Course: **Introduction to Engineering**

Unit: **Engineering Project Management**

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1. INTRODUCTION

1.1 IMPORTANCE OF PROJECT MANAGEMENT FOR ENGINEERS

- A typical engineering project goes through stages such as: idea → applied research → initial development → marketing → engineering design and development → industrialisation and production → sales and distribution → commissioning / deployment → maintenance / upgrading → phase-out and disposal. (Also refer to ANGUS & GUNDERSEN 1997.)
- Assigning the responsibilities for these stages to different organisational entities is done as part of *project management*, which involves planning, organising, staffing, leading and controlling the project.
- Many engineers do some form of management on their projects, while others' careers develop into full-time project management.
- Therefore it is important for any engineer to understand the concepts of project management.

1.2 SCOPE OF THIS LECTURE

- This lecture provides students with a high-level overview of the following major aspects of managing an engineering project:
  - **Planning an engineering project**: requirements definition, work breakdown, effort estimation, and scheduling.
  - **Organising and staffing an engineering project**: organisational- and team structures, and filling the organisational positions.
  - **Directing an engineering project**: leadership, delegation, and goal setting and career planning.
  - **Controlling an engineering project**: quality assurance and project documentation as elements of project control.
- (Refer to HAYNES & FRITZ 1997, KERZNER 1997, LANIGAN 1992, LEWIS 2000, THOMSETT 2000 and WEISS & WYSOCKI 1992 for more detailed discussions on project management.)

2. PLANNING AN ENGINEERING PROJECT

2.1 FUNDAMENTALS OF PROJECT PLANNING

2.1.1 Purpose of Project Planning

- The purpose of planning an engineering project is to establish a foundation for execution and successful completion of the project, by deciding in advance:
  - what problem to solve (requirements definition),
  - what to do in order to solve the problem (work breakdown),
  - with what to do it (definition of resources required), and

- when to do it (schedule).

- Deciding by whom the tasks must be done (allocation of responsibilities) is normally done later, as part of organising and staffing the project (refer to section 3 below).

2.1.2 Major Issues in Project Planning

- Attempting a project without a proper requirements definition is as futile as attempting to answer an unknown question.
- Schedule and cost are often based on marketing needs or guesses, and not on functional requirements and technical constraints.
- It is difficult to estimate the extent and duration of activities for a complex project.
- When functional requirements change, cost and schedule are often not adapted accordingly.
- Risk factors are often not assessed during the planning phase of a project.
- Project data (e.g. resources used for execution of specific tasks) is often not adequately recorded, and is therefore mostly not useful in the planning of new projects in future.
- Development policies are often not compiled or are used inconsistently.
- Often project plans are not deliverable documents, and are therefore compiled superficially.
- Some engineers feel that planning is unnecessary or a waste of time, since:
  - there are too many uncertainties; and
  - they want to get going with “the real work”.

2.1.3 Two “Legs” of Project Planning

- There are two interactive areas in which project planning is normally done:
  - *System Engineering* (SE) – mostly concerned with requirements definition and -analysis.
  - *Project Management* (PM) – mostly concerned with work breakdown, cost, and schedule.
- After the project planning phase, system engineering plays a major role in the project again – refer to the lecture on System Engineering.
- Project planning typically entails:
  - Define the problem to be solved (requirements definition). [This aspect is not included in this lecture, since it was addressed in the lecture on System Engineering.]
  - Do a work breakdown.
  - Estimate the effort required to do the work, prepare budgets, and allocate resources to the activities.
  - Schedule the activities and the use of resources.
  - Document the problem definition, chosen course of action, policy decisions, work breakdown, budget, schedule, and contingency plans in a project plan.

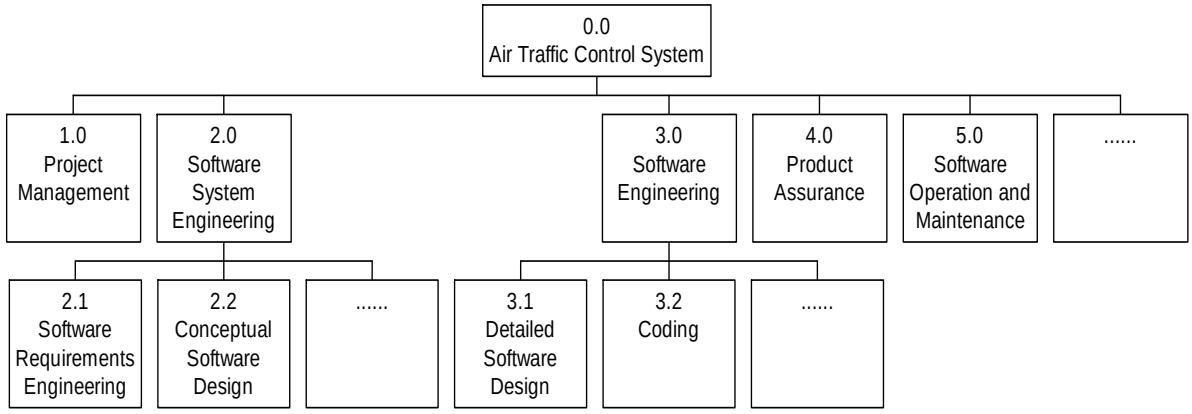
2.2 WORK BREAKDOWN

2.2.1 Introduction

- After defining requirements and choosing one or more possible solutions (part of System Engineering), a project must be broken down into smaller tasks.
- This is done in the form of a work breakdown structure (WBS), which helps to ensure that most aspects of the project are considered from the start.
- There are two main methods of representing a WBS (illustrated in the next section):
  - Tree-structured graph (hierarchical decomposition into smaller elements).
  - Indented list.
- With the tree-structured graph it is easier to visualise the work breakdown and its different layers, than with the indented list.
- Note that the WBS is a ***hierarchical breakdown of tasks***, not an organizational chart or a schedule chart.

2.2.2 Types of Work Breakdown Structures

- Process WBS:
  - This type of WBS is primarily used by project managers.
  - It provides a hierarchical picture of **activities** necessary for successful project completion.
  - It partitions a large process into smaller processes, down to individual tasks.
  - Example of the first three layers of a process WBS, represented as a tree structured graph:



- Product WBS:
  - This type of WBS is primarily used by system engineers.
  - It provides a picture of the **components and interfaces** comprising a total product.
  - It partitions large product entities into its components, for clearer understanding.
  - Example of a product WBS as an indented list (which can still be further subdivided to lower levels if necessary):

0.0 Air Traffic Control System

1.0 Radar Segment

1.1 Search radar

1.2 Radar signal transmitter

1.3 .....

2.0 Tower Segment

2.1 Radar signal receiver

2.2 Radar signal processing system

2.3 Radar signal display system

2.4 .....

3.0 Communications Segment

3.1 Ground-to-air system

3.2 Voice network

3.3 .....

4.0 ……..

- Hybrid WBS:
  - A hybrid WBS includes both process and product elements.
  - It normally alternates processes and products on sequential layers of the hierarchy, but it can start with either a process or a product.
  - Rationale: processes produce products, and these in turn require development processes.
  - The terminal elements (lowest level of the WBS) should always be product components.
  - It is primarily used to determine and control cost and schedule for each product element.
  - Example of a hybrid WBS as an indented list (which can also be further subdivided to lower levels if necessary):

0.0 Automated Bank Teller System *(Product)*

1.0 Project management *(Process)*

2.0 Training software development *(Process)*

3.0 Software development *(Process)*

3.1 Financial transactions modules *(Product)*

3.1.1 Transaction validation *(Process)*

3.1.1.1 Transaction validation software *(Product)*

3.1.1.2 User data base *(Product)*

3.1.1.3 ..... *(Product)*

3.1.2 Transaction processor *(Process)*

3.1.3 Transaction recording *(Process)*

3.1.4 ….. *(Process)*

3.2 Maintenance modules *(Product)*

4.0 Software integration and testing *(Process)*

4.1 ..... *(Product)*

4.2 ..... *(Product)*

5.0 ….. *(Process)*

2.2.3 Developing a Work Breakdown Structure

- The typical steps in developing a WBS are:
  - Determine the purpose of the WBS - e.g. to identify product elements, or to help determine cost, or to help determine staff requirements, or to assign work elements to individuals, ...
  - Partition the first level into its major components (typically 3 to 9 elements per level).
  - Partition each major component into its next level (3 to 9 elements).
  - When more than 9 elements are required to partition an element, that element should rather be split into two - if possible.
  - Repeat the partitioning, down to lowest level.
  - Document and review the results.
- An alternative approach (the “rolling wave method”) to developing a WBS involves:
  - The WBS is developed down to the second or the third level.
  - Analysis is then done to determine which processes or products must be developed first.
  - Only these elements are then developed down to their lowest level on the WBS.
  - All other elements are deferred (rolled over) until shortly before they must be done.
  - Advantage: new information can be incorporated when the latter elements are further planned.
  - Disadvantage: a complete picture of the work breakdown is not available at the beginning.
- Each lowest level work activity on the WBS must be specified in a “work package description”, containing aspects such as:
  - Identification number, name and brief description of the work package.
  - Predecessor and successor tasks.
  - Inputs required for this work package.
  - Tasks forming part of this work package.
  - Outputs to be produced by this work package.
  - Entry criteria (i.e. criteria to be satisfied before this work can commence).
  - Completion criteria (i.e. criteria to be satisfied before this work can be considered done).
  - Risks associated with the work package.
  - Estimated resources required to execute the work. (Detailed effort estimation is done later – refer to section 2.3 below.)
  - Estimated duration of the work activity. (Detailed scheduling is done later – refer to section 2.4.)

2.3 EFFORT ESTIMATION

2.3.1 Introduction

- One of the keys to a successful project is an accurate estimate of the expected effort required to complete the development.
- *Effort* is normally estimated in terms of *person-hours* ("manpower requirements"), before being converted to cost.
- Effort estimation is a subset of cost estimation, since the latter also includes estimates about other resources required (the remaining three of the "four Ms": manpower, money, materials, and machines).
- The prerequisites for proper effort estimation are: requirements must be defined, and a work breakdown must exist.
- Major issues in estimating system development effort include:
  - Lack of historical data (data for previous projects was either not collected when it should have been done; or it is a first-of-a-kind system).
  - Lack of experience by the estimator.
  - Omissions of some system functions during requirements definition.
  - Productive time is not 40 hours per week per person.
  - Failure to update estimates as more information becomes available.
  - Updating of estimates not allowed by the customer, or the project manager, or upper management.
  - Unfounded optimism with developers – it is oven guessed that a job won't take longer than a few days to do, and then it eventually takes several months to do.
- Commonly used effort estimation techniques include:
  - Empirical models (algorithms for producing cost estimates, derived from previous projects). This method is widely used in software engineering project management (BOEHM 1981, BOEHM *et al* 1995, LEGG 1997, and THAYER 1997, GOUWS & GOUWS 2006a).
  - Rules of thumb (guidelines evolving over time).
  - Expert judgement (consulting one or more experts).
  - Estimation by analogy (compare on a high-level with previously completed projects).
  - Design to cost (output from each block of the WBS is matched to available resources, which are allocated top-down after an estimate had been made for the effort required to execute the total project).
  - Price-to-win estimating (cost believed necessary to get the job – typically determined by the marketing department).
  - Bottom-up estimating (effort required for execution of each component on the lowest level of a WBS is estimated, and then "rolled up" until an effort estimate is made for the total project).

This method can result in high estimates, because reserves are often built in at each level.

- Guessing ("Give me five people and one year .....").

2.3.2 Steps for Improving Effort Estimation Accuracy

- Effort estimation is a difficult, but important part of project planning; and therefore it is essential to make sure that it is done accurately (GAFFNEY & CRUICKSHANK 1997).
- As a first step, it is important to define and document the estimation process used, in order to later be able to verify why certain decisions were made.
- Use complementary estimation methods - e.g. manual estimation and a computerised estimation model - and compare their results.
- Regular reviews are essential, to adapt remaining estimates with results already achieved.
- Estimation techniques for projects within an organisation should be standardised as far as possible - and management must help enforce these standards.
- Project management resources must be made available to allow for adequate estimation (i.e. don't rush the estimation merely to get going with the project).
- A project estimation assistance team can be very useful on large projects, to help with using the available technology, perform manual estimations, help to review estimates, etc.

2.4 PROJECT SCHEDULING

2.4.1 Introduction

- A project consists of a set of well defined, related tasks culminating in a major output.
- Large engineering projects require extensive periods for completion.
- The role of the project manager is to effectively schedule, allocate, use, and replace resources (manpower, materials, money and machines) to achieve specified project goals.
- The Project Master Schedule is a valuable tool for doing this, since it tells the manager *when* the resources will be required.

2.4.2 Preparing a Project Master Schedule

- The project master schedule is a graphical representation of the timing of all project related activities required to produce a required output.
- Important steps for development of any project master schedule:
  - Compile a work breakdown structure (WBS).
  - Estimate each activity's duration.
  - Sequence the tasks:
    - indicate the sequence in which activities must be performed;
    - indicate which activities can be done in parallel; and

- indicate a start date and end date for each activity.

* Reconcile the estimated duration with the overall project time constraints.
* Reconcile the schedule with resource constraints.
* Review the schedule with knowledgeable people.

2.4.3 Scheduling Techniques

2.4.3.1 The Milestone Chart

- The milestone chart is the simplest scheduling method, and is mainly suitable for small projects.
- It provides a list of major activities to be completed, and their end dates, but it does not indicate any interrelationships between activities.
- It can be used to summarise complex schedules of large projects.
- Advantage: ease of preparation.
- Disadvantage: only shows completion dates, and not start dates too.
- The following is an example of a simple milestone chart:

No.	Task	14 Jan	21 Jan	28 Jan	4 Feb	11 Feb	18 Feb	25 Feb	4 Mar
1	Design & Build Electronics	∇							
2	Test Electronics		∇						
3	Design & Code Software				∇				
4	Test Software					∇			
5	Integrate System							∇	
6	Test Integrated System								∇

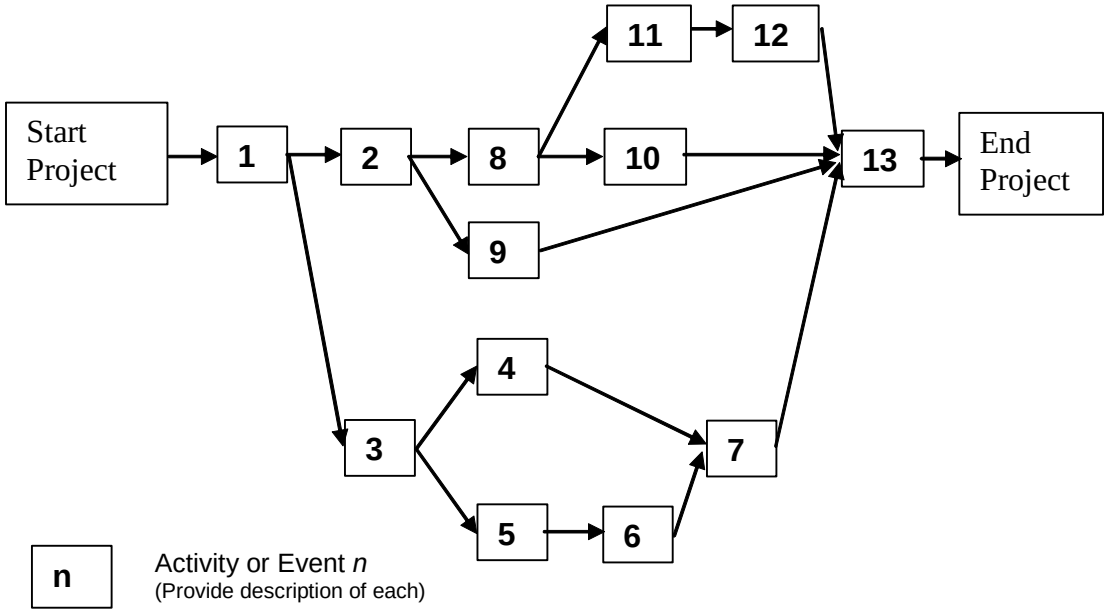
2.4.3.2 The Gantt Chart

- The Gantt chart is a list of tasks and a bar chart indicating:
  * The start date, duration (calendar time), and end data of each task.
  * The overlap between tasks.
- The main advantages of this method are:
  * it is easy to understand;
  * overlaps between tasks are clear; and
  * the start date, duration and end date of each task is very clear.
- The following is an example of a simple Gantt chart:

No.	Task	Week ending on:								
		7 Jan	14 Jan	21 Jan	28 Jan	4 Feb	11 Feb	18 Feb	25 Feb	4 Mar
1	Design & Build Electronics	XXXX	XXXX							
2	Test Electronics		XXXX	XXXX						
3	Design & Code Software	XXXX	XXXX	XXXX	XXXX	XXXX				
4	Test Software			XXXX	XXXX	XXXX	XXXX			
5	Integrate System							XXXX	XXXX	
6	Test Integrated System								XXXX	XXXX

2.4.3.3 Precedence Networks

- The most popular types of precedence networks are the critical path method (CPM) and the program evaluation and revision technique (PERT).
- CPM shows *activities* (e.g. “Design & Build Electronics”) in circles / blocks, with arrows linking the activities.
- PERT shows *events* (e.g. “Electronics designed & built”) in circles / blocks, with activities shown as arrows between events.
- PERT also shows estimated minimum, most likely, and estimated maximum duration of activities - i.e. allowing some degree of uncertainty.
- With precedence networks, the *critical path* can be identified - i.e. those activities for which schedule slip will cause overall schedule slip.
- *Float* (allowable schedule slip, without impact on overall schedule) for non-critical path activities can also be determined.
- Advantage: shows sequence, duration and interrelationships.
- Disadvantage: can be difficult to interpret.
- (Refer to BLANCHARD & FABRYCKY 1990, LANIGAN 1992, and SHTUB *et al* 1994 for detailed discussions on, and examples of PERT and CPM.)
- The following shows the structure of a simple CPM or PERT chart.



3. ORGANISING AND STAFFING AN ENGINEERING PROJECT

3.1 ORGANISING

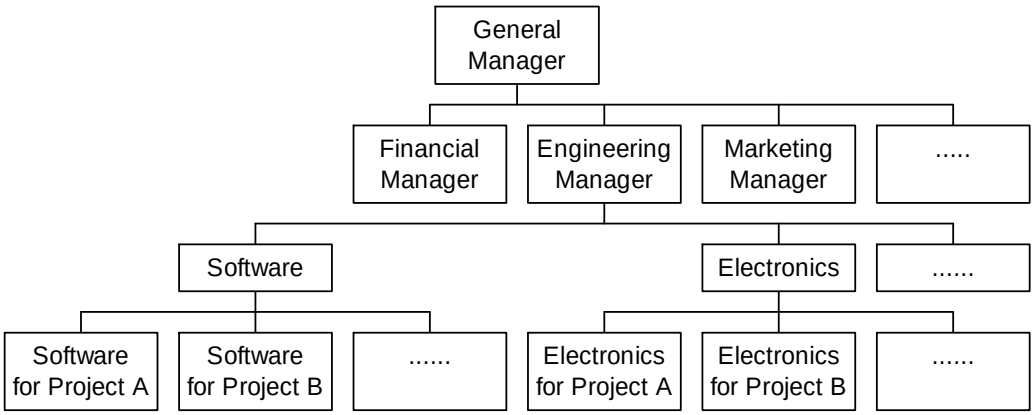
Organising involves:

- Deciding upon the most suitable organisational structure to achieve project goals.
- Choosing suitable group structures within the chosen organisational structure.
- Determining the relationships within and between these groups.
- Assignment of responsibilities to the organisational entities.
- Delegation of responsibility and authority to these organisational entities.

3.2 ORGANISATIONAL ALTERNATIVES

3.2.1 Functional Organisations

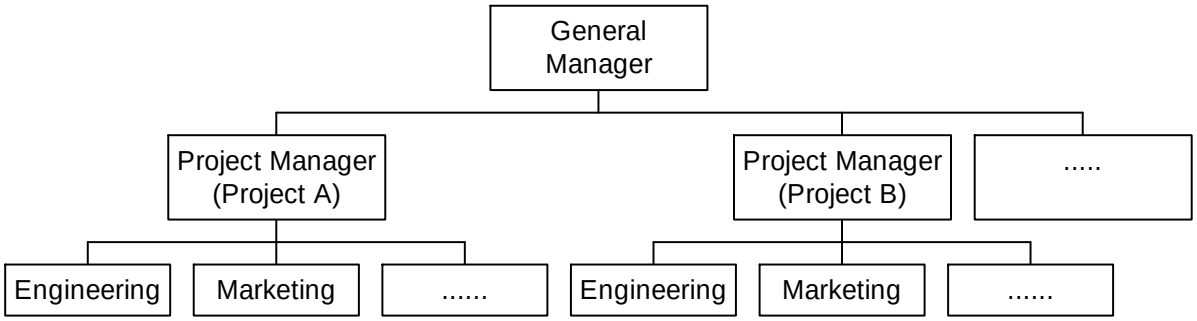
- The most common organisational structure is the functional hierarchy.
- It keeps specialists together, fragments a complex problem, and assigns it to different departments (functional lines).
- Typical functions: Engineering, Finance, Research, Marketing, Production, ...
- Each of these functions is typically further divided into sub-functions.
- The following is an example of a typical functional structure:



- (Note that each of the blocks on the second level can be divided into sub-functions as shown under "Engineering Manager".)
- Typical advantages of the functional structure:
  - centralisation of similar resources and control thereof;
  - simplified training; and
  - no duplication of similar responsibilities on different projects.
- Typical disadvantages of the functional structure:
  - difficult to prioritise different assignments when more than one project is done;
  - the functional group's goals can become more important than the project's;
  - group members don't get wider experience; and
  - difficult progress reporting when staff work and report on different projects simultaneously.

3.2.2 Project Organisations

- A Project Structure makes use of self-contained business units - each with all the necessary resources managed by a project manager.
- It keeps the problem together, fragments the departments, and assigns personnel to the project team.
- The following diagram shows an example of a typical project structure:



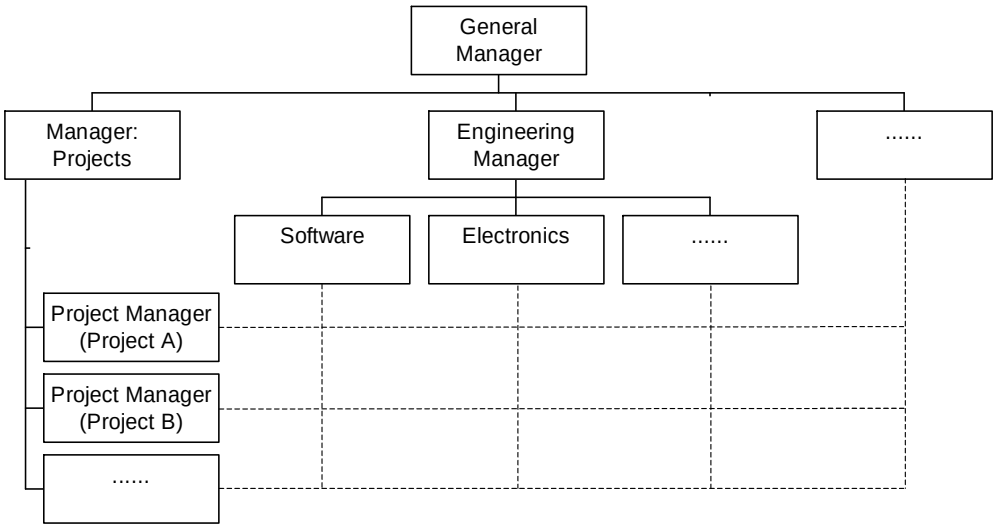
- Note that the internal structure of each project is mostly functional (engineering, marketing, finance, etc.); and that each of the blocks from the third level downwards in a project structure is

typically further divided into sub-functions as for a functional structure (figure 2).

- Typical advantages of the project structure:
  - project responsibilities are kept together;
  - effective project communication; and
  - the project manager has direct control over all resources necessary for the project.
- Typical disadvantages of a project structure:
  - staff don't have "fall-back" positions in a functional group, and must therefore be repositioned after each project;
  - structures change as projects mature - e.g. some resources become redundant;
  - duplication of facilities; and
  - lack of strategic control of resources.
- Successful project organisations require project managers with broad general management skills, as well as technical knowledge.

3.2.3 Matrix Organisations

- Matrix organisations superimpose functional- and project organisations.
- It keeps specialists together, keeps the problem together, and transfers specialists to a project team on an as-required basis.
- Staff have "home bases" under the functional groups, but are seconded to projects, when required.
- Example of a typical matrix structure:



- Typical advantages of the matrix structure:
  - resources no longer required on a project can be reassigned by the functional group;
  - staff don't loose their positions in the functional group - i.e. they have better job security; and
  - no unnecessary duplication of facilities.
- Typical disadvantages of the matrix structure (which can be alleviated by proper definition of roles):

- each staff member has two bosses; and
- conflicts between project- and functional managers.

3.2.4 Selecting an Organisational Structure

- There is no "best" organisational structure.
- To decide on the most suitable organisational structure, questions such as the following must be answered:
  - How will each structure add value to the organisation ?
  - Will the structure be flexible enough to handle changes ?
  - What are the advantages and the disadvantages of each structure in the specific organisation?
- Different structures can be used for different projects in the same organisation - depending on what is best for each situation.

3.3 TEAM STRUCTURES

3.3.1 Introduction

- A project team is small group functioning within a chosen organisational structure.
- It can be a software design team, or a software coding team, or a product testing team, or a hardware design team, or a maintenance management team, etc.
- There are three main types of team structures – depending on the amount of centralisation and control used – as discussed in sections 3.3.2 to 3.3.4 below.

3.3.2 The Democratic Decentralised Team

- This team structure is typically used for teams of ten or less persons, who:
  - exchange their work with each other for examination;
  - set goals by group consensus;
  - rotate group leadership (assigned to the individual who is most suited to lead in a specific situation); and
  - communicate freely with each other.
- It is also known as Weinberg's Team Structure (WEINBERG 1971).
- This type of structure can be very time consuming, due to excessive democracy and communication, making it unsuitable for projects with tight schedules.
- Some democracy can be beneficial for complex projects, while autocracy often works best for simple projects.
- Excessive democracy can lead to the syndrome where "everybody" thinks "somebody" will do the work, and eventually "nobody" does it.

3.3.3 The Controlled Centralised Team Structure

- This is typically a two-level hierarchical model, with a team leader managing a number of team members (also known as Baker's team structure - BAKER 1972).
- Communication is limited to that between the team leader and the team members.
- The management style is largely autocratic, with goals set from the top.
- The main problem with this structure is "information overload" at the top of the structure, since the team leader acts as the communication node for the whole team.
- The team leader must have excellent technical abilities, plus extraordinary communication and management skills - which is often a rare combination.
- Depending on individuals' needs, some can be dissatisfied by the autocracy, while others might appreciate the opportunity to focus on the technical work, while the team leader takes care of other aspects.

3.3.4 The Controlled Decentralised Team Structure

- In practice, team structures vary considerably, and are mostly a mix of the Weinberg and the Baker structures.
- The controlled decentralised team is typically a three-level hierarchical structure, with a project leader, managing some senior team members, who in turn manage junior team members.
- Communication between team members at different levels of the hierarchy takes place freely; while the team leader is simultaneously kept well informed of all activities.
- This approach is suitable for large teams, with short schedules (requiring strict control).

3.3.5 Choosing a Team Structure

- The recommended team structure depends on factors such as:
  - Difficulty of the task.
  - Extent of the work.
  - Project duration.
  - Modularity of the task.
  - Available time (schedule).
  - Required communication between team members.
- The following table can help to choose a suitable team structure, depending on the above factors:

Group Structure	Difficulty		Extent		Duration		Modularity		Schedule		Communi-cation	
	High	Low	Large	Small	Short	Long	High	Low	Strict	Lax	High	Low
Weinberg	√			√		√		√		√	√	
Controlled Decentralised		√	√		√		√			√		√
Baker		√	√		√		√		√			√

- The more difficult a task is, the more group initiative (democracy) is required to solve it.
- The larger a task is, the more control (structure) is required to solve it.
- The longer a task's duration, the less rigid (more democratic) the control must be to ensure sustained group morale.
- High task modularity ensures that independent tasks can be assigned to group members in a highly controlled team.
- Decentralised groups take longer to complete tasks than centralised groups, making decentralised structures more suitable when schedule requirements are lax.
- Extensive communications requirements are fostered by the style of the democratic decentralised structure.

3.4 STAFFING AN ENGINEERING PROJECT

- *Staffing* covers all activities involved in filling and keeping filled the positions established in the organisational structure.
- Staffing includes:
  - defining the extents of different jobs in the organisation;
  - recruiting and selecting suitable candidates;
  - training new candidates and existing incumbents to accomplish their tasks effectively;
  - appraising performance;
  - compensating; and
  - redeployment or termination when the organisational position or the incumbent is no longer necessary.
- The lecture *Staffing for Engineering Projects* addresses staffing in more detail.

4. DIRECTING AN ENGINEERING PROJECT

4.1 INTRODUCTION

- *Directing* entails all management activities dealing with aspects such as leadership, delegation,

and career planning aimed at motivating employees to follow a specific course of action.

- Once employees have been appointed and oriented, the manager has a continuing responsibility for monitoring their assignments, and motivating them to perform to the best of their abilities.

4.2 LEADERSHIP: THE EFFECTIVE USE OF POWER

4.2.1 Introduction

An effective leader is a person who can:

- make other people feel strong and in control, and help them to feel they have the ability to influence their future and their environment;
- build others' trust in the leader;
- structure co-operative- rather then competitive relationships;
- resolve conflicts by mutual discussion of issues instead of avoidance or forcing; and
- stimulate and promote goal-oriented thinking and behaviour.

4.2.2 Types of Power

- Power is the ability of one person to influence another; and there are different types of power.
- Reward power:
  - Based on one person's ability to reward others.
  - Example: being in a position to give raises, bonuses, promotion, or more job responsibility.
- Coercive power:
  - Based on one person's ability to punish others.
  - Example: being in a position to reprimand, withhold rewards, or deny promotion.
- Expert power:
  - Based on a person's expertise and knowledge.
  - Example: being aware of new trends, having knowledge of new methodologies and having experience.
- Identification / Personal power:
  - Based on one person's perception of similarity with another person, and the desire to be like that other person.
  - Often based on one person's liking / trusting of another.
- Legitimate / Position power:
  - Stems from acceptance of a social structure, and from the power given by a legitimising agent.
  - Examples: employees accept instructions from their manager, since the manager is entitled to give them instructions; and military orders.

4.2.3 Making People Feel Strong

- When a person feels strong (in control), he/she enjoys the work, feels involved, and is motivated to continue.

- The opposite is true for people feeling weak (out of control).
- Using reward-, coercive- and legitimate power makes people feel weak and not in control.
- Using expert- and identification power makes people feel strong.
- An effective leader helps subordinates to set meaningful goals.
- People work better if they know what is expected, and if they were involved in deciding that.
- Participation of subordinates in goal-setting allows the leader to use more identification power than reward, or coercive, or legitimate power.

4.3 DELEGATION

- Most managers realise that the best way to get their work done is to make optimum use of others.
- However, most managers don't delegate as much as they should.
- Effective delegation is one of the most difficult managerial tasks, and it depends on:
  - the relationship and mutual trust between the manager, subordinates and higher level management; and
  - the type of organisation and its goals.
- Most employees are eager to face tasks delegated to them, instead of merely doing *ad hoc* pieces of work.
- It is important for managers to instruct subordinates to accomplish certain results (what), rather than to perform certain activities (how).
- A prime requisite for effective delegation is a comprehensive inventory of subordinates' capabilities: skills, qualifications, experience, special talents, interests, motivations, attitude, potential and limitations.
- These capabilities should be assessed in conjunction with the subordinate.
- Delegation should help an employee develop both skills and judgement.
- If a subordinate is held responsible, the authority to make decisions must go with the delegation.
- Effective delegation includes the right to make decisions and mistakes.
- Delegation requires meticulous planning: task breakdown; setting of objectives; deciding by whom, and how well it should be done; and estimating how long it should take.
- Typical reasons why managers don't delegate include:
  - Lack of confidence in subordinates.
  - Poor definition of duties (if a manager is unsure of his/her responsibilities and authority, these cannot be delegated).
  - Aversion to risk-taking (fear that something might go wrong when a task is delegated).
  - Fear of subordinates as competitors (fear that subordinates might take over).
  - An inflated self-image (manager considers him-/herself to be the kingpin in the organisation, who must be involved in everything).
  - Equating action with productivity (the manager wants to feel "hands-on busy").

- Fear of appearing lazy (fear that superiors or subordinates might consider delegation as a way to avoid work).
- Poor example (when top managers don't delegate, the next level managers also don't delegate).

4.4 GOAL SETTING AND CAREER PLANNING

- Goal setting and career planning are essential to keep good team members, and also essential parts of directing a project.
- It is very important to take the person's own goals and needs into account when planning someone's career - not everyone is interested in moving to the next higher level job.
- The four main steps of career planning are:
  - discuss the individual's needs and aspirations with him/her;
  - compare the person's current job description with that of the job aspired for;
  - list and analyse the person's strengths and weaknesses in the current job; and
  - prepare a set of actions, intended results, and how success will be measured.

5. CONTROLLING AN ENGINEERING PROJECT

5.1 FUNDAMENTALS OF PROJECT CONTROL

5.1.1 Purpose and Scope of Project Control

- Project control (THAMHAIN & WILEMON 1986) can only take place after desired performance had been defined in the *planning* stage of project management.
- Project control broadly involves:
  - measurement of progress and actual performance;
  - comparing actual performance with desired performance;
  - revealing deviations between actual- and desired performance; and
  - implementation of corrective actions in order to close the gap between actual- and desired performance.
- Effective project control means:
  - to meet schedule, cost and functionality requirements for a specific project; and
  - to do this consistently from project to project.

5.1.2 Measurement as the Basis of Control

- In order to exercise control, desired outcomes must be defined first, and then steps must be taken to ensure that the actual outcomes meet the desired ones.
- You can't control what you can't measure; and you can't measure what you can't define.

- Project control therefore strongly relies on proper requirements definition, and on progress measurement.
- Project control is similar to a digital control system:
  - It cannot tolerate a too small or a too large sampling frequency.
  - A too low sampling frequency (large sampling period) causes important events to be missed by the measurement process, leading to the control system responding to these events.
  - A too high sampling frequency (small sampling period) causes information overload for the control system.

5.1.3 Binary Reporting

- Once an agreed-upon project plan (requirements definition, work breakdown, schedule, resource definition, and allocation of responsibilities) is in place, performance must be measured against it.
- It is important to know when a project is falling behind schedule, or spending too much resources, so that corrective actions can be taken.
- It is easier to correct small deviations than large ones.
- "To measure is to know", and accurate measurement is the basis of good control.
- However, measurement of project progress is one of the most difficult tasks in management.
- The hurdle to overcome is to have concrete evidence of the amount of work performed, instead of just knowing how much effort had been spent.
- It is possible to spend 100% of the planned resources, without accomplishing any of the goals of the project.
- When tasks are too large, progress is typically reported in terms of effort spent - i.e. how much resources had been used, instead of how much of the planned work had been done, and how much money had been earned by doing the work.
- Reporting on effort spent leads to the "90% syndrome", where team members typically report that tasks are "90% complete", for several weeks.
- This is only overcome by lower-level definition of tasks, with well-defined and tangible outputs.
- A rule of thumb for task sizing is that task duration should typically be one to six weeks or between 40 and 500 staff hours.
- Although a too fine resolution can lead to micro-management, it is very helpful for close monitoring and control.
- By using small tasks, binary reporting (complete / incomplete) can be used.
- This provides the project manager with an indication of progress, instead of effort spent.

5.2 QUALITY ASSURANCE

5.2.1 Introduction

- Ensuring product quality is often considered to be a primary aim of project control.

- Quality assurance relies on proper development processes and checks during all phases of development.
- Quality assurance focuses on:
  - continuous improvement of a process, through audits and analysis;
  - defect prevention;
  - product analysis; and
  - product testing (from the smallest building block level to the total system level).
- It is uncommon to find quality problems where strict project control was executed.

5.2.2 Major Techniques of Quality Assurance

The major techniques used for product quality assurance, are:

- Process and product audits, to ensure that both process (the "creating system") and product (the "created system") have the desired characteristics (BERNSTEIN 1981).
- Product testing, according to test plans and procedures.
- Design reviews, in order to have work reviewed, and to get inputs from other team members.
- Configuration Management, to ensure that changes to documents and products are made in a structured manner.
- Trend data, used as measurable performance parameters, or indicators of project status.
- Failure analysis, to find root causes of failures; and weak spots in the development process.
- Pareto analysis, to find those components which cause the most defects. (This type of analysis is based on an observation made by Pareto in the early 1900s that about 20% of the population in many countries typically control 80% of resources. This principle generally applies to many aspects of life, e.g. in many technical systems 20% of the components cause 80% of the defects.)
- Early defect removal: The earlier a problem is found, the cheaper it is to fix.
- Adherence to task entry / exit criteria: Ensuring that a task is not started before all entry criteria had been met, or that task execution is not stopped before all exit criteria had been met, is an important project control aspect.

5.3 PROJECT DOCUMENTATION

- For effective project control it is essential that reasons for decisions can be traced again later.
- This is only possible if all aspects of the project are properly documented, and if the documents, as well as the delivered products are placed under configuration control.
- No project can be executed successfully if the team members consider documentation as yet another *necessary evil.*
- Only well-structured documents can ensure the same baseline for interpretation of a project's goals and objectives, for understanding requirements, for measuring progress, etc.
- Project team members tend to think much more carefully about their ideas, when they have to

write it down.

- Proper project documentation therefore ensures clearer project communication, by:
  - linking the management functions (planning, organising, staffing, directing and controlling) with each other;
  - making goals and objectives clear; and
  - linking the project with its external environment.
- Refer to the lecture on Communication and Documentation; and to the three eBooks by GOUWS & GOUWS (2006b,c,d) for more information on proper project documentation.

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7. SELF-ASSESSMENT

7.1 TRUE / FALSE QUESTIONS

Indicate which of the following statements are TRUE and which are FALSE.

1. The sole purpose of planning an engineering project is to decide by whom tasks must be done.
2. Some engineers feel that planning is unnecessary or a waste of time.
3. Forecasting future situations is not part of project planning.
4. The goal of the requirements phase is to decide whom to appoint.
5. After requirements definition, a project must be broken down into smaller tasks.
6. Effort estimation is the same as budgeting.
7. The most common organisational structure is the functional structure.
8. Successful project organisations require project managers with broad general management skills, as well as technical knowledge.
9. Matrix organisations superimpose functional- and project organisations.
10. Different organisational structures cannot be used simultaneously in the same organisation.
11. Once employees have been appointed and oriented, they should be left alone to carry on with their work.
12. Power is the ability of one person to instruct another on what to do.
13. Using reward-, coercive- and legitimate power makes people feel strong and in control.
14. Most managers don't delegate as much as they should.

15. Effective delegation is not a difficult task.
16. Project control can only take place after desired performance had been defined.
17. A rule of thumb for task sizing is that task duration should typically be one to six months long.
18. It is common to find quality problems where strict project control was executed.
19. Proper project documentation ensures clearer project communication.
20. A Project Management Plan is an important document for project control.

7.2 MULTIPLE CHOICE QUESTIONS

Choose the one correct answer for each of the following questions:

1. The purpose of planning an engineering project is to establish a foundation for execution and successful completion of the project, by deciding in advance:
   a. What to do, with what to do it, and when to do the work.
   b. By whom the tasks must be done.
   c. Both (a) and (b).
   d. None of the above.
2. The most likely phases of a project for which the engineering manager and his/her department will have direct responsibility, include:
   a. Planning, Design, and Marketing.
   b. Planning, Design, and Implementation.
   c. Planning, Design, Implementation, and Building customer relations.
   d. Requirements definition, Design, Sales, Implementation, and Maintenance.
3. Which of the following is not a major issue in estimating system development effort ?
   a. Lack of historical data.
   b. Lack of experience by the estimator.
   c. Omissions of some system functions during requirements definition.
   d. Unfounded pessimism with marketing personnel.
4. Which scheduling technique is commonly considered to be the simplest one ?
   a. Gantt chart.
   b. PERT diagram.
   c. Guessing.
   d. Milestone chart.
5. Organising a project includes:
   a. Deciding upon the most suitable financial structure to achieve budget objectives.
   b. Choosing suitable group structures within the chosen organisational structure.
   c. Determining the relationships with competitors.
   d. All the above.
6. A typical disadvantage of the functional structure is:
   a. Ease of assigning responsibility when more than one project is done.
   b. The functional group's goals can become more important than the project's.

c. Group members get too wide experience.
d. Difficult progress reporting when staff report on one project at a time.

7. A typical advantage of a project organisation is:
   a. There is only one boss (unity of command).
   b. Ineffective communication.
   c. The project manager does not have to worry about the resources necessary for the project.
   d. None of the above.
8. There is no “best” organisational structure. The best way to decide on a structure, is to ask:
   a. How will each structure add value ?
   b. Will the structure be flexible enough to handle changes ?
   c. What is best for the manager ?
   d. Both (a) and (b).
9. The most fundamental part of staffing is:
   a. Finding suitable candidates to fill the organisational structure, and to keep the structure filled.
   b. Training staff who don’t want to learn.
   c. Both (a) and (b).
   d. None of the above.
10. Directing a project involves:
   a. Leadership and delegation.
   b. Deciding what to do.
   c. Doing the work when you can.
   d. All the above.
11. Effective delegation is one of the most difficult managerial tasks, and it depends on:
   a. The relationship and mutual trust between the manager and others.
   b. The type of organisation and its goals.
   c. Both (a) and (b).
   d. None of the above.
12. A typical reason why managers don’t delegate is:
   a. Lack of confidence in their managers.
   b. Fear of subordinates as competitors.
   c. Fear of appearing too eager.
   d. Delegation is only viable in large organisations.
13. Effective project control means:
   a. To meet schedule, cost and functionality requirements for a specific project.
   b. To do (a) consistently from project to project.
   c. Ensuring that a project makes money.
   d. None of the above.
14. Binary reporting involves:
   a. A manager can decide whether to do a task or not.
   b. All tasks are reported on two-weekly.

c. A task is not reported on when it is incomplete.
d. A task is either reported to be complete or to be incomplete.

15. Quality assurance focuses on:
    a. Sporadic improvement of processes.
    b. Defect prevention.
    c. Product analysis and synthesis.
    d. All the above.

7.3 ESSAY QUESTIONS

Write an essay of 300 to 400 words on one of the following topics. Do not merely copy the course notes, but write the essay **in your own words** such that your understanding of the topic becomes clear.

1. Discuss the high-level procedures for effectively managing an engineering project.
2. Discuss the stages and major issues involved in planning an engineering project.
3. Discuss the stages and major issues involved in organising and staffing an engineering project.
4. Discuss the stages and major issues involved in leading / directing an engineering project.
5. Discuss the stages and major issues involved in controlling an engineering project.

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