# MEE 411 Valuation and Cost Engineering 3 Credits (45 LH)

## Cost Engineering

Cost - an engineering function.
Cost engineering function as distinct from Design engineering function.
Supporting skills and knowledge.
Canons of ethics for cost engineers
Role of cost engineer during evaluation phase.
Role of cost engineer during the basic design phase.
Role of cost engineer in contractor selection.
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Basic capital cost estimating.
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**Engineering Valuation**

Objectives of valuation work
Valuers' Primary duty and responsibility.
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Real property valuation.
Personal property valuation.
Machinery and equipment valuation.
Oil and gas valuation.
Mines and quarries valuation.

**INTRODUCTION**

**Cost Dimension of Engineering**

No bridge has ever been built without dealing with both the physical and cost dimensions. The engineering skills and knowledge required to deal with "costs" are quite different from those required to deal with the physical design dimension. From that difference, the field of cost engineering was born. So, cost engineers work alongside of and peers with engineers (or software analysts, play producers, architects, and other creative fields) to handle the cost dimension.

## COST - AN ENGINEERING FUNCTION.

### Cost

Cost is one of the three fundamental attributes associated with performing an activity or the acquisition of an asset that includes.

1. Price (cost),

2. Features (performance) and

3, Availability (schedule).

Cost is the value of an activity or asset. This value is determined by the cost of the resources that are expended to complete the activity or produce the asset. The need to understand and quantify the attributes of cost spawned the engineering discipline of cost.

**Application of Cost in Engineering**

Cost is in the forefront of the following:

1. in considering different technical options,
2. in conducting cost/technical trade-offs,
3. in establishing budgets,
4. in the submission and evaluation of price proposals,
5. in preparing for contract negotiations, and
6. in assessing the cost impact of introducing changes to existing designs.

engineering.

**Cost Engineering**

The American Association of Cost Engineers (AACE) defines cost engineering as “that area of engineering practice where **engineering judgement and experience** are utilized in the **application of scientific principles and techniques** to the problems of cost estimation, cost control, and profitability.” Wholistically, cost engineering is the application of scientific principles and techniques to the problems of estimation, cost control, business planning and management science, profitability analysis, project management, planning and scheduling.

**The Scope and Nature of Cost Engineering**

The discipline of ‘cost engineering’ can be considered to encompass a wide range of cost related aspects of engineering and programme management, but in particular:

1. cost estimating,
2. cost analysis/cost assessment,

3. design-to-cost,
4. schedule analysis/planning and
5. risk assessment.

These are fundamental tasks which may be undertaken by different groups in different organizations, but the term cost engineering implies

1. that they are **undertaken throughout the project life cycle** by:
2. trained professionals
3. utilising appropriate techniques, cost models, tools, and databases in a rigorous way, and
4. applying expert judgement with due regard to the specific circumstances of the activity and the information available.
5. In most instances, the output of a cost engineering exercise is not an end but rather an input to a decision-making process.

**Cost Engineering Post**

A **Cost Engineering Post** requires that the Cost Engineers

- specializes in one function with a focus on one side of the asset and project business.
- may have titles such as cost estimator, parametric analyst, strategic planner, scheduler, cost/schedule engineer, project manager, or project control lead.
- works for the business that owns and operates the asset (emphasis on economics and analysis), or
- works for the contractor that executes the projects (with emphasis on planning and control).

But, no matter what their job title or business environment, a general knowledge of, and skills in, all areas of cost engineering are required to perform their job effectively.

**The Purpose Cost engineering.**

Cost engineering problems include:

1. to be best able to predict or assess cost,
2. to minimise the risk and impact of overspends against budgets, and
3. to ensure that there is an appropriate balance between technical aspects and the related costs.

**Cost Engineering Function as Distinct from Design Engineering Function-Design to Cost Approach.**

Traditionally, the roles of establishing design solutions (Design Engineering) and of assessing the related costs (Cost Engineering) have been separated both in time and responsibility. Hence, the designer produces a design solution, which is then passed to other functions such as manufacturing and testing to add their inputs and finally ends up with the estimator to calculate the cost of implementing this solution., These exercises are often subject to time pressures that:

- do not allow for a solution that is optimal,
- likely to be too late, and
- would normally require the design loop to be repeated.
- which may be too expensive to be changed in a controlled way.

The alternative offered by cost engineering is to have cost information available when design choices are being made, so that they will be made in the knowledge of approximately what the different potential solutions are likely to cost. This awareness of the likely cost is essential:

1. To be able to make effective cost/ benefit trade-offs.
2. To drive the choice of solution (especially in circumstances where cost is a critical factor).
3. To be applied in a design-to-cost approach.

This is the distinction between Cost Engineering Function and Design Engineering Function**.**

**Cost Control through Design**

Cost of design depend on

- Design and design changes.
- Engineering innovation and solutions
- Choice of material etc.
- Choice of type of contract/condition of contract

Cost is therefore controlled through design by**:**

1. Controlling activities and managing resources and time
2. Defining the responsibilities of the design team
3. Giving scrupulous attention to minute detail of design
4. Constantly monitoring the financial provision throughout the entire design period by

- Undertaking various “stop and check”.
- Involving the client through monthly design progress report

Strict control at this stage will produce an in-house estimate which would become the cost-control document or financial guideline in the contract stage.

## SUPPORTING SKILLS AND KNOWLEDGE FOR COST ENGINEERING.

Engineering requires **special skills** which include:

- to think logically,
- use numerical techniques, and
- understand planning, design and construction methods.

A **cost engineer** is an engineer whose judgement and experience are utilize in the application of scientific principles and techniques to problems of estimation, cost control, business planning and management science, profitability analysis, project management etc. Hence, the cost dimension of engineering requires:

- calculation,
- analysis,
- planning, and
- control.

The **knowledge** needed by the cost dimension of engineering are therefore:

1. Broad technical background. The CE must be able to discuss problems intelligently with specialists, such as instrument and electrical engineers, structural and piping designers, scheduling engineers, and purchasing agents.
2. Previous experience as a project or field engineer.
3. An interest in nontechnical matters, such as labor productivity, union problems, overtime pay, construction tools, warehousing, and the many other items that make up the total project cost.
4. Ability to communicate successfully with all other members of the task force in the areas of:
    i. business and program planning
    ii. cost estimating.
    iii. economic and financial analysis.
    iv. cost engineering.
    v. program and project management.
    vi. planning and scheduling
    vii. schedule performance measurement and
    **viii.** change control.
5. Project Cost Accounting**:** The CE must be familiar with cost accounting though it is the accountant who keeps the cost records. It is essential that the CE gains an understanding

of cost accounting because he/she should be part of a team in the allocation of overhead and other indirect costs and should therefore understand:

- the terms total cost and profit. For a business to be successful, it must earn a profit.
- several sales terms employed by accountants, including project sales, income, selling price, contract value, or billable value. These represent the total expected income from the customer.
- the estimated costs of producing the product, be it a manufactured item or a service. Many firms use the term **total base cost** and commonly have a standard list that defines all the elements that account for the cost of the work. Subtracting the total base cost from the estimated project sales or income gives what is commonly termed **gross profit or total overhead and profit**. Another term used is **gross margin.**
- the costs involved in selling the product or service. The most common terms used are overhead cost or selling and general administration expenses. After deduction of the overhead costs there remains the **profit or loss before taxes**.

## CODES OF ETHICS FOR COST ENGINEERS

Codes of ethics

1. defines ideal behaviors for the purpose of enhancing public image,
2. establishes rules of conducts for policing its own members and
3. encourage value lading decision for public good (Poston 2000)

The code of ethics for cost engineering profession is encapsulated in:

1. The preamble (opening remark)
2. Fundamental canons

### 1. Association for Advancement of Cost Engineering (AACE) Code of Ethics

The Association for Advancement of Cost Engineering **AACE** has as its **Preambles**:

AACE members should uphold and advance the honour and dignity of cost engineering and the cost management practice and in keeping with the high standards of ethical conducts shall:

1. Be honest and impartial.
2. Should serve employer, client and the public with dedication.
3. Strive to increase the competence and the prestige of their practice and
4. Should apply knowledge and skill to advance human welfare.

In her canons of ethics are:

Canon 1. Members should hold paramount the safety, health and welfare of the public including that of the future generations.

Canon 2. Members should act in technical matter for each employer or client as faithful agents or trustees

Canon 3. Members should act in good faith toward all other members, other professionals and the AACE international on all matters.

Canon 4. Members should abide by the byelaws, policies, rules, requirement and procedures of AACE International and should not knowingly engage in any activities intended to compromise the integrity, reputation, property and or the legal rights of AACE International or any of its members.

2. **The International Cost Engineering Council (ICEC) Canons of Ethics**

ICEC did not believe that it could adopt a detailed Code of Ethics such as that of the National Society of Professional Engineers (NSPE) or any of the disciplinary engineering societies in the United States because it recognizes the different ethical criteria that apply around the world. ICEC instead, adopted a very simple set of ethical canons based upon the "Preamble" and "Fundamental Canons" of the "Code of Ethics for Engineers" of the National Society of Professional Engineers (NSPE).

Hence, in 2000, the International Cost Engineering Council (ICEC) adopted a set of "Canons of Ethics for Cost Engineers, Quantity Surveyors, and Project Managers." The ICEC Canons are brief but provide, in a limited number of words, a broad set of ethical guidelines (ICEC Canons of Ethics for Cost Engineers, Quantity Surveyors, and Project Managers Adopted by The ICEC Executive, July 21, 2000). The full text of the ICEC Canons is as follows:

**The Preamble**:

Cost engineering, Quantity Surveying, and Project Management

- are important and learned professions
- **members** of these professions are therefore expected to exhibit the highest standards of honesty and integrity.
- The **services provided** by cost engineers, quantity surveyors, and project managers require honesty, impartiality, fairness, and equity, and must be dedicated to the protection of the public health, safety, and welfare.
- all members of these professions must perform under a standard of **professional behaviour** that requires adherence to the highest principles of ethical conduct.

**Cannon of ethics:**

Cost engineers, quantity surveyors, and project managers, in the fulfilment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.

2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honourably, responsibly, ethically, and lawfully so as to enhance the honour, reputation, and usefulness of their professions.

**Question: Discuss the code of ethics for cost engineers from the perspective of Association for Advancement of Cost Engineering (AACE) and International Cost Engineering Council (ICEC).**

**Solution:**

- **Association for Advancement of Cost Engineering (AACE)** Preambles**:**

Members should uphold and advance the honour and dignity of cost engineering and the cost management practice and in keeping with the high standards of ethical conducts shall:

1. Be honest and impartial.
2. Should serve employer, client and the public with dedication.
3. Strive to increase the competence and the prestige of their practice and
4. Should apply knowledge and skill to advance human welfare.

- **The International Cost Engineering Council (ICEC)** Preambles:

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- all members of these professions must perform under a standard of professional behaviour that requires adherence to the highest principles of ethical conduct.

## NEW PRODUCT DEVELOPMENT PHASES

New product development process consists of six steps which include:

1. Idea generation
2. Product selection
3. Preliminary product design
4. Prototype construction.

5. Testing
6. Final design

**Idea generation**: Idea can be generated from

i. Market e.g., customer need, performance of other products
ii. Existing technologies

**Product selection**: This is the screening out of worst ideas and selecting those ideas which meet at least the following three conditions:

i. Market potentials
ii. Financial feasibility
iii. Operational compatibility

New product idea can be selected using the check list scoring method based on minimum acceptable performance.

**Preliminary product design**: concerned with

i. Developing the best design for the new product idea
ii. Ensure trade-off between cost, quality and product performance.
iii. Design that is competitive in market and producible by operators
iv. It must specify the product completely.

**Prototype construction**: Can take the form of

i. Handmade clay e.g., auto industries
ii. Single test by service industries

**Testing**: This is to verify market and technical performance of the product. Market test is to obtain quantitative data on the customer acceptance of the product and involves

i. Building enough prototypes
ii. Last for six months to 2 years
iii. Limited to small geographical region

Product technical performance test result is incorporated as part of the final design package.

**Final design**: This involves:

i. Developing the drawing and specification for the product
ii. Incorporating changes made during the prototype testing
iii. For service, fine tuning of standards and procedures.

**PROJECT COST ENGINEERING**

This is the engineering practice devoted to the management of project cost, involving such activities as estimating, cost control, cost forecasting, investment appraisal and risk analysis. Cost engineers also budget, plan and monitor investment.

**Project**

A project is a "temporary endeavor undertaken to create a unique product, service, or result" (Stackpole, 2010, p. 7). A project does not last indefinitely but instead has time constraints and is focused on generating a product, service, system or result that is distinctive to the organization. This uniqueness of project differs from a program, which can last indefinitely, or a portfolio, which is a collection of projects (Stackpole, 2010). A Project is therefore a specific activity on which money is spent in the expectation of return. Hence it has a specific objective, specific geographical location and would serve a group of population. It may be either a manufacturing project, construction project or research project. A Project includes all the activities which are necessary for

(1) Production of goods or services or both
(2) Increasing the capacity of existing projects
(3) Increasing the productivity of the existing means of production

**Purpose of Project Cost Engineering**

As the practice of applying formal processes, procedures, and techniques systematically, throughout each phase of the project in the areas of business analysis, planning and scheduling, estimating and cost control, the purpose of project cost engineering is to enable the project team to:

1. forecast and communicate realistic end of job costs and
2. forecast and communicate completion dates continuously during the project.

**Duties of CE in Project Cost Control**

On a project management team, the cost engineering group is the focal point of cost control. Its specific duties can be categorized as follows:

1. Provides project management with the information needed to control costs.
2. Points out areas of cost overruns.
3. Investigates and recommends corrective action.
4. Forecasts and prepares a complete project cost outlook monthly.
5. Monitors costs between outlooks and immediately advises the PM of any event or decision that has a significant cost impact.
6. Keeps a complete record of changes to the project.
7. Provides quick cost estimates for design alternatives.

8. Sends cost information back to home office or central file for use in future estimates.

**The three Ds of Project Cost Engineering: Definition, Documentation and Discipline.**

The three D's, Definition, Documentation, and Discipline are absolute essentials and, if any one of these are missing, project control is often compromised, with the familiar results of cost and schedule overruns.

**Definition**: The most essential ingredient for successful cost engineering is reliable and accurate project definition which:

1. establishes the scope and basis for the cost estimate and the project schedule, and
2. creates the budgets (both cost and time) for the project.

Its quality determines the accuracy of the budgets which is essential to the control of project changes and determines the use of the cost.

Without adequate project definition it is difficult, if not impossible, to budget and to exercise project control. Therefore, the CE, the project management personnel, and upper management need to devote considerable effort and time to establish good project definition early in and throughout the project life cycle.

**Documentation & Discipline:** In addition to the all-important project definition, concise and timely documentation and effective discipline or follow-up are two other elements essential to successful cost engineering and Total Cost Management (TCM).

Throughout the project life cycle, one of the CE's major responsibilities is to ensure that the requirements of the three D's are being met.

**Project Development Stages and Type of Cost Estimate**

Figure 1 below illustrates the typical life cycle of a project. Although the time spans will vary from project to project, the four phases shown will apply to all projects. The historical project phases, duration, activities and types of estimates are as follows:

1. Evaluation and planning- 3 months to 3 years- Preliminary estimates
   i. Screening studies
   ii. Early planning
   iii. Early economics
2. Conceptual engineering- 3 to 9 months – semi-detailed estimate
   i. Set design basis.
   ii. Major decisions
   iii. Set minimum cost.
   iv. Seldom questioned later.

v. Economic evaluation

3. Detailed engineering-1 to 2 years- definitive estimate
   i. Equipment definition
   ii. Equipment purchase
   iii. Bulk quantity designs
   iv. Construction drawings
   v. Definitive economics
   vi. Subcontract development.
4. Construction-1 to 3 years – start up.
   i. Labour productivity
   ii. Overtime
   iii. Wages
   iv. Construction overheads
   v. Subcontract administration.

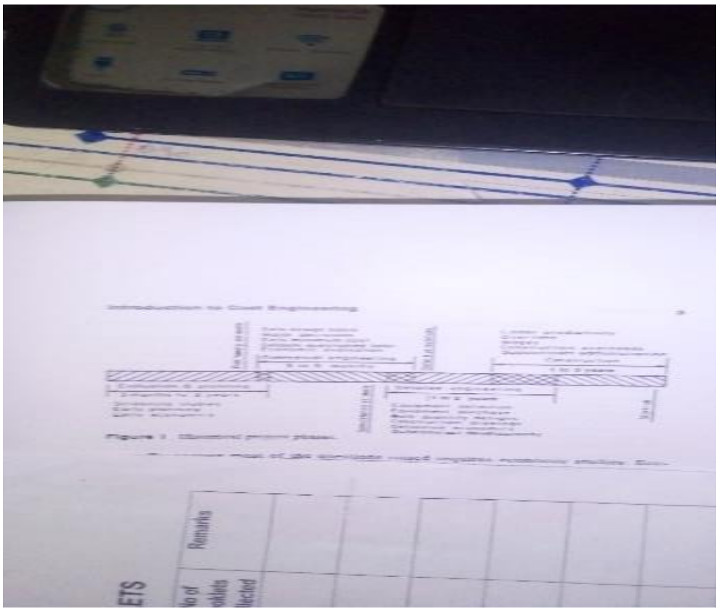

Figure: Typical life cycle of a project

In practice however, there are three basic stages or phases in project development (if we combine the execution phases of detailed design and construction into one phase), and, for each of these, estimates are made. The phases and some of the terms often used to describe these estimates are as follows:

1. Planning/evaluation stage: Screening, Preliminary, Quickie, Order-of-magnitude/guesstimates, Rough, gross, scope, etc.

2. Basic design stage: Preliminary, Budget and Semi detailed.
3. Detailed engineering design and construction: Definitive, Appropriation, Lump sum, Detailed.

The main purpose of this information is for the CE to analyse where the major cost elements are for the various projects for which the estimator will be asked to prepare estimates. From this, the CE will be able to determine where the effort and time are required to achieve the best results in both estimating and in cost control.

## THE ROLE OF CEs DURING THE CONCEPTUAL/EVALUATION PHASE

The evaluation or planning phase covers the period from inception until a decision is made on a definite plan of execution (i.e., what will be built, where, and why). Consequently, the first or evaluation stage can be the most critical because it is a period of

- screening,
- market evaluations,
- political and geographic considerations, and
- major high-level decisions (and indecisions!),

During this stage, the highly critical project decisions are made, involving the largest amounts of money. Once the project is approved, future decisions often involve only a portion of the project, but at the early evaluation stage, a “make-or-break” decision is made on the total project value. The length of this phase is subject to far more variation than any of the other three phases., The earlier the CE is brought into the picture, the more effective he can be. During the evaluation phase

- The CE provides the cost estimates needed in the **economic evaluations of several different areas**. For example, Different case studies reflecting alternate processes or alternate product yields of different geographic locations.
- **Evaluation of a preliminary sketch of a new process being developed**, in most cases, by a research or new-ventures department. In these evaluations, normally carried out by a planner or economist in the company, many factors must be considered, and, in most cases, cost is the most important factor.

Unfortunately, this is the stage where often, little or no cost-engineering assistance is sought by or made available to management. CE are therefore **challenged** as follows:

- The least information is available to CEs and, consequently, unless a concerted effort is made, their estimates will tend to have a poor and often unreliable basis.

- Further, because key people in the project are thoroughly engrossed in the selection process, CEs find it difficult to extract from them the necessary information to improve the estimate basis.
- In undisciplined organizations, CEs are often not consulted at all or only superficially during the evaluation stage, with the designer or researcher developing their own estimates through prorations of costs from general published data, their own "gut" feel, or other similar undesirable means.
- Inevitably, CEs are brought into the picture, usually during a later stage of project development. Often, they can, then, play only the role of "spoiler," uncovering the fact that a poor decision was made to proceed, the project is uneconomical and has to be scrapped at a hefty cancellation charge to the owner plus valuable lost time.

It is therefore essential to make CEs key persons in early project planning and to make a specific concerted effort to develop reliable data for the estimate basis. Once a decision has been made to proceed (with the assistance and involvement of CEs), the project moves on to the next phase, that of establishing a firm design basis for the selected route.

**In Summary**

- CE provides the cost estimates needed in economic evaluation of alternatives.
- CE provides cost estimate needed in the evaluation of a preliminary sketch of new process being developed.

## THE ROLE OF CEs DURING THE BASIC-DESIGN PHASE

The basic-design phase is the stage in project development at which, for the first time, the project and management persons involved turn their attention to the **specific basis for the selected route rather than the more generalized approach taken during the prior evaluation stage**. During the evaluation or screening phase, the main emphasis was placed on the evaluation of the difference in the costs of alternative approaches to select the most economical case. Little time or effort was spent establishing the basis for a total-cost picture.

Having selected a route from these many alternatives investigated during the evaluation stage, the owner now needs to finalize a total investment, based on the specifics of the selected case. In many cases, this investment will be the basis for a request to higher management for project approval and, therefore, must be of higher quality than the earlier **screening estimates**. Hence during this phase,

- The process or basic design is finalized.
- The physical layout of the facilities involved is given consideration.

- The need for support facilities (utilities and off-plot items, such as storage, roads, and fire protection) is reviewed.
- Timing (schedule) is given more serious consideration.
- The project execution strategy is also discussed (who does what, when, where).

Although during the basic-design phase the design basis will be finalized, many other areas that have significant impact on costs will not yet be sufficiently developed to have a firm basis; for the purpose of making the estimate, **CEs, with the assistance of the project people, will have to make certain assumptions**.

**In summary**

- CEs, with the assistance of the project people, will have to make certain assumptions in order
- To establish the total-cost picture of selected alternative for total investment for the owner.

## THE ROLE OF CEs DURING DETAILED ENGINEERING

Detail design is done by the Engineer and provides adequate information upon which the contractors can later be invited to tender. It may require:

i. Further site investigation
ii. Laboratory and experimental model's tests
iii. Paying more attention to aesthetic aspects of the design
iv. Obtaining the approval of external enforcing authority for certain aspects of the proposed works
v. Consulting with specialists and manufacturers of plant and equipment before finalizing the design.
vi. Consulting with contractors for informal check on

- Feasibility of construction method envisaged.
- Feasibility of cost estimates
- Ensure that detail comply with contractors manufacturing method of working if already appointed.

Ideally, detail design is required prior to inviting tender for construction because:

i. Tenderer understand what is required better.
ii. Price is more accurate.
iii. Execution would be smoother.

Where it is not practicable however, contract drawing upon which tenders are invited is supplemented by series of working drawings issued by the Engineer during construction.

After contract award, the term “cost engineer” means one thing to an owner and often something else to a contractor. An owner’s definition of a CE is an engineer who can and, most likely, will be involved in all aspects of cost engineering (i.e., cost estimating, cost control, and profitability). On the other hand, most contractors still use the term “cost engineer” to describe only their cost-control engineer and refer to the engineer developing the cost estimates as an estimator. Hence, after contract award, CEs embark on dual roles.

**Owner CE**

- is needed on the project by the owner throughout the project life to protect and monitor the economic decisions that were made much earlier by the owner,
- have the responsibility of reviewing and commenting on contractors’ detailed control estimates,
- reviewing their estimates for extra costs and change orders and,
- most important on a reimbursable project, appraising and monitoring the contractors’ efforts in cost control.

**Contractor CE**

- assist their project people to exercise cost control on the project.
- prepare the definitive control estimate (if not already done by the owner, as is sometimes the case) during the detailed-engineering phase.
- prepare the estimates for change orders (which, unfortunately, occur on all jobs), and
- fill the key role of cost-control engineer for the contractor’s project management team.

**Both CEs**

- the role of each of the cost-control engineers is considerably different, that of
- the contractors’ CEs is more detailed while
- the owners’ CEs works in broader terms,
- they are both working toward a common goal viz:
- **to complete the project at the lowest possible cost consistent with the project’s objectives and,**
- **hopefully, within the project budget**.

**In summary**

- CE protects and monitors the economic decision made earlier by the owner.
- The owner CE reviews and comment on the contractor’s detail control estimates, review the contractors estimate for extra costs and the contractors change orders.
- The CE also appraise and monitors the contractors cost control efforts.

On the other hand,

- The contractor CE assist the project people to exercise cost control on the project.
- Prepares the definitive control estimates and
- Fill the key role of cost engineer for the contractor project management team.

## ROLE OF CEs DURING CONSTRUCTION

The last phase of project development is construction, when the hardware that was designed and procured during the detailed-engineering phase is installed by contractors in the field. Here again we have both the owner's and the contractors' CEs playing important roles.

The role of the owners CE is summarized as follows:

1. Appraise contractors cost control performance.
2. Report/Analyze trends of costs outside contractor's scope.
3. Responds to managements cost related requests.
4. Interpret owners estimate.
5. Review contractors change orders and study estimates.
6. Administer cost incentive plan.

Roles of contractor CE include:

1. to carry the full responsibility for project cost control.
2. On reimbursement contracts the owner CE will monitor and evaluate the contractors cost control program and the contractor CE will operate accordingly.
3. must have a close but formal working relation with the owners CE.
4. implementation and execution, and the owner's CE role is appraisal and constructive suggestion.

**Both CEs**

- The owners' CEs continue to appraise the contractors' cost control efforts, monitor changes, and review extras.
- The contractors' CEs now become more deeply involved in providing input to the contractors' planning and scheduling team in addition to the areas of responsibility they had in detailed engineering.
- Their forecasts of labor workhour requirements are an essential ingredient for the project schedule and have an impact on predicting both final costs and final completion date.

***ROLE OF COST ENGINEER IN A PROJECT*: *A CASE STUDY OF EUROPEAN SPACE AGENCY* (*ESA*)**

**Introduction**

The European Space Agency (ESA) is Europe’s gateway to space. ESA is an international organization with 22 member states.

**Mission**

Its mission is the development of Europe space capabilities and to ensure that investment in space technology continue to deliver benefits to the citizens of Europe and the world. It is a multinational organization that provides for and promote cooperation among its members (of European countries) in space research and technology.

**Objectives**

Cost engineering in ESA is concerned with:

- estimating the cost of ESA procurements and
- evaluating the prices of the offers at different stages of consolidation of the technical definition of the items and of the programmatic context in which the procurement is performed.

**Framework**

ESA has a centralized Cost Engineering **Section** within the Systems Engineering and Support **Division** which is part of the Agency’s **Directorate** of Technical and Quality Management. Its centralization ensures a systematic gathering of cost, technical and schedule data for all areas of activity and all user Programmes in support of the preparation of independent cost estimates.

**Role of Cost Engineer During Conceptual Phase in ESA.**

**Programme preparation**: Programme Directorates often enlist the services of Cost Engineering when putting numbers together to present the financial elements of a programme proposal to Programme Boards. This may involve coming forward with **preliminary cost estimates** when there may be few or no inputs from industry yet available. An example would be the early consideration of candidate projects for future science missions.

At the Creative/Speculative Phase,

- Brainstorming techniques are used.
- All ideas are submitted without prejudgment:
- Use positive thinking.
- List all ideas.
- Use checklists to help.
- Use Imagination.
- Think of similar applications that may be unrelated.
- Locate where function is performed.

- Can item perform dual function.
- Creative techniques are used.
- Three-dimensional dimensioning.
- Criticizing ideas not allowed
- Accept all ideas.
- Encourage freewheeling.
- Atmosphere free of negative attitudes

**Role of Cost Engineer during Evaluation Phase.**

1. **Participation in Reviews**: Cost Engineering is sometimes invited to participate in design reviews, especially when there are some deliverables related to cost estimates or where there are cost implications with solutions adopted. This usually involves **providing independent assessment and analysis of the concepts proposed by the Contractor.**
2. **Participation in Cost Design Function (CDF) activities**: Cost Engineering participates in CDF activities as a member of the core team. In some ways this is the most fulfilling role as it is very much proactive, permitting the cost engineer to make a real contribution to **finding cost-effective design solutions.**
3. **Focus on the added value**: Whilst cost estimating and cost assessment remain fundamentally important activities, there is also a new focus on the added value coming about because of earlier cost-engineering involvement in programme life cycles.
4. **Identify affordable solutions to achieve programme objectives:** Its operations within the context of the CDF are a good model to illustrate its value and potential in this respect, namely working in a proactive way and making a major contribution to **identifying affordable solutions to achieve programme objectives**.

**The Processes at The Development/Evaluation Phase for The Cost Engineer Includes**:

1. Combine Ideas.
2. Refine Ideas.
3. Develop Alternative Functions.
4. List Advantages/Disadvantages.
5. Price-Out the Recommended Function.
6. Compare Original to Proposed Methods.
7. Include Sketches and Complete Description Of Proposed Methods.
8. Determine How Ideas Would Work.
9. Determine Approximate Cost of Each Idea.

10. Will Ideas Provide Basic/Secondary Functions?
11. Filter Out Better Alternatives.
12. Quantify Differences Between VE Team Proposal and Original Design.
13. Prepare Sketches for The VE Team Proposals And
14. Compare To Original Design Intent.
15. Select Evaluation Criteria for Matrix.

**Role of Cost Engineer during the Basic Design Phase.**

Offers general support to the project at the early phases of major projects.

1. Cost Engineering has the capability **to define and animate Design-to-Cost exercises** in cooperation with the Contractor and the ESA Project Team.
2. There is also the possibility **to carry out an internal independent cost-estimating exercise** involving the Project Team members, thus combining the benefits of cost-engineering tools and experience and the specific knowledge of those closest to the work. This may then be used in support of decisions concerning the project, or to provide inputs to reinforce the Agency's negotiating position.

**Role of Cost Engineer in Contractor Selection.**

1. Invitations to Tender (ITT) preparation: the costing requirements expressed in European Space Agency (ESA) Invitations to Tender (ITTs) for major projects are quite standard in terms of the need to complete the Price Breakdown Forms (PSS-A forms) and to submit the financial proposal (ECOS files). There is also a standard format for expressing the costing requirements in early phases with respect to the format and content of the cost estimates that the contractor is to produce.

2. Participation in Tender Evaluation Board (TEB): Cost Engineering is systematically involved in the main procurement actions as Tender Evaluation Board (TEB) or Cost Panel members.

i. The first responsibility when industrial financial proposals are received is to interpret them (using the ECOS files) to give Panel/TEB members the best possible understanding of the price as proposed by the bidder.

ii. In addition, a "should cost" analysis is usually prepared to support the assessment of the cost which has been proposed and to subsequently allow the ESA negotiation team to orientate its discussions with the selected or short-listed bidders.

3. Industrial Cost Auditing Section: The Cost Engineering Section also works closely with the Industrial Cost Auditing Section with respect to determining the acceptability of the rates and overheads, profit rates and price-revision formulae proposed by tenderers.

4. ESA is also actively encouraging the development of the cost-engineering capabilities of its contractors, apart from identifying cost-engineering principles and practices in its own.

**Role of Cost Engineer during Construction**

During construction the cost engineer analyses Value Analysis Change Proposals (VACPs) of the contractor. VACPs

- reduce the cost or
- duration of construction or
- present alternative methods of construction,

without reducing performance, acceptance, or quality. At this stage the alternatives presented to the user/owner are VACPs. To encourage the contractor to propose worthwhile VACP's the owner and the contractor share the resultant savings when permitted by contract.

**Benefits of Cost Engineering for ESA and Industry**

1. ESA and its industrial contractors have a mutual interest in practising and promoting cost-engineering in support of **the goal of achieving cost-effective performance.**
2. Space projects tend to be inherently complex and costly, and so being able to control costs and to **achieve cost-effective missions** is extremely important for the Agency and its Member States who ultimately provide the funding.

# COST ESTIMATING

## Introduction

**Cost estimating is** the predictive process used to quantify, cost, and price the resources required by the scope of an investment option, activity, or project. It is one of the cornerstones of cost engineering and total cost management. The output of the estimating process, the cost estimate, may be used for many purposes, such as

• determining the economic feasibility of a project,

• evaluating between project alternatives,

• establishing the project budget, and

• providing a basis for project cost and schedule control.

- quantifying, costing, and pricing or any investment activity such as building an office building, process power plant, developing a software program, or producing a stage play.

**Cost Estimating & Cost Accounting**

1. Cost estimating is the estimation of the expected cost of producing a job or executing a manufacturing order before the actual production is taken up or predicting what new product will cost before they are made. On the other hand, costing or cost accounting means classifying, recording and allocating the appropriate expenditure for determining the cost of production and achieved by keeping a continuous record of all the costs involved in manufacturing.
2. Hence costing or cost accounting gives the actual expenditure incurred on the production of components based on the record of expenditure on various activities involved when the product has already been manufactured whereas estimating is a type of forecasting and gives the expected expenditure to be incurred on the manufacture of the product before the actual manufacturing is taken up.
3. Further, cost estimating is done by qualified engineers whereas costing is done by accountants or cost accountants.

**Application of Cost Estimates**.

Estimates are the foundation of all cost engineering activity. They are made for several reasons including:

1. Feasibility studies
2. Selection from alternate designs
3. Selection from alternate investments
4. Appropriation of funds
5. Presentations of bids and tenders

**Purpose of Cost Estimation**

The purpose of cost estimation are:

i. To give an indication to the manufacturer whether the project to be undertaken will be economical or not.
ii. To enable the manufacturer to choose from various methods of production the one which is likely to be most economical, as all possible methods of production for product are analysed and evaluated.
iii. To enable the manufacture to fix the selling price (sales price) of the product in advance of actual production. This is required to ensure that products will be

competitive and the also to provide a reasonable profit on the investment of the company.

iv. To help in decisions to make or buy.

v. To give detailed information of all the operation and their costs, thus setting a standard to be achieved in actual practice.

vi. To give an estimate of the total expenditure expected to be made on a project enabling the management to arrange the necessary finance or capital.

vii. To help a contractor to submit accurate tenders for entering contract to manufacture certain products.

viii. To enable the management to plan the procurement of raw material etc. as it gives detailed requirements.

**Cost of Making Estimates**

A cost estimate does not come free, and the cost of preparing the estimate rises rapidly with the accuracy required. From a practical point of view, the estimate cannot be prepared without adequate engineering work to support the estimate. In other words, engineering must be done to an adequate level to support the estimate.

The expense of an estimate may or may not be calculated to include the cost of detailed engineering required to prepare the estimate.

Thus, whether engineering costs are a part of the cost of making an estimate, the point is moot. Engineering costs will still be incurred. For example,

- in an order-of-magnitude #1 million estimate, estimate cost is about 0.15% of the estimated amount.
- a budget estimate increases this cost to about 0.6%.
- a definitive estimate raises the cost to about 2.0%.

In another scenario,

- for an order-of-magnitude #1 million estimate, estimate cost increases to about 1.4% of the estimated amount.
- the budget estimate increases to about 3.5%; and
- the definitive estimate raises to about 6.0%.

Clearly, the cost of engineering work must be considered when deciding upon the level of estimate which is required. To perform an estimate at a higher level of accuracy than required is a waste of resources. On the other hand, to attempt to save money by not doing sufficient engineering work leads to estimates which are far less accurate than may be necessary. The estimator must understand the purpose of an estimate and the level of accuracy which is needed.

**Methods of preparing a cost estimate**

There are several different methods of preparing a cost estimate depending on the purpose, the level of planning, and/or design, as well as the project type, size, complexity, circumstances, schedule, and location.

The level of requirements and techniques therefore depend

(1) status of Project life cycle,

(2) the detail information available,

(3) cost estimation methods (e.g., parametric vs. definitive),

(4) constraints and other estimating variables such as time.

These methods can fall into categories such as

- parametric,
- historical bid based,
- unit cost/quantity based, range, and
- probabilistic risk-based estimates

**Deterministic and Probabilistic (Conceptual) Approach for Cost Estimation**

(1) Generally, in the deterministic approach, information about uncertainties and their characteristics such as higher or lower values, ranges of quantities, and potential costs cannot easily be taken into consideration even though this information is generally available or can be estimated. On the other hand, the probabilistic approach used best fit probability distributions to model the uncertainties and risk in the cost estimate. Hence the fundamental difference between these two cost estimation approaches (probabilistic and deterministic) is that by using the probabilistic cost estimation approach, we are explicitly enabling the modelling of the uncertainties and risk associated with the estimate using appropriate statistical distributions. The main advantages of the probabilistic cost estimating approach is therefore its ability to provide insight into the accuracy of the estimate and the impact of uncertainties and risks of cost overruns.

(2) As the level of project definition increases, the estimating methodology tends to progress from conceptual - stochastic or factored to deterministic methods.

(3) With conceptual estimating methods, the independent variables used in the estimating algorithm are generally something other than a direct measure of the units of the item being measured. They usually involve simple or complex modelling (or factoring)

based on inferred or statistical relationships between costs and other, typically design-related, parameters. Often, the cost estimating relationships used in conceptual estimating methods are at least somewhat subject to conjecture.

(4) For deterministic estimating methods, the independent variables used in the estimating algorithm are more or less a direct measure of the item being estimated, such as straight forward counts or measures of items multiplied by known unit costs. It requires a high degree of precision in the determination of quantities, pricing, and the completeness of scope definition. Of course, any estimate may involve a combination of conceptual and deterministic methods.

(5) Further, conceptual estimating methods require significant effort in data-gathering and methods development before estimate preparation ever begins. There is a significant effort in historical cost analysis to develop accurate factors and estimating algorithms to support conceptual estimating. Preparing the conceptual estimate itself takes relatively little time, sometimes less than an hour. In contrast, a deterministic (or detailed) estimate requires a large effort during the actual preparation of the estimate. The evaluation and quantification of the project scope can take a substantial amount of time, sometimes weeks or even months for extremely large projects. Research and application of accurate detailed pricing information, and application of specific estimating adjustments to the quantified scope, can also take considerable time.

**Types of Cost estimates**

Under Deterministic cost estimating are the

- Parametric,
- Detailed,
- Comparative, (Unit, cost, and Power law and sizing method).

Parametric cost estimating (top-down estimating) method is generally used during the earliest stage of the project. However, it can also be used to establish a baseline at any stage, for comparison or validation of other estimate.

One classification system for cost estimates is based on design level when the product is designed. The three level of design considered are:

i. Conceptual design
ii. Preliminary design
iii. Detailed design

**Conceptual Design Cost Estimating Methods**

Conceptual design stage is that stage at which

- only the functional requirements are considered by the designer
- using techniques such as feature-based design and/or solid modelling and
- only a rough magnitude of estimate can be obtained.
- Geometry of parts and materials are not known at this stage.
- The accuracy of conceptual cost estimates is approximately -30% to +50%.
- The cost estimation methods used at this level are:

1. Expert opinion
2. Analog methods
3. Formula based methods.

**1. Expert Opinion**

Here, back up and /or historical cost data are not available, getting expert opinion is the only way for estimating cost. The disadvantages of this method are:

1. The estimate is subjected to bias.
2. The estimate can't be quantified accurately.
3. The estimate may not reflect the complexity of the product or project.
4. Reliable data base for future estimates are not possible.

Despite these disadvantages the expert opinion is useful when historical data base is not available. It is also useful to verify cost estimate arrived at using other methods of conceptual estimating (like analogy method and formula-based methods)

**2. Analogy Method**

Analogy estimating derives the cost of a new product based on past cost data of similar products. Cost adjustments are made depending on differences between the new and previous product/system. Analogy estimating requires that the products be analogous or similar and products manufactured using similar facilities or technology.

- If the technology changes the analogy estimating relationship must be changed to reflect the changes in in technology.
- Another limitation of this method is that analogy estimates often omit important details that makes cost considerably higher than the original cost estimates.

**3. Formula Methods**

a. Factor method.
b. Material cost method
c. Function method
d. Cost -size relationship

These methods are known as Global Cost Estimation methods. When applying conceptual formulae care must be exercised since the cost data needs to be updated and, they should be documented as to the range applicable.

a. **Factor Method**: According to this method:

   Estimated cost of an item = Factor for total cost estimate x Quantity of major cost item

Some examples of factors are:

i. Cost of construction per km of highway
ii. Cost of fabricated component per kg of casting
iii. Cost of house construction per SQ, M of liveable space.

**Example**: If a casting weighed 15kg, and the factor of the cost of casting per kg of casting #75, what is the estimated cost of the casting?

Estimated cost of the casting = 75 x 15 = #1125

b. **Material cost method**: Material cost method predicts the total cost of the product based on the ratio of the material cost of the product to the material cost share of the total cost i.e.,

$$\text{Estimated cost of item} = \frac{\text{Material cost of item being estimated}}{\text{Material cost share of item being estimated (in \%)}}$$

Used in complex assemblies. Example of material cost share:

| Product | Material cost share (%) |
|---|---|
| Passenger car | 65% |
| Diesel engine | 50% |
| Clocks, watches | 25% |
| Glass products | 10% |

**Example**: If the material cost of an automobile was #2.5, what would be the total cost of the automobile? Use the table above.

Estimated total cost of automobile = 2.5/0.65 = #3.85

c. **Function Method**: This method is also referred to as Parametric cost estimating. It is like factor method, but more variables are used. It uses mathematical expression with constants and parameters derived for specific process, such as casting or machining or for specific classes of parts base on material, size, weight or other cost parameter: E.g., for machine component.

Estimated cost of an item = G x (a +b) + (R x c) + (N x d)

where G = Weight of the item, kg

a = Material cost per kg

b = Tolerance cost per kg

R = Weight of material removed kg

c = Cost per kg of material removed

N = No of dimension of product surface

d = Cost per dimension

In practice the expression is generally, non-linear such as cost for turbo fan engine development in #

$= 41.2 \times a^{0.74} \times b^{0.08}$

where a = maximum engine thrust, in kg

b = No. of engines produced

**Example**: If the engine thrust is 7,500kg and the number of engines to be produced is 100 what is the development cost?

Development cost = $41.2 \times 7500^{0.74} \times 100^{0.08}$

#43,897.78

The disadvantage of such formular is that the range limitations of the expression are not given in the formula i.e., there is a range of thrust for which the expression is applicable (e.g., 50000 kg thrust may be outside the range of data used to develop the formula.). The accuracy of such cost equations or models is about +-10%.

d. **Method based on cost size relationships**: Another approach to the determination of conceptual costing is by considering the cost-size relationships. In this approach one can compare the cost of different designs on a relative basis or on an actual cost basis. The cost-size relationship in respect of investment casting is given below.

**Example**: Relative cost of an investment casting volume V $cm^3$ is given by $5.0V^{0.6}$

where 5.0 represent cost of 1 $cm^3$ investment casting

V volume of investment costing, $cm^3$

0.6, size cost exponent for investment casting (the relationship is less than linear)

This relationship was developed for a volume range of 1.5 to 160 $cm^3$)

a. If one wanted to double the volume of an investment casting turbine blade from 4 to 8 cubic centimetres, what would be the increase in cost?

b. What would be the cost of an 8 cubic centimetre turbine blade compared to the cost of 1 $cm^3$ turbine blade?

**Solution**:

$$Cost = 5.0V^{0.6}$$

a. $C_8 = 5.0(8)^{0.6}$

$C_4 = 5.0(4)^{0.6}$

Increase in the cost = $5.0(8)^{0.6} / 5.0(4)^{0.6} = (8/4)^{0.6} = 1.5$ (times)

The cost of $8cm^3$ investment casting is 1.5 times the cost of $4cm^3$ investment casting i.e., the cost would increase by 50% when the volume of investment casting is doubled.

b. The cost of an 8 $cm^3$ investment casting turbine blade compared to the cost of 1 $cm^3$ turbine blade

$$= (8/1)^{0.6} = 3.5 \text{ (times)}$$

i.e., cost of an 8 $cm^3$ investment casting is 3.5 times the cost of 1 $cm^3$ investment casting i.e., the cost increased by 250%.

**Accuracy of Cost Estimates**

Cost estimates are opinion of probable cost, not an exact calculation. The type of estimate to be made and its accuracy depends upon many factors including:

- the purpose of the estimates,
- how much is known about the project, and
- how much time and effort are spent in preparing the estimate.

The accuracy and reliability of an estimate is therefore totally dependent upon

- how well the project scope is defined and
- the time and effort expended in preparation of the estimate.

The one thing that is known with 99.9+% certainty about any estimate is that it is wrong.

- Actual cost will rarely, if ever, equal the estimated cost.
- The final cost of a project will be more or less than the estimate.
- The only time an estimate is correct is after the project is complete and all the bills have been paid and totalled.

The value of an estimate lies in its accuracy, which depends on the care with which it is prepared. Carelessly prepared estimates may prove to be harmful to the organization or may even result in the closure of the firm.

- If a job is overestimated i.e., the estimated cost is much above the actual cost of the product, the shop or firm will not be able to compete with its competitors who have estimated the price correctly and loses the order to its competitors.

- If underestimated i.e., estimated cost is below the actual cost of product means a financial loss to the firm and too many losses mean failure or closure of shop.

The difference may be very small, but there will nevertheless be a difference. This fact must always be kept in mind when making project decisions based upon any estimate of costs. When the cost estimate is to be used as a goal i.e., target cost to be achieved in production, it should be set on lower side rather than actual estimated cost. The factory is more likely to try to meet a low-cost target than to try to get cost down very far below an overestimated target cost.

# JOB COST ESTIMATE

## Components of Job Cost Estimate

The total estimated cost of a product consists of the following cost components/elements.

1. Cost of design
2. Cost of drafting
3. Cost of research and development
4. Cost of raw material
5. Cost of labour
6. Cost of inspection
7. Cost of tools, jigs and fixtures
8. Overhead cost

## Job Cost Estimation Categories

**Direct material costs**: it is the cost of those materials which become a part of the final product

**Direct labour costs**: It is the expenditure made on the wages and salaries of workers who are directly engaged in the manufacturing processes e.g., turners, milling machine operators, painters etc.

**Direct other expenses**: These are the expenses except direct materials cost and direct labour cost which can be identified and allocated to a particular product, e.g., cost of machine hours and cost of tools, jigs and fixtures etc.

**Overhead costs**: Overhead expenses include all other expenditure made on the product except direct material cost, direct labour charges, and direct other expenses. Administrative expenses, sales and advertisement cost etc. form a part of overhead expenses.

## Steps in Job Cost Estimation

The basic estimating steps are to:

- Understand the scope of the activity.
    - Make thorough study of cost estimation request to understand it fully.
- Quantify the resources required,
    - Make an analysis of the product and prepare a bill of material (BOM).
    - Make separate lists of parts to be purchased from market and parts to be manufactured in plant.
    - Make manufacturing process plan for the part to be manufactured in plant.

    - Estimate the machining time for each operation listed in the manufacturing process plan.
- Apply costs to the resources,
    - Determine the cost of part to be purchased from outside.
    - Estimate the material cost for the parts/components to be manufactured in plant.
    - Multiply each operation time by labour wage rate and add them up to find direct labour cost.
    - Add the estimate of the 3-steps above to get prime cost of component.
    - Apply overhead costs to get the total cost of the component.
- Apply pricing adjustments.
    - Obtain selling price by adding profit to the total cost obtained in the last step above.
- Organize the output in a structured way that supports decision-making.

After estimating all the elements of cost, they are entered in a **Cost Estimate Form** as attached**.**

**Data Requirements and Sources of Information for Job Cost Estimation**

1. Man-hour cost (labour rate) i.e., hourly cost of skilled, semi-skilled and unskilled labourers of the company
2. Machine-hour cost for different types of equipment and machinery available in the company
3. Material cost in respect of commercially available materials in the market – cost in # per kg for different categories of materials like ferrous, non-ferrous, special teel etc., the rods of different diameters and different thickness in respect of flat/sheet metals.
4. Scrap rates i.e., scrap values of different material in # per kg
5. In respect of welding operations information such as electrode cost, gas cost, flux cost, power cost etc.
6. Set up time for different processes.
7. % Allowances to be added for computing standard time, relaxation allowance, process allowance, special allowance as % of normal time as per the policy of the management
8. Standard time for different types of jobs if available
9. Overhead charges in terms of % direct labour cost or overhead rate in # per hr.

10. Life in years permitted for various types of equipment and machines available in the plant for calculation of depreciation, for cost recovery and for calculation of machine – hour rate.
11. Data base of cost calculations carried out by the company in respect of earlier products or jobs (historical cost data).
12. Cost data of products available in the market like the ones manufactured by the company.
13. Budget estimates prepared by the company for new projects/products.
14. Journal or Data sheets of Professional Association dealing with costs and accounting.

## BASIC CAPITAL COST ESTIMATING

Capital cost estimating is estimating as applied to support the creation of capital assets (a building, industrial facility, bridge, highway, etc.); however, the estimating processes described can be applied to any investment activity. The conventional deterministic cost estimation methods for capital improvement projects in most municipal agencies and the local governments are based on preparing a single-point-estimates. A single-point-base-estimate is based typically on

- the level of a project's scope definition and the project design phase,
- available historical data,
- current contractor rates and
- preliminary quotes from sub-contractors and other vendors

**Purpose of Capital Cost Estimate**

The cost estimate serves other purposes besides establishing the budget for a project.

- It serves as a tool or resource used for both scheduling and cost control of projects.
- It establishes a project budget and plays an equally important role in monitoring the budget during project execution.
- It is the relationship between estimating, scheduling, and cost control, that serves as a driver for successful and cost-effective projects. This relationship is typically identified by the term "cost engineering".

Thus, **an effective estimate** must not only

- establish a realistic budget but must also
- provide accurate information to allow for scheduling, cost monitoring, and progress measurement of a project during execution.

**Types of Capital Cost Estimating Method**

The estimating method used for any particular estimate will depend on many factors:

- the end use of the estimate,
- the amount of time and money that is available to prepare the estimate,
- the estimating tools and data available, and, of course,
- the level of project definition and design information on hand.

The various types of capital-cost estimates are made for a variety of reasons, the principal ones being:

**Order-of-magnitude estimates.**

- Feasibility studies
- Selection from alternative designs
- Selection from alternative investments
- Budgeting or construction forecasting

**Budget**

- Budgeting or construction forecasting
- Authorization—partial or full funds

**Definitive**

- Authorization—full funds
- Check of an authorized project
- Presentation of bid

**Components of Capital Investment.**

Capital investment is made up of two components:

Total capital = fixed capital + working capital

That is, the total investment to put a project in operation is comprised of:

1. **Fixed capital cost**: a one-time cost for all the facilities for the project, including land, design and engineering, equipment, utilities, freight, start-up, etc.
2. **Working capital**: the funds in addition to fixed capital and land investment that a company must contribute to the project (excluding start-up expense) to get the project started and to meet subsequent obligations as they come due. Working capital includes inventories, cash, and accounts receivable minus accounts payable. Characteristically, these funds can be converted readily into cash. Working capital is normally assumed to be recovered at the end of the project.

As a rough estimate, working capital for a project will be approximately 10 to 20% of the fixed capital or about 25% of annual operating costs in most manufacturing industries. However, working capital requirements can exceed 50% of the fixed capital investment in service industries, industries with high sales costs, and seasonal industries such as construction materials manufacture.

As an example, brick is generally manufactured 12 months per year to obtain maximum productive use of the kilns used to fire the brick. However, in colder climates construction with brick may be possible for only six months or less each year. Thus, the brick manufacturers build large inventories during the non-construction months, thereby requiring considerably more working capital than might otherwise be needed.

**Factors to Consider in Capital-Cost Estimating**.

Projects are becoming larger in scale, they are increasingly more international in scope, and competition is keen worldwide. Hence, more factors than ever before have to be carefully considered regarding their impact upon an estimate to include:

1. Technological advances
2. Inflation forecasts
3. Potential price controls
4. Safety and environmental regulations
5. Social concerns
6. Currency fluctuations
7. Import and export considerations.
8. Taxation and trade barriers
9. Escalation inflationary pressures, etc.

Moreover, to adjust for inflation, costs of labor, material, and equipment, additional Consumer Price Index (CPI) is added to each cost item every year. This poses a challenge on the accuracy of the project cost estimate and/or budget(s) and may cause cost overruns.

**Uncertainty in Capital Cost Estimates**

Accurately estimating the costs of complex infrastructure projects in the design, and construction phases have typically become a unique challenge for engineers, architects, owners, municipal agencies, and contractors. Complex and technologically advanced projects usually contained much uncertainty and related challenges than other projects. Hence, dealing with risks and uncertainties are usually a problem The sources of risks and uncertainties in a project are several.

- At the early stage of the project, the uncertainty in a cost estimate increases due to the limited available information in quantity and quality.

- As the design progress, more and better information becomes available, the uncertainty in the cost estimate is gradually reduced.

Therefore, engineering cost estimates must adequately address uncertainty at the preliminary stages of projects where neither the exact quantities nor specific costs or ultimate prices are known.

**Accuracy of Capital Cost Estimates**

The overall purpose of an accurate cost estimate is its use in establishing the budget for a project and as a tool used for scheduling, monitoring and controlling of the project cost. The level of accuracy of engineering cost estimates increases as the project phase progresses and the potential risks are identified. The earlier the estimate in the life of the project, the lower its accuracy. Consequently, assessments of conceptual estimate accuracy are quite low.

Project cost estimate is obviously of paramount importance to the success of the project because the capital cost of a proposed project is one of the key determinants in evaluating the financial viability and business case of the project.

- **Viewed from the perspective of the owner**, if the cost estimate is not accurate, the financial return from the capital investment may not be realized. Compounding this problem is the fact that other deserving projects may not have been funded. Hence, accurate estimation is critical for the economic and optimal use of an owner's limited capital budget.
- **From a contractor's perspective**, accurate estimating is just as important.
- In a lump-sum bidding situation, the profit margin of the contractor is dependent on the accuracy of his estimate. If the project is exceptionally large, the loss from an in accurate estimate on a lump-sum bid can potentially put a contractor out of business.
- For cost-plus projects, the contractor will face less direct economic risk from an inaccurate estimate, but the damage to the contractor's reputation can be severe.

**Estimate Classification**

Degree of project definition is the primary (or driving) characteristic used to identify an estimate class. The other characteristics are "secondary," with their value typically determined by the level of project definition.

**A) The American National Standards Institute (ANSI, 1991)**

The American National Standards Institute **(ANSI,** 1991) defines three types of estimates:

- Order-of-magnitude,
- Budget, and
- Definitive.

1. **Order-of-magnitude estimates** have an *expected accuracy between +50% and -30%*. They are generally *based on cost-capacity curves and cost capacity ratios* and *do not require any preliminary design work*.
2. **Budget estimates** are *based on flowsheets, layouts, and preliminary equipment descriptions and specifications* and have *an accuracy range of +30% to -15%. Design generally must be 5 to 20% complete* to permit such an estimate to be performed.

3. **Definitive estimates** require *defined engineering data, such as site data, specifications, basic drawings, detailed sketches, and equipment quotations. Design is generally 20 to 100% complete and estimate accuracy should be within +15% to -5%*. The nonuniform spread of accuracy ranges (e.g., +15% to -5% rather than ±10%) reflects the fact that most estimates tend to fall short of actual costs instead of exceeding them.

**B) AACE Estimate Classifications**

American Association of Cost Engineers (AACE) International has proposed an expansion of the ANSI estimate classifications to five types with expected accuracy levels based upon the amount of project definition available when the estimate is prepared (AACE, 1997). The accuracy of each class of estimate depends on
- the technological complexity of the project,
- appropriate reference information, and
- inclusion of an appropriate contingency determination.

In all cases, accuracy ranges could exceed the ranges indicated below in unusual circumstances. The revised classifications are:

1. **Class 5 estimates**: These estimates are generally based on **very limited information**. They may be prepared within a **very limited amount of time** and with **little effort expended**—sometimes less than one hour. Often little more is known than the proposed plant type, location, and capacity. This class of estimate falls into the **ANSI order-of-magnitude classification**. The required level of **project definition is 2% or less** and the expected accuracy is -20% to -50% on the low side and +30% to +100% on the high side.
2. **Class 4 estimates**: Class 4 estimates also are generally prepared based upon **limited information** and have wide accuracy ranges. They are typically used for **project screening, feasibility determinations, concept evaluation, and preliminary budget approval**. **Engineering is only 1% to 5% complete** and comprises, at a minimum, plant capacity, block schematics, indicated plant layout, process flow diagrams (PFDs)

for the main process systems, and preliminary lists of engineered process and utility equipment. Typical accuracy ranges for this class of estimate are -15% to -30% on the low side, and +20% to +50% on the high side. This class of estimate falls into the **ANSI budget estimate** classification.

3. **Class 3 estimates**: These are estimates which form the basis **for budget authorization**, appropriation, and/or funding. These estimates typically form the initial control estimate against which all actual costs and resources will be monitored. The required level of **project definition (i.e., completed engineering) is 10% to 40%** and includes at a minimum: process flow diagrams, utility flow diagrams, preliminary piping and instrument diagrams, plot plans, developed layout drawings, and essentially complete engineering process and utility equipment lists. **Accuracy ranges** for this class of estimate are -10% to -20% on the low side, and +10% to +30% on the high side. This class of estimate also falls into the ANSI budget estimate classification.
4. **Class 2 estimates**: This class of estimate falls into the **ANSI definitive estimate** category. Class 2 estimates are generally prepared to form detailed control baselines against which all project work is monitored in terms of cost and progress control. For contractors, this class of estimate is often used as the “bid” estimate. Typically, **engineering is 30% to 70% complete** and comprises, at a minimum: process flow diagrams, utility flow diagrams, piping and instrument diagrams (P&IDs), heat and material balances, final plot plans, final layout drawings, complete lists of engineered process and utility equipment, single line electrical diagrams, electrical equipment and motor schedules, vendor quotations, detailed project execution plans, resourcing and work force plans, etc. **Accuracy ranges** are much improved over the prior classes of estimates. On the low side they are -5% to -15%. On the high side, the ranges are +5% to +20%.
5. **Class 1 estimates**: Also included in the **ANSI definitive estimate** category, this is the most accurate classification of estimates. Class 1 estimates are generally prepared for **discrete parts or sections** of the total project rather than for the entire project. The parts of the project estimated at this level of detail are typically used by subcontractors for bids, or by owners for check estimates. The updated estimate is often referred to as the current control estimate and becomes the new baseline for cost/schedule control of the project. This type of estimate is often made to evaluate and/or dispute claims. Typically, **engineering is 50% to 100% complete** and comprises virtually all engineering and design documentation of the projects, and complete project execution

and commissioning plans. Typical **accuracy ranges are -3% to -10%** on the low side and +3% to +15% on the high side.

**Comparison of ANSI & AACE Capital Cost Estimation Standards**

The table below is adapted from the AACE International practice guideline which applies the principals of cost estimating classification for process industry engineering, procurement, and construction projects. This guideline is applicable for surface finishing process projects. The table shows five AACE cost estimate classifications with the following information and characteristics:

i. Comparison of the five AACE classes to the three traditional, widely used ANSI cost estimate classifications.

ii. Typical uses of each class of estimate for support, from project conceptualization and development through project delivery and completion.

iii. Level of project definition, expressed as a percentage of engineering and general project (e.g., scope, schedule, work breakdown structure, contracting strategy, escalation strategy) documentation development. For process projects, the engineering development typically progresses:

   a. From early definition, including project location and constraints, general scope, processes and chemistries, production requirements and work envelopes, and process flow diagrams (PFDs).

   b. Through process layouts and implementation phasing plans (if applicable), piping & instrument diagrams (P&IDs), utility flow diagrams, mass and energy balances, building integration plans, and equipment schedules.

   c. Through detailed, multidiscipline engineering plans (structural, mechanical, electrical, I&C) and drawings (3D and 2D), specifications and data sheets, functional descriptions, O&M and commissioning plans, and lists of spare parts included in the project.

iv. Expected Range of Accuracy: The accuracy ranges for each estimate class represent a range around an estimated expected cost value for a specific scope, including appropriate contingencies. The +/- percentage ranges represent an 80% confidence interval that completed actual project costs for a given scope will fall within the estimated ranges (assuming project implementation at specific location, under planned schedule, etc.). For each estimate class, the ranges for the low expected actual cost and high expected actual cost represent typical variances that result from individual project complexity and level of definition. These ranges also vary with estimating methods and engineering and estimating experience applicable for a specific surface finishing project. The ranges are asymmetric with higher percentage variations on the high costs. This is due to historical cost outcomes for specific project scopes that demonstrate factors combine to make the magnitude of probable final project cost increases from estimated values more likely than cost decreases.

v. Other Terms: These other commonly used estimate names are approximately correlated with the AACE estimate classes. Use of these other terms is not always specified with expected ranges of accuracy and may differ in meaning for different circumstances.

| | | | | Expected Range of Accuracy | | |
|---|---|---|---|---|---|---|
| **AACE Class** | **ANSI Classification** | **Typical Use** | **Project Definition** | **Low Expected Actual Cost** | **High Expected Actual Cost** | **Other Terms** |
| Class 5 | Order-of-Magnitude | Strategic Planning; Concept Screening | 0% to 2% | -50% to -20% | +30% to +100% | ROM; Ballpark; Blue Sky; Ratio |
| Class 4 | | Feasibility Study | 1% to 15% | -30% to -15% | +20% to +50% | Feasibility; Top-down; Screening; Pre-design |
| Class 3 | Budgetary | Budgeting | 10% to 40% | -20% to -10% | +10% to +30% | Budget; Basic Engineering Phase; Semi-detailed |
| Class 2 | Definitive | Bidding; Project Controls; Change Management | 30% to 75% | -15% to -5% | +5% to +20% | Engineering; Bid; Detailed Control; Forced Detail |
| Class 1 | | Bidding; Project Controls; Change Management | 65% to 100% | -10% to -3% | +3% to +15% | Bottoms Up; Full Detail; Firm Price |

**REFERENCE**

https://www.processengineer.com/capital-cost-estimate-classes

https://share.ansi.org

**Sources of Capital Cost Data**

Capital Cost estimates can be prepared from three sources of data:

1. Similar project costs: costs of similar projects, and costs of project components
2. Proprietary cost data files: historical company costs, and in-house projects
3. Published cost information

**Extreme care should be applied when using published information** because:

- the accuracy level of such data is not known.
- Sometimes the basis for such data is not even indicated (e.g., whether purchased or installed costs are being presented).
- Installed cost figures also may or may not include auxiliary equipment,

- Some costs might be for entire plants while others may be for battery-limit installations only.
- Further, unless the published data is dated or includes a cost index value, it is often virtually impossible to correct for inflation since the data was obtained.

Do not assume that the publication date reflects the date at which the data was obtained. Publication often takes months or years after an article is first written. Unless the publication is very specific about exactly what is included in the cost figures and about the date of the information, the published data should not be used.

## OPERATING COST ESTIMATION

Operating cost or manufacturing cost is the expenses incurred during the normal operation of a facility, or component, including labor, materials, utilities, and other related costs.

**Elements or Component of Operating Cost**

**Overhead**: a cost or expense inherent in the performing of an operation, i.e., engineering, construction, operating or manufacturing, which cannot be charged to or identified with a part of the work, product or asset and, therefore, must be allocated on some arbitrary base believed to be equitable, or handled as a business expense independent of the volume of production. Plant overhead is also called factory expense.

**Direct Costs**: the portion of the operating costs that is generally assignable to a specific product or process area.

**Indirect Costs**: costs not directly assignable to the product or process, such as overhead and general-purpose labor, or costs of outside operations, such as transportation and distribution.

**Purposes of Operating Cost Estimates**

Operating cost estimates can be important from several standpoints.

- They are necessary to determine the potential profitability of a product or process and are
- very useful for screening alternative project possibilities.
- Frequently they can act as a guide to pinpoint potential areas in which to conduct research and
- to evaluate the commercial viability of research results.
- And they provide a tool for sensitivity analysis for individual components.

**Operating Cost Estimating Decisions Guidelines**

- Perform operating cost estimates at both full and reduced capacities for the operating system in question. It is not uncommon for a system to be highly efficient at full capacity, but very inefficient when operating at less than design capacity.
- Determine what range of operations a plant can operate over and still make a profit. Such costs can be calculated either as stand-alone estimates or as incremental costs for specified projects.
- When making comparisons, make sure that each iteration or calculation is made using the same techniques and assumptions. Otherwise, comparisons may not be valid.

Depending upon the situation, these different viewpoints could result in different decisions.

**Bases of Operating Cost Comparison**

Commonly, three differing bases for comparison are used, although others may be used for special applications. The most common are:

• Daily cost

• Cost per unit-of-production

• Annual cost

A cost-per-unit analysis can be valuable for some manufacturing considerations.

**Annual cost Comparison**

All other factors being equal, **making comparisons using an annualized basis instead of on shorter time increments has several advantages:**

• Seasonal variations are evened out.

• On-stream time factors are considered.

• More accurate analysis of less-than-full capacity situations is obtained.

• Infrequently occurring large expenses are factored in (scheduled maintenance, vacation shutdowns, catalyst changes, etc.).

• The output is in a form easily used in standard profitability analysis.

• The annual basis is readily convertible to the other bases, daily cost and unit-of-production, yielding mean annual figures rather than a potentially high or low figure for an arbitrarily selected time of the year.

**Raw Materials and Utilities Operating Cost Estimates:**

Raw materials and/or utilities are frequently the largest operating cost being considered in an estimation.

**The estimations involving raw materials are not always straightforward,** as the following list of considerations shows.

• Raw materials frequently are the largest operating cost.

• By-products and scrap may be a debit or credit.

• Prices may be obtained either from suppliers or from published data.

• Raw materials costs may vary significantly depending upon the quality required (concentration, acceptable impurity levels, etc.).

• Raw materials costs entail quantity discounts in many cases leading to a trade-off of lower prices for purchase of large quantities vs. storage and inventory cost for raw materials that cannot be used immediately.

• Raw materials costs vary significantly depending upon the mode of purchase and transport (bulk quantities, truck lots, rail car lots, pipeline delivery, bags, boxes, etc).

• Supplies and catalysts are sometimes considered to be raw materials.

• Fuels may be either raw materials or utilities.

• Freight and handling costs must be included in pricing raw materials.

- Accepted local practice can have a large impact on the operating cost estimate.
- The cost of utilities can vary widely with the location, with the size of the service required, with the national and local economy, and even with the season.

Utilities must be examined closely on a local basis, especially if they form a major part of the operating costs. Generally utility pricing is regulated, and the approved tariffs are readily available from the utility company or the cognizant regulatory agency. However, if the utilities are internally generated within a process, a separate estimate of the utility cost must be performed.

**Operating Labour Cost Estimate**:

The best estimates of operating labour are based on a complete staffing table. This table should indicate the following:

• The craft or skill required in each operation

• Labour rates for the various types of operations

• Supervision required for each process step

• Maintenance personnel required

• Overhead personnel required

**In the absence of a staffing table, an order-of-magnitude approximation of labour requirements can be made using the Wessell equation.** The Wessell equation is

$$\frac{\text{Operating workhours}}{\text{Tons of product}} = T \left[ \frac{\text{Number of process steps}}{(\text{capacity, tons/day})^{0.76}} \right]$$

where

T=23 batch operations with maximum labour

T=17 for operations with average labour requirements

T=10 for well-instrumented continuous process operations

**Supervision costs** may vary from 10% to 25% of operating labour cost. On average, an allowance of 15 to 20% of operating labour cost is usually satisfactory for early-on estimates.

**Maintenance**:

Few published data on maintenance data are available. Maintenance cost can vary from 1 or 2% to over 15% of the project capital cost per year. For

- simple plants with relatively mild, noncorrosive conditions, an allowance of 3 to 5% should be adequate.
- complex plants and severe corrosive conditions, this factor can be 10 to 12% or even higher.

Maintenance costs consist of labour and material components with the total maintenance cost divided

- 50 to 60% labour and
- 40 to 50% material.
- For most early-on estimates, it is sufficient to assume a 50:50 split.

Maintenance varies with rate of operation, but not linearly. When operating at less than 100% of capacity, maintenance costs generally increase per unit of production as follows: Maintenance costs increase with equipment or system age, but the average values are normally used in estimates.

**Indirect Payroll Cost:**

Indirect payroll cost includes workers' compensation, pensions, group insurance, paid vacations and holidays, social security, unemployment taxes, fringe benefits, and so on. It is generally based on labor cost, usually at about 30 to 45% of the labour cost in the United States. In other countries, this percentage may vary greatly and should be verified locally.

**Operating Supplies Cost Estimate**:

Operating supplies include lubricants, instrument charts, brooms, and so on, and may be generally assumed to be 6% of the operating labor or as 0.5% to 1% of the capital investment per year. For highly automated, complex operations these costs can increase substantially as a percentage of labor costs.

**Laboratory and Other Service Costs**:

Laboratory and other service costs can be based on one or more of the following:

1. Experience
2. Workhours required
3. A percentage of operating labour cost (3 to 10% is common, but it may be as high as 20%).

**Royalties and Rentals Cost Estimate**:

Royalties and rentals are generally an operating expense but may be part of capital investment. Single-sum payments for royalties, rental, or license payments are properly considered as capital investment items, whereas payments in proportion to production or fixed payments per annum are treated as direct operating costs. Royalty payments may range between 1% and 5% of product sales price.

**Indirect Cost Estimate**:

Factory overhead is the indirect cost of operating a plant. It may also be called general works expense, but it is not general and administrative expense (G&A). G&A covers plant administrative costs, accounting, auditing, research and development, marketing and sales expense, etc). It is dependent upon both investment and labor.

**Distribution Cost Estimate**:

Distribution costs include handling and transportation costs. These costs vary with the types of containers and with methods of shipment. Cost without distribution cost is called bulk cost.

**Avoidance of Nuisances Cost Estimate**:

Nuisances include waste disposal and pollution control costs. Each case must be calculated individually. The topic is becoming increasingly more expensive and includes such items as product liability. These costs are mounting rapidly.

**Contingencies Cost Estimate**:

As is true for the capital cost estimate, an operating cost estimate should include a contingency allowance to account for those costs that cannot readily be determined or are too small to be readily determined or defined but may be significant in the aggregate. The contingency allowance applies to both direct and indirect costs and ranges from 1% to 5% or more in some cases. Hackney (1971) has suggested the following guidelines for operating cost contingency:

1. Installations similar to those currently used by the company and for which standard costs are available: 1%
2. Installations common to the industry for which reliable data are available: 2%
3. Novel installations that have been completely developed and tested: 3%
4. Novel installations that are in the development stage: 5%

**Summary Cost Estimating**

The basic cost estimating procedure is as follows:

1. Scope the job or problem.
2. Establish the estimate format; use a code of accounts.
3. Prepare your estimate area by area and category by category.
4. Check your work; verify your data.
5. Review and adjust.
6. Finalize.
7. Complete the documentation.
8. File.

In general,

- Understand the overall picture.
- Document well.
- Analyse your figures.
- Tailor your estimate to the job.
- Plan.

## BASIC PROJECT PLANNING AND SCHEDULING.

**Definition**: Planning can be defined as influencing the future by making decisions based on missions, needs, and objectives. It is the process of stating goals and determining the most effective way of reaching them. This future-oriented decision process defines the actions and activities, the time and cost targets, and the performance milestones that will result in successfully achieving objectives.

**Nature of Planning**

Everyone involved in an undertaking must plan, whether their charge is to develop a long-range plan for company growth or to develop a personnel procurement plan for a specific project. Planning is not done by upper management alone; it exists in a hierarchical structure made up of policies, strategic plans, and operational plans. Different organizational levels produce plans that are quite different in type and scope.

**Planning Process**

The process involves several steps:

- setting objectives,
- gathering information,
- determining feasible alternative plans,
- choosing the best alternative,

• communicating the plan,

• implementing the plan,

• adjusting the plan to meet new conditions as they arise, and

• reviewing the effectiveness of the plan against attainment of objectives.

**The Importance of Planning**

An organization makes implicit assumptions about its future so it can act today. Accordingly, we must rely on some indicators to quantify the importance of planning.

- Measure planning payoff by relating the value of what we have achieved through planning to the cost of the planning (theoretically).
- Quantify both the outcomes attained through planning and the outcome attained without planning. Unfortunately, it is a rare situation that offers the opportunity.
- Finding that companies that supported planning programs experienced superior growth rates when compared to companies that did not. The Stanford Research Institute did this in a formal study some years ago.

**Planning Cycle**

The planning cycle involves the following:

- a company develops a plan to maximize that opportunity. In doing so, it uses the best information available.
- When the plan is implemented, activities are carefully monitored and controlled, using the plan as a reference baseline.
- Complete records are maintained through the execution phase.
- Finally, the experience gained is fed back to the company to increase its knowledge base for the next planning action.

This cycle represents the learning curve in action, whereby each repetition makes planning for and achieving the next opportunity much easier. Without a firm commitment to the planning cycle, a company is continually “reinventing the wheel,” wasting time and money, and jeopardizing its place in the competitive marketplace.

**Establishing a Planning Culture**

Effective planning becomes routine when planning is an integral part of the company's culture. This begins with

i. commitment by top management,

ii. continues with communication of that commitment to mid-level managers, and

iii. becomes rooted when every employee relates unequivocally with the company's goals.

As with any operation, if those who are to manage a plan do not participate in its preparation, their level of commitment to success may be less than total. Therefore, using a team approach to planning involves

- builds participant confidence in the organization,
- stimulates communication among the parties, and
- promotes their feelings of ownership in the outcome.
- It also demonstrates that top management has a direction,
- that decision-making is under control, and
- that the total organization is working to achieve the same objectives.
- An additional, but no less important, result of the team approach is the training "in-action" that lower-tier managers receive as they participate with upper management in the planning process. They are thus better able to assume higher levels of responsibility as opportunities develop, bringing with them a planning philosophy that is fully in grained.

**Benefits of Structured Approach to Planning**

There are numerous reasons why a company that encourages a proactive, structured approach to planning will reap significant benefits over a company whose planning approach is reactive or random:

• preparing a clear scope definition minimizes the potential for overlooking an aspect critical to success.

• if undertaken as a team effort, it permits various viewpoints and ideas to be expressed.

• the resultant plan, if well documented, provides a means of communication between the participants.

• the plan provides a baseline for control during the execution phase; and

• post-completion reviews greatly reduce the potential for planning errors on subsequent activities.

**Planning tools**

When planning tools are mentioned, the tendency is to think in terms of hardware, software, and procedures. Yet,

- The most fundamental and useful planning tool available is **the experience planning team participants have gained** during previous undertakings. While impossible to quantify, this experience provides a sound basis for using the other, more tangible planning tools.

Others are:

• **Commercial handbooks and software programs**, a variety of which are available. These should be used, of course, with an understanding of their basis and limitations rather than applying them across the board.

• **Standard, companywide policies and operating procedures** that have been officially issued. Planners can then feel free to use them without having to continually seek management guidance and approval.

• **Model plans that can be adapted as necessary to specific undertakings**—Organizations that tend to undertake repetitive work should develop a model project and plan for each type of work.

• **Checklists** that will support planning and help prevent overlooking key items that may have cost or schedule implications.

• **Historical databases** cataloguing company experience on past projects in a standard format for use in new endeavours.

• **Codes of accounts** structured to catalogue work, cost accounts, resources, and other information—These are essential if planning is to take advantage of available software. Codes of accounts should be standardized to the extent practical to ensure consistency of data cataloguing and use. For work breakdown structures and cost breakdown structures, the codes should be hierarchical to permit capturing information at various levels of detail.

**Major Elements of Planning**

1. **Goals and the Scope of Work**. Every undertaking, whether large or small, has a goal: construct a building, produce a certain number of items, or obtain new or additional financing. This goal should be clearly understood and agreed upon by all planning participants (including top management) before any actual planning is begun.

i. The **basic approach** to planning involves:

- segmenting the total endeavor into manageable parts,
- planning each part in detail,
- combining the parts,
- testing the total against project objectives, and then
- refining the planning as necessary to eliminate variances from the objectives.
- In addition, great attention should be paid to accurately defining the scope of work since scope definition in and of itself provides a means of identifying areas where planning for changes.

ii. **Work Breakdown Structure (WBS).** The most effective tool to use in ensuring that all work scope is planned is the Work Breakdown Structure (WBS). It is a tree structure of successive further breakdowns of work scope into component parts for planning, assigning responsibility, managing, controlling, and reporting project progress. All planning efforts are organized to the WBS as developed for the project.

**2. Planning Categories**

Planning takes place in numerous categories, but the most important of these are

- time,
- cost,
- resources, and
- quality.

**i. Time Planning**:

Time planning entails developing plans, usually in the form of summary schedules, to accomplish all elements of an objective within an established time. Later in the life cycle, these summary schedules are developed into detail schedules for accomplishing discrete tasks. This process begins with

- establishing a need date or other milestone at which all actions must be complete and works backward from that point.
- Dividing the total effort into component parts.
- And arrayed in the order of their accomplishments. This goes beyond merely preparing a list, since some activities must be handled in strict sequence while others may be executed simultaneously. For still others, several options may exist. The results of time planning can be displayed in numerous ways: the critical path logic diagram, a bar chart, or a simple timetable.
- **Critical path logic diagram is o**ne of the most advantageous formats for arraying activities is the critical path logic diagram. In this format, arrows or nodes representing each component or activity are displayed in logical sequence, showing dependencies among all activities where an actual constraint is present (e.g., one activity cannot start before another is finished). Since several ways of handling the overall project may exist, it may be appropriate to develop two or more logic diagrams and then test each option.

After the logical display is complete, a duration is assigned to each activity, based either on data contained in a software program or on experience of the planning participants. Then, using critical path techniques, the total time requirement for the endeavor is determined. If the total exceeds the available time, planners must re-evaluate their work and take whatever action is needed to meet time objectives: perhaps optional activities can be dropped, and others can be shortened by applying more resources or other schedule compression techniques.

**ii.** **Cost Planning:** Just as total time effort was partitioned; total cost must be partitioned as well. This may be done using a cost breakdown structure (CBS), like the WBS mentioned earlier, which is merely a catalogue of all cost elements expected to be incurred, the sum of which equals the budget for the endeavor. Ideally, this segmentation will parallel the time breakdown; in fact, the objective is to have the time breakdown exist within the cost breakdown. This, however, may not be possible since not all costs are directly related to a specific activity, i.e., they may be overhead costs or general and administrative costs, which will appear in the cost breakdown but not in the work breakdown. Where costs and actions do coincide, a control account is created.

**iii.** **Resource Planning:** Resources **i**nvolved in an undertaking generally include personnel, support equipment and tools, permanent materials and installed equipment, and expendable supplies. Some combination of these is involved in each control account that appears on the integration of the WBS/CBS. The decision as to the resources to be applied is primarily based on experience and judgment, although specific undertakings may require other input as well. Every resource requirement must be accounted for in the cost breakdown so that estimates of costs for individual control accounts, as well as total estimated costs, can be generated.

Identifying resource requirements is only a first step in the resource planning process, since the resources also must be available in the quantities needed at the proper time. Thus, supporting resource plans will exist behind the total resource plan. In most instances, certain resources will be identified as critical to project success, and their management will be given particular attention.

**iv.** **Quality Planning**: The overall objective of planning is to achieve a high-quality result on time and within budget. Quality objectives are met if this is done without undue confusion or disruption. This requires developing a quality plan that consists of

- the undertaking's requirements (goals),
- a method for communicating the requirements to those responsible for achieving them,
- a plan for training the responsible persons,
- and a way of measuring successful achievement.

3. **Review Post-action**: Review of the planning that went into an endeavor is an important, yet often neglected area. Still, without good reporting and review even while the undertaking is in process, control does not exist. Therefore, everyone involved must be kept informed as to progress, problems, modifications, and other factors critical to success. This requires making an early assessment of the required reports, meetings, presentations, and project documents, and determining which ones are vital to accurate performance assessment.
4. **Integrating the Elements of Planning**

Integrated project or process control is possible only if the planning also has been integrated. In other words, when time, cost, and resource planning have been accomplished against the same basic structure. The WBS and CBS provide the common structure for this planning, since one level of the WBS elements becomes activities for scheduling as well as a center for tracking resources and costs. This enables.

- resource - loading the-schedules,
- resource budgeting against time, and
- developing a variety of cost budgets plotted against time.

**Planning for Change**

A frequently neglected aspect of planning is contingency planning. Change is inevitable, whether it is internally or externally driven. But even though it is unlikely that the objectives set forth at the beginning of an undertaking will change, the possibility of everything going according to plan is quite remote. Recognizing that change is inevitable, plans almost invariably must be based on assumptions subject to some variability. They must not be cast in stone but rather should be flexible enough to allow for changes at any point during the life cycle of the endeavor. A good plan provides sufficient alternatives, so it still functions even when extreme changes occur.

Contingency planning can take at least two forms, both based on “what-if” type questions.

- The first is developing an **alternate plan** that can be implemented in the event an adverse situation arises: e.g., what if a concrete pump breaks down in the middle of a large pour? Even though every eventuality cannot be addressed, concentration on critical areas is advised.
- The second form of contingency planning addresses **budget and schedule** and sets out a way to handle unfavourable variances in these areas.

In establishing **contingency accounts**, planners must first attempt to identify risk elements—accidents, vandalism, theft, work quantity variances, productivity, unfavourable weather, adverse labor activity, etc. While certain of these risk elements are insurable, it is seldom at the 100 percent level. Structured techniques are available for evaluating combined exposure to uninsured risk elements in which exposure is usually expressed in terms of a probability of loss not exceeding certain limits. Using this information, amounts are established for both cost and schedule contingency. These accounts are managed with the same care as any other control account.

**Concluding Remarks**

- Strong, effective planning is the main ingredient in project or opportunity success since it focuses the attention of an organization on its future.
- Planning is the responsibility of all participants: thus, companies should strive, through training and practice, to develop a planning culture and to provide the tools necessary to facilitate the planning process.
- Plans should be documented and made available as appropriate to all individuals involved in the undertaking.
- Plans must always be flexible since the future is unknown, and changes will occur despite the best planning efforts.
- While time and cost planning are important, planning in other areas will reap nearly as many benefits.
- Finally, management should have rigid standards for bidding on projects, thus allowing staff resources to be applied where they will be most productive.
- Planning for success is no small endeavor. When done well, however, it will reap many large rewards

## SCHEDULING

The cost engineer must understand the importance of using schedules effectively. Knowing only the cost and cost estimating functions limits the ability of the cost engineer to perform as a true project control professional.

**Scheduling Concept**

- Scheduling is the process that converts the project work plan into a road map, that if followed, will assure timely project completion.

- Scheduling is one of the tools used for monitoring and controlling projects to ensure the objectives of cost, quality, and time are met.
- Schedules provide the baseline against which progress is measured.
- Schedules are used to assess time impact of changes to the work scope.

**Purpose**

Scheduling means-

- when and in what sequence the work will be done.
- as and when the work will start and
- how much work will be finished in a certain duration of time.
- deals with orders and machines i.e., which order will be taken up on which machine and in which department by which operator.

The **aim** is to schedule as large amount of work as the plant facilities can conveniently handle by maintaining free flow of material along the production line.

**Loading**

Whereas scheduling includes, in addition, the specification of time and sequence in which the order/work will be taken, loading means the assignment of task or work to a facility.

**Factors affecting Scheduling**:

The following factors affect production scheduling and are considered before establishing the scheduling plan.

1. External factor
   - Customer demand
   - Customer delivery date
   - Stock of goods already lying with dealers and retailers
2. Internal factors
   - Stock of finished goods with the firm
   - Time interval to process finished goods from raw materials.
   - Availability of equipment and machinery; their total capacity and specification
   - Availability of material; their quantity and specifications
   - Availability of manpower; (number, types, and kind of skills)
   - Additional manufacturing facilities if required.
   - Feasibility of economic production runs.

**Benefits of Scheduling:**

1. Scheduling provides a basis for management of the work, improves communications, and facilitates coordination. Using a schedule improves the effective use of resources.

2. The project schedule gives the user a baseline to monitor and control the work.
3. Scheduling provides a way of contributing input during project execution concerning means, methods, techniques, sequences, or other conditions affecting the plan's outcome.
4. Scheduling provides a means for obtaining feedback since the development and use is a team effort incorporating the ideas and objectives of those responsible for the work.
5. Schedules are good motivational tools providing intended work plans to those having to perform the work and reporting progress against them.
6. Schedules provide a baseline for measurement and a means for collecting and recording progress.
7. Budgets, costs, and resources can be integrated into project schedule activities providing a basis for measuring cost as well as time performance.
8. Schedules may be used as a basis for payment applications supporting work completed.
9. Critical path schedules are used and relied upon by courts for amending contract completion dates.
10. When projects are faced with significant cost and time overruns, schedules are used as analytical tools to support assessments of labor efficiencies resulting from compression or extension of time, congested work areas, and disruption to planned work.

**Tools for Developing Schedules**

Computer software for developing, progressing, and updating schedules is affordable and readily available. Although computers are the tools, and software provides the means for developing schedules, the individual user must understand what the computer is performing. While numerous scheduling methodologies exist for developing project schedules, two of the most common are:

- bar charts and
- critical path.

A third method, project evaluation review technique (PERT), is mostly used by government agencies for calculating the most likely duration for networks.

**Bar Chart (Gantt Chart) Method:**

The bar chart, also called a Gantt chart, is primarily meant to control only time elements of a program or project. However, since there are no relationships between the activities, it is not possible to assess the impact of one activity on another nor on the time of completion of the project. When preparing a bar chart, the work effort must be divided into components, which are then scheduled against time.

Preparing a bar chart involves several steps:

1. Analyze the program or project and specify the basic approach to be used in its execution.
2. Segment the program or project into a reasonable number of activities that can be scheduled.
3. Estimate the time required to perform each activity.
4. Place the activities in time order, considering both sequential and parallel performance.
5. Adjust the diagram until the specified completion date, if one exists, is satisfied.

The status shows that Activity B has not started and is behind schedule (by 5 weeks), Activity C is slightly ahead of schedule (by 1 week), Activity E is slightly behind schedule (by 2 weeks), and all other activities are on schedule. However, it cannot be determined if Activity B or Activity E will have an impact on another activity or on the project completion.

**Advantage of Bar Chart**

This graphical representation of work versus time is easy to read and provides a simple, understandable way to schedule small undertakings. The primary advantage of using a bar chart is that:

- it is simple to read.
- The plan, schedule, and progress of the program or project can be depicted graphically on a single chart.

**Disadvantages of bar Chart**

Bar charts have not been used successfully for large-scope, one-time-through projects primarily due to the following reasons:

• The inherent simplicity precludes including sufficient detail to enable timely detection of schedule slippages on activities of relatively long duration.

• The dependent relationships between activities cannot adequately be shown; thus, it is difficult to determine how progress delays in individual activities affect project completion.

• Developing bar charts is essentially a manual, graphical procedure, which makes them difficult to establish and maintain for large projects; they also tend to become quickly outdated, thus diminishing their usefulness.

Many large and technically demanding undertakings, such as developing weapons systems or constructing power plants, require schedules showing thousands of activities that take place in widely dispersed locations. Manually developed bar charts cannot adequately display this data and are thus unsuitable for anything other than a summary display of information.

With today's computer technology, however, if a network diagram is prepared and the work scheduled, the display of relationships between the activities can be turned off or masked. This masking produces a bar chart, at any level of the project schedule, which can be used as a communication tool for the most complex and largest of projects.

**Critical Path Method (CPM):**

The disadvantages of manually developed bar charts, coupled with other disadvantages that became evident during the mid-1950s, set the stage for development of network-based project management methodology. One of the methods that emerged to overcome these weaknesses was critical path scheduling.

The critical path method (CPM) is a scheduling technique using arrow, precedence, or PERT diagramming methods to determine the length of a project and to identify the activities and constraints on the critical path. The critical path method enables a scheduler to do the following:

• Determine the shortest time in which a program or project can be completed.

• Identify those activities that are critical and that cannot be slipped or delayed.

• Show the potential slippage or delay (known as float) available for activities that are not critical.

The critical path method (CPM) was designed for, and is useful on,

- projects where the duration of each activity can be estimated with reasonable certainty.
- it predicts how long an endeavor will take to complete.
- It also identifies the activities that control the overall length of the project.
- CPM is widely used in the process industries, construction, single industrial projects, prototype development, and for controlling plant outages and shutdowns.

CPM computer software, known also as project management software, allows for the assignment of resources to activities. Assigning resources to the activities and allowing the resources to accomplish their assigned work based on their availability provides another variable in the overall project duration. Since the software has this capability, CPM networking is also used by industries with fixed pools of resources such as maintenance and information technology projects.

**Project Evaluation Review Technique (PERT)**:

Project evaluation review technique (PERT) is a probabilistic technique, used mostly by government agencies, for calculating the "most likely" durations for network activities. During development of the Navy's Polaris Missile Program in the late 1950s, the team had no historical basis to draw upon when estimating the length of time, it would take to accomplish certain tasks. For each of the activities, the developers of PERT estimated a best or shortest time, worst or longest time, and the most probable time to accomplish the tasks defined.

Concurrent with the PERT network development, the team also developed computer software to run a probability analysis to arrive at a "most likely" duration for each activity and the overall project.

PERT is considered an indeterminate process for activity and project durations, while CPM is considered a deterministic process. The network of activities developed for PERT are like the arrow diagramming method (ADM) and precedence diagramming method (PDM) networks. Because of the similarity and resemblance of a CPM network to PERT, the term PERT has been used as a synonym for CPM.

**Summary of Basic Planning & Scheduling**

Although many people can schedule, only a few are expert planners. The secret to a good plan is to put the whole project on a single sheet of paper. This figure shows each phase of the project from the contract award to the mechanical completion; studying this figure will help develop an appreciation for the depth of information and timing presented on this single page. The result of all planning is to come up with a time-phased plan; this process is called scheduling

**Project Success**

Consideration of the following items will contribute to the success of a matrix budget:

i. Top management must define responsibilities and authority for the project manager.
ii. The project manager must anticipate conflicts.
iii. The project manager must take positive steps to develop teamwork.
iv. Documentation should be used to hold departments to their commitments.
v. Functional managers should review and sign all documents relating to plans and schedules for the project.
vi. The project manager must avoid direct conflict with the department heads.

vii. The project manager should limit the task to “what” is to be done, not “how.”

viii. The project manager must realize that each project is a new effort, and that careful and continuous planning is necessary.

## COST ENGINEERING STANDARDS

In standard cost system, product costs for materials, labour and overhead are budgeted or planned before the actual production takes place. The pre-established costs then provide a point of reference for analysing the costs of actual production. By analysing the variances from these standards, the manufacturer can identify the sources of excessive cost and investigate the causes. The identification of a problem is important while the discovery of its cause can point the way to action that will reduce costs and improve profits.