BS ISO 15663-2:2001

Petroleum and natural gas industries — Life-cycle costing —

Part 2: Guidance on application of methodology and calculation methods

ICS 75.180

National foreword

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The UK participation in its preparation was entrusted to Technical Committee PSE/17, Petroleum and natural gas industries, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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Part 2: Guidance on application of methodology and calculation methods

Industries du pétrole et du gaz naturel — Estimation des coûts globaux de production et de traitement —

Partie 2: Lignes directrices relatives à l'application de la méthodologie et aux méthodes de calcul

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 15663 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 15663-2 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*.

ISO 15663 consists of the following parts, under the general title *Petroleum and natural gas industries — Life-cycle costing*:

— *Part 1: Methodology*

— *Part 2: Guidance on application of methodology and calculation methods*

— *Part 3: Implementation guidelines*

Introduction

This part of ISO 15663 was developed in order to encourage the adoption of a common and consistent approach to life-cycle costing within the petroleum and natural gas industries. This will occur faster and more effectively if a common approach is agreed internationally.

This part of ISO 15663 has been prepared to provide guidance on the application of the methodology given in ISO 15663-1 [1] and on the calculations related to it.

It provides practical guidance towards the individual steps of the life-cycle costing process and aims to

— show how the potentials for added value can be achieved without life-cycle costing turning into a costly and time-consuming process;

— indicate how to structure the work within the process and define focus areas;

— transfer the experience of industry in applying the methodology, so that a common and consistent approach can be achieved.

It also promotes an understanding of the related methodologies and techniques and their application within the life-cycle costing framework.

Life-cycle costing is distinct from investment appraisal in that it is not concerned with determining the financial viability of a development. It is concerned only with determining the differences between competing options and establishing the options which best meet the owner's business objectives.

This part of ISO 15663 is based on the principles defined in IEC 60300-3-3, *Dependability management — Part 3: Application guide — Section 3: Life cycle costing*.

Petroleum and natural gas industries — Life-cycle costing —

Part 2: Guidance on application of methodology and calculation methods

1 Scope

This part of ISO 15663 provides guidance on application of the methodology for life-cycle costing for the development and operation of facilities for drilling, production and pipeline transportation within the petroleum and natural gas industries.

This part of ISO 15663 also provides guidance on the application and calculations of the life-cycle costing process defined in ISO 15663-1.[1]

This part of ISO 15663 is not concerned with determining the life-cycle cost of individual items of equipment, but rather with life-cycle costing in order to estimate the cost differences between competing project options.

2 Terms, definitions and abbreviated terms

For the purposes of this part of ISO 15663, the following terms, definitions and abbreviated terms apply.

2.1 Terms and definitions

2.1.1
initial investment
investment outlay for a project

NOTE Also known as CAPEX.

2.1.2
present value
value of the project cash flow excluding the initial investment outlay

2.1.3
life-cycle costing
process of evaluating the difference between the life-cycle costs of two or more alternative options

2.2 Abbreviated terms

CAPEX	capital expenditure
FMECA	failure mode effect and criticality analysis
FV	future value
H,S&E	health, safety and environment
IRR	internal rate of return
NPV	net present value

OPEX	operating expenditure
OREDA®	offshore reliability database
PI	profitability index
PV	present value
RAM	reliability, availability and maintainability
RCM	reliability-centred maintenance
TTE	tools and test equipment
WACC	weighted average capital cost

3 The process of life-cycle costing

3.1 The project focus

This subclause provides a guideline for the different steps of the methodology described in ISO 15663-1[1]. It should be recognized that the contribution of life-cycle costing to a project is no more or less important than that made by other support functions such as design, reliability or engineering.

Each of these functions provides its own unique perspective on the problem and each examines some aspects of performance. Life-cycle costing adds a long-term financial perspective and provides the means to

— predict financial performance through life on a quantitative basis,

— assess the financial implications of the contributions made by other functions,

— compare alternative options on a common financial basis.

Life-cycle costing cannot act in isolation and should interact with the other functions as part of the team approach.

3.2 Step 1 — Diagnosis and scope definition

3.2.1 Identify objectives

The objectives should be established through discussion with stakeholders and other members of the team, particularly the manager responsible for the overall work.

Two important aspects need to be established.

a) **What are we looking at?**

This provides the focus for the work and should establish what functions, systems or equipment are being examined.

b) **Why are we looking at it?**

This establishes the reason for the work.

These questions can be used to allow the user to relate the life-cycle costing work to the objectives.

Simple examples might be as follows.

EXAMPLE 1 **What** — a pumping system is being examined. **Why** — because the hydrocarbons need to be moved from one location to another.

The objective that life-cycle costing should address is the function of transferring the flow, and a pumping system may only be one of several options.

EXAMPLE 2 **What** — maintenance costs across the platform. **Why** — because maintenance is considered excessive or unless maintenance costs are reduced, production may be terminated early.

If a decision has already been taken to focus on maintenance and exclude other elements of OPEXs, this should be questioned. The objective of life-cycle costing is confirm the significant platform cost drivers and then assist in quantifying the opportunities for reducing costs.

EXAMPLE 3 **What** — gas compression. **Why** — there are gas reserves to exploit.

This is sufficient, the objective has been identified and a technical need already established for gas compression. This would lead into identification of the options available. The objective of life-cycle costing is to support the evaluation of alternative methods for compression.

EXAMPLE 4 **What** — a 20 MW power generation package. **Why —** a response should be made to a formal invitation to tender that includes life-cycle costing requirements.

The objective is not to provide a response to a tender, but to produce a winning bid, the discussion should now focus on how the bid team can use life-cycle costing to advantage.

In subsequent iterations of the process, this task may be limited to reconfirmation. However, it may be found that the life-cycle costing work changes the overall objective. Taking, as an example, maintenance cost optimization, the first iteration may show that downtime (lost production) is the cost driver, not maintenance costs.

3.2.2 Identification of constraints

The relevant constraints will arise from three principal sources as follows:

— **project constraints** on what can be achieved within the life-cycle costing work;

These will arise from resource and time scale limitations of the work. A typical example would be the need to change the contracted specification during construction and hook-up. This might require a response in a few days, or at least a couple of weeks. The life-cycle costing approach should be tailored to this time scale (“quick and dirty”). This may mean a go/no go response, i.e. either the change has little impact on life-cycle costs or it has a significant impact. Generally, where there is a constraint on either the time or resources available to undertake the work, the level of detail should be reduced and not the number of options considered.

— **technical constraints** which limit the options available;

EXAMPLE A change to an existing facility that requires additional equipment means there may be topside weight and space constraints on the options, or an operator may be constrained to certain technical options;

— **budgetary constraints**.

There may exist limitations on CAPEX or alternatively, the outcome may be subject to hurdle rates, e.g. an option must achieve an IRR of 10 % before it merits further consideration.

Constraints can be imposed by third parties or other external influences. Examples of such constraints are environment discharge or health and safety issues.

3.2.3 Establishment of decision criteria

3.2.3.1 General

For life-cycle costing within the oil and gas industry, the decision criteria selected should always reflect the corporate requirements of the end user, generally the operator. At a lower level, additional considerations may be associated with the contractor's or vendor's corporate objectives. In an alliance partnership, the criteria will need to be agreed by all partners.

In defining the decision criteria, reference should always be made to the originator or customer, both to establish the criteria and to ensure there is sufficient understanding as to how to apply them. The user's understanding is not simply limited to technical comprehension, but should also include an agreement as to how criteria should be used to select options.

3.2.3.2 Measure economic evaluation method

The measure that is selected should enable alignment of technical decisions with corporate objectives. It should therefore be a structured approach for defining the economic impact of technical decisions.

The most common measures are described in clause 4. These are:

— NPV;

— life-cycle cost;

— IRR;

— PI;

— the payback method;

— break-even;

— cost per standard barrel of oil.

The selection of measure depends on the item under consideration and on which phase or iteration the project has entered. For the first iterations of the life-cycle costing process, the object investigated is the field development itself or the development concept. The revenue stream in total can be dedicated to this object. All the traditional economic evaluation methods can therefore be applied.

For the further iterations, the concept is broken down into the individual systems and further into equipment units. For these iterations no particular part of the revenue can be related to the object under consideration. The measure of life-cycle cost can then be applied. Through minimizing the total life-cycle cost of an asset or a function, where impact on the revenue stream of failures occurring are taken into consideration as a cost, asset value can be maximized in a consistent manner.

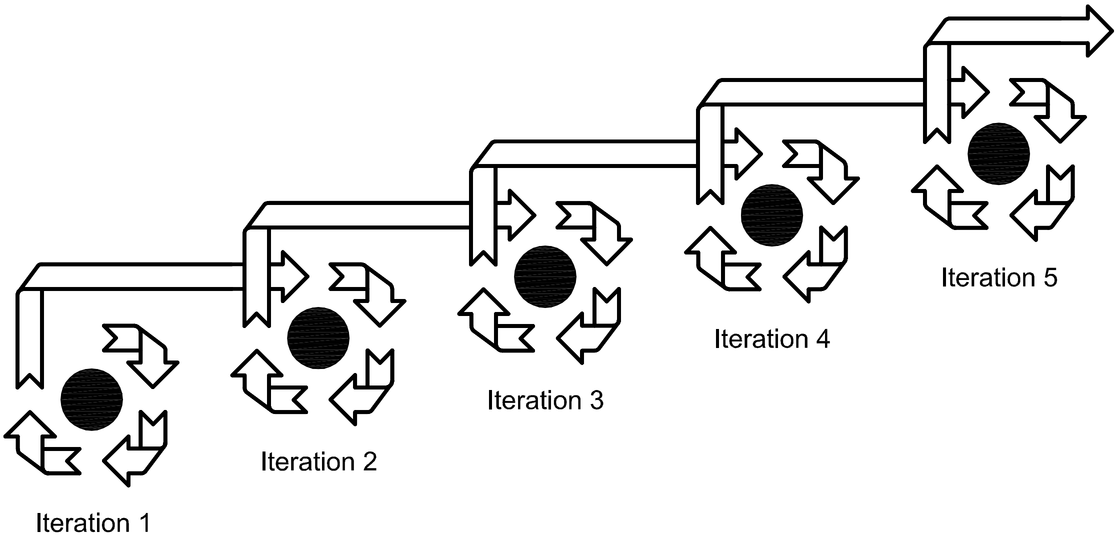
For these later iterations NPV and IRR can be applied when evaluating additional CAPEX resulting in reduced OPEX. The difference between the options of making the investment or not can then be considered as an investment appraisal evaluation.

An example of application of different measures or criteria is shown in Figure 1.

In the process of life-cycle costing, often only the difference between various options for filling a function can be evaluated. The possible measures that can be applied are then reduced to NPV or life-cycle cost, since the others listed are calculated from the total cost and revenue stream associated with the decision.

3.2.3.3 Assumptions

The assumptions that are set for calculations are vital for the evaluation of alternatives in order to determine which gives the highest added value. The most important assumptions are listed in Table 1. The areas to be aware of for calculations are addressed under 3.4.1.



	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5
Activity:	Field commerciality	Concept selection/ optimization	Outline design Process flow	Detail design	Procurement
System optimization					
Result:	Go/No go	Concept	Functions	Design alternative selection	Equipment
			Main equipment list	Material selection	
Criteria:	NPV/IRR/PI, etc.	NPV/IRR/PI, etc.	Life-cycle cost	Life-cycle cost	Life-cycle cost
	The traditional economic evaluation		Life-cycle cost		
The process of life cycle costing					

Figure 1 — Asset boundaries and evaluation of functional requirements

Table 1 — Assumptions

— Timing — Investment year — Start of operation — Life of field — Discount rate — Pre-tax / After-tax-calculations	How costs during operation are weighed against the initial investment	Which is the best system solution/equipment alternative?
— Output requirement over time — Cost of power	The impact of improving efficiency	
— Production profile — Criticality	The potential cost of failures	

3.2.4 Identify potential options

Options and sub-options for the function under review should be considered by a multidisciplinary team.

The use of a facilitator who can structure the meeting and log all options generated by the team can significantly improve the quality of the exercise. A well-proven technique to generate options and identify cost drivers is a functional/cost analysis of the investment. This technique is part of value engineering or functional value analysis workshops. Reference is made to clause 4. In function/cost analysis, a multidisciplinary team establishes the main functions of the investment and then establishes the sub-functions for the main functions. The equipment options for each sub-function are then identified and evaluated by the team. The evaluation of options will normally be in two stages: initial evaluation is carried out on a qualitative basis and some options may be evaluated from further study. Remaining options after the first screening are evaluated by undertaking life-cycle costing. Option generation and evaluation are normally carried out in distinct phases to ensure that evaluation does not inhibit the option generation process.

3.2.5 Establish options

Establishing the potential options implies screening the options arising from the previous task. The work can be carried out as the second half of the function/cost analysis, carried out in a full value engineering or functional value analysis workshop. This can save time and effort, and the ideas from the brainstorming are still fresh in people's minds.

The screening process should be applied consistently, in that each option should be subject to the same assessment criteria. A typical range of screening criteria may include the following questions:

— Is it technically feasible?

— Is it practical?

— Is it too expensive?

— Can it meet the programme?

— Can it meet the HS&E programme?

— Are the risks acceptable (technical, financial, revenue)?

— Is it consistent with corporate policy and is it acceptable to our partner?

— Can we evaluate it?

3.2.6 Define costs to be included in the analysis

To identify the cost elements related to an asset or a system, the function of the asset and the interrelations/dependencies toward the other systems should be evaluated.

Evaluation of operation can be in terms of what should be added to get the right output. This may include

— output requirements,

— power requirement,

— requirement of utilities/support systems,

— downstream effect of efficiency, resistance, etc.

Evaluation of maintenance can be in terms of what should be added to keep the process going. This may include

— regularity requirements for the system,

— maintenance concept/workload.

Revenue impact can be evaluated in terms of the consequence of failures.

ISO 15663-1 [1] describes the approach that should be followed. The output from these activities is a list of cost issues for possible inclusion in the assessment, and taken together they define the life-cycle cost boundary. They need to be agreed among the team members.

3.3 Step 2 — Data collection and structured breakdown of costs

3.3.1 Identify potential cost drivers

A key issue within life-cycle costing is to keep the focus on the cost drivers, the major cost elements. What constitutes the largest costs can come as a surprise if similar assets have not been evaluated earlier.

The cost drivers vary according to

— application,

— equipment type,

— equipment configuration.

For the offshore oil industry, the major cost elements are normally found among

— CAPEX,

— OPEX,

— maintenance cost,

— revenue impact of failures leading to production shutdown.

A cost driver can be one dominating cost or a combination.

All the basic information required to undertake this step is established in the previous step. In this task the user should take the list from the previous task, and for each option review each cost issue to determine if it is likely to be a life-cycle cost driver. This is an attempt to second-guess the outcome of the assessment. To assist in this process, it may be convenient to group the issues under related headings.

Useful tools in determining the cost drivers can be FMECA or a functional value analysis, as described in clause 4.

The outcome of this task will be the list of cost issues, but with the potential drivers highlighted.

3.3.2 Define cost elements

This task pursues the focus of the previous task, in that its principal aim is to identify the minimum level of detail necessary to discriminate between options. Although all the cost issues identified during Step 1 need to be addressed and estimated, effort in this task should be concentrated on identifying the cost elements required for the potential cost drivers.

The approach for each cost driver should be to consider the minimum number of cost elements required to estimate the cost driver.

The remaining cost issues should be considered in terms of whether can they be estimated directly, i.e. are they cost elements, and is it possible to group any of the cost issues under single headings.

The aim of the work is to identify the minimum number of cost elements, so that sensitivity analysis can be conducted on the cost drivers, and to reduce the effort associated with the remaining cost issues. A candidate list of cost elements is provided in 4.1.3.

The important features of the task are that it starts the user thinking about

— how the costs are calculated in the model,

— how sensitivity analysis will be accommodated, with the focus on the cost drivers,

— the practical issues associated with data collection, such as its availability, its quality and to whom the user needs to talk. It also provides an insight into the amount of effort likely to be required and how this may be tailored to the available resources.

The focus of the evaluation should be on differences between alternatives. Cost elements that are the same for all alternatives can normally be excluded.

This work provides the user with an agenda for the discussion that will follow on the structured breakdown of costs.

3.3.3 Establish structured breakdown of costs

The objective of this task is to align the need for information, as defined by the cost elements, with the ability of the organisation to respond.

All main elements of life-cycle cost should be considered, i.e. CAPEX, OPEX, revenue impact and commissioning cost.

The cost elements should be structured taking into account

— the way in which costs are acquired and recorded,

— the way cost elements are calculated.

The output from the task will be an agreed structured breakdown of costs.

3.3.4 Identify and collect data

3.3.4.1 General

The structured breakdown of costs identifies the cost data required. Of necessity, the previous discussions defining the structured breakdown of costs will have addressed practical issues such as the data sources.

A data collection procedure should be identified and defined.

The aim of setting up and implementing a procedure for collecting data is to

— define data requirements for life-cycle costing analysis,

— identify the sources from which to obtain data,

— establish the necessary level of quality control.

3.3.4.2 Data generation

This subclause outlines the sources from which the input data for the calculations can normally be obtained.

As a general statement, most data that are to be used in life-cycle costing analysis can be retrieved in the following two basic forms:

a) paper-based;

b) computer-based.

Appropriate data can be obtained from operators, contractors and vendors, in either format from their existing sources and databases, such as:

— accounting and financing system;

— purchasing system;

— engineering system;

— maintenance management system;

— reliability management system.

Data for CAPEXs can be:

— design and administration man-hours;

— equipment and material purchase;

— fabrication cost;

— installation cost;

— commissioning cost;

— insurance spares cost;

— reinvestment cost.

For new equipment, adjustments should be made from comparison with similar existing equipment.

Data for OPEXs can be:

— man-hours per system;

— spare parts consumption per system;

— logistic support cost;

— energy consumption cost;

— insurance cost;

— onshore support cost.

Data for revenue impact can be failure data. The following types of data can be extracted or referenced using OREDA®:

— **inventory data**, covering the identification information of the equipment of concern, including the design characteristics, the environment and the operation conditions;

— **operating data**, that are necessary for calculating the failure rates (calendar/operating time, number of demands);

— **failure event data**, including failure rate, failure mode, the subsystem/item failed, the degree of failure (severity class, according to OREDA® terminology);

— **maintenance data**, including the type of maintenance, the repair activity, the downtime/repair time, maintenance program/interval, the resources required (which are very useful for estimating OPEXs).

Revenue impact is based on the production profile given in the plan for development and operation. For fields already in operation, actual and predicted future production form the basis.

3.3.4.3 Data quality and adjustment

3.3.4.3.1 Data adjustment

3.3.4.3.1.1 General

Historic data should be adjusted for differences in system design and capacity, difference in oil characteristics, time in operation, monetary inflation/deflation, and cost development over time/trend prediction.

3.3.4.3.1.2 System design and capacity

Adjustment should be made for significant differences in system design and in different number of equipment units within the system to be evaluated, and the source of the historic data for the existing systems.

3.3.4.3.1.3 Oil characteristics

Adjustment should be made for significant differences in expected lifetime or failure frequencies for equipment due to characteristics of the oil or fluid handled.

3.3.4.3.1.4 Time in operation

Failures normally are more frequent early in operation (running-in period), and after long times in operation when the equipment is starting to deteriorate. Adjustment should be made for the operating phase of the reference systems and equipment.

Due to product development and feedback to the vendors, equipment quality normally improves over time. Adjustment of historic data should be made for significant design improvements.

3.3.4.3.1.5 Monetary inflation/deflation

Adjustment should be made for cost differences due to monetary inflation/deflation occurring between the historic records and the time of investment.

For cost adjustment, the cost index for the oil industry over the relevant years should be used.

3.3.4.3.1.6 Forecasting cost development

When the time span from the evaluation to cost occurrence and the deviation between cost development rate and the inflation rate are significant, methods for trend prediction should be used to forecast future cost development.

For expected cost development close to the inflation rate:

a) adjustments of the costs per year for inflation should be performed when using a nominal discount rate;

b) adjustment for inflation should not be done when using a real-term interest rate.

3.3.4.3.2 Data qualification

The sample of historic data should be large enough to obtain data of acceptable accuracy in relation to the decision to be made.

Man-hours and spare parts consumption should be averaged over enough years to give a calculation of sufficient accuracy.

3.3.4.3.3 Data quality

Poor data quality is a common challenge in many life-cycle costing applications. However, in most cases this should not disqualify the life-cycle costing analysis. Poor data quality can be treated through risk and uncertainty analysis, as referred to in 3.4.3.

3.4 Step 3 — Analysis and modelling

3.4.1 Developing a life-cycle costing (LCC) model

3.4.1.1 General

In the majority of cases, a spreadsheet represents the most economical and flexible solution for modelling life-cycle cost differences. The model developed should be simple enough to be transparent to the user but accurate enough to represent the difference between options.

There are instances where more complex models are appropriate, for example:

— for spares modelling at system or equipment level, where typically the range and scale of spares are estimated to meet a performance parameter such as availability, stock-out risk or fill rate;

— for maintenance assessment studies at system or equipment level involving multiple operating, repair and stores locations;

— for detailed manpower assessment studies examining staffing, skills and resource requirements.

In such cases proprietary models may be used, or special models may be developed specific to the application.

In constructing a model for a specific application, the following issues should be considered:

— all cost data should be normalized to a fixed economic base year;

— agreed inflation and exchange rates should be applied;

— non-appropriate overhead rates should be removed;

— manpower cost rates should be checked to ensure they reflect marginal cost of employment, so that fixed costs are treated appropriately;

— taxes and credits should be identified and isolated;

— committed costs should be identified and excluded;

— appropriate discount rates should be agreed and applied;

— the agreed financial and economic measures should be included: NPV, cash flow, PI, etc.;

— expenditure and revenue profiles should be developed;

— the areas for sensitivity analysis should be identified.

The period used for discounting (monthly, quarterly, annual) should be determined, taking into consideration the need to compare options. In particular, the need to examine sensitivities to programme changes may dictate a monthly period for discounting.

When developing a specific model the need for subsequent sensitivity analysis and further iterations will need to be considered. In particular, wherever possible, the parameters that will be varied in sensitivity analysis should be anticipated and the model organized such that changes can be made through single changes to the data; for example, the ability to vary all CAPEXs by a set percentage.

When further options are identified, it is inevitable that compromises will be made to accommodate these options which may include features not previously anticipated. A well-structured model will reduce the probability of error when these compromises are made.

3.4.1.2 Discounting

The model should discount future costs and revenues back to today's value.

An amount of money today is worth more than the same amount of money received in the future, i.e. money has a time value. Income and costs related to different activities at different points in time during the life cycle should be compared on an equal basis. All future incomes and costs for each year in the life cycle are discounted to the value today.

Discounting is a technique for converting different cash flows appearing at different points in time to comparable amounts at a specified point in time. After a cash flow is discounted, the different alternatives are evaluated from the sum of these as if all incomes and costs happened at the same point in time.

The FV in one year of \$100 presently held is equal to \$100 plus the annual rate of interest times \$100.

That is:

$$\text{FV} = \text{PV} \times (1 + k) \tag{1}$$

where k is the interest rate.

For a k of 10 % the FV is

$$\text{FV} = \$\,100 \times (1 + 0{,}1) = \$110 \tag{2}$$

The PV of \$100 received today is the same as \$110 received in one year if the relevant interest rate is 10 %.

The other way around, the PV of receiving \$110 in one year is

$$\text{PV} = \frac{\text{FV}}{(1+k)} = \frac{\$110}{(1+0{,}1)} = \$100 \tag{3}$$

Similarly, receiving \$121 in two years has the PV of

$$\text{PV} = \frac{\text{FV}}{(1+k)(1+k)} = \frac{\$121}{(1+0{,}1)(1+0{,}1)} = \frac{\$121}{(1+0{,}1)^2} = \$100 \tag{4}$$

A cash flow with investment of \$200 now for receiving \$100 each of the next three years has a NPV of

$$\text{NPV} = -200 + \frac{100}{1{,}1} + \frac{100}{1{,}1^2} + \frac{100}{1{,}1^3} = -200 + 90{,}90 + 82{,}60 + 75{,}1 = \$48{,}60 \tag{5}$$

The general formula for discounting a FV is

$$\text{PV} = \frac{\text{FV}}{(1 + \text{discount rate})^t} \tag{6}$$

where t is the number of years into the future.

By inspection, the discount factor is

$$\text{Discount factor} = \frac{1}{(1 + \text{discount rate})} \tag{7}$$

3.4.1.3 Discount rate

The discount rate used determines how costs during operation are balanced against the investment.

Figures 2 and 3 show the effect of using different discount rates for balancing an annual constant OPEX of $10 million over 25 years against an investment of $120 million occurring 2 years before operation.

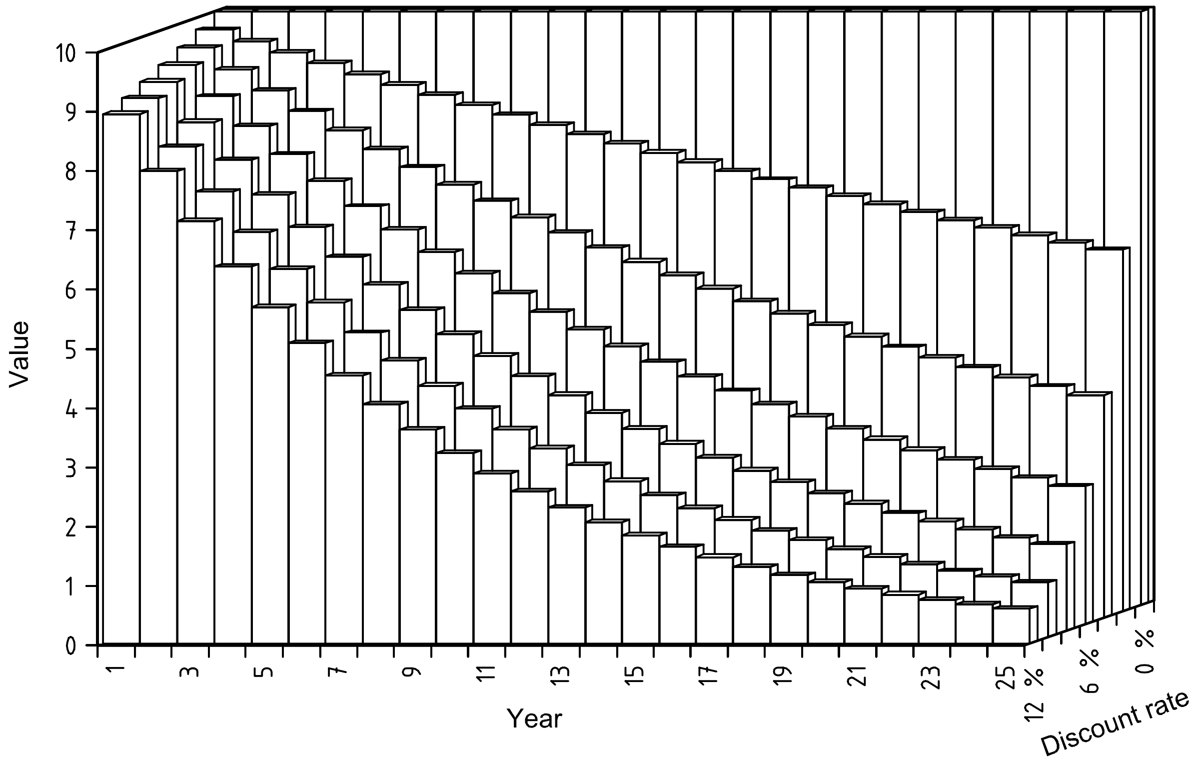


Figure 2 — Effect of discount rate on operating costs over time

Figure 2 shows how the discounted OPEX develops during operation with different discount rates. Figure 3 shows the discounted sum of the OPEXs over the lifetime against the investment. At a rate of 12 % the OPEX is only 50 % of the investment, while at 0 % it is more than double the investment.

This illustrates the importance of using the right discount rate.

3.4.1.4 Inflation

When a nominal discount rate is applied, the costs should be adjusted for inflation. In the evaluations in field development, it is normally easier to use only a real rate which is adjusted for inflation. As illustrated in Figure 4, the results should be the same.

3.4.1.5 Taxation

The implications of the fiscal regime should be evaluated. Ranking of alternatives can be altered by pre-tax/after-tax calculations dependent on tax regime.

For the larger decisions, after-tax calculations are normal. For the smaller technical decisions, pre-tax calculations are normally sufficient.

When calculating after-tax, the cash flow should be adjusted for inflation and the discounting nominal rates.

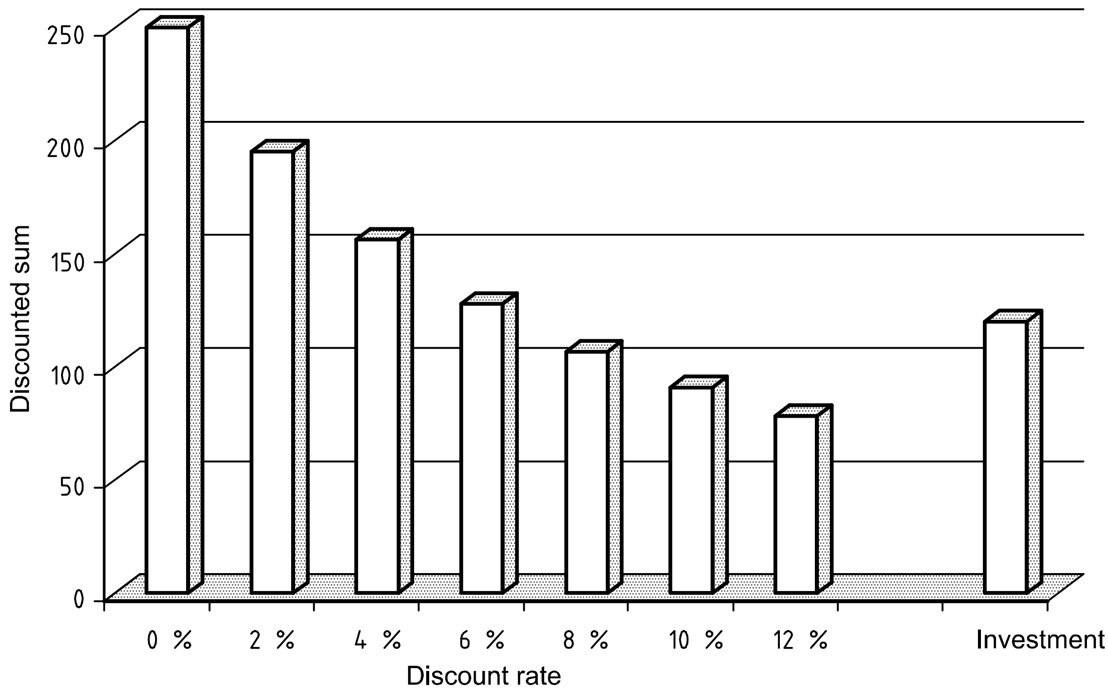


Figure 3 — Effect of discount rate on weighing of operating costs

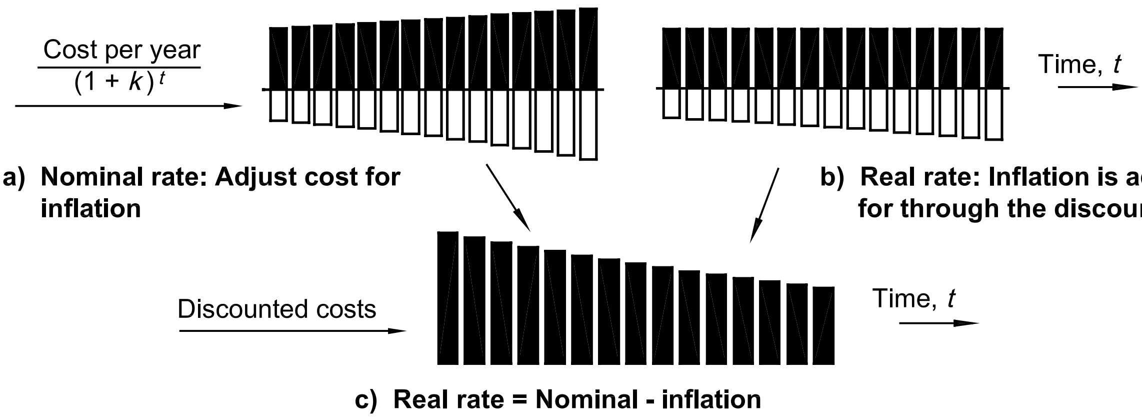


Figure 4 — Inflation adjustment

3.4.1.6 Life-cycle costing evaluation levels and tools

The evaluation methods to be used throughout the field development should be established at the start of the project to ensure consistency throughout the project. The main levels of life-cycle costing evaluations are

— “rules of thumb”,

— discounting models,

— economic assessment.

For most project decisions, the first two are sufficient. Most technical decisions are very small. They are often not even considered to be decisions, but everything we do in relation to design has economic consequences.

EXAMPLE The following is an example of how a project can formulate its own rule of thumb.

Criteria given at project start:

— Investment year: 1997

— Start-up production: 1999

— Field lifetime: 25 years

— Discount rate (risk-free): 6 % nominal

— Inflation rate: 2 %

— Discount rate: 4 % real

Rule of thumb for balancing CAPEX vs. OPEX:

— Discount factor = $\sum_{t=2}^{25} \frac{1}{(1+4\,\%)^t} = 15$ (real)

— Life-cycle cost = CAPEX + [15 × OPEX (annual)] + (15 × revenue impact)

Tools available range from simulation models to simple discounting. The selection of tools should be based on the individual needs of the problems investigated. For most cases a tailor-made spreadsheet model is easily developed, and more than sufficient for the problem at hand. Due consideration should be given to the ease of auditing and tracing the calculation flow.

3.4.2 Analysis and evaluation

When performing an analysis the focuses should be on

— identifying the design difference between alternatives and their economic impact,

— identifying the cost drivers and seeking to reduce these,

— participation from the discipline engineers to qualify input and results,

— sensitivity of the result towards the input parameters.

The key is to keep life-cycle costing as uncomplicated as possible.

The reason for analysis and evaluation being split into separate tasks apart from sensitivity analysis is to emphasise the need to check the results when they are first produced. The results should not be taken at face value. The output from the analysis will be a ranking of the options in accordance with the decision criteria specified, and a summary of the life-cycle cost or the life-cycle cost differences, identifying the cost drivers.

Evaluation of the analysis consists of checking the differences and finding out why they occur, if they are logical and can be explained. In addition, the total cost picture is checked to see if it is in accord with expectations.

3.4.3 Sensitivity analysis

3.4.3.1 General

Having established that the initial results are reasonable, the sensitivity analysis aims to provide the basis for reducing the number of options and improve confidence in those going forward, whether for implementation or for further evaluation. An output from this task should be the identification of further options.

For at least the cost drivers of the options, the following sensitivity questions should be answered:

— By how much should the estimate change to alter the ranking and hence the decision?

— How likely is the estimate to change by that amount?

In addressing these questions, the make-up of each cost driver should be established. The following categories may help.

— **Cost**, such as manpower rates, helicopter costs, overhaul cost;

— **technical factors**, such as mean time to repair, failure rates, time between overhauls, production capacity, field size;

— **programme plan**, such as time to first oil, production time scale.

The questions should not be addressed in isolation, and the views of relevant team members should be included. This will provide two benefits.

a) It will assist in identifying ideas and opportunities: in examining the cost drivers, it is usual to also ask how they may be reduced. Further options are likely to emerge from this discussion.

b) It will promote commitment from the participants through their active role in the process.

There will be occasions when this straightforward treatment of risk and uncertainty is inadequate. Where this occurs, other techniques will need to be employed in order to first find the probability of the uncertain event happening at any given time, and then to determine the risk associated with it. This will result in a corresponding increase in the complexity of the work and its attendant cost.

3.4.3.2 Uncertainty investigation

3.4.3.2.1 General

Uncertainty is normally handled through risk-adjusted discount rates. For life-cycle cost calculations, a risk-free rate can be used and uncertainty handled separately.

Uncertainty should be evaluated in relation to

— the input data,

— the result,

— the ranking of alternatives.

3.4.3.2.2 Uncertainty in the input data

The quality of the result is a reflection of the quality of the input data. What level of uncertainty is acceptable is dependent on the objective of the life-cycle costing evaluation.

3.4.3.2.3 Uncertainty in the result

Validation of the result is done by quantifying uncertainty involved. To estimate the uncertainty in the results, the cost elements can be assumed to be independent and normally distributed. The standard deviation can then be calculated as follows:

$$\sigma_{\mathrm{T}} = \sqrt{\sum \sigma_e^2} \qquad (8)$$

where

σ_{T} is the total standard deviation;

σ_e is the standard deviation for cost element e.

An example of simplified uncertainty qualification of the results is shown in Table 2.

Table 2 — Example of simplified uncertainty qualification of the results

Cost elements	Alternative A			Alternative B		
	Value	Standard deviation		Value	Standard deviation	
	USD	Absolute	Relative	USD	Absolute	Relative
Capital expenditure	4 629 225			3 755 787		
Equipment purchase cost	3 755 787			2 969 692		
Installation cost	349 375	17 469	5 %	349 375	17,499	5 %
Commissioning cost	262 032	13 102	5 %	262 032	13,102	5 %
Insurance spares cost	262 032	13 102	5 %	174 688	8,734	5 %
Reinvestment cost						
Operating expenditure	70 099 653			71 788 286		
Man-hour cost	723 091	144 618	20 %	723 091	144 618	20 %
Spare parts consumption cost	802 364	160 473	20 %	751 689	150 338	20 %
Logistics support cost			20 %			20 %
Energy consumption cost	68 574 197	1 371 484	2 %	70 313 506	1 406 270	20 %
Revenue impact	32 679 485	1 307 179	4 %	41 088 537	1 643 541	4 %
Life-cycle cost						
High	109 315 455			118 205 831		
Medium	107 408 363	1 907 092	1,8 %	116 632 609	2 173 222	1,9 %
Low	105 501 270			114 459 388		

A more accurate, but a lot more time-consuming approach, is to take the same approach for all cost elements for all the years.

3.4.3.2.4 Uncertainty in the ranking of alternatives

When using equation (8) after evaluating two alternatives A and B and finding that A has the lowest life-cycle cost, the result is indicated reliable when:

$$\text{life-cycle cost}_{\text{A}} + \sigma_{\text{A}} < \text{life-cycle cost}_{\text{B}} - \sigma_{\text{B}} \qquad (9)$$

where σ is the standard deviation,

or a higher confidence level can be specified. In the example, the high life-cycle cost of alternative A is less than the low life-cycle cost of alternative B, i.e. the ranking of alternatives is indicated reliable and alternative A is considered best.

The approach outlined is only one of the options, and gives a fairly rough estimate. There will often be a need for a more complex approach.

The alternatives and the uncertainty in life-cycle cost can be pictured as shown in Figure 6.

Alternative A has the lowest expected life-cycle cost, but there is an overlap in the possible life-cycle cost range which indicates that alternative B could become better than alternative A.

A picture of alternative B minus alternative A is shown in Figure 5.

This distribution can, when evaluating the range of possible results, be derived by subtracting the result of alternative A from the result of alternative B. This difference between alternatives can then be visualized against the probability of occurrence.

When alternative B minus alternative A is greater than 0, alternative A is best. Initially there was a relatively high probability that the opposite could be the case. When correlated uncertainty (affecting both results the same way and by the same magnitude) is taken into account this probability is significantly reduced, and the ranking can be qualified.

The overlap in the potential range of results of the alternatives is evaluated in terms of the probability that the ranking of alternatives could be reversed. When investigating what parameters lead to the uncertainty, and neglecting those that give the same effect to all options, the overlap is reduced and the uncertainty that alternative A is better than alternative B increases.

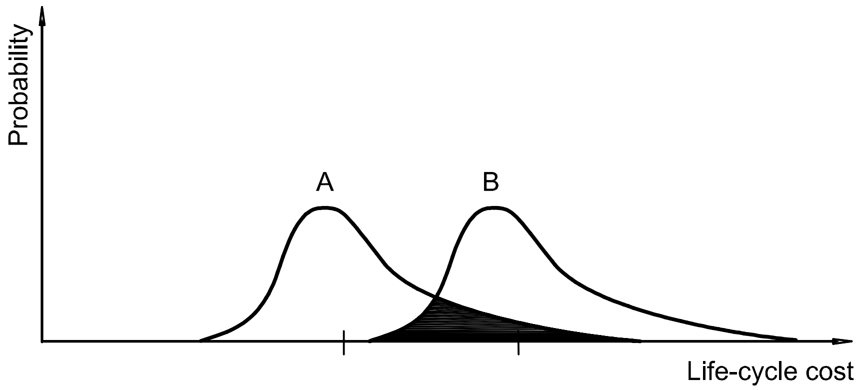
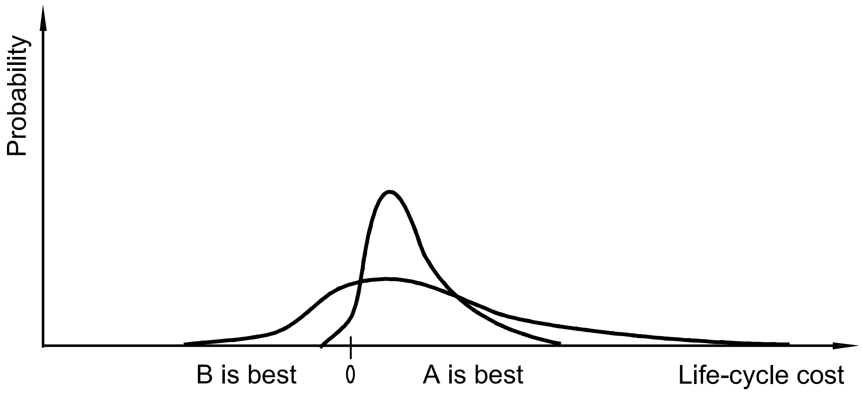


Figure 5 — Potential result range of alternative options A and B



Δ Life-cycle cost = alternative B – alternative A

Figure 6 — Possible range in difference in result, alternative B minus alternative A

3.5 Step 4 — Reporting and decision making

3.5.1 Reporting and decision making

Reporting and decision making implies applying the decision criteria that are set in Step 1 and documenting the options considered and the choices that are made. Irrespective of whether the report is formal or informal, written or verbal, the results should be presented with supporting arguments. Clarity and focus are important if the work is going to influence the decision. The following should be considered in preparing recommendations:

— the ranking allows the lower-order options to be eliminated;

— sensitivity analysis provides the arguments for the preferred solution;

— sensitivity analysis also identifies the opportunities to improve the solution;

— cost drivers identify the potential magnitude of the improvement, either through the definition of new options or changes to existing options.

The recommendations may take three forms as follows:

a) **the preferred option**, with supporting arguments;

b) **further iterations**, where there is potential to provide a significant improvement over the preferred option;

c) **future studies**, for work required in subsequent project phases.

The life-cycle costing model and results should be included in the final project documentation and operating manuals.

Not all life-cycle costing assessments will identify a clear choice, the difference between options may be small and within the range of uncertainty of the options. In these circumstances, the recommendation can be to take the final decision on some other basis.

3.5.2 Design iteration strategy

The focuses of the next life-cycle costing iterations should be identified. For example, after the process of system selection, the natural next iteration is system optimization with material selection, capacity and component optimization.

When defining the different system options, a number of different system solutions exist with regard to, e.g., selection of type and capacity of the different equipment units. To be able to make a good decision on system selection, one should go into some detail on the individual systems, but it is difficult to know when to stop. If not, the number of alternatives to be investigated increase dramatically, as shown in Figure 7.

For the iteration of system selection, choices should be made on issues such as pump type, capacity, levels of instrumentation, material selection, etc. One cannot carry out a full system optimization for all systems, but should establish those systems good enough for identifying the best system for that application.

The task of system optimization will then be the next iteration where materials, capacity, etc. are selected.

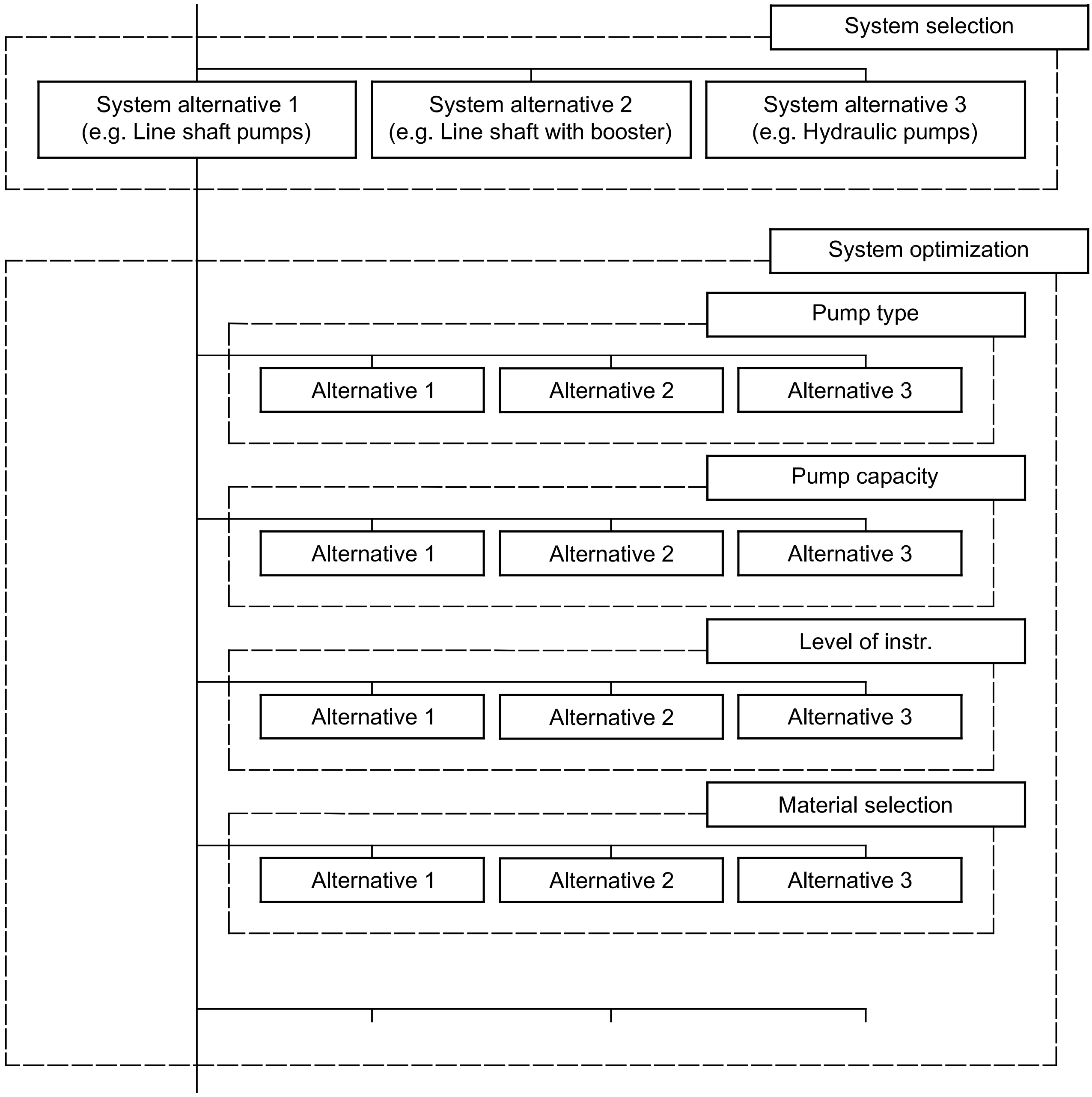


Figure 7 — Objective of life-cycle costing iteration vs level of detail for optimization

3.5.3 Future studies

When no further iterations are required for an option, the foreseeable studies for the next phase should be established. These can be issues such as:

— integration with the other systems;

— possibilities of combining functions;

— standardization of components, spares, storage locations, etc.;

— maintenance strategy;

— others.

4 Life-cycle costing related techniques

4.1 Economic evaluation methods

4.1.1 General

Alternative economic evaluation methods can be applied as criteria in the life-cycle costing process. However, the individual methods should be applied in a manner consistent with corporate policy and criteria.

The weaknesses of the methods applied should be kept in mind, and the decision rules of the individual methods must not be confused with the corporate decision criteria.

The methods are developed with a set of assumptions and the decision rules work only in that framework.

EXAMPLE When applying NPV in a normal situation with limited amount of capital for investment, a ranking of options with positive NPV is required and a decision is needed taking into consideration other company policies, such as impact on environment.

4.1.2 Net present value (NPV)

The NPV method is applied to evaluate the desirability of an investment. NPV can be defined as

$$NPV = \frac{S_1}{(1+k)} + \frac{S_2}{(1+k)^2} + \frac{S_3}{(1+k)^3} + ... + \frac{S_n}{(1+k)^n} - I_o \qquad (10)$$

or

$$NPV = \sum_{t=1}^{n} \frac{S_t}{(1+k)^t} - I_o \qquad (11)$$

where

S_t is the net cash flow at the end of year t;

t is the number of years into the future;

I_o is the initial investment outlay;

k is the discount rate, i.e. the minimum required return on the investment;

n is the lifetime (project duration) in years.

The NPV of a project is derived from discounting the net cash receipt at a rate which reflects the value of the alternative use of the investment funds, summing them over the lifetime of the project and deducting the initial capital outlay.

The decision rule associated with the NPV method is as follows:

— if NPV is positive, the project gives a positive return on investment and can be accepted;

— if NPV is negative, reject the project.

For investment analysis, the discount rate represents the company's requirement for return on investment for that specific level of risk. WACC is normally applied. This rate is the weighted average of interest rate on external capital (loans) and required return on equity.

The NPV of a project depend on the discount rate applied. This can be visualized as a NPV profile, see Figure 8.

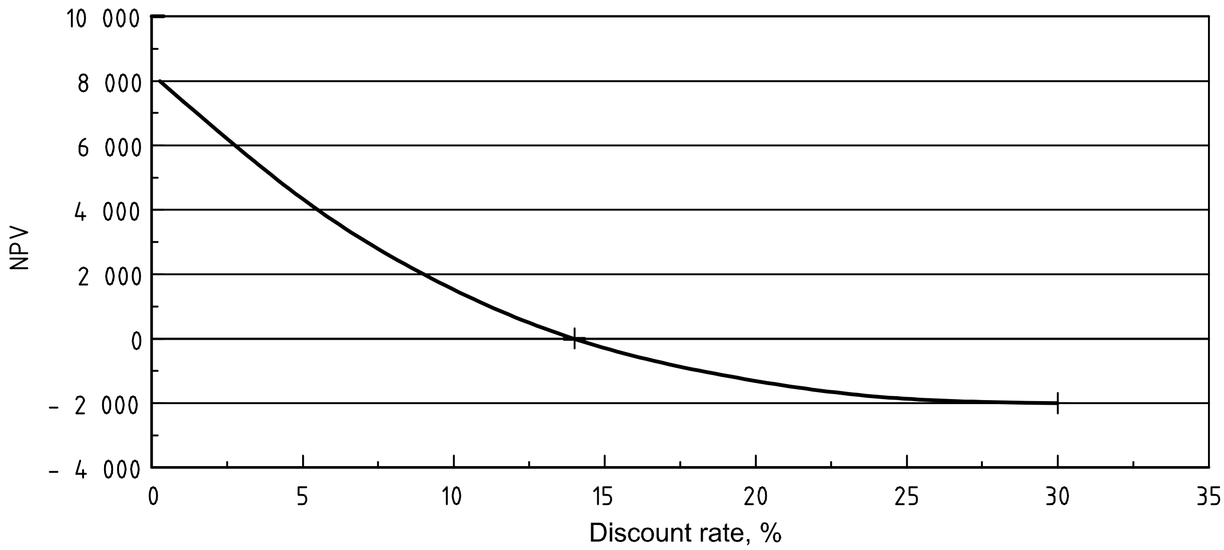


Figure 8 — NPV profile — The NPV as a function of discount rate applied

4.1.3 Life-cycle cost

The measure of life-cycle cost is applied for ranking the desirability of options when any particular of the revenue stream cannot be related to the objects under evaluation. Through minimizing the total cost of an asset or a function where impact on the revenue stream of failures occurring are taken into consideration as a cost, asset value can be maximized in a consistent manner. Life-cycle cost calculations are therefore applied to align technical decisions with corporate objectives.

The formula for discounting to be applied is the same as for calculating NPV. Different assumptions can be applied, and life-cycle cost is therefore defined as a separate measure.

Life-cycle cost is defined as the discounted sum of the main cost elements of

— CAPEX,

— OPEX,

— revenue impact,

— decommissioning.

CAPEX should cover the relevant initial investment outlay (I_o), from discovery through appraisal, engineering, construction and commissioning including modifications until normal operations are achieved.

OPEX should cover the relevant costs over the lifetime of operating and maintaining the asset.

Revenue impact should cover the relevant impact on the revenue stream from failures leading to production shutdowns, planned shutdowns and penalties. Only effects from the specific asset or system alone should be considered.

Decommissioning cost should cover relevant costs of abandonment of the asset, if there will be a cost difference between alternatives evaluated.

The elements to be included as main cost elements, and calculated, should reflect the level of detail necessary for arriving at the right decision.

The following cost elements should be considered for inclusion:

a) CAPEX

- — project management;
- — engineering personnel;
- — contractor project support;
- — asset purchase cost;
- — fabrication follow-up cost;
- — initial spares;
- — TTE;
- — documentation;
- — installation;
- — commissioning manpower;
- — commissioning consumables;
- — transport cost;
- — materials;
- — initial training;
- — insurance;
- — reinvestment cost, for equipment of expected lifetime shorter than installation/function lifetime.

b) OPEX

- — operation man-hours;
- — maintenance man-hours;
- — maintenance spares and materials;
- — tools and equipment;
- — scheduled overhaul;
- — sub-contractor’s manpower;
- — transport of personnel;
- — transport of consumables;
- — fuel/oil;
- — energy consumption cost;
- — chemicals;
- — onshore support;

- — rental/lease payments;
- — insurance.

c) revenue impact

- — cost of lost/deferred production — planned shutdown;
- — cost of lost/deferred production — unscheduled;
- — penalties;
- — tax credit/debit.

d) decommissioning cost

- — project management;
- — survey costs;
- — scheme development;
- — scheme implementation;
- — transportation;
- — plant and equipment;
- — care and maintenance;
- — storage costs;
- — asset sale.

Sunk costs, which are not relevant for the decisions to be made, should not be included in the calculations.

4.1.4 Internal rate of return (IRR)

The method of IRR is another time-discounted measure of investment desirability. The IRR of a project is defined as the discount rate that gives NPV $=$ 0.

$$NPV = \sum_{t=1}^{n} \frac{S_t}{(1+IRR)^t} - I_o = \sum_{t=0}^{n} \frac{S_t}{(1+IRR)^t} = 0 \qquad (12)$$

This is the discount rate that equates the PV of the net cash flow with the initial capital outlay, so that

$$I_o = \sum_{t=1}^{n} \frac{S_t}{(1+IRR)^t} \qquad (13)$$

where

S_t is the net cash flow at the end of year t;

I_o is the initial investment outlay;

t is the number of years into the future;

n is the lifetime (project duration) in years.

IRR shows how high the requirement for return on investment can be for the project to still be profitable. It finds the expected return on investment in the project.

The decision rule associated with the IRR method is as follows:

— when IRR exceeds the discount rate, the project gives a higher return on investment than the required minimum and can be accepted;

— when IRR is less than the discount rate, reject the project.

The normal decision rule is that an option which requires additional capital should only be selected if the IRR is greater than the hurdle rate or discount rate specified in the acceptance criteria.

The method of IRR is closely related to NPV. However, the methods can give different results when evaluating options against each other.

This is visualized from two investment alternatives, represented as NPV profiles in Figure 9.

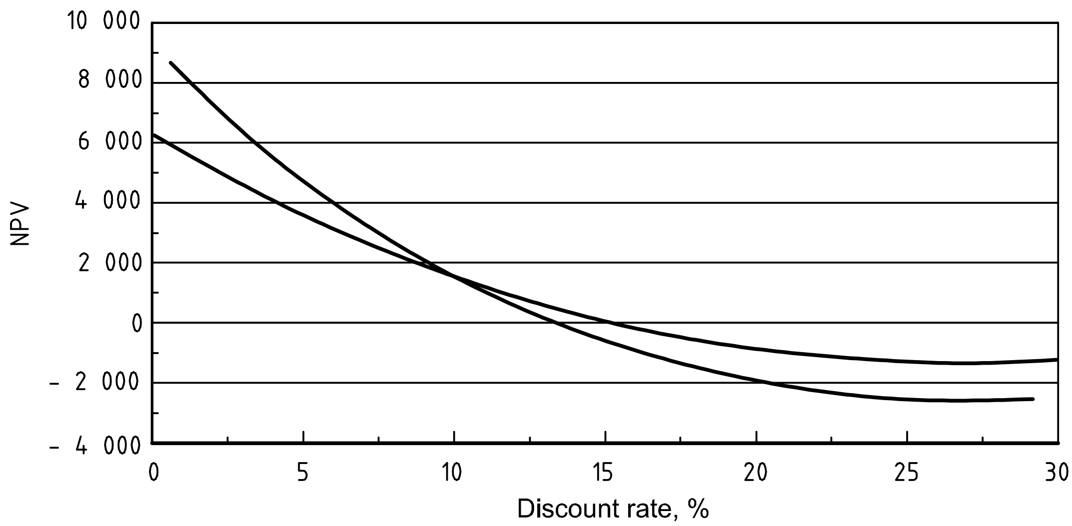


Figure 9 — NPV profiles of two alternative investments

From this representation of investment alternatives, it can be derived that

— NPV can give a different ranking of alternatives than IRR.

— NPV can give a different ranking of alternatives by using different discount rates if the pattern of the cash flow varies.

A project that has a net cash flow that fluctuates between positive and negative will have several IRR. The NPV profile will cross the axis at zero several times, see Figure 10.

Where there are several rates of return, this criterion is not a good basis for decision.

4.1.5 Profitability index (PI)

A variant of the NPV criterion is the PI.

The PI is defined as the PV of the project divided by the initial investment outlay (I_o), that is

$$PI = \frac{PV}{I_o} \tag{14}$$

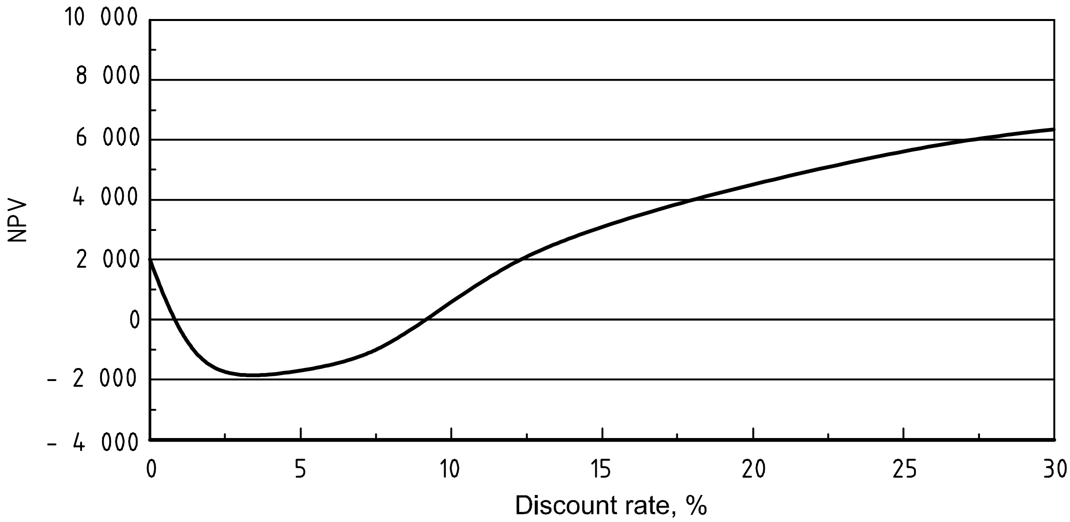


Figure 10 — NPV profiles of a cash flow fluctuating between positive and negative

The decision rule associated with the method of PI is as follows:

— if the PI is greater than 1, the project gives a positive return on investment and can be accepted;

— if the PI is less than 1, reject the project.

In the case of independent projects, the PI and the NPV criterion yield the same acceptance/rejection decision. If $NPV > 0$, then $NPV = PV - I_o > 0$ and $PV/I_o > 1$.

4.1.6 The payback method

The payback period is a simple method for determining a project's desirability, based on the number of years required to recover the initial investment outlay (I_o) from the project’s future cash flows.

$$\text{Payback period} = \frac{I_o}{\text{annual cash receipts}} \tag{15}$$

When the receipts fluctuate over time, the payback period is calculated by summing the receipts until the initial investment outlay (I_o) is covered.

4.1.7 Break-even

The break-even point is defined as the point where revenues and costs balance, i.e. where NPV $= 0$.

Break-even analysis is performed with respect to both cash flow and costs. The most common application is determination of sales volume required for generating positive net revenue.

$$\text{Break-even volume} = \frac{I_o}{\text{Price per unit} - \text{Operating cost per unit produced}} \tag{16}$$

The OPEX per unit constitutes both fixed and variable production costs, and represents a simplification for application on limited production opportunities such as a field reservoir.

4.1.8 Cost per standard barrel of oil

Cost per standard barrel of oil is a method for determining the lowest oil price a field development project can withstand and still be profitable.

$$\text{Cost per standard barrel of oil} = \frac{\text{CAPEX + OPEX}}{\text{expected total production}} \tag{17}$$

CAPEX and OPEX represent the discounted total cost of investments and operation for the project's life-cycle. Lifetime and resulting total production and OPEX are calculated from the expected oil price.

The method of cost per standard barrel of oil can provide a measure of the robustness of options, but is insufficient to determine which option is expected to be most profitable.

4.2 Reliability, availability and maintainability (RAM) techniques

4.2.1 General

In the process of life-cycle costing, the RAM techniques address the aspects of operation and can provide a basis for establishing the cost of sustaining a function over its lifetime.

In the iteration of life-cycle costing, the identification of cost drivers and the generation of options are important steps. The techniques listed can provide a structured approach for this.

4.2.2 Failure-mode effect and consequence analysis (FMECA)

The FMECA is a tool for establishing the effect a failure may have on a piece of equipment and the consequences this failure may have on the functionality of the equipment and the system of which the equipment is an integrated part.

The technique focuses on the weaknesses in a design with respect to availability and reliability. In principle the technique provides a ranking of the most frequent/severe and undetectable failures. It can be applied to the last nut and bolt, as in the aircraft industry, or at a higher level of interfaces between equipment, systems or plants. The highest-ranked failures are further analysed on a cost/consequence basis. Life-cycle costing is an ideal tool to assist in these evaluations.

An asset is broken down into its components. The potential failure modes of the individual components are evaluated. For the individual failure modes, the following should be established:

— the local effect of the failure and the failure frequency;

— the system consequence in terms of functionality and cost of re-establishment of the function.

These results can be applied as part of the life-cycle costing process, such as in identification of the potential cost drivers and the establishment of a structured breakdown of cost.

4.2.3 Availability and regularity modelling

Availability and regularity modelling is based on the predefined criticality of an equipment's role in a system, and the system's criticality in the overall production system. The system's failure modes and frequencies are modelled and simulated to determine the expected overall regularity of a production system.

The level of availability of equipment/systems is one of the elements which forms the basis for life-cycle costing evaluations in which life-cycle cost is balanced against the demand for availability.

The production unavailability contributions of the individual systems and the relationship between system downtime and production availability form the basis for life-cycle costing optimization of the process regularity and system capacities and configurations.

4.2.4 Reliability-centred maintenance (RCM)

RCM is a method or an approach toward maintenance of equipment, in which the focus is on the reliability of the equipment. The level of reliability of the equipment is directly related to the level of availability demanded for the equipment or the system. The reliability of equipment is calculated on the basis of the data derived from the FMECA analysis.

This technique is applied to optimize preventive maintenance activities. The RCM methodology involves both detailed evaluations and calculations and the process of continuous improvement of maintenance, in relation to reliability through monitoring and feedback.

Its application in relation to life-cycle costing is a part of optimizing the cost of operation.

4.2.5 Functional value analysis or value engineering

This is a technique which is particularly useful for the identification of cost drivers and subsequent option generation. Via a systematic approach, the functions of a procedure or design are analysed and costed. By proper definition of the functions, it is possible to create a distance from the design and come up with alternative solutions. The technique focuses on the high-cost functions for the generation of options. It is important in these studies to include all relevant stakeholders of the procedure or design under review. Life-cycle costing techniques should be used to carry out a screening of the most valid options. The process can be summarized in the following steps:

- information stage, in the form of presentations by participants on details of the procedure/design;
- function analysis;
- cost analysis;
- idea generation;
- idea ranking;
- idea evaluation;
- decision building;
- action planning.

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