Turner, J. Rodney
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8
Managing cost

8.1 Introduction

Let us now consider the fourth project objective, managing cost, by which the project manager ensures the project's product is financially viable and worth while. The next section considers the purpose of estimating costs, and shows how this leads to several types of estimate, of different accuracy prepared at different stages of the project management life cycle. Later sections explain how the estimate is structured through the cost control cube, and describe several methods for preparing the estimate. Finally, we shall discuss how costs are controlled by comparing actual expenditure against the value of work done, and show how S-curves can provide a pictorial representation of this.

8.2 Estimating costs

There are several reasons why we estimate costs. The most obvious is to provide a measure against which to control costs. Other reasons are given below.

AS A BASIS FOR CONTROL

The estimate is prepared as a measure against which to control expenditure on the project. This measure is known as the *baseline*. The classic control process has four steps (Section 7.3):

- estimate future performance
- monitor actual performance
- calculate the difference, called the *variance*
- take action according to the size of the variance.

There are three basic actions:

- if the variance is zero or negligible: continue without change

– if the variance is significant but recoverable: plan recovery
– if the variance is large: revise the estimates.

As a basis for control the estimate may need to be quite detailed, prepared at a low level of the WBS.

ASSESS PROJECT VIABILITY

Before getting to a position where you need to prepare a control estimate, you need to determine whether the project is worth undertaking. You therefore prepare an estimate of the costs to compare with the estimates of returns. (Methods of assessing project viability are beyond the scope of this book, except as they were covered in Chapter 2.[1]) Furthermore, the appraisal estimate goes through various stages of increasing accuracy, at the start of proposal and initiation, at the transition from that stage to design and appraisal, and at the transition from that stage to execution and control.

OBTAIN FUNDING

After approval has been obtained, the project must be financed. Funding will also be awarded on the basis of a comparison between estimates of costs and future returns. The accuracy will usually be similar to that for project approval. (Obtaining finance is also beyond the scope of this book.[1])

MANAGE CASH FLOW

Once funding has been obtained, and work starts, the project must be managed so that work takes place and consumes cash no faster than the rate agreed with the financiers (bankers). There are apocryphal stories about zealous project managers finishing their projects early and underspent, (Figure 8.1), and wanting a pat on the back. However, the company has gone into liquidation because the bankers called in the overdraft half-way through the project.

ALLOCATE RESOURCES

Human resources are a special form of project funding. The business plans their allocation in advance against an estimate of the accuracy of the project approval estimate. They will be assigned to the project week by week against the control estimate.

ESTIMATE DURATIONS

The duration of a work element is calculated by comparing the estimate of work content to resource availability, and so the cost estimates form an input to time estimating. Time estimating is performed for similar reasons to cost estimating, and so similar types of estimate are required.

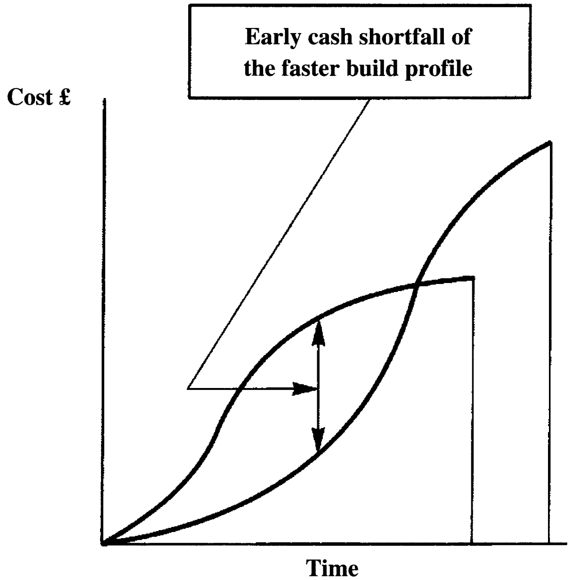

Figure 8.1 Different build profiles for a project

PREPARE TENDERS

Contracting firms tendering for bespoke contracts need to prepare estimates for the tender. They may use the cost estimate in several ways including:

- to forecast the profit by subtracting the estimated cost from the market price
- to calculate the price by adding a fixed percentage to the cost
- for passing on to the client. Clients in the public sector often demand a cost breakdown.

8.3 Types of estimate

The same estimate cannot satisfy all six purposes above. Five types of estimate, of varying accuracy, are required (Table 8.1). There is another purpose for each type, namely to prepare the equivalent estimate of duration. The levels of accuracy in Table 8.1 are those obtainable on engineering projects. Those for IS projects are said to be half this level (double the figure). Table 8.2 summarizes an idea first introduced in Section 5.3: you obtain increasing accuracy of estimate by estimating at lower and lower levels of WBS. If the estimates are truly mean values, errors cancel out. Table 8.2 implies that to obtain an estimate to the correct accuracy at

Table 8.1 Types of estimate: purpose and accuracy

Type of estimate	*Range of accuracy (%)*	*Purpose*
Proposal	±50	Appraisal viability to start, feasibility study
Budget	±20	Appraisal viability to start, systems design
Sanction	±10	Appraisal viability to approve project, obtain funding, allocate resources
Control	±5	Measure progress, assign resources
Tender	±2	Prepare tender

Table 8.2 Types of estimate: level in work breakdown structure

Type of estimate	*Lowest level of estimate in WBS*	*Accuracy of estimate (%)*			
		Project	*Work area*	*Work pack*	*Activity*
Proposal	Areas of work	±50	±100	–	–
Budget	Work packages	±20	±40	±100	–
Sanction	Work-package scope statements	±10	±20	±50	±150
Control	Activities	±5	±10	±25	±75
Tender	Tasks	±2	±4	±10	±30
Assumed number per project		1	4	25	200

the project level, you need only estimate to the order of magnitude at the currently lowest level of the WBS. There are two provisos to this:

1. A consistent error will reinforce: for instance if all activities are under-estimated by 20%, the project will be under-estimated by 20%.
2. The absolute error at the project level is worse than at the lower levels.

Table 8.2 can be taken to lower levels of WBS for larger projects. On one large engineering project worth several hundred million pounds, I prepared a WBS which had approximately 100 areas of work and a ratio of 1:10 for each subsequent level of work breakdown, down to the task level. On the same project, estimators were estimating costs accurate to the nearest pound at all levels of WBS, and yet including contingencies of several hundreds of thousands of pounds at the work-package level. This is clearly absurd. It is the right level of contingency, but the wrong level of accuracy. Table 8.3 shows appropriate levels of accuracy and contingency at different levels of the WBS for a project worth £100 million. The table is based on three simple ratios:

1. The average cost of an element of work is inversely proportional to the number in the project.
2. The accuracy as a percentage is proportional to the square root of the number in the project, or inversely proportional to the square root of the size, (see Section 5.3).
3. The accuracy as an absolute value is the accuracy as a percentage multiplied by the average cost.

At any level of breakdown, there is no point calculating and quoting estimates to a greater degree of accuracy than the figure in the right-hand column. Any contingency added at that level of breakdown must be at least this amount as a level of contingency is already included through the accuracy to which figures are calculated.

Table 8.3 Levels of estimating in a large engineering project

Level of breakdown	*Number in project* (*N*)	*Average cost* (*£*) (*C*)	*Accuracy* as ratio (%)	as value (±£)
Project	1	100 000 000	± 1	±1 000 000
Area of work	100	1 000 000	± 10	± 100 000
Work package	1000	100 000	± 30	± 30 000
Activity	10 000	10 000	±100	± 10 000
Task	100 000	1 000	±300	± 3 000

8.4 When to estimate costs

It follows from Table 8.2 that to prepare estimates of increasing accuracy requires increasing effort as you estimate at lower levels of breakdown. Ratio 2 above implies that to double the accuracy at the project level requires you to estimate at a level of breakdown with four times as many work elements, requiring four times the effort. This has been measured in the engineering industry[2] (Table 8.4). When plotted (Figure 8.1), this is a learning curve, with greater effort giving greater accuracy, but with diminishing returns. In addition, there is a point, at 5 per cent accuracy with effort 5 per cent of project cost, where the effort does not justify the return. This has three consequences:

1. On projects internal to an organization, it is not worth while producing an estimate more accurate than the control estimate, because it costs more to produce than the value of the data. This is a consequence of the uniqueness of projects (Chapter 1). On a production line, costs may be estimated to a low level of detail, because the saving is made many

Table 8.4 Level of effort and stage of production of project estimates

Type of estimate	*Accuracy (%)*	*Level of effort as % of project cost*	*Stage of production*
Proposal	±30–±50	0.02–0.1	Preproposal and initiation
Budget	±20–±35	0.1–0.3	Proposal and initiation
Sanction	±10–±25	0.4–0.8	Design and appraisal
Control	± 5–±15	1–3	Implementation planning
Tender	± 2–± 5	5–10	Tender preparation

times over. On projects, the saving is made once only. It is not worth while producing plans in great detail, because the effort is not rewarded. It is better to put management effort into eliminating risk, not quantify it. The problem arises for contracting companies who, when tendering, must prepare estimates which will allow them to make a profit (Example 8.1).

2. The way to improve accuracy of estimates is not to put more effort into estimating, but to improve the estimating data, effectively to move the curve in Figure 8.2 to the left using historical data. However, this too

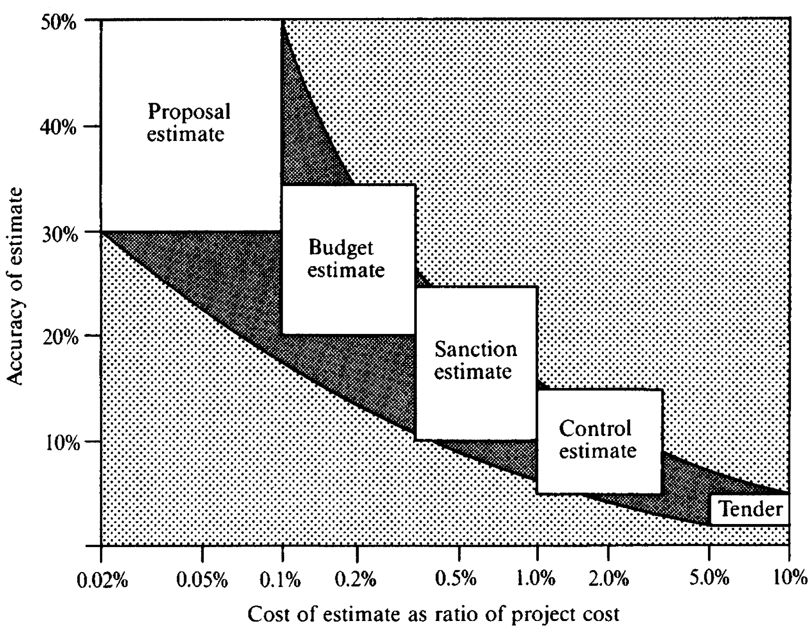

Figure 8.2 Accuracy of estimate vs cost of estimate (a learning curve following an inverse square law)

suffers from the law of diminishing returns. On engineering projects, 80 years of effort has gone into preparing data.[2] The IS industry has only 20 years of experience, which is why the accuracy of estimates for each type is only half as great (double the figure) – four times the effort doubles the accuracy.

3. The estimate at one level should not be prepared before the estimate at the previous level. Each estimate is therefore prepared at a given stage of the life cycle (Table 8.4), and these stages should be followed rigorously. Effectively, the comparison of costs and returns at the end of one stage of the life cycle justifies the commitment of resources to planning, design and estimating at the next stage. If the project is not viable at these high levels of estimate, work should not proceed to the next stage (Example 8.2).

I facilitated a bid management workshop run by a major IS vendor at Henley Management College. They spend 3 per cent of contract value preparing estimates, are successful at winning one contract in five, and have traditionally made profit margins in excess of 50 per cent. The contract they win pays the estimating costs of the four they do not, but the net margin was still in excess of 35 per cent. However, margins are being squeezed, and they are now lucky if they make a gross margin of 15 per cent. That means they must increase the number of contracts won, reduce the estimating costs, or make a loss. A bid manager from one of the major engineering contracting firms in the petrochemical industry spoke at the workshop. He said they had reduced the bidding costs to 0.75 per cent of contract cost. They also win one contract in five, but need to make a margin of only 4 per cent on that contract to cover the bidding costs on the five. The way they reduced bidding costs is to have a department of bid managers, who are the centre of expertise for tendering. That department can make maximum use of historical data. Effectively:

- they accelerate the learning curve
- they reduce the unique elements of projects, and so turn the bidding process into a repetitive operation
- they achieve quality through using historical data (Chapter 7).

Example 8.1 Recovering the cost of estimating on contracts

I worked in one company where the IS Department prepared control estimates at project initiation, only to find projects were not viable. If you expect an internal rate of return of 20 per cent on projects, you can only make that mistake three times per year until you cannot afford projects at all.

Example 8.2 Tailoring the estimate to the current stage of the project

8.5 Structuring the estimate

Cost components

The cost of a project may consist of several components, some of which are detailed below.

LABOUR

This includes the cost of people employed by the parent company involved in executing project tasks, including people designing and delivering the facility. I have worked in some manufacturing companies that do not attribute design labour to contracts. It is absorbed into company overheads and shared between all contracts. The result is the company only wins contracts with a high design element, and they have no control over design costs. Some other labour costs are included under other headings. The labour cost may be measured in monetary terms, or in man-hours. The latter is also called the *work content* (Section 6.5), and is a measure of the total effort required, independent of the duration and number of people performing the task. Clearly, effort can be converted into monetary terms by applying known costs per man-hour for each resource.

MATERIALS

This includes the cost of materials bought via the parent company and consumed in delivering the facility. This may be materials contained in the final product or consumables used on project tasks. On engineering projects materials include machinery, vessels, piping, structures, and instrumentation, but also include things like welding rods and coffer dams. On information systems projects, materials include main and peripheral hardware, proprietary software and coding sheets. On organizational development projects, materials may be more peripheral to the project, but include materials used on training programmes, furniture for new offices and stationery for new management procedures.

PLANT AND EQUIPMENT

These are materials used in delivering the facility, but which are not consumed, and so are available for re-use on subsequent projects. They may be either bought or hired, but either way each project only pays a part of their price new. This cost component should only include the cost of plant and equipment borne by the parent company. On engineering projects, plant and equipment includes welding machines and earth moving machinery. On information systems projects it includes hardware used by programmers. On organizational development projects it may include equipment used in the preparation and delivery of training programmes, temporary accommodation used during office moves and printing equipment if hired especially for the project.

SUBCONTRACT

This includes the cost of labour and materials as above provided by outside contractors. Costs will be included in this heading where their control is not within the scope of the parent organization.

MANAGEMENT

This should include the cost of people and materials involved in managing the project. These costs are directly attributable to the project, but not specific tasks, and include the cost of the manager and team leaders (integrators); the project support office; a project management information system if required; and temporary site services. The cost of management gets smaller as a proportion of the total cost as the size grows. Typically it is about 5 per cent on a project of £10 million, and 1 per cent on a project of £1 billion.[2] For projects of less than £10 million, many of the routine project management tasks must be undertaken by the manager if this is not to become a burdensome overhead, and on very small projects it may not be treated as a direct cost at all, but borne by the parent organization as an overhead. (The risk of this, of course, is the same as treating design as an overhead.)

OVERHEADS AND ADMINISTRATION

This should include the cost of administering items included in labour, materials and subcontract. These will include: costs directly attributable to some items such as transport, but included under this heading for convenience; costs shared between items such as procurement and storage; and absorption of some parent company overheads.

FEES AND TAXATION

Fees may include insurance, finance; licence agreements; and taxation may be regarded as a special type of fee.

INFLATION

This may or may not be ignored in the estimates.

1. Two cases when it is ignored are on publicly funded projects, and projects where project costs, raw material costs and revenues are expected to inflate at the same rate. In the former case it is assumed tax revenues will rise as fast as costs, and so the project will not become a larger burden on the public purse. For many public projects there are no

direct revenues; the benefit is to the economy and is expected to grow in real terms. The Thames Barrier for instance was 400 per cent overspent on the original budget, but it is claimed that 80 per cent of that was due to inflation.[3] Only 20 per cent of the overspend was due to unforeseen costs. In the latter case, accounting for inflation will make the returns from the project appear better than they actually are, and so it is often ignored. In fact its main impact will be to decrease financing costs as a percentage of the total cost, but to increase taxation as the project will appear to be more profitable than it actually is.

2. Two cases where it is not ignored are where there is expected to be differential inflation between project costs, raw material costs and revenues, and by contractors preparing fixed-price tenders. In the former case it is necessary to account for it to calculate the true return of the project (Example 8.3). In the latter case, the contractor must either include inflation in the price, or agree with the client to increase the price against an agreed index, called escalation.

When preparing the case for the construction of an Ammonia plant for ICI in the mid-1980s, I had to account for inflation. The price of the plant was expected to rise with the construction index (CI), which was running ahead of the retail price index (RPI), the price of the gas feedstock was expected to rise faster than the CI, the price of electricity with the RPI, while it was expected that the price of the product, ammonia, would remain static.

Example 8.3 Allowing for inflation in the estimates

CONTINGENCY

Contingency may be added as blanket figures or calculated according to risk. In the copy of the estimate shown to the owner, contingency is usually distributed among the other headings. In the copy shown to the team, the manager should keep contingency back, and show them just the raw estimates. Given that 'work done expands to fill the time available', if contingency is included in the subbudgets given to work package managers and subcontractors, then they will spend up to that amount. In fact it is common for project managers to maintain three or four estimates:

1. The *baseline* or *estimated prime cost*: the raw estimate without contingency. This is the sum of the most likely out-turn for each activity (Chapter 10). There is typically no chance of achieving an out-turn less than this, but it is given to the project team to provide them with a tight target.
2. The project manager consumes contingency to give a *current estimate*

when there is significant variation. Then baseline is impossible to achieve, and to hold the team to it would be demotivating. Contingency is consumed to update the baseline, but this must be done through strict change control. If the baseline is updated lightly, the project is always on budget and control is lost. On the National Gallery Extension, the project manager would allow no contingency to be apportioned to any of the work packages as he wanted to maintain strict control of costs.

3. The *most likely out-turn* is the estimate the project manager thinks is most likely, with contingency apportioned appropriately. This is the sum of the average out-turn in each activity (Chapter 10). There is typically a 55 per cent chance of achieving an out-turn less than this.
4. The *budget* is the amount the owner is willing to spend. This is what the project manager is measured against by the owner, and is justified by the expected returns from the project. There should typically be an 80 per cent chance of achieving an out-turn less than this.

On a typical engineering project the budget will be 10 to 20 per cent greater than the baseline, and the most likely out-turn half way between. On IS and R&D projects the contingency may be much higher.

FINANCE

Finance is the most significant cost on a project,[1] being greater than any other single cost and yet is ignored by most project managers. To them it is almost a phantom cost. It is the one area still remaining to make significant cost savings on projects.

Structuring the estimate

These components constitute a third breakdown structure, the *cost breakdown structure* (CBS). The CBS is usually simpler than the other two, although one more level of breakdown can be derived under most headings. The three structures, PBS, OBS and CBS, form the *cost control cube* (Figure 8.3), developed by the United States Defense Department, in the 1950s, as the basis of their C/SCSC methodology for controlling project costs. All costs can be assigned to a cell of the cube, and through the cube all costs have a position in each of the three breakdown structures. A project aggregate can then be prepared by summing along any of the three directions. Of course a large number, often the majority, of cells in the cube will contain no costs. For instance:

- a work element may be assigned to one subcontractor, a single entity in both the OBS and CBS
- a work element may consume labour only and of one type only
- a work element may be created to assign management costs.

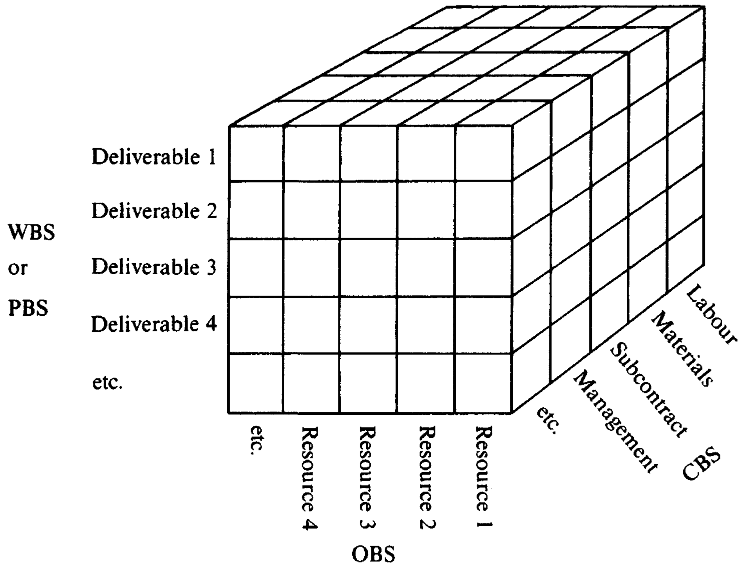

Figure 8.3 Cost control cube

Any two of the breakdown structures taken together form a matrix:

- the matrix formed by the PBS and OBS forms the responsibility chart, (Chapter 6)
- the matrix formed by the OBS and CBS is called a 'code of accounts'; it is used to apportion the costs in the parent company's accounts
- the third matrix is seldom encountered.

The cost control cube provides a structure for the estimate, is used to create it and is used in the subsequent control of costs. The PBS and OBS are evolved to the current lowest level according to the stage of production (Table 8.4), and costs assigned to each element in the PBS/OBS matrix against each costs element. The estimate is then aggregated to the project level. In this way, the cost control cube is amalgamated through a series of pages (Figure 8.4). Figure 8.5 shows a typical OBS for a chemical plant, and is adapted from an estimate I prepared for ICI. A page like this would be prepared for the facility as a whole. That is aggregated from similar pages for each part (intermediate product) of the facility, and those in turn for each subassembly of the part. Figure 8.6 is the plant in Figure 8.5 at a lower level of work breakdown.

Estimates can be similarly structured for IS, organizational change, training and other projects. Figure 6.12 contains a simpler estimating sheet for a smaller project, the CRMO Rationalization Project. This sheet has

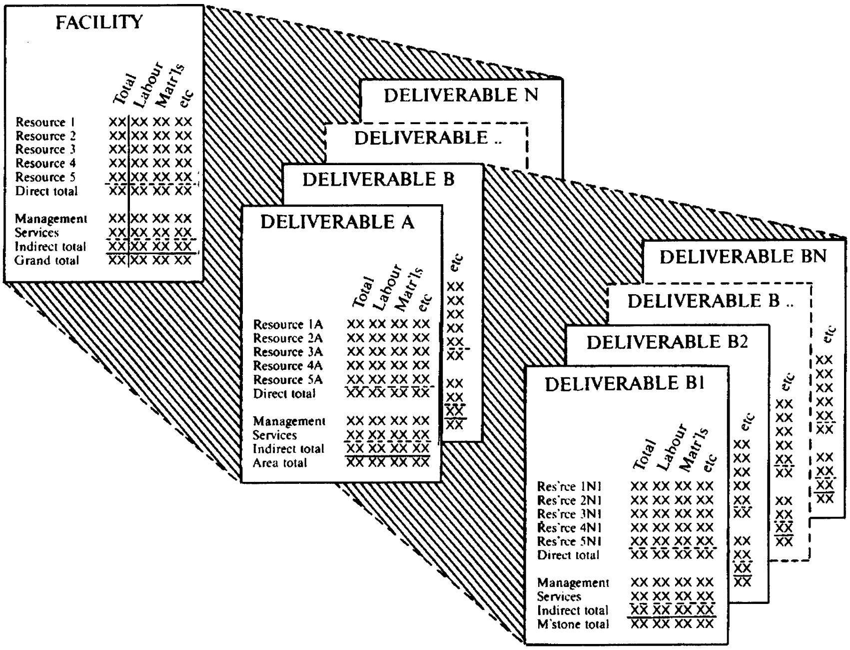

Figure 8.4 Cascade of estimates through the PBS, OBS and CBS

only two dimensions of the cost control cube, work and organization. It relates to only one component of the CBS, labour. If estimates were required for other components, such as materials or plant and equipment, then similar sheets could be developed, or more columns added to this sheet, especially if it is held in a spreadsheet package on a personal computer.

8.6 Estimating techniques

There are several ways of preparing estimates for the various cost components. The most direct is to break the work down to a lower level of detail, estimate the cost at that level and sum back up. However, the arguments of Section 8.4 imply that level of detail cannot always be justified, especially at earlier stages of the project life cycle. It is therefore necessary to use other methods which enable estimates to be produced at higher levels of work breakdown. The engineering and civil construction industries have well advanced methods of estimating at all levels of work breakdown.[2,4] These rely heavily on historical data and include step

PROJECT ESTIMATE	NORTHERN ENERGY AND CHEMICAL INDUSTRIES PLC					02-Jan-9X
PROJECT:	Petrochemical Plant	CODE:	THNS	ISSUE:	A	
WORK AREA:	....	CODE:	....	AUTHOR:	JRT	
WORK PACKAGE:	....	CODE:	....	APPRVD:	CME	
ACTIVITY:	....	CODE:	....	DATE:	02-Jan-9X	

	1000 tonne per day plant				SCALE	COST	1500 tonne per day plant			
	Material	Erection	Function	Plant	EXPONENT	FACTOR	Material	Erection	Function	Plant
	£,000	£,000	£,000	£,000	n	1.5^n	£,000	£,000	£,000	£,000
Main plant items										
- Vessels	13.33	0.63	13.96		0.65	1.30	17.35	0.82	18.17	
- Furnace and boiler	2.89	0.14	3.03		0.70	1.33	3.84	0.18	4.02	
- Machines and drives	9.73	0.46	10.19		0.75	1.36	13.19	0.62	13.81	
- Vendor packages	6.77	0.32	7.09		0.75	1.36	9.18	0.43	9.61	
- Other	0.00	0.13	0.13		0.70	1.33	0.00	0.17	0.17	
MPI total: Materials	32.72	—	32.72				43.55	—	43.55	
MPI total: Erection	—	1.67	1.67				—	2.22	2.22	
Bulk Items										
- Piping	1.22	1.88	3.10		0.70	1.33	1.62	2.50	4.12	
- Instruments	0.64	1.10	0.74		0.60	1.28	0.82	0.13	0.94	
- Computer control system	1.56	0.88	2.44		0.70	1.33	2.07	1.17	3.24	
- Electrical	1.82	0.53	2.35		0.70	1.33	2.42	0.70	3.12	
- Structural		0.26	0.26		0.65	1.30	0.00	0.34	0.34	
- Civil		2.11	2.11		0.65	1.30	0.00	2.75	2.75	
- Painting		0.10	0.10		0.65	1.30	0.00	0.13	0.13	
- Insulation		1.50	1.50		0.65	1.30	0.00	1.95	1.95	
- Buildings		0.12	0.12		0.65	1.30	0.00	0.16	0.16	
- Plant modification		0.70	0.70		0.70	1.33	0.00	0.93	0.93	
Bulk items total	5.24	8.18	13.42				6.93	10.75	17.68	
TOTAL DIRECT COSTS				47.81						63.45
Engineering - Design			8.40		0.50	1.22			10.29	
- Software			0.53		1.20	1.63			0.86	
Construction - Management			3.22		0.65	1.30			4.19	
- Services			1.50		0.65	1.30			1.95	
Works - Start-up			6.70		0.65	1.30			8.72	
- Working capital			9.56		1.00	1.50			12.69	
Contingency			4.78						6.34	
TOTAL INDIRECT COSTS				34.69						45.05
CAPITAL COST OF ERECTED PLANT				82.50						108.50
Inflation			4.13						5.42	
Licence fees and royalties			0.41						0.54	
Insurance			0.83						1.08	
TOTAL OVERHEADS				5.36						7.05
TOTAL CAPITAL COST				87.86						115.55

Figure 8.5 Sample OBS for a chemical plant (plant level)

PROJECT ESTIMATE	NORTHERN ENERGY AND CHEMICAL INDUSTRIES PLC					02-Jan-9X
PROJECT	Petrochemical Plant	CODE:	THNS	ISSUE:	A	
WORK AREA:	Synthesis	CODE:	THNS5	AUTHOR:	JRT	
WORK PACKAGE:	....	CODE:	....	APPRVD:	CME	
ACTIVITY:	....	CODE:	....	DATE:	02-Jan-9X	

	Material £000	Erection £000	Function £000	Plant £000	Parametric ratio Function %MPI	Parametric ratio Plant %MPI
Main plant items						
- Vessels	4.85	0.23	5.08			
- Furnace and boiler	0.00	0.00	0.00			
- Machines and drives	3.67	0.17	3.84			
- Vendor packages	1.55	0.07	1.62			
- Other	0.00	0.00	0.00			
MPI Total: Materials	10.07	—	10.07		100.0%	
MPI Total: Erection	—	0.47	0.47		4.7%	
Bulk items						
- Piping			1.21		12.0%	
- Instruments			0.23		2.3%	
- Computer control system			0.82		8.1%	
- Electrical			0.81		8.0%	
- Structural			0.09		0.9%	
- Civil			0.76		7.5%	
- Painting			0.03		0.3%	
- Insulation			0.50		5.0%	
- Buildings			0.06		0.6%	
- Plant modification			0.24		2.4%	
Bulk items total			4.74		0.47	
TOTAL DIRECT COSTS				15.29		1.52
Engineering - Design			1.72		17.1%	
- Software			0.09		0.9%	
Construction - Management			0.80		7.9%	
- Services			0.33		3.3%	
Works - Start-up			1.43		14.2%	
- Working capital			3.06		30.4%	
Contingency			1.53		15.2%	
TOTAL INDIRECT COSTS				8.96		0.89
CAPITAL COST OF ERECTED PLANT				24.24		2.41
Inflation						
Licence fees and royalties						
Insurance						
TOTAL OVERHEADS				0.00		
TOTAL CAPITAL COST				24.24		

Figure 8.6 Sample OBS for a chemical plant (plant area level)

counting, exponential, parametric, and detailed and computerized methods. The IS industry is now developing similar techniques, and it is possible to postulate similar approaches for organizational development projects. I describe the methods from these three industries, engineering construction, building and IS. I hope that from these you may be able to develop techniques appropriate to your industry.

Methods in the engineering construction industry

The engineering construction industry has well-advanced methods of estimating at all levels of work breakdown[2] (Table 8.5). These rely heavily on historical data and include:

STEP COUNTING METHODS

These assume cost is a function of the number of functions and plant throughput. In the engineering construction industry standard formulae and tables have been derived from empirical data. Some of these formulae are still valid after 20 years, because of the stability of the technology. The formulae exist at several levels of breakdown, the plant level, plant area level or main plant item (MPI) level.

EXPONENTIAL METHODS

These assume cost is proportional to the size of the facility, to some power. In the engineering construction industry, this is called the 'two-thirds power law' because the exponent is usually between 0.6 and 0.75. If you know the cost of a plant of standard size, the cost of a larger or smaller one can be derived. The law can be applied at several levels of breakdown; the lower the level, the more accurate the estimate at the plant level. Figure 8.5 contains exponents from George[2] for a chemical plant, applied at the first level of OBS, showing how they can be used to convert from a 1000 tonne/day plant to a 1500 tonne/day plant.

Table 8.5 Estimating methods used to prepare types of estimate

Type of estimate	*Accuracy (%)*	*Estimating methods*
Proposal	±50	Step counting Exponential (plant level)
Budget	±20	Exponential (MPI level) Parametric (plant level)
Sanction	±10	Parametric (MPI level, vendor quotes)
Control	± 5	Parametric (MPI level, firm prices)
Tender	± 2	Detailed estimating

PARAMETRIC METHODS

These assume costs are proportional to some core cost. On chemical plants this is the MPI. Tables of ratios exist giving the cost of other items as ratios of the MPI, dependent on its value, its type and the severity of duty. These tables exist at several levels of WBS. Figure 8.6 contains data at the plant area level, from George.[2] The techniques are so advanced in the engineering construction industry, that estimates based on prices of a placed order and derived at the equipment levels are sufficiently accurate for the control estimate. It is in this way that the cost of estimating is being reduced.

DETAILED ESTIMATES

They are prepared by contracting companies tendering for work, where the level of accuracy is of the same order of magnitude as the expected profit margin. At the lowest levels the costs are derived from standard cost books or from parametric data.

COMPUTER AIDED ESTIMATING

This has been derived to support parametric estimating and detailed estimating. These are often based on a bill of materials (BOM) or a bill of quantities (BOQ) for standard components.

Possible sources of data for preparing estimates are:

- suppliers' quotations (typical, budget, detailed)
- trade literature, technical literature, textbooks, government literature
- company historical data, standard costs, personal records
- computer systems.

Estimating methods in the building industry

Table 8.6 shows when by whom and how estimates are made in the building industry. Methods of estimating include:

APPROXIMATE METHODS

The cost is assumed to be proportional to the lettable floor area for a building of appropriate type, use and quality. Tables of figures are given, for instance, in Spon.[4,5] The figures given include costs not only for the whole building, but also for individual services within the building (all related back to the area of the whole building). The cost, given in £/million^2, can range by a factor of three for a given type of building, and so it is important to be aware of the use and quality. The user must also be aware of what services are and are not included in the costs calculated. However, the figures give estimates accurate enough for proposal estimates. The figures given are also only valid in Outer London at a certain time. Tables are given to update the estimates for other locations and other times (see below).

Table 8.6 Method of estimating vs stage of use

Level	*WBS unit*	*Estimate*	*User*	*Method*	*Design stage*
1	Unit	Preproposal	QS	Functional	Brief
2	Space	Proposal	QS	Approximate	Sketch
3	Element	Budget	QS	Elemental	Sketch/detail
4	Feature	Sanction	QS	Empirical	Detail
5	Item	Control	QS	BOQ	Detail/working
6	Operations	Tender	Contractor	Network	Working
7	Resources	Work	Contractor	SOR	Working

FUNCTIONAL METHODS

A coarser method of approximate estimating is to estimate in terms of the functional requirements, that is cost per bed in a hospital, the cost per pupil in a school, the cost per seat in an office building. These estimates have the same validity in terms of location and time as the approximate methods, and will be prepared at an earlier stage of the project than the approximate methods.

ELEMENTAL ESTIMATING

The building is broken down into major elements, and the cost estimated as a ratio of the assumed duty or floor area of that element. The difference between this and the previous method is that the cost of each service is calculated from the size of that service, not the floor area of the whole building. This method can produce an estimate accurate enough for budget, or even sanction, purposes. Once this estimate has been accepted, it can be used to generate a complete bill of quantities.

EMPIRICAL ESTIMATING

Costs are extrapolated from the cost of schemes of similar size, scope and type. Historical data is used to establish overall parameters and indicators which influence cost. These can be derived by regression analysis or curve fitting, from established data or industry standard formulae.[4]

SCHEDULE OF RATES

This is not so much an estimating method, as a detailed breakdown of the cost of doing individual tasks on a building or construction site. A schedule of rates can be used for building up a detailed estimate. Or they can be used for building up costs associated with small projects, or even individual, isolated tasks, such as maintenance projects and maintenance jobs respectively. A schedule of rates will often be used on cost plus contracts.

BILL OF QUANTITIES

This is equivalent to the computerized estimate described above. It will often be built up from a CAD drawing of the building, using standard bills of quantities for repeated elements.

Estimating methods in the IT industry

The IT industry has developed a set of estimating techniques to meet its own particular needs. There are major differences between estimating on software projects vs construction projects, for the following reasons:

1. Software projects are not mechanistic, (though neither is engineering design). The activities are indeterminate and cannot be measured by simple means. Task size and complexity can be assessed by experts, but this is not normally reliable. The more complex the project, the less reliable the estimate.
2. Because of the rapid change of technology, there is not a wealth of historical data. The COCOMO model described later was based on information from 63 projects. While it gives a good base estimate for software projects, it is only applicable to programming using 3GLs.

Techniques for estimating on software projects are described by many authors,[6] and include:

ANALOGY

Estimates are made by comparison to previous, similar projects. This is probably the most valid technique for many organizations, but does rely on historical records. The technique relies on the use of a consistent software development life cycle. Using the technique to extrapolate between projects of different size can also be fraught with danger, given the non-linear relationship between size, effort and time scale.

TOP-DOWN ESTIMATING

The estimate is made against stages of a standard life cycle, and activities within the life cycle, often applying fixed percentage allocations to each stage. This approach has several advantages:

- a detailed design of the final system is not required, so the approach can be used at an early stage
- the technique is comparatively inexpensive
- it does not constrain the use of other techniques.

BOTTOM-UP ESTIMATING

This is the detailed estimate built up from a knowledge of the design of the system. It is most effectively used to provide an estimate of the next stage of a project prepared on completion of the current stage. The technique is expensive, and has several disadvantages which means it must almost always be used in conjunction with other techniques:

- errors tend to compound, usually resulting in underestimation of the total cost of a system
- it takes no account of the shortened project time scales – two people do not take half the time of one person to do a job.[7]

MATHEMATICAL MODELS

These relate effort and time to lines of code, similar to step counting and exponential methods. They rely on historical data, and must be tailored to an organization's needs. The models only apply to the development stage of a project. In many of the models, the equations take the following form:

$$\text{effort} = A * (\text{size})^b$$
$$\text{time} = C * (\text{effort})^d$$

where size is measured in thousands of lines of code, effort is measured in man-months, and time in months. Table 8.7 contains coefficients for several models.[8] In most cases, the exponent b is greater than one, giving relatively larger cost for bigger systems. These models take no account of the effects of time compression. The constraint models provide correction factors. Table 8.7 also shows the effort and time predicted by the different methods for a system of 40 000 lines of code, and software development costs of £4 000 per man-month. The figures vary quite wildly. Each model was all developed within one organization, and therefore represent its own characteristics. This means organizations should develop their own models. It also means they should question their software development environment if their estimates are uncompetitive.

Table 8.7 Mathematical estimating models

Model	*A*	*b*	*C*	*d*	*Effort (m-mths)*	*Duration (months)*	*Cost (£'000s)*
Watson Felix (IBM)	5.2	0.91	2.47	0.35	149	14.2	592
Nelson, SDC	4.9	0.98	3.04	0.36	192	19.8	728
COCOMO, organic	2.4	1.05	2.5	0.38	115	15.2	462
COCOMO, semi-d	3.0	1.12	2.5	0.35	187	15.6	747
Frederic	2.4	1.18	–	–	186	–	746
COCOMO, embedded	3.6	1.20	2.5	0.32	301	15.5	1205
Phister	1.0	1.275	–	–	110	–	441
Jones	1.0	1.4	–	–	175	–	700
Halstead	0.7	1.5	–	–	177	–	708

FUNCTION POINT ANALYSIS

The mathematical models apply only to the development stage of the project (cutting code), which typically accounts for only 50 per cent of the cost. Function point analysis count the function points, which represent the total functionality of the system.[8] Function points include:

- inputs: forms and screens
- outputs: reports and screens
- end-user enquiries
- logical data files
- interfaces to other systems.

Function points are converted to an estimate by:

- comparison with previous systems – applicable to the whole life cycle
- converting to lines of code – applicable to the development stage only.

CONSTRAINT MODELS

The models above take no account of the reducing efficiency caused by decreasing duration.[7] Reducing duration increase costs. Constraint models have been developed in an attempt to calculate the effects of time-scale compression. They are still relatively new.

The methods compared

Table 8.8 compares the methods from the three industries. The equivalence is not exact, but hopefully the comparison will help you to derive similar approaches for your industry.

Table 8.8 Comparison of the estimating methods for three industries

ECI	*Building*	*IS*
Step counting: plant level	Functional Approximate	Mathematical
Step counting: area level	Elemental	Function point analysis
Exponential	Empirical	Analogy
Factorial	–	(Function point analysis)
Detail	Schedule of rates	Bottom-up
Computer based	Bill of quantities	Top-down

Updating estimates

Estimating data is only valid at a certain time, in a certain place and in a given currency. It will often be necessary to allow for inflation, and may be necessary to convert from one country to another and one currency to another. Tables of ratios exist for these conversions.[2] Without any other guidance you can use the retail price index (RPI). However, tables exist for many industries giving inflation rates different to RPI. Tables are published for most countries of the world. They also exist for ratios of exchange rates for years past, and for differences in labour and material costs between different countries. Therefore, given the price of a project in one country in its local currency in a year past you can calculate the cost of the same project in another country in its local currency in another year past.

8.7 Controlling costs: obtaining value for money

Up to this point of the chapter, I have talked about estimating costs. I close by discussing the control of costs. This was stated as the first purpose of preparing the estimate, and so the structure has been derived to facilitate this process. In Section 8.2, I said that the estimate is prepared as a measure against which to compare actual performance. In this section I consider:

- the appropriate measure for cost control
- when to make the comparisons
- using the comparison to forecast cost to completion
- the use of S-curves to provide a visual representation.

We shall not discuss how to overcome variances (differences) identified for now, but leave that to Chapter 12, where we shall discuss execution and control. The techniques described below are known as *earned value analysis*.[9]

The measure for cost control

The commonest mistake of cost control is to use as the measure, or baseline, for control the predicted rate of expenditure with time, and to compare the actual rate of expenditure with this. A cost estimate is prepared against the work breakdown structure. This is then scheduled in time by scheduling the work elements to produce an expenditure profile. (How to schedule the work will be discussed in Chapter 9.) This predicted rate of expenditure is variously called:

- scheduled cost
- predicted cash flow
- baseline cost of work scheduled (BCWS)
- planned cost of work scheduled (PCWS).

The last two are the most descriptive. As work is done, actual expenditure is recorded. This actual rate of expenditure is variously called:

- the accrual
- the actual cash flow
- the actual cost of work complete (ACWC).

To determine whether the project is over- or underspent, actual expenditure is compared to the scheduled cost, and if less all is assumed to be well. However, this assumption may be false because no measure is made of what work has been done for the expenditure. In the most extreme case, no work may have been done, and yet expenditure accrued. I conducted a post-completion audit on a project where the company's finance director realized something was wrong when all the project's budget had been spent and yet only 50 per cent of the work done. To control costs you must compare the actual expenditure not to the schedule of expenditure, but to some measure of the value of work done. The PBS or WBS provides the means to do this. As an element of product is delivered, or work is completed, (the former is better), you can compare how much it actually cost against what it was estimated to cost. This estimated cost of the actual work done is variously called:

- earned value
- baseline cost of work complete (BCWC)
- planned cost of work complete (PCWC).

The *earned value* for a work package or the whole project is the sum of the estimate of the completed activities which constitute it. Cost is controlled by comparing the earned value to the actual expenditure, and calculating a *cost variance*:

$$\text{Cost variance} = \text{Accrual} - \text{Earned value}$$
$$\%\ \text{Variance} = (\text{Variance}/\text{Earned value}).$$

If this variance is positive the project is overspent, and if it is negative it is underspent. Action is taken if this variance is non-zero (positive) (Section 8.2).

If we used the strict definition of earned value given above, based only on work complete, a bias would be introduced, because no allowance is made for work in progress. At the work package or project level some allowance must be made for activities started but not finished. A subjective estimate of percentage completion of activities can be made, but this is usually an over estimate (always 99 per cent!). It is more accurate to assume that on average activities in progress are half finished. We therefore have:

- for activities:
  % Completion = 0%, 50% or 100%
- for the project and work packages:
  % Completion = (earned value/original estimate)
- where:
  Earned value = Sum of (% completion × original estimate)
  with the sum taken over the constituent activities.

It was implied above that the comparison between the scheduled cost and actual cost is meaningless. If the actual cost is less than the scheduled cost it does not tell us whether the project is underspent or late. It was shown that it is the comparison between earned value and actual cost that indicates whether the project is over- or underspent. The comparison between the earned value and the scheduled cost does however, tell us whether the project is early or late; if the earned value is greater than the scheduled cost, the project is on average early, and if it is less, it is on average late. I say on average, because it gives us no information about progress on the critical path. Critical work can have been delayed, but a larger, non-critical job brought forward, and the project appears to be early. We can calculate a second variance, the volume variance:

$$\text{Volume variance} = \text{Earned value} - \text{Scheduled cost}$$
$$\%\ \text{Variance} = (\text{Variance/Scheduled cost}).$$

Example 8.4 presents a simple example of an earned value calculation, for a project to make a hundred pairs of shoes. Accountants talk about variances being favourable or unfavourable, rather than positive or negative, since the latter can be misleading. In this simple production model, it would be more common to talk about the cost variance as being £2 per pair (or 20 per cent) on the standard cost of £10 per pair; and the volume variance as being 20 pairs (or 20 per cent) on a production target of 100 pairs. Because projects are unique, it is not possible to talk of 'standard costs', and because they usually comprise quite a variety of work, the only standard for comparison is in expenditure, either of money or man-hours, and so everything must be translated to this standard for control purposes. Example 8.4 shows that earned value analysis is just standard management cost accounting, but applied to an endeavour which is unique, novel and transient, rather than repetitive.

Consider a very simple example of a 'project' to make 100 pairs of shoes at £10 per pair. At the end of the period, only 80 pairs have been made at £12 per pair. In this simple case we have:

Scheduled cost	=	100 pairs @ £10 per pair	= £1000
Actual cost	=	80 pairs @ £12 per pair	= £ 960
Earned value	=	80 pairs @ £10 per pair	= £ 800
Cost variance	=	£960 – £800	= £160 unfavourable
			= 20% unfavourable
Volume variance	=	£800 – £1000	= £200 unfavourable
			= 20% unfavourable

Example 8.4 Earned value calculation

When to make the comparisons

A second mistake in cost control is to record accrual and earned value only as invoices are paid. Although this provides a valid comparison, it is too late to overcome problems. You must therefore record accrual and earned value at an earlier time. This is usually as the cost is committed, when effective action can be taken. The cost may be committed either when the order is placed, or when the work is done:

1. The cost is committed when the order is placed for:
   - large material items
   - fixed price contracts.
2. The cost is committed when the work is done for:
   - labour
   - cost plus contracts
   - bulk materials.

For cost control purposes, it does not matter what is assumed for individual cost elements, as long as the same assumption is made throughout for each element; that is, the cost is accrued and the value earned together, and at the same time as the planned expenditure. However, the above gives the most effective means of control.

Forecasting completion

The variance calculation can be used to forecast the likely cost to complete the project. There are two simplifying assumptions:

1. The absolute variance at completion equals the variance to date:
   - Cost at completion = original estimate + variance to date.
2. The percentage variance at completion equals the percentage variance to date:
   - Cost at completion = original estimate × (1+% variance to date).

The latter is more realistic, but it is common to use the former because:

- some cost overspends are unlikely to be repeated
- those likely to be repeated may be reduced using experience to date
- some cost savings will be made to balance further overspend.

In fact the most accurate forecasts are obtained by applying the second formula above at lower levels of the WBS, using as the percentage variance to date, than on similar work elements modified in the light of experience.

Figure 8.7 shows a cost report prepared during the CRMO Rationalization Project, showing estimates percentage of completion and expenditure to date against both labour and materials, and comparing these to the scheduled percentage of completion, planned cost of work scheduled

PROJECT COST REPORT — TRIMAGI COMMUNICATIONS BV — 31-Aug-9X

PROJECT: CRMO RATIONALIZATION
WORK AREA: —
WORK PACKAGE: —

WORK NO	PACKAGE DESCRIPTION	ORG DUR (D)	REM DUR (D)	BASE COMPL (%)	PERCT COMPL (%)	BASELINE LABOUR (£,000)	BASELINE MAT'L (£,000)	BASELINE TOTAL (£,000)	CURRENT ESTIMATE LABOUR (£,000)	CURRENT ESTIMATE MAT'L (£,000)	CURRENT ESTIMATE TOTAL (£,000)	SCHEDULED COST LABOUR (£,000)	SCHEDULED COST MAT'L (£,000)	SCHEDULED COST TOTAL (£,000)	EARNED VALUE LABOUR (£,000)	EARNED VALUE MAT'L (£,000)	EARNED VALUE TOTAL (£,000)	ACTUAL COMMITMENT LABOUR (£,000)	ACTUAL COMMITMENT MAT'L (£,000)	ACTUAL COMMITMENT TOTAL (£,000)
P1	Project definition	30.0		100.0%	100.0%	11.2	6.4	17.6	11.2	6.4	17.6	11.2	6.4	17.6	11.2	6.4	17.6	11.0	6.3	17.3
T1	Technology design	40.0		100.0%	100.0%	12.8		12.8	12.8	0.0	12.8	12.8	0.0	12.8	12.8	0.0	12.8	12.1	0.0	12.1
01	Communication plan	5.0		100.0%	100.0%	1.2	2.5	3.7	1.2	2.5	3.7	1.2	2.5	3.7	1.2	2.5	3.7	1.2	2.4	3.6
02	Operational proc.	15.0		100.0%	100.0%	9.6		9.6	9.6	0.0	9.6	9.6	0.0	9.6	9.6	0.0	9.6	9.8	0.0	9.8
03	Job/Management desc.	20.0		100.0%	100.0%	12.8		12.8	12.8	0.0	12.8	12.8	0.0	12.8	12.8	0.0	12.8	12.5	0.0	12.5
T2	MIS function spec.	15.0		100.0%	100.0%	4.8		4.8	4.8	0.0	4.8	4.8	0.0	4.8	4.8	0.0	4.8	4.5	0.0	4.5
04	Staff allocation	15.0		100.0%	100.0%	3.6		3.6	3.6	0.0	3.6	3.6	0.0	3.6	3.6	0.0	3.6	3.7	0.0	3.7
A1	Estates plan	10.0		100.0%	100.0%	1.6		1.6	1.6	0.0	1.6	1.6	0.0	1.6	1.6	0.0	1.6	1.6	0.0	1.6
T3	Technical plan	10.0		100.0%	100.0%	0.8		0.8	0.8	0.0	0.8	0.8	0.0	0.8	0.8	0.0	0.8	0.8	0.0	0.8
P2	Financial approval	15.0		100.0%	100.0%	3.6	1.5	5.1	3.6	1.5	5.1	3.6	1.5	5.1	3.6	1.5	5.1	3.6	1.5	5.1
A2	Sites 1&2 available	15.0		100.0%	100.0%	8.4	6.6	15.0	8.4	6.6	15.0	8.4	6.6	15.0	8.4	6.6	15.0	7.5	6.9	14.4
05	Management changes	10.0		100.0%	100.0%	2.4		2.4	2.4	0.0	2.4	2.4	0.0	2.4	2.4	0.0	2.4	2.4	0.0	2.4
06	Redeployment/train	40.0	10.0	100.0%	75.0%	25.6	55.2	80.8	24.4	52.6	77.0	24.4	52.6	77.0	18.3	52.6	70.9	17.9	52.2	70.1
T4	System in sites 1&2	30.0	20.0	100.0%	33.3%	19.2	44.0	63.2	19.2	44.0	63.2	19.2	44.0	63.2	6.4	44.0	50.4	4.5	42.4	46.9
A3	Sites 1&2 ready	15.0	15.0	50.0%	0.0%	8.4	60.0	68.4	9.2	66.0	75.2	4.6	66.0	70.6	0.0	0.0	0.0			
T5	MIS delivered	15.0	9.0	50.0%	40.0%	4.8	38.0	42.8	4.8	38.0	42.8	2.4	38.0	40.4	1.9	38.0	39.9	1.6	40.2	41.8
07	Procedures implem.	10.0	10.0	0.0%	0.0%	4.0	10.8	14.8	4.0	10.8	14.8	0.0	0.0	0.0	0.0	0.0	0.0			
P3	Intermediate rev.	40.0	40.0	0.0%	0.0%	1.6		1.6	1.6	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0			
A4	Roll-out implem.	80.0	80.0	0.0%	0.0%	64.0	240.0	304.0	70.4	264.0	334.4	0.0	0.0	0.0	0.0	0.0	0.0			
P4	Benefits obtained	60.0	60.0	0.0%	0.0%	2.4		2.4	2.4	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0			
						202.8	465.0	667.8	208.8	492.4	701.2	123.4	217.6	341.0	99.4	151.6	251.0	94.7	151.9	246.6

Figure 8.7 Cost report for the CRMO Rationalization Project

(SCHEDULED COST), and planned cost of work complete (EARNED VALUE). Table 8.9 contains an explanation of abbreviations used. At the time of the report, the project is behind schedule, marginally underspent on labour and overspent on materials.

Table 8.9 Explanation of abbreviations in Figure 8.7

Abbreviation	*Meaning*
ORG DUR	The originally planned duration of each work package
REM DUR	The remaining duration with some work done
BASE COMPL	The expected (baseline), percentage completion at the time of reporting
PERCT COMPL	The actual percentage completion, calculated as: (ORG DUR – REM DUR)/ORG DUR
BASELINE	The original estimates of labour and material
CURRENT ESTIMATE	Are updated estimates after the project manager has consumed contingency
SCHEDULED COST	Is the planned cost of work scheduled for completion by this date
EARNED VALUE	Is the actual cost of work complete
ACTUAL COMMITMENT	Is the expenditure to date against each cost item

S-Curves

It is common to plot earned value and accrual on a time chart at each reporting period. As the project progresses they form the customarily shaped curve, called an 'S-curve'. The shape is caused by the work of the project taking some time to accelerate at the start, and slowing down towards the end. It provides a visual representation of whether the project is under- or overspent as it progresses. If the originally planned expenditure profile also happens to be plotted on the curve, the comparison of earned value to planned expenditure tells you whether the project is ahead or behind schedule (on average) and so provides an element of time control. Figure 8.8 shows S-curves for the four cases of projects over- and underspent and ahead and behind schedule.

8.8 Summary

1. A cost estimate is prepared as:
   - a basis for control
   - to assess the projects viability
   - to obtain funding

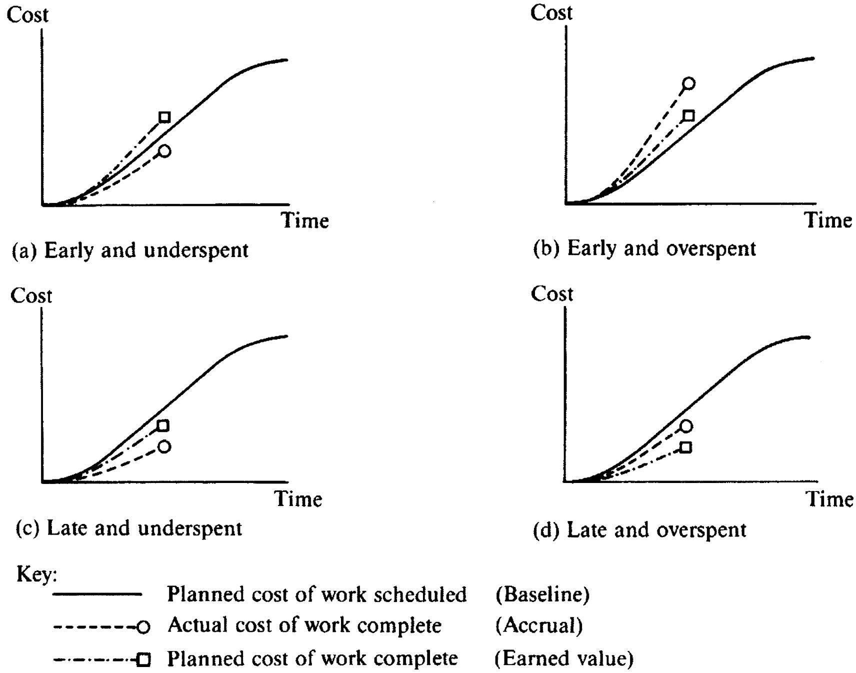

Figure 8.8 Monitoring costs using S-curves

   – to allocate resources
   – to estimate durations
   – to prepare tenders for bespoke contracts.
2. There are five types of estimate of increasing accuracy requiring proportionately more work to prepare:
   – proposal estimate
   – budget estimate
   – sanction estimate
   – control estimate
   – tender estimate.
3. The proposal estimate is prepared at proposal and initiation to commit resources to the first stage of the project. The budget estimate is prepared during proposal and initiation to initiate the project, and commit resources to design and appraisal. The sanction estimate is prepared during design and appraisal to gain funding for the project, or approval from the project sponsor. The control estimate is prepared during implementation planning. A tender estimate is prepared as part of the process of bidding for a contract.

4. There are over ten types of cost to be estimated, including:
   - labour
   - materials, plant and equipment
   - sub-contract
   - management, overhead and administration
   - fees, and taxation, inflation, and other contingency.
5. The cost control cube, a three-dimensional matrix of the PBS×OBS×CBS provides a structure for estimating and controlling costs. The estimate is prepared by breaking the work down to an appropriate level of WBS, and then estimating the cost of each element in the cost control cube.
6. Methods of estimating from the engineering construction industry include:
   - step counting methods
   - exponential methods
   - parametric methods
   - detailed and computerized methods.
7. Estimating methods in the building industry include:
   - approximate methods
   - functional methods
   - elemental prices
   - empirical studies
   - schedule of rates
   - priced bill of quantities.
8. Estimating methods in the IT industry include:
   - analogy methods
   - top-down and bottom-up estimating
   - mathematical models and Function point analysis.
9. Cost is controlled by comparing the earned value, a measure of the amount of work performed to date, to the actual expenditure to date. A comparison of earned value to the originally planned spend helps to control elapsed time. S-curves provide a visual representation.

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