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1 Basics of Cost Estimation

Determining the investment costs of a project is a significant part of project planning and profitability calculations. When determining the costs, a difference is made between cost calculation and cost estimation. Cost calculation is particularly used to determine production costs; cost estimation, on the other hand, serves to estimate investment costs based on planning [16; 27].

The exemplary schematic representation of a distillation process in figure 1.1 illustrates the key aspects of this book. According to the classical project cycle, the construction of such a plant can be divided into planning, procurement, construction and operation. Based on this cycle, the cost estimation book focuses on the systematic estimation of planning services, the procurement of equipment and materials as well as the construction and site costs. The operating costs are not taken into account, as the project is usually completed after plant construction and handover to operation along with a performance test.

The operating costs are company-specific. For an estimate of these costs, please refer to [15].

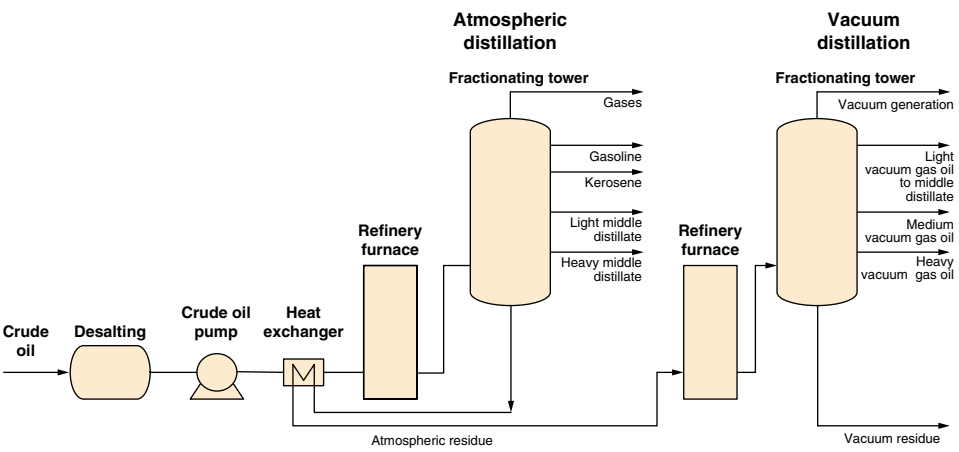

Figure 1.1 *Schematic representation of a distillation process* (according to [54])

1.1 Purpose and Objectives of Cost Estimates

Cost estimates support the investor in performing the following main tasks:

- Investment estimation
- Budget planning & cost monitoring
- Planning of the expenditure for an investment over time

For investment estimation, the expected costs have to be known, for example, in order to compare two alternative plants. Budget planning not only requires knowledge of the total amount of costs but also the costs related to the individual disciplines (mechanical / civil / piping / electrical & instrumentation, etc.) to facilitate budgeting and cost monitoring. In addition, knowledge of the expenditure over time is important for a company to provide for sufficient liquid assets.

1.2 Key Terminology Used in Cost Estimates

The following terminology is widely used in cost estimation:

- Basis of Estimate
- Cost Estimate
- **I**n**s**ide **B**attery **L**imits (ISBL)
- **O**ut**s**ide **B**attery **L**imits (OSBL)
- Allowances
- Contingency
- Escalation
- Total Base
- **T**otal **I**nvestment **C**osts (TIC)

2 Cost Estimates in the Project Phases

Project phases are a classification of systematic project management. The project begins with the so-called **F**ront-**E**nd **L**oading phases "Appraise" (FEL-1), "Select" (FEL-2) and "Define" (FEL-3), followed by the *execute* phase with detail engineering, the *construction* (plant construction) and *commissioning* phase as well as the *as-built* phase (recording of the new actual situation in all documents). A *gate review* takes place after each FEL phase to decide whether the project shall be transferred to the next phase. At the end of the FEL-3 phase, the ***F**inal **I**nvestment **D**ecision* (FID) is made. If the decision is positive, the project is transferred to the detail engineering and construction phase. No further cost estimate is scheduled after the FEL-3 phase (see table 2.1). If necessary, a review of the cost estimate versus actual costs is performed to increase the quality of future cost estimates.

Figure 2.1 shows the project process with the phases "Appraise", "Select", "Define", "Execute" and "Operate" [35; 41]. Final reviews are performed at the end of each phase where the planning services (*engineering*), cost estimate and schedule are scrutinized and approved. After successful completion of the define phase, the **F**inal **I**nvestment **D**ecision (FID) is made.

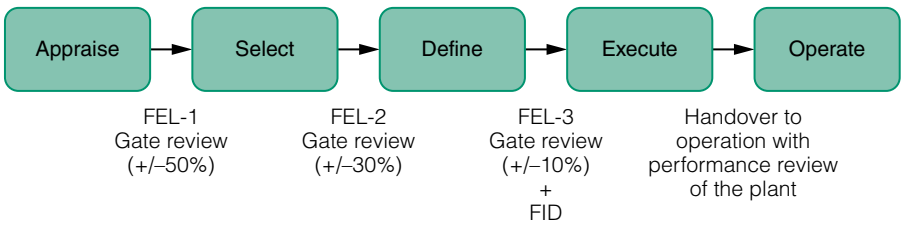

Figure 2.1 *Project process*

The cost estimates have different accuracies in each phase, ranging from ± 50 % (end of appraise) to ± 10 % (end of definition), and include the following cost centres: engineering (planning services), procurement (procurement costs for equipment and materials), construction (construction and installation costs) and miscellaneous (contingencies, commissioning services, etc.).

Table 2.1 *Summary of project phases*

Project Phase	Cost Estimate Type	Cost Estimate Accuracy	Gate Review
Appraise (FEL-1)	Cost estimate class 5	± 50 %	1
Select (FEL-2)	Cost estimate class 4	± 30 %	2
Define (FEL-3)	Cost estimate class 2	± 10 %	3 + FID
Execute	–	–	Handover to operation with performance test
Operate	–	–	–

IMPORTANT NOTE

The range (e.g. ± 50 %) of the first cost estimate from the appraise phase must not be exceeded by subsequent cost estimates (e.g. ± 30 %) in the further course of the project (with the same performance scope), see figure 2.2.

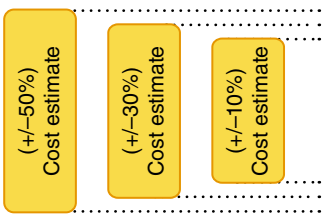

Figure 2.2 *Range (accuracy) of cost estimates*

2.1 FEL-1: Appraise (Feasibility)

In the FEL-1 phase, the following planning documents should be prepared for the project:

- Performance description of the plant, e.g. throughput (scope of work)
- Service description of the engineering office, such as preparation of the pressure drop calculation or static proof of pipe racks (scope of services)
- Preliminary heat and material balance
- Block flow diagram
- Preliminary equipment list
- Preliminary layout plan
- Level 1 schedule (milestone plan)
- ± 50 % cost estimate

For projects with **O**ut**s**ide **B**attery **L**imits (OSBL), the pipe rack length / sleeper length as well as the lengths of the main pipes in the OSBL range with **N**ominal **D**iameter (DN) and material are also required.

2.2 FEL-2: Select (Concept)

In the FEL-2 phase, the following planning documents should be prepared for the project:

- Performance description of the plant, e.g. throughput (scope of work)
- Service description of the engineering office, such as preparation of the pressure drop calculation or static proof of pipe racks (scope of services)
- Heat and material balance
- Preliminary one-line diagram (circuit diagram)
- Preliminary piping and instrument flow diagrams
- Preliminary layout plan
- Equipment list (number and types of equipment have to be defined)

- Equipment data sheets
- Requests for budget offers
- Preliminary piping list
- Preliminary tie-in list
- Level 1 schedule (milestone plan)
- Level 3 schedule
- ± 30 % cost estimate

2.3 FEL-3: Define (Front-End Engineering Design (FEED))

In the FEL-3 phase, the following planning documents should be prepared for the project:

- Performance description of the plant, e.g. throughput (scope of work)
- Service description of the engineering office, such as preparation of the pressure drop calculation or static proof of pipe racks (scope of services)
- Final one-line diagram (circuit diagram)
- Final piping and instrument flow diagrams for equipment and main piping
- Heat and material balance
- Final layout plan
- Final equipment list
- Final equipment data sheets and specifications
- Requests for offers
- Final piping list
- Final tie-in list for product-conveying lines
- Level 1 schedule (milestone plan)
- Level 3 schedule
- ± 10 % cost estimate

2.4 Execute

Detail engineering, purchasing and construction tasks are performed in the execute phase.

2.5 Operate

After the project is handed over to operation at the end of the execute phase, the operation phase begins, i.e. the so-called start of production with the new or modified plant.

2.6 Development of Costs Depending on Project Phases

Figure 2.3 shows the cumulative development of expenditures as well as the uncertainties in each project phase. It should be noted that up to 25 % of the total project costs (expenditures) are generally incurred up to and including the FEL-3 phase.

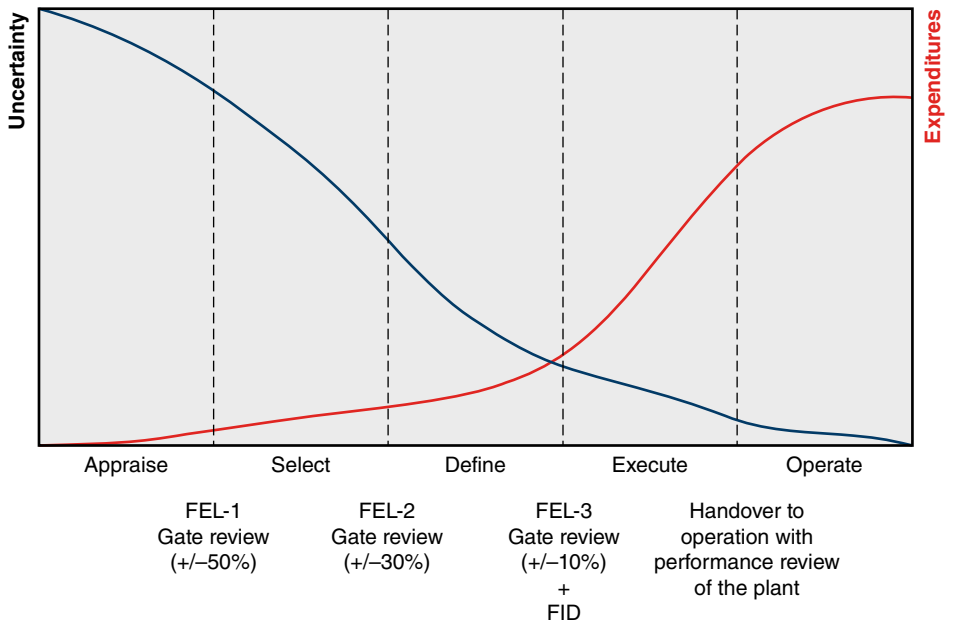

Figure 2.3 *Project expenditures versus project uncertainties*

The costs of implementing a change follow a similar pattern depending on the project phases. As a rule, changes can be integrated in planning at low cost up to the define phase (see also "Changes" in chapter 7).

3 Cost Estimation Types resp. Classes

In phases FEL-1, FEL-2 and FEL-3, cost estimates have different accuracies of ± 50 % to ± 10 %. There are three cost estimate classes, with the classification defined by AACE (**A**ssociation for the **A**dvancement of **C**ost **E**ngineering):

- ± 50 % cost estimates (class 5)
- ± 30 % cost estimates (class 4)
- ± 10 % cost estimates (class 2)

3.1 ± 50 % Cost Estimates (Class 5)

± 50 % cost estimates (class 5) are usually made in the appraise phase of a project. At this stage of the project, only the main equipment is known. The two methods "**factorised cost estimates**" and "**cost estimates based on comparable projects**" are particularly suitable for ± 50 % cost estimates.

3.2 ± 30 % Cost Estimates (Class 4)

± 30 % cost estimates (class 4) are usually made in the select phase of a project. At this stage of the project, the erection sites and basic piping route without utilities are known, besides the main equipment. ± 30 % cost estimates are normally performed using the "**M**aterial **T**ake-**O**ff (MTO)" method.

3.3 ± 10 % Cost Estimates (Class 2)

± 10 % cost estimates (class 2) are usually made in the define phase of a project. At this stage, all equipment as well as the erection sites and piping route of a project are known. ± 10 % cost estimates are normally performed with MTO-based cost estimates.

Table 3.1 documents the project phases with the cost estimate accuracies.

Table 3.1 *Classification of project phases with cost estimate accuracies*

Project Phase	Cost Estimate Accuracy	Cost Estimate Preparation Methods
FEL-1 phase (Appraise)	± 50 %	Factorised cost estimates, cost estimates based on comparable projects, MTO-based cost estimates
FEL-2 phase (Select)	± 30 %	MTO-based cost estimates
FEL-3 phase (Define)	± 10 %	MTO-based cost estimates

4 Cost Estimation Methods

This chapter highlights different methods of preparing cost estimates (factorised cost estimates, cost estimates based on comparable projects and **M**aterial **T**ake-**O**ff (MTO-) based cost estimates). It furthermore describes the requirements and the procedure for preparing partial cost estimates for the individual disciplines.

4.1 Factorised Cost Estimates

Factorised cost estimates always serve to draw conclusions about the total costs of a project based on a few known costs. This method of estimation is suitable for ± 50 % cost estimates and only for equipment related items, i.e. the costs of equipment including the other disciplines (such as civil, steel, piping, etc.) and planning services – all related to the ISBL section.

For example, if a project requires a new 1 000 m pipe rack and/or a new transformer house in addition to three tanks and six pumps, the costs for the pipe rack and the transformer house are **not included** in the factorised cost estimates.

Costs for the OSBL section must be estimated separately; this also applies to infrastructure measures (also in the **ISBL section**).

DEFINITIONS

ISBL: **I**n**s**ide **B**attery **L**imits – definition of the plant limits within which the main process takes place

OSBL: **O**ut**s**ide **B**attery **L**imits – all activities outside the defined plant limits

4.1.1 Lang Factor

The Lang factor is named after Hans Lang who, in the late 1940s, described the total costs of a project by the ratio of equipment costs to total costs.

Methodology

The estimation of equipment costs (including delivery and allowances) multiplied by a factor (Lang factor) yields the TIC value (**T**otal **I**nvestment **C**osts).

The factors differ for projects with [8]:

- solids [3.1]
- liquids (4.74)
- both (3.63)

The above factors are typical values found in published sources, however, the factor should be determined based on the project scope and location; if necessary, the Lang factor has to be adjusted.

EXAMPLE

Given:
Equipment costs (including delivery and allowances, but excluding installation costs) = 1 000 000 €
Products are liquids ⇒ Lang factor 4.74
Wanted: TIC
Solution:
TIC = 1 000 000 € × 4.74 = 4 740 000 €
TIC = 4 740 000 €

In the industry, however, it is also common practice to consider escalation and contingencies in addition to the TIC value.

4.1.2 Hand Factor

The Hand factor is named after W. E. Hand who, in the late 1950s, described the total costs of a project by means of equipment and discipline related allowance rates based on equipment costs.

Methodology

The equipment costs have to be determined (including delivery and allowances). Depending on the type of equipment, a percentage allowance is then added and multiplied for the various disciplines (piping, insulation, electrical, etc.). The costs of instrumentation material are to be calculated separately including allowances. Table 4.1 shows the accumulated allowances for **C**arbon **S**teel (CS) per equipment type [10].

Table 4.1 *Allowance rates for the Hand factor method*

	Columns	Heat Exchangers	Vessels, Tanks	Pumps	Compressors	Furnaces	Instrumentation
Allowance rate for CS	400 %	350 %	400 %	400 %	250 %	200 %	400 %

For higher grade equipment material, which is usually also more expensive, the allowance rate is multiplied by 0.8 for the remaining project costs, as some cost items are mostly independent of the equipment material, e.g. civil and electrical. The costs of the foundation of a tank made of stainless steel or CS remains the same.

Contingencies and escalation have to be considered when calculating the **T**otal **I**nvestment **C**osts (TIC).

EXAMPLE

a) Given:
Equipment costs for a stainless steel column (SS = **S**tainless **S**teel) incl. delivery and allowances, but without installation costs = 1 000 000 €
Instrumentation material costs amount to 150 000 €
Column allowance rate: 400 % × 0.8 = 320 %
Instrumentation allowance rate: 400 % × 0.8 = 320 %

b) Wanted: TIC

c) Solution
Total installation costs: 1 000 000 € × 320 % + 150 000 € × 320 % = 3 680 000 €
+
Contingency 25 % = 3 680 000 × 25 % = 920 000 €
+
Escalation 2 % = 3 680 000 € × 2 % = 73 600 €
=
TIC = 4 673 600 €

The Hand factor method has two essential advantages over the Lang factor method:

1. Different allowance rates are used for different types of equipment.
2. Using a factor that is relevant to the equipment material helps avoid overestimation.

4.1.3 Checklist for Factorised Cost Estimates

All factorised cost estimate methods are only suitable for ± 50 % cost estimates with the ISBL project share, the Total Base value of which comprises at least 20 % equipment costs. It is difficult to estimate the equipment share in advance. The following checklist can be used to determine the applicability of the Lang / Hand factor:

- No major new construction works like pipe racks or larger buildings necessary
- No modification work on columns, vessels, etc.
- No completely new DCS/FCS systems to be installed / set up
- No major temporary measure such as building a prefabrication infrastructure
- No OSBL project scope
- No infrastructure measures, such as new steam distribution stations or control rooms
- No overtime premiums and inefficiencies in turnarounds

All costs documented above have to be calculated separately (incl. planning services + contingency + escalation) and added to the TIC value from the factorised cost estimates.

4.2 Cost Estimates Based on Comparable Projects

Haven't we all heard this statement: "It's nothing but a copy and paste job" – and in the end, everyone wonders why the total costs have gone up and the costs for planning services are higher than expected. After all, the complete planning documentation was already available.

For this reason, cost estimates based on "comparable" projects should not be created rashly. The following questions should be considered instead:

- Are the comparable costs based on a cost estimate or an actual cost statement?
- Who verified that all costs are included in the reference project?
  - All planning phases?
  - Client costs?
  - Were costs transferred from the project to other items at that time?
- What are the differences to the reference project?
  - Building ground?
  - Distance between the plant components?
  - Existing plant or new construction?
  - What are the differences in planning (technical and commercial contract type)?

A deviation list needs to be prepared by the project team and discussed with everyone involved in the project who may introduce items for additional or reduced costs; these items shall be priced separately.

This procedure can only be used for ± 50 % and ± 30 % cost estimates. ± 10 % cost estimates should be created on an MTO basis. For reasons of plausibility, the values should by all means be compared with a reference project (adjusted if necessary).

4.3 Material Take-Off (MTO-) Based Cost Estimates

An MTO- (bill of materials) based cost estimate is applicable for all 3 types of cost estimates (± 50 %, ± 30 % and ± 10 %). Only the level of detail has to be matched with the project phase and thus the accuracy.

4.3.1 Structure and Approach

Each discipline involved in the project prepares an MTO with at least the following information:

- Category (such as civil or piping)
- Performance description (for example, mechanical excavation or pipe with nominal diameter DN100)
- Material
- Quantity

These items will be priced, and the respective MTO allowances have to be considered to cover any possible design changes. Chapter 5 "Structure of Cost Estimates" describes the basic structure. The MTOs can be either priced individually or summarized in a document, depending on the respective project requirements. In terms of transparency, the MTOs should be priced individually, and the totals of direct costs shall be summarized per category for all disciplines in a "details block" of the cost estimate. It should be possible to enter the allowances in this details block individually for each discipline.

4.3.1.1 MTO for Equipment

± 50 % Cost Estimates
Preparation of the equipment list with the following information (as applicable):

- Revision – to give a quick overview of changes in the project and to verify that the latest version is used for the cost estimate
- Equipment type (pump, tank, etc.)
- Type of construction (plate heat exchanger, etc.)
- Material
- Weight
- Wall thickness
- Power
- Delivery head
- Volume flow
- Insulation
- Heating (electric/steam)

Budget offers are preferred, but costs can also be based on in-house prices or calculated with cost estimation tools (such as Aspen Capital Cost Estimator).

± 30 % Cost Estimates
Equipment list like in ± 50 % cost estimates. To determine the costs, the scope has to be requested (budget inquiry). In-house estimations for main and secondary equipment are recommended for general comparison and for a comparison of ± 30 % offers.

± 10 % Cost Estimates
Equipment list like in ± 50 % cost estimates. To determine the costs, the scope has to be requested. In-house estimations for main and secondary equipment are recommended for general comparison and for a comparison of ± 10 % offers.

4.3.1.2 MTO for Civil & Steel

± 50 % Cost Estimates
Preparation of the civil MTO with the following information (based on applicability; a rough percentage breakdown by category is also possible if the planning status does not allow estimation by detail yet):

- Revision – to give a quick overview of changes in the project and to verify that the latest version is used for the cost estimate

Civil:

- Excavation volume in m^3 with machine excavation
- Excavation volume in m^3 with hand excavation
- Excavation volume in m^3 with mixed excavation
- New earth / gravel in m^3
- Disposal earth in m^3
- Contamination in m^3
- Quantity of concrete in m^3
- Reinforcement in kg

- Trench lining in m^2
- Cable trenches in m (AwSV area yes / no)
- Fire protection at the frame of columns etc. in m^2
- Additional project-specific requirements

Steelwork:

- Primary steel construction in the category <20 kg/m
- Primary steel construction in the category 20 kg/m < × <50 kg/m
- Primary steel construction in the category 50 kg/m < × <100 kg/m
- Primary steel construction in the category × >100 kg/m
- Special supports in kg for existing plants
- Gratings in m^2
- Ladders in m
- Handrails in m
- Fire protection on steel construction in m^2
- Additional project-specific requirements

The costs can be based on in-house prices or calculated with cost estimation tools.

± 30 % Cost Estimates
Preparation of the civil MTO with the following information (as applicable):

- Revision – to give a quick overview of changes in the project and to verify that the latest version is used for the cost estimate

Civil: Preparation of the MTO like in 50 % cost estimates, without percentage allocation.
The costs can also be based on in-house prices or calculated with cost estimation tools.

Steelwork: Preparation of the MTO like in 50 % cost estimates, without percentage allocation.
The costs can also be based on in-house prices or calculated with cost estimation tools.

± 10 % Cost Estimates
Preparation of the civil MTO with the following information (as applicable):

- Revision – to give a quick overview of changes in the project and to verify that the latest version is used for the cost estimate

Civil: Preparation of the MTO like in 30 % cost estimates.
The costs must be based on reliable prices; therefore, the MTO has to be requested or evaluated with framework contract prices.

Steelwork: Preparation of the MTO like in 30 % cost estimates.
The costs must be based on reliable prices; therefore, the MTO has to be requested or evaluated with framework contract prices.

The structure used for the different phases should be maintained in order to simplify comparison of quantity changes in the individual phases, see key quantities list (chapter 5.4).

4.3.1.3 MTO for Piping

± 50 % Cost Estimates

Preparation of a piping overview with the following information (based on applicability; a rough percentage breakdown by category is also possible if the planning status does not allow estimation by detail yet):

- Revision – for a quick overview of changes in the project and to verify that the latest version is used for the cost estimate
- Preparation of a pipe list for all medium-conveying lines (no trace heating pipes, nitrogen lines, etc.):
  - Information on the **N**ominal **D**iameter (DN)
  - Pipe length in m
  - Preliminary pipe class or pressure rating and wall thickness
  - Information on whether the pipe is in the ISBL or OSBL section
  - Insulation data
  - Weld annealing data (for material or medium)
  - Information on the weld seam percentage to be X-rayed
- Additional project-specific requirements (90 % prefabrication, etc.)

Complexities are then defined for piping, either in groups (ISBL / OSBL) or individually for each pipe.

Typical complexities are documented in table 4.2.

Table 4.2 *Complexity*

Project Area (Scope Area)	Complexity Values
ISBL	7 – 15
OSBL	2 – 5

EXAMPLE

The following example illustrates complexity determination:

Complexity 7 (corresponds to approx. 7 fittings and flanges on a 10 m pipe)
Pipe length = 100 m, DN25
There are various ways of having 7 fittings and flanges per 10 m pipe.

Table 4.3 *Complexity example*

Quantity of Fittings	Quantity of Flanges	Complexity
50	20	7
20	50	7

Table 4.3 shows that there are several options with different probabilities to meet the complexity specification. Therefore, the complexity structure should be coordinated with the piping department.