailed cost breakdown confirming the viability of the scheme and appraisal of detailed design options. Sensitivity and risk analyses may also be carried out.
Detailed design also requires final selection of components. Decisions on some systems might also need to be finalised. Potentially, similar decisions will subsequently be required in the event of their replacement during operation and maintenance	LCC analysis can be focused on the specific component or system with the benefit of related cost data from manufacturers' specifications, as well as from similar projects and national price books. The main focus will be on option evaluation, ranking and selection.
Refurbishment of some elements of the scheme might be required during operation and maintenance, driven by (for example): • High operational costs • High energy consumption • Need for a capacity increase • Conditions no longer being acceptable	LCC can be applied in supporting selection of the refurbishment option most applicable to the objectives of the proposal to refurbish. The analysis can be based on detailed cost data derived from manufacturers' specifications and comparable cost-in-use data. It is essential that the analysis takes into account the impact on interdependent systems and the overall asset.

1.3 The need for clarity of objectives

The different purposes for which LCC may be employed, and the different stages of the life cycle at which it is used, imply the need for different levels of detail and accuracy in the process, and in the inputs and outputs. For example, if LCC is employed to support a budgeting process, all costs must be considered and special care taken to assemble them all. Further, as the LCC analysis is refined through iteration, further detail will be required on all cost items. The process may also need to support auxiliary outputs such as an estimate of resources or a reporting schedule to ensure all necessary support for decision-making.

If the primary purpose is to appraise options, the process of iteration will involve refining or eliminating the available alternatives as they are measured against project objectives and budget constraints. This process will involve identifying those cost elements that do not have a significant impact on the overall LCC or which do not vary between the alternatives. These elements can be then be eliminated from further consideration.

Accordingly, clearly defining the objectives of a proposed LCC analysis must be seen as an essential first step in ensuring that it will be fit for the user's purpose.

1.4 The ingredients for success

Successful application of an LCC approach requires:

- A team approach incorporating all key players in a project
- Integrating the LCC exercise into the whole investment decision-making process through the conception, design, construction and operation of a facility
- Recognition of the limitations of the techniques employed, leading to the proper exercise of professional judgement.

1.5 At the end of Step 1

At the end of Step 1 the user will have developed:

- A clear and comprehensive statement of the purpose of the proposed LCC analysis
- An understanding of how LCC analysis can be appropriately and successfully applied and the outcomes that can be expected.

2 STEP 2: Identify the initial scope of the LCC analysis

2.1 The scale of application of LCC

LCC analysis may be undertaken to support a project to invest in:

- A single complete constructed asset that comprises a usable facility such as a building or civil engineering structure
- An individual component of system within such an asset
- A portfolio comprising a number of assets

For clarity, this methodology assumes the scenario of a project to construct and use a building, but the same principles and basic processes apply whatever the scale of application of LCC.

The scale of application for a proposed LCC analysis will be defined by the user, in the light of the objectives defined as discussed in section 1 above.

2.2 Stages in the life cycle of a project to construct and use an asset.

For the purposes of this methodology, the life-cycle of a project to construct and use an asset is divided into the following stages (see figure 3 below at end of section):

- Investment planning, pre-construction
- Design, construction
- Operation, maintenance
- End of life / disposal

Activities in the investment planning / pre-construction phase might typically include:

- Acquisition of site(s) or of existing asset(s)
- Professional consultancy
- Inspections and surveys
- Arranging finance
- Assembling the project team / consortium
- Procurement planning

Activities in the design and construction phase might include:

- Scheme design
- Detailed design
- Site clearance
- Placing contracts for construction
- Construction of the fabric
- Fitting out
- Commissioning and handover
- Landscaping

Activities in the operation and maintenance phase might include:

- Employing an FM team or placing an appropriate contract
- Placing contracts for energy supply and other utilities
- Arranging insurances and compliance with regulatory requirements, eg inspections
- Arranging for and carrying out pre-planned replacements, refurbishment and/or adaptation (any such works carried out on an ad hoc or contingency basis are better considered as separate projects subject to their own LCC considerations)
- Cleaning

- Redecoration
- Grounds maintenance.

A proposed LCC analysis might take place over one or more or all of these stages, as discussed below. Its scope must be defined by the user, in the light of the objectives defined at step 1.

2.3 Use of LCC through successive stages.

LCC analysis is used to inform different decisions at different stages of the project life cycle. Input data is progressively refined as the project moves through successive stages. Accordingly, as calculations are based on increasingly detailed and reliable data and initial assumptions are tested and validated, early strategic decisions are confirmed and subsequent decisions taken at increasing levels of detail.

2.3.1 Investment planning / pre-construction

Decisions at planning / pre-construction stage are of a strategic nature relating to the essential features of the proposed scheme, with data input at a low level of detail. They typically cover the following considerations:

- The essential features of the proposed scheme
- Methods of investment appraisal
- Finance – costs, budgets, cash flow
- Procurement policy and methods
- Balance between economic, technical and sustainability considerations
- Risk management strategies and techniques
- Key project drivers and overall priorities.

The application of LCC in the project is also considered at this stage:

- Purpose(s) of using LCC
- Methods of analysis
- Cost drivers
- Data needs.

2.3.2 Design and construction

Design and construction is a broad stage with design decisions taken successively through three levels:

- Scheme level, fixing the basic physical characteristics of the facility
- System level, deciding the major installations and assemblies
- Detail design.

The level of detail in the LCC analysis increases progressively though these levels and its purpose and implementation should be kept under review as it is reiterated. Considerations through this stage typically include:

- Design, from outline through to detail and issue for construction
- Selection of components
- Cost and performance drivers during construction
- Phasing of construction
- Contractual framework
- Resource implications
- Need for and ease of functional reconfiguration / adaptation during operation

- Any planned replacement / refurbishment during operation
- Impact on quality of life for project stakeholders

2.3.3 Operation and maintenance

The need for decisions and opportunities for LCC continue into the operation and maintenance stage and might typically relate to:

- Occupancy policy and data
- Cost and performance drivers during operation and maintenance
- Denial-of-use costs
- Strategies for operation and maintenance and related cost models:
    - FM
    - Energy
    - Other utilities
    - Cleaning
    - Waste disposal
- Strategies for support functions and related cost models:
    - Mail
    - IT
    - Transport
    - Archiving
- Strategy and planning for maintenance, repair and replacement:
    - Internal systems and components
    - External systems and components
    - M&E
- Collection and use of feedback data
- Risk centres for operation, maintenance and finance costs

2.3.4 End-of-life / disposal

LCC considerations at the end-of-life stage might include:

- Strategy for demolition / disposal – methods, costs, residual values
- Collection and use of feedback data
- Strategy for salvage and recycling – opportunities, costs, potential value
- Site and land clean-up
- Cost drivers

2.4 At the end of Step 2

At the end of step 2, the user will have developed a clear understanding of:

- The scale of application of the LCC exercise
- The stage(s) of the project over which it is likely to be undertaken
- The scope and nature of the issues and information likely to be relevant.

Figure 3: Potential for LCC through the life cycle of a project

<table>
<tr><td colspan="6">**Stages of project life cycle** →</td></tr>
<tr><td>Investment planning; pre-construction</td><td colspan="3">Design and construction</td><td>Operation, maintenance</td><td>End of life / Disposal</td></tr>
<tr><td colspan="6">WLC</td></tr>
<tr><td></td><td colspan="5">LCC in construction</td></tr>
<tr><td></td><td colspan="3"></td><td colspan="2">LCC in use</td></tr>
<tr><td colspan="6">**Output data – LCC informs:**</td></tr>
<tr><td>**Strategic** level option appraisals:
• Definition of need
• Client priorities
• Acquisition route
• Design concepts
• etc</td><td colspan="3"></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">**Design** decisions, successively at:</td><td></td><td></td></tr>
<tr><td></td><td>Scheme level
- Structure
- Envelope
- Services
- Finishes</td><td>System level</td><td>Detail level</td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2">Choice of **components**</td><td></td></tr>
<tr><td></td><td colspan="3"></td><td>**Benchmarking**,
Future costs</td><td></td></tr>
<tr><td colspan="6">**Input data progressively refined** →</td></tr>
<tr><td colspan="6">***Assumptions tested and validated*** →</td></tr>
<tr><td>Strategic assumptions:
• Future requirements, eg:
- Accommodation
• Cost variables, eg:
- Energy
- Discount rate
- Timing of cost flows</td><td>Technical assumptions:
• Service life
• etc</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">***Calculations based on:*** →</td></tr>
<tr><td>• ‘Benchmark’ figures, eg per:
• Functional unit
• Total area</td><td>Elemental analysis</td><td></td><td>Design detail and quantum
Service life data</td><td></td><td></td></tr>
</table>

3 STEP 3: Identify the period of analysis and methods of economic evaluation.

3.1 Period of analysis

In step 2 the User identified the likely broad timescale of the LCC exercise. In this step, the timescale over which the analysis takes place is confirmed as the 'period of analysis'. This is formally defined in ISO15686 Part 5 as follows:

- "The length of time over which an LCC assessment is analysed. This period of analysis shall be determined by the client at the outset (e.g. to match the period of ownership) or on the basis of the entire life cycle of the asset itself."

ISO 15686 Part 5 provides further definitions as follows:

- Life Cycle as "Consecutive and interlinked periods of time between a selected date and the disposal of the asset, over which the criteria (e.g., costs) are assessed. This period may be determined for the analysis (e.g., to match the period of tenancy or ownership) or cover the entire life cycle. The life cycle period shall be governed by defining the scope and the specific performance requirements for the particular asset."
- Entire Life Cycle as "Consecutive and interlinked periods of time between a selected date and the end of service life of the asset, including the end of life period."

In practice, the term "life" applied to a constructed asset bears a number of logical definitions according to the interests and objectives of the user, as follows:

- **Physical life** (from construction to demolition). Every asset has a predicted length of life at the end of which a physical collapse is possible. However most assets never reach that point and are demolished beforehand, generally due to economic obsolescence.
- **Economic life** (from construction to economic obsolescence). Economic obsolescence happens when the further use of an asset is the least economic solution among alternatives.
- **Functional life** (from construction to the point when the asset ceases to function for its intended purpose). An asset reaches the end of functional life when it can no longer function for the purpose for which it was constructed.
- **Technological life** (from construction to the point when the asset is technologically obsolete). End of technological life occurs when an asset, typically a system or component, is no longer technologically equal to or better than available alternatives.
- **Social / legal life** (from construction to the point when replacement is required for social or regulatory reasons). An asset reaches the end of its social or legal life when requirements other than economic dictate replacement or change, e.g. H&S issues
- **Contractual / 'duration of interest' life** (for any period of time during the duration of the physical life of an asset). This period of analysis covers the length of a contract for a particular service, e.g. construction, operation, etc.
- **Arbitrary life** (length of time e.g. 25, 30, 50 years), assumed due to national practice, local best practice, client's stipulation, etc.

While the term 'LCC' tends to be associated with the physical life of an asset, that is, from "cradle to the grave", the period of interest to the practitioner is likely to be shorter, as indicated by the range of the potential practical definitions. The 'period of analysis' must therefore be specifically defined for each LCC exercise.

3.2 Discounting

3.2.1 The purpose of discounting

Discounting is a technique used to compare costs and revenues occurring at different points in time on a common basis, normally the present time. It is based on the principle that a sum of money to hand at the present time has a higher value than the same sum to hand at a future date, because of the earning power of that sum in the interim.

Discounting to present value makes an adjustment to the future costs of an asset that takes account of inflation and the real earning power of money, allowing them to be compared and evaluated on the same basis as costs incurred at the present.

The need to discount depends on the use to which the LCC analysis will be put. It is necessary only where a series of costs over time has to be put onto a common basis for the purpose of a decision, not where the objective is simply to project annual costs on a year by year basis.

3.2.2 The effect of discount rates

A decision not to discount, that is, to apply a zero rate, implies that the timing of a cost (eg for repair or renewal) is immaterial and disregards the earning power of money. However, it presents the best case for spending a bigger sum up front in order to save even bigger sums later and it can be argued that a zero discount rate should be applied to all public sector investments intended to leave a lasting legacy for future generations.

Conversely, a high discount rate will present options with a low up-front cost as appearing more desirable and it can be argued that this has the effect of sacrificing the interests of future generations to those of the present decision-makers. However, future uncertainties unrelated to the asset, eg budgetary crises or changed political priorities, may have an impact on the timing or extent of future costs. It can be argued that this represents an argument for affording future costs less weight in decision-making and hence for discounting.

3.2.3 The treatment of inflation

The discount rate is the investment premium over and above inflation and as such is a separate concept and distinct from it. There are two possible approaches to dealing with inflation:

- Using a ‘nominal’ interest rate, that is a rate that is not adjusted to remove the effects of actual or expected inflation. This means that inflation predictions are built into forecast costs and prices
- Using a ‘real’ interest rate, that is a rate that has been adjusted to remove the effect of actual or expected inflation. This means that future costs and prices are estimated at present day (‘real’) prices and inflation can be dealt with separately.

If inflation rates for all costs in the analysis are approximately equal, it is common practice to exclude inflation from the LCC analysis. However, if the analysis includes commodities subject to widely differing rates of inflation, for example energy prices and labour rates, inflation would have to be included.

3.2.4 Selecting the discount rate

Selecting the most appropriate discount rate is critical to the success of an LCC exercise. In the private sector, selecting the rate is a highly judgemental process with reference to the financial status of the client and the circumstances of the particular project, and in practice rates can vary widely. Key considerations will be the cost of capital, the perceived level of project risk and the opportunity cost of capital.

In the public sector, national ministries of finance generally publish discount rates to be used in the economic analysis of publicly funded projects. These typically fall into the range of 3 to 5%; for example, the UK Treasury currently (February 2007) recommends a real discount rate of 3.5%, with a declining schedule of rates for projects with very long-term impacts, that is, over 30 years

Because constructed assets have long service lives and it is difficult to predict inflation in the long term, it is generally recommended to carry out LCC analyses on using real costs and discount rates. It is further often recommended that results should be tested by applying two real discount rates, including one relatively lower rate, and appraising the difference in outcomes. Long-term costs and savings become much more apparent at a lower rate, whereas a high rate might discriminate against long-term conservation if applied blindly.

3.3 Methods of economic evaluation

A number of techniques are available in which in which investment options may be assessed. Using them together provides a broad picture of value implications.

3.3.1 Net Present Value (NPV), Net Present Cost (NPC)

The NPV is the sum of the discounted future cash flows, both costs and benefits/revenues. Where only costs are included this may be termed Net Present Cost (NPC).

NPV is a standard measure in LCC analyses, used to determine and compare the cost effectiveness of proposed options. It can be applied across the full range of construction investments, covering whole schemes, systems, components, O&M models. The costs and revenues/benefits to be included are identified for each analysis according to its objectives.

3.3.2 Payback (PB)

The PB period is the measure of how long it takes to recover investment costs and a useful basis for evaluating investment options. It may be calculated using either real (non-discounted) values for future costs, that is ‘Simple PB’, or present (discounted) values, that is ‘Discounted PB’. PB in general ignores all costs and savings after the payback point has been reached and it is possible that an investment with a short PB is a poorer option than one with a longer payback over the entire period of analysis.

3.3.3 Net Savings (NS), Net Benefit (NB)

NS/NB is the present value of savings/benefits in the operation phase less the present value of the additional investment costs to achieve them. It provides a measure of cost-effectiveness and of the benefits to be achieved from investment options. NS/NB greater than 0 indicates positive cost-effectiveness.

3.3.4 Savings to Investment Ratio (SIR)

The SIR is a measure of the cost-effectiveness of a proposed investment (an SIR greater than 1 is positive) and can be used to prioritise and select investment options.

3.3.5 Adjusted Internal Rate of Return (AIRR)

The AIRR is a measure of the annual yield from a project over the period of analysis taking into account reinvestments of interim receipts, indicating projects with greater NS. An AIRR greater than the minimum acceptable rate of return (ie the discount rate) is positive.

3.3.6 Annual Cost and Annual Equivalent Value (AC or AEV)

The AC or AEV is a uniform annual amount that, when totalled over the period of analysis, equals the total net cost of the project taking into account the time value of money over the period. It is used to compare investment options where the natural replacement cycle cannot easily be directly related to the period of analysis. The lowest AEV indicates the lowest cost option.

3.4 At the end of Step 3

At the end of step 3 the user will have developed a clear understanding of:

- The need clearly to define the period of analysis and the considerations governing its choice
- The analysis of future costs and revenues by the use of discounting and the considerations relating to its application, particularly the choice of discount rate
- The other economic evaluation methods available and their appropriate use.

4 STEP 4: Identify the extent of sustainability – and specifically environmental – analysis required and how it relates to LCC

4.1 Purpose of this step

Sustainability is becoming an essential consideration in relation to LCC analyses of constructed assets. The extent and manner in which it is taken into account is defined at this step.

4.2 Assessing sustainability

Practitioners recognise three fundamental and interlinked sets of issues within the 'sustainability' agenda:

- **Environmental** – relating typically to air quality, land use, energy and water use, transportation, local ecology, cultural heritage
- **Social** – relating typically to access, amenity, user comfort and satisfaction, community health and welfare
- **Economic** – relating typically to opportunities for employment, skills development, local businesses including SMEs,

Use of **natural resources** may also be a consideration alongside the foregoing, with reference typically to use of minerals and other materials, water, energy, land utilisation, waste disposal.

Many sustainability issues are intangible and subjective, and accordingly difficult to measure and to incorporate into an LCC analysis. However, LCC practitioners widely accept that the environmental impact associated with constructed assets can be significant and should always be considered (see section 4.3 following). A range of approaches to assessing environmental impact are available to suit the type of asset, the aspects of the environment that are of concern and the particular parameters that are of interest. The following are the most frequently used:

- **Life Cycle Assessment** (LCA) – a process to evaluate the environmental burdens associated with an asset by identifying energy and materials used and wastes released to the environment during its whole life cycle, together with use of land and impact on biodiversity (see section 4.3 following)
- **Environmental Impact Assessment** (EIA) – a process for informing decision-makers of the potential environmental consequences/effects of development options
- **Multi-Criteria Analysis** (MCA) – a process that initially identifies a set of goals or objectives and then seeks to identify the trade-offs between those objectives for different options. The 'best' environmental solution is identified by attaching weights (scores) to the objectives.
- **Environmental Risk Assessment** (ERA) – a process of collecting, organising, analysing and presenting scientific risk data to aid decision-making.

A number of techniques and tools may be employed in support of these methods, including:

- Indoor Air Assessment
- Mass Flow Analysis
- Input / Output Analysis
- Production Analysis
- Eco-scoring and Eco-indicators
- Impact checklists, impact matrices, cause / effect networks, etc.

While a number of approaches to assessing environmental impact are available to suit individual requirements, as discussed above, LCA is one of the most versatile and widely recognised in construction and is referred to in this methodology.

To be properly comprehensive, an environmental impact assessment of a constructed asset must extend to the manufacturing process and transport of materials and components.

4.3 Drivers for assessing environmental impact

It may be costly not to consider environmental impacts when undertaking a construction project. Causing damage to the environment can have significant direct or indirect financial consequences in terms of damage to the reputation of the stakeholders in the project, fines or litigation. Positive reasons for considering environmental impact include:

- Compliance with:
  - EU regulations and guidelines
  - Country-specific regulations and guidelines
  - Local legal obligations
  - Company corporate green polices and strategies
- Implications for taxation
- Membership of corporate social responsibility programmes, ‘green’ public procurement programmes and the like
- Opportunity to improve reputation and ‘image’ of project stakeholders
- Competitive advantage arising from being in the lead and building a track record on sustainability issues
- Ultimately, increase in shareholder value.

4.4 Measures employed in LCA

Environmental impact is caused primarily by the consumption and/or transformation of materials and energy. Accordingly LCA measures the consumed and emitted flows (that is, raw material and energy consumption, and emissions to air, water, soil) over the whole life cycle of the asset. These are aggregated and interpreted in terms of impact categories on natural ecosystems, a number of which are the subject of consensus at international level, for example:

- Global Warming Potential (GWP) in kg of CO^2 equivalent
- Ozone Deletion Potential (ODP) in kg of CFC 11 equivalent
- Acidification Potential (AD) in kg of SO^2 equivalent.

Measures may be expressed in qualitative terms; for example, soil pollution is measured in qualitative terms, contribution to indoor air quality in semi-qualitative. The associated environmental costs cannot be assessed in economic terms and thus cannot be input directly into LCC analyses.

Quantitative measures are expressed in terms of raw material and energy consumption and resulting emissions per functional unit (FU), that is, the amount associated with fulfilling a given function, for example:

- Consumption of energy resources in MJ/FU
- Consumption of non-energy resources in kg/FU
- Water consumption in litres/FU
- Solid waste in kg/FU
- Climate change CO^2 equivalent in kg/FU
- Air pollution in m^3/FU

- Water pollution in m^3/FU

There is no single accepted method carrying out LCA. The approach is tailored and the time frame and degree of detail specified according to the needs, circumstances and priorities of the individual client. Costs can be firmly attributed to some environmental factors but there is no accepted methodology for others and some cannot be quantified in cost terms.

4.5 The application of LCA

LCC and LCA have developed and are practised as separate disciplines in the construction industry. There are a number of similarities, for example both:

- Use similar data on inputs of materials and energy
- Take into account operation and maintenance
- Consider opportunities for recycling vs. disposal
- Provide a basis for rational decision making, particularly in appraising options.

However, they differ in the basis of the resulting decisions:

- LCC combines all relevant costs associated with an asset into outputs expressed in financial terms as a basis for investment decisions
- LCA enables decisions to be made on the basis of environmental performance by scoring and rating on environmental criteria, not all of which can be accurately costed.

As a result LCC and LCA do not produce a common output. Nevertheless environmental impact assessment has a place in overall decision-making and a decision to undertake it should be taken at the earliest stage of the LCC process, introducing environmental knowledge and expertise from the outset. It is strongly recommended that at least a preliminary environmental impact analysis should be undertaken at investment planning stage to set a proposed project in its environmental context and provide a view of the extent and significance of its environmental impact.

Subsequently considerations relating to environmental impact arise at every stage of the life-cycle of a constructed asset; these are illustrated for a complete facility in table 3 below.

Table 3: Typical environmental impacts through the life-cycle

In-flow	Stage in life-cycle	Out-flow
Energy (earth moving, transport)	Construction – site preparation	CO^2 Dust, dirt, run-off Noise Loss of amenity, habitat Waste
Energy Materials, components	Construction	CO^2 Dust, dirt, run-off Noise Waste
Energy Materials, components	Operation and maintenance	CO^2 Waste Effect on internal environment
Energy	End of life, demolition	CO^2 Dust, dirt, run-off Noise Waste

4.6 The use of LCA with LCC

As discussed above, in LCC the primary driver in decision-making is cost and LCA informs decisions on the basis of environmental performance. The use and sequence of LCC and LCA will depend on the priorities of the decision-maker. The range of approaches might cover, for example:

- Selecting the lowest capital cost option, ignoring any environmental impact assessment and accepting the cost implications of poor environmental performance
- Feeding the outputs from LCA that can be quantified in cost terms into the LCC analysis, for example the tax implications of using a system which has a poor performance in terms of kg of CO^2/FU, and ignoring others
- Selecting cost-effective options through LCC analysis and making a final decision in the light of a process of LCA carried out on those options only
- Selecting options with good environmental performance through LCA and carrying out LCC analysis on those options only
- Seeking to make a balanced judgement in the light of both LCA and LCC in parallel.

Some examples of the use of the results of environmental impact assessments are given in table 4 below.

Table 4: Typical uses of environmental impact assessments

Environmental impact assessment by LCA	Use of results
Comparing options for internal panelling – cork and balsa wood: Cork: • Thermal conductivity, λ=0.04W/m^{0}K • Direct energy 10X greater than Balsa, approx 10MJ/panel • Feedback energy approx 5X greater, 1100MJ/panel Balsa • Thermal conductivity, λ=0.03W/m^{0}K	Additional information is required on costs and availability. Cork has greater environmental impact and slightly poorer insulation qualities. If it is substantially cheaper in LCC the options are: • Select cork, but check for breach of regulations/policy and/or tax implications • Select Balsa and accept higher costs (as "environmental costs"
Comparing heat sources, for which FU= 1MJ of heat delivered at low temperature, measuring CO^2 emissions in kg/FU: • Electric boiler: 0.25 • Natural gas boiler: 0.07 • Solar thermal boiler: 0.007	Additional information is required for each: • Installation cost • Assessment of suitability • Maintenance and replacement cycle & costs • Cost of disposal, Etc. Selection might be based on: • Environmental performance, accepting any higher costs • Lowest cost, either capital or life cycle • A combination, balancing higher cost and environmental objectives
LCA can be used to assess diverse options for reducing energy consumption for hot water, heating, light and appliances during 'operation' phase of a domestic dwelling: • Energy efficiency – better standard of insulation, orientation to exploit solar gain, etc • Clean and renewable energy sources – solar thermal systems, photovoltaics, biomass boilers	Additional information is required, as above. Similarly, selection may be based on cost, environmental or on balanced mixed criteria.

4.7 At the end of Step 4

At the end of step 4 the user will have developed a clear understanding of:

- The value and application of sustainability assessments
- How the outcomes can contribute to and be used in conjunction with LCC
- How sustainability will be further taken into account in later steps

5 STEP 5: Identify the need for additional analyses (risk/uncertainty and sensitivity analyses)

5.1 The purpose of this step

Risk and uncertainty analysis is a body of theory and practice which has been developed to help decision-makers assess their risk exposure and attitudes in a systematic manner. At this step the user considers how it can be applied in conjunction with LCC analyses to support decision-making, in particular which methodologies will be appropriate.

5.2 Risk and uncertainty in LCC

Investment in a constructed asset is a long-term project and as such characterised by a range of uncertainties, for example the useful life of the facility, the service life of systems and components, and energy and other costs during operation and maintenance. Within this context, LCC is a forward looking process that inherently requires the identification and forecasting of these factors that are unknown at the time of the analysis, and which thus inevitably involves the management of uncertainty and risk (where ‘risk’ relates to probabilities that can be estimated and ‘uncertainty’ to those that cannot).

The range of predictions required in LCC and the related uncertainties make it difficult to undertake analyses with a high degree of reliability. This represents a potential barrier to the wider use of LCC. Assumptions, for example regarding the performance of an asset over its life cycle, can only be made with the knowledge available at the time. For the LCC analysis to be relied upon, these uncertainties must be identified and quantified. Risk assessment and management techniques allow the reliability of an analysis to be assessed, giving the decision-maker a percentage level of confidence.

Generally, the identification and assessment of risk can have a significant influence on decision-making, with a resulting impact on the LCC of a project – examples are given in table 5 below.

Table 5: Impact of risk on decision-making

Examples of risks identified	Possible decisions taken in response
Risk of more demanding environmental legislation	• Selection of higher cost HVAC system with improved environmental performance • Selection of low cost HVAC system with short life and due for replacement in short period of time
Risk of business climate or strategy change and putting an asset on the market after completing construction	• Selection of alternative methods of funding for the project • Partial change of use of the asset (e.g. adding retail)
Risk that labour costs will rise	• Selection of less labour-intensive construction methods and solutions

A common approach to project investment analysis is first to carry out an LCC analysis using the ‘best-estimated’ values of project variables, acknowledging that the result has a level of uncertainty built into it. This gives an initial view of the probability of the project having an economic outcome less favourable than expected, or even unacceptable, and obliges the decision makers to consider their attitude to risk on a spectrum from 'risk averse' to 'risk taker'. This can be followed up by further analyses using appropriate techniques to provide the decision-maker with further information on risk exposure, as discussed below.

5.3 Managing risk/uncertainty

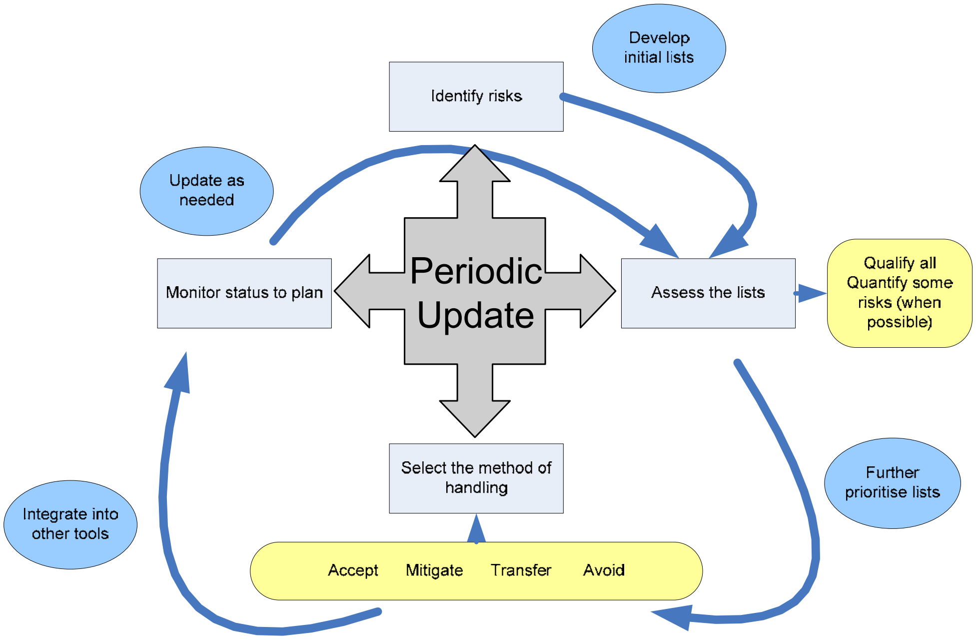
The management of risk fundamentally involves three processes:

- Identifying the risk
- Assessing the risk in terms of its likelihood and impact
- Taking appropriate action in response, which might variously be to accept, mitigate, transfer or avoid the risk.

The formality and scope of a risk management plan is a matter for judgement in the light of the scope and complexity of the project to which it relates. It requires a decision at senior level in the client organisation, which should be taken at this step. For a major investment the plan should be formally established with clear objectives and success criteria, proper planning and resourcing, and effective management and control.

A risk management plan should be progressively updated as a project moves through its stages. The overall process is illustrated in figure 4 below.

Figure 4: Risk management cycle.



5.4 Identifying risk

A number of methods are used for identifying risks including:

- Accessing relevant databases, where available
- Scanning records of past projects held by organisations in the project team
- Drawing out the knowledge and experience of individuals within the team by 'brainstorming' techniques
- Conducting interviews

- The ‘Delphi’ method, gathering risk information from project participants by email or post
- Checklists of risk factors commonly associated with particular tasks.

Risks commonly identified as affecting project performance include:

- Discount rate / inflation rate used in the analysis
- Service life of systems / components
- Obsolescence / technological development
- Change in the fiscal regime
- Fresh legislation, for example on sustainability issues.

Only risks that are strictly relevant to the LCC exercise in hand should be considered. ISO15686 Part 5 identifies some of the principle risks and uncertainties in undertaking LCC and should be consulted (section 9 refers).

During this process initial views may be formed on the probability of occurrence, ownership, likelihood and impact and other parameters potentially subject to formal assessment, similarly possible management actions.

A preliminary risk identification process should be carried out on every project at this step, unless the scope of the project is such that risk is manifestly very low. The depth and rigour of the process should be appropriate for the scope and nature of the project. The results should be recorded on the first draft of a risk register (see section 5.6.1 following).

5.5 Assessing risk

Risks and uncertainties can be assessed using a variety of tools and techniques. These fall into two broad categories:

- Qualitative, employing subjective scoring techniques
- Quantitative, using mathematical approaches.

Quantitative techniques fall into two categories:

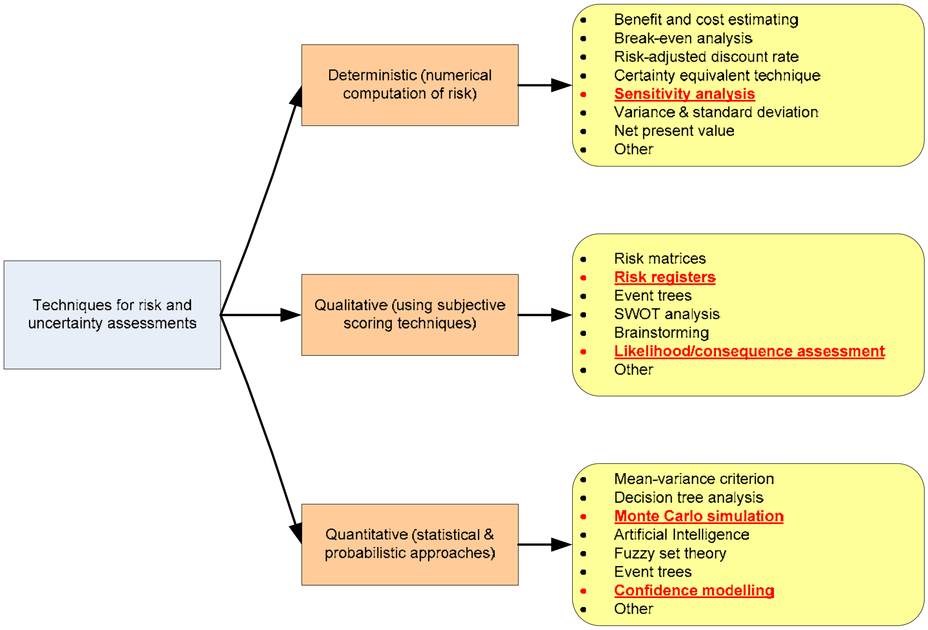
- Statistical and probabilistic (stochastic) approaches
- Deterministic, with numerical computation of risk.

The range of approaches is illustrated in figure 5 below.

Choice of an appropriate methodology depends not only on the scope and rigour of the analysis required but also on the quality and extent of data available. Relevant historical data might be available in databases, whether held nationally or internationally or by organisations in the project. However, there is little reliable historical data held at national or international level, accordingly the availability and quality of relevant data should be reviewed before undertaking a risk assessment exercise.

As a general rule the best approach is to use empirical evidence wherever it is available. When it is not, common-sense approximations should be used rather than aim for unrealistic or spurious levels of accuracy. What this means in practice, depends on the nature of the risk. The objective is always to obtain an unbiased estimate of the cost for the scheme. It is important to distinguish between planned costs (which assume everything goes well) and expected costs (which include an allowance based on experience for problems such as cost and time over-runs).

Figure 5: Common tools and techniques in risk/uncertainty analysis



5.6 Qualitative risk assessment

Qualitative risk assessment is essentially a subjective process relying on the knowledge, skills and experience of the participants, but undertaken in a managed manner. Methods of drawing out this information are broadly similar to those used for risk identification, that is, brainstorming, reference to databases, interviews, etc. For each of the identified risks the team will typically consider:

- Their likelihood
- Who / what is likely to be affected and to what extent
- Who owns them
- How important it is to mitigate them
- What action should be taken.

A number of tools are used in qualitative risk assessment, of which risk registers are the most user-friendly and commonly used. Their use is considered further and implemented if required at step 12.

5.6.1 Risk registers

Compiling a risk register is normally the first step in risk management and it provides a format for systematically recording the outcomes of risk identification and assessment. As such, it is a descriptive control tool for identifying, analysing and responding to perceived risks. The register should be continuously updated to contribute to risk management throughout the project life cycle. The information available in risk registers can be used to initiate quantitative risk analysis and to support subsequent risk mitigation.

5.6.2 Other tools

Other tools which may be applicable include probability matrices and impact assessment matrices.

5.7 Quantitative risk assessment

Quantitative risk analysis involves formulation of a model for computing the risk impacts on quantifiable project performance measures such as cost and duration. In theory quantitative assessment provides much better insights into risk and risk management, but it is subject to potential caveats in a construction context.

One group of techniques for quantitative risk assessment assume that uncertainties are random in nature, and the probabilities of occurrence can be quantified accurately based on historical data. However, uncertainties can be caused by vague or incomplete information, and the ambiguities and subjectivities cannot be captured effectively. In construction, due to the uniqueness of individual projects, historical data, if available, cannot be precisely related to a future project. Subjective judgements are usually made throughout the decision-making process. Although methods have been developed to convert subjectivities to subjective probabilities, construction practitioners often lack the knowledge to do so. Accordingly the availability of expert advice is an essential prerequisite for quantitative risk analysis, both for setting up models and selecting relevant data and interpreting the results.

In practice, two techniques are likely to be of value in support of LCC in construction and are identified as such in ISO 15686 Part 5, namely Monte Carlo simulation and sensitivity analysis.

5.7.1 Sensitivity analysis

Sensitivity analysis measures the impact on project outcomes of changing key input values about which there is uncertainty, typically:

- discount rate
- period of analysis
- service life or maintenance, repair or replacement cycles
- cost data.

The ‘expected’, a ‘lower’ and a ‘higher-than-expected’ values are chosen to be input. In comprehensive sensitivity analyses, the parameters are changed by a careful assessment of the underlying risks rather than by arbitrary plus/minus percentages.

Sensitivity analysis can be carried out for different combinations of input values and several parameters can be altered at the same time.

Sensitivity analysis shows how significant single input parameters or combinations of parameters are in determining project outcomes and indicates the range of variability in the output, allowing decision makers to concentrate on analysis of the most critical parameters. One scenario might include ‘pessimistic’ values for a number or all parameters to indicate the severity of economic exposure in that event. Carrying out sensitivity analysis can also indicate an inefficient outcome not otherwise apparent.

Sensitivity analysis is also useful for identifying critical estimating assumptions, but it has limited effectiveness in providing a comprehensive sense of overall uncertainty

5.7.2 Monte Carlo simulation and confidence modelling

Monte Carlo Simulation uses a simple technique of sampling the probability distributions of uncertain input values and combining them the certain input values to calculate the measures of worth for many hundreds or thousands of trial scenarios. Bespoke software is employed for this purpose, typically to generate graphs that:

- show the probabilities of project completion at various costs, for example, 90% certainty for completion for less than a specific sum of £k
- show the distribution of out-turn costs, for example to indicate the most likely cost outcome
- identify the risks that have the most impact on project outcome.

Other statistical information can also be generated.

A primary value of the technique is in improving the client's confidence in the results of LCC analysis.

5.8 At the end of step 5

At the end of step 5 the user will have:

- Carried out a preliminary risk identification process and prepared a first draft of a risk register
- Identified the extent to which the LCC analysis should be supported by risk analysis and management, in particular:
    - Whether a formal risk management plan is required
    - Whether, and if so which, risk assessment procedures should be carried out at steps 12, 16 and 17

6 STEP 6: Identify asset requirements – *the key features of the facility*

6.1 The essential features of the facility

At this step, all the key features of a proposed scheme are identified to allow the first stage of LCC to take place, that is, in support of investment planning (see figure 1). These are considered below under the headings of the facility's functionality, its physical characteristics and qualities that are intangible but add value.

Not all information about the project will be available at this stage, requiring assumptions to be made. These will be tested and confirmed and information refined as the project proceeds, as considered at step 2. The approaches discussed at step 5 will enable the decision-maker to identify and respond to the corresponding uncertainties at this step.

6.2 Defining functionality

The key aspects of functionality can be defined under the headings of access, space and use.

The **use** of the facility will fundamentally be defined by the social, commercial or industrial activity(ies) which will take place within it. However, best practice performance requirements should also be defined, for example in terms of:

- Fully accommodating user needs
- Contributing to organisational efficiency
- Enhancing user activity(ies)
- Adaptability for possible change of use
- Health, safety and security

Issues to be defined in relation to **space** include:

- Gross requirement in terms of floor area, etc
- Layout, size and co-location of enclosures
- Circulation
- Balance between different needs and requirements (eg, private and communal spaces)

Issues relating to **access** include:

- Current local provision of public transport and proposed future developments
- Requirement for car parking
- Accessibility for all users in accordance with relevant regulations (for users with impaired mobility, vision or hearing)
- Internal and external layout and landscaping

6.3 Defining key physical characteristics

The key physical characteristics can be defined under the headings of the physical performance of the facility itself, its environmental engineering and the process of its construction.

The criteria relating to the **physical performance** of the facility itself differ from the criteria for its functional performance, as considered above. They should include:

- Resistance to wear and tear
- Other aspects of durability
- Ease of cleaning and maintenance
- Economy and effectiveness of structural and environmental engineering design
- Fitness for purpose of materials and components

- Provision of an appropriate lighting, thermal, acoustic and air quality environment

The physical characteristics of the **environmental engineering systems** should meet the following main criteria, by design:

- Energy efficiency and minimisation of energy consumption
- Minimisation of CO^2 emissions
- Simplicity of replacement at component and system level
- Safety and simplicity of operation
- Fire safety engineered in.

Aspects of the construction process to be taken into account through all stages of concept and design should include:

- Health and safety of the workforce
- 'Buildability'
- Design for demolition and recycling

6.4 Identifying the intangibles

Investment in a facility may have aims and purposes that cannot be defined and measured in tangible terms. These might include:

- Motivating the workforce and reducing stress by providing a working environment that is not just fit for purpose but which delights
- Making a statement to the local or wider community on the prestige or the "green" credentials of the occupying organisation
- Providing a catalyst for regeneration.

If so, the factors in the project designed to contribute to such objectives should be identified and given a value in the LCC analysis. These might include:

- High quality of design internally and externally
- Generous working spaces
- Well-fitted and enjoyable circulation spaces and common ares
- Good acoustics
- High quality of natural and artificial light
- Good acoustics

6.5 At the end of step 6

At the end of step 6 the user will have developed:

- A full description of the intended function(s) of the asset/facility
- A clear description of its key physical characteristics and performance requirements
- An understanding of the information still to be provided, and the assumptions currently made and how these will be managed.

7 STEP 7: Identify sustainability requirements / options for costing based on result of sustainability assessment (if required)

7.1 Purpose of this step

At step 4 the decision-maker developed a view of the potential value and application in the project of methods of assessing sustainability issues, and how the outcomes could contribute to and be used in conjunction with LCC. Depending on the outcome of step 4, consideration of sustainability issues is taken forward at this step in the light of the functional and performance requirements identified at step 6.

7.2 Basis of guidance

The guidance given at this step takes account of:

- relevant definitions in ISO 15686:2004 Part 6, “Procedures for considering environmental impacts”
- ISO 14040:2006 “Environmental management – Life Cycle Assessment – Principles and Framework”
- ISO 14044:2006 “Environmental management – Life Cycle Assessment – Requirements and Guidelines”

7.3 Ensuring compliance with legislation

At step 4 the decision-maker considered the significant legal and financial reasons for giving due consideration to sustainability, in particular the environmental impact of a proposed scheme. At this step it is essential to ensure that knowledge of relevant EU and national legislation is up to date and duly considered in detail.

EU legislative initiatives that have been among the major drivers towards sustainability in construction include the directives on:

- Energy performance of buildings
- Promotion of co-generation
- Eco-design requirements of energy-using products
- Environmental Management and Auditing (EMAS)
- Construction Products
- Energy Efficiency and Energy Services.

Most member countries have existing national building codes that prescribe minimum energy performance for newly constructed assets. Most EU legislation in this field is relatively recent, having been adopted over the past 4-5 years, and is still in the process of being adopted into national measures. However, its effect should be anticipated in proposed new investments.

7.4 Identifying key environmental objectives

In setting and measuring environmental objectives, the considerations can generally be grouped under five main headings:

- Energy embodied in an asset at construction
- Energy consumption of the asset in use
- Energy required for transport
- CO^2 emissions
- Biodiversity

However, these are a starting point only for consideration of environmental objectives and how they should be measured. These requirements should be identified case-by-case in the light of the overall objectives and parameters of an individual project and with the help of advice from environmental experts. High level objectives should similarly be broken down into requirements that can more easily be measured. These can relate both to the facility as constructed and to the processes of constructing and operating it. They commonly include:

- Energy efficiency
- Water conservation
- Minimising the need for transport
- Use of sustainable materials – eg recycled, recyclable, from renewable sources, non-toxic, low embodied energy, locally sourced
- Use of durable materials
- Provision of a healthy environment, eg good air quality
- Design for personnel safety, security and well-being
- Design for enhanced productivity
- Design for ease of decommissioning, demolition and disposal
- Safe, easy and efficient operation and maintenance routines
- Installation and maintenance processes for systems and components that ensure systematic testing and performance verification prior to setting to work.

7.5 Selecting a method of measurement

In step 4 the user reviewed commonly used methods of assessing environmental performance. This step considers in more detail the use of Life Cycle Assessment (LCA) and Environmental Impact Assessment (EIA), which are the more frequently used methods and which are supported by a formal process recognised by environmental practitioners. Both are widely applied and produce tangible outputs.

7.5.1 Environmental Impact Assessment

The term EIA is usually understood to refer to individual project-based assessments. It delivers a systematic and objective account of the significant environmental impacts of a constructed asset during both construction and use, providing decision-makers with better information about the environmental consequences of their decisions. However, EIA does not in itself provide a procedure for aggregating the impacts, so as to give an overall measure of the total environmental effects of a given action, nor is there a formal 'decision rule' to determine whether or not a given action is acceptable. However, this may not be important if it is accepted that its main purpose is to 'screen' impacts to indicate if a project may need to be redesigned.

The generally acknowledged benefits of using EIA include inputs to decision-making and pointers towards measures needed to mitigate serious negative impacts. Possible shortcomings for some users include the lack of a decision rule and of a procedure for aggregating environmental impacts.

7.5.2 Life Cycle Assessment

The consideration given to LCA at step 4 should be reviewed at this step. In summary, LCA offers a thorough procedure for assessing the environmental effects of a project to construct and use an asset. It generates performance data against a list of objectives and requirements defined by the client, providing a basis for selecting the options that achieve the required environmental performance. The main possible drawback is that the reliability of the results is highly dependent on the weighting procedure used in aggregating impacts.

It is more suitable for application with LCC than EIA and is considered further below.

7.6 Using LCA

LCA examines every stage of the life cycle of a product, from the mining of raw materials through manufacture to disposal. For each stage, the inputs (e.g. in terms of materials and energy) and outputs (e.g. in terms of emissions to air, water and solid waste) are calculated and these are then aggregated over the life cycle.

The LCA process can be divided into three stages:

- goal definition and scoping
- life cycle inventory analysis (LCIA)
- impact assessment, including valuation.

For scope and specification of an LCA study to be finalised, the user must define its precise purpose in terms of the environmental targets and goals for the project (section 7.3 above refers). For the purposes of LCA these might include:

- Choice of materials and components that cause minimum environmental impact
    - Selection of materials / components according to environmental criteria
    - Seeking alternatives to materials that pose any hazard to health or the environment
- Minimising environmental damage resulting from the generation and treatment of waste:
    - Maximising recycling on site
    - Assessing and planning demolition for maximum ‘environment-friendliness’
- Minimising energy consumption:
    - Monitoring of energy consumption in operation
    - Orientating, shaping, equipping the building to maximise/minimise solar gain according to season
    - Testing all scheme and system design options for energy efficiency
    - Selecting and designing heating / cooling systems according to environmental criteria
    - Installing energy management systems

LCIA quantifies the material and energy inputs and emissions to air, land and water.

At impact assessment stage, the inventory data is aggregated and interpreted into forms more manageable and meaningful to the decision-maker. A number of approaches are available, of which the SETAC (Society of Environmental Toxicology and Chemistry) problem-oriented approach is the most widely accepted method within the LCA community. It involves:

- classification, which groups the data into impact categories, eg global warming, acidification
- characterisation, which assesses the relative contribution of burdens in each impact category
- valuation, which evaluates the relative importance of the impacts categories by assigning weights to them.

Other approaches, notably the economic valuation methodology, may omit either or both of the classification and characterisation steps.

Conventional LCA does not prescribe which form of weighting should be used. Instead, it offers a list of options, including:

- single factor dominance
- equal weighting
- expert judgement
- social preference
- ranking according to nuisance
- economic valuation.

As the reliability of the outcome is highly dependent on the weightings applied, this process should be undertaken by an expert in LCA.

7.7 Making comparisons on a cost basis

Two approaches are in general use for comparing on a cost basis options that have been evaluated on environmental criteria, that is:

- cost effectiveness analysis
- cost benefit analysis.

7.7.1 Cost effectiveness analysis

Cost effectiveness analysis compares the estimated costs of achieving a given quantum of environmental benefit under each of the the options being considered. For example:

- option A secures a reduction of X tonnes of CO2 emissions for cost of €Y
- option B secures a reduction of 0.8X tonnes of CO2 emissions for cost of €0.5Y

The simple quotients reveal option B to be more cost-effective. The main value of this assessment is that it indicates the best value for money to be obtained from a given budget. The main disadvantage is that it indicates only how an option compares with other options, not whether it is intrinsically worthwhile.

7.7.2 Cost benefit analysis

Cost benefit analysis compares the value of the environmental benefits of an investment option with all the associated costs, each on a monetary basis. A “benefit” is defined as any outcome that represents improved environmental performance. A “cost” includes any outcome perceived as a disadvantage, for example, the need to tolerate higher noise levels from an HVAC system that performs better on other environmental measures.

Environmental performance can be determined by a process of LCA. Preferences are identified by the client and project advisory team, and measured in terms of willingness to pay for a benefit or for avoiding a cost, or willingness to accept the consequences of tolerating a cost or foregoing a benefit.

The main advantage of the approach is that it allows the 'absolute' desirability of an option to be determined in economic terms and forces consideration of cost as an indicator of foregone benefits (ie the opportunity costs). Potential drawbacks include:

- it deals only with economic efficiency and has potential for discrimination against sustainability concerns
- available data may not permit all relevant benefits and costs to be monetised.

7.8 At the end of step 7

At the end of step 7 the user will have:

- identified all relevant EU and national legislation and guidelines
- identified the key environmental objectives in making the investment

- selected an appropriate method of assessing environmental performance
- confirmed the view formed at step 4 of how environmental assessments may be incorporated into LCC analysis

8 STEP 8: Identify project requirements – *confirm key parameters*

8.1 Confirming the scope of the project

At this step the user clarifies and confirms the scope of the project in terms of its scale and its relationship to its context and to other projects. Considerations might include:

- Scale:
  - Any demolitions
  - Any temporary facilities to be installed / maintained / decommissioned
  - Size, capacity of new structures
  - Provision of M&E services, other utilities, IT
  - External works, reinstatements, landscaping
  - Operation and maintenance regimes on completion
- Logistics
  - Source of materials
  - Transport of workforce and goods/materials
  - Arrangements for disposal
- Relationship with / impact on local environment
  - Interaction / compatibility with local historical / cultural heritage
  - Interaction with / impact on social context
  - Interaction with / impact on local ecosystems
  - Impact on local traffic systems, public transport
  - Impact of noise, dust, other emissions
- Impact of local environmental features on project
  - Weather patterns (eg snow, liability to flooding)
  - Geology (risk of subsidence, other instability)
- Infrastructure
  - Interaction with existing underground services
  - Requirement for running in new utility service mains
  - New water mains, reservoirs, pumping stations
  - Disposal of sewage / run-off, holding tanks, treatment works
- Impact on / interaction with other projects
  - Third party construction projects in the area
  - Other projects in the client's portfolio
  - Other projects being undertaken by other members of the project team

8.2 Identifying project constraints

A project will potentially be constrained by a wide range of factors that, most profoundly, can impact on the essential viability of the proposal, but also particularly on programme and cost. These might relate to:

- Site constraints – access, topography, geology
- Finance – limits on budget, cash flow
- Time – required dates for completion, date for release of site
- Legal / regulatory – Town and Country Planning, restrictive covenants
- Environmental – restrictions on noise, emissions, working hours.

Constraints should be systematically identified in the earliest stages of a project and kept under review throughout. During the pre-construction phase in particular, the key constraints should identified and kept in the view of all project stakeholders.

Some constraints might change in the course of a project and new ones might appear. These should be managed in an agreed manner by risk and uncertainty management processes as considered at step 5.

8.3 Defining quality requirements

Some aspects of quality will be examined and refined by a process of LCC analysis, for example to determine an optimum level of durability of systems and components. However, clients will normally also wish to define certain levels of quality reflecting their specific requirements, for example particularly relating to aesthetics.

It is essential that all quality requirements, whether expressed in terms of a material or component specification or a performance specification are unequivocally captured in contracts placed for supply, installation or construction.

Effective project management and quality control must then follow during the construction phase to ensure compliance with the specifications.

8.4 Confirming the project budget

Budgeting is a critically important process undertaken to:

- Ensure that sufficient finance is available for the project to be successfully undertaken and thereby fulfil the client's objectives
- Allow the efficient and effective management of project finances during implementation.

While the process of budgeting itself requires the investment of time and effort and hence carries a cost, it also delivers significant benefits through:

- Clarifying and expressing the targets and priorities of the project in financial terms
- Providing early warning of affordability and other potential problems
- Indicating and helping to avoid or manage potential cash-flow problems
- Helping to manage potential conflict between sub-phases of the project
- Setting a benchmark for financial performance in the project, thereby motivating the team.

Good practice in setting an overall project budget includes:

- Identifying appropriate and discrete phases in the project and determining the sub-budgets to be spent on each
- Itemising the sub-budgets, starting from initial global estimates and progressively detailing costs as information on the project is clarified and confirmed
- Reflecting performance / quality requirements
- Making appropriate allowance for risk and uncertainties (ie contingency sums, allowance for inflation), taking into account any analyses undertaken following step 5.

Subsequent control and management of the budget during project implementation will be hindered unless:

- The budget is compiled on the basis of an adequate level of design, also other information on the proposed facility as established at step 6
- The number of subsequent variations is strictly controlled
- Protocols are set and observed for regular review of the budget – budgetary control involves setting and monitoring of short-term objectives for different aspects of the project, for which a formal process is essential
- Effective risk and uncertainty management is in place.

- Expenditure is appropriately timed.

Artificially lowering a budget below the realistically estimated level in to incentivise contractors is not recommended practice. It puts at risk the culture of openness and collaboration between project participants which provides the best basis for undertaking a project.

8.5 Confirming the project timescale and programme

A robust and realistic programme is essential for successful delivery of a project, providing a basis for:

- Monitoring and managing progress at all levels
- Planning and delivering the resources required for the project
- Cash flow planning by the client
- Contractual commitment to timely delivery by project participants.

The process of programming must take into consideration:

- Relevant constraints as discussed in section 8.2 above, especially:
  - Release of site
  - Required dates for overall / sectional completions
  - Restrictions on working hours
- Need for sequencing
  - Between activities
  - Between phases of the project
- Resource levels, with reference to:
  - Local labour markets
  - The physical configuration and constraints of the site and structure(s)

As with the budget, the detail and firmness of the programme will progressively reflect the quality and extent of the information on which it is based. Similarly it should be regularly reviewed and updated as the project proceeds.

The format and presentation of the programme will depend on the complexity of the project and user needs. It should normally clearly indicate the phasing of the project ands the key milestones. A range of software packages to facilitate both the preparation and the presentation of programmes.

8.6 At the end of step 8

At the end of step 8 the user will have:

- Clearly defined the scope of the project
- Developed a statement of project constraints
- Defined all relevant quality requirements
- Developed a robust and detailed budget
- Prepared a comprehensive project programme.

9 STEP 9: Identify and estimate costs options or cost of preferred option of an asset – *assemble time and cost data to be considered in LCC analysis*

9.1 Identifying relevant costs

The process of LCC analysis depends fundamentally on identifying all relevant costs falling due over the period of analysis. Table 6 below sets out a typical generic cost classification with an illustrative check-list of items, based on ISO 15686 Part 5, figure 3. Not all will be relevant to a particular project and further items will be required.

Table 6: Generic cost classification and check list

Acquisition – non-construction costs
- Site – lease/purchase of land and/or existing building(s)/asset(s), including related fees and local taxes
- Finance – interest or cost of money; wider economic impacts
- Client's in-house resources – property/project management, administration/overheads
- Professional advice – planning, legal, preparing brief, sustainability

Acquisition – design and construction
- Professional services – project management, architecture, structural/civil/environmental engineering, cost and value management
- Site clearance, temporary works
- Construction – infrastructure, structure, envelope, services, fitting out, commissioning, handover
- Fixtures, fittings, furnishings
- Landscaping, external works

Operation
- Rent
- Rates / local taxes, land charges
- Insurances
- Energy – heating, cooling, small power, lighting, internal transport (lifts)
- Utilities – water, sewerage, telephone
- Facilities management – cleaning, security, waste management
- Regulatory costs – fire, access inspections

Maintenance
- Maintenance management – inspections, contracts management
- Minor repairs/replacements/renewals
- Cleaning
- Grounds maintenance
- Redecoration
- Loss of facility / business opportunity costs during downtime

Planned re-work
- Adaptation – evacuation, works, re-commissioning, fit-out
- Major replacement/renewal/refurbishment – evacuation, works, re-commissioning, fit-out
- Loss of facility / business opportunity costs during downtime

End of life/disposal/hand-back
- Final condition inspection including fees
- Restoration/reinstatement – as required by lease/contract

- De-commissioning
- Demolition, disposal, site clean-up

Income

- Sales of land, interests in assets, salvaged materials
- Grants, tax allowances
- Third party income – rents, service charges

9.2 Classifying costs

Construction costs can be classified in many different ways depending on the objective of the costing exercise. Making meaningful comparisons requires a common cost breakdown structure (CBS) but there is currently no EU-supported CBS standard. Several national classifications exist and comparisons carried out by the Comite des Economistes de la Construction (CEEC) indicate that:

- All countries use elemental estimating and cost planning systems
- The elements used are similar but are grouped and coded in very widely differing cost classification systems
- Some are more detailed than others (eg comparing DIN with Nordic, as in NS3454)
- There is no consensus on which approach is best
- Price comparisons can be misleading, for example, costs per square metre where floor areas are measured on a different basis.

An EU standard classification system that could accommodate data from national systems would greatly increase the comparability of data. The CEEC has issued for consultation a ‘Code of Measurement for Cost Planning’ as a platform for reconciling different cost and data structures. This provides a standard basis for the sub-division of costs and for measurement of basic quantities of buildings for pan-European budgeting, comparison and analysis at management level. The structure is organised to permit the use of existing national classifications at a more detailed level of information.

The CEEC code aims to facilitate comparisons by defining typical areas used and cross-referencing to local definitions. As a result if areas are measured differently, the differences can be identified, permitting adjustment of square metre prices. Definitions of quantities have been restricted to twelve basic quantities for site areas, floor areas and functional units. Elemental quantities are not defined, as local definitions may be more suitable for analysis of elemental unit rates.

The code provides a framework to consider the global cost of buildings. It goes further than traditional practice in some countries and groups costs into four blocks:

- construction costs
- design and incidental costs
- costs in use
- land and finance.

This permits overall project appraisal and if items are not included in individual countries this will be clearly apparent and avoid misunderstandings on the overall scope of the costs. It is compatible with the structure proposed in table 4 above.

9.3 Identifying time profiles

Time is the other key variable to be considered alongside cost elements in LCC. Costs are fundamentally grouped into two categories, one-off and recurring.

One-off costs may be further classified:
- those current at the time of the LCC analysis
- those occurring at a point in future time, which needs to be predicted for the purposes of discounting, etc. This can be done with progressively greater clarity and reliability as a project proceeds

Two key variables need to be defined for recurring costs – the point in time of the first occurrence and the intervals thereafter, which may be either regular or variable. The practitioner needs also to identify whether a cost is fixed or variable over the period of analysis.

9.4 Sources of data

As considered in step 1 (figure3 and table2), LCC analyses at the earliest stages of a project draw mainly on generic sources of data, typically historic costs drawn variously from the client’s own records, the records of his professional advisors and published national data sets. As a project proceeds, time and cost parameters can be defined in greater detail and with greater reliability, based on data from a number of sources, for example:
- manufacturers and suppliers of materials, components and systems often issue data sheets providing performance data, recommended maintenance routines, etc
- specialists will have valuable experience in their fields and may offer a technical advisory service.

Data from these sources will generally be in a variety of formats and will need to be distilled and grouped into a suitable format for LCC analysis.

The initial capital cost of construction is likely to be a major if not the single most significant factor in the analysis. In traditional forms of procurement work items are collated into schedules setting out quantities, descriptions and unit pricing, drawn up by appropriately qualified professionals. Together with a time commitment, these provide the basis of a contract for delivery by the selected contractor(s), thereby firmly fixing the related time and cost parameters for LCC.

9.5 At the end of step 9

At the end of step 9 the user will have:
- Identified all costs relevant to the LCC analysis within an appropriate itemised CBS
- Made the best estimate for the value of each cost
- Drawn up the time profile of each cost.

10 STEP 10: Identify costs effects/impacts of sustainability assessment (if required) – *ensure implications of environmental assessment are taken into account, including costs*

10.1 Purpose of this step

The purpose of this step is to ensure that sustainability issues are appropriately taken into account in step 9.

As at step 7, the guidance given at this step takes account of:

- relevant definitions in ISO 15686:2004 Part 6, "Procedures for considering environmental impacts"
- ISO 14040:2006 "Environmental management – Life Cycle Assessment – Principles and Framework"
- ISO 14044:2006 "Environmental management – Life Cycle Assessment – Requirements and Guidelines"

10.2 Review outcomes of environmental assessment and apply to decision-making

At this step, the decisions taken at steps 4 and 7 regarding the approach to environmental issues and their assessment are implemented and the outcomes reviewed. Potential outcomes are illustrated in table 7.

Table7: Potential outcomes of environmental impact analysis

Environmental consideration	Potential negative impact	Potential positive impact
Biodiversity, flora, fauna	• Loss/damage to habitat • Disturbance • Pollution of air/water • Changes to hydrological regime	• Replacement / improvement of habitat • Contribution to habitat networks
Population	• Noise • Disturbance • Visual impact • Reduction in amenity eg recreational space	• Improvement in amenity
Soil	• Loss • Degradation	• Reclamation
Water (surface and groundwater)	• Pollution • Hydrological changes	• Improvement in quality
Air	• Pollution by emissions • Dust	
Climate	• Green house gases	
Culture, heritage	• Direct loss or damage • Damage by pollution • Effect on setting • Loss of access	• Better access
Landscape	• Intrusion • Loss of access	• Improvement via restoration, regeneration

As discussed at step 4, many sustainability issues, such as those noted above, cannot be objectively assessed in cost terms. However, different approaches to integrating LCC and LCA can be adopted according to the priorities of the decision-maker and are implemented at this step.

Where reasonably practical, costs should be identified for inclusion in the LCC analysis. If options for LCC analysis are selected on environmental criteria rather than only on technical and cost grounds, the related ‘sustainability premium’ can be calculated. Instances might include:

- Configuration of the building and fenestration to maximise solar gain in winter
- Window fins to reduce solar gain in summer
- Using advanced technology to control lighting and HVAC systems
- Incorporating additional thermal mass
- Incorporating more insulation than required by regulations

10.3 At the end of step 10

At the end of step 10 the user will have identified the key implications of the environmental assessments and ensured they are taken into account with the time and cost data identified at step 9.

11 STEP 11: Identify values of financial parameters – *also define period of analysis, fiscal strategy*

11.1 Purpose of this step

At this step the user:
- confirms the period of analysis, following its preliminary consideration at step3.
- identifies appropriate values for the relevant financial parameters
- develops a strategy for managing fiscal issues.

11.2 Confirm period of analysis

As a key parameter in LCC analysis, the period of analysis identified at step 3 should be reviewed and confirmed in the light of the clarification and decisions reached in the steps that followed, in particular regarding:
- The key features of the facility / asset in view (step 6)
- Approach and objectives regarding sustainability (step 7)
- The scope and key parameters of the project being set up to invest in the facility (step 8).

11.3 Define key parameters

Sufficient clarity has similarly been achieved in the steps above for the values of other key parameters in the LCC analysis now to be decided, including:
- Discount rate
- Treatment of inflation
- Treatment of tax issues.

11.3.1 Discount rate

As considered at step 3, a discount rate can be either:
- ‘real’, that is, with cost data denominated in ‘constant’ currency, excluding the effects of inflation on purchasing power, or –
- ‘nominal’, that is, with cost data denominated in ‘actual’ or ‘current’ currency, which reflects actual purchasing power. Market rates are normally nominal rates.

National ministries of finance generally publish rates to be used in the economic analysis of public sector projects, reflecting the economic conditions of the member state concerned. The rate may also be assessed on a case by case basis by reference to:
- The opportunity cost of capital
- The societal rate of time preference
- The cost of borrowing funds.

The ‘opportunity cost of capital’ is the cost of foregoing an alternative investment. This approach assumes that finance for public sector projects is withdrawn from private savings and which would otherwise have gone into private investment. Hence the discount rate is equated to the pre-tax rate of return available to private capital.

The ‘societal rate of time preference’ is the interest rate that reflects a government’s judgment about the relative value which society as a whole assigns (or which the government feels it ought to assign) to present versus future consumption. The societal time preference rate is not observed in the market and bears no relation to the rates of return in the private sector, interest rates, or any other measurable market phenomena.

The rationale of the ‘Cost of Borrowing Funds’ approach is that the interest rate should match the rate paid by government for borrowed money. This approach is favoured by many agencies and is supported by the argument that government bonds are in direct competition with other investment opportunities available in the private sector.

Some advocate use of a zero interest rate in the public sector, arguing that when tax monies (eg road tax) are used, such funds are “free money” because no principal or interest payments are required. A counter-argument is that zero or very low interest rates can produce positive cost/benefit ratios for even very marginal projects and thereby take money away from more worthwhile projects. A zero interest rate also fails to discount future expenditure, making tomorrow’s relatively uncertain predicted costs as significant in the decision as today’s known costs.

Because the outcome is highly sensitive to the discount rate, a number of trial rates may be applied and the results assessed. ISO 15686 Part 5, Annex A1, Table A1 presents an example, mapping the effect of discount rates of 1, 3, 5 and7 %.

11.3.2 Inflation

Appropriate treatment of inflation in LCC analysis requires consideration of a number of issues, including:

- The need to distinguish the effects of inflation from other causes of increased costs
- Whether and by how much the rates of inflation applying to the cost items identified at step 9 differ between themselves and from general ‘headline’ rates of inflation
- Whether data used to provide present-day costs requires adjustment
- The terms of contracts placed to provide goods and services over the life of the facility

Even if costs are expressed in ‘real’ or ‘constant’ terms, the prices of individual items in the CBS may rise over time, for example, the cost of maintenance and repair of a system or component may increase as the item ages and becomes worn or unreliable. This needs to be taken separately into account item by item before any adjustment for inflation is applied.

For many purposes in LCC analysis the effect of inflation can be ignored if the inflation rates for all items in the CBS are approximately equal. However, if they differ significantly a ‘real’ discount rate must be used with inflation dealt with separately.

The data used in building the CBS may derive from documents that are dated prior to the date of the analysis. In such cases the unit values must be updated to the present by applying a multiplyer equivalent to the increase in the relevant price indices

At later stages in the life cycle, the CBS can reflect known costs derived from the contracts entered into by the client. Contracts for goods and services delivered over time, for example for maintenance, will normally make provision for inflation in costs which can be directly reflected in the analysis.

11.3.3 Tax, VAT

Fiscal considerations can be highly significant in LCC analyses, particularly in the private sector, with tax efficiency a major objective in designing investment portfolios, finance arrangements and individual projects. It is a complex area, varying between member states. Accordingly it is important at this step to develop a strategy on managing fiscal issues, taking the benefit of the specialist professional advice which is available in this area and which should be sought at the earliest stage. Such a strategy should be designed to minimise the tax burden on the project by identifying appropriate innovative and practical tax and business solutions.

Key considerations in the strategy include:

- The tax relief or offsets which may be available against certain costs in the overall CBS, eg typically for repairs and maintenance, which would tend to favour options with lower initial costs
- Similarly the tax penalties which might apply to the use of certain materials or have an indirect impact, eg through higher energy costs.

Tax might also be an issue in:

- Identifying joint venture partners
- Framing contract terms
- Seeking local partners
- Generally undertaking due diligence.

Tax represents an area of risk, for example in:

- The probability of environmentally inefficient structures attracting environmental taxes
- The possibility of any other tax rates changing.

VAT is subject to similar considerations. Both the rate and accounting methods vary between member states and specialist advice is again likely to be essential.

11.4 At the end of step 11

At the end of step 11 the user will have:

- confirmed the period of analysis
- identified appropriate values for the relevant financial parameters
- developed a strategy for managing fiscal issues.

12 STEP 12: Identify parameters for sensitivity and risk/uncertainty analyses (if required) – *carry out qualitative risk analysis*

12.1 The purpose of this step

At this step the project team implements the approach to risk assessment identified at step 3 by:

- carrying out a qualitative risk assessment
- confirming the need for qualitative risk assessment and preparing for it to be carried out at steps 16 and 17.

12.2 Confirming the schedule of identified risks

In the first instance, the project team should review the preliminary schedule of risks drawn up at step 5 in the light of the greater clarity relating to the scope and nature of the scheme, the project and the LCC analysis achieved in steps 6, 8 9 and 11.

12.3 Updating the risk register

The risk register initially drafted at step 5 should similarly be fully updated, potentially to include:

- title and description of risk
- description of causes
- dates when the risk was identified / modified
- risk code
- ownership
- likelihood of occurrence
- impact
- ranking
- mitigation action plan
- residual risk effects.

The headings typically found in a risk register are illustrated in figure 6 below:

Figure 6: Typical headings on a risk register

Risk ID	Project component	Risk	Risk description	Affected activities	Likelihood	Impact	Impact of schedule	Other impacts	Risk owner	Mitigation strategy	Timescale

The level of detail on the risk register is a matter for judgement with reference to the scope and complexity of the project.

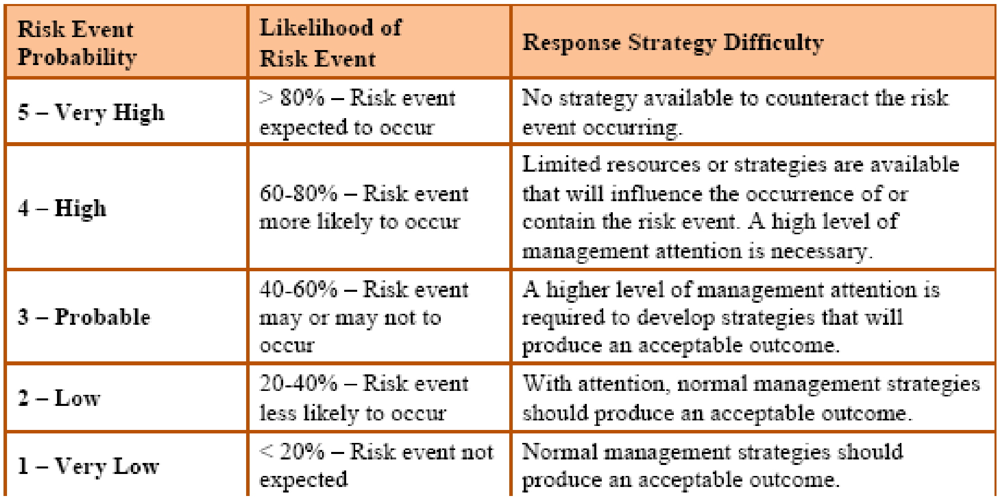
12.4 Applying other qualitative risk assessment tools

Probability and impact assessment matrices can be used by the team to facilitate the related assessments for entry onto the risk register.

12.4.1 Probability matrix

A ‘probability matrix’ facilitates the essentially subjective process of assessing the likelihood of a risk event occurring by clarifying the concept of ‘probability’. A typical matrix is illustrated in figure 7. The process still depends fundamentally on the project team and key stakeholders contributing to the process – knowledge of the project and related activities within it, experience and historical data will all be relevant.

Figure 7: Probability matrix



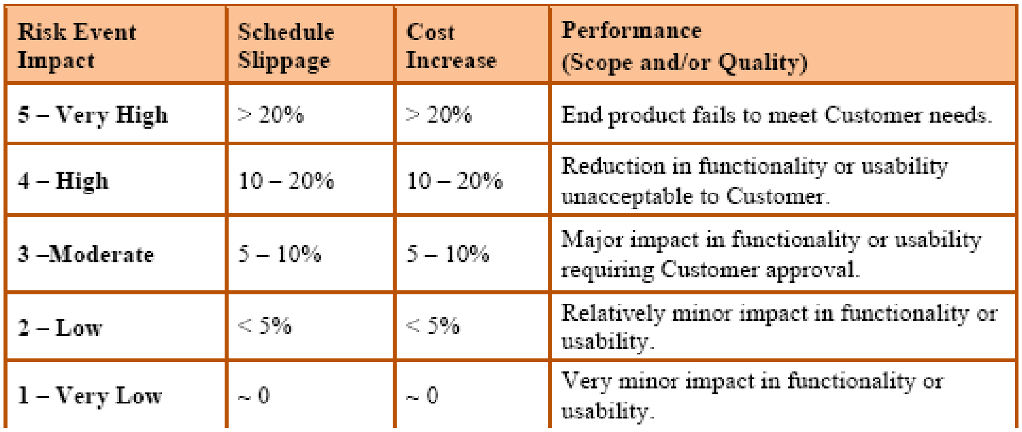
Risk Event Probability	Likelihood of Risk Event	Response Strategy Difficulty
5 – Very High	> 80% – Risk event expected to occur	No strategy available to counteract the risk event occurring.
4 – High	60-80% – Risk event more likely to occur	Limited resources or strategies are available that will influence the occurrence of or contain the risk event. A high level of management attention is necessary.
3 – Probable	40-60% – Risk event may or may not to occur	A higher level of management attention is required to develop strategies that will produce an acceptable outcome.
2 – Low	20-40% – Risk event less likely to occur	With attention, normal management strategies should produce an acceptable outcome.
1 – Very Low	< 20% – Risk event not expected	Normal management strategies should produce an acceptable outcome.

12.4.2 Impact assessment matrix

An ‘impact assessment matrix’ similarly facilitates the process of assessing the impact of each risk, requiring a comparable contribution of knowledge and experience. A typical matrix is illustrated in figure 8.

Impact should be assessed with reference to time, cost scope and quality. The worst-case scenario should be used. Where possible the impact should be expressed in cost terms by evaluating financial implications, for example of slippage against time schedules, of a reduced scope or of poorer quality.

Figure 8: Impact assessment matrix



Risk Event Impact	Schedule Slippage	Cost Increase	Performance (Scope and/or Quality)
5 – Very High	> 20%	> 20%	End product fails to meet Customer needs.
4 – High	10 – 20%	10 – 20%	Reduction in functionality or usability unacceptable to Customer.
3 –Moderate	5 – 10%	5 – 10%	Major impact in functionality or usability requiring Customer approval.
2 – Low	< 5%	< 5%	Relatively minor impact in functionality or usability.
1 – Very Low	~ 0	~ 0	Very minor impact in functionality or usability.

12.5 Confirm need for quantitative risk assessment and identify relevant parameters

At this step reviews the approach to quantitative risk assessment identified at step 5 in the light of:

- the further information generated about the project in the interim steps
- the qualitative risk assessment undertaken at this step
- further consultation with the client, particularly regarding the level of confidence required in the outcomes of the LCC analysis..

In particular, the need should be confirmed or not to carry out sensitivity analyses or Monte Carlo simulations. If required the key parameters for these analyses should be identified and agreed with the client, particularly the risks and uncertainties to be the focus of the analyses and the applicable ranges.

12.6 At the end of Step 12

At the end of step 12 the project team will have:

- Undertaken a qualitative risk analysis including:
    - Applying probability and impact assessment matrices as required
    - Updating the risk register
- Confirmed the scope and extent of quantitative risk assessment and the techniques to be employed as required
- Selected the key parameters, as required.

13 STEP 13: Apply financial parameters

13.1 Purpose of this step

At this step the user reviews and confirms how the financial parameters and fiscal strategy identified at step 11 are to be applied in detail. This is essential if the full benefits of LCC analysis are to be realised; for example, if rigorously undertaken the process may help to:

- Illuminate the differing impacts of different cost groups on the overall financial performance of an investment project
- Establish the links between design decisions and the different cost groups and their financial performance, thereby facilitating the selection of cost-effective design solutions
- Highlighting the trade-offs to be made between cost and performance, including environmental performance, down to system and component level
- Provide all project stakeholders, each with a potentially limited cost perspective, with the overall picture, thereby facilitating fully-informed decision-taking.

13.2 Applying financial parameters within the CBS

Discounting and adjustment for inflation cannot be applied on a ‘blanket’ basis across all items in the CBS assembled at step 9. Rather, the CBS must be reviewed item by item to identify the appropriate treatment, in particular testing any assumptions made.

Regarding discounting, the fundamental question is whether a cost will be incurred at a future time and thus should be subject to discounting, or whether it is assumed to be incurred instantly and taken at its present value. Assumptions to be challenged might include, for example:

- taking the capital cost of construction as ‘instant’, whereas it might need discounting if the design and construction period is forecast to be lengthy
- taking investment costs as required to be discounted, whereas they might effectively be incurred ‘instantly’.

More specifically, for accurate discounting, the time profiles identified at step 9 must be reviewed and confirmed for each item.

The key issue to be confirmed in relation to inflation is the extent to which the forecast rates of inflation differ between items.

13.3 Confirming fiscal strategy

As considered at step 11, taxation is one of the biggest and potentially most complex cost considerations in any investment, yet also potentially also one of the most manageable if continuing recourse is made to specialist advice and use is made of the sophisticated methodologies and software sites that are available.

Accordingly the fiscal strategy developed at step 11 should be reviewed with reference to each of the cost categories within the CBS, with the benefit of specialist advice. Attention should be paid to further identifying opportunities for reducing the tax burden through action in areas such as:

- Investment strategy
- Analysing contract terms
- Identifying joint venture partners

- Raising finance
- Concessions; production sharing

Particular attention should be paid to sustainability issues with the likelihood of tax regimes being weighted to favour environmentally-friendly design and construction solutions.

13.4 At the end of step 13

At the end of step 13 the user will have:

- Drawn up a decision matrix setting out the application of the key financial parameters to cost categories/items in the CBS
- Confirmed the fiscal strategy to be followed in the project
- Recorded the justification for these decisions, with relevant supporting evidence.

14 STEP 14: Perform required economic evaluation.

14.1 Purpose of this step

In step 9 the required cost data was assembled and in steps 11 and 13 the necessary parameters defined and assigned for the purpose of carrying out an LCC analysis. At this step the analyst identifies and implements the particular method(s) of evaluation that will best employ these inputs to inform the particular decision(s) to be taken.

14.2 Informing the decision

Defining the objectives of the LCC analysis in step 1 necessarily identified the nature of the decision which the LCC analysis was intended to support. In summary, this might be to:

- Accept or reject a single option presented for investment
- Select the most cost-effective option from a number that satisfy other relevant criteria
- Rank options that have been identified as acceptable on cost-effectiveness and other relevant criteria, typically necessary when insufficient funding is available to implement all such projects in a potential programme.

The different methods of economic analysis identified at step 3 provide a number of measures that support these types of decision in different ways, as considered below. The same principles apply whether the decision applies to a complete scheme, a system or component. In all cases, for the LCC analysis to be reliably used in support of decision-making, the analyst must ensure that:

- All non-quantifiable issues are properly considered
- Any uncertainties are properly addressed, as considered at steps 3 and 12.

14.3 Calculating and using the NPV

The NPV is the standard criterion for deciding whether an option can be justified on economic principles. Its derivation is illustrated in figure 9 below, indicating:

- Cost categories as defined in step 9
- The cost models typically applied in each category, as discussed in step 11
- The derivation of total LCC costs and total present value costs (NPV).

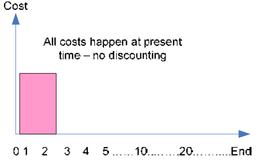
This measure can be applied in each category of decision:

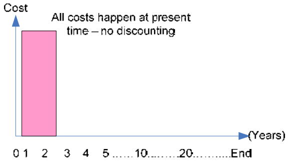
- A single option can be accepted/rejected according to whether the project has a lower/higher LCC than the base case
- The NPV returned by a number of options can be used to rank them for cost-effectiveness over the period of analysis, thereby also identifying the most cost-effective option.

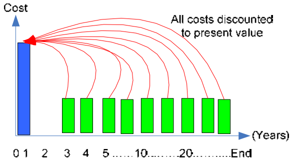
Figure 9: Calculation of NPV

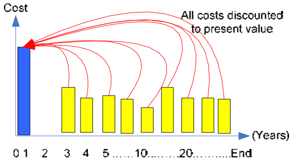
Cost Categories	Commments
Acquisition Stage Costs – Non-Construction Costs 1. Site for construction or asset purchase/leasing including associated fees and local taxes 2. Development of client brief, procurement, cost, value and risk management, planning, regulatory and legal 3. Design and engineering (client advisors) 4. In-house resources and administration 5. Finance, interest or cost of money and wider economic impacts	Investment (capital) costs (one off costs) at present time (beginning of the contract)
Acquisition Stage Costs – Construction Costs 1. Design and engineering – professional fees, statutory consents 2. Temporary works, site clearance or groundwork 3. Construction, fitting out, commissioning 4. Validation and handover 5. Adaptation, refurbishment, fitting out, commissioning, validation and handover 6. External and infrastructure works 7. Project management and planning supervision (CDM Regulations) 8. Fixtures, fittings, furnishings and loose equipment	Investment (capital) costs (one off costs) at present time (beginning of the contract)
Operation Costs 1. Rates (and rent if applicable) 2. Insurance 3. Energy costs for heating, cooling, power and lighting, and utilities – water, sewerage costs 4. Facilities management, cleaning, security, H&S, waste management, landscape maintenance, etc. 5. Annual regulatory costs (e.g. fire, access inspections) 6. Others (local taxation, land charges, etc.)	Reoccurring costs, usually on a annual basis. Usually these costs are similar from year to year
Maintenance Costs 1. Repairs, routine component replacement and minor refurbishment 2. Loss of the facility during maintenance procedures 3. Reduced building service life (if appropriate) resulting from any maintenance option 4. Restoration (or replacement) of minor components (sub-elements and sub-systems) to their original aesthetic and functional performance	Reoccurring costs, usually on a annual basis. These costs may vary from year to year
Replacement Costs 1. Restoration (or replacement) of the main elements or systems to their original aesthetic and functional performance at various stages of the life of the facility, including associated management costs 2. Loss of the facility during replacement, downtime and loss of business costs 3. Unanticipated costs resulting from legislation introduced subsequent to completion of the constructed asset, e.g. in relation to environmental, H&S requirements or fiscal matters 4. Adaptation, refurbishment, fitting out, commissioning, validation and handover	Periodical costs depending on the replacement schedule and durability of materials and components. Different systems may be replaced at different periods
Hand back costs/Disposal/Demolition 1. Final condition inspection and associated fees 2. Additional costs of meeting assets' contractual performance and condition criteria for hand back 3. Provision for spares and consumables 4. Cost of demolition and disposal (income from salvage not included)	One-off cost at the end of the period of interest or working life of an asset

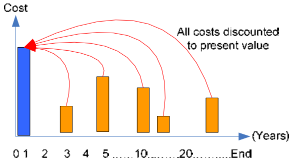
Cost Models

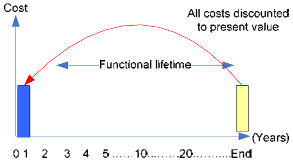












Economic evaluation at present time

Cost elements	Present time	Future years 1 2 3 4 5 ………………10………N
Non-construction costs – N	N (present value)	
Construction costs – C	C (present value)	
Operating costs – O	O (present value)>> $O_p = \sum_{n=1}^{N} O_n q_n$	O1 O2 O3 O4 O5 ……O10…..ON
Maintenance costs – M	M (present value)>> $M_p = \sum_{n=1}^{N} M_n q_n$	M1 M2 M3 M4 M5 ……M10…..MN
Replacement costs – R	R (present value)>> $R_p = \sum_{n=1}^{N} R_n q_n$	R3 R5 R10 RN
End of life costs – E	E (present value) $E_p = E_n q_n$	EN
Total LCC costs	Total Present Value costs of relevant costs only – NPV	

Other forms of economic evaluation

NS (Net savings) = the difference in NPVs between two options A and B
NPV(A) – NPV(B) = NS
NS is positive

SIR (savings to investment ratio) =
NPV(A) – NPV(B) without investment divided by
Difference in investment costs between A & B
SIR has to be >1 for more economic option

Discounted (DPB) and simple (not discounted) (SPB) paybacks =
Minimum number of years when investment costs are recovered with time adjusted (or not) benefits or savings

Adjusted Internal Rate of Return (AIRR) = the annual yield from a project over the study period

Annual Cost (AC) or Annual Equivalent Value (AEV) = annual costs when discounted equal to NPV of the investment
Lowest AEV (AC) indicates the economic option

14.4 Applying other measures

14.4.1 Payback (PB)

Both simple and discounted PB are primarily useful as screening tools, however if the discounted PB period is less than the useful life of the asset, the investment will be cost effective. Choice of discount rate is significant; at low rates discounted PB and simple PB periods are closely related, at higher rates discounted PB may be significantly longer. PB is not reliable and should be avoided for ranking multiple options.

14.4.2 Net savings (NS) / Net Benefit (NB)

If the NS/NB of a single option is positive, it can be accepted as cost-effective, if negative it should be rejected. The NS measure can also be used to compare multiple investment options – selecting the highest NS is the same as selecting the lowest LCC. It may similarly be applied for ranking purposes.

14.4.3 Savings to Investment Ratio (SIR); Adjusted Internal Rate of Return (AIRR)

Both SIR and AIRR may be employed for accept/reject decisions and for ranking / selection of optimum from multiple options. An SIR greater than one is positive (ie ‘accept’) and is ranked in rising order. An AIRR greater than the discount rate is positive and is similarly ranked in rising order. Both measures lead to the same outcome.

14.4.4 Annual Cost and Annual Equivalent Value (AC or AEV)

AC/AEV is used to compare investment options where the natural replacement cycle cannot easily be directly related to the period of analysis. The lowest AEV indicates the lowest cost option.

14.5 Typical examples of the use of LCC analysis

Table 8 below includes a range of scenarios where LCC analysis is undertaken in support of investment decisions, illustrating:

- The costs taken into account
- Where sensitivity analysis is usefully applied, similarly risk assessment
- An appropriate method of evaluation.

14.6 At the end of step 14

At the end of step 14 the user will have:

- Identified and applied appropriate LCC measures to the available option(s)
- Recorded the results to be interpreted for an initial presentation to the client at step 15

Table 8 Examples of the application of LCC analysis

Decision required	Costs taken into account	Sensitivity analysis applied	Risk assessment undertaken	Economic evaluation
To proceed or not with installing energy saving system	• Energy costs with/without new system • Capital cost • Operation and maintenance			• LCC – NPV • PB • NS • SIR
Selection from options for replacing energy saving system	For each option: • Energy costs • Capital cost • Operation and maintenance		Decision tree – each option – costs and probability of achieving energy savings	• NB from all options
Selection of option for energy saving at new building design stage	• Capital cost • Fuel • Operation • Repair and maintenance	Sensitivity of NS to energy consumption (unpredictable within +/- 25% of first estimate)		• NS • SIR
Location of new manufacturing facility, without market ties	Fixed: • Land • Construction Variable: • Production, annually • Distribution, annually	Sensitivity of annual costs at each location to production volume (uncertain)		• Annual cost models
Location of service facility with strong market ties	Fixed: • Rent • Utilities Variable: • Staff, labour • Materials • Income		Probability of achieving different sales volumes at optional locations, translated into net profits/losses (income based on market research)	• NB
To lease or buy facility	Leasing costs, including: • Increase clause • Deposit / refund with interest Purchase, including: • Loan • Down payment • Resale			• LCC – NPV • Annual cash flow

15 STEP 15: Interpret and present initial results in required format.

15.1 Purpose of this step

At this step the analyst reviews and interprets the results obtained from the analysis, recognising the limitations of the cost techniques applied and hence the need for the exercise of professional judgement, also ensuring that risks and uncertainties have been properly addressed.

The analyst also identifies at this step the most appropriate graphic, tabular or other means of presenting the results, agrees them with the client organisation and incorporates them in an interim report for discussion.

15.2 Exercising professional judgement

It is essential that the analyst applies professional judgement in interpreting the results of the analysis and that the user does not attribute to them a spurious accuracy, in recognition of the limitations of the techniques that have been used in the exercise. Those commonly cited include:

- LCC is not a precise science and the reliability of the outcomes should be regarded at best as ‘reasonable’
- LCC outputs can never more accurate than the inputs, in particular the estimates and assumptions made regarding both time and cost
- The accuracy of results is difficult to measure as the variances obtained by statistical methods are often large
- Relevant data can be both difficult and expensive to acquire, particularly regarding the operation and maintenance phase in the life cycle
- LCC requires numbers of scenarios to be modelled representing many variables of both time and cost.

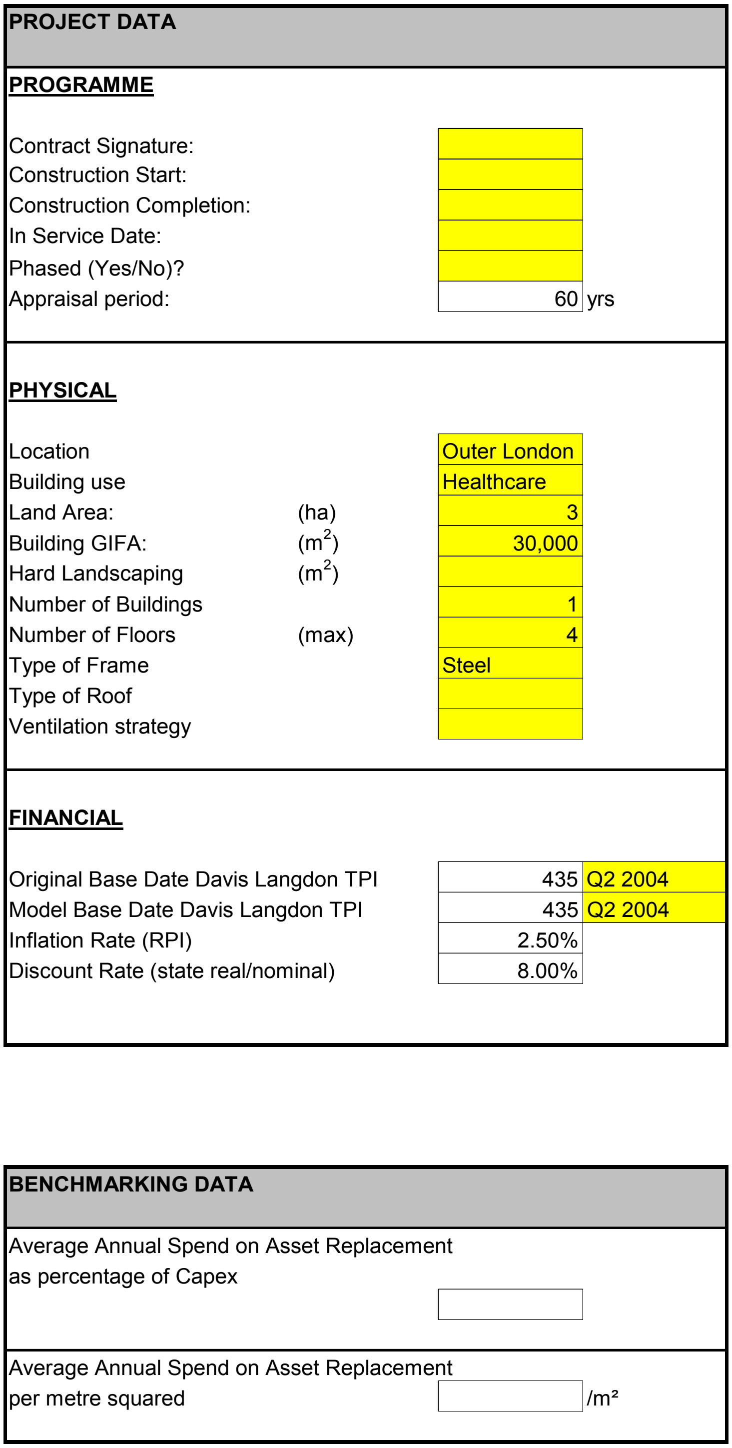
15.3 Ensuring that uncertainty and risk is addressed

Investment in a constructed asset is a long-term project and as such characterised by a range of uncertainties and risks. At steps 5 and 12 the user considered how these would be addressed by risk and uncertainty analysis. In the light of the initial LCC results now available, at this step the user confirms implementation of the selected approaches at following steps 16 and 17.

15.4 Selecting an appropriate format and presenting initial results

ISO 15686 Part 5 includes a series of headings for the final report on the LCC analysis, so that the user can understand both the outcomes and the implications – these are considered at step 18. Key information, including the initial results at this step, can be presented in a range of tabular and graphic formats to assist understanding. The analyst should select these to suit the purpose of the exercise, in particular the specific needs – and skills – of the client organisation. A number are illustrated below.

Figure 10: Project data table



PROJECT DATA			
PROGRAMME			
Contract Signature:			
Construction Start:			
Construction Completion:			
In Service Date:			
Phased (Yes/No)?			
Appraisal period:		60	yrs
PHYSICAL			
Location		Outer London	
Building use		Healthcare	
Land Area:	(ha)	3	
Building GIFA:	(m^2)	30,000	
Hard Landscaping	(m^2)		
Number of Buildings		1	
Number of Floors	(max)	4	
Type of Frame		Steel	
Type of Roof			
Ventilation strategy			
FINANCIAL			
Original Base Date Davis Langdon TPI		435	Q2 2004
Model Base Date Davis Langdon TPI		435	Q2 2004
Inflation Rate (RPI)		2.50%	
Discount Rate (state real/nominal)		8.00%	

BENCHMARKING DATA		
Average Annual Spend on Asset Replacement as percentage of Capex		
Average Annual Spend on Asset Replacement per metre squared		/m²

Figure 11: Annual expenditure table (part)

ANNUAL EXPENDITURE to year 60 at:-			
Year	Base Date Prices £	Inflated Prices (inflation rate 2.5% pa)	Discounted Prices at 8% pa
Capital Cost	20,000,000	20,000,000	20,000,000
1	(2,067,300)	(2,118,983)	(1,962,021)
2	(3,067,300)	(3,222,582)	(2,762,845)
3	(3,067,300)	(3,303,147)	(2,622,144)
4	(3,067,300)	(3,385,725)	(2,488,609)
5	(3,067,300)	(3,470,368)	(2,361,874)
6	(3,067,300)	(3,557,128)	(2,241,594)
7	(2,067,300)	(2,457,370)	(1,433,852)
8	(2,067,300)	(2,518,804)	(1,360,832)
9	(3,067,300)	(3,830,637)	(1,916,272)
10	(3,067,300)	(3,926,403)	(1,818,684)
11	(4,067,300)	(5,336,650)	(2,288,798)
12	(4,067,300)	(5,470,066)	(2,172,239)
13	(4,067,300)	(5,606,818)	(2,061,615)
14	(3,067,300)	(4,334,015)	(1,475,563)
15	(3,067,300)	(4,442,365)	(1,400,419)
16	(4,067,300)	(6,037,930)	(1,762,414)
17	(4,067,300)	(6,188,878)	(1,672,662)
18	(4,067,300)	(6,343,600)	(1,587,480)
19	(4,067,300)	(6,502,190)	(1,506,636)
20	(4,067,300)	(6,664,745)	(1,429,909)
21	(3,067,300)	(5,151,781)	(1,023,431)
22	(3,067,300)	(5,280,576)	(971,312)
23	(4,067,300)	(7,177,201)	(1,222,387)
24	(4,067,300)	(7,356,631)	(1,160,136)
25	(4,067,300)	(7,540,547)	(1,101,055)
26	(4,067,300)	(7,729,061)	(1,044,983)
27	(4,067,300)	(7,922,287)	(991,766)
28	(3,067,300)	(6,123,849)	(709,838)
29	(3,067,300)	(6,276,945)	(673,689)
30	(4,067,300)	(8,531,437)	(847,831)
31	(4,067,300)	(8,744,723)	(804,655)
32	(4,067,300)	(8,963,341)	(763,677)
33	(4,067,300)	(9,187,424)	(724,786)
34	(4,067,300)	(9,417,110)	(687,876)
35	(3,067,300)	(7,279,332)	(492,334)
36	(3,067,300)	(7,461,316)	(467,262)
37	(4,067,300)	(10,141,197)	(588,045)
38	(4,067,300)	(10,394,727)	(558,098)
39	(4,067,300)	(10,654,595)	(529,676)
40	(4,067,300)	(10,920,960)	(502,702)
Continued	**(121,692,000)**	**(230,973,444)**	**(34,192,001)**

Figure 12: Table of key parameters

KEY PARAMETERS

Appraisal period	60	years
Start year	0	
Original base date	435	Q2 2004 Outer London
Model base date	435	Q2 2004
Location factor	1.00	
Inflation rate	2.50%	
Nominal discount rate	8.00%	
Adjust cycle length	0%	no adjustment

Figure 13: Tabulation of total cost profile (years 0-5, 59-60)

TOTAL COST PROFILE

at today's price level (£199,788,000)

Capital Costs Included

ANNUAL CASH FLOWS

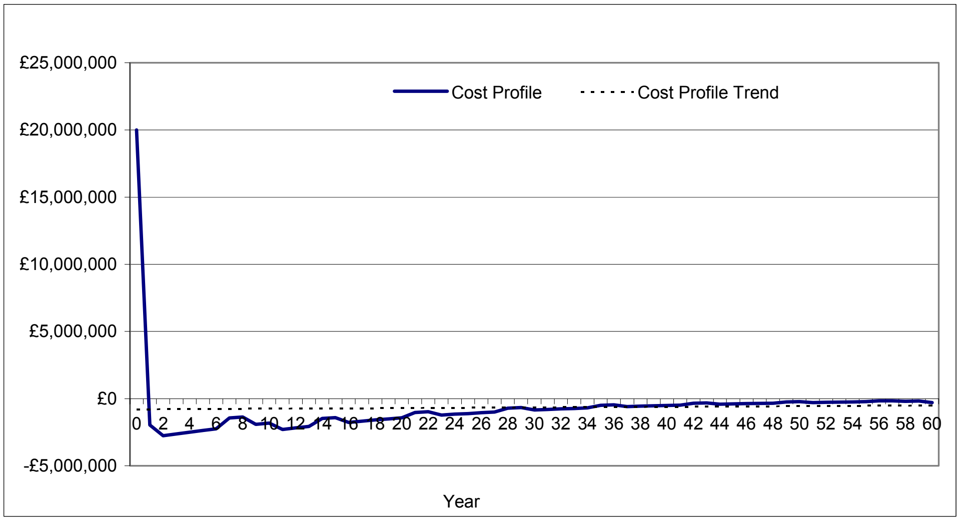
	0	1	2	3	4	5	59	60	*Residual value at year* 60
Cost in year (constant values)	20,000,000	(2,067,300)	(3,067,300)	(3,067,300)	(3,067,300)	(3,067,300)	(4,067,300)	(6,817,300)	**(4,228,248)**
Cumulative Costs (constant values)	20,000,000	17,932,700	14,865,400	11,798,100	8,730,800	5,663,500	(192,970,700)	(199,788,000)	
Inflation factors for inflation rate of 2.5% pa	*1.000*	1.025	1.051	1.077	1.104	1.131	4.292	4.400	*4.400*
Nominal (inflated) cost in year	20,000,000	(2,118,983)	(3,222,582)	(3,303,147)	(3,385,725)	(3,470,368)	(17,458,795)	(29,994,687)	**(18,603,402)**
Discount factors for Nominal discount rate of 8% pa	*1.000*	*0.926*	*0.857*	*0.794*	*0.735*	*0.681*	*0.011*	*0.010*	*0.010*
Net Present Value of Cost in year	20,000,000	(1,962,021)	(2,762,845)	(2,622,144)	(2,488,609)	(2,361,874)	(186,214)	(296,223)	**(183,724)**
Net Present Value of Cumulative Cost	20,000,000	18,037,979	15,275,134	12,652,990	10,164,381	7,802,507	(39,618,312)	(39,914,535)	

Figure 14: LCC model (part)

Item Description/Category of Cost	Quantity	Unit	Unit Rate	First Year	Cycle *(Years)*	Work Period *(Years)*	Last Year	Spend		Residual value at end of appraisal	DETAILED COST PROFILE Year		
			£					Per Cycle £	Total Over 60 Years £	£	0	1	2
A. CAPITAL COSTS													
Land Acquisition incl. Stamp duties and agents fe	2	ha	500,000	0				1,000,000	1,000,000	16,393	1,000,000	-	-
										0			
Demolition and Site Clearance	1	item	400,000	0				400,000	400,000	6,557	400,000	-	-
										0			
Capital Construction Cost	7,000	m²	1,800	0				12,600,000	12,600,000	206,557	12,600,000	-	-
										0			
Professional Fees at 15%	1	item	1,950,000	0				1,950,000	1,950,000	31,967	1,950,000	-	-
										0			
FF&E	1	item	900,000	0				900,000	900,000	14,754	900,000	-	-
										0			
VAT	1	item	2,950,000	0				2,950,000	2,950,000	48,361	2,950,000	-	-
										0			
User Commissioning Expenses	1	item	200,000	0				200,000	200,000	3,279	200,000	-	-
										0			
B. FINANCING COSTS										0			
										0			
Finance for land purchase and during constructio	1	item	1,000,000	1	1		10	1,000,000	10,000,000	1,000,000	-	1,000,000	1,000,000
										0			
Finance during period of intended occupation	1	item	200,000	1	1			200,000	12,000,000	200,000	-	200,000	200,000
										0			
C. OPERATING COSTS										0			
										0			
Utilities										0			
- Water (including drainage)	7,000	m²	3	1	1			17,500	1,050,000	17,500	-	17,500	17,500
- Electricity	7,000	m²	6	1	1			44,100	2,646,000	44,100	-	44,100	44,100
- Gas	7,000	m²	4	1	1			26,600	1,596,000	26,600	-	26,600	26,600
- Telecommunications	7,000	m²	3	1	1			17,500	1,050,000	17,500	-	17,500	17,500
										0			
Cleaning	7,000	m²	22	1	1			154,000	9,240,000	154,000	-	154,000	154,000
										0			
Business Rates	1	item	53,000	1	1			53,000	3,180,000	53,000	-	53,000	53,000
										0			
Insurances	1	item	200,000	1	1			200,000	12,000,000	200,000	-	200,000	200,000

Figure 15: Cost profile chart

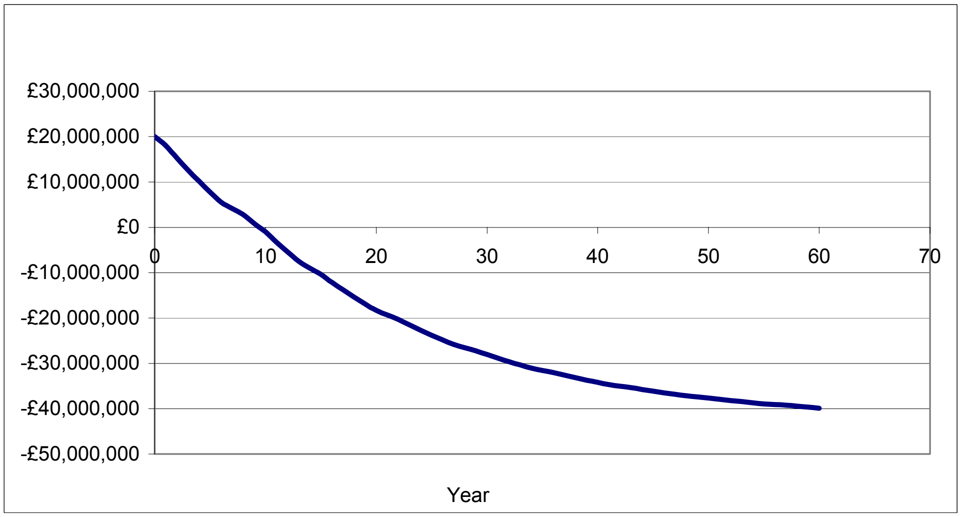
COST PROFILE CHART (Discounted at 8% pa)



Appraisal period 60 years **Total NPV of Project Cost £-39,914,535**

Figure 16: Cumulative cost chart

CUMULATIVE COST CHART (Discounted at 8% pa)



Appraisal period 60 years **Total NPV of Project Cost £-39,914,535**

15.5 At the end of step 15

At the end of step 15 the analyst will have:

- Reviewed and interpreted the initial results
- Presented these results to the client for discussion, using appropriate formats

16 STEP 16: Carry out risk/uncertainty analysis (if required) – *carry out qualitative risk analysis*

16.1 The purpose of this step

At this step the project team carries out quantitative risk analyses, in particular Monte Carlo Simulations, to the extent identified as required at step 5 and confirmed at step 12, in order to illuminate and support decisions arising in the LCC exercise.

16.2 Carrying out Monte Carlo Simulation as required

The risk register, updated at step 12 or subsequently, can be used as the basis for running a Monte Carlo Simulation, for which the following information is necessary:

- Distinct probabilities / likelihood of each risk occurring
- Information to statistically model the impact of each risk, should it occur. The distribution may be:
  - Uniform – that is, there is an equal chance that the parameter will have any value between two limits, eg a cost per tonne between €X and €Y
  - Triangular – that is, the minimum value of the parameter is identified as X, the most likely as Y, the maximum as Z
  - Discrete – that is, either the event happens or it does not.

The outputs will typically be expressed as graphs that:

- show the probabilities of project completion at various costs, eg 90% certainty for completion for less than a specific sum of £k
- show the distribution of out-turn costs, for example to indicate the most likely cost outcome.

16.3 Interpreting the results

The term risk usually expresses not only the potential for an undesired consequence, but also how probable it is that such a consequence will occur. If the analysis had been conducted according to a traditional deterministic approach, only the mean values would be available as a basis for comparing NPVs. For example, if the NPV for alternative A is €28 million and for alternative B is €27 million, respectively, it appears that alternative B is less than alternative A by €1 million. However, depending on the decision maker's tolerance for risk, a decision based on NPV may prove to be a poor choice if variability about the mean is not taken into account.

Interpretation of risk analysis results goes beyond a simple comparison of average costs by analysing the likelihood that any particular outcome will occur. There is no presumption that any particular alternative is better. Figure 17 below illustrates the risk profile of the NPV for alternatives A and B in histogram form, where the probability is represented by the area under the curve. The entire range of conceivable outcomes is arrayed with the estimated probability of each outcome actually occurring. The main advantage of such a histogram is that it readily shows the variability about the mean – the wider the distribution, the greater the variability. In the example shown, the outcome for alternative B is more uncertain than alternative A.

In interpreting the risk profile it is important to distinguish between upside risk and downside risk. ‘Downside’ risk for project cost implies cost overrun – chance of financial failure. ‘Upside’ risk for project costs implies cost under-run – opportunity for lower cost. In the example, alternative B has greater upside risk than alternative A. However, it is important also to quantify the probability of cost overrun for alternative B.

Figure 17: Risk profile in histogram form

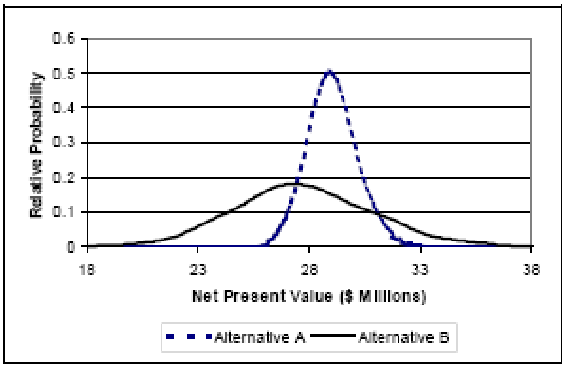
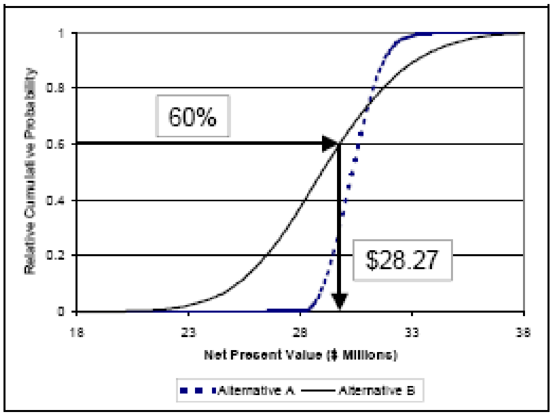


Figure 18 below plots the risk profiles for alternatives A and B in cumulative form, showing a 60 percent probability that project costs for Alternative B will be less than €28 million. (This means that for the 10,000 iterations that were processed, 60 percent of the calculated values for NPV were less than €28 million.) The variability for an alternative is inversely proportional to the slope of the cumulative curve, that is, the steeper the slope, the less is the variability. In the example shown, the slope for alternative B is flatter than that for Alternative A, and is therefore more variable.

Figure 18: Risk profile in cumulative form



Such analysis provides much more information than a simple deterministic solution. Additional information may come in the form of simulation results that reveal the underlying uncertainty associated with each alternative. In interpreting the risk involved with each alternative, it is important to identify the magnitude of the extremes of the distributions shown in the figure 17.

Scenario analysis can identify those variables that may cause a project to have significant cost overrun. Such analysis is easily accomplished using any risk assessment software, which generally uses the following procedure to identify significant inputs for a particular scenario:

- Identify each input variable that affects the selected output
- Calculate the median and standard deviation of each input
- Create a subset containing only the iterations in which the output achieves the defined target;
- For each input variable identified step 1:
- Calculate the median for the subset data
- Calculate the difference between the simulation median and the subset median and compare with the standard deviation of the input data.

If the absolute value of the difference in medians is greater than 0.5 of the standard deviation of the whole, then the input variable is deemed significant — otherwise the input is ignored.

In order to make a decision based on risk analysis results, it is important for the decision maker to define the level of risk the organisation can tolerate. Decision makers who can tolerate little risk prefer a small spread in possible results. If the decision makers are risk-takers, they will accept a greater spread and possible variation in the outcome distribution. Most decision makers can reach a consensus decision after weighing the probability for upside and downside risk. In the example shown, alternative B appears the better alternative since there is far greater likelihood of cost savings compared with alternative A. Further, the probability of cost over-run, appears to be quite low compared with alternative A.

All stakeholders should be involved early in the process of developing the input probability distributions, to avoid any negative reaction special interest groups might have with the outcome. In this way the risk analysis process can facilitate consensus-building among stakeholders so that action may be taken in the best public interest.

16.4 At the end of Step 16

At the end of step 16 the project team will have:

- Undertaken the quantitative risk assessments identified at step12 as required
- Interpreted the results to illuminate and support decisions to be taken in the LCC exercise

17 STEP 17: Carry out sensitivity analysis (if required)

17.1 The purpose of this step

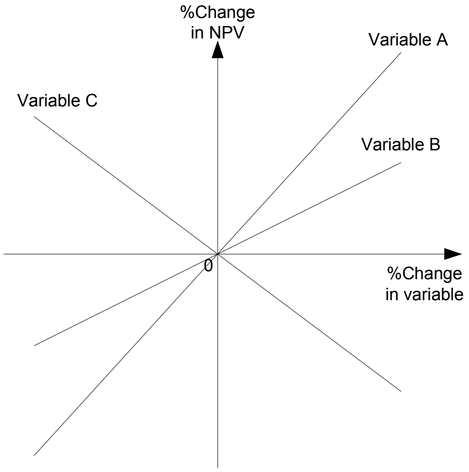
At this step the project team carries out sensitivity analyses to the extent identified as required at step 5 and confirmed at step 12, in order to illuminate and support decisions arising in the LCC exercise.

17.2 Sensitivity analysis in LCC

As considered at step 5, sensitivity analysis determines the sensitivity of LCC outcomes to variability in input parameters representing uncertainties or risks. By iteratively increasing or decreasing the value of the selected variables within the possible range, risk-adjusted LCC values may be computed and tabulated. The technique is conceptually and practically simple and the most widely used deterministic risk analysis technique in project risk management. It is easy to perform and easy to understand, and requires no additional methods of computation.

The results for different risk variables may be comprehensively displayed on a spider diagram, illustrated in figure 19 below, to show their relative sensitivities. The more critical risk variables have steeper curves. More attention can then be directed to understanding them and planning in advanced for mitigation actions.

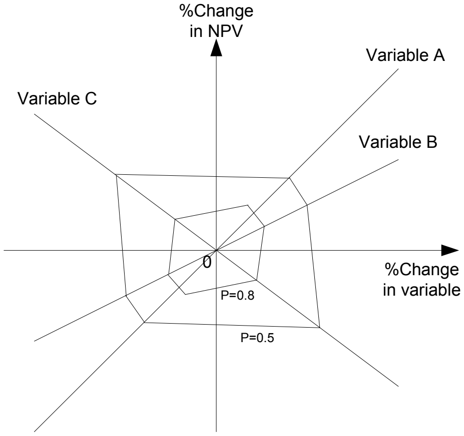
Figure 19: Spider diagram



If the probabilities of change in the risk variables have been assessed, this can be shown on the spider diagram as contour lines, illustrated on figure 20 below, indicating the likelihood of occurrence of a scenario.

Sensitivity analysis assumes that other risk variables remain unchanged while the impact of a given variable is assessed. In practice, more than one risk event can occur at any time and scenario analysis may be attempted by varying several risk variables simultaneously. However, studying multiple variables concurrently substantially increases the effort required and makes interpretation more difficult. In addition, the analysis will not effectively highlight the more critical variables when too many variables are taken into account.

Figure 20: Spider diagram with contour lines



17.3 Interpreting the results

Sensitivity analysis allows the upper and lower bounds of an economic measure to be by recalculating the measure with the lowest and highest likely cost estimates. For example, an HVAC system with night time setback and economiser might be under consideration as an energy-saving alternative to a conventional system. If the cost of electricity has the greatest impact on Net Savings, the range of Net Savings for the alternative system might be determined based on the most likely highest or lowest costs of electricity. Because of uncertainty about how much electricity the alternative system will actually use, it might be postulated that the present value of energy costs for the 20-year study period could be 20 to 40 percent higher or lower than the current best-guess estimate for electricity consumption.

Net Savings for the energy-saving alternative might be calculated as follows based on different assumptions for its electricity consumption:

- €83,000 on basis of best-guess estimate for consumption
- €44,000 if the alternative HVAC system used 20 percent more electricity than expected
- €5,000 if its electricity consumption were 40 percent more than expected
- €123,000 if its electricity consumption were 20 percent less than expected.

This analysis shows that even if energy usage was 20% higher than expected, the HVAC system with the night-time setback and economiser cycle would still be preferred over the conventional system. Even with a 40 percent increase in energy usage the system would still generate more savings than it would cost when compared with the base case over a period of 20 years. It may be concluded that the breakeven point would be reached if energy consumption were slightly higher than 40% more than the best estimate.

The major disadvantages of sensitivity analysis are that it gives no probabilistic measure of the risk of choosing an uneconomic option, and that it does not include an explicit measure of risk attitude. It can be misleading if all the optimistic or pessimistic assumptions about input values are combined when calculating economic measures.

17.4 At the end of Step 17

At the end of step 17 the project team will have:

- Undertaken sensitivity analyses as required by the decisions taken at step 12
- Interpreted the results while acknowledging the limitations of the technique.

18 STEP 18: Present final results in required format and prepare a final report.

18.1 Purpose of this step

This step completes the LCC exercise with the preparation and submission of a final report, in a format and degree of detail agreed with the client, and including a complete set of records for retaining/archiving according to ISO 15686:2005 Part3, to provide an audit trail if required.

18.2 Scope and format of the report

The format and style of the final report should be discussed and agreed with the client to suit the client's particular needs and purposes. As a general rule key information, including initial assumptions and all numerical data, should be expressed in tabular format, as considered at step15. If bespoke software is used that has embedded reporting formats, the suitability of these formats should be discussed and agreed with the client. Otherwise if dedicated LCC software is used, the results should still generally be presented in tabular format.

Typically the final report will comprise:

- A narrative section in MS Word, describing the asset, the project to invest in it and the LCC process carried out in support
- Tabulated information, typically in MS Excel, covering:
    - Project Summary including tables with summary of costs, project data and annual expenditure.
    - Key parameters (appraisal period, start year, original base date, model base date, location factor, inflation rate, nominal discount rate, adjust cycle length, etc.)
    - Total cost profiles (at today's price level and as discounted cost)
    - Annual cash flows (cost in a year, cumulative costs, nominal (inflated) costs in a year, NPV of cost in a year, NPV of cumulative cost)
    - Detailed LCC model with detailed costs profiles for each year for every item/category of cost.

18.3 Format and extent of analysis

ISO 15686 Part 5 requires that the format and extent of analysis should be agreed in advance with the client, including:

- The decision and cost variables that are analysed, noting any exclusions relative to the scope of the exercise agreed at step 2
- The scope of sensitivity analyses, including confidence ranges. Other risk analyses carried out should also be covered in the report, including justification of the selected parameters
- The data and analysis structure. The report should describe the corresponding attributes of the software and calculation tools employed.
- The method of accounting for the time value of money. The report should cover any differential application of discount and inflation rates between cost headings
- The period of analysis

- Any other specific client requirements.

These points would have been agreed with the client during the first steps of the exercise and reflected in the initial presentation of results at step 15, but should be confirmed at this step for the purposes of the final report.

18.4 Detailed content of the report

ISO 15686 Part 5 sets out the headings that the final report should address, as sub-headings 18.4.1 to 11 following.

18.4.1 Executive summary

The executive summary should briefly describe the client organisation and the project, followed by:
- The aims and objectives of the LCC exercise
- Key assumptions
- Extent of the calculations
- Limitations, uncertainties and risks
- Brief summary of results and conclusions

18.4.2 Purpose and scope

The statement of purpose and scope of the LCC exercise under this heading should be based on the conditions of contract with the client.

It should describe the period of analysis, setting out the background and reasoning. If the period varies for different parts of the project this should be similarly justified.

It should make clear which costs have been considered or excluded. Examples of inclusions might be:
- Design and project management fees
- Site management
- Temporary works

Examples of exclusions might be:
- VAT
- Financing charges
- Property rates
- Ground rent
- Business interruption costs
- Relocation costs

18.4.3 Statement of objectives

This should briefly describe the main purposes of the LCC exercise, as developed at step 1, together with the implications for the level of detail and accuracy in the process.

18.4.4 Materials under consideration

Sources should be described under this heading, together with the methodology for assembling the information/data. This might include:

- Familiarisation with any documentation – lists of documents to be included
- Site visits
- Attending design / other reviews
- Attending/facilitating workshops
- Boundaries agreement between LCC O&M and FM companies' obligations
- Identifying assets (existing and new) for modelling
- Analysing cost plan (either developed or provided by client)
- Formulation of the model
- Review of the cost profile

18.4.5 Assumptions

All assumptions should be listed under this heading together with a brief discussion of their reliability and implications, particularly with reference to prediction errors, illustrated as follows.

The most frequent assumptions relate to the financial parameters:
- Discount rate – the usual practice of using market interest rate of borrowed funds and assuming that it will be constant over the period of analysis ignores the possibility of variations resulting from changes in monetary of fiscal policy
- Inflation rate – the general approach ignores the effect of inflation on the assumption that costs will inflate at the same rate. This is unlikely to be true.

Determining the life of materials, components and systems is another difficult area in LCC forecasting. In theory it can be related the probability of failure but in reality data is difficult to obtain and rarely complete, leading to assumptions regarding service life and thus repair and replacement costs.

Other assumptions might relate to energy escalation rates, obsolescence rates and salvage value.

18.4.6 Constraints and risks identified

Constraints on both the project and on the LCC exercise should be identified, with a separate statement on risk and uncertainty. If risk was not considered as part of the LCC exercise this should be recorded. Any future risk management arrangements proposed should be identified, with any cost implications.

18.4.7 Alternatives considered in the analysis.

Two groups of 'alternatives' should be reported under this heading, with justification for the selection considered in each case:
- Options evaluated at scheme, system and component/material level
- Alternative values tested for the key parameters.

18.4.8 Thorough discussion of the interpretation of the results

The analyst's interpretation of the results should be discussed with the client upon their initial presentation at step15 with specific reference to:
- the objectives of the analysis, as determined at step1
- the techniques and measures selected and implemented at step 14.

The outcome of this discussion, amplified by the analyst as necessary, is recorded under this heading.

18.4.9 Graphical representation of results

ISO 15686 Part 5 notes that, while not essential, graphical representation frequently aids understanding. This, the final report should normally include appropriate charts, as considered and agreed with the client at step 15.

18.4.10 Replacement and maintenance plan (if required)

The detailed cost profiles within the report will indicate maintenance cycles, items and costs throughout the period of analysis. A separate maintenance/replacement plan can be distilled from the overall calculations, if included in the client's requirements and supported by the level of analysis carried out. Similarly to the main report, it should be presented primarily in tabular form supported by appropriate graphics.

18.4.11 Presentation of the conclusions

The core of the conclusions will address the initial objectives and will reflect the background and skills of the analyst carrying out the assessment, typically a cost consultant or other relevant construction expert. However, the client may require more detailed discussion and conclusions focused on specific aspects, to be commissioned from other experts such as environmental engineers or financial analysts. These are normally included in the initial report as an appendix but should be integrated into the final report.

18.5 Documents required for audit trail

ISO 15686:2005 Part3 requires a complete set of records for retained/archived to provide an audit trail if required. These should include:
- cost calculations;
- evidence of service life;
- sources of cost data and any validation undertaken;
- discussions on the scope of analysis;
- copies of software packages/ LCC models.

In view of the potential liabilities for professional staff engaged in LCC exercises, their records (whether paper or electronic) should include:
- evidence of insurance cover
- records of handing over deliverables
- all discussion and agreements with the client organisation.

18.6 At the end of step 18

At the end of step 18 the analyst will have completed the client's commission by submitting:
- A final report to an agreed scope and format, setting out the conclusions drawn from the LCC exercise in response to its defined objectives
- The records required for the purpose of an audit trail, in accordance with ISO 15686:2005 Part 3.