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Chapter 15

Fixed-capital cost estimating

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1. Fixed capital investment – definition and content

The planning, engineering and construction of a chemical process plant finds its justification in economic life. One of the essential phases in the evaluation of the economic soundness of a plant is Cost Estimation.

The scope of cost estimating activities is to calculate the cost of facilities, called fixed capital investment (FCI), which is "the sum of all direct and indirect costs, plus additional amounts for contractor's charges, incurred in planning and building a plant ready for start up".

It is first important to define the inclusions and exclusions of the FCI and particularly its physical battery limits:

· ISBL (inside battery limits) or "Onsite" costs are the costs of installing the process plant equipment and materials within a specific geographical location (battery limits).

· OSBL (outside battery limits) or "Offsite" costs are the costs of facilities located outside the process plants battery limits:

– Process buildings, like the control room, electric cabins, etc. (sometimes these buildings are part of ISBL costs)

– Auxiliary buildings, with services and furniture

– Site development (landscaping, site clearing and grading, roads, fences, connections to external railways and road networks, etc.)

– Utilities production (steam, water, power, air, fuel, refrigeration, hot oil, etc.) and distribution up to the plant BL

– Offsite facilities (waste disposal, incinerator, flare, storage, loading, electric substation, fire protection)

– Non process equipment (laboratory, workshop, maintenance, firefighting, lifting and handling equipment).

The OSBL costs can be evaluated, separately from the ISBL costs, using the same methodologies or, in case of very rough estimates, as a percentage of the ISBL cost.

The OSBL costs vary from 30–40% of the ISBL in the case of an expansion of existing facilities and up to 100–200% of the ISBL costs for the construction of a grass-roots plant.

Moreover the FCI does not usually include the following costs, which can be estimated separately or included under "Owner costs" or "Preproduction costs":

- Royalties, licence fees
- Platinum and other noble metals
- Raw materials and chemicals first filling
- Training costs
- Start-up costs
- Interests during construction

The FCI is normally built-up in two steps:

1. Total base cost, which is the bare sum-up of all direct costs and services related to the plant, at the date of the estimate

2. Additional amounts and contractor's

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charges, the content of which is described in 11.6.

In detail the total base cost, which can be evaluated by the estimating methods described in 11.3. to 11.5., is made up of the following:

1. Equipment costs; which include the cost of all itemized (or tagged) equipment listed in the flowsheet.

2. Bulk materials costs; which include the cost of:

– piping (pipes, flanges, fittings, valves, pipe supports)

– steel structures (racks, equipment supporting structures, stairs and ladders)

– electrical equipment and materials

– instrumentation and control equipment and materials

– insulation and painting materials.

3. Various materials: spare parts, catalysts (except Platinum), firefighting materials.

4. Transport and packing.

5. Construction: all field costs to build the plant on a given site, on a subcontract or on a direct hiring basis, such as:

– civil works (including civil materials that are normally part of the sub contract)

– mechanical erection (piping, equipment, steel structures)

– instruments and electrical erection

– painting and insulation

– vendors assistance.

6. Contractor services, like:

– Basic and detailed engineering

– Procurement activities

– Site supervision including the relevant temporary construction equipment and running costs.

2. Estimating levels and accuracy

Cost estimates may be required for a variety of reasons, such as:

– to provide project analyses and evaluations in the research and development phase

– to enable feasibility studies to be carried out

– to enable a company to select among alternative investments

– to assist in selection among alternative designs

– to provide for planning the appropriation of funds

– to enable a contractor to bid for a new project

– to serve as a basis for the cost control activity during job execution.

Each of the above estimating reasons is related to a moment of the project life cycle, from early screening and feasibility studies up to plant start-up.

Fig. 1 shows the project life cycle with the four phases that the project life can be split into and the corresponding type and level of estimating required.

From early feasibility studies, through the bidding or appropriation phase, up to the design and construction phases of a project, the estimates become more detailed and, normally, more accurate.

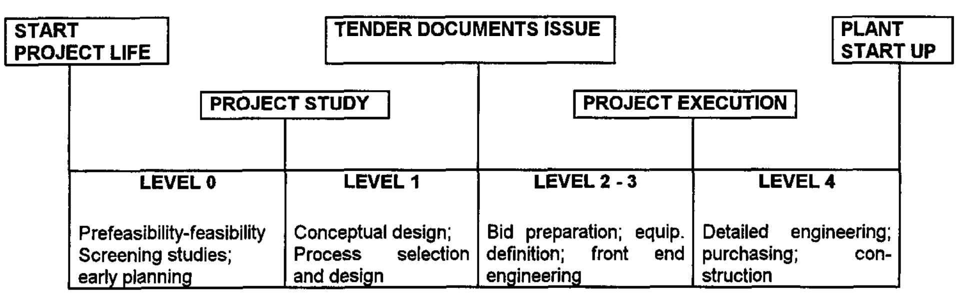

Fig. 1. Project life cycle.

Different types (or Levels) of estimates can be defined during the life cycle of the project, characterized by an increase in project definition and in accuracy of the information available for the estimate.

Since estimate accuracy is a function of the information available, each estimating type (Level) has its range of accuracy, or range of possible error.

Various classifications of estimating types are to be found in literature. This document describes the classification adopted in Italy by SNAMPROGETTI, which identifies five estimating levels divided into two groups:

· *Non definitive (or preliminary) estimates*: normally requested in the early stages of a project life when only few parameters (like capacity) or non definitive process sizing are available;

Two levels are envisaged, corresponding to two different estimating methods:

– Level 0 – Order of magnitude estimate (see 11.3.)

– Level 1 – Semidetailed estimate, or study estimate or factored estimate or intermediate estimate (see 11.4.).

These estimating methods are normally used for non binding estimates, cost comparisons, feasibility studies, etc.

· *Definitive (detailed) estimates*: the estimates used for binding quotations. They have good accuracy levels, require an extensive use of manpower resources and consequently have a high cost (in the range of 0.5 to 2.0% of the total investment cost).

Three Levels have been classified (levels 2, 3, 4) for this category of estimating, as explained in 11.5.

2.1. Estimate accuracy

This is defined as the assumed degree of possible "error" between the actual cost and the estimated cost. It is not, in reality, an "error" but the logical consequence of the poor or non final basic information available and the statistical averaging methods used.

As firmer basis information becomes available, the estimate becomes more accurate.

An indicative relationship can be suggested between the accuracy level of the estimate and the estimating level.

Fig. 2 shows this tentative relationship.

It should be noted that:

– In the early phases of a project the accuracy range is heavily affected by the type of plant to be evaluated and the quantity of statistical data available (better accuracy for well-known units).

The dotted lines show the accuracy range in relation to the type of plant. The higher line is for unknown plants, and the lower line for well-known units.

– Estimate accuracy is a function of the company's experience and its approach to project execution.

– The curve in Fig. 2 gives only a broad statistical indication of accuracy versus estimating level. In fact a Level 0 estimate for a plant that is very similar to a hundred other already carefully estimated and/or built plants will probably have a better accuracy than a Level 1 estimate for a completely new plant.

3. Order of magnitude estimate (level 0)

This is a rough estimate, with the widest range of error (probable error within 25 and 40% – in Fig. 2).

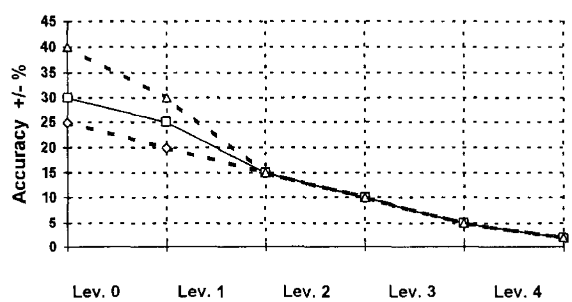

Fig. 2. Estimating levels and accuracy.

It is only necessary to know the plant type and feed capacity (e.g. Topping unit for 100 000 BPSD of crude) or the product capacity (e.g. 1000 T/day of ammonia).

It is based on the cost data available within the company for past jobs. This type of estimate cannot be used if statistical data on past jobs are not available.

Cost data taken from literature are sometimes utilized, but the result is not reliable as it is not possible to check the appropriateness of the information used.

This kind of estimate can be done in two ways:

(a) *Scaling up / down* (proratio): this is used when few or only one historical cost data is available for the plant.

The estimate can be made by using ''scaling factors'' (or exponents) with the following formula, which is applicable to a plant but also to each component:

$$C_1 = C_0 \times \left(\frac{P_1}{P_0}\right)^n$$

where: C_1 = cost of plant (or component) to be evaluated, P_1 = capacity of plant to be evaluated, C_0 = cost of reference plant, P_0 = capacity of reference plant, n = scaling factor.

Each plant has its scaling factor which represents the degree of cost variation in relation to the capacity ratio.

The factors range between 0 (no cost variation versus capacity) and 1 (directly proportional variation between cost and capacity). The above extremes are obviously only theoretical values and normally the factor for a plant varies between 0.5 and 0.8.

The factor for a plant is a function of the type of plant equipment.

For instance, instrumentation has a very low degree of variation (0.3–0.4), while big furnaces (like steam reforming) have exponents close to 0.85–0.9.

Exponents for plants are published in literature or can be taken from past experience.

When no values are available, a medium value of 0.6–0.65 can be assumed with no substantial error if the plant capacities are reasonably close.

For a correct estimate the following steps are to be taken into consideration:

– update the historical cost by cost indices

– adjust for significant project differences (i.e. piling, air cooling, sea water cooling, auxiliary boiler, utilities and offsites included/excluded, etc.)

– prorate the cost for capacity as per formula

– adjust for different plant location (location factor).

The closer the reference plant to the plant to be estimated, the better the accuracy of this kind of estimate.

(b) *Curve*: this consists in the use of plant capacity versus cost curves, developed on the basis of past jobs data. With this method it is necessary to have a large amount of historical data in order to be able to draft a curve.

Fig. 3 shows a curve for a plant, while the total cost of materials, escalated at a common

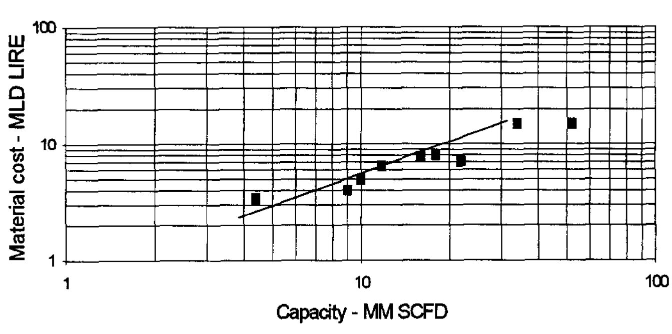

Fig. 3. Capacity curve for hydrogen plant.

data (year 1984 in the example) is plotted versus the production capacity of the plant.

It should be noted that the slope of the curve in the logarithmic scale represents the scaling factor (0.63 in the example).

The material cost has been considered in order to have a common basis not affected by the location factor, as the cost of materials from the historical data is mainly that of materials purchased in Italy.

The total investment cost in Italy can be obtained from the material cost by a factor: an overall factor 2 can be used in this case.

The curve represents an average interpolation among the various cost data (which are represented by points in the curve), and therefore the curve method has a better accuracy than the proratio method.

Table 1
Carbon Steel equipment and materials Snamprogetti Index

Year	Index	Ratio
1968	100.0	14.256
1970	134.3	10.616
1975	294.7	4.838
1980	581.9	2.450
1981	662.6	2.151
1982	813.7	1.752
1983	884.6	1.612
1984	956.4	1.491
1985	1050.9	1.356
1986	1113.8	1.280
1987	1163.5	1.225
1988	1221.0	1.168
1989	1336.6	1.067
1990	1382.2	1.031
1991	1419.8	1.004
1992	1386.5	1.028
1993	1425.6	1.000

3.1. Cost indices

Doing cost estimates normally requires, especially in the lowest estimating levels, extensive use of data banks, purchase order values, and cost records for plants or components.

Cost data are valid only on the day when they are materialized and in a relatively short time they become out of date due to inflation.

Hence cost records, data for equipment or plants purchased in the past are to be up-dated to present-day values by means of cost indices. The present cost of each item or plant can be obtained by multiplying the historical cost by the ratio of the present cost index divided by the index applicable at the date of the historical cost.

Obviously the escalation indices are strictly related to the country considered and differ from one country to another.

The cost indices applied to a project are normally composite indices obtained by adding weighted fractions of the basic component indices, mainly raw materials and labour, taken from official publications (in Italy ISTAT, ANIMA, ANIE, Camera di Commercio, etc.).

Composite indices are published, specially for the United States, like the ''Nelson Refinery Index'' in the Oil and Gas Journal, and the ''Chemical plant cost index'' in Chemical Engineering.

In Snamprogetti indices applicable to the Italian market have been built up since 1968.

As an example, the average annual value of the carbon steel materials index is shown in Table 1.

4. Semidetailed estimate (level 1)

This type of estimate is used when a certain degree of process work has been developed, even though it is not final or completed but only preliminary (for estimating purposes), on the basis of previous jobs. The following documents serve as the basis for this type of estimate:

– Process flow diagram (PFD).

– Equipment list by category, giving equipment size, design pressure and temperature, construction materials.

– Site survey, including labour productivity, availability of manpower and materials, local costs.

The PFD and equipment list are products of the process engineering development described in Chapter 9.

A significant improvement in information is clearly required above Level 0 estimate, and consequently a better level of accuracy obtained.

On the basis of the above information it is possible to establish the cost of the individual equipment items via equipment cost curves as described below.

Preliminary (budget – by telephone) quotations from vendors can be requested for critical items or when curves or in house data are not available.

The total erected cost of the plant is derived from the equipment cost in the following ways described below:

(a) factored estimate

(b) quantity parameters estimate.

The semidetailed estimate method, based on cost correlations, is the basis for most of the computer programs in the field of cost estimation and related aspects of process economics, and especially for costing sections of process flowsheet simulation or computer-aided process design programs, which are widely used as tools to prepare preliminary cost estimates, profitability analyses and project evaluations in research and development.

4.1. Factored estimate

Factor estimating is based on the principle that statistically a ratio (or factor) exists between the bare cost of equipment ex-workshop and the total erected cost of equipment including associated bulk materials.

A great variety of factors can be found in literature, based on studies produced in the US in the sixties and seventies, for each type of equipment or plant.

The factors are greatly affected by the plant construction materials (high cost materials, like SS, produce lower factors) and by plant sizes.

The overall factor TIC/E ranges from 3 (big or heavy plants; SS plants) to 5 (small plants in CS).

Table 2
Factored estimate scheme

Equipment cost (E)	
Bulk materials (piping, steel structures, electrical, instrumentation, insulation-paint mat.)	Fb – Bulk factor (40–100% of E)
Material Cost (M)	
Transport	Fc – Construction factor (50–80% of M)
Civil works (Mat. + Lab.)	
Erection	
Insulation-painting	
Erected cost (M + L)	
Services (engineering, procurement, Supervision)	Fs – Services factor (15–30% of M + L)
Total base cost (BC)	
Contingencies	Fk – Markup factor (10–20% of BC)
Escalation during construction	
Insurances	
Financial charges (except interests)	
Risk and profit (before taxes)	
Total investment cost (TIC)	

All the factors for construction refer to a base location.

The estimate is to be transferred from the base location to the actual site by applying "location factors" taken from previous experience or from a site survey.

Table 2 shows a factored estimate scheme, with a range of values for petroleum and chemical process plants (within battery limits) in Italy.

4.2. Quantity parameters estimate

The "bulk factor" shown in Table 2 has a wide range of variation according to the type of plant and its size.

The "quantity parameters estimate" improves the factored estimate accuracy, because bulk materials are calculated by means of overall quantity parameters, such as:

– Piping: total weight as the statistical ratio of equipment weight

– Steel structures: total weight as the statistical ratio of equipment weight

– Electrical equipment: total installed power

– Instrumentation: total number of control loops

– Insulation-painting: insulated/painted surfaces as a ratio of the equipment–structures–piping weights.

The above overall quantities are priced by ''all-in'' unit costs taken from past jobs on similar plants.

The cost of construction and services can be calculated by factors as per the factored estimate, or by estimating the total man-hours for construction and for engineering (standard man-hours plus local productivity factors to compute the actual man-hours) and the use of ''all-in'' hourly rates.

Table 3 summarizes the ISBL cost estimate (at 1993 costs in Italy) for a chemical plant in carbon steel and the resulting factors.

4.2.1. Equipment cost curves

Equipment cost curves are the most important estimating tool to evaluate the cost of main equipment estimates for Level 1, and also for Levels 2 and 3.

These curves are generally based, directly or indirectly, on a correlation of capacity versus cost. The capacity parameters normally used are: weight (for vessels, columns, heat exchangers); bare surface (air coolers); duty (furnaces); horsepower (pumps, compressors); inlet capacity (filters, vacuum equipment, etc.).

The curves are plotted taking information from recent purchase orders, or quotations, adjusted, when necessary, to the base data, base material (normally carbon steel) and base type of the equipment considered (normally the simplest one).

Factors are applied to the data derived from the basic curves, to account for different material, or different types of equipment.

A typical equipment cost curve is shown in Fig. 4 for a carbon steel pressure vessel, where each point represents a purchased vessel. The range of the observed data is indicated by the dotted lines, while the continuous line indicates the average or medium value, to be normally considered in the evaluation because it repre-

Table 3
ISBL cost estimate – level 1. Mtbe Unit

	Quantities	Cost (million lire)	Factor
Reactors (by vendor)	2 items	2.600	
Other equip. (by curves)	64 items	2.725	
Equipment cost		5.325	100
Piping	270 Tons	725	14
Steel structures	100 Tons	200	4
Electricals	700 kW	340	6
Instruments	43 loops	1.410	26
Insul.-painting materials		150	3
Materials cost		8.150	153
Transport and packing	5%	400	
Civil works (M + L)	29.000 hours	1.780	
Erection	80.000 hours	3.180	
Paint.-insulation	18.000 hours	500	
Miscellaneous, field costs	10% of constr.	590	
Erected cost		14.600	274
Services (engineering, procurement, supervision)	46.000 hours	4.000	
Total base cost		18.600	349
Contingencies, escalation, insurances, profit	(15%)	2.800	
Total investment cost		21.400	420

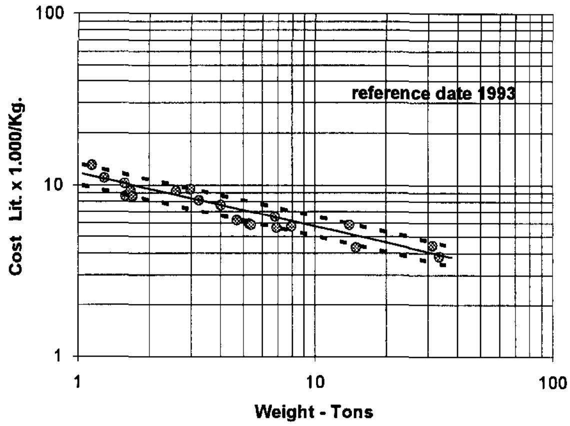

Fig. 4. Carbon steel pressure vessels cost.

sents the average of the company's performance (averaging concept).

5. Definitive-detailed estimate (Levels 2–3–4)

This is the most accurate estimating type, requiring the greatest effort to prepare. Whereas Level 0 and 1 estimates can be completed in a matter of hours or days by one estimator, definitive estimates require months to complete and, for large projects, can require the effort of thousands of man-hours involving all the company departments in the determination of quantities and costs.

It is important to bear in mind that an estimate is made up of essentially two ingredients: quantities (hardware) and unit costs. The best definition of hardware is the most important goal for a definitive estimate.

Therefore it is necessary to have the process design almost defined, and on this basis a certain degree of detailed engineering is to be developed in order to define the characteristics of all the items of equipment and bulk quantities.

There are basically three levels of detailed estimates: levels 2, 3 and 4.

The first one (Level 2) requires process design defined for the major items and is mainly based at least on the estimating method developed for each class of materials and services from past historical data (in-house averaging approach).

The second type of detailed estimate (Level 3) can be prepared after the process design has been completed and is much more detailed, especially for bulk materials, for which preliminary take-offs are made (specific project tailored estimate).

The third level of detailed estimate (Level 4) is similar to Level 3, but it is done when the detailed design is well under way and utilizes vendors' firm quotations or orders, final drawings and take-offs.

Tables 4 and 5 show respectively the basic documents required for each level and a summary of the methods used.

6. Additional amounts

To arrive at the total fixed-capital cost the estimator has to add to the base cost calculated in the previous chapters a number of provisions, normally expressed as percentages over the base cost, in order to cover:

- Escalation

Table 4
Detailed estimates. Basis documents

	Level 2	Level 3	Level 4
Process flow diagrams	*	*	*
Equipment summary (1)	*	*	*
Process specs.	(2)	*	*
Mechanical spec.	no	(2)	*
P. and I. diagram	prelim.	*	*
Plot plant	prelim.	*	*
Line specs	no	*	*
One line diagram – electric user list	prelim.	*	*
Instruments specs.	no	process	*
Foundations design	no	major	*
Underground layout	prelim.	*	*
Building	volume	dimensions	details
Local survey	*	*	*
Transport architecture	prelim.	*	*
Construction architecture	prelim.	*	*
Bar chart schedule	*	*	*

(1) Equipment list with sizes, materials and main process characteristics (i.e. DP/DT).

(2) Only for critical items (furnaces, compressors, package groups, big columns, reactors and pumps).

Table 5
Detailed estimates. Estimating methodologies

	·Level 2	·Level 3	·Level 4
Critical equip. and machines	·Budget quotes	·Binding quotes	·Precommitment or purchase order
	·Similar equipment cost	·Technical appraisal	
Other equipment	·Weight estimated via short cut methods	·Weight calculated	·Binding quotes
	·Cost from curves	·Cost from curves or budget quotes	·Technical appraisal
Piping instrumentation electrical mat. insul.-paint. mat.	·Weight/quantities estimated on statistical basis	·Weight/quantities from preliminary take-off	·Weight/quantities from definitive take-off
	·Average unit costs from in-house data	·Costing by price lists	·Costing by price lists or quotes
Civil works	·Quantities estimated on statistical basis	·Quantities by prelim. dimensioning	·Quantities by take-off
	·Cost as per construction	·Cost as per construction	·Cost as per construction
Construction	·In-house estimate (SMH ×efficiency× "all-in" hourly cost)	·In-house detailed estimate and/or S/C inquiries	·S/C quotations or precommitments
Services (engineering, supervision)	·Detailed estimate of engineering man-hours for each engineering activity and of man months for field supervision		
	·Costing by the official rates of the company		

- Contingencies
- Insurances–bank guarantees
- Financial charges
- Contractor's fee
- Local taxes and branch office

The above amounts, which are sometimes called "mark-up", are quite obviously considered by contractors in case of binding lump sum quotations but are to be taken into account also for preliminary, budget estimates.

6.1. Escalation

The Base estimate is calculated at the time when the estimate is prepared (present-day costs).

This estimate is valid only if the project is built instantaneously (overnight construction), which is not, of course, realistic.

Therefore, to arrive at the correct estimate of the final cost, the cost estimator must add a cost increase for inflation between to day and the plant completion date.

This is done for each major component of the estimate by multiplying the annual predicted escalation rate by the time period having as its starting point the estimate preparation date and as its final point the "centroid" (weighted average period) of execution of the activity.

The following items are to be considered for the escalation amount:

– annual escalation rate: this is assumed on the basis of the predicted change in labour cost and raw materials cost (specially C.S. or S.S. plates). The inflation rate in the country (consumer price index) is not a correct basis for this assumption;

– time period: this includes the period that elapses between the estimate preparation and the start of contract execution, plus the execution period of the relevant activity, calculated as follows:

· materials cost: the centroid is normally the centroid of the purchasing period. The materials are normally purchased at a fixed price lump sum cost and therefore the vendors have predicted and included the relevant escalation in their price

· construction: the centroid is normally considered at 2/3 of the construction period

6.2. Contingencies

This is a budgetary provision to cover:

- unforeseen costs or events
- errors in estimating
- inadequacies in scope definition
- uncertainties in unit costs and in estimating methods.

Contingencies are added mainly because the estimator feels that without this additional amount his estimate is on the low side, below the final actual cost.

The project uncertainties and the contingencies amounts are clearly linked to the degree of

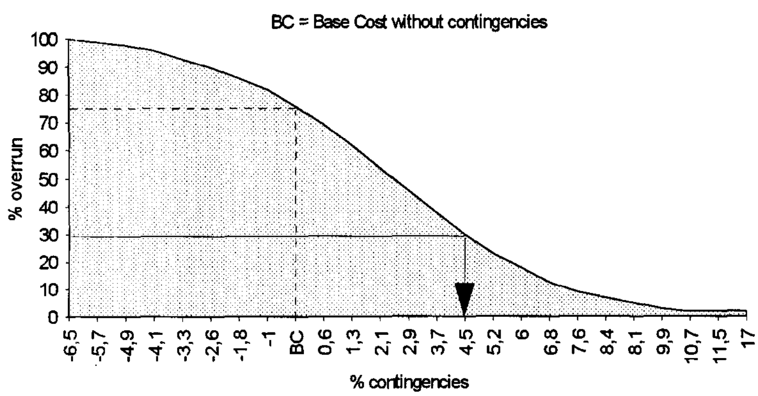

Fig. 5. Percent overrun risk versus contingency.

accuracy of the estimate and to the estimate level.

Contingencies are defined by the estimator and can range between a minimum of 3–5% for well-defined cost items and a maximum of 10–15% for items with a high degree of uncertainly.

Estimate risk analysis computer programs exist to help the estimator in evaluating contingencies.

ERA programs analyze the uncertainty factors and the corresponding range of values for each cost.

The result of the risk analysis program, using the ''Monte Carlo'' method, is a curve where the probability of overrun of the final cost in respect of the estimated cost is plotted against estimate variations (see Fig. 5).

In the example, the base cost (BC) without contingencies has 74% probability of overrun (too much!). By assuming an acceptable overrun risk value (30%), the corresponding contingencies value (4.5%) is suggested.

6.3. Insurances–bank guarantees

This cost item includes the cost of insurance policies, mainly erection all risk and third parties insurance, and the cost of bonds requested by Clients in the contract (bid bond, performance bond, etc.).

These costs are in the range of 1–1.5% of the total base cost.

6.4. Financial charges

This is related to the difference between the incomes curve and the expenditures curve. The amount can be calculated by multiplying the interest rate prevailing over the project time period by the average gap, in number of months, between the two curves.

6.5. Contractor's fee

This item covers all the contractor's overheads, risks and profit (before taxes) and it is obviously determined by:

- Contractor's policies
- Market situation
- Type of contract and relevant amount of risks.

For estimating purposes the contractor's fee can be considered between a minimum of 5% and a maximum of 10%.

6.6. Branch office and local costs and taxes

For plants built in foreign countries, when a branch office is to be established and local costs, taxes or duties are to be paid, the relevant amounts are to be carefully calculated on the basis of local investigations and added to the base cost.

7. For further reading

7.1. Books

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