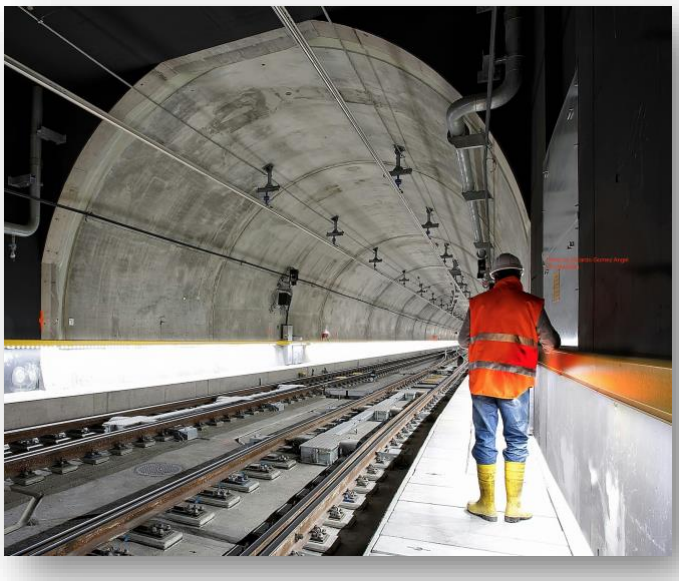
School of Engineering

Engineering Project Management

Course Notes

23rd Edition (2026-27)



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Delivery in Semester 1, Academic Year 2026-27

LEARN is the hub for this course and we encourage everyone to regularly check-in to the site to find new materials as the course progresses.

What is on LEARN?
The LEARN site is arranged firstly with the overall materials such as these course notes, schedule, past exam papers etc.

The site will also then be arranged by TOPIC. The course has six topics plus a series of detailed case studies. Each topic will have:

- Pre-reading material in addition to the notes in this workbook. The pre-readings will be a mixture of text book chapters, journal papers and articles, and occasionally blog-posts. The pre-readings are to let you appreciate the breadth of the individual topics and gain some initial understanding
- "Tutorial" exercises and tests to develop learning and gauge understanding.
- Any other materials which are relevant to the topic such as links to external video material and websites.
- Lecture recordings (i.e. recordings of the live lectures delivered this semester)

There is a Piazza discussion board on the LEARN site also, which we encourage you to use for queries about any of the topics.

I hope you will enjoy this course.

Any queries or issues please email me as course organiser in the first instance (simon.smith@ed.ac.uk) or Dr Fred Bosché (f.bosche@ed.ac.uk).

Dr Simon Smith CEng FICE
Reader in Construction & Project Management
Course Organiser
August 2026

Acknowledgements

This book accompanies the course *Engineering Project Management* within the School of Engineering at the University of Edinburgh.

It has been developed over many years, with contributions from various co-authors (see below). Previous versions of the book will exist but students should note that only the current edition is valid for the year in which the course is delivered: some material in the course may be new; material that was previously in the course and appears in previous editions of the book may no longer be included. *This version is valid for the course delivered in Semester 1 of the 2026-27 Academic Year*.

The material has been developed by various co-authors and their intellectual property is acknowledged below:

Mr Colin Balchin (of Adept Knowledge Management)
Dr David Ponniah (Independent Consultant and University of Edinburgh)
Dr Simon Smith (University of Edinburgh)
Dr Frédéric Bosché (University of Edinburgh)

SCHOOL OF ENGINEERING

ENGINEERING PROJECT MANAGEMENT

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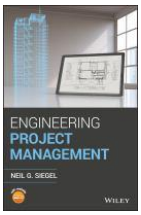
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SUGGESTED READING LIST (SEE ALSO THE "LIBRARY RESOURCES" ON LEARN)

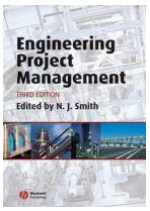
This course is a *Level 10* course which means that in order to obtain the best possible grades, students must demonstrate a deeper and broader knowledge and understanding of the subject than in earlier years. This will primarily come from the lectures and the accompanying notes – **but also from beyond that primary source**. The following books provide further reading for this course from which some deeper and broader understanding can be obtained. The shelf mark [in square brackets] refers to the University of Edinburgh Library – most are in the Murray Library. **Those at the top of the list in bold are recommended reading.** It should be noted that those who do best in this course are those who are willing to read and understand extensively beyond the core material.

- **Siegel, N.G., 2019. *Engineering project management*, Hoboken, NJ, USA: John Wiley & Sons, Inc.**



  - https://discovered.ed.ac.uk/permalink/f/1njkql8/44UOE_ALMA51210198950002466
  - This book was published in 2019 and as it has full Online Access (i.e. you can download this book as a PDF rather than have to read online) I have made it one of the key texts for the course. Additionally, the author is a Professor of Engineering Project Management who has experience of a wider range of disciplines that both the course lecturers and also the other main text that I recommend with the same title by Nigel Smith (see below) who focusses mostly on Civil & Infrastructure projects.

- **Smith, N.J., 2008 (Ed.). *Engineering project management* Third Edition, Oxford: Blackwell Science. [TA190 Eng]**



  - This title is my favoured text and follows closest (but not exactly) to the content of the course. It has a UK focus and context – the author is Professor of Project and Transport Infrastructure Management at University of Leeds within the Department of Civil Engineering. This tells you that there is a focus on Civil Engineering projects and so has a disadvantage compared to that of Prof. Neil Siegel above.
  - Unfortunately it is only available in hard-copy at the Murray Library. I have requested an online version be purchased but it seems none is available.

- **J.R. Meredith and S.J. Mantel *Project management: a managerial approach (Editions 2-4)*, Wiley, Chichester, 1989-2000. [HD69.P75 Mer]**



  - This is the standard text for most North American university courses in project management. It therefore has a distinct North American context (& bias) but has two advantages in that it covers *all* project management, not just that of engineering, and is also the most comprehensive text you can find. It would take you a whole semester just to read the book!



- **P.D. Gardiner, *Project Management – A Strategic Planning Approach*, Palgrave Macmillan, 2005. [HD69.P75 Gar. – note, main library, 1 copy]**
    - **Paul Gardiner** used to be Professor of Project Management at Heriot Watt University and was also the predecessor to Simon Smith in teaching Project Management on the MBA programme at University of Edinburgh. His book therefore has a UK context but it is also discipline non-specific. It has advantages that therefore span across all of the above texts.

Other suggested texts that are in the University Library

- M. Mawdesley et.al. *Planning and controlling construction projects*, Longman, Essex, 1996. [TA190 Maw]
- F. Harris and R. McCaffer *Modern Construction Management 4th Edition*, BSP Professional, Oxford, 1995. [HD9715.A2 Har.]
- K.F.Potts. *Major Construction Works: Contractual and Financial Management* Longman, 1995. [TA190 Pot.]
- R.H. Clough. *Construction Project Management*. Wiley-Interscience, New York, 1972. [TH438 Clo.]
- D.S. Barrie & B.C. Paulson *Professional Construction Management, 3rd ed.* McGraw-Hill, New York, 1992. [TH438 Bar.]
- F.F Mazda, *Engineering Management*, Addison-Wesley, Harlow, 1998. [TA190Maz.]
- A.C. Payne; J.V. Chesholm & R.P. Lawrence *Management for Engineers*, Wiley, Chichester, 1996. [TA190 Pay].
- R. Stone (Ed) *Management of engineering projects*, Macmillan, Basingstoke, 1988. [62:658 Sto].
- S.H. Wearne (ed) *Control of engineering projects*, Arnold, London, 1974. [RR(Engin)].
- M. Brook *Estimating and Tendering for Construction Work 2nd Edition*, Butterworth-Heinemann, Oxford, 1998. [TH435 Bro].
- *Spon's Civil Engineering and Highway Works Price Book, 12th Edition*. E & FN Spon, London, 1998. [Ref. TA183 Spo.] (There are likely more recent versions of this text available, as well as other similar titles from the publisher 'Spon'.)

Topic 1 PROJECT MANAGEMENT PRINCIPLES

Topic Lecturer: Simon Smith (simon.smith@ed.ac.uk)

Read (see "Suggested Reading List" on page 4):

- Engineering Project Management (Nigel Smith) Chapter 1
- Engineering Project Management (Neil Siegel) Chapter 1 and (particularly for Section 1.3) Chapter 2
- Project Management – A Strategic Planning Approach (Paul Gardiner) Chapter 1

1.1 INTRODUCTION & PROJECT DEFINITION

1.1.1 What is a Project?

Almost everything we do as engineers is part of a *project*. It's what we do. We conceive, we design, we implement and we manage things; things that change and improve lives, things that make a difference. Many people have attempted to formally define what precisely a project is but is difficult to do. However, projects almost always have the following characteristics:

- **Clear objective** It must fulfil and satisfy the need that has been identified
- **Constraints of Cost, Quality and Time** These are not unlimited and will be set by the projects owners, giving a fixed timescale and a fixed budget with clear specifications for quality.
- **A team of people** Who may or may not be familiar with the work to be done, and may or may not be familiar with the other team members
- **Little practice or rehearsal** There is very rarely more than one attempt to get the project right, and no opportunity for 'prototypes' (c.f. manufacturing)
- **Change and uncertainty** Project attributes and other influencing factors (weather? ground conditions?) will vary with time.
- **UNIQUENESS** No project is *exactly* the same as a previous project.

Projects have a definable start and endpoint, which is what differentiates them from continuous processes such as operations. Within most organisations a project starts when approval is granted for work to proceed to the initial stage and ends when the objectives are achieved. Project scale can be quite broad – you may encounter small projects that take only days to perform, require few people and cost very little; or you may encounter projects which are vast in terms of the cost, time scales, end product or number of people involved.

1.1.2 Examples of engineering projects:

- The design and construction of an offshore oil drilling platform;
- The introduction of a new computerised accounts system;
- A new highway;

- The production of a new automobile/aircraft/spacecraft;
- Re-landscaping of a company's headquarters grounds;
- Demolition and rebuilding of an existing building.

1.1.3 What is Project Management?

Why is it distinguished from ordinary management? Management can be defined as *The technique, practice or science of managing or controlling; the skilful or resourceful use of materials, time etc.*, which is what the managers of companies, organisations, institutions do in order to achieve the efficient and effective progress of their services. Project management is specific:

- it is the management of entities which are unique and one-off;
- from conception to completion (including commissioning);
- usually on behalf of a 'client' organisation;
- involving the identification of the client's objectives in terms of utility, function, quality, safety, time and cost;
- requiring the integration, monitoring and control of the contributors to the project and their output, and the evaluation and selection of alternatives.

1.1.4 Where does it differ from other types of management?

To understand *project* management it may help to define other types of management:

- **Business management** concerns the ongoing operations of an enterprise, that is characterised by an indefinite endpoint, gradual growth and many differing teams of people.
- **Facilities management** concerns the development and management of buildings, offices, hospitals schools etc.
- **Crisis management** is a relatively new field of management. Typically, proactive crisis management activities include forecasting potential crises and planning how how to deal with them. Hopefully, organisations have time and resources to complete a crisis management plan before they experience a crisis.

1.1.5 Project Compromises

The management of projects is all about dealing with compromises. A traditional view of a project is that there are three aspects of a project which the Project Manager is striving to maintain, but each are dependent upon each other to some degree: Cost, time and Quality.

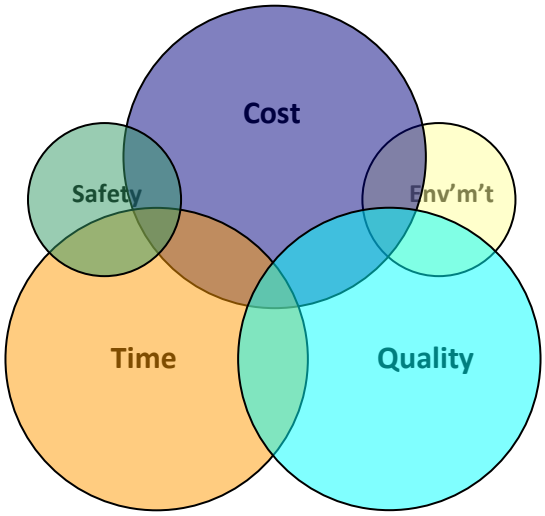


Figure 1 The Project "Iron Triangle" here shown as circles

The implication here is that, for example, to improve the project costs (finish within budget) may result in a detriment to project quality (cheaper materials). Or, for example, to improve on the project time (finish early) may result in an increase in project cost (pay for overtime).

This simple three way system is extended for almost all projects to include the aspects of safety and environment. The implication being that any project decision on saving on cost, time or quality will have an implication on safety and the environment: the cheapest project will not be the safest project.

The importance of each of these five attributes on a specific project will vary. For example, the organisers of the Olympic Games would place a higher priority upon *time* than they would on *cost*, (and possibly quality?) as the stadium has to be completed by the event date.

1.2 THE HEILMEIR CATECHISM

In the lectures we will explore more on *What is a project?* and *What does a project manager do?* This awareness is essential in order to then further understand *what* a project is expected to do, *why* we should do it, *how* we should do it, *when* and *where* and with *who?*

These fundamental questions are important in order to understand the Project Life Cycle, which we will consider in the next section. But before we do, it is useful to know that these considerations are not new – and we can learn a little from how early engineering project managers conceptualised these issues.

One of the most influential Project Managers of the 20th Century was George H. Heilmeier. It is a shame that his name is not known more widely, but his influence was significant. He was an electrical engineer and started his career in 1958 with RCA Laboratories and was a pioneer in the development of Liquid Crystal Displays. Later he worked with DARPA (the US Defense Advanced Research Projects Agency) and then at Texas Instruments and at all these organisations he led many major, successful projects. As a project leader he realised that once a project is conceived, it needs very clear definition and the answer to the what, why, how, when, where and who questions. He knew that unless these questions could be answered at the very early stages then the project would proceed with inadequate definition. So, he proposed the Heilmeir Catechism[1]:

1. **What** are you trying to do? Articulate your objectives using absolutely no jargon.
2. **How** is it done today, and **what** are the limits of current practice?
3. **What** is new in your approach and **why** do you think it will be successful?
4. **Who** cares? If you are successful, **what** difference will it make?
5. **What** are the risks?
6. **How** much will it cost?
7. **How** long will it take?
8. **What** are the mid-term and final "exams" to check for success?

In our Engineering Project Management course, the main topics cover these questions. Questions 1 to 4 are covered in the project definition and project life cycle; Question 5 is covered by the topic of *Contract Management*; Question 6 is covered in *Estimating*; Question 7 by *Planning*; and Question 8 by the final topic of *Monitoring and Control*.

Above all, the most important question for anyone involved with projects is ***WHY?*** If we don't know why we are doing something, then how can we ever know if what we do is the right thing to do? This is essential for any endeavour, and for example is a big part of anyone's final thesis project[2].

[1] Whether George himself called it a *catechism* is unknown. The term means "a summary of the principles of Christian religion in the form of questions and answers, used for religious instruction". While George himself was known to have strong Christian beliefs, it is still perhaps a bit grand to tag these questions alongside fundamental religious doctrine.

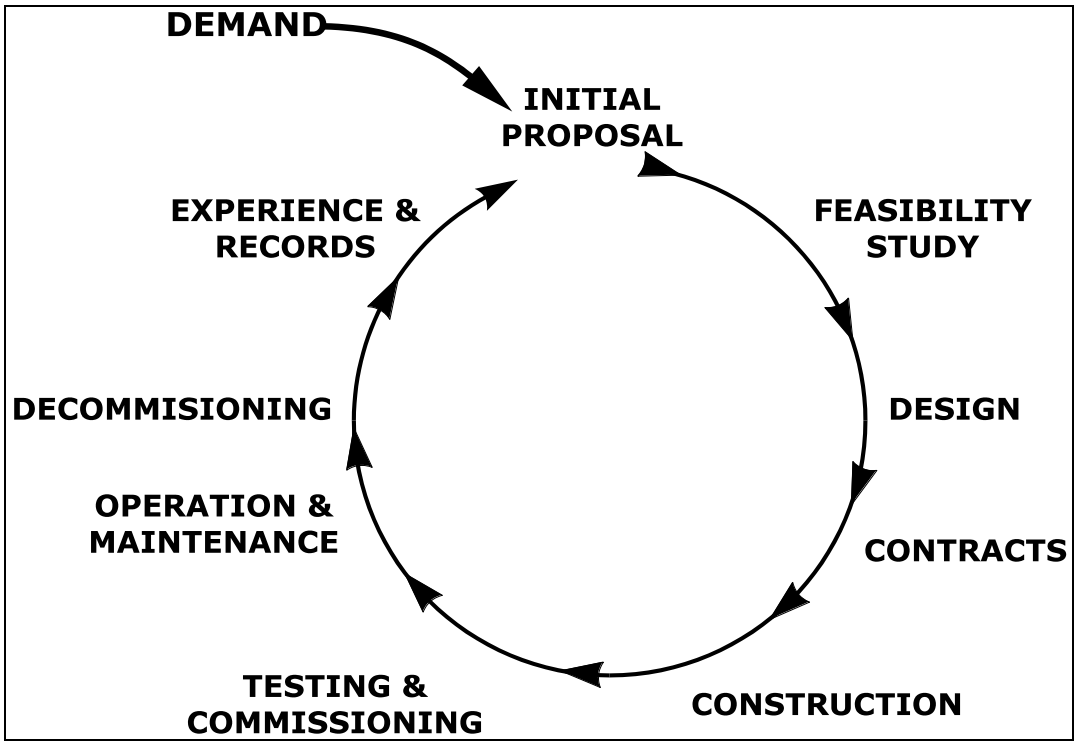
[2] In my career I have supervised and assessed in the region of 200 theses. Those that considered *why* the work was being done *always* did better. Those that did poorly – or failed, and there have been some of these – never adequately explored why their work was being done.

1.3 PROJECT LIFE CYCLE

Note: it is often not clear whether the *Project Life Cycle* or the *Parties to a Project* should be discussed first – they both inform each other. So I suggest you read this section, then that of *Parties to a Project* (page 6), then come back to this section again. One point you will spot below is reference to "the client", which I believe to be a straightforward concept to comprehend, but is not defined formally in these notes until Section 1.4.1.

A project will always have a start and end point. The project's commencement occurs with a demand or need for a product or 'solution' to overcome a particular problem. At this stage a client will recognise this need and make an initial proposal: these are the first two stages in the project cycle.

The figure below summarises the project cycle and indicates that the final stage (experience and records) leads to the first stage in another cycle and this is an important point. Wise clients will modify the way future projects are developed in the light of data from previous experiences.



Simon Smith's Project Life Cycle Model (note: many other models are available)

A. Initial Proposal: Project Brief

One of the initial tasks of the PMT is to prepare a project brief. The purposes of the brief are straightforward:

- To state the objectives, aims and priorities of the client in terms of her proposal
- To identify how resources are to be deployed. This may include the appointment of various consultants

- To provide an outline budget and programme for the project. This will indicate key dates for the completion of initial investigations and design studies as well as cost targets for these tasks.

Once the project brief has been drawn up by the project team and approved by the client, the feasibility of the proposed project can be investigated.

B. Feasibility Study

The feasibility study on a potentially attractive scheme has one purpose: to provide a specific conclusion. It should indicate to the client whether to go ahead with the proposed project or abandon it. The report that is prepared on the findings of the study should also detail the exact reasons for the decision - it may be that the scheme is unviable for simple reasons that may be overcome through time or other processes.

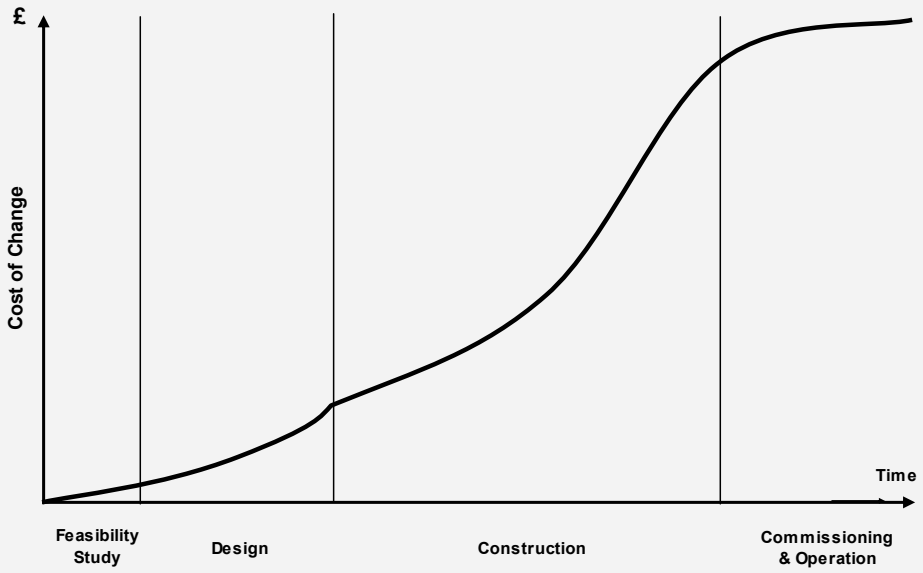
Any feasibility study has several aspects:

- **Determining the extent of the demand**
  Although a demand has been identified, which triggers the start of the project, the extent of this demand must be established. The demand must also be estimated for future years and hence economic forecasts should be used to predict growth.
- **Scope of investigations**
  Not all feasibility studies will be the same: the scope of the study in hand should be determined.
- **Financial objectives**
  There are at least two financial objectives that a client will have in mind when a proposal is made: to provide a satisfactory financial *return*; and to be undertaken at a estimated *total cost*. If it is determined that these financial objectives cannot be met then it may be that the project is unfeasible.
- **Service objectives**
  The performance required of a project should be determined and considered in any feasibility investigation. These may include the throughput or productivity of the project, or the life span of the project.
- **Statutory approvals**
  Statutory Regulations require compliance with certain procedures and the feasibility study should determine which these are and if they can be achieved. In addition it may be that a satisfactory environmental impact assessment is required along with a health and safety study.
- **Information**
  If a good decision is to be made as to the feasibility of a project, the quality of the information provided and obtained is paramount. This information will relate to the suitability of the proposed site and will include data on the ground itself and of the locale in general.
- **Public consultation**

Some people will gain by an engineering project; others will lose. Recent protests over capital projects such as new roads and runways have heightened the awareness of the public consultation stage. It is worthwhile including the public at the earliest possible stage in order to both reduce objections at later, more expensive stages and perhaps provide positive ideas. If alternative schemes are proposed the public deserve a choice; any decision made should take account of their consensus.

- **Recommended design**

  At some stage in the feasibility study there will have to be a decision made as to what is the ideal design and this will involve an evaluation of the alternatives. The reason for making a correct choice at this stage can be seen from the chart below. During the initial stages, i.e. the feasibility and design stages, it is relatively cheaper to make fundamental changes than during the construction stage. In addition, the effect on the motivation and morale of those involved if changes are made can have particularly negative results.



The effect of change on project cost

1.3.1 Report

At the end of the feasibility study, the project teams findings should be presented to the client. Essentially, the viability of proposed project should be initially stated followed by a description of the scheme that would be best suited to the client's needs. The report should be presented in a way that can be readily understood by the client who may not be able to appreciate the finer technical details. Such details may be contained within appendices in order that any other suitably qualified engineer may advise the client on the report's contents.

C. The Design Stage

Assuming that a feasibility study has recommended that a project should proceed, the next stage in the project cycle is that of design. It is important to appreciate, however, that the services of the designer are incorporated into most of the successive stages in the project's cycle, not least of which is the construction phase.

The design stage itself has its own process or cycle of stages to achieve the required results. It could be argued that the design process begins with the feasibility study, especially if that stage recommends construction - much information used during the design process will have been gleaned during feasibility investigations.

The main parts of the design process are:

- the design brief;
- detailed design; and
- construction support.

D. Contracts for Construction

A contract is a formal agreement between two or more parties that is enforceable in law. No construction work is ever undertaken without there being a contract of some form between the client and the contractor. Essentially, a construction contract commits a contractor to construct the works and the client to pay for it. The form of contract, or the conditions of contract is a legal document that sets out the exact terms of the contract and details the liabilities and obligations of each party.

Construction contracts are covered in greater detail later in the course.

E. Construction

The construction stage of a project is the most expensive, labour intensive and active part of a project. The exact form of how the various parties interact at this stage will depend on the type of contract used but there are many common elements to this stage. These can be summarised by:

- Estimating
- Planning and programming
- Implementation (or construction) of the works (the built items)
- Health and safety
- Temporary works
- Cost monitoring
- Execution of contract
- Claims and disputes

F. Testing and Commissioning

Essentially this is the transition from the construction phase of the project to the occupation by its eventual users. It is a period of time whereby the client satisfies herself that the

project does indeed work in accordance with her requirements that were set down in the design brief and contractual specifications.

G. Operation and Maintenance

The extent of periods of operation and maintenance will vary according to the type of project. Some parts of a project may require regular inspection and maintenance if necessary while the whole project needs adequate planning for its use.

H. Decommissioning

This is the part of a project's life cycle that gets perhaps the least attention. It is possible that there is no anticipated natural life of the constructed facility with the result that the client is unwilling to commit time and money to a non-planned event. However, many projects will come to the end of their working life after a relatively short period of time; good examples of this are nuclear power stations and oil facilities.



Nuclear decommissioning. This is Dounreay, which will not be declared a clear site until 2336



Off-shore decommissioning. This is the decommissioning of Brent Spar which is discussed in more detail in the lectures

1.4 PARTIES TO A PROJECT

In Project Management the needs and interactions of all the players in that project need to be understood. There are three main players, or parties: the *client*, the *designer* and the *contractor* alongside the project manager and the project manager's team.

1.4.1 The Client

This is the organisation that owns the project and has the overall responsibility to ensure the project is delivered satisfactorily. In the case of project management it can be more rigorously defined as the body of persons who have a need for a particular solution to a problem. The completed project is the eventual solution and will, hopefully, fulfil the needs the client expects of it.

Note: in previous versions of this course I used the term "The Promoter" and you may see this term in some older materials or exam questions. For the purposes of this subject, you can assume the two terms – client & promoter – are interchangeable. In fact there are other terms, for instance "The Owner" or "The Employer". The word used can depend on the type or discipline of project and the geographical location. It is an example of project management's tendency to have a very variable array of terminology for many aspects.

In practice these terms have developed slightly differently, and they actually have slightly different meanings. The *Promoter* is technically a legal body who authorises and arranges the finance for a project. Very often this is the client, but may not be. It's confusing, but try not to be too concerned! For our purposes we will use the term "The Client" simply as this is the most common term used in the UK and Europe (North Americans may be more familiar with the term "The Owner").

1.4.2 Aims and Responsibilities of the client

The client of a project has certain aims and responsibilities which can be summarised as:

Aims:

- To obtain the best economic solution to a problem whilst
- Bearing the safety of all who work on the project, at any stage in its cycle, in mind without
- Compromising unnecessarily the environment in which the project takes place

Responsibilities:

- To identify the needs and satisfy itself that the project will serve these needs
- To define the nature and functions of the project
- To obtain any statutory powers necessary for the construction and operation of the project
- To (usually) operate the project at completion; and
- To (usually) find the money to pay for the design and construction work.

1.4.3 The Project Management Team

The project management team simply interprets the client's requirements and implements the project. The client will have the need but not always the expertise or manpower to evaluate the best means of satisfying the need. They may not, also, have the managerial experience to convert the optimal solution into physical terms. The role of the project management team (PMT) within a project is:

- to develop the client's requirements by using PMT experience to achieve the optimal solution, and
- to manage the finally defined project on behalf of the client to ensure that the objectives advised to the client as being achievable are actually implemented.

1.4.4 The role of the project manager

The job of a project manager is to foresee as many dangers as possible. Then to plan organise and control activities in such a way that risks are avoided or countered leading to a final result that satisfies the requirements of the project sponsor. Doing this without using more money and resources than those that were included in the budget.

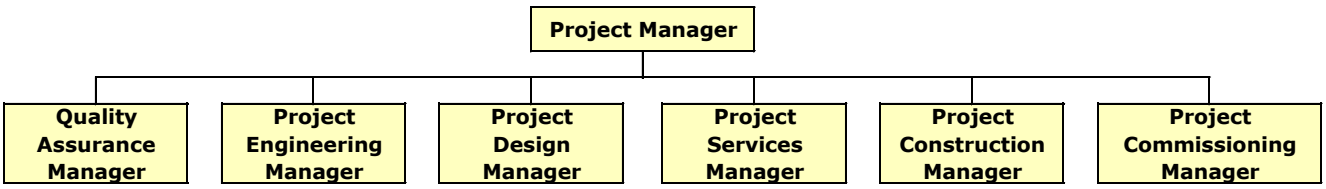
What functions is a Project Manager typically expected to perform?

- Ensure achievement of Project Objectives
- Control costs
- Control schedule
- Lead people and teams
- Liaise with client
- Liaise with contractors
- Measure and report on progress

1.4.5 The role of the project team

Because of the complexity of the average project it is impractical for the project manager to control it on her own. He or she needs a team of people also dedicated to the task in hand. The composition and organisation of the project team and the working location of its members will depend upon the particular project, its size and siting, the contract strategy proposed and the experience and resources of the other project parties involved.

A typical project team may be established as follows:



1.4.6 The Designer

The designer of an engineering project has various duties, the extent of which depends on the type of contract that is used in the execution of the project. At the simplest level, the designer will provide only an outline design for a project client, for example the route of a road and perhaps it's vertical alignment. At the other end of the scale, the designer will undertake all design duties for the client as well as supervise the construction of the project, authorise changes to the design and manage the necessary payment details.

1.4.7 Aims and Responsibilities of the designer

Aims:

- Produce a design that will achieve the client's objectives, including requirements for minimum cost and environmental sensitivity.

Responsibilities:

- To undertake feasibility studies on the project and report and advise the client on its findings
- To develop design options and advise the client
- To obtain any necessary approvals and consents
- To define the next stages in the project
- To prepare contract documents such as specifications, bills of quantities and contract drawings
- To advise the client on the correct choice of contractor
- To technically supervise the construction work
- To measure, value and authorise payment for the completed works

1.4.8 The Contractor

Contractors are companies which specialise in the mobilisation and control of labour, plant and materials and in the planning, programming and execution of engineering works.

1.4.9 Types of contractor

It is very common for contractors to 'sub-let' or 'sub-contract' certain specialist items of work to smaller companies who have a greater experience in particular types of work. In such instances, the contractor is known as the Main Contractor and the specialist as the Sub-Contractor. In certain cases a Sub-Contractor may be 'nominated' which means that the client or designer has stipulated that only that company is to provide specific items of work.

The contractor may also be responsible for the design of the project: in the case of the offshore industry, this is usually the case. Civil engineering contractors will rarely carry out design 'in-house' i.e. by the contractor's own staff; they will usually, if required to design the project, engage the services of civil and structural consulting engineers.

1.4.10 Aims and Responsibilities of the Main Contractor

Aims:

- To provide a quality project
- On time and within budget
- Safely and with consideration to the environment
- To maximise profit

Many observers criticise that contractors concentrate too much on the last aim and that there is a conflict between providing a safe, environmentally sensitive and quality budget whilst also maximising profit. In the past this has unfortunately been true and is why the industry in general and builders in particular have had a bad name. However, contractors now realise that they cannot survive with such an image and are making definite

improvements to their act. Many clients are also stipulating that only the most 'caring' contractors will be allowed on to their tender lists.

Responsibilities:

- To appoint staff and mobilise labour, plant and materials
- To design the works (if required under the contract)
- To (usually) insure the construction works until completion
- To provide a plan and programme of construction for approval by the client or project manager
- To design and construct temporary works
- To supervise sub-contractors

1.4.11 The Operating Company

Not all clients of projects will eventually operate the project once construction is complete. This task may be carried out by a number of alternative bodies depending on the requirements of the client. Possible operating companies may be:

- Separate, independent company employed by the client to run the project on their behalf. This company may or may not be involved with the maintenance of the completed project, the exact details would be contained in the contract or service agreement between client and company.
- The contractor may be required to operate and maintain the project. If this is the case, the details would be set out in the original contract established for the construction of the project. Examples of this set up are the privately financed infrastructure projects in the UK.
- The client may operate the project; this may be a separate division of the client's organisation.

Topic 2 PROJECT PLANNING & PROGRAMMING

Topic Lecturer: Dr Frédéric Bosché (f.bosche@ed.ac.uk)

Note: you can find on Learn other recorded lectures as well as quizzes and tutorials to further help you understand this topic and become proficient at applying the Critical Path Method (CPM) described herein.

Project Planning focuses on defining clear, discrete activities and the work needed to complete each activity within a single project. Once these activities and their scope have been defined, programming (or scheduling) tools can be used to fit these activities into an appropriate timescale. In this section, we focus on the programming process but present it in a complete way that includes planning activities.

2.1 PROJECT PROGRAMMING OVERVIEW

As the introductory House example illustrates, a certain process must be followed to programme (or schedule) a project. This process can be formally presented as having four steps:

1. Decompose project into a **Work Breakdown Structure (WBS)** defining individual smaller **Work Packages (WPs)**.
2. WPs are defined so that resources and duration (and cost) for each of them can be estimated, a process called **WP Programming (or Activity Programming)**
3. To establish the overall project duration, it is necessary to develop suitable **Network Logic** with all the WPs - i.e. the relationships between different WPs
4. Once the logic has been determined, a **Network Analysis (or Optimisation) method** can be used to calculate the overall project duration, the start and finish dates for all activities and other useful information. All these will vary depending on the Network Analysis method used.

In this process, the first two steps may be considered Planning activities, while the latter two are specific to Programming.

There are four Network Analysis methods that can be found in the literature and to various levels in practice. These are:

- **Critical Path Method (CPM) (also sometimes referred to as Gantt Chart, but this is misleading)**
- **Programme Evaluation Review Technique (PERT)**
- **Monte Carlo Simulation**
- **Linear Scheduling Method (LSM)**

The CPM method is by far the most used method in practice; maybe 99% of all programming is currently done with that method. For this reason, we focus on that method in this course. PERT and Monte Carlo Simulation constitute some forms of generalisation of the CPM method, but are used very rarely. You are not expected to know anything about them. The LSM method is increasingly considered and has a certain relevance to civil engineering. For this reason, it was covered in a Year-3 course taken by Civil Engineering MEng/BEng

students only. Students of other disciplines are not expected to know anything about this method either.

To summarise this discussion, the programming process can be synthesised as:

1. Work Breakdown Structure (WBS)
2. Activity Programming
3. Project Logic Evaluation (PLE)
4. Network Analysis

And, in this course, the "Network Analysis" method we focus on is the "Critical Path Method (CPM)".

2.2 WORK BREAKDOWN STRUCTURE (WBS)

At the start of a project – or a project phase – all relevant information must be gathered. This information is then assessed, with discussions and assistance from as many teams involved in the project as possible, leading to the creation of a project or **Work Breakdown Structure (WBS)**. This is simply a hierarchical division of the project into technically coherent blocks of related activities broken down into levels of increasing detail. The blocks may be *product-oriented* and broken down into levels of hardware, e.g. main equipment, sub-assemblies, major and minor components, systems-oriented, or *function-oriented* and broken down into levels of organisational disciplines.

By extending the breakdown structure so that related products and functions are brought together, work packages may be defined, i.e. parcels of work which can be individually planned (i.e. resourced, scheduled and costed). **Work package**s **(WPs)** normally represent smallest entities to carry costs at total project level, although further breakdowns may be possible dependent upon each participating organisation's own cost collection and control systems. Work package costs can then be used, firstly to produce a project budget (using costs estimated during planning) and secondly to monitor performance against this (using actual costs).

Figures 2.1 to 2.3 below show three WBSs developed in different types of projects at different levels of granularity. Importantly, the level of granularity of a WBS depends on the context, the detail of information required for planning and management and the number of resources that can be allocated to that process (a more granular WBS may require more resources to plan and monitor).

Taking the WBS in Figure 2.1 as example, it is important to understand that it is the leaf WPs in the WBS that are planned and managed. The boxes higher in the WBS structure are only there to enable aggregation of information at higher levels, and ultimately at the overall project level.

As illustrated in Figure 2.3, the top level (overall project) is normally referred at **WBS Level** 1. The level underneath is then WBS Level 2, Etc. Each component and sub-component in the WBS (i.e. boxes in the above figures) must be allocated a unique identification ID to prevent misunderstanding from WP names (that could in fact be the same in different

branches). For example, in Figure 3, the activities at WBS Level 2 are numbered 1.1, 1.2, 1.3, etc., and the activities below 1.1 are numbered 1.1.1, 1.1.2, etc.

<u>Note:</u> In these notes, we often use the word "Activity" as a synonym to "Work Package".

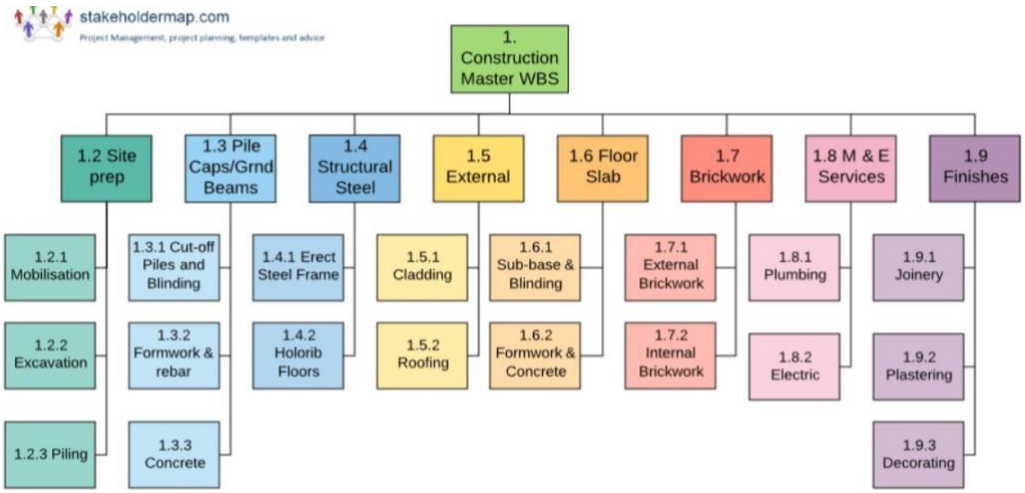


Figure 2.1: WBS in Construction.

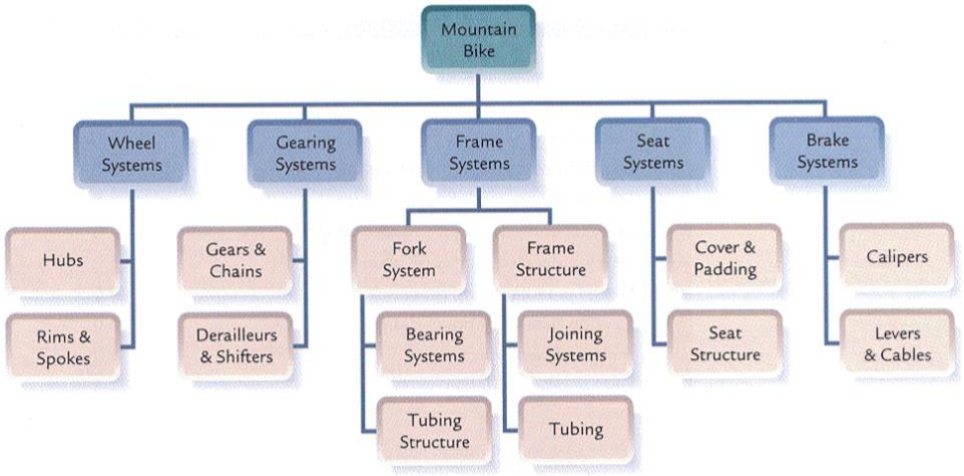


Figure 2.2: WBS Bike.

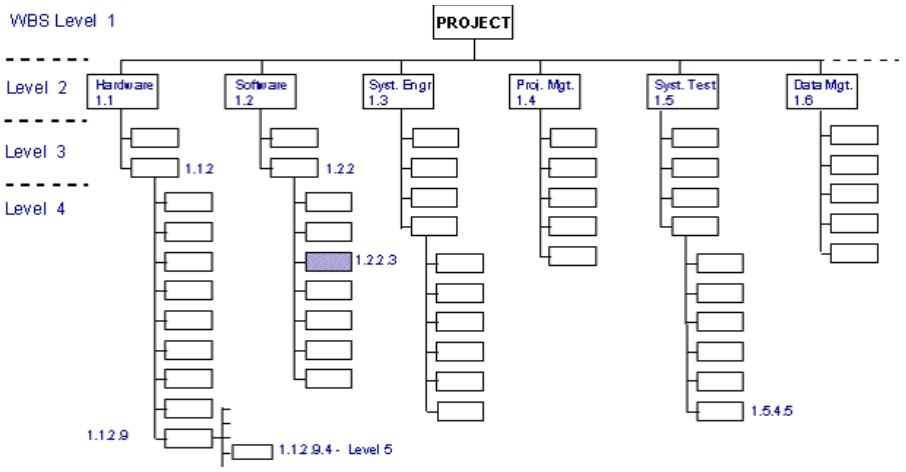


Figure 2.3: WBS example showing levels

2.3 ACTIVITY PROGRAMMING

Factors affecting the Work Breakdown Structure

- Detailed planning should be pushed down to the lowest level of management which is acceptable without affecting efficiency.
- Most projects can be divided into a number of distinct chronological stages, each of which is likely to have a different set of objectives and organisation. These greatly influence the project plans, and many different plans may be set up, such as those for management functions, quality assurance and reliability, contracting, design engineering, procurement and construction, as well as programming and cost control.
- Planning should be initiated early to be of help in project control, so that as many foreseeable questions as possible can be dealt with before the project gets under way.
- Historical data is important but only the future can be changed. Therefore, project management should concentrate on planning work to be done rather than in analysing the finished article.
- Before embarking upon a detailed plan of any project, especially the larger, more complex ones, it is advisable to summarise and assess all available data and relevant knowledge explicitly.
- Negotiations at high management level may already have occurred prior to this stage and preliminary study or proposals will have been undertaken. Unfortunately, the project manager is often not appointed at this early stage and may later be committed to conditions which she may consider unsound or invalid.

Activity Programming is about identifying the work to be conducting for that activity and selecting a method and relevant resources to conduct that work. This ultimately enables the planner to calculate a duration for that activity (as well as its cost, or budget).

Assessing the duration of each activity can be difficult. There are three steps:

- Determine the **quantity (Q)** of each item; by doing a Material Take Off (MTO) from the drawings and/or from the Bills of Quantities (BoQs),
- Determine the **resources (n_r)** required; usually from experience of managing these types of resources, and
- Determine the **unit output (or production rate p_r)** of each resource. This is by far the most difficult but may be accomplished:
    i. from experience or by using historical production records (sometimes documented as an estimating manual);
    ii. by using published "standard" outputs;
    iii. from work study, although this only is used with repetitive processes;

In these cases, the duration is simply given by the formula:

$$D = \tilde{D} = \frac{Q}{\tilde{p}_r . n_r}$$

In this formula, "~" is used to highlight the values that have most uncertainty. As mentioned above, defining production rates is not easy at all and thus these values have to really be seen as *estimates*. As a result, one must accept that the duration is also an estimate that could vary if the conditions under which the production rate was established change.

Example

Estimate the duration for the activity described as 'Steel Erection for East Facade', where (i) the total quantity of steel is 456 tonnes; (ii) the resources to be used are 2 teams of 1 no. one 40 tonne mobile crane and four steel erectors; and (iii) the unit output (i.e. the quantity of steel erected per unit time) of one team is 11 tonnes per day.

456 / 2 teams = 228 tonnes/team

228/11 T/day = 20.7 days

The duration for this activity would be rounded up to 21 days – it is unlikely that the steel erection teams would move on to another activity in the remaining 0.3 days.

2.4 PROJECT LOGIC EVALUATION (PLE)

After the establishment of the basic factors related to the project, the next step is to prepare the plans of work to be carried out: the programmes (or schedules) and the budgets. If WPs have been defined by a suitable breakdown structure, detailed planning can be made against each of these. To relate the work packages in the overall programme, it is necessary to develop suitable **network logic**. This activity can be referred to as **Project Logic Evaluation (PLE)**.

The main requirement is that the network should be representative of the project delivery, including all activities identified in the WBS (leaves) and their sequencing.

We shall now look at two project programming tools.

2.4.1 *Gantt* chart

One of the first attempts at a formal planning system was the *Gantt chart,* also commonly called *bar chart*. It was developed by Henry Gantt, an American pioneer of scientific management. This is the most common and well-known technique. It graphically describes the sequence and duration of activities over a time scale. The project activities are identified and represented by horizontal lines on a calendar. The length of the line or *bar* is proportional to the scheduled time of the activity or operation. An example is shown below.

The major disadvantage of Gantt charts is their lack of consideration upfront for resource requirements and resource flow (something discussed later).

To prepare a Gantt chart, determine the:

- order, and in what manner, the work is to be carried out;
- operations which are fixed in sequence and time;
- operations which have a degree of latitude;
- expected duration;
- calendar format;
- list of activities. This should, of course, match the WBS
- then prepare a bar chart.

There are many advantages to bar charts and some of these are:

- simplicity;
- ease of preparation for recording progress;
- ease of rescheduling;
- ease of producing resource schedules from bar charts;
- ease of reading/understanding;
- dates for long lead items can be easily seen;
- short term programmes can be easily developed;
- suitable for many projects.

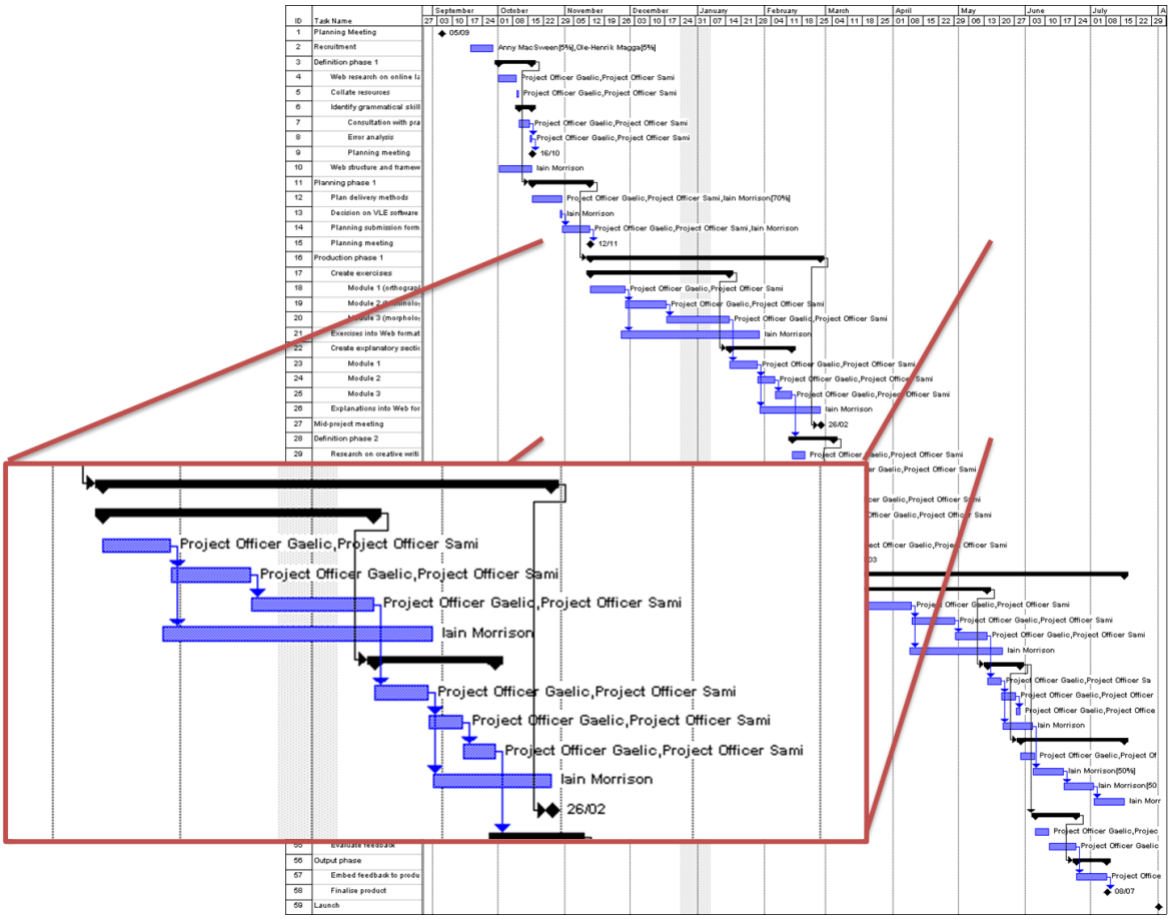


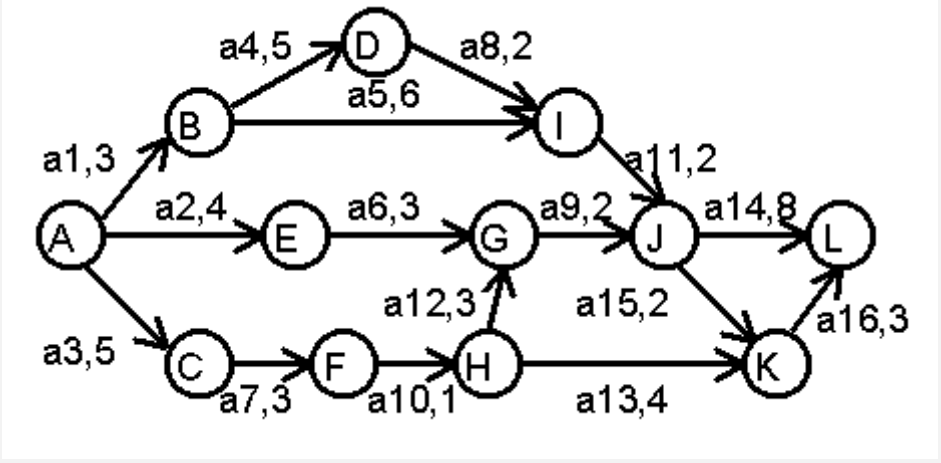
Figure 2.4: Example Gantt Chart.

2.4.2 Network Precedence Diagram (NPD)

An alternative representation of programmes, which is arguably more suited to education and training is expressed in the form of a logic network. The mid-1950s and 1960s saw an explosion of interest in the problems of planning, and the family of methods, *Project Network Techniques* (PNT) was born.

The developments were aimed at improving the ability to plan and control complex engineering projects. However, networks are not as easy to understand as Gantt charts and many people feel that they are unlikely to use them comfortably immediately.

A schematic representation of a project network is shown below. The nodes in the diagram represent the activities. The logic and interdependencies of the activities are represented by the lines which are known as *dependencies*.



Example of Activity on Node network

The most commonly used form of network diagram is the Network Precedence Diagram (NPD). In a NPD, each activity is denoted by a box containing the activity description, number duration, resources and possible start times:

ES	Duration	EF
Activity Label, Description, (resources)		
LS	Total Float	LF

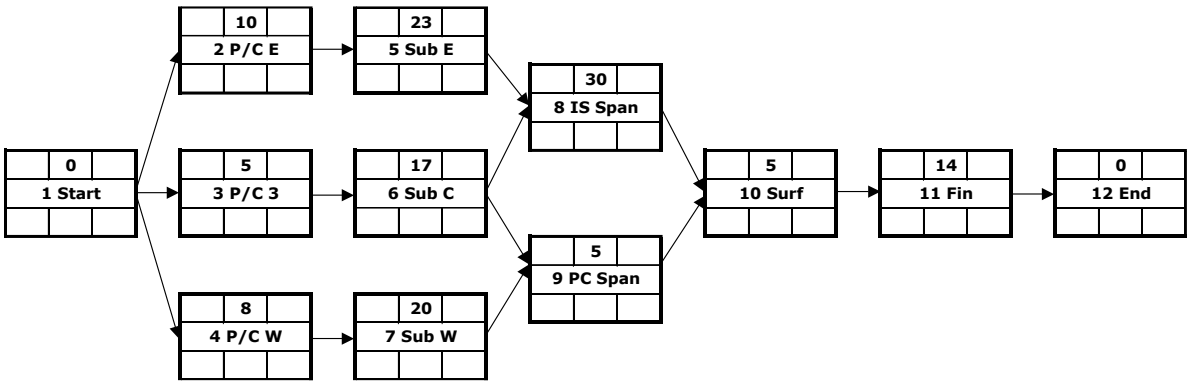
ES: Earliest Start Time
EF: Earliest Finish Time
LS: Latest Start Time
LF: Latest Finish Time

Note that the following format is also used:

ES		EF
Total Float	ID	Duration
LS		LF

- The size of the box is irrelevant, and bears no relation to the time the activity takes or to the resources it consumes.
- Completion of an activity allows the start of subsequent activities.
- Activities are controlled by start and finish constraints which determine the nature of the relation to **preceding and succeeding** activities.
- Each activity is identified by allotting it a unique number (which could be or refer to the ID in the WBS).

A simple network is shown below. That network includes 'dummy' activities (i.e. artificial activities with duration 0) for the Start and Finish of the project. These are not strictly necessary, but can help clarify the network.



Gantt vs NPD:

It must however be highlighted that, a Gantt Chart or a Network are in fact two representations of the same information. Indeed, they use the same predefined list of activities with the same durations and the same dependencies (i.e. sequencing).

2.4.3 Logical constraints and Time Lags

At least four types of dependency, or precedence relationships, can be shown in a Gantt chart or NPD, each having different locations on the associated activity nodes, namely:

- **Finish-to-start** the start of an activity depends on the finish of its predecessor or preceding activity(ies). This is the normal dependency.
- **Start-to-start** the start of an activity depends on the start of its predecessor or preceding activity(ies)
- **Finish-to-finish** the finish of an activity depends on the finish of its predecessor or preceding activity(ies).
- **Start-to-finish** the finish to an activity depends on the start of its predecessor or preceding activity(ies)

By far, the Finish-to-Start relationship is the most common (maybe used 99% of the time). Aside from its type, the dependency arrow can carry information about delaying the successor by an amount of time, called a *lag*. The convention is normally that a *lag* is a positive value that, when used on a Finish-to-Start constraint, delays the Start of the successor by that amount. A negative lag is often referred to as a *lead* and means that the successor may actually start earlier by that amount.

Examples:

- Finish to Start (FS) with Lag of 10 days: Delays start of successor by 10 days.
- Finish to Start (FS) with Lead of 7 days (i.e. lag of -7 days): Start of successor should be 7 days earlier than Finish of predecessor.
- Start to Start (SS) with Lag of 10 days: Delay to start of successor by 10 days after start of predecessor.
- Finish to Finish (FF) with Lag of 15 days: Delay to finish of successor by 15 days after finish of predecessor.

Figure 2.5 below shows the convention used to draw these four types of dependencies in an NPD.

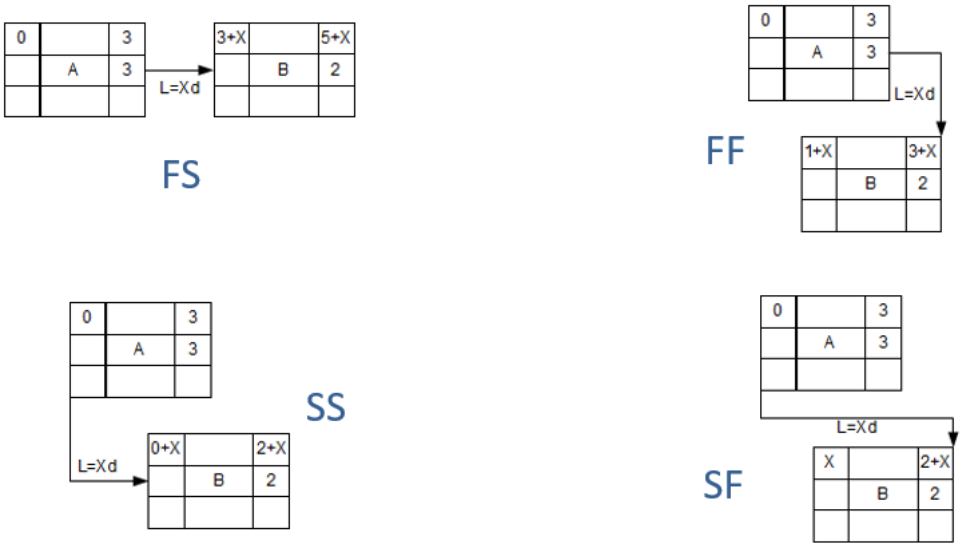


Figure 2.5: Convention used to distinctly draw these four types of dependencies in an NPD.

Finally, it should be highlighted that in most projects FS, SS and FF dependencies are by far the most common (with FS itself probably used for representing > 95% of dependencies). The SF dependency is very rarely used.

2.5 NETWORK ANALYSIS USING THE CRITICAL PATH METHOD

The Critical Path Method (CPM) is the scheduling method used in virtually all project management computer software today. It was developed by DuPont and Remington Rand in the 1950s to improve project scheduling techniques. It is a modelling process that identifies all the project's **critical activities** – those activities that must be completed on time if the entire project is to be completed on time and calculates the start and finish dates of all activities in the project.

With CPM, calculations of the schedule are based on the duration of the activities and the precedence relationships between the activities. The schedule is calculated twice - first from

the earliest start date forward (*forward pass*), and then from the latest finish date backwards (*backward pass*).

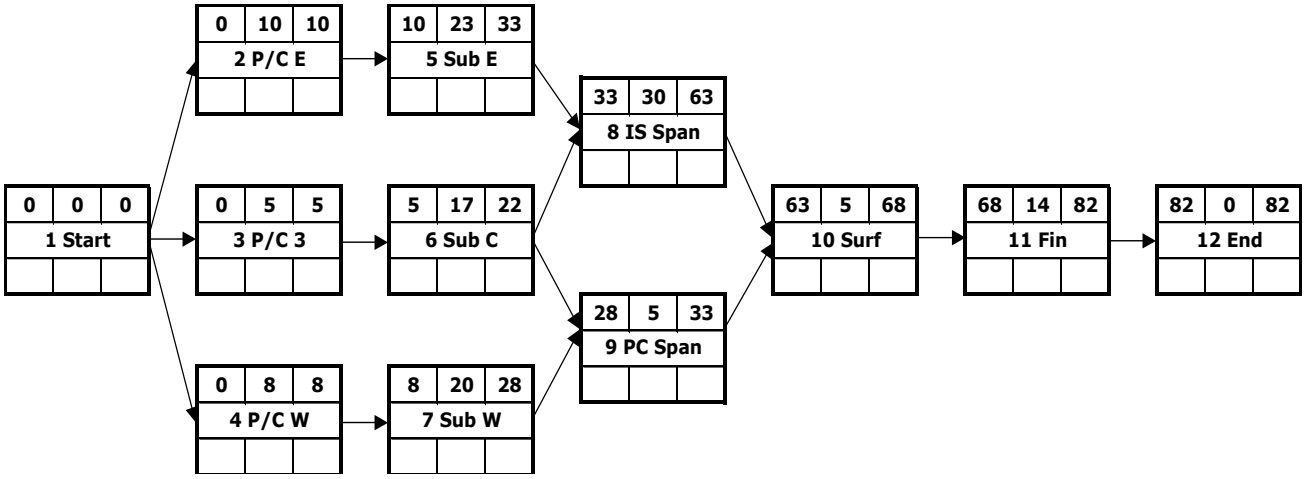
2.5.1 Forward Pass - Calculation of Early Start and Finish Times

Earliest start time of an activity (ES) is the earliest possible time at which an activity can start without affecting either the total project time or the logic of the network. So the earliest start time of an activity is that which allows ALL the ACTIVITIES which must immediately PRECEDE that activity, to be finished.

Earliest finish time of an activity (EF) is the earliest possible time at which an activity can finish without affecting the total project time or the logic of the network. The earliest finish time for an activity is therefore its earliest start time ES plus its duration.

The **Forward Pass** is a repeating sequence of the above calculation for all the activities. The earliest start time of each activity is written at the left side of each activity box, and the earliest finish time in the right-hand side for each activity node, when using the NPD representation.

Example:



A Forward Pass calculates the Earliest Start and Earliest Finish times.

Note that when there is more than one EF from preceding activities (as in activities 5&6 that precede activity 8) the new ES is the latest of the two EFs.

2.5.2 Backward Pass - Calculation of Latest Start and Finish Times

The latest times by which an activity must be started or finished if there is to be no delay in the completion of the project are called the latest start and finish times.

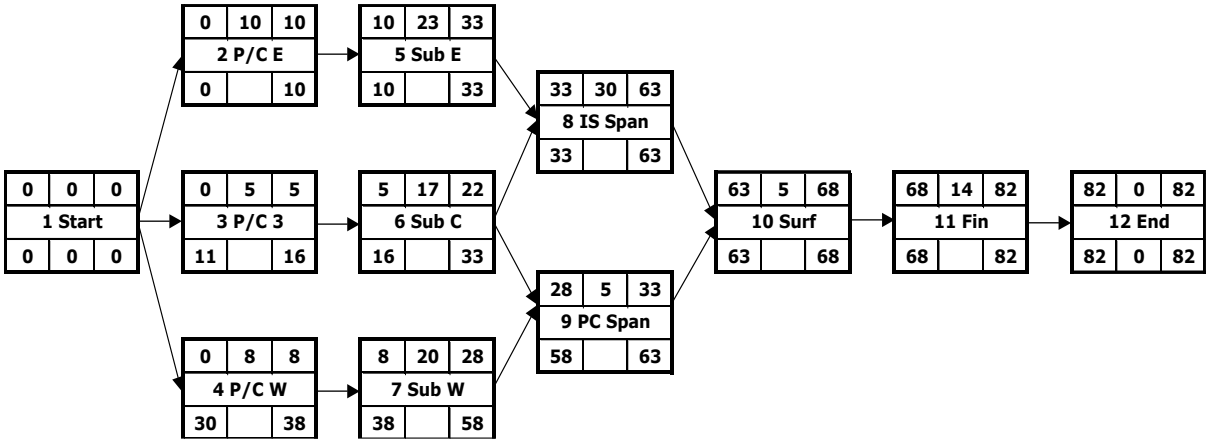
Latest start time of an activity (LS) is the latest possible time by which an activity can start without affecting either the total project time or the logic of the network.

Latest finish time of an activity (LF) is the latest possible time by which an activity can finish without affecting either the total project time or the logic of the network.

So, any latest start time is that which ALL the *preceding activities* must be completed by, *without increasing the overall project duration*. The latest start time is therefore the earliest of the latest finish times of all the preceding activities.

We establish the latest finish times in a process called the Backward Pass. This is based on the fact that the latest finish time of the final activity is equal to its earliest finish time, i.e. the overall project duration. So, the latest finish time of an activity is that which allows ALL the ACTIVITIES which must immediately succeed that activity, to be finished without delay to the project completion.

The latest start time LS, of an activity is its latest finish time LF, minus its duration. The latest finish time LF, of an activity is the earliest, latest start time of its successors. The latest start time of each activity may be written on the lower left side of each activity box, and the latest finish time in the lower right side of the box. Continuing our example:



A Backward Pass, calculating the Latest Start and Latest Finish times

2.5.3 Float and Critical Path

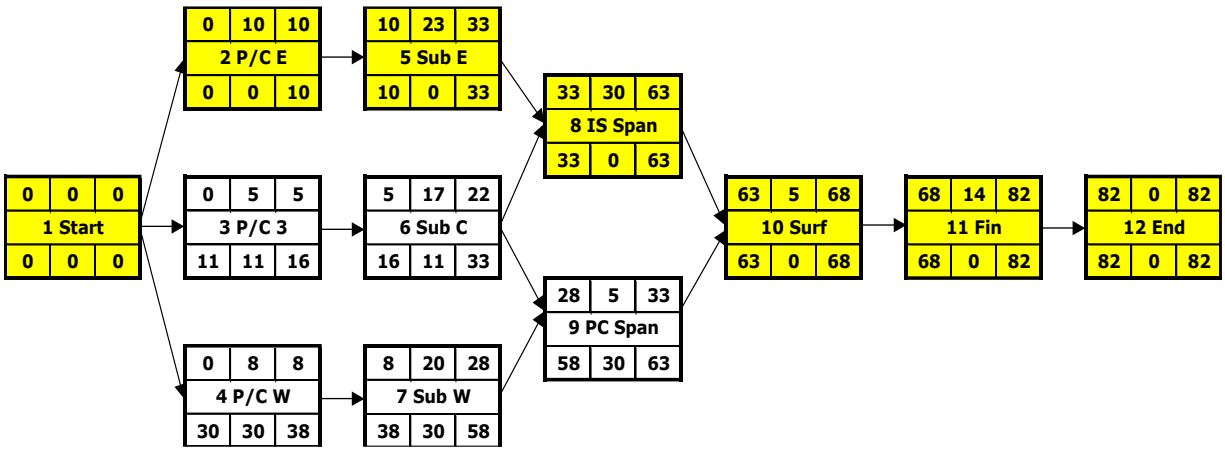
Total Float is the amount of time that an activity can be delayed without delaying the project completion date. The **critical path** is that sequence of activities which represent the longest total time required to complete the project. A delay in any activity on the critical path causes a delay in the completion of the project. **Critical activities** - activities on the critical path - have no slack time or **Zero Float**. **Non-critical activities** - activities not on the critical path - have a slack time or **Positive Float**.

Activities and events lying on the critical path are called **Critical Activities** and any delay in the completion of a critical activity (e.g. an increase in duration) or in the achievement of a critical event will automatically increase the duration of the project by an amount equal to the increase in the duration or the activity or delay in achievement or the event. In a network diagram, the critical path contains those activities with zero total float.

Non-Critical activities are said to have Float, which is the term for time or schedule contingency.

The concept of float is particularly useful for deciding priorities. If resources require scheduling, one would not delay a critical activity. Of the non-critical activities, the preferential activities to delay would be those with greatest total float.

Continuing our example, the total float has been calculated and the critical path is defined by those activities with zero total float. This is indicated by shaded activities:



Total float and Critical Path

An important use of a network plan is to forecast the resources to find the minimum resources required to complete the project. Although the critical path network cannot be used directly for resource scheduling (which is in fact the main drawback of the CPM), it offers the facility, when computerised, to analyse the effects of alternative allocations at high speed.

Topic 3 COST ESTIMATION

Topic Lecturer: Simon Smith (simon.smith@ed.ac.uk)

Read (see "Suggested Reading List" on page 4):

- Engineering Project Management (Nigel Smith) Chapter 7 (and also, for Section 3.2, Chapter 3)
- Engineering Project Management (Neil Siegel) Chapter 7.3.
- Project Management – A Strategic Planning Approach (Paul Gardiner) Chapter 9

3.1 INTRODUCTION TO THE ESTIMATION PROCESS

The objective of cost estimating (or cost planning) is to define as accurately as possible the minimum realistic cost of executing an activity. The estimating task may be carried out by any project party but is usually done by, or on behalf of, the contractor or client to determine their costs.

There are various purposes an estimate can be used for:

- comparing alternative technical solutions;
- identifying financial commitment;
- as a basis for tendering;
- as a yardstick against which performance can be measured.

The results of an estimating task can be either a ***cost plan*** or a ***tender***: a cost plan, in this context, is developed from the point of view of the client and can be used to first budget for the project and also to evaluate many tenders. It usually becomes the baseline for cost comparisons and monitoring during construction.

A tender is the result of a contractor's estimating activities and provides a bid for the work to be done for the client.

This topic will look at the fundamental aspects of estimating and estimating methods, whether from the point of view of the client or contractor.

The estimator and his or her team are vital to the success of any organisation. If the estimate originates with a promoting body then it will be used as a basis for deciding if a project should go ahead. If the estimate is produced as part of a contractor's tender (as the majority of these lectures refer to) then it is even more critical: if an estimate is too high the contractor does not win the work and suffers. If the estimate is too low the contractor does win the work, loses money on it and also suffers.

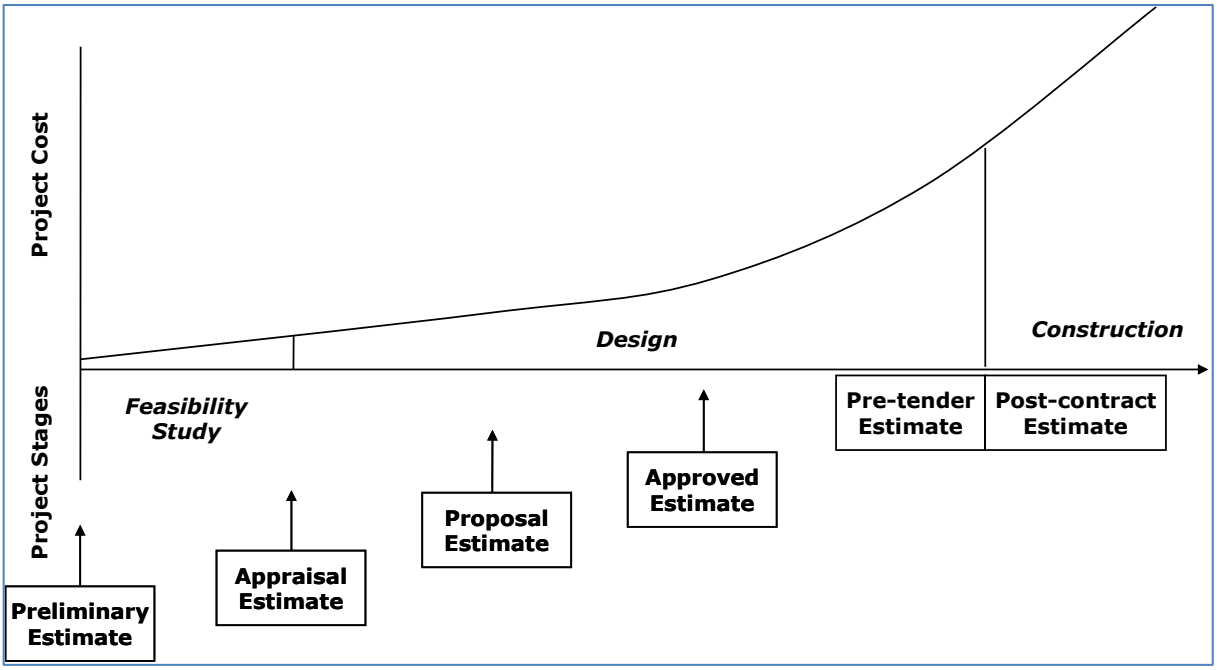
3.1.1 The Estimating Process

The process of estimating is an extremely variable one and depends on many factors such as the type of project (civil, offshore, process etc.), the organisation doing the estimate (client, contractor, sub-contractor etc.) and the stage of the project (concept, design, pre-tender etc.) and we therefore cannot hope to cover all aspects in a few lectures. Various people have indicated different names to the types of estimate done at various stages (see Figure 6.1) and also the range and accuracy of estimates naturally varies throughout the project life cycle (see Figure 6.2).

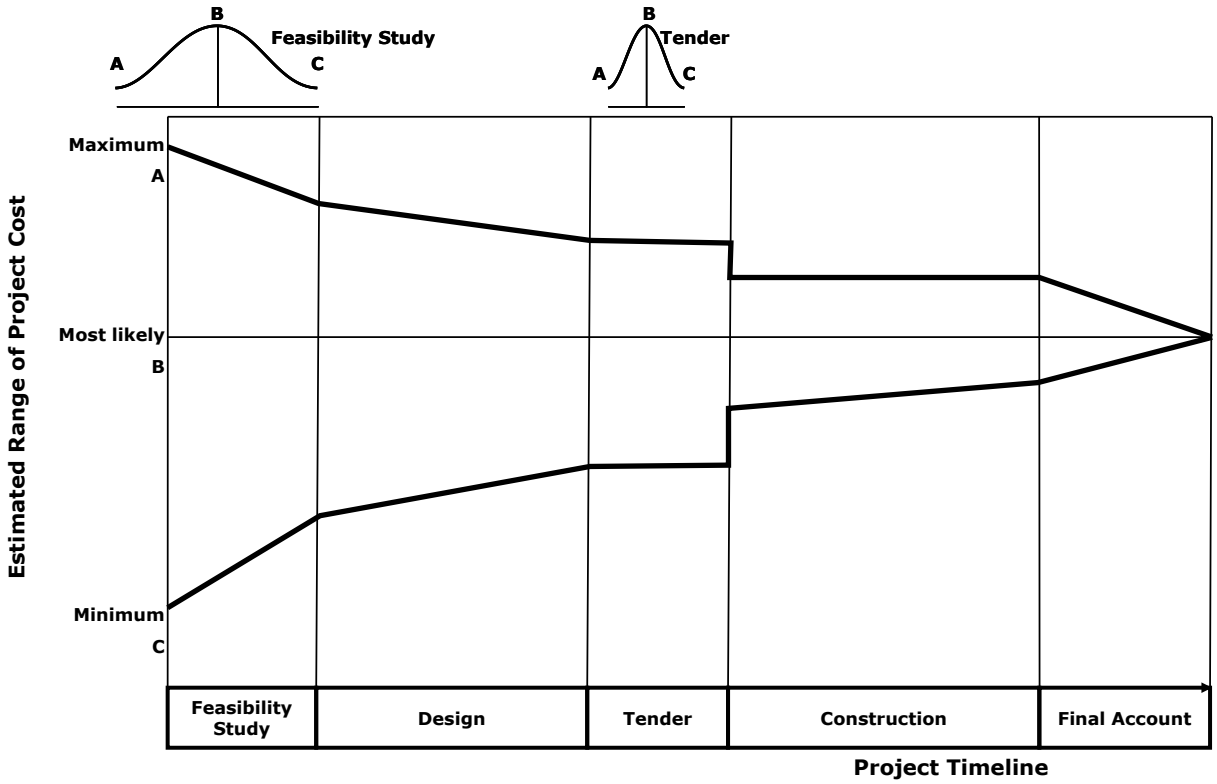
What I shall try to do is base the estimating process on the following:

- elements of cost;
- cost data;
- applying the data (estimating methods);
- conversion of estimate into a tender bid (obviously for contractors only);
- consideration of other factors.

A key part to estimating can be seen to be *costs* of *resources*. Usually we think of physical resources and these partly make up the elements of cost. It is also important to consider financial resources.



Estimates at various project stages (from Engineering Project Management, Nigel Smith, Page 27+114)



Range of Estimates over the project cycle (from Engineering Project Management, Nigel Smith, Page 114)

3.2 FINANCIAL RESOURCES

Some authors consider money itself to be a resource that can be considered in a similar manner to physical resources. It is my opinion that this *comparison* actually confuses the issue – but nevertheless, finance is important to any project and we shall briefly look at the way in which it can be classified.

Any organisation needs to consider its *income* and its *expenditure*. These two concepts are fundamental to estimating and the success of that organisation.

3.2.1 Expenditure

When a project is undertaken, the parties involved will have to make various payments – their expenditure. The client generally has to make payments to one or more main contractors. On traditional contracts they may have to pay designers' fees and other specialist fees.

A main contractor will incur expenditure along the following lines:

- to suppliers of materials;
- to subcontractors for work carried out;
- to internal or external plant hire companies; and
- to directly employed labour;
- overheads.

It is clear that contractors' expenditures fall along lines of elements of cost that will be considered next, i.e. physical resources and overheads, the latter being costs incurred that can't be attributable to an element of work. Subcontractors will incur expenditure along the same lines.

3.2.2 Income, profit and surplus

As money flows out of a company (be it client or contractor) money also flows in as payment for work undertaken. If any organisation is to survive and grow its income must be greater than its expenditure – it must receive a higher sum of money for an element of work than its cost. This is where the term *price* comes in – the price is the sum of money charged by a contractor or supplier to cover its costs and also pay a profit.

Of course it may be that the *actual* cost incurred may be different from the *estimated* cost, in which case the profit will be different from that anticipated. The price will invariably remain the same so often the profitability is indicated by the *surplus* – quite simply the difference between the expenditure and the income. A negative surplus indicates the actual costs are greater than the price received.

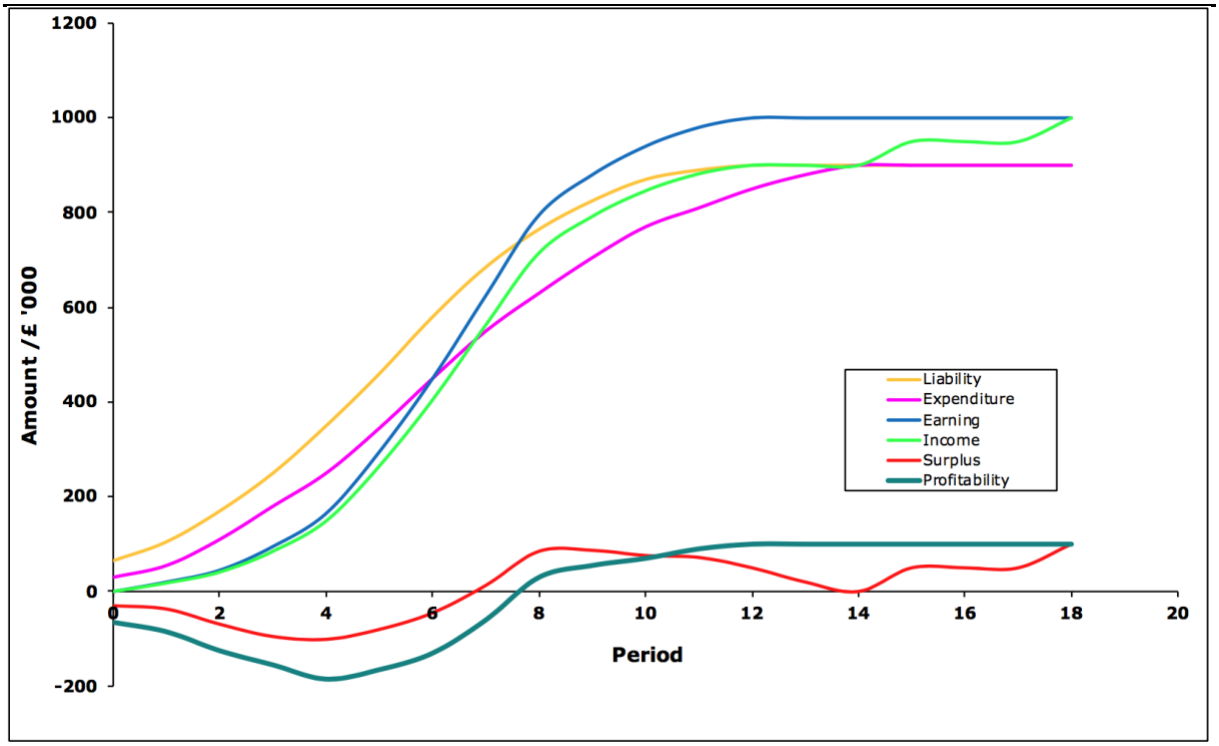
3.2.3 Liability and earning

The provision of work and services rarely occurs at the same time as an exchange of money. In the same way as someone who has a job rarely gets paid in advance a contractor will get paid by the client some time after an element of work is completed. The contractor itself will pay its labour force, material suppliers and subcontractors in arrears.

In financial terms when work or service is provided by one of the areas of cost a liability is incurred by the receiver of that work or service. After a period of time (that is negotiated and indicated by the contract between these two parties) a payment is made and the liability becomes an expenditure. The supplier of the work or service has provided some value but will not get paid for it for the (agreed) period of time. The supplier has generated earnings – this earning becomes income once payment is made.

This may seem irrelevant – the money is paid eventually, and as long as everyone's income is greater than its expenditure they will all be happy. However, the time delay between liability and expenditure will vary depending on type of expenditure and between projects; there may also be retentions written into the contract (money held back) that are only paid at the end of the project. All this means that projects measured on a comparison of income and expenditure may give a false impression of profitability. It is far better to plan and present a project on a comparison between liability and earning.

All these concepts of financial resources can be summarised by the curves shown below.



Financial curves for sample project (Mawdesley et.al. 1996)

3.3 ELEMENTS OF COST & COST DATA

3.3.1 Elements of Cost

Estimating, as we shall see, is a process which requires *data.* This data is broken down into identifiable areas which are considered in turn to determine the cost of an individual item of work.

These areas, or cost headings, are usually:

- personnel;
- plant (or equipment);
- materials;
- subcontractors;
- specialist services;
- overheads;
- risk.

A. Personnel

The personnel used in a project will vary tremendously: it will depend on the type of project and also from the context of the party carrying out the estimate. For example, the labour required for a civil engineering construction project may be considered under the following headings:

- concrete placing teams;

- steelfixing and formwork teams;
- scaffolding teams;
- paving teams;
- general labour;
- pipe laying and drainage teams.

B. Equipment

Again, the type of equipment will vary depending on the type of project but it is usual to categorise depending on use. An engineering contractor's equipment may be categorised by:

- Non-mechanical equipment such as scaffolding and access equipment;
- Mechanical plant:
  - ⇒ excavation plant;
  - ⇒ piling plant;
  - ⇒ pipe laying plant;
  - ⇒ cranage plant;
  - ⇒ pumping plant.

C. Materials

The material cost of many construction stages is commonly up to 40% of total construction cost. Whilst engineering costs may dilute this proportion somewhat in some industries, the correct identification and estimation of material costs is crucial to the overall estimation process. Example materials categories (not an exhaustive list):

- consumables;
- steel, pipes, piles,
- bricks, blocks, tiles etc.;
- cladding;
- steelwork;
- concrete;
- fill materials.

D. Sub-contractors

In most cases the Contractor will not undertake the whole of the work of a major project entirely from within the Contractor's own resources. The contractor usually divides the work up into a number of elements and enters into separate agreements with *subcontractors* to carry out some of the work directly for the Contractor. The Contractor, of course, may undertake some of these elements using the Contractor's own resources and work staff.

E. Specialist Services

Such services may include:

- Engineering and Design Consultancy
- Model Building and Testing
- Process Engineering and Computer analysis
- Project Management

F. Overheads

Site overheads need to be included to allow for all indirect costs not determined through the estimation of the actual work. Head office overheads may include head office staff; bank guarantees; insurances; running costs etc.

G. Risk

Risk, if not adequately identified, estimated and managed can have severe financial consequences for a project. Matters for consideration may include:

- weather;
- safety of personnel;
- technical problems;
- unexpected adverse conditions;
- interpretation of contract documents;
- client's attitude to claims / errors;
- finance costs and inflation;
- industrial disputes and productivity.

3.3.2 Cost data

The next stage in any estimating process is to determine the actual costs for these headings. Basic cost data fails into three categories: *period-based* i.e. usually hourly, daily or weekly costs, *fixed costs*, and *unit output* costs.
Some considerations:

A. Personnel

The cost of personnel will obviously vary depending on the type: general labourers will cost less than senior management. In addition, the calculation of the cost will vary with type. For example, a senior manager will be paid a flat salary, usually with no overtime. Additional costs to the employer are national insurance, pension contributions plus any perks such as a company car (which may well be considered as an overhead).

However, the calculation of the cost of labour is more difficult, especially when applying the cost to an item of work. For example, in estimating a pipelaying operation we are not interested in the actual cost of the labour but in the labour cost per linear metre laid (i.e. the unit output cost). In order to determine such costs we need to combine knowledge of two pieces of data: the cost of the labour (termed the 'all-in' rate) and the productivity or output rate. The process is as follows:

1. determine a base period, usually a year;
2. determine the number of normal hours worked per base period (i.e. hours in employment, not actual productive time);
3. determine the number of overtime hours worked (assumptions will generally have to be made);
4. determine the cost of employment over the base period; this will include items such as:
    - normal hourly rate;
    - overtime rate;
    - bonus;
    - tool money;

- holiday stamps;
- sick pay (assumptions made);
- national insurance;
- training board levy;
- allowances for severance pay and insurance;

5. all-in rate is the ratio of base period cost to base period normal hours (overtime usually assumed to be non-productive);
6. determine productivity of labour, which will include allowances for downtime, expressed in unit of production per hour;
7. labour cost of unit of production is ratio of all-in rate to productivity.

B. Equipment

The cost information for all types of mechanical and non-mechanical equipment will vary depending on whether the supply is internal or external. If the supply is internal (from the company's own plant division) rates will be easily available. For those items of plant that have to be externally hired, quotations must be sought early in the estimating process.

Equipment is usually costed on the basis of a real or notional hourly, daily or weekly hire rate. As with labour, allowance must be made for ineffective time and a similar process is employed.

It is important to ensure that the choice of equipment is optimised and this might involve consideration of:

- Suitability: e.g. a wheelbarrow is not suitable for movement of large amounts of material;
- Capacity: e.g. a 500tonne crane is too large to lift small pieces of reinforcement;
- Output: e.g. the output of the item must match the material input;
- Availability: specialised pieces of equipment may be difficult to obtain;
- Reliability: older plant may be cheaper but unreliable;
- Maintenance: newer plant may be more expensive but require less intensive maintenance;
- Redundancy: e.g. a welding plant used once a week is mostly redundant.

C. Materials

Materials prices are obtained finally by competitive tender but at the estimate stage a number of sources will be used. These include past records, current contracts in other projects and requests for information or indicative quotes from suppliers. A balance must be struck between discounts available for bulk purchase, the cost of storage and the cost of transport.

Allowance must be made for wastage and materials whose quantity is unspecified. Historical wastage rates from company records can be used: for example, it may be recognised that 2.5% of all concrete delivered is not used. Consumables may be treated in the same way as the materials, or by a percentage addition to labour or equipment costs.

D. Subcontractors

A decision must be made about which section of the job to subcontract, or alternatively, which processes. It may be that such decisions are left to the contractor, but the PMT may wish to 'nominate' a subcontractor for certain parts of the construction.

E. Overheads

Site Overheads

Overheads are all those items necessary to complete the job, but which do not form part of the permanent works. They may include:

- staff;
- accommodation (i.e. offices);
- small tools and plant;
- welfare & first aid provisions;
- transport;
- insurance;
- security;
- storage;
- workshops;

as well as any risk the contractor requires to be included. These costs are usually then attributed to items in the bill of quantities (if it exists) in what is known as the 'preliminaries' section.

Head office overheads

These can only be determined from a careful record of the costs associated with running a head office. The importance of maximising turnover for a given level of overhead cannot be over-emphasised.

3.4 ESTIMATING METHODS

The way in which an estimate is conducted and produced depends on many things, such as the stage of the project, the purpose of the estimate and the party carrying it out.

In this lecture and the next we shall look at the methods in which the cost data that is gathered as part of an estimating exercise is put together to produce a final total estimated cost of the project. The methods we shall consider are:

- Global/approximate
- Factorial
- Labour-hours
- Unit rate
- Operational

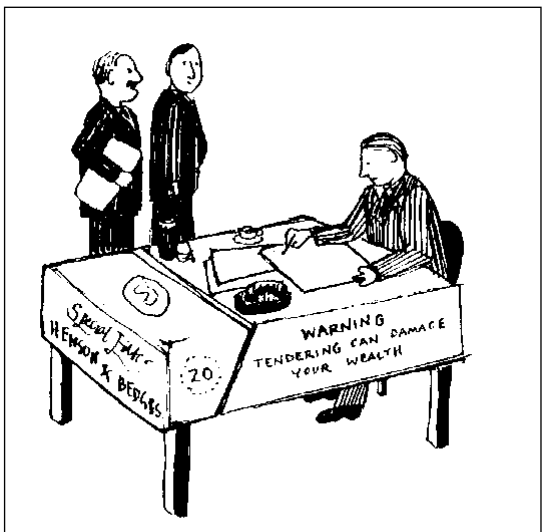
Table 1 shows the form of the cost data that is needed for each method.

Table 1 *Data for basic estimating techniques (Smith 1995)*

Estimating Method					
	Global	**Factorial**	**Labour-hours**	**Unit rate**	**Operational**
Project Data required	• Size/capacity • Location • Completion date	• List of main items • Location • Completion date	• Quantities • Location • Key dates • Simple method statement • Completion date	• Bill of quantities • Location • Completion date	• Materials quantities • Method statements • Programme • Key dates • Completion date
Cost data required	• Overall costs of similar projects • Inflation indices • Inflation forecasts	• Factorial estimating system • Quotes for main plant items • Inflation forecasts	• Hourly rates • Productivities • Overheads • Materials costs • Hourly rate forecasts • Material costs forecasts • Plant data	• Historical unit rates for similar work items • Preliminaries • Inflation indices • Inflation forecasts	• Labour rates and productivities • Plant costs and productivities • Materials costs • Overhead costs • Materials costs forecasts • Plant capital an operating cost forecasts

Method 1. Global Estimating

This is the term Smith has used for what could be considered the simplest form of estimating – other terms that could be used are *approximate* (Brook, 1993), *rule of thumb, ballpark*. It is perhaps somewhat more accurate than the long established *back-of-a-cigarette-packet* method.



'Brian does his estimates on the back of a cigarette packet'

(*Brook, 1993)*

The technique relies on a library of archive costs for similar projects related to its overall capacity or size. Quite simply, the cost of a new project is the cost/capacity (historical)

multiplied by the capacity (new project) plus allowances for inflation and market trends. It is therefore used at the conception and feasibility study stages to allow the client to base decisions on.

Examples of the historical data may be:

- cost per linear metre of highway/railway;
- cost per tonne of output for process plants;
- cost per bed for hospital;
- cost per square metre or cost per unit volume for buildings;
- cost per megawatt for power stations;
- cost per flight capacity for airports; etc.

There are many dangers with this type of estimating. Specifically:

1. What is the cost of a completed project? Does it include:
   - final account sums;
   - design & engineering fees;
   - finance costs;
   - land; etc.

2. How is the measurement of the capacity defined?:
   - how does linear capacity of linear projects (highways, railways) allow for interchanges;
   - how does associated infrastructure be allowed for (access roads, power supplies, etc);

3. Not comparing like with like:
   - different ground conditions;
   - different site locations (flat terrain compared to mountainous);
   - different standards of quality (a motorway compared to a minor road);

Like in any application it is clear that the quality of the database will influence the quality of the estimate. It is also beneficial to have data coming from just one organisation – a wide range of data with its origin unclear will lead to like not being compared to like.

Brook describes the above global concept as 'single-rate approximate estimating'. Spon's (a series of books of rates for a wide range of engineering estimating applications[3]) calls this method 'approximate estimating'. The data shown in table 2 provides an example of global estimating rates based on floor area capacity. In this case it is important to know that the area is measured between external walls and no deduction necessary for internal walls, columns, staircases liftwells etc.

[3] *Spon's civil engineering and highway works price book 1998* (Robertson Library Reference Section) or *Spon's civil engineering and highway works price book 2005* (Robertson Library Reserve Section) or *Spon's mechanical and electrical services price book 1998* (Robertson Library Reference Section)

	Cost/m² excluding VAT £
Surface car parking	29 to 46
Multi-storey car parks	
split level	165 to 220
split level with brick facades	176 to 264
flat slab	176 to 214
warped	192 to 231
Underground car parks	
partially underground under buildings	253 to 307
completely underground under buildings	362 to 505
completely underground with landscaped roof	549 to 615
Railway stations	1016 to 1724
Bus and coach stations	516 to 862
Bus garages	494 to 538
Petrol Stations	648 to 950
Garage showrooms	384 to 604
Garages, domestic	214 to 346
Airport passenger terminal buildings (excluding aprons)	
national standard	862 to 1016
international standard	1213 to 1526
Airport facility buildings	
large hangars	862 to 1016
workshops and small hangars	544 to 620
TV, radio and video studios	626 to 1016
Telephone exchanges	516 to 824
Telephone engineering centres	434 to 538
Branch Post Offices	538 to 730
Postal Delivery Offices/Sorting Offices	434 to 648
Mortuaries	988 to 1367
Sub - Stations	730 to 1098

Table 2 *Global rates for a variety of facilities, Spon's 1998*

Method 2. Factorial estimating

Some engineering projects, such as power stations or process plants have a large element of fixed plant. The costs of these items can be determined readily from suppliers at a very early stage in the project but nevertheless they will also require a large amount of ancillary engineering work such as pipework, electrical work, structural work (foundations etc.), instrumentation etc.

Each of these ancillary items will have a factor associated with it, determined from costs on historical projects. The cost of the ancillary item is therefore simply the product of the cost of the main plant item and its factor.

Comments to make about factorial estimating:

- The reliability and accuracy of the factors can significantly influence the overall reliability of the estimate. The factors should be built up from extensive experience by the organisation's estimating department. It should be noted that as the design changes the factors may well change also – for example the factor might be sensitive to slight changes in plant specification.
- The estimate also depends on the reliability of the price of the plant items. The estimators may like to make their own judgements as to the value of these items when drafting the estimate.
- Similarly, the technique should not be applied blindly to all areas of the estimate. The estimators must use their own judgement as to the validity of the estimates they

are making – the estimate for item of ancillary engineering should be assessed to see if it is realistic.

- As the technique is based on current costs obtained from suppliers little adjustment for inflation is needed.

Barrie[4] & Paulson (1992) have provided the factors shown in Table 3 for process plants – these are shown as an example and it should be noted they are based on US projects. Taking this information the example shown in Table 4 indicates the technique in its simplest form, which does not allow for associated civils works.

PROCESS-PLANT COST RATIO FROM INDIVIDUAL EQUIPMENT*

Equipment	Factor†
Blender	2.0
Blowers and fans (including motor)	2.5
Centrifuges (process)	2.0
Compressors:	
Centrifugals, motor-driven (less motor)	2.0
Steam turbine (including turbine)	2.0
Reciprocating, steam and gas	2.3
Motor-driven (less motor)	2.3
Ejectors (vacuum units)	2.5
Furnaces (package units)	2.0
Heat exchangers	4.8
Instruments	4.1
Motors, electric	8.5
Pumps:	
Centrifugal, motor-driven (less motor)	7.0
Steam turbine (including turbine)	6.5
Positive displacement (less motor)	5.0
Reactors—factor as approximate equivalent type of equipment	
Refrigeration (package unit)	2.5
Tanks:	
Process	4.1
Storage	3.5
Fabricated and field-erected (50,000 + gal)	2.0
Towers (columns)	4.0

*From W. F. Wroth, "Factors in Cost Estimation," *Chem. Eng.*, vol. 67, October, 1960, p. 204; and F. C. Jelen (ed.), *Cost and Optimization Engineering*, McGraw-Hill Book Company, New York, 1970, p. 317.

†Multiply purchase cost by factor to obtain installed cost, including cost of site development, buildings, electrical installations, carpentry, painting, contractor's fee and rentals, foundations, structures, piping, installation, engineering, overhead, and supervision.

Table 3 *Factors for process plants (Barrie & Paulson, 1992)*

Item	Cost/£	Factor	Plant cost/£
Blowers and fans	15,000	2.5	37,500
Compressors	70,000	2.3	161,000
Furnaces	100,000	2.0	200,000
Heat exchangers	95,000	4.8	456,000
Instruments	70,000	4.1	287,000
Motors	55,000	8.5	467,500
Pumps	32,000	7.0	224,000
Tanks	145,000	2.4	348,000
Towers	250,000	4.0	1,000,000
Total	**832,000**		**£3,181,000**

Table 4 *Example of factorial estimating – data from Table 3*

[4] D.S. Barrie & B.C. Paulson *Professional Construction Management, 3rd ed.* McGraw-Hill, New York, 1992. [TH438 Bar.]

Method 3. Labour-hours estimating

Perhaps the simplest and, according to Smith, one of the earliest estimating techniques. It is suitable for labour intensive operations such as fabrication and mechanical/electrical installations. It tends to be more commonly used in North America than Europe.

The technique is similar to operational estimating, which will be detailed later. However, it assumes that most operations do not vary in their method from project to project. The technique requires that the total labour-hours are estimated for an operation and are then costed at current labour rates – known as 'All-in-rates' – i.e. it is the rate of employing labour that includes all costs. The final cost is produced by adding on allowances for materials and plant. These extras should be easily identified hence the method's suitability for operations such as M&E or low material operations. Civil engineering operations usually have a high material element that will vary considerably throughout a project – this is one of the reasons the operational estimating technique is used, which requires the use of a programme and method statement.

Spon's (see footnote[5] - online access) shows all-in labour rates. See page 66.

Method 4. Unit-rate estimating

This method could be compared to the global method indicated. Whereas in global estimating we may apply a rate to a project's overall capacity (for example cost per length of motorway), unit-rate estimating will produce an estimate built up from rates applied to individual items. The technique therefore requires the existence of a 'bill-of-quantities' in one form or another.

3.4.1 Context

Unit-rate estimating is an extension of labour-hours estimating where the cost and output rates are applied to each major resource – that is labour, plant and materials. The term 'unit-rate' is used as a rate (cost) is estimated for each unit of an item. For example, if the item is 'place and compact concrete' the unit would normally be m^3 and the rate would be the amount of money associated with *one* m^3 of concrete – including the cost of labour, plant, materials and other costs.

The overall cost of the item is then determined by multiplying the rate by the quantity.

[5] Spon's Civil Engineering and Highway Works Price Book 2018 https://discovered.ed.ac.uk/permalink/44UOE_INST/7g3mt6/alma9924045052402466 (accessed 11 August 2026)

Where do these rates come from? Usually from one of the following:

- historical rates based on productivity data from similar projects;
- rates based on data given in price books (e.g. Spon's);
- rates built-up from an analysis of labour, plant and materials for each item and costed at current rates;
- taken from an estimator's 'personal' manual

The technique is most appropriate for building and repetitive work where the allocation of costs to items of work is well defined. Standard method of measurements (for example CESSM for Civil Engineering works or SMM for building works) define quite clearly the scope for most items of work in such projects and therefore the estimator has no confusion as to what should be included.

Whilst in most situations is should be possible to determine all-in rates for both labour and plant, and get adequate rates for materials, poor estimates of productivity will lead to poor estimates. Hence the technique is not likely to be successful in locations where few similar projects have been completed in the past – in general the techniques success depends on the experience of the estimator and the quality of the historical rates for productivity.

3.4.2 Example of unit-rate estimating

This example provides rates built-up from an analysis of the labour, plant and material requirements of the item. It is also covered directly in the lectures.

Item	Description	Unit	Quantity	Rate	Amount
G526.0	Fix high yield steel bars BS 4449 Grade 460/425, diameter 20mm, length 15m	tonnes	6.350	£630.50	£4,003.68

Calculations on the next page.

Calculations

The following resources are used in this operation:

- 20mm high yield rebar – cut, bent and delivered
- One steelfixer
- 20tonne mobile crane for off loading

Output (productivity) rates must be stated. These are taken from company and/or personal data an amended to suit specific site conditions:

- Material – rebar 1.1 tonnes/tonne
- Labour – steelfixer 0.054 tonnes/hr
- Plant – crane 5 tonnes/hr

The last piece of data required is the costs. A quotation is received for the steel and all-in rates are calculated for the steelfixer and the crane:

- Rebar £397.93 per tonne
- Steelfixer £10.12 per hour
- Crane £26.89 per hour

Direct costs can then be calculated for each resource:

- Rebar = 1.1 x 397.93
  = £437.72 / tonne
- Steelfixer = 10.12/0.054
  = £187.40 per tonne
- Crane = 26.89/5
  = £5.38 per tonne

The individual rates are then added to give the total and entered into the bill. The item amount is calculated by multiplying the rate by the quantity:

- Total item rate = 437.72 + 187.40 + 5.38
  = <u>£630.50 per tonne</u>
- Total item amount = 630.50 x 6.35
  = <u>£4,003.68</u>

Notes

How does the estimator determine this? Either from experience or by looking at the plans for the operation – a method statement may include this information

Remember, materials have an 'output' rate also. Here we are saying that for every tonne fixed, 1.1 tonnes must be delivered to allow for wastage.

Working conditions may vary project-to-project so all-in rates must be calculated fresh. The rate for the crane includes for fuel, oil and a category 4 operator.

As the unit of this item is 'tonne' (see table above) we need to get all costs 'per tonne'.

3.4.3 Problems with Unit-rate estimating

The above example provides what appears to be a detailed (to 2 decimal places) estimate of the cost per tonne to fix steel. It covers all three physical resources and has taken into account productivity rates.

However, the method may not provide the whole picture and may hide associated costs. If this rate were to be used as the basis for a tender, these associated costs may not be recovered.

- As far as materials are concerned it assumes they can be off loaded at the moment they are delivered and at the place where they are needed. This may not always be the case.

From the above example, 6.35 tonnes would take 117.6 steelfixer hours. For one steelfixer this is 12 days at 10 hours per day – or three steelfixers for 4 days.

- What happens if during the actual construction only 2 steelfixers are available?
- Or if the programme allows 2 weeks for fixing with just one fixer?
- In addition, this item of work may actually cover all the 20mm rebar for a number of structures – therefore no account is taken for travelling between them.
- Finally there may be another item for bent bars, or some for other diameter bars. Carrying out such fixing concurrently may slow down the output rate for the straight bars.

Perhaps the biggest problem is with plant. No account of plant idleness is allowed for. In this case, 6.35 tonnes of steel will only take 1¼ hours – what does the crane do then? Can it go on to another similar job or does it then have to wait?

The main problem with unit-rate estimating can therefore be seen to be that it does not take account of the programme. It assumes that all the resources will be available all of the time. It also cannot take in to account the way in which the activities are to be carried out. Operational estimating, the final method, uses both the programme and the method statements.

A final note about the use of this technique: there is a danger that the precision and detail of the individual rates can lead to a misplaced confidence in the figures. It cannot be assumed that previous work (upon which historical rates may be based) was of the same nature, carried out in identical conditions and with the same duration.

Method 5. Operational estimating

The most fundamental type of estimating, which is compiled from a consideration of the constituent operations and activities that are indicated in the construction programme. It is ideal for civil engineering operations which tend to be unique to the project in consideration. Its main disadvantage is that to be effective it must have programmes and method statements prepared. This is outweighed by the advantages which can be summarised as:

- It will allow for idle time which is common in plant dominated work. Instead of costing the plant on an assumed output it will determine the cost for the time that it is on site.
- It can allow for operations where there are significant uncertainties and risks. As it will show the basic sources of costs, rather than the cost derived from an output, the sensitivity of the overall estimate to changes in assumptions and methods can be investigated. The reasons for variations in costs can be investigated.
- The technique, through its requirement for preparation of programmes will help in identifying sources and risks of delay for individual operations.
- Although time consuming, organisations carrying out this technique will soon accumulate a library of operational data which will allow an appreciation of the best way in which to carry out work.

It should be pointed out that estimators may still need to fill in a rate and an amount for items in a bill of quantities. The most common way is simply to assign the total cost of a group of items pro-rata to each individual item.

3.4.4 Example of operational estimating

From the same book as the example for unit-rate estimating. The estimator will usually be faced with a similar bill item:

Item	Description	Unit	Quantity	Rate	Amount
F523.0	Placing 50N concrete to bases thickness 300-500mm	m^3	12.71	£16.52	£209.97

This item is possibly the concrete part of a larger element of the overall project. The total amount of concrete in the bill (not necessarily of the same quality) is 8000m^3. From historical records and by discussion with the planners the estimator knows that concrete can be poured at an average of 210 m^3/week thus giving a total duration of 38 weeks. The maximum pour to a base slab is 160m^3.

Plant:

The plant requirements for concreting are:

- 1 no. concrete pump, truck mounted @ £985.00 per week
- 6 no. concrete vibrators @ £28.50 per week each

The plant will be hired from the company's own internal hire division at a weekly rate and held on site for the full 38 weeks. The plant will be used solely for the purpose of placing concrete.

- The total plant cost is therefore:
- Concrete pump: 1 x 985 x 38weeks = £37,430.00
- Vibrators: 6 x 28.50 x 38weeks = £6,498.00
  - Total direct plant cost = £43,928.00
  - Plant cost per m^3 = 43,928/8000 = £5.49/m^3

Labour:

The gang will be one concrete finisher (ganger), four general labourers and a plant operator for the pump.

The cost for this is:

• Conc. finisher (cat 2)	1	x	7.15	x	53.25	x	38	= £14,468.03
• General labs (cat 1)	4	x	6.82	x	53.25	x	38	= £55,201.08
• Plant op. (cat 4)	1	x	9.16	x	53.25	x	38	= £18,535.26
▪ Total direct labour cost								= £88,204.37
▪ Labour cost per m^3								= £11.03/m^3

Material:
This item (check its description) does not include for the supply of concrete. Separate items will be provided for this. The estimator will simply need to insert the quote obtained from the concrete supplier.

Therefore the total plant and labour rate for placing of concrete = **£16.52/m^3**
This can be inserted into all the bill items for the placing of concrete that make up the 8000m^3 used in the example.

3.5 FURTHER ISSUES IN ESTIMATING

Note: This section provides some extra aspects of cost estimating. It may not be covered in the actual lectures – if so then you may assume that the subjects are *not* examinable.

This last section will tie up the estimating process in construction project management by looking at some further issues in estimating and the budgeting process.

3.5.1 Conversion to Tender Bid

We have seen how the *Direct Costs* of individual items can be 'built-up'. Whether or not this is done by Unit-rate or Operational estimating, these direct costs can be summed for the whole project to give the direct cost to the contractor for the whole project.

This, however, is not the tender bid – the contractor needs to allow for overheads, risk, profit etc.

On completion of the direct cost estimates, the contractor's estimators prepare a report for the consideration by senior management. This should contain:

- Project description;
- General method statements;
- An indication of risks within the project that may not be adequately covered by items contained in the bill of quantities;
- Contractual issues that may remain unresolved;
- The financial consequences of the design process – i.e. are their areas that may present technical risks or are there areas that have been poorly designed (remember the contractor may have more expertise than the designer on some matters;

- Notes of the major assumptions made in the preparation of the direct cost estimates (such as assumptions made in preparing operational rate build ups);
- An indication of its profitability;
- Market and industrial conditions that may be pertinent to the project (for example, an upswing in certain sectors of the construction industry may push up prices greater than inflation;
- Direct costs, broken down into resource areas, including subcontractors;
- The Bill of Quantities with direct costs.

This report serves to provide the senior management with all the information they need to assess the commercial aspects of the project. Their initial aim is to ensure that the direct cost estimate is adequate – have the estimators allowed for everything?, are their assumptions correct? If not then it may be that extra costs need to be included or removed (to make it commercially viable) either in the form of lump sums or increased/decreased rates.

The senior management must then decide what 'mark-up' or 'uplift' is applied to the rates. This allows for:

- *Risk* for individual areas or the project as a whole if it is considered the probability of losing money is considered intolerable;
- *Overheads* to cover both central head office costs and site costs;
- *Profit* which will depend on the prevailing market conditions.

In a Bill of Quantities this uplift will have to be distributed amongst the different item rates, and may be weighted more heavily in some areas.

Once the final considerations have been assessed and the uplift established, a priced BoQ will be submitted as a tender bid in the manner prescribed in the contract documents. This procedure is discussed in more detail in the *Contract Management* section of the module.

3.5.2 Estimating Accuracy

We shall now, very briefly, look at how accurate our individual rate build-ups need to be. The accuracy of a tender estimate is, of course, highly important. If the estimator is too high with the overall estimate then the chances of winning the tender are lowered. If the estimate is too low (i.e. below actual costs) then the chances of returning a loss on the project are increased.

We need to be able to relate the overall tender estimate accuracy to the accuracy of the individual items. We shall look at this using the *binomial theory* (note, this is not a maths lecture – derivations on mathematical formulae are not my speciality!):

> The error (expressed as a percentage) of a part as a ratio of the error of the whole is inversely proportional to the root of the ratio of the respective sizes.

Let's say that the error of the overall (whole) estimate is $\pm E\%$ and the whole project duration (S) is 52 weeks. Also, let's assume that the error of an individual activity is $\pm e\%$ and that the average duration of one activity (s) is 2 weeks.

If the acceptable error on the whole estimate is, say 10%, then the binomial theory states:

$$\frac{\pm e}{\pm E} = \sqrt{\frac{S}{s}}$$

$$\pm e = E\sqrt{\frac{S}{s}}$$

$$\pm e = 10\sqrt{52/2}$$

$$\underline{\pm e \approx 51\%}$$

In essence the binomial theory is indicating that, for a project with many individual activities, the errors on these activities are distributed such that they will tend to cancel each other out and so estimating accuracy need not be too great at the micro level. In reality it is more likely that the estimator will continually err on the plus *or* minus side and therefore activity accuracy may not be allowed to be as great as 51%.

3.5.3 Learning and Forgetting

We have all heard of a learning curve – output will increase as operatives are familiarised with an activity. For work of a repetitive nature, the effect may be enough to have a significant effect on the cost of an item.

Similarly, if there are delays or interruptions to repetitive job operations then some of the enhanced skills gained previously may be lost. Whilst the work done in investigating forgetting is not as developed as that looking at learning, both situations can be represented by simple mathematical functions.

The most basic of these was first proposed by T.P.Wright in 1936[6] and is known as the *straight-line model*:

$$T_{an} = T_1 n^r \qquad \textit{equation 1}$$

where:

T_{an}	=	the cumulative average labour-hours or average cost per unit after the construction of *n* units (assumes cost is proportional to labour duration)
T_1	=	labour-hours or cost per unit for the first unit
n	=	unit number, i.e. 1,2,3,…, *n*
r	=	improvement function

The model also states that the time taken by the n^{th} unit is given by:

$$T_n = nT_{an} - (n-1)T_{a(n-1)} \qquad \textit{equation 2}$$

The unknown and variable quantity is the improvement function. Where improvement is shown to be a fixed percentage each time output doubles, then:

[6] Wright T.P. Factors affecting the cost of airplanes, *Journal of Aeronautical Science*, 3, Feb 1936, 122-128.

$$r = \log(learning\ rate/100)/\log 2 \qquad \textit{equation 3}$$

where the learning rate is = T_{an}/T_1. Note therefore that a learning rate of 60% represents a better improvement than a learning rate of 80%. In construction we can expect learning rates of between 80 and 95 percent, depending on factors such as work conditions, environmental conditions, quality of supervision, nature of work etc. The table below shows what the improvement function is for various learning rates:

Learning Rate / %	Improvement Function / *r*
100 (i.e. no improvement)	0
95	-0.074
90	-0.152
85	-0.234
80	-0.322
75	-0.415
70	-0.515
65	-0.621

Learning rates and improvement functions

3.5.4 Example of learning curve use

An estimate for the direct labour cost of the production of 75 precast concrete beams is required. The labour all-in-rate is £7.50 per hour. Company records show that the steady-state production rate is 100 labour-hours per beam. If the learning rate is 90% calculate the total direct labour cost of producing these beams if the steady-state output rate is reached after 50 beams.

For a learning rate of 90%, the improvement function *r* is –0.152

From equation 2 and 1:

$$T_n = nT_{an} - (n-1)T_{a(n-1)}$$
$$T_n = nT_1 n^r - (n-1)T_1(n-1)^r$$
$$= T_1\left[n^{r+1} - (n-1)^{r+1}\right]$$

Therefore:

100 = $T_1(50^{0\text{-}848} - 49^{0.848})$

= $T_1(27.59 - 27.12)$

= $0.47T_1$

T_1 = 212.77 labour-hours

The cumulative average labour-hours during the learning process is:

T_{an} = $212.77(50)^{-0.152}$

117.41 labour-hours

Therefore the total direct labour cost for making 75 beams is:

= 7.50[50(117.41)+25(100)]

= **£62,778.75**

The additional cost for learning is therefore:

= 7.50[50(117.41 – 100]

= **£6,528.75**

Topic 4 CONTRACT MANAGEMENT

Topic Lecturer: Simon Smith (simon.smith@ed.ac.uk)

Read (see "Suggested Reading List" on page 4):

- Engineering Project Management (Nigel Smith) Chapter 11 and 12
- Engineering Project Management (Neil Siegel) Chapter 7 (though does not go into much detail)
- Project Management – A Strategic Planning Approach (Paul Gardiner) Chapter 6

For most projects, the client is not usually in a position to undertake the execution of the work. This is the same for all industries and all types of client, whether private or public. In order for the work to be carried out, the client and their project management team must select a suitable party to carry out these works and then manage the relationship with that party accordingly. This process is contracting.

Contracting has an important effect on the client's success in producing the new project as well as its investment efficiency and competitive position. This is because there are large differences in the abilities of various contractors to perform, and there are large differences in the contract terms available. How the contracting is done in a project is known as the *contract strategy*, and this is one of the most important management decisions taken in the project. The core element of contracting is the contract itself.

4.1 THE FUNCTION OF AN ENGINEERING CONTRACT

An *Engineering Contract* is a mutual agreement negotiated between two parties for the purpose of undertaking, on a commercial basis, certain clearly specified engineering works. However, the structure of such a contract can also be used to undertake a range of work, e.g. Development, Facilities Management, and Functional Management.

Who are the Parties to an Engineering Contract?

Most contracts in an engineering project are for the provision of construction. In legal parlance the party that requires the work to be done is known as the ***Principal*** and hence these notes on contract management will refer to the *client* as the Principal. The Principal is the party who wants the work done and is prepared to pay for it and the ***Contractor*** is the party who agrees to undertake the work in return for payment.

What are Negotiations?

Negotiations are the spoken and written transactions between the Principal and the Contractor leading to the contract agreement to undertake the work or to supply goods and/or services under the contract.

How is a Contract Negotiated?

The Principal, inviting an offer or a proposal to undertake the work under a contract from one or more suitably qualified individuals or corporations, begins negotiations for a contract. The formal offer made by a contractor in response to such an invitation is referred to as a ***tender*****.**

Where one party only is invited to submit a tender, the agreement may be reached by direct negotiation. Where two or more parties are invited the agreement is usually reached by a competitive tendering process, in which tenders are invited and evaluated in accordance with clearly defined provisions.

Reaching the final agreement may be a lengthy procedure, during which the negotiating parties prepare and exchange documents setting out their respective requirements, offers and counter offers. These documents must be carefully and meticulously prepared so as to avoid misunderstandings and misinterpretations – which could lead to disputes during the contract stage.

How is the Existence of a Contract Demonstrated?

To ensure that the finally negotiated agreement is enforceable in law, the Contract should be clearly 'evidenced' by writing down the agreed terms and conditions under an ***Instrument of Agreement*****,** to be signed by the parties to the Contract. The legal aspects of the procedure have been outlined below in - 'The Law of Contract'.

4.1.1 The Law of Contract[7]

Anyone involved in the preparation of documents that are to be used in the negotiation and formation of an engineering contract will inevitably encounter a situation that requires some knowledge of contract law. While one may have little or no legal training, an overall understanding of the law in this matter is advisable, if only to be aware of the necessity of obtaining professional advice when the limit of one's legal knowledge is reached.

This brief discussion of the law of contract is appropriate to English common law, which forms the basis of the legal systems of most English speaking Commonwealth countries. While the law may differ in detail between such countries, the basic principles enunciated will generally apply. In real situations the project manager is advised to consult a lawyer or an appropriate textbook dealing with the legal aspects of contract law.

Definition of a Contract

A contract, in the simplest definition, is a promise enforceable by law. The promise may be to do something or to refrain from doing something. The making of a contract requires the mutual assent of two or more persons, one of them ordinarily making an offer and another accepting. If one of the parties fails to keep the promise, the other is entitled to legal recourse against him. The law of contracts considers such questions as

- whether a contract exists,
- what the meaning (i.e. intentions) of it is,
- whether a contract has been broken, and
- what compensation is due the injured party.

[7] For an informal discussion of Law of Contracts see: http://en.wikipedia.org/wiki/Contract

4.1.2 Origins of Contract Law

Contract law is the product of a commercial civilisation. There is therefore no basis for its existence, in any significant degree, in pre-commercial societies. Most primitive societies had other ways of enforcing the commitments between individuals; for example, through kinship ties or by the authority of religion. These pre-commercial societies based their trade on barter and most transactions were self-enforcing because the transaction was complete on both sides at the same moment. Problems arose if the goods exchanged were later found to be defective, but such problems were, and are, handled through property law rather than through contract law. It was the market economy of the Roman Empire that established what could be considered a true law of contract.

Roman Law

The Roman law of contracts reflected a long economic, social, and legal evolution. It recognised various types of contracts and agreements, some of them enforceable, others not. But it was only at its final stage of development that Roman law enforced, in general terms, informal executory contracts, that is, agreements for commitments to be carried out after they were made. Unfortunately this stage of development was lost with the break-up of the empire. As Western Europe declined from an urbanised, commercial society into a localised, agrarian society, the Roman courts and relatively weak and imperfect institutions replaced administrators.

The rebirth and development of contract law was a part of the economic, political, and intellectual renaissance of Western Europe. It was everywhere accompanied by a commercial revival and the rise of national authority. Both in England and on the Continent, the customary arrangements were found to be unsuited to the commercial and industrial societies that were emerging. The informal agreement, so necessary for trade and commerce in market economies, was not enforceable at law. The economic life of England and the Continent flowed, even after a trading economy began to develop, within the legal framework of the formal contract and of the half-executed transaction (that is, a transaction already fully performed on one side). Neither in continental Europe nor in England was the task of developing a law of contracts an easy one. Ultimately, both legal systems succeeded in producing what was needed: a body of contract doctrine by which ordinary business agreements, involving a future exchange of values, could be made enforceable.

The new contract law began to grow up throughout Europe through the practices of merchants; these were at first outside the legal order and could not be upheld in courts of law. Merchants developed informal and flexible practices appropriate for active commercial life. By the 13th century, merchants' courts had been established at the international trade fairs. The merchant courts provided expeditious procedures and prompt justice and were administered by men who were themselves merchants and thus fully aware of mercantile problems and customs.

In the 12th and 13th centuries the development of the law of contracts on the Continent and in England began to diverge. In England the common law of contracts developed pragmatically through the courts and through the actions of debt and covenant. On the Continent the process was very different, with speculative and systematic thinkers playing a much larger role; Continental civil law evolved from the classical Roman Law, influenced by the canon law of the Church.

4.1.3 Format of Contracts

Traditionally there are two main genres or formats of contracts, namely ***formal*** contracts and ***simple*** contracts.

A *formal contract*, also referred to as a *contract under seal*, is a deed whose validity depends solely upon its form. In legal terms, *form* refers to the manner in which the agreement is expressed. A *deed* is an instrument in writing and must be signed 'under seal' by the party executing the deed and attested by a witness who is not a party to the contract. It is not necessary for a party executing the deed to actually place a seal on the document, provided that the deed states that it is signed 'under seal'. However, since a corporation does not have a signature, it can only execute a deed by affixing its common seal in the manner prescribed in its articles of association.

The party executing the deed must then hand or deliver the signed deed to the other party - 'signed, sealed, and delivered as a deed'.

A *simple contract* on the other hand, does not have to be in any particular form. It can be made verbally or in writing or partly in both.

In practice, there are only a few differences between formal contracts and simple contracts in writing:

- The first difference is that, to be enforceable, a simple contract must be supported by ***consideration***. Consideration is an inducement to enter into a legally enforceable agreement. It can be either a detriment incurred by one party or a benefit received by the other party. Thus, the party seeking to enforce the agreement must have paid, or promised to pay, some money, parted with some goods, or forgone some benefit.
- The second difference concerns the ***limitation period*** (the time following a breach of contract in which the innocent party may take action on the other). This period can vary, depending upon the jurisdiction under which the contract is established, but generally, it is longer for formal contracts than it is for simple contracts. In an engineering situation, a formal contract therefore gives the Principal greater protection.
- The third difference is that a contract under seal creates an ***estoppel***[8]. This estoppel is a rule of law which precludes a party from later claiming that a statement expressed in the contract is incorrect, especially if others may have been led to rely or act upon that statement.

4.1.4 The Principal's representative

On all projects there will be one person or body who will represent the Principal in all matters relating to the management of the contract, both before and after the contract award. It is rare for the Principal to undertake this task herself. On traditional civil engineering projects this role has been undertaken by the 'Engineer' (capital 'E') who is commonly a senior manager or partner in the firm of consulting engineers who designed the project. However, in other industries, such as electrical / mechanical or offshore this role is less clearly defined. It may be the project manager or indeed the Engineer in common with civil engineering. In addition, modern civil engineering projects may have someone with a different title coming from a different organisation than the Engineer. In the ***Engineering and Construction Contract***, this role is provided by the Project Manager.

It is important to realise, however, that such a party exists and is usually independent of the Principal and always independent from the Contractor. In these notes, the 'Project

[8] 'Estoppel' simply means a 'stop'. The peculiar form of the term is attributed to an inebriated judge who could not enunciate very well...

Manager' will be referred to. In many contracts the Project Manager, as well as being the Principals representative, may also be the contract administrator.

4.1.5 Elements and Requirements of a Contract

There are four basic requirements to be satisfied to form a valid contract **whether it is a simple or a formal one:**

1. the intention by both parties to form an enforceable contract must be demonstrable.
2. the consent of both parties must be genuine.
3. the legality of the agreement must be objective.
4. both parties must have the legal capacity to form an agreement.

In addition the parties may formalise a simple contract by executing a formal ***Instrument of Agreement***; a process that does not necessarily result in a formal contract.

1. Intention

It must be clear that the parties intended to create a legally binding agreement. There can be no contract unless the parties' intention to enter into an agreement enforceable at law can be demonstrated. Where such an agreement can be shown, usually it will be accepted that the parties intended to create such an undertaking.

In an engineering context, where one party has invited bids and another party has made an offer, the intention to enter into an agreement will be assumed.

2. Genuine consent

For a contract to be valid, the consent of the parties must be genuine. Consent obtained under duress or by undue influence can make a contract invalid at the application of the weaker or injured party.

3. Legality of purpose

A contract may be held to be illegal by common law or by statute. Contracts deemed illegal by common law (for example to commit a crime; or to hinder the administration of justice; or to injure public services; or to attempt corruption) rarely arise in engineering situations.

However, illegality by statue commonly arises in engineering contracts: a contract may be legally entered into, yet its performance may be in breach of a statue or regulation – for example health & safety legislation. Such a contract will be void and unenforceable at law and neither party can claim relief under it.

4. Legal capacity

Not all persons can enter into a legally binding agreement. Infants and persons deemed incapable of rational action such as those who are under the influence of alcohol or narcotics cannot legally enter into a valid contract. The law also takes into account the general incapacity of bankrupts and persons in legal custody.

Formal Instrument of Agreement

Sometimes the parties to a simple contract later execute and substitute a formal Instrument of Agreement. This written agreement identifies the parties by name and registered address, states the date of the agreement and sets out the terms and conditions of the

contract, frequently by reference to annotated, annexed documents. It is the form of the agreement primarily established by the manner of signing that determines whether it is a simple or formal contract:

- If both parties sign as individuals, without the presence of witnesses, the agreement becomes evidence in writing of a simple contract.
- If, on the other hand, the instrument of agreement states that it is a deed and that it is signed, sealed, and delivered by the parties in the presence of attesting witnesses, it becomes a formal agreement.

If the parties to a simple contract later execute and substitute a formal deed in its place, the formal deed takes precedence. The simple contract ceases to exist provided that the same parties sign the formal deed and that it covers the same matters. In legal terms this is known as a merger.

This situation frequently arises in engineering contracts. Contracts are negotiated and agreed upon, either verbally or in writing, and the parties later execute a formal Instrument of Agreement, possibly some time after work under the contract has commenced.

4.1.6 Further Elements of a Simple Contract

It may seem paradoxical – but a simple contract actually requires two further elements to demonstrate that it actually exists:

- an offer and an acceptance;
- a valuable consideration.

Offer and acceptance

A simple contract is formed when an offer is made by one party to another party and is unconditionally accepted by the second party. The keyword is *unconditional*. An acceptance with conditions does not form a contract but constitutes a counter-offer. This in turn requires an unconditional acceptance of the counter-offer by the first party before a contract exists. Offers and counteroffers may continue to be exchanged until an unconditional acceptance is made and then, and only then, will a contract be constituted.

An offer and an acceptance do not have to be made in writing, but can be made orally or implied by conduct. For example, a hand raised at an auction is a case of implied acceptance by conduct. In an engineering situation if, with the knowledge of the Principal, the Contractor who has made an offer starts work on a job, it would be held that the offer had been accepted if the Owner was in a position to object and did not do so.

Valuable consideration

Consideration is a peculiar entity in contract law[9]. It simply means that which is exchanged. In an engineering contract, the money paid by the Principal to the Contractor is the consideration given by the Principal to the Contractor. In return, the work performed or the equipment supplied by the Contractor for the Principal is the consideration given by the Contractor to the principal.

In earlier times, a nominal consideration, such as a single coin or a peppercorn, was held to be sufficient but today the courts require that the consideration be significant, although not necessarily equal in value to what is received.

4.1.7 Rights and Liabilities Under a Contract

When a contract is formed, the parties to that contract have legal rights and liabilities. The two principal elements to be considered are privity and assignment.

[9] See http://en.wikipedia.org/wiki/Consideration

Privity

Privity of contract means the legal relationship and mutual interest that exists between the parties to a contract. The word *privity* itself implies that the relationship is private and concerns only the parties to the contract. Only the parties to a contract can acquire rights or incur liabilities under it. Two parties to a contract cannot make a third party liable under the contract unless the third party is also a party to the contract.

Assignment

An assignment occurs when one of the parties to a contract substitutes another party in its place as a party to the contract for all or some of the purposes of the contract. Many engineering contracts include a clause specifically denying either party the right to assign unilaterally all or part of the contract. However, since a contract is an agreement, the parties can mutually agree to an assignment.

4.1.8 Discharging a Contract

A contract is *discharged* when it is completed or otherwise terminated. There are five ways in which this is deemed to have taken place.

A contract may be discharged by:

1. performance of its provisions;
2. agreement between the parties;
3. operation of the law;
4. frustration; or
5. fundamental breach.

1. Discharge by performance

When the parties to a contract fulfil all their obligations in strict accordance with the provision of the contract, the contract is said to be discharged by performance.

2. Discharge by agreement

Since a contract is an agreement between two or more parties, it may be discharged by a further agreement between the parties. Such a further agreement may cancel the original contract by mutual consent, or it may vary the terms of the original agreement by a substituted agreement.[10]

[10] For football fans only: with players' contracts with clubs, this happens all the time of course. Indeed if a player negotiates a 5 year contract it seems that both are well aware that it will probably end 'by agreement' after only 2 years or so. Within the EU, on the rare occasions where the fulfilment of the original contract actually takes place then a free transfer can occur – which clubs do not like, of course, as their transfer fee, which is technically a compensation paid by the third party to break the contract, is not then due. There is a further complication to this issue in that the European Commission considers the very high 'transfer' fees that are now commonplace do not actually reflect the value of that player to its 'selling' club. See https://en.wikipedia.org/wiki/Bosman_ruling

3. Discharge by operation of law

A contract may be discharged by operation of the law independently of the wishes of the parties to the agreement. A contract *may* be discharged if it is held to be illegal by common law or by statue or if one of the parties becomes bankrupt[11].

4. Discharge by frustration

The term *frustration* is used to describe the situation that arises when, without default of either party to an agreement, a contractual obligation has become incapable of performance. It can occur when the circumstances under which the performance required become radically different from those that were envisaged by the contract. Frustration must have the effect of frustrating the performance of the whole of the contract and not merely some of its terms. Frustration cannot be claimed because some or all of the work under the contract has become more difficult or more costly. Frustration is sometimes referred to as *force majeure*.

5. Discharge by fundamental breach

Every breach of contract will entitle the injured party to sue for damages but not every such breach will have the effect of discharging the contract. Whether or not a particular breach is a *fundamental* breach giving grounds for the injured party to terminate the contract is a matter of determining whether the breach amounts to a 'repudiation' or whether it merely amounts to a breach of certain provisions of the contract.

A 'repudiation' usually arises when one party to the contract creates an impossible situation either before the contract is due for performance or during the performance of the contract. A party to a contract cannot terminate the contract by unilaterally repudiating the obligations under the contract. If a party attempts to repudiate its obligations under the contract, there are two courses open to the injured party - either accept the repudiation and sue for damages or ignore the repudiation, reaffirm the contract and then sue for damages.

It is rare for a party to breach the contract by a complete repudiation of the whole of the work under the contract. A breach in performance usually involves a breach of certain obligations under the contract.

Remedies for Breach of Contract

Any breach of a contract will entitle the injured party to sue for damages, whether or not the particular breach is considered to be grounds for treating the contract as discharged.

In assessing a claim for damages, it is first necessary to determine the grounds upon which the claim is made and then to assess the amount of compensation. The injured party usually will be awarded such damages naturally arising from the breach. In assessing the amount of the damages, the courts usually place the injured party, in a financial sense, in the same position as they would have been had the contract been discharged by performance, provided that the injured party had taken all reasonable steps to mitigate the loss occurred by the breach.

[11] Though in the UK check the *Corporate Insolvency and Governance Act 2020*, which makes it harder to terminate contracts in the event of insolvency. Generally, one should not assume that bankruptcy and insolvency will lead to a contract discharge.

4.2 TYPES AND CLASSIFICATIONS OF ENGINEERING CONTRACT

4.2.1 Classification of Contracts

Contracts for any particular engineering project can be classified in the first instance as either ***Main Contracts*** or as ***Subcontracts***. The essential difference is that a Main Contract is directly between the principal and a Main Contractor, whereas a Subcontract is between a Main Contractor and another contractor, referred to as a Subcontractor.

Engineering contracts, whether Main Contracts or Subcontracts, can be further described in a number of ways of which depends upon a particular characteristic or feature.

The three most commonly used classifications for this purpose are:

A. the method by which the Contractor is selected;

B. the method by which payment for the work under the Contract is evaluated;

C. the method by which responsibility for the technical and administrative aspects of the work is allocated.

Subcontracts can further be classified in a number of ways, depending upon procedures laid down in the Main Contract.

A. Classification by the Method of Selecting the Contractor

The principal has two options when selecting the Contractor:

- by a competitive tendering procedure;
- by direct negotiation with a selected contractor.

Competitive Tendering

An agreement is reached between the Principal and a Contractor following a formal competitive tendering procedure in which a number of tenderers are invited to submit bids against a common set of tender enquiry documents (see section 4.3.2). This is the most widely used form of engineering contract and is suitable for engineering projects where the nature and extent of the work under the Contract can be clearly identified.

Negotiated Contract

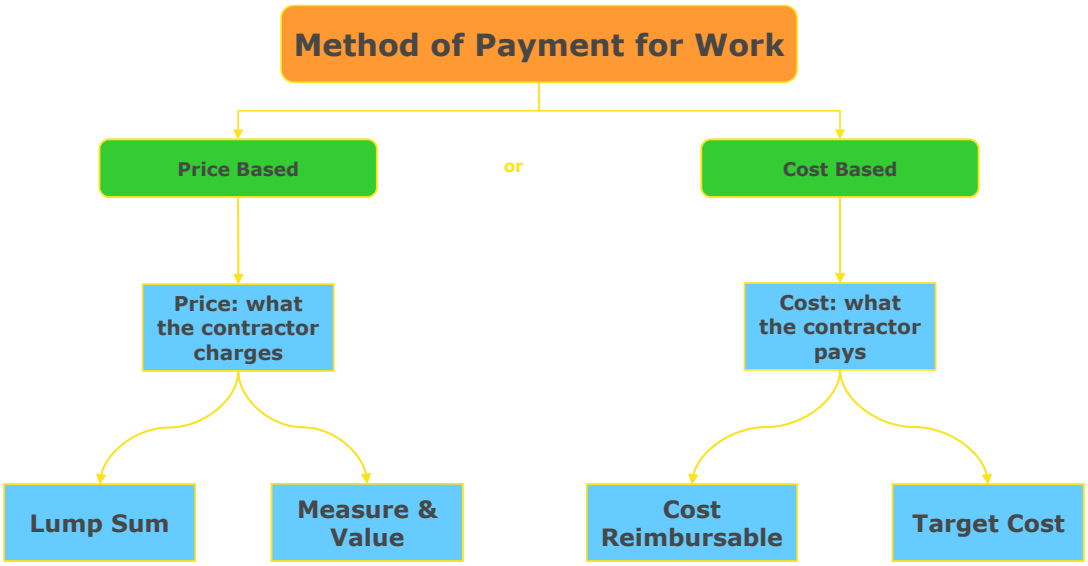
The principal negotiates directly with a contractor to arrive at a mutually satisfactory agreement to undertake the work. This form of contract is suitable for work of a highly specialised nature or where there are a limited number of contractors experienced in the work required or where the nature of the work cannot be precisely defined.

A contract can sometimes be negotiated by a combination of these methods. For example, tenders can be invited from a shortlist of suitable contractors for that part of the work under the contract, which can be precisely defined, and an agreement negotiated for the whole of the work with the contractor who submits the most attractive offer.

B. Classification by the Method of Payment for the Work

The method of payment is of such importance, particularly to the Contractor, that contracts are often classified solely by the method of payment. Payment can be based either on ***prices*** (which are submitted by or agreed with the contractor as what she will be paid) or on the actual ***costs*** that the contractor incurs. Main choices are:

- Price Based: Lump Sum or Measure and Value (i.e. Schedule of Rates or Bill of Quantities).
- Cost Based: Cost Reimbursable or Target Cost



The main factors influencing the choice are the:

- degree of certainty about the final contract price desired at tender stage.
- flexibility required to cope with design changes likely to be encountered during the contract (can they be systematically and equitably evaluated).
- contractor's incentive for efficient performance, matched by the client's incentive to provide the contractor with timely information and decisions.
- extent of risk likely to be encountered during the contract and the most cost and time efficient way of allocating it.

i. Lumpsum

Also known as a *Stipulated Price Contract.* The Contractor is paid the amount nominated in the Contract for the work as agreed with the Principal when negotiating the Contract. This amount may of course, be increased or decreased owing to additions to or deletions from the scope of the work under the Contract in accordance with the terms of the agreement. This type of contract is commonly used where the nature and extent of the work can be precisely defined when the Contract is negotiated. Payments may be staged at intervals of time or related to achieved milestones.

The implications for **lump sum** are:

- complete, final design at tender, so minimum change / variations expected.
- high degree of tender competition.
- contractor plans efficient use of resources to reduce cost.
- no contractual mechanism for price adjustment.
- unsuitable when change is expected, therefore rarely used in engineering construction.
- price may include high level of financing by contractor and includes risk contingency - likely to be high.

i. Measure and Value

The Contractor is paid for the work actually done at ***pre-agreed unit rates***. In this type of contract it is important that the items in a *Schedule of Rates* or the Priced *Bill of Quantities* cover the whole of the work and that the method of measurement of quantities is clearly defined. Schedule of Rates Contracts are generally used where the nature and extent of the work can be accurately defined but the quantity of work cannot.

Bill of Quantities

Used where ***items*** of work are listed with estimated quantities. In UK building and civil engineering, standardised item descriptions and limits to the work included in the item have been drawn up in 'Standard Methods of Measurement'. Contractors then tender rates against each item. Payment is usually monthly and is derived from measuring quantities of completed work and valuing at rates in the priced Bill of Quantities.

It can be seen therefore that Bills of Quantities have two purposes:

- To provide a basis for the build-up of a contractor's tender estimate and thus to allow tender totals to be compared between bidding contractors; and
- To provide the basis for payment to the contractor once the contract has been awarded.

Example:

-56-

A123 Fulton to Exwood Trunk Road

Item	Description	Unit	Quantity	Rate		Amount	
1.2.2.1	Removal of topsoil less than 100mm deep	m^2	20,000	0	30	6,000	00
1.2.2.2	Removal of topsoil greater than 100mm deep and less than 300mm deep	m^2	45,000	0	70	31,500	00
1.2.2.3	Removal of topsoil greater than 300mm deep	m^2	15,000	1	15	17,250	00
1.2.3.1	Excavation of unacceptable material	m^3	207,500	1	05	311,250	00
1.2.3.2	Excavation of acceptable material	m^3	508,900	0	95	483,455	00
1.2.3.4	Disposal of unacceptable material	m^3	207,500	2	50	477,250	00
1.2.3.5	Deposition of acceptable material in embankments	m^3	508,900	1	90	966,910	00
1.2.3.6	Compaction of acceptable material in embankments	m^3	508,900	0	20	101,780	00
					Carried forward to summary	**2,395,395**	**00**

Schedule of Rates

Used where prices are tendered against unit – rather than total – quantities, i.e. the overall quantity of work is unknown at tender stage. This provides an increased risk to the contractor. The implications of this are:

- design may be only partially complete at tender.
- final price invariably different from Tender Total - due to change and delay - which produces claims.
- high degree of tender competition, but uncertainty as to whether the lowest tenderer will yield the lowest final price.
- variations must be provided for with procedure for their evaluation.
- magnitude of contractor financing depends on disparities between costs and revenues.
- price includes risk contingency.

ii. Cost Reimbursement

The Contractor is reimbursed the actual costs incurred in carrying out the work under the Contract plus a fee to cover overhead costs and profit. The *fee* can be one of the following:

- a fixed sum.
- a fixed sum with a profit-sharing or a bonus arrangement.
- a fixed fee with a sliding-scale adjustment.
- a percentage of the costs.

A cost reimbursement contract may also have a guaranteed ceiling price nominated. The main use for a cost reimbursement contract is where the nature, extent or quantity of the work cannot be accurately defined when negotiating the Contract. It requires the contractor's cost accounts (also called "control accounts") to be open to the client.

Implications of cost reimbursement payment are:

- allows early contractor involvement with low level of design;
- final price depends on extent to which risks materialise;
- efficiency of contractor will influence the cost to the client;
- zero or low financing charges since costs and revenue are closely matched;
- allows client participation in project management;
- allows contractor input to design.

iii. Target Cost

Based on the setting of a probable (or target) cost for the work. The target cost will subsequently be adjusted for major changes in the work and cost inflation. The contractor's actual costs are monitored and reimbursed as in a cost-reimbursable contract. Any difference between actual cost and target cost is shared in a specified way between the client and the contractor. The sharing is usually set as a percentage ratio e.g. 80:20 with different allocation for savings and excess costs.

Both client and contractor must be satisfied with the target estimate that should have a reasonable maximum and minimum cost for the work. Usually, as with cost reimbursement, there is a separate Fee for overheads and profit.

Incentive Provisions

A cost reimbursement contract on a target cost basis automatically includes an incentive for the contractor to reduce costs. For price based contracts such an incentive is already there: if the contractor reduces costs the margin between cost and price is automatically increased. However, any of the payment methods can have some form of additional incentive provisions attached to them. In addition, incentives can relate to criteria other than cost. For example, bonuses may be awarded for early completion (or indeed penalties incurred for late completion).

C. Classification by Technical and Administrative Responsibility

The implementation of an engineering project involves a number of separate tasks, the responsibility for which must be established clearly from the outset:

- project management and co-ordination;
- engineering design: conceptual, process, detailed (if applicable), documentation
- procurement and supervision;
- construction and supply and/or installation;
- contract administration.

Engineering contracts can therefore be classified by the manner in which these responsibilities are allocated.

There are a number of classifications under this method (see Gardiner Chapter 6 for a much more detailed discussion), the principal ones being:

i. separate design and construction;

ii. design and construct contract;

iii. construction supply / installation contract;

iv. management contract;

v. construction management contract;

vi. design and management contract;

vii. turnkey contract.

i. Separate Design and Construction

As in traditional UK Civil Engineering (which, in the 2020s is actually now quite rare). Here, the consulting engineer (or client's in-house engineering team) is responsible for design and the contractor for construction. The consulting engineer is thereafter known as the ***Engineer*** and is responsible for supervision of construction and, also, for administration of the construction contract. The Engineer thus has a 'dual role' with potentially split loyalties.

Implications of separate design and construction:

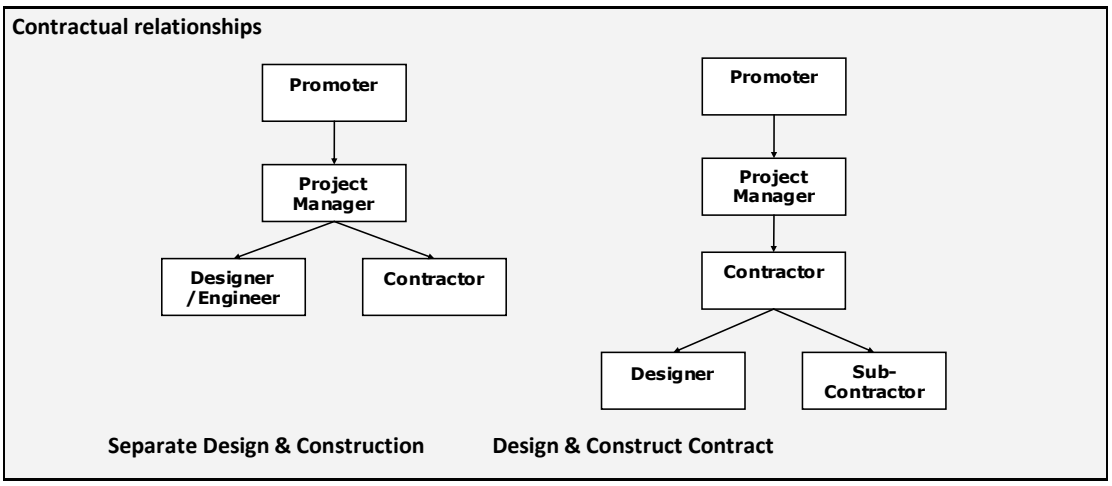
- familiarity with the approach has led to widespread use;
- the most appropriate and experienced designers can be selected;
- normally used with measure and value (i.e. uses BoQ);
- the design is *usually* complete before tender;
- management is divided between the parties;
- the use of this approach with traditional model forms of contract tends to lead to frequent disputes over claims.

ii. Design and Construct Contracts

The client may wish for the detailed design as well as the construction to be put out to tender. In such cases she must appoint her own engineer to provide information on the scope of the project through outline designs, design criteria and performance requirements. This information is supplied to the tendering contractors who will submit enough details for

the client to appraise the contractor's proposals and prices. The contractor need not necessarily at such a stage submit detailed drawings.

It is unusual for a contractor to carry out design 'in-house' even though most big companies have their own design departments. A design and construct contract usually involves the same types of parties as a traditional contract except that the relationships between them are slightly different:



iii. Construction supply / installation contract

In this type of contract it is the Contractor's responsibility to carry out the work under the Contract in accordance with designs, specifications and other details provided by the Principal. In some cases, such as in process and industrial projects, the Contractor may be required to undertake all or part of the design.

The principal is responsible for all the other tasks; these may be carried out on the Principal's behalf by one or more specialist consultants.

iv. The Management Contract

The management contractor is appointed to manage the design and construction phases and contribute to the design itself. Such a contractor is normally precluded from carrying out construction, although they may provide common facilities. The management contractor becomes part of the client's professional team, and construction contracts are placed with the management contractor.

Implications:

- payment of the management contractor is by fee, sometimes plus reimbursable costs.
- the client – through the management contractor – pays the construction contractors.
- construction is usually broken into small packages with designs complete with high competition at tender.
- designers must make more decisions early in the design than with separate design and construction.
- since the management contract itself is low risk the client carries more risk, offset by the high level of management control.
- some management contractors carry normal construction risks.

v. The Construction Management Contract

The construction management contractor carries similar responsibilities to the management contractor. The important difference is that ***construction contracts are placed directly with the client***.

This produces the following differences from a management contractor:

- the construction management firm need not be a construction contractor.
- construction contracts can carry the normal risk required by the client.
- the construction management firm has no commercial professional conflict of interest;
- the construction manager is treated as a professional service provider and is paid a fee accordingly

The construction management contract is similar to the conventional approach of separate design and construction except that the management responsibility is separately identified and likely to be more rigorously defined and executed.

vi. The Design and Management Contract

This is a version of management contracting in which the detailed design is the direct responsibility of the design and management contractor.

It therefore has similarities with Design and Construct in that:

- there is a single point of contact for the client.
- management of design and construction is integrated.
- specification must be defined early in the design phase.
- time is saved from the design/construction overlaps.
- the likelihood of better design *buildability* is enhanced.

It differs from Design and Build in that payment is similar to the management contract, the client has greater control (e.g. over sub-contract content and sequence) and is less committed to the whole technical package.

vii. The Turnkey Contract

The contractor undertakes detailed design, procurement and construction. A scope design is prepared by a separate designer.

Points to consider:

- payment may be staged lump sums or BoQ.
- a clear and full specification must be drawn up early in the design stage.
- post contract the client's negotiating position is generally weak.
- arrangements may be needed to cover the cost of design done by the contractor in the tender period.
- the extent of, and methods for, checking the contractor's design can be contentious.
- the client's commissioning requirements must be written into the contract.

It is a contract in which the Contractor assumes complete responsibility for the project and, in effect becomes the Client.

4.2.2 Subcontracts

In most cases the Contractor will not undertake the whole of the work of a major project entirely from within the Contractor's own resources. The contractor usually divides the work up into a number of elements and enters into separate agreements with *subcontractors* to carry out some of these elements directly for the Contractor.

Although such a procedure is at the Contractor's option, it is usual for the Contract to require the principal to approve any such subcontract agreements when they are proposed, which may be after the main contract has been awarded. It is not always practicable to require tenderers to nominate the subcontractors on whom they will call when preparing a tender, and many like to keep their options open until after they have been awarded a contract.

Sometimes the principal has very definite ideas on subcontracts and which organisation they would prefer to do certain elements of the work. The Principal has three options to choose from in such cases:

1. Designated Subcontractor

Highlighted by the client/principal before tender to carry out certain work or to supply certain items or services. The nature and extent of these are clearly described in the tender documents and the Contractor can be reasonably expected to price and allow for at the time of tendering. It is up to the Contractor to ***negotiate with the designated subcontractor before submitting the tender***. As the Contractor knows right from the beginning who the Subcontractor is, there can be no right of objection to the designation once an agreement has been reached with the principal.

The principal usually accepts responsibility for default by a Designated Subcontractor.

2. Selected Subcontractor

Selected by the Contractor from a restricted list of approved subcontractors supplied by the principal. As long as the work is carried out by one of the selected subcontractors on the list, the principal must approve the subcontractor. As with a Designated Subcontractor, the Main Contractor ***must negotiate with the subcontractor***.

In the event of a Selected Subcontractor defaulting, it is usually the Main Contractor's responsibility to negotiate with one of the other subcontractors on the list to complete the work.

3. Nominated Subcontractor

Selected by the Principal without reference to the Main Contractor. As a general rule, a ***Provisional Sum*** in the Contract covers the work carried out by a Nominated Subcontractor. Frequently, the Principal independently invites tenders for the work under the subcontract, and directs the Main Contractor to enter into a subcontract with the Nominated Subcontractor selected on terms and conditions negotiated by the Principal. As with Designated Subcontractors, the principal accepts responsibility for nominating a new subcontractor in the event of the Nominated Subcontractor defaulting and is liable for any resulting costs.

In each of the above situations, notwithstanding the approval of the subcontractor by the Principal, the Main Contractor is entirely responsible for subcontractor supervision and seeing that the subcontractor undertakes the work under the subcontract and fulfils the terms of the Main Contract which have been delegated to them.

4.3 CONTRACT PLANNING AND CONTRACTOR SELECTION

The activities leading to Contract Award are normally extremely concentrated, requiring very close co-ordination by the Project Manager and her team. Although a prolonged period may be required for early development of the project, once the release is given the principal objective is to achieve a Contract Award as soon as possible. This is because delay in award will usually be reflected in equal delay in completion of the project.

The actual procedures of planning the contract to be used, determining the best contractor for the job and awarding the contract will vary considerably: every project is unique and this includes the contract management aspects. The following notes therefore try to give an overall picture of the stages involved, appropriate for most engineering and construction industries.

4.3.1 Stages in Contractor Selection

There are three distinct stages in the negotiations leading to a final agreement between Principal and Contractor:

The Invitation to Tender. The first stage is begun by the Client inviting one or more parties to submit offers to undertake the work.

The Submission and Receipt of an Offer. The second stage involves each tenderer submitting the results of their tender activities. The contents of this submission will depend on the rules set out within the *invitation to tenderers* but in effect it represents the Contractor's offer - one part, of course, of the formation of a simple contract.

The Consideration and Acceptance of the Offer. The third stage will involve the Client and its project management team evaluating each offer. It may be that one tenderer is selected but is not accepted unconditionally. As we saw earlier this forms a counter offer and thus the process of negotiation has begun. When both parties are satisfied and an unconditional acceptance of an offer has taken place, the formation of a formal contract, if required, can begin.

Further details of the tender process are given later but first we shall look at the documentation required.

4.3.2 Documents

In selecting a contractor and managing the subsequent contract, various documents are produced which play a central role in the negotiations and dealing between the parties and subsequent contract management.

Unfortunately, the various documents required at each stage are often given titles carelessly, with consequent ambiguity and imprecision. Terms such as *Tender Documents*, *Contract Documents*, and *Specification* are often used loosely for any, or even all the documents, and then quite inconsistently applied. In some cases, terminology can vary from country to country and industry to industry.

This can lead to confusion and misunderstanding. To avoid these problems, it is recommended that particular attention be paid both to the purpose of each stage of the contractor selection procedure and subsequent management, and to the nomenclature used to identify the relative sets of documents.

The following is a common model of these documents, split into three distinct stages, each of which relate to the three stages of the contractor selection process:

Tender Enquiry Documents

Sometimes abbreviated to *Enquiry Documents*, these comprise the documents involved in the first stage of selection - the Invitation to Tender. They include all the documents which are issued to tenderers and which prescribe the principal's requirements for the preparation and submission of bids and the performance of the work under the Contract.

Clear and unambiguous documentation is vital. Important information includes:

- The source of the Conditions of Contract, e.g. a model form, an in-house form, a specially prepared form or a contractor proposed form. Forms of Conditions of Contracts will be discussed later.
- The type of pricing schedule, e.g. Bill of Quantities, Schedule of Rates, Activity Schedule.
- The freedom given to the Contractor in preparing the pricing schedule.
- The nature of information required in the contractors tender and the use of pro-forma for such information, e.g. programme, proposed subcontractors.
- Method of construction / fabrication, proposed resources.

Tender Documents

Documents involved in the second stage - the Submission and Receipt of an Offer. They are all those documents that comprise tenderers offer; they form the actual tender to be submitted.

Contract Documents

Those involved in the third stage - the Consideration and Acceptance of an Offer, and are also the formal documents that are used during the management of the contract. They comprise all the documents referred to in the contract agreement and must incorporate all amendments made to the Enquiry Documents and Tender Documents arising from negotiations before the signing of the Contract.

Enquiry Documents	Tender Documents	Contract Documents
		• Form of Agreement • Pre-Contract Minutes or Correspondence
• Conditions of Contract	• Conditions of Contract	• Conditions of Contract
• Site Regulations (if any)	• Site Regulations (if any)	• Site Regulations (if any)
• Specifications	• Specifications	• Specifications
• Tender Drawings	• Tender Drawings	• Working/Contract Drawings
• Pricing Schedule (Unpriced)	• Pricing Schedule (Priced)	• Pricing Schedule (Priced)
• Instructions to Tenderers	• Form of Tender	• Other tendered information

4.3.3 The Invited Tenderers

As discussed earlier, a contractor can be selected by open tendering or by negotiation. In each case, the procedures are similar and are as defined before, i.e. the three stages of contractor selection. What may differ is choosing the one or more contractors to invite for tender.

Open competition

On face value, open competition between all contractors who express an interest may appear to offer the principal the greatest value. This is not always the case, apart from the smallest of projects, as those contractors who are not particularly suited for the work can apply.

Pre-Qualification: select competition

This is to ensure that those contractors who eventually tender for the work have appropriate experience, expertise and capacity and are financially sound. A full pre-qualification procedure may include:

- Either press announcement requiring response from interested firms or direct approach to known acceptable firms.
- Issue by the client of brief contract descriptions including value, duration and special requirements.
- Provision of information by the contractor including affirmation of willingness to tender, details of similar work undertaken, financial data on number and value of current contracts, turnover, financial security, banking institutions, and the management structure to be provided with names and experience of key personnel.
- Discussions with contractors key personnel.
- Discussions with other clients who have experience of the contractor.

Pre-qualification can be done specifically for the contract, and periodically to update standing lists of contractors acceptable for various types of work and contract values.

Two stage

A contractor is selected competitively, but early in the design process. The tender documents contain approximate quantities of the major value items. As design and planning proceeds the final tender is developed from cost and price data supplied with the initial tender. There is a separate technical and commercial assessment; eliminating bidders at each stage as more information is tendered, e.g. for a design competition.

Negotiated

In some cases the principal may know exactly which contractor is required for the work. This may be simply because there is only one available or because that contractor has worked very successfully for the principal in the past. Negotiation is also not restricted to one contractor but may simply be a very informal tendering process.

4.3.4 Tendering Rules

All tenderers should know the rules that exist through the Instructions to Tenderers or by reference to another document if one exists. They should include rules that apply to the tendering period and tender evaluation. Issues to consider include:

- **Dealing with Queries**. Tender queries should be in writing and question and answer given to *all tenderers*. Any meetings with tenderers should be minuted.
- **Presentation and Submission of Tenders**. Clear instructions must be given about the timing of submission and the form and format of the information requested.
- **Special Features of Tender Evaluation**. Tenderers should be advised of the main points that will be considered in the evaluation.
- **Tender Opening Procedure**. Tender opening for major contracts should be by panel including at least one independent. A formal minute of the process should be prepared and signed. The original of all pricing schedules should be evidenced.
- **Site Inspection Arrangements**. Site inspections must be planned, controlled and minuted. Only issues relating to site facilities should be discussed.
- **Late Tenders and Extension of Tendering Period**. Generally late tenders should not be accepted and be returned unopened.
- **Qualified Tenders and Alternative Tenders**. Qualified tenders may endanger possibility of award. Where possible the tender should be priced unqualified with an alternative being offered for the condition which the tenderer would prefer not to accept.
- **Treatment of Errors**. Any errors or changes advised before the tenders are opened should be treated as if they were the original tender. Any changes or errors advised after tenders are opened should be treated with caution and only be accepted in exceptional circumstances where the tenderer can fully justify the change as the result of clarification of workscope
- **Publication of Tender Results**. All tenderers must be advised of the outcome. However the successful tender should be formally accepted before the award is made public.
- **Commencement Date**. Contract documents should be signed upon award and before work commences. In some cases it may be necessary to issue a or Letter of Intent. This should always be for a limited duration and price and is discussed in more detail later.

4.3.5 Tender Evaluation

When evaluating the tenderers submissions, the principal and her project manager must be wary of very low bids. A low bid is sometimes difficult to ignore, especially for public works, which is why pre-qualification can be vital. The situation for open tendering can be neatly summed up by a quotation by John Ruskin, a 19th Century English author, art critic and social reformer:

> It's unwise to pay too much, but it's worse to pay too little. When you pay too much, all you lose is a little money - that is all. When you pay too little, you sometimes lose everything because the thing you bought was incapable of doing the thing it was bought to do. The common law of business balance prohibits paying a little and getting a lot - it can't be done. If you deal with the lowest bidder, it is well to add something for the risk you run, and if you do that, you will have enough to pay for something better.
>
> **John Ruskin**

For major contracts a team that has the knowledge and skills to properly assess the tenders should always carry out evaluation.

Factors to consider include:

Responsiveness to the Tender Documents. The response to the requirements and the quality of the tender documents can be a good indicator of the suitability of any particular tenderer.

Acceptability of Alternative or Qualified Tenders. All qualifications must be assessed for their commercial impact and bids normalised to take account of this. Evaluation should be based on both base and alternatives if they are acceptable.

Arithmetical Errors. Arithmetical errors should be corrected before evaluation. Tenderers should be advised of any errors.

Adequacy of Resources. The contractor's current and planned workload must be taken into account in evaluating the adequacy of resources. The quality of the resources must also be evaluated.

Differences in Timing of Payments. The differences in timing of payments must be included in the commercial evaluation. Discounted Cash Flow techniques should be used.

Reasonableness of Advance Payments. Advance payments should be avoided where possible. If they are to be made a Repayment Bond should be obtained to protect the client against non-performance.

Different Contract Duration. This must be evaluated both in terms of cost impact and project schedule.

Whether to give a "Margin of Preference" Price Comparison. This should only be considered where there is an incumbent contractor and should be limited to the additional costs associated with changing out the contractor.

It is common, if there are many bids, to select the best of the submitted tenders and then invite a team from the contractors' organisation for interview. This allows queries which may have been raised by the evaluation team to be cleared up before award is made. It also allows the evaluation team to meet some of the contractor's personnel.

4.4 CONTRACT AWARD

The client and their project management team have determined the contracting strategy, prepared the documentation and undertaken a Contractor selection procedure. Eventually they have chosen the Contractor(s) who they want to undertake the various portion(s) of the works and the client is in the position of becoming Principal to the chosen Contractor. Under a contract in which services may be provided to the value of millions of pounds it is essential that there is no misunderstanding and ambiguity between the Principal and the Contractor: the period between choosing the Contractor and awarding the contract is therefore very sensitive.

4.4.1 The Letter of Acceptance

As soon as practicable after the decision is made to accept a tender, a Letter of Acceptance, signed by the person authorised to do so by the Principal, should be sent out to the successful tenderer. As we saw earlier – a legally binding contract is formed when an offer made by one party is accepted unconditionally by another party. If the original conforming tender or an alternative tender is accepted without qualification or amendment, the Letter of Acceptance need only accept the nominated tender as submitted in order to form a legally binding contract. If an original offer has been amended or qualified in subsequent

negotiations, the agreed changes must be documented and then proposed or acknowledged by the tenderer as a revised offer. The Letter of Acceptance can then unequivocally accept the amended tender to form a valid contract.

In addition to accepting the tender, the Letter of Acceptance should:

- Nominate those enquiry documents and any documentation of amendments, minutes of meetings and qualifications which will be incorporated in the contract documents.
- Confirm that an Instrument of Agreement will be prepared by the Project Manager and, together with the updated contract documents, forwarded to the tenderer (now the Contractor) for signature.
- Point out that the Specification and Drawings issued with the enquiry documents are provisional and must not be used for construction purposes unless or until otherwise approved or amended.
- Indicate who will represent the Principal in all matters dealing with the contract. (Referred to as the 'Project Manager' in these notes.)
- Nominate that the date of the Letter of Acceptance is the *Date of Acceptance of Tender* or the *Date for Commencement of Work*, as appropriate.
- In the case of Lump Sum contracts, confirm the Lump Sum.
- Until the Agreement is signed, the Letter of Acceptance and the referenced documents will form the contract.

4.4.2 Letter of Intent

If for some reason it is not possible to issue a Letter of Acceptance immediately after a decision is made to accept a tender, a *Letter of Intent* may be sent to the successful tenderer as a precursor to the Letter of Acceptance. The purpose of a Letter of Intent, by advising the tenderer that the Principal intends to accept the tender, is to avoid unnecessary delays to the work under the contract by authorising the successful tenderer to commence preliminary planning and mobilisation.

It must be emphasised that a Letter of Intent is not an acceptance. Unless the Letter of Intent makes specific provision, the successful tenderer would be unable to recoup the cost of such preliminary work in the event that the Principal decided not to proceed.

The Letter of Intent should, therefore:

- Advise the tenderer that it is the Principal's intention to accept the nominated/amended tender within a stated period or by a certain date.
- Authorise the tenderer to proceed with certain nominated preliminary work up to a specified cost limit.
- Confirm that in the event that the Letter of Intent is withdrawn and the tender not accepted, the Principal will pay to the tenderer the cost of such of the authorised work undertaken on a basis to be set out in the Letter of Intent.
- State that when the Letter of Acceptance is eventually issued, the provisions therein will supersede those in the Letter of Intent; and
- Request the tenderer to acknowledge receipt of the Letter of Intent and confirm acceptance of the conditions therein.

4.4.3 Notifying Tenderers

On the issue of the Letter of Acceptance or the Letter of Intent, all other tenderers should be individually notified that a tender has been accepted; no public announcement should be made until all tenderers have been notified. All Tender Deposits should be returned and, where requested, the unsuccessful tenderers requested to return their copies of the enquiry documents.

4.4.4 Preparing a Formal contract

i. The Requirement for a Formal contract

Provided that the Letter of Acceptance identifies all the documents and encompasses all the provisions which comprise the agreement between the parties, a *simple* contract is formed by the issue of the Letter. While in law this may be sufficient to evidence the contract, the parties may, either as required by the terms of the contract or else through subsequent agreement, ***merge*** the simple contract into a formal one by signing a formal Instrument of Agreement.

We saw earlier (page 39) the added advantages to an engineering project a formal contract brings.

ii. The Agreement

The Agreement itself need only be short document incorporating the respective promises of the parties, identifying the work under the contract and specifying the consideration.

Most general conditions provide a *pro-forma* Form of Agreement. The Project Manager's choice of the form of the Agreement will depend upon local legal requirements; in any case, the Principal's legal advisers may wish to draw up the Agreement. For example (taken from ICE 6th Edition Conditions of Contract):

Form of Agreement

THIS AGREEMENT made the ..... day of ..... 19 .....

BETWEEN .....

of .....

in the County of ..... (hereinafter called "the Employer")

and .....

of .....

in the County of ..... (hereinafter called "the Contractor").

WHEREAS the Employer is desirous that certain Works should be constructed, namely the Permanent and Temporary Works in connection with .....

.....

and has accepted a Tender by the Contractor for the construction and completion of such Works.

NOW THIS AGREEMENT WITNESSETH as follows

1. In this Agreement words and expressions shall have the same meanings as are respectively assigned to them in the Conditions of Contract hereinafter referred to.

2. The following documents shall be deemed to form and be read and construed as part of this Agreement, namely

(a) the said Tender and the written acceptance thereof
(b) the Drawings
(c) the Conditions of Contract
(d) the Specification
(e) the priced Bill of Quantities.

3. In consideration of the payments to be made by the Employer to the Contractor as hereinafter mentioned the Contractor hereby covenants with the Employer to construct and complete the Works in conformity in all respects with the provisions of the Contract.

4. The Employer hereby covenants to pay to the Contractor in consideration of the construction and completion of the Works the Contract Price at the times and in the manner prescribed by the Contract.

IN WITNESS whereof the parties hereto have caused this Agreement to be executed the day and year first above written.

SIGNED on behalf of the said ..... Ltd/plc

Signature ..... Signature .....

Position ..... Position .....

In the presence of ..... In the presence of .....

or SIGNED SEALED AND DELIVERED AS A DEED

by the said ..... Ltd/plc

in the presence of .....

iii. Date of the Agreement

Most Forms of Agreement commence with the words 'This Agreement made [date inserted]...'. The significance of the date inserted is primarily for convenience in referring to or identifying the document. However, unless the ***Date for Commencement of Work*** is clearly stated in the Letter of Acceptance or elsewhere in the contract, the date on the Agreement will be construed as that date.

4.5 CONDITIONS OF CONTRACT

4.5.1 The Role of the conditions of contract

The conditions of contract contain all the clauses relating to the respective rights and obligations of the parties of the contract. These are mostly administrative provisions as distinct from technical requirements. Technical matters should be confined to the Specification and the Drawings, which should not contain any administrative requirements. It is important to keep separate these two groups of requirements because misplacement of clauses is a frequent cause of their being overlooked and can possibly lead to a dispute.

4.5.2 Responsibility for preparing the conditions of contract

The dangers and possible adverse legal consequences arising from engineers attempting to work outside their areas of competence should not be underestimated. Preparing the

conditions of contract is one of those situations where an engineer must exercise particular care and discretion in this regard.

Most standard general conditions have either been prepared by or have received close scrutiny and been approved by legally trained persons. For large projects and clients it is common to have a team specialised in this area. In such cases, the Project Manager prepares the Specifications and the Drawings and the specialist team prepares the conditions of contract (and, frequently, the Requirements for Tendering) under instructions prepared by the Project Manager. This specialist team may also invite and receive tenders and be involved in the evaluation process.

The Project Manager must retain ultimate responsibility for all the enquiry documents and should closely examine the documents drafted by the specialist team to ensure that all the requirements have been met. While the documents as drafted or amended may be legally correct, they may not achieve the result desired by the Project Manager. Lawyers can sometimes get things wrong, particularly if they have not been adequately briefed.

4.5.3 The documents comprising the conditions of contract

It is common for the Principal to adopt what is known as a 'general form of contract' or 'general conditions of contract' which have been prepared and published by a professional organisation. Examples may be the ICE Conditions of Contract or the FIDIC Conditions.

Such conditions will have been prepared for projects of a particular nature, for example, a traditional civil engineering using a measure and value method of payment. However, most projects will be unique in some way and there will be particular requirements which are not met by the general conditions. The Project Manager must therefore include specific provisions in addition to the general conditions.

This is achieved in two ways - by completion of an ***Annexure*** attached to the general conditions and by the preparation of the ***supplementary conditions*** which amends and complements the general conditions. The conditions of contract thus comprises two parts:

- Part I general conditions (with Annexure).
- Part II supplementary conditions.

4.5.4 The general conditions and Annexure

4.5.5 Selecting the Appropriate general conditions

If the Project Manager is experienced in contract documentation, the choice of which general conditions to use will be made on her assessment of the requirements of the contract, based on previous experience. However, if the Project Manager is inexperienced then she should approach firstly the Principal or alternatively the national standards authority, professional association or other organisation which publishes standard general conditions and obtain copies of their respective documents together with any commentaries available.

In the United Kingdom, general conditions have traditionally been, and still are, prepared and published by the various professional societies and associations such as the *Institution*

of Civil Engineers (referred to in these notes as the 'ICE Conditions of Contract') and the *Institution of Mechanical Engineers* (the 'Model Form' or MF/1). On the industrial side, organisations such as *British Coal*, the UK *Atomic Energy Authority* and large commercial and industrial corporations have also prepared conditions of contract for their own use.



For international use by consulting engineers, the *Federation Internationale des Ingenieurs-Conseits* (FIDIC) has published a 'conditions of contract for Civil Engineering Work' (known as the 'Red Book'), and a 'conditions of contract for Electrical and Mechanical Work' (known as the Yellow Book). These appear to have been modelled largely on the ICE and IEE conditions of contract and they are both published in English, French and Japanese language versions.

Of particular note should be the *New Engineering Contract*, now known as the *Engineering and Construction Contract* which has been developed by the Institution of Civil Engineers. These conditions have been drafted in an attempt to firstly reduce the amount of confrontation and conflict between Principal and Contractor that can occur in traditional contracts and also to attempt to provide a set of conditions that can be used with many different types of project and payment methods. We shall look at these conditions in more detail later.

Each of these documents reflects the particular requirements of the individual bodies preparing them; there is no one generally accepted conditions of contract. As such it would not be ideal to provide a detailed summary of each set in these notes. The publishers of all conditions of contract will also provide additional commentaries.

Fundamental requirements of general conditions of contract

Presentation In the more recent editions of general conditions the layout and presentation has been improved and the documents are easier to follow. The language is simpler and more in keeping with modern legislative drafting practice. However, some conditions of contract still have sentences with over 100 words.

Equitability Older editions of general conditions have had accusations of bias, generally in favour on the Principal. However, the conditions of contract should not necessarily be equitable to both parties - only fair and reasonable. After all, it is the purpose of the party offering the contract (the Principal) which is to be served, not the security of the other party (the Contractor). Nevertheless, most of the more obvious grounds for discontent on this subject have been addressed and Contractors now have little reason to claim the documents are biased.

The Project Manager There are usually only two parties to an engineering contract - the Principal and the Contractor. However the Project Manager is also present and it is common for her to act as an administrator, who is not a party to the contract, as well as being the Principal's representative. As referred to earlier (page 39) The Project Manager commonly has two functions:

- the Principal's representative or agent;
- an administrator and impartial decision maker.

In her role as Principal's representative, she must take care of the Principal's interests; as impartial decision maker she must act fairly with due regard to the interests of both parties. This is a difficult situation and while both roles must be kept separate the Project Manager must ensure that she does not act negligently on behalf of the Principal. A third factor may be that the Project Manager on traditional contracts (when she is known as the Engineer) could also be the designer of the works and thus must be careful when assessing potential cases of poor design or re-design.

In this situation the requirements for the Project Manager to act with the utmost integrity, partiality and professionalism may be difficult and can lead to Contractors to feel unfairly treated within the contract. Unfortunately, newer forms of contract do not recognise the situation: the *Engineering and Construction Contract* for example places the Project Manager in a similar dual role.

4.5.6 Completing the Annexure

General conditions usually provide an Annexure as a form to be completed by the Project Manager and issued as a schedule with the enquiry documents. The purpose of an Annexure is to avoid the necessity to fill in blank spaces in the general conditions for each new contract with data which may vary from one contract to another. These Annexures can vary from a simple form covering a limited number of items of data to be inserted to a more detailed format with a large number of items to be included.

The ICE conditions of contract and the SAA general conditions both have places in Annexure for inserting the name and address of the Principal and Project Manager. The MF/l general conditions indicates that the name of the Project Manager and the addresses of the Principal, the Project Manager and the Contractor should be stated in the supplementary conditions. Other general conditions also have space for the name and address of the Contractor to be inserted in the Annexure.

Where the information to be inserted is more than a single statement or figure, the best solution is to provide a separate clause in the supplementary conditions dealing with the matter and make a simple cross-reference in the Annexure such as 'See supplementary conditions'. When completing the Annexure, it is important to ensure that the data or information inserted is clear and unambiguous.

4.5.7 Amending general conditions

Inevitably, the selected general conditions will have some provisions which are not relevant to the contract. Unless these are directly at variance with what is required, there is little point in deleting such requirements. Everyone realises that such situations can occur when a standard document is used, and in most cases no harm is done if those requirements remain.

However, it may be that one or more of the conditions are unacceptable and the Project Manager may decide that certain clauses require amendment. It must be reiterated that amending individual clauses in a standard general conditions should be done with caution: most standard general conditions have been in use for a number of years and have been refined and amended so as to meet the requirements of most users. The clauses have been fully integrated with each other and most discrepancies and inconsistencies eliminated.

The safest way to amend a clause in general conditions is to delete the clause entirely and substitute an amended or reworded clause; but beware the 'bumping truck' syndrome. Amending a clause in a general conditions many affect one or more other clauses, which, in turn, may have repercussions to clauses 'further down the line'. Some of these effects may not be immediately apparent and if not picked up and corrected, may have unforeseen legal consequences. Thus, an amendment such as 'Clause X, paragraph Y, line Z, delete the words [...] and substitute' is all too frequently seen; it is regrettable that FIDIC suggests this method of amendment in their 'Guidelines for the Preparation of Part II Clauses'. Not only is such an amendment clumsy but it is also open to misinterpretation. Such an amendment is often unnecessary and is frequently the result of the Project Manager not really understanding the full legal implications of the clause. If the Project Manager is completely satisfied that the provisions of the clause are unsatisfactory, the clause should be deleted entirely and, if necessary, replaced by a completely new clause.

4.5.8 The supplementary conditions of contract

There are five purposes to the supplementary conditions of contract:

- to *add* a new clause to cover matters not dealt with in the general conditions;
- to *add* a new clause which supplements a clause in the general conditions;
- to *delete* unnecessary and inappropriate clauses within general conditions;
- to *substitute* an alternative clause in place of one deleted from the general conditions;
- to provide information normally included in the Annexure where the form and layout of the Annexure is inadequate.

The supplementary conditions are unique to each individual contract and so the provisions must necessarily vary. Both FIDIC and the IEE produce guidelines for the preparation of supplementary conditions appropriate to their respective general conditions.

Having read the general conditions carefully, the Project Manager will have to decide what supplementary conditions are required. The individual clauses dealing with the above listed matters must be carefully drafted to ensure that there is no discrepancy or ambiguity in relation to the Annexure or the corresponding clauses in the general conditions.

4.5.9 Engineering Contracts: Some Difficult Areas

Claims on engineering contracts are, due to modern contractual arrangements and conditions such as the Engineering & Construction contract are less common than they once were. In the very recent past it was a standard part of an engineering contract for contractor and principal to be constantly at loggerheads and formally arguing over contractual requirements. That this should happen is not too surprising – after all, a contract requires two parties to work towards a detriment to themselves and it is only natural that each should try to limit the impact of this detriment. The fundamental causes for this would be the contractual requirements of ensuring the work is complete and getting paid for it and the conditions of contract have clauses which cover these and the following are four areas of common contention:

i. Commencement and Completion

The contract must state the dates by which under the contract is to be commenced and is to be completed.

Unfortunately, many general conditions do not precisely define the meaning of 'completed'. Strictly speaking, the work under the contract is not 'complete' until after the expiry of the Defects Liability Period (see below) and all remedial work has been completed. This may be up to twelve months (or even more) after the Works are handed over to the Principal and is the reason why the term *substantial completion* is used. It is the stage when the Works can be handed over to and used by the Principal.

There are two dates which arise from this definition:

The ***Date for Substantial Completion*** is the date nominated in the contract by which the Contractors to execute the work under the contract. This date will depend on when the contract is awarded and when the Contractor can or does start on work under the contract.

The ***Date of Substantial Completion*** is the date *certified* by the Project Manager as the actual date when the Contractor has completed the works substantially.

As we shall see later, the importance of these two dates coinciding can be extremely important and so all contracts will be very careful to define the correct date.

The dates for commencement and completion can be specified in a number of ways. Tenderers can:

- ***nominate*** in their tenders a *period* or time for substantial completion;
- ***nominate*** in their tenders a *date* for substantial completion based on the contract being awarded on or before a specified date.
- ***confirm*** in their tenders that they can *reach* substantial completion by the date, or within the period specified, stated in the Tender Enquiry Documents (based on the contract being awarded on or before the date nominated).

ii. Retention

Retention is a portion of the payment that is held back by the Principal as a guarantee that the work will be completed. Its amount (not usually more than 5%) should be inserted into the contract documents and is deducted from each payment certificate. In addition it is usual for an upper limit on retention to be set, usually 3% of the *tender total.*

Under most forms of contract, the Principal must repay to the Contractor, within a set period after the date of substantial completion, half of the retention monies. The final retention monies are paid after the end of a defects liability period.

iii. Defects Liability

Most engineering contracts require the Contractor to rectify any omission or defect in the work which may be revealed within a specified period after substantial completion. It is important to recognise that such omissions or defects are technically breaches of contract and thus the Contractor will not be paid for works she carries out to correct these items.

This period is usually referred to as the *Defects Liability*, *Defects Correction* or *Maintenance Period*. Maintenance is, strictly speaking, a more widespread activity and encompasses servicing works and replacing consumables and parts subject to normal wear and tear in operation, as well as making good defects. Consequently, it usually applies to mechanical and/or electrical equipment.

Most general conditions provide for the Defects Liability Period to be nominated in the Annexure. There are two points to consider when determining the Defects Liability Period.

- The first is that Defects Liability, while time-related, does not necessarily have to be defined as an actual period of time. In mechanical installations, it can be defined as a throughput quantity. For example, in a bulk materials handling facility, the Period may terminate when a certain volume or mass of product has passed through the facility. Most general conditions assume that the Defects Liability will be for a specific time period; other situations the provision will required amendment by means of a supplementary condition.
- The second is to ensure that where separate sections of work are specified in the contract, the Defects Liability Period for each portion must be separately defined.

iv. Liquidated Damages

Most, but not all, engineering contracts provide for the payment of *Liquidated Damages* by the Contractor in the event of failure to complete the work under the contract by the agreed date. The intention of the provision is to ensure the due performance of the contractual obligations undertaken by the Contractor and to agree in *advance* the amount of any damages in the event of a breach of the contract, rather than leaving it to a court or arbitrator to make the assessment.

Points to note are:

- The imposition of liquidated damages is ***not a penalty*** and should not be treated as such. The basis for liquidated damages must be a genuine agreed pre-estimate of the cost to the Principal as a result of late completion.
- Most general conditions require the liquidated damages to be nominated in the Annexure as a monetary amount for every day (or other nominated period) for the ***interval between*** the *Date for Substantial Completion* and the *Date of Substantial Completion*.
- At any stage, the Contractor may apply for an ***Extension of Time*** if she feels she has been reasonably delayed. If such time is awarded to the Contractor, the Date of Substantial Completion is adjusted to a later date accordingly and liquidated damages for this period are not due.
- If the Principal does not wish to nominate an amount for liquidated damages, but wishes to retain the right to general damages without a limit being imposed on those general damages, the clause(s) relating to liquidated damages should be deleted. In such instances, the imposition of damages may be considered as a penalty by the courts.
- In determining the amount of liquidated damages the Project Manager must make a ***fair estimate*** of the amount by which the Principal would lose as a result of late completion. It could be based on a number of calculations such as:

i. interest payments on funds borrowed to finance the project;

ii. cost income as a result of non-operation of the project;

iii. consequential damages or costs as a result of the Principal being unable to honour commitments.

- One way to establish the validity of an amount nominated for liquidated damages is for the Principal, before the contract is signed, to disclose to and obtain the acknowledgement of the Contractor of the basis for the calculation of the damages. In the event of a dispute over damages, the basis for their assessment has at least been agreed.
- A ***corollary*** to liquidated damages is the inclusion into the contract of a ***bonus*** that is paid if the Date of Substantial Completion is ***earlier*** than the Date for Substantial Completion. The sum per unit time for a bonus need not be the same as that for liquidated damages although the principle for its calculation is similar.

Topic 5 TEAMS & LEADERSHIP

Topic Lecturer: Simon Smith (simon.smith@ed.ac.uk)

Read (see "Suggested Reading List" on page 4):

- Engineering Project Management (Neil Siegel) Chapter 13.
- Project Management – A Strategic Planning Approach (Paul Gardiner) Chapter 8

Additionally you may wish to complete the online Team Role Survey (see Learn)

5.1 WHAT IS A TEAM AND WHAT IS A LEADER

A team is a small group of people (6-8 people) who co-operate together on a task in such a way that they accomplish more than the sum of individuals. This is synergy. The idea that a combination of different people working together can achieve synergy is central to the concept of a team as opposed to a mere group. Eight people, each with different views, who fail to cohere or who simply proceed by letting the majority view prevail (as in voting), are a group (i.e. a collection of individuals) not a team.

5.1.1 What is a leader?

The definition and discussion of what makes a leader will never be complete. However, it may be helpful to think of a leader more as a role with characteristic ways of behaving (style) than as a particular person. Sometimes a team will have a designated leader but even then it doesn't necessarily follow that that person will behave as a leader. If we examine their behaviour we may discover someone else in the team has taken on the role and is acting as an official leader. Sometimes the role is shared and different people at different times do the leading.

The role of team leader includes the following key behaviours:

- Bringing team members in by inviting their comments and soliciting their idea .
- Clarifying the team's objective. .
- "Grasping the nettle" by raising issues and problems which the team ought to face and tackle.
- Listening to team members opinions and checking that they have been understood.
- Steering conversations through to consensus decisions by encouraging team members to say what they really think and genuinely agree on a course of action
- In difficult situations, where a consensus cannot be reached or where time is tight, leading from the front by deciding what needs to be done.

An effective team leader is therefore concerned both with the task (the 'what') and the decision-making processes (the 'how'). An effective team leader also uses a range of different styles from participative through to consultative and, on occasions, even tending to autocratic depending on the situation.

5.1.2 What roles make up a successful team?

Research into the differences between successful and unsuccessful teams all highlight the importance of a mix of people with different ways of behaving. It is the combination of different mix and roles within a team that seems a crucial factor in its success. There are a

number of 'models' of successful teams that can be used in real situations to ensure that that a team put together will actually be successful. Later we will be considering the work of Dr Meredith Belbin but for now we shall look at a simpler model, which serves to highlight the general mix of people a successful and effective team needs:

Besides the ***leader***, essential roles in a team are:

- **Doer.** Someone who is action oriented, constantly urging the team to get on with the task in hand. They tend to be totally concerned with the task (the 'what') often at the expense of the process (the 'how'). They are impatient with 'waffle' and tend to swing into action without thinking things through carefully enough or considering alternatives.
    - always wants to be active;
    - is prepared to get involved to help others;
    - wants to see progress and adherence to plans;
    - gets bored with too much discussion;
    - hates time wasting;
    - works hard to finish the task.
- **Thinker**. People who are good at producing carefully considered ideas and weighing up ideas from other people. They rarely have the most to say; in fact they are amongst the quietest members of the team. When they do speak they are the sort of people who come up with a winning idea, as long as it is listened to.
    - collects and analyses information;
    - listens to what is being said and watches what is going on;
    - is sometimes quiet before contributing ideas;
    - thinks through the problem;
    - sees solutions anticipates problems.
- **Carer**, who is people oriented. These tend to be alert to relationship issues within the team and to be good at cheering people up, easing tensions and maintaining harmony. Carers therefore help the leader to counterbalance the doers and thinkers in the team who both tend to be task, not people, oriented.
    - is concerned that everybody is fitting in;
    - contributes humour and builds bridges around the team;
    - works to develop a team spirit;
    - is keen to get everybody to agree;
    - watches out for others feelings and attitudes;
    - eases tension and fosters a positive spirit.

A successful team blends these different roles together so that the strengths of one compensate for the weaknesses of another. This is why a mix of different people is more likely to dovetail and become a team rather than just a group of individuals. It is the leader's job to aid and abet this dovetailing process.

The four roles can all be found in most people in various degrees.

5.1.3 What are the hallmarks of a good team?

1. has a high success rate i.e. mostly it achieves what it sets out to do.
2. agrees, clear, challenging objectives i.e. everyone in the team contributes to, shares understanding of, and is committed to the objectives.

3. has a leader (it may not always be the same person) who adjusts the leadership style from participative to autocratic in the light of the circumstances.
4. a mix of people who contribute in different but complementary ways thus achieving synergy i.e. the team produces more than the sum of the equal parts.
5. operates in such a way that a balance is struck between concern for the task (the 'what') and concern for the process (the 'how').
6. creates a supportive atmosphere where people are happy to accept risk, say what they really think, develop one another's ideas, and commit to an agreed course of action even though there may be differences of opinion.
7. learns from experience, both successes and failures, by reviewing its processes and thus constantly improving its own performance.
8. works hard and plays hard i.e. its members not only enjoy achieving challenging objectives but enjoy themselves as they do so inside and outside of work.

5.1.4 How do teams develop?

It is important to understand that teams develop through an evolutionary process. The process can be speeded up by, for example, training in team building but left to its own devices a group develops into a team by going through the following stages[12]:

Stage 1 - The Chaotic Stage

Groups of people who are thrown together and given a task to tackle tend to underestimate the complexities of getting a group to cohere. This is especially true if the group starts from scratch with no designated roles or previous experience of working together.

A group in the chaotic stage tries to overcome uncertainty and ambiguity by flinging itself headlong into the task in hand without giving enough, if any, thought to the process. The most noticeable characteristics of a group in the chaotic stage are as follows:

- No time given to setting clear objectives that everyone subscribes to. The group assumes that everyone knows what the objectives are.
- Inadequate time given to planning how to tackle the task.
- If a leader is appointed, no thought is given to clarifying the leader's role and it is likely that the appointed leader will try to impose his or her authority on a group who will not consent.
- Ideas will be voiced but not listened to and developed or rejected because the level of interrupting and over speaking will be inefficiently high.
- The success of the group will be patchy; sometimes despite the chaos, it will get by; sometimes it will fail. Whatever the outcome the tendency to rationalise i.e. for people to claim they did achieve what they set out to, is high.

Stage 2 - The Formal Stage

Eventually a group will react against the chaotic stage by tightening up and becoming more formal. It is very likely to overreact, however, and introduce formal procedures that swing the pendulum too far the other way. The characteristics of a group in the formal stage are:

- There will be rigid, step-by-step, procedures for agreeing objectives and plans. Typically a group might have a system of going round the table getting everyone to

[12] See also www.srds.ndirect.co.uk/stages.htm

have their say. It might also instigate a system whereby the objective is written up in large letters for all to see.
- The need for strong leadership is frequently emphasised. 'Strong leadership' is something which the whole team must be involved in, ensuring that each member sticks to the procedures, do not interrupt one another, speak 'through the chair' etc. Seen as the solution to the problems of a chaotic stage – failure means the leadership is not strong enough.
- Different people in the group will be given specific roles such as time keeper, secretary and there will be explicit rules of behaviour, considering one idea at a time, recapping frequently from the secretary's minutes and so on.
- The success of the group will improve if the time limits are sufficiently elastic to allow extra time for all the formalities.

Stage 3 - The Skilful Stage

Clearly, the formal stage allows the team to increase its effectiveness compared to the chaotic stage. But it can be too formal, rigid and inflexible, limiting over time its effectiveness. Gradually a group will outlive the formal stage and begin to 'take liberties' with its own procedures without slipping back into chaos. Sometimes a group rebels against the rigidity of the formal stage too early and might oscillate between the chaotic and formal stages. Sometimes a group gets stuck in the formal stage convinced that formality and rules are the only antidote to chaos.

The breakthrough to the skilful stage usually occurs when the group realises that some part of its formal procedures is inappropriate to the particular task in hand. It therefore cuts some corners and in so doing discovers that it can cope. The most noticeable characteristics of a group in the skilful stage, i.e. a team, are as follows:

- All procedures for objective setting, planning, time keeping etc. are agreed in the light of the task to be done and the situation. The procedures are therefore flexible rather than rigid.
- The leader is less directive and more participative.
- Team members, in whatever role, share equal responsibility for the success of the team.
- The atmosphere in the teams is trusting and co-operative.
- The team is more successful in achieving challenging objectives.

One of the interesting discoveries about this evolutionary process is that a team operating at the skilful stage will always get there via the formal stage. The skills acquired from rigid planning are different in degree, not in kind, from the skills required for flexible planning. So the formal stage is an essential step in the learning process. It is the equivalent of learning to walk before you can run.

5.1.5 What is leadership?

The need for managers to study leadership is not new. As workers become better informed about the rest of the world through television, free press, etc., their expectations of the workplace and the worth of the activities which they carry out come into question. Managers of people are criticised, and their performances are compared with others. From this comes the obvious recognition that some managers are more effective than others, particularly in the way that they are able to command respect from their subordinates and

"lead the team". Why is it that some people seem to be natural leaders? Are they born? ...or trained? Over time there have been three different ways of studying this problem:

- The Qualities Approach
- The Situational Approach
- The Functional Approach.

5.1.6 The Qualities Approach - what you must BE

One famous study took place in the U.S.A. in 1940 where two researchers compiled a list of personal qualities that executives thought a leader should have. They collected 17,000 different words! In another survey, 75 top managers compiled a list of fifteen essential qualities, the most popular of which was "dependable". When examined, however, they found 147 meanings of this word alone. From 20 different lists in yet another survey, only 5% of the qualities appeared in more than three lists. Apparently then, if leaders are born with some natural gift, then we are incapable of defining it, or measuring it, or agreeing on what it is. Many people who are not leaders also have these qualities.

The Qualities Approach has some worth, however, in that it is easy to see why, for example, a leader with integrity and enthusiasm, to name but two qualities, would tend to be a more effective leader than one without these qualities.

The main disadvantage about the Qualities Approach is that qualities cannot be taught. They can, however, be developed from within and with experience.

The Situational Approach - what you must KNOW

This is a school of thought which believes that leaders are created by situations. Being in the right place at the right time, and having the necessary skills to solve the group's problem is one way that you will be allowed to assume command. When one problem is solved, and a new one emerges, the authority flows to those who know.

For example, a junior nurse (who would not normally be considered a leader) at the scene of a road accident is a typical situational leader. Unfortunately, it is difficult to judge how newly appointed supervisors can learn anything from this; they face hundreds of differing situations every week and are unlikely to have the knowledge and skills to deal with all of them as an expert would.

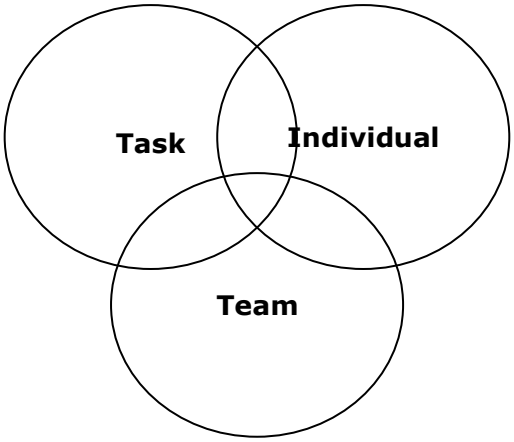
The Functional Approach - what you must DO

Functional leadership is now the most accepted way of developing leadership awareness in supervisors and managers. Because it is concerned with what a leader must do, it can be taught.

John Adair[13], a British professor and well-known writer on the subject of leadership, developed the functional approach to leadership, taking into account earlier studies and research in the areas of motivation and team building. Adair defined three areas in which a leader must work:

[13] See www.johnadair.co.uk

- The Task
- The Individual
- The Team



This is sometimes known as the three circles approach – if they are indicated as three overlapping circles it shows how a breakdown in one area will affect the others, and prevent the job being done as effectively as it could be. The effective functional leader must be aware of each three of these needs to ensure they are all given enough attention.

5.1.7 Traditional Leadership Styles

- **Autocratic / Directive**

The leader dictates what goes on, takes all the decisions herself and does not involve her staff, nor seek their views. The task in hand is the only real concern of the leader, and the style involves very close direction and control by the leader. It is sometimes referred to as the "Tell" style of leadership.

- **Persuasive / Co-operative**

The leader attempts to sell her ideas to her staff, once she has taken a decision. This begins to be two-way communication, where the leader is concerned with her team's views and opinions. This is sometimes known as the "Sell" style.

- **Consultative / Participative**

The leader discusses issues with her staff. After considering their views and suggestions the leader will still make the decision themselves. In this participative style, working relationships feature much more strongly. Employees are made to feel that their contributions count for something, and that their views are important.

- **Democratic / Self-Directive**

The leader accepts full involvement of her staff, and everything is shared. This style involves maximum delegation of authority. Employees are often left on their own to "get on with the job", without any real direction from the leader.

Variables affecting leadership style

The effectiveness of a particular leadership style will depend on the following factors:

- **Organisational philosophy**, e.g. whether formal or informal traditions; size and geographical dispersion of the department.
- **Employees' competences**. The knowledge, skills and abilities of the employee will to a large extent determine which style you should use.
- **Employees' attitudes**. The extent to which the employee has a positive attitude to her job, and to the company, will be another important factor in determining style.
- **Employees' expectations**. If employees are used to a particular style, e.g. authoritarian, they may expect to be told what to do. If they are used to working on their own initiative, a democratic style may work.
- **Nature of the task**. The nature and complexity of the task and time constraints.

- **Group's ability to work together**. Mutual acceptance; cohesiveness; size of group; effect of errors.

5.2 THE BELBIN MODEL OF TEAM ROLES

For many years the search for successful management has been seen almost exclusively as a search for the right individual. Corporations have been preoccupied with the qualifications, experience and achievement of individuals. Yet it is often the case that the ideal individual for a given job cannot be found. She cannot be found because she (maybe) does not or cannot exist. Dr Meredith Belbin[14] discovered some fascinating facts about the importance of teams. He also defined some (possibly) essential types:

- Co-ordinator
- Shaper
- Plant
- Monitor-Evaluator
- Implementer
- Resource Investigator
- Team Worker
- Completer-Finisher
- Specialist

Any attempt to list the qualities of a good manager demonstrates why she cannot exist: far too many of the qualities are mutually exclusive, for instance, she must be :

- highly intelligent and must not be too clever
- highly forceful and she must be sensitive to people's feelings
- dynamic and she must be patient
- a fluent communicator and
- she must be a good listener

And if you do find and hire this jewel among managers, this paragon of mutually incompatible characteristics, what will you do when she steps under a bus, or goes to live abroad or leaves to take up a better job with your principal competitor?

5.2.1 Perceived Roles

Dr Belbin's crucial perception is that all members of a management team have a dual role. The first role, the functional one, is obvious: a manager belongs to the team because she is an accountant or production engineer or regional service manager or group marketing executive, or whatever.

The second role, what Dr Belbin would call the team role, is much less obvious. Yet in a sense, we have all been dimly aware of it ever since we first started to work in teams. We know for instance, that Tom is always coming up with bright ideas; that Dick wants to get decisions finalised and allocated; and that Harry tends to pour cold water on other people's

[14] See also Belbin, R.M. *Management Teams – Why they succeed or fail.* Butterworth Heinemann, 1981. Belbin, R.M. *Team Roles at Work.* Butterworth Heinemann, 1993

proposals. And what is more, we know that Tom, Dick and Harry are likely to show these same characteristics whatever team they are in – the new product planning group, the social committee of the golf club, or the board of governors of the local school.

It is these enduring characteristics, these team roles, that have been the subject of Dr Belbin's research. The result is that he has isolated and identified just nine roles as the only ones available to team members.

He was able to do so by finding a unique human laboratory and being able to work in it for seven years, forming his hypotheses, testing, discarding, revising and retesting until he was able to produce a remarkable study of the anatomy of teams with quite unusual volume of experimental evidence to support it.

5.2.2 Team-Roles

Here are the nine team-roles which Dr Belbin and his colleagues identified.

5.2.3 Co-ordinator

Clarifies the groups objectives and sets its agenda.

Traits:

- Mature,
- Confident,
- Dominant,
- Extrovert.

The co-ordinator role was originally called the 'chairman' by Belbin and it is team leadership that she is best fitted for. She is the one who presides over the team and co-ordinates its efforts to meet external goals and targets. She is distinguished by her preoccupation with objectives.

You would expect this person to be at least normally intelligent, but not in any sense brilliant, and not an outstanding creative thinker; it is rare for any of the good ideas to originate from her. She is much more remarkable for what used to be called 'character; her approach is self- disciplined, and it is founded on self-discipline. She often has what is called 'charisma', but it is perhaps easier to think of it as authority. She is dominant but in a relaxed and unassertive way - she is not domineering. She has an instinct to trust people unless there is very strong evidence that they are untrustworthy, and she singularly free from jealousy.

Shaper

Only results can reassure her. Her drive has a compulsive quality.

Traits

- Anxious,
- Dominant,
- Extrovert.

The *Shaper* is full of nervous energy; she is outgoing and emotional, impulsive and impatient, sometimes edgy and easily frustrated. She is quick to challenge, and quick to

respond to a challenge (which she enjoys and welcomes). She often has rows, but they are quickly over and she does not harbour grudges. Of all the team, she is the most prone to paranoia, quick to sense a slight and the first to feel that there is conspiracy afoot where she is the object or victim of it!

The principal function of the Shaper is to give a shape to the application of the team's efforts, often supplying more of her own personal input than the Chairman does. She is always looking for a pattern in discussions, and trying to unite ideas, objectives and practical considerations into a single feasible project, which she seeks to push forward urgently to decision and action.

The Shaper exudes self-confidence, which often belies strong self-doubts. Only results can reassure her. Her drive, which has a compulsive quality, is always directed at her objectives. They are usually the team's objectives too, but then the Shaper, much more than the Chairman, sees the team as an extension of her own ego. She wants action and she wants it now. She is personally competitive, intolerant and muddled thinking, and people outside the team are likely to describe her as arrogant and abrasive. Even people inside the team are in danger of being steamrollered by her on occasions, and she can make the team uncomfortable: but makes things happen.

Plant

Team's source of original ideas, suggestions and proposals.

The Plant originally received this name when it was found that one of the best ways to improve the performance of an ineffective team was to 'plant' one of this team type in. This role can also be thought of as the one who scatters the seeds which the others nourish until they bear fruit (!).

Traits:

- Dominant,
- very high IQ,
- introvert.

Other team members will have ideas too; what distinguishes the Plant's ideas is their originality and the radical- minded approach she brings to problems and obstacles. She is the most imaginative as well as the most intelligent member of the team, and the most likely to start searching for a completely new approach to a problem if the team starts getting bogged down, or to bring a new insight to a line of action already agreed. She is much more concerned with major issues and fundamentals than with details, and indeed she is liable to miss out on details and make careless mistakes.

She is thrustful and uninhibited in a way that is fairly uncharacteristic of an introvert. She can also be prickly and cause offence to other members of the team, particularly when criticising their ideas. Her criticisms are usually designed to cleat the ground for her ideas and are usually followed by her counter-proposals.

The danger with the Plant is that she will devote too much of her creative energy to ideas which may catch her fancy but do not fall in with the team's needs or contribute to its objectives. She may be bad at accepting criticism of her own ideas and quick to take offence

and sulk if hid ideas are dissected or rejected: indeed, she may switch off and refuse to make any further contribution. It can take a lot of careful handling and flattery (Chairman's role) to get the best out of her. But for all her faults, it is the Plant who provides the vital spark.

Monitor-Evaluator

She likes to be given time to mull things over.

Traits:

- High IQ,
- stable
- introvert.

By temperament she is likely to be serious and not very exciting. Her contribution lies in measured and dispassionate analysis rather than creative ideas, and while she is unlikely to come up with an original proposal, she is the most likely to stop the team from committing itself to a misguided project.

Although she is by nature a critic rather than a creator, she does not usually criticise host for the sake of it, but only if she can see a flaw in the plan or argument. Curiously enough, she is the least highly motivated of the team: enthusiasm and euphoria simply are not part of her make-up. Has, however, the compensating advantage that ego-involvement does not cloud or distort her judgement. She is slow to make up her mind, and likes to be given time to mull things over, but her is the most objective mind in the team. One of her most valuable skills is in assimilating and interpreting and evaluating large volumes of complex written material, and analysing problems and assessing the judgements and contributions of the others.

Implementer

Is the practical organiser. She is the one who turns decisions and strategies into defined and manageable tasks that people can actually get on with. She is concerned with what is feasible, and her chief contribution is to convert the team's plans into a feasible form. She sorts out objectives, and pursues them logically.

Give her a decision and she will produce a schedule.

Traits:

- Disciplined
- Reliable
- Conservative and efficient.

Like the Chairman, she too has a strength of character and a disciplined approach. She is notable for her sincerity, her integrity, and her trust of her colleagues, and she is not easily deflated or discouraged: it is only likely to upset her, because she is liable to flounder in unstable, quickly changing situations.

Because she needs stable structures, she is always trying to build them. Give her a decision and she will produce a schedule; give her a group of people and an objective and she will product an organisation chart. She works efficiently, systematically and methodically, but

sometimes a little inflexibly and she is unresponsive to speculative ill-formed ideas that do not have a visible immediate beating on the task in hand. At the same time she is usually perfectly willing to trim and adapt her schedules and proposals to fit into agreed plans and established systems.

Resource Investigator

Is probably the most immediately likeable member of the team. She is relaxed, sociable and gregarious, with a high degree of interest in the task. Her responses tend to be positive and enthusiastic, though she is prone to put things down as quickly as she takes them up.

Traits:

- Stable,
- Dominant,
- Extrovert,
- Communicative

The Resource Investigator is the member of the team who goes outside the group and brings information, ideas and developments back to it. She makes friends easily and has masses of outside contacts. She is rarely in her office, and when she is she's probably on the phone. She is the salesman, the diplomat, the liaison officer, always exploring new possibilities in the wider world outside. Her ability to stimulate ideas and encourage innovation would lead most people to mistake her for an ideas person, but she does not have the radical originality that distinguishes the *Plant*; for all that, she is quick to see the relevance of new ideas.

Without the stimulus of others, for example in a solitary job, the Resource Investigator can easily become bored, demoralised and ineffective. Within the team, however, she is a good improviser, active under pressure, but can over-relax when it eases. She can fail to follow up tasks she undertook in one of her frequent bursts of short-lived enthusiasm. Her range and variety of outside interests can lead her, like the Plant, to spend too much time on irrelevancies that interest her; nevertheless hers is the most important team role to preserve the team from stagnation, fossilisation and losing touch with reality.

Team Worker

Is the most sensitive of the team. This is the role which is most aware of individuals' needs and worries, and the one who perceives most clearly the emotional undercurrents within the group. As a promoter of unit and harmony she counterbalances friction and discord.

Traits:

- Stable,
- Low in dominance,
- Co-operative,
- Listens.

She is the most active internal communicator; likeable, popular, unassertive, the cement of the team. She is loyal to the team as a unit (though this does not mean she does not take sides when there is a split) and supports all the others. If someone produces an idea, her instinct is to build on it, rather than demolish it or produce a rival idea.

She is a good and willing listener and communicates freely and well within the team, and also helps and encourages others to do the same. As a promoter of unity and harmony, she counterbalances the friction and discord that can be caused by the Shaper and the Plant, and occasionally by the Monitor evaluator.

When the team is under pressure or in difficulties, the Team Worker's sympathy, understanding, loyalty and support are especially valued. Her non-competitiveness and dislike of friction may make her a permanent force operating against division and disruption in the team. She is an exemplary team member, though in normal times the value of her individual contribution may not be as immediately visible as most of the other team roles. The effect, however, is very noticeable indeed when she is not there, especially in times of stress and pressure.

Completer-Finisher

This role worries about what might go wrong. She is never at ease until she has personally checked every detail and made sure that everything has been done and nothing has been over-looked. A.

Traits

- Painstaking,
- Conscientious,
- Anxious,
- Introvert.

The Finisher is not an assertive member of the team, but she maintains a permanent sense of urgency which she communicates to others to galvanise them into activity. She has self control and strength of character, and is impatient of, and intolerant towards the most casual and slap-happy members of the team.

If she is not careful she can be a morale lowering worrier with a depressing effect on the rest of the team, and she can too easily lose sight of the overall objective by getting bogged down in small details. Nevertheless her relentless follow-through is an important asset.

Specialist

The specialist provides knowledge and technical skills which are in rare supply within the team. They are often highly introverted and anxious and tend to be self-starting, dedicated and committed.

Traits:

- Single-minded,
- Self-starting,
- Dedicated.

A lot of people get confused about the 'Specialist' role this and tend to think of it in terms of a person's function rather than behaviour. This is particularly so at a senior level, for example, the production or operations director may regard the finance director as a 'Specialist'. The true behavioural 'Specialist' however is driven by the pursuit of knowledge and information. These people just love the process of learning. It pervades everything they do and they want to go into things very deeply, thus they will be seen as truly

knowledgeable by everyone and not just those who are impressed by their functional expertise.

Topic 6 PROJECT MONITORING AND CONTROL

Topic Lecturer: Dr Frédéric Bosché (f.bosche@ed.ac.uk)

Note: you can find on Learn recorded lectures on the content in this section, as well as quizzes and tutorial documents to further help you understand this topic.

We are nearing the end of the course and at this stage it is worth sitting back and allowing ourselves a little recap:

A greater proportion of the course so far has considered, essentially, a definition of the project. We have looked at what constitutes a generic project, who is involved and what the key stages are. For a particular project we have considered, generally, two of our initial three compromises – time and cost – in that we have looked at how both can be planned. The transformation of a work breakdown structure into a programme; and the application of cost data into a cost estimate are statements – at the start of a project – of how we intend to undertake that project.

In the contract management section of the course, we consider what are the best ways of managing the interface between the party who wants the project done and the party who will do it for them.

What all the preceding sections have in common is that they are parts of the plan of the project. How we intend to undertake it and what are the objective criteria for considering whether a project is successful or not. The most successful projects are those in which the planning is done comprehensively, and no work commenced until this is complete. As we know, however, projects rarely go according to this plan and so a successful project will also be one which both measures the extent of any deviation and, *if necessary,* applies corrections to bring it back on track.

The plan has, therefore, to be *monitored* and *controlled*.

6.1 WHAT IS MONITORING AND CONTROL?

It is a very wide area. *Monitoring* is the process of checking that as a project progresses it will actually turn out the way in which it was planned. *Controlling* is the processes that are undertaken in bringing the project back to the way it was originally intended whenever deviations are observed.

In the introduction to his book, Gardiner (page 6) talks about 'Controlling' in a holistic sense, considering three criteria of technical, financial (business) and functional. He poses three questions that the project management team need to be asking at various stages:

- Are we still going about the project in the right way – is it still on schedule?
- Is the project still cost effective – is it still within budget?
- Is the project still going to give us what we want – is the scope still the same?

If not, then the project may need to be adjusted. This may require a re-planning exercise or it may, in certain circumstances, require the project to be halted.[15] The questions are also a re-examination of the three main compromises and suggest that it is not just the (relatively) measurable aspects of time and cost that need to be monitored but the more intangible and subjective aspects of the project as well.

Monitoring and control can therefore be summarised as:

- determination of the appropriate control measures;
- observation, measurement and collection of control data;
- comparison of control data with the planned data.
- assessment of whether any controlling action is needed, selection and implementation of any such action. Remember always that the result of a monitoring exercise can be no action:

> Monitoring compares the current status of the project with the planned status. If the two are different then this will be for one of two reasons: either the performance so far has been defective; or the performance has actually been satisfactory and it is the initial plan which was defective.
>
> A good project manager will always consider the original plan and may conclude that no controlling action is necessary. One result of this may be that the plan needs to be adjusted for use in the remainder of the project.
>
> If the performance so far has been deficient then the project manager needs to make further investigations and determine why this is the case. She needs to understand what the sources of change are.

6.2 WHAT IS MONITORED – CONTROL MEASURES AND SOURCES OF CHANGE

The main areas of a project that can be considered are: schedule, cost, resources and function. Some authors use the word 'performance' instead of 'function' – but 'quality', 'scope' or 'specification' could also be used – they are the measures which tell us whether or not the project will still do what it is expected to do.

6.2.1 Control Limits

For quantifiable control measures it is important that limits are imposed when the comparison between actual performance and planned performance is done.

- **Upper limit**. A check against what is considered the maximum deviation from planned performance will ensure the budget is not overrun. Measuring actual cost differences will be relatively easy to check against an upper limit, but all control measures, even the most subjective ones, will usually be quantifiable against a cost.
- **Lower Limit**. It is important that a lower limit is also imposed as expenditure which is below what is expected is usually a sign that there is a delay, or a lessening of productivity, in the output of the project.

[15] In the case study of the Holyrood parliament, this decision was almost reached. If more accurate or truthful reporting had been employed then this would have been the likely outcome...

Examples of sources of change on project performance parameters

Source of Change	Performance parameter affected
Critical tasks not started on time	Schedule
Critical tasks not finished on time	Schedule
Non-critical tasks becoming critical	Schedule
Supplier price changes	Cost
Increased overhead rates	Cost
Changes in labour supply	Resources, cost
Changes in labour productivity	Cost, schedule
Changes in labour quality	Cost, function
Delays in material supply	Cost, schedule
Changes in material quality	Cost, function, schedule
Failure of tests / non-conformance	Cost, function, schedule, resources
Delay or errors in supply of technical information	Function, cost, schedule
Design changes	Cost, schedule
Reductions in resource utilisation	Cost, schedule, resources
...	

6.2.2 Schedule and cost

Clearly, the two most important control measures – or at least those which will attract most attention – are time/schedule and cost/budget. We will consider two methods for monitoring and controlling time and cost below, but first it is important to appreciate how these two go together, and must be measured together alongside a knowledge of the actual *progress* of the project – i.e. how much has actually been done.

Consider the examples on the next page:

Example 1:

You are the project manager of a software project which is scheduled to last for 20 weeks. The anticipated total cost of this project is £20,000. At week 14 the total expenditure on the project has reached £16,000.

Do we conclude that the project is currently overspent? Can we conclude that the project will remain overspent at the end of week 20?

Answer:

Unfortunately, we are not in a position to make any conclusions on either cost or schedule as we have no measure of the amount of work actually undertaken.

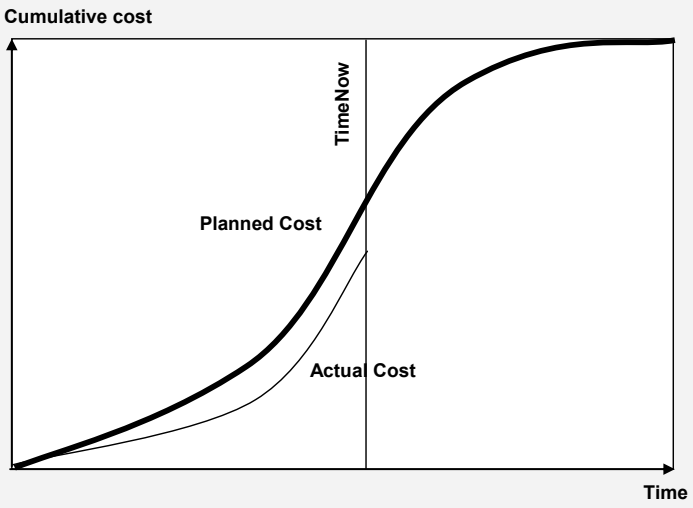
If, at week 14, 70% (i.e. 14/20) of the work had been completed then we could conclude that yes, the project is currently overspent, whilst remaining on schedule. If the project manager was aware of this fact she could re-plan the remaining 6 weeks to try and bring the project back on budget.

Alternatively, the project could have actually achieved only 60% of the anticipated work. In this case the project is both overspent and behind schedule.

Or it could be that by week 14 the amount of work completed is actually 80%. If this were the case then the expenditure is as expected whilst the project is actually ahead of schedule. If performance were to continue in the same manner then the project would be expected to be complete halfway through week 17 on budget.

Example 2:

Consider the cumulative cost curves shown below:



Which of the following statements are true:

- at TimeNow, actual project expenditure is less than planned project costs?
- if this rate of expenditure continues then final project cost will be less than estimated/budgeted?

Answer:

In this example, the actual costs are certainly less than planned – cost is the only measure being examined. But, this is not particularly meaningful.

As we should probably know by now, we cannot conclude for certain that the second statement is true. As in the previous example we need to know information about the actual progress of the project. If the progress is on schedule, then we are in a good position and eventual project cost may well be lower than budgeted. What is probably more likely is that the progress is less than planned and thus less money has been spent. This situation is more alarming in some respects than the example given by Gardiner where the actual cost is greater. In the example given here the project manager may get a false sense of security and take no controlling action. If the situation remains unchecked then not only could the project finish late but costs could rise at least because overhead rates would be applied for longer.

The examples above highlight the challenge that cost data simultaneously integrates schedule performance and cost performance. There is thus a need for a method that can distinguish (i.e. disentangle) time and cost performance.

In the remaining of this Topic, we will present two such methods that can be used to effectively monitor time and cost independently from one another: *Milestone Monitoring* and the *Earned Value Analysis (EVA)*.

Note that for both of the methods, it is essential – as highlighted above -- that information on both time and cost is gathered both for the planned project and as the project progresses.

6.3 MILESTONE MONITORING

Milestone monitoring is much simpler than the Earned Value Analysis method presented below in that the measured data is in a much simpler form. As the project is planned, milestones for project progress are set and fixed. They need to be easily determined and there can be no ambiguity over what constitutes a completed milestone. The main principle with milestone monitoring is that there is one of just two conclusions: the milestone is either achieved or it is not. There is no halfway point, or partly complete outcome.

If planned information about the *date* and the *cost budget* for each milestone is provided then the actual data can be very simply compared. Such information can be provided in tabular format or it can be plotted on a graph. What will result is a more granular chart of project progress.

Milestone monitoring can be simple to implement as the milestones can be easily aligned with the work breakdown structure and project programme/schedule which has been previously determined. On physical projects the conclusion of ‘complete/not-complete’ should be objective and straightforward, though on other types of projects, IT projects for instance, it may be more difficult to make this judgement. If this is the case, however, the next method of Earned Value Analysis will be no easier as it requires a much greater degree and accuracy of progress measurement. The disadvantage of the Milestone Monitoring approach, however, is that it can only provide performance information at the times of the milestones. In-between those milestones, the project manager is essentially blind. In

contrast, the EVA method can be used to provide time and cost performance at any time during the delivery of a project.

6.4 EARNED VALUE ANALYSIS (EVA)

Originated with the US Department of Defense, EVA is a method which allows a detailed monitoring of a project's progression. It allows the following to be done:

- A consideration – or integration – of both time and cost allowing an indication of whether the project is on schedule and/or on budget. As we saw in the examples above, it is sometimes difficult to get an assessment of both simultaneously and independently.
- An estimation of what the outcome of the project will be in terms of the final cost of the project and its duration.

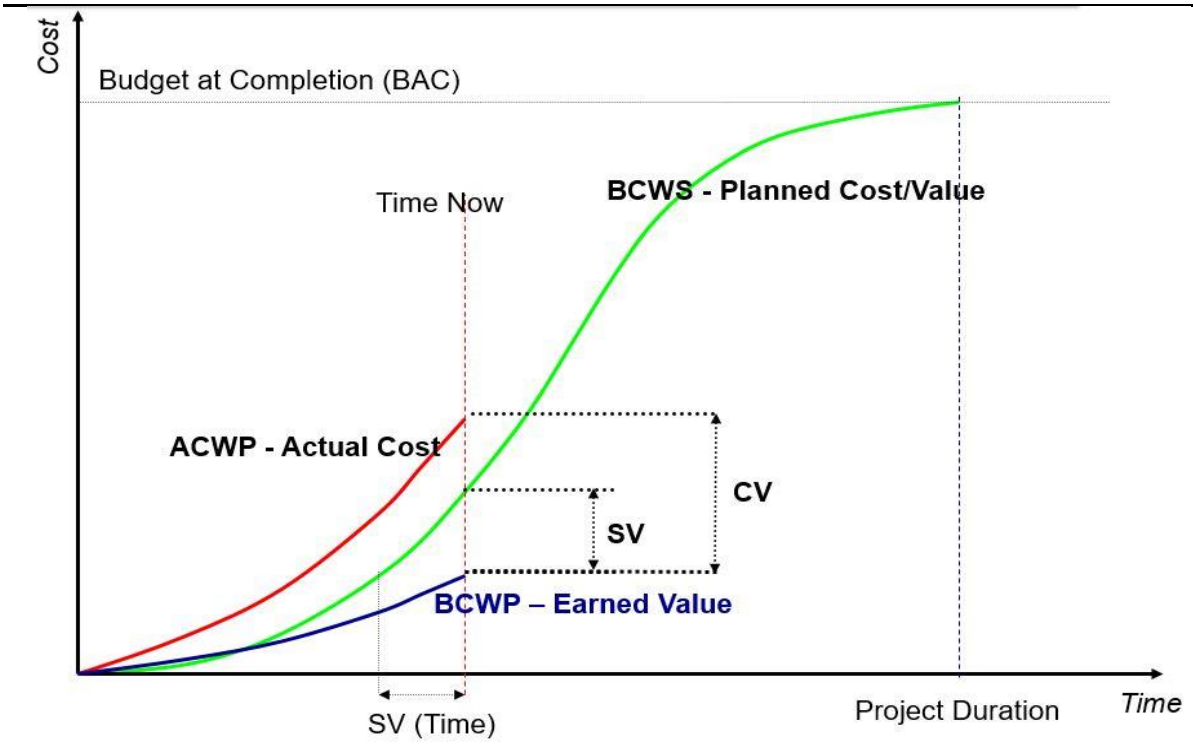
6.4.1 What is measured?

The measurement variables are similar to those considered in Milestone Monitoring, the difference being that the variables are measured at any temporal point in the project, not just on the completion of a milestone. While this process may be more difficult to do, it does allow the project manager to keep a more regular track of the project.

At any stage in a project – the measurement point – the variables are:

- **Budgeted Cost of Work Performed (BCWP) – also called "Earned Value".** For the actual work complete to the measurement point, this is the proportion of the budget assigned to that work
- **Budgeted Cost of Work Scheduled (BCWS).** Instead of the value of the *actual* work done to the measurement point, we determine the value of what should have been done to that point, i.e. the planned value.
- **Actual Cost of Work Performed (ACWP).** We also need to know what was actually spent on the project so far.

The figure below shows the plots that can be developed using the EVA method. In contrast to the graph in Example 2 above, you can see that the actual cost (ACWP) and planned costs (BCWS) curves are complemented with the third curve of Budgeted Cost of Work Performance (BCWP).



EVA can be performed on the project as a whole, but it is more effective when applied to the individual activities and then aggregated for the project as a whole.

If the Measurement Point is the scheduled completion date, then the sum of each activity's BCWS is the Budget at Completion (BAC), i.e. total **BCWS = BAC**.

Whether undertaken by project or by activity, the project manager will need to make an assessment of the actual work done to the measurement point, and this is usually expressed in terms of the Percentage Complete (**PC**). This is the difference between milestone monitoring and EVA – in the former this assessment is deliberately simple. In the latter it may be very difficult to determine just how much of an activity has been done. We shall consider this more later.

Based on the assessment of work complete, BCWP:

- **BCWP = PC x Total Budget** (for that activity or project as a whole)

For BCWS we need to determine how much work we expected (i.e. planned) to be done up to that point, the Percentage Planned (PP):

- **BCWS = PP x Total Budget** (for that activity or project as a whole)

For example, Activity A in a project has an original scheduled duration of 10 days and an original estimated cost of £10,000.

After 5 days it is assessed that the activity is 60% complete.

BCWP = 0.6 x 10,000 = £6,000

BCWS = 5/10 x 10,000 = £5,000

ACWP would be the actual amount of money spent over 5 days.

A. Assessing work complete (PP and PC)

In Milestone Monitoring the work complete is assessed on an 'all or nothing' basis. If the work is 99% complete then the milestone has not been reached. EVA allows the actual amount of work done to be analysed, but the difficulty may be in determining what the `**Percentage Planned (PP)**' and '**Percentage Complete (PC)**' actually are.

For '**Percentage Complete (PC)**', if the project activities are physical then they will usually be measured in physical units – for example, **m^3**, **tonnes** or **m^2** and thus the actual amount of work done in an activity can be determined quite accurately.

Some activities may not be in physical units and percentage complete may not be physically measurable. For example, it is difficult to 'measure' the amount of work completed in a design activity. This may not be the total number of drawings completed as drawings are only one aspect of a design process – a great deal of calculation may be needed before drawings are started. In another example, how do we determined how much programming has been done in an IT project? We could count the number of lines of code written – but we may not know what the final line count should be, nor will this indicate how much effort has been done in de-bugging that code.

In these situations, the measurement is likely to be relatively subjective and care will need to be taken in assessing the significance or impact of any monitoring outcomes based on such assessments.

For `**Percentage Planned (PP)**', a common way is to calculate the proportion of an activity, the project was planned to be at the measurement point, i.e.

$$PP = \frac{TimeNow - Activity\ Start\ Date}{Activity\ Duration}$$

Note that this assumes that progress within the given activity is linear with time, which may be overly simplistic but more realistic than when considering an overlap project (see how the curves in the above graphs have a "S" shape suggesting the progress is normally slow at the beginning and end of project).

6.4.2 Variances

The measured variables (see Graph above) give a vague indication of the absolute performance of the project in monetary terms and this can also be expressed in terms of the difference or variances between the variables:

- Schedule Variance, **SV = BCWP – BCWS**. This will indicate the difference between the value of the work actually done and the value of what was expected to be done up to the measurement point. If **SV** is positive, indicating the value of the work done is greater than planned to that point, then this is a measure of the amount the project is ahead of schedule. Whilst SV indicates any deviation between planned schedule and actual progress, it is expressed in terms of money.
- Cost Variance, **CV = BCWP – ACWP.** This will indicate the difference between the value of the work actually done and the *cost* of the work actually done up to the measurement point. It is a measure of the cost deviation of the project/activity so far – a positive **CV** indicating the spend is less than expected.

Note: both CV and SV have monetary units, e.g. £. While this makes sense for CV because it is about cost, it is less meaningful for SV which is about time. It is however possible to obtain a schedule variance expressed in time unit, $\mathbf{SV_{(time)}}$, as the difference on the horizontal axis between BCWP and BCWS (see Graph above)

6.4.3 Performance Indices

Variances will measure absolute deviations but care must be taken over their interpretation. A negative cost variance of £10,000 after 50 weeks of a £3M project may be considered very good performance, but after 4 weeks of a £100,000 project this would be worrying.

We may also, therefore, determine proportional measures giving a better impression of actual performance:

- Schedule Performance Index, **SPI = BCWP/BCWS**. If this value is greater than 1 then it indicates the value of the work to the measurement point, and hence the schedule, is greater than expected. An advantage of using SPI instead of SV is that it is not expressed in monetary units. However, monetary values can be useful to assess the potential benefits of control measures (which will likely also have a cost).
- Cost Performance Index, **CPI = BCWP/ACWP**. If this value is less than 1 then the project/activity is overspent.

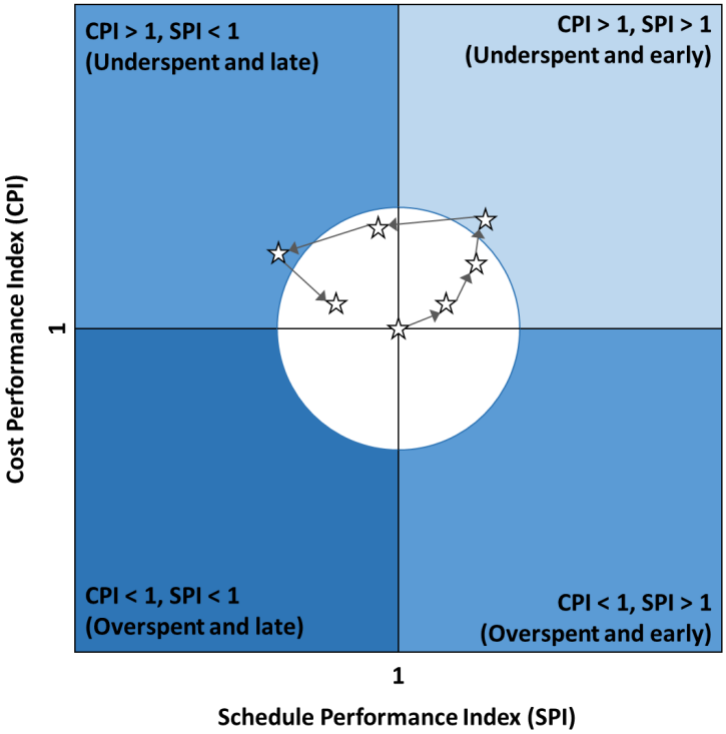
6.4.4 Trend monitoring

The EVA calculations and performance metrics presented so far enable the monitoring of the performance of the project at each given point in time for a given period (e.g. last month and/or since the start of the project). However, they provide limited value to understand the trend of that project performance over time (like the Milestone Monitoring graph enables).

For this, the *bullseye chart*, illustrated in the figure below, can be used to summarise the evolution of the project (or WP) performance indices over time (i.e. at all measurement points up to now), enabling managers to understand whether the situation is deteriorating

or improving in terms of both time and cost performance. A circle (or ellipse) can be drawn to highlight the maximum agreed threshold outside which specific action may be triggered.

Note that other graphs exist to monitor EVA performance trends over time, such as variance trends graph that plots the variance metrics over time.



6.4.5 Estimating final cost & duration

Aside from trend analysis, a benefit of the EVA method is that it allows estimates to be made on the eventual turnout of the project.

Duration at completion (DAC). This can be determined using a variety of methods depending on the assumptions made as to the expected future schedule performance of the project:

- **DAC = PD - $SV_{(time)}$:** This assumes schedule performance will continue as originally planned.
- **DAC = PD / SPI:** This assumes schedule performance will continue as observed to date. PD is the originally planned Project Duration.

Estimate (of cost) at completion (EAC). There are a variety of ways in which this can be determined, depending on whether the actual cost performance so far is seen as an indicator of future performance.

- **EAC = BAC – CV**. This assumes cost performance will continue as originally planned. It is used when the cost performance experienced so far is not expected to continue for the remainder of the project.
- **EAC = BAC/CPI**. This assumes that the cost performance so far will continue to the end of the project. BAC is the original budgeted cost. This formula may be based on a broad assumption but this is the simplest and most common way of calculating the EAC.

- **EAC = BAC/(CPIxSPI)**. This assumes that both the schedule and cost performance to date will impact the final costs. This can well be justified if the project has high levels of fixed costs. Indeed, fixed costs are incurred each day regardless of the amount of work complete. So, for each day a project is extended, one additional day's worth of fixed costs will be incurred by the project.
- **EAC = ACWP + (new estimate)**. If the monitoring exercise has concluded that the original cost plan was defective then a new estimate may be undertaken. This new estimate for the remainder of the project can be added to the actual cost already experienced.

IMPORTANT NOTE: While we have presented *trend analysis* and *estimations at completion* with the EVA method, the exact same time of analysis can in fact be conducted with the Milestone Monitoring method. For example, each star in the Bull's Eye chart is the performance measured at each milestone. And, at each of those milestones, variances and performance indices can be similarly calculated which can then be used to estimate DAC and EAC using the same approaches as above.

6.4.6 EVA Example

Consider the project, with a total duration of 29 weeks, shown in the table below:

Activity	Start	Finish	Duration	Budgeted Cost	Progress	Actual Cost
	week	week	weeks	£k		£k
A	0	8	8	150	100%	175
B	0	1	1	50	100%	52
C	0	10	10	650	100%	670
D	8	14	6	400	90%	380
E	1	8	7	300	100%	310
F	1	2	1	100	100%	120
G	10	16	6	200	80%	175
H	10	20	10	200	70%	150
I	10	12	2	150	100%	165
J	14	17	3	90	80%	80
K	14	15	1	300	100%	320
L	20	29	9	160	0%	0
M	17	23	6	250	40%	120
N	2	8	6	150	100%	160
O	12	17	5	100	80%	85

The progress column indicates the measurement exercise taken at a *measurement point* of week 20. This represents the monitoring stage.

We need to assess the monitoring outcome to determine if any further project control is necessary. The EVA process can tell us the cost and schedule performance and provide estimates for the final duration & cost.

Performance

First we need to determine the BCWP and the BCWS and if a spreadsheet is used we can establish this information quite easily:

Activity	Start	Finish	Duration	Budgeted Cost	Progress	ACWP	BCWS	BCWP
	week	week	weeks	£k		£k	£k	£k
A	0	8	8	150	100%	175	150	150
B	0	1	1	50	100%	52	50	50
C	0	10	10	650	100%	670	650	650
D	8	14	6	400	90%	380	400	360
E	1	8	7	300	100%	310	300	300
F	1	2	1	100	100%	120	100	100
G	10	16	6	200	80%	175	200	160
H	10	20	10	200	70%	150	200	140
I	10	12	2	150	100%	165	150	150
J	14	17	3	90	80%	80	90	72
K	14	15	1	300	100%	320	300	300
L	20	29	9	160	0%	0	0	0
M	17	23	6	250	40%	120	125	100
N	2	8	6	150	100%	160	150	150
O	12	17	5	100	80%	85	100	80
			Total:	**3250**		**2962**	**2965**	**2762**

For the project as a whole:

- Schedule Performance Index = BCWP/BCWS = 0.93
- Cost Performance Index = BCWP/ACWP = 0.93

Indicating that the project is both *behind schedule* and *over budget*. Performance indices can also be established for each activity, as shown in the table below:

Activity	Start	Finish	Duration	Budgeted Cost	Progress	ACWP	BCWS	BCWP	SPI	CPI
	week	week	weeks	£k		£k	£k	£k		
A	0	8	8	150	100%	175	150	150	1.0	0.86
B	0	1	1	50	100%	52	50	50	1.0	0.96
C	0	10	10	650	100%	670	650	650	1.0	0.97
D	8	14	6	400	90%	380	400	360	0.9	0.95
E	1	8	7	300	100%	310	300	300	1.0	0.97
F	1	2	1	100	100%	120	100	100	1.0	0.83
G	10	16	6	200	80%	175	200	160	0.8	0.91
H	10	20	10	200	70%	150	200	140	0.7	0.93
I	10	12	2	150	100%	165	150	150	1.0	0.91
J	14	17	3	90	80%	80	90	72	0.8	0.90
K	14	15	1	300	100%	320	300	300	1.0	0.94
L	20	29	9	160	0%	0	0	0	-	-
M	17	23	6	250	40%	120	125	100	0.8	0.83
N	2	8	6	150	100%	160	150	150	1.0	0.94
O	12	17	5	100	80%	85	100	80	0.8	0.94
			Total:	**3250**		**2962**	**2965**	**2762**		

though for activities complete (progress = 100%) the SPI does not give an indication of how they were actually performed. We can see, though, that for all activities, apart from the one that has not yet started, the CPI is below 1.

Estimates of final cost and duration

The estimate of duration at completion of the project can be estimated to be:

- DAC = Original Scheduled Duration / SPI **= 29/0.93 = 31.1 weeks**

If the cost performance is expected to continue for the remaining 11 weeks, then the estimate (of cost) at completion is:

- EAC = **BAC/CPI** = 3250/0.93 = **£3,494,623**
- (Note – if you use CPI with more significant figures, for example 8 significant figures, then a different estimate is obtained: £3,485,337)

If the cost performance is expected to revert back to expected for the remaining 11 weeks, then the estimate (of cost) at completion is:

- EAC = **BAC – CV** = **£3,450,000**

Therefore, if the management of the project is improved to the level that it was originally planned a potential saving of **£35,337** could be made. Compare this to the potential loss of **£235,337**.

Do you think it is worth trying to exert greater control on this project?

Topic 7 CASE STUDIES

7.1 CASE STUDY A: CONTRACT FORMATION

In our notes on the elements and requirements of a simple contract we understand there to be 6 requirements for a contract to be formed:

- Intention
- Genuine consent
- Legality of purpose
- Legal capacity
- Offer and acceptance
- Valuable consideration

The following is a report (from *Vincent Powell-Smith's Legal Compendium*), which is a true case where the existence of a contract was in some doubt. Read the report and enter into discussion… [text in square brackets my own comments].

G Percy Trentham Ltd v Archital Luxfer Ltd (1993) (63 BLR 44) [case reference] is an interesting case on contract formation and deals with those circumstances in which a contract might come into existence even if there is no precise coincidence between offer and acceptance.
Trentham were main contractors for two phases of industrial units at Farnborough. In January 1984 subcontractor Archital submitted four alternative quotations for the Phase 1 work to Trentham. They then submitted a revised quotation of one of these, subject to their own standard conditions. Trentham counter-offered, requiring written acceptance by Archital. Archital did not accept the order.

Negotiations continued but no written sub-contract was signed. Archital carried out the work on both phases and received stage payments. The employer [client] obtained an arbitrator's award for damages [from the main contractor] arising out of alleged defects in Archital's work. Trentham then claimed an indemnity [i.e. an assurance that they were not responsible for the defects] from Archital.

Archital said that there were no contracts between them and Trentham; the trial judge found otherwise and Archital appealed.

The Court of Appeal dismissed their appeal. The reasons, according to the *Building Law Report*, were as follows:

- The court held that where a transaction was fully performed the argument that there was no evidence on which the judge could find that there was a contract was implausible.
- The various discussions and exchanges and the carrying out of what was there agreed [i.e. the work done by Archital] supported the view that there was a course of dealing which effectively resulted in a contract. Archital was to perform the work and Trentham was to pay.
- A contract came into existence during performance. This was so even if the affair could not be precisely analysed in terms of offer and acceptance.

Archital's case depended on there being no contract for Phase 1 and that assumption was wrong. Further, the exchanges showed that a contract had been made.

In some ways, the decision is a surprising one; lawyers normally analyse contracts in terms of offer and acceptance, and the holding that there can be a contract without a cross offer and unequivocal acceptance 'during and as a result of performance' should not be taken as a general rule, even if the decision was a unanimous one.

Lord Justice Steyn - a lawyer originally trained in the civil law tradition - delivered the Court's judgment. In his view, there were four important matters.

- English law generally adopts an objective theory of contract formation and the governing criterion is the reasonable expectations of honest men. 'In the present case that means that the yardstick is the reasonable expectations of sensible businessmen.'
- In the vast majority of cases the coincidence of offer and acceptance will represent the mechanism of contract formation. 'But that is not necessarily so in the case of a contract alleged to have come into existence during and as a result of performance.'
- The impact of the fact that the transaction is executed rather than executory [i.e. nothing further remains to be performed]. The fact that the transaction was performed on both sides will often make it unrealistic to argue that there was no intention to enter into legal relations.
- [Not relevant to our discussion].

The learned editors of *Building Law Reports* evidently like this case as little as I do. 'Steyn's judgment could also lead to uncertainty Facts such as those... in the present case are quite common in engineering projects… It is extremely common for work to start whilst negotiations are in progress. If these were the only two criteria necessary to the formation of a contract then in many cases a contract would be held to exist even though, objectively, there was no evidence that the parties were in agreement on all essential points.'

Discussion

- What are your own views on whether each of the requirements for a simple contract had been satisfied?
- How was the *consideration* satisfied?
- Why did Archital undertake the work if they didn't think there was a contract?
- Is there any implication by conduct?
- What do you think of the *Building Law Report's* conclusion?
- What can you conclude about avoiding court in contract situations?
- What should Trentham have done to avoid this situation?

7.2 CASE STUDY B: SCOTTISH PARLIAMENT BUILDING

The Scottish Parliament Building at Holyrood is now generally viewed as an architectural icon – a unique piece of post-modern architecture[16]. But at the time of its design and construction it was very controversial. There were question marks over the appointment of both architect and contractor, how the building was procured and the role (or lack of it) of the ministers in this process, and ended up being delivered very late and at a highly inflated

[16] Architecture critic Charles Jencks praises it – see https://edin.ac/3SvpBFj for a fuller overview of the design and his critique. He, interestingly, was much less impressed with the Welsh Senedd building, describing it as a 'glorified shed space'.

cost. These are all Project Management concerns and even now, 16 years later, it is imperative to remember the mistakes that were made and learn from them. This is why I include it as a case study in this course, and of course it has local interest to Edinburgh as well.

How much the increased cost was is not actually definitively known. The final turn-out cost was over £400million and, with an initial 'estimate' being £40million, it has been a media stock quote of being 'ten times over budget'. This has been repeated so often that it is now accepted as the truth.

But the initial figure of £40million was never a true estimate. It was a sum of money stated before the location, size, capacity, design and procurement were all even known. And as the Estimating lectures of this course should tell you by now, an estimate with such limited information will be highly inaccurate.

Nevertheless, it is fair to say it did cost more than it should and it has been a case study for many people looking into how large projects are procured. There are suggestions that many biases were at play - possible strategic misrepresentation, confirmation bias, self-justification and optimism bias, with almost definitely evidence of 'Escalation of Commitment' – a bias which makes it more difficult to pull back from a project once participants are 'locked-in' to seeing it through to completion. Ahiaga-Dagbui and Smith (2014)[17] explore this in much more detail and this paper is available on Learn.

The problems led to the Scottish First Minister at the time, Jack McConnell, announcing a Public Inquiry into how the project was delivered. Just before the building was opened the Inquiry chair, Lord Fraser, published his critical findings and for those interested a copy of this report is on Learn.

Just before Lord Fraser published his Public Inquiry findings, the BBC broadcast a documentary on the project and this provides great insight into the key issues and problems. This documentary can be viewed via Learn, together with a brief discussion from Simon Smith on the main issues.

7.3 CASE STUDY C: EDINBURGH TRAMS PHASE 1

Trams were a very common form of public transport across the UK but by the mid-point of the 20th century had largely been replaced with bus networks. In Edinburgh there was an extensive network of trams but these ceased operation by 1956.

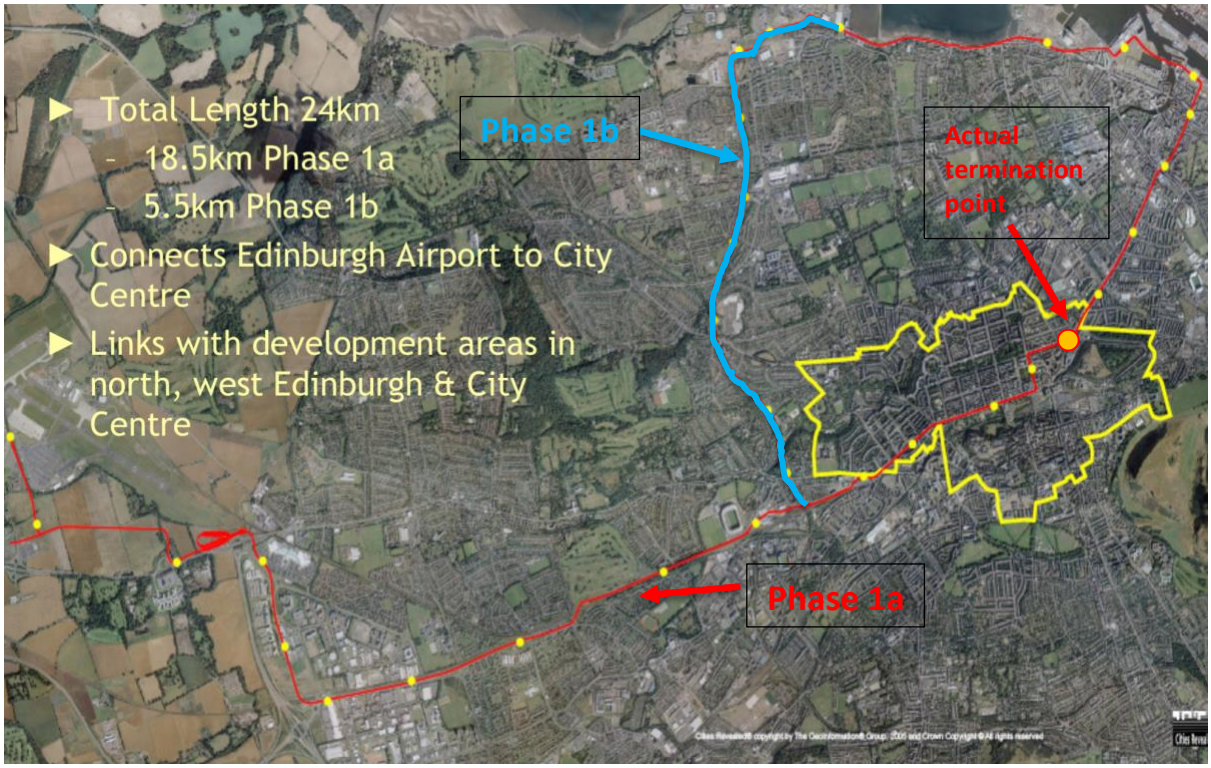
In the latter years of the 20th century many towns and cities in the UK had reintroduced tram networks, which were mostly more like on-street, light-rail systems and thus very large and complex projects to design, procure and build. Edinburgh followed suit with their own proposals which, after much deliberation and political manoeuvring, was finally approved in December 2007.

[17] Ahiaga-Dagbui, D D and Smith S D (2014) *Exploring escalation of commitment in construction project management: Case study of the Scottish parliament project* In: Raiden, A B and Aboagye-Nimo, E (Eds) Procs 30th Annual ARCOM Conference, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 753-762.

The interesting aspect about the Edinburgh Trams is that the case for it was very well made. Earlier in this course I emphasised the point that the demand for a project needs to be very well established and understood – *why* is a project necessary? and in this case there was a well-considered business case that recognised the following:

- Population of Edinburgh predicted to increase by 10% (44,000) between 2004 and 2024
- Major residential, retail and commercial developments at both the Leith & Granton waterfronts and the west of Edinburgh
- The existing road network through a historic city would experience unsustainable pressure.

The original plan was therefore to link the airport with the developments in the west of the city (Edinburgh Park/South Gyle area) with the city centre with the waterfront to the North:



Unfortunately, the project did not proceed very well from that point with funding shortfalls and contractual disputes. The main consequence of this was that the project scope was reduced – instead of meeting its identified need of transport through to the Edinburgh Waterfront, it terminated at the East End of Edinburgh. It opened late, over budget and under scope in May 2014.

The key parts of this saga were recounted in a BBC Scotland documentary in 2011. At that time the project was still very much underway but it is a useful means to understand the key problems which had already manifested by then. This documentary is provided as a pre-recorded lecture on Learn, together with a brief discussion from Simon Smith on the main issues.

7.4 CASE STUDY D: EDINBURGH TRAMS PHASE 2

In 2017 the business case to extend the network to Newhaven (i.e. the original planned final point of Trams Phase 1) was approved in a projected (at that time) £165.2million project. This is now currently under construction.

We take the opportunity to hear more about this project from the project's Project Manager, Michael Motion. Michael works for a company called Turner and Townsend who are a business providing professional project management services. This in itself is a move away from Trams Phase 1, which was project managed by "Transport Initiatives Edinburgh" which was a City of Edinburgh Council owned business. Another key difference is that Trams Phase 2 has been procured using the *New Engineering Contract* rather than a bespoke contract used on Phase 1.

Michael talks more about these aspects in his Guest Lecture. It is not confirmed at the time of writing whether he will give this lecture in 22/23, but the lecture from 2021 has been recorded and is available to watch on Learn.