CHAPTER 2

Literature Review

2.1 Introduction

This chapter concerns the theories related to this research. First, project management concept in general is discussed. Then project elements are discussed with special attention on project planning, project scheduling, and resource allocation. By the end of this chapter, reader should be presented with some information about tools and techniques that will be used in this research to deal with problems for the case company.

2.2 Definition of project

First of all, what involves in project management must be defined. In the very beginning, what is a project. Project Management Institute has given a definition of project as “a temporary endeavor undertaken to create a unique product or service” (PMI, 1996). The keyword here is temporary because project is different from operations in terms of the frequency of the work. Operation is what a company does everyday and mostly repetitive, on the other hand project is normally unique from one another. Project also has a definite beginning and a definite end that is why it is temporary. Lewis (2001, 5) has given the definition of project as a multi-task, one-time job that has definite starting and ending point with clearly defined scope and budget, and mostly it will be performed by a temporary team.

Many authors also give similar definitions for project which discusses basically the same thing. Project is temporary, unique, and definite start and stop time. There are many different type and size of project in the company. To give an example, a big project might be construction project which involve the whole company and a small project could be project for procuring office equipment. Everyone is involved with project one way or another, hence project management should be a topic that every company should pay attention to.

2.3 What is Project Management?

Project Management is the application of knowledge, skills, tools, and techniques in order to exceeds stakeholders needs and expectations from a project (Duncan, 1996). While Martin and Tate (2001, 9) have compared project management to a game plan in american football for project team member being the player and project manager being the coach. To put in another word, project management is an approach or a process of applying the knowledge, skills, tools, and techniques to manage the project. It is not required that everyone who involves in project should practice project management, however, the use of project management will help control time and money. As Meredith and Mantel (2000, 12) mention, a proper use of project management by many companies indicates that they are experiencing better control, better customer relations, and increase return on investment. Other benefits from the users also include shorter development times, lower costs, higher quality and reliability, and higher profit margins. Therefore, project management is acting as a tool to manage project more effectively and it is undeniably an essential part of doing projects.

2.4 Project Phases and Project Life Cycle

Duncan (1996, 11) has defined these processes in the form of project phases or project life cycle. By dividing project into phrases, it becomes easier to manage and control the project as a whole. Each phase will have its own indicators or deliverables that will be measured and decided that the project is ready to move on to the next phase. The sample generic project life cycle is shown in the figure below.

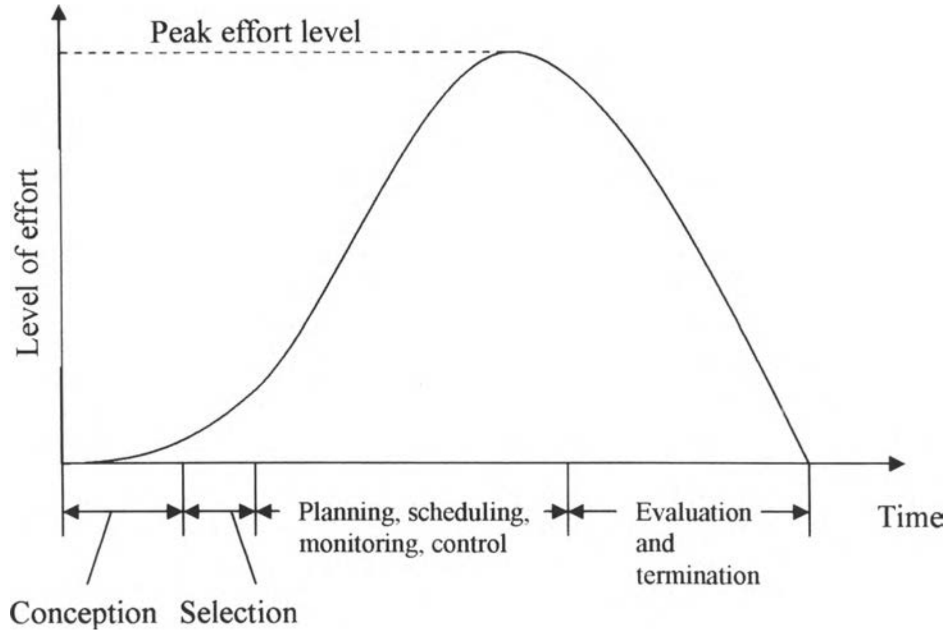

Figure 2.1Generic Project Life Cycle

For each stage or phase of the project, there are different activities level and effort level required. The effort in this case means both cost and staffing. Each phase also consists of many processes and each process will be dealt with separately.

The project life cycle is different from business to business. Since our research is conducted on a mechanical and electrical installation of water treatment plant project, it is somewhat related to the construction project. The representative construction project life cycle is shown below (Duncan, 1996:14).

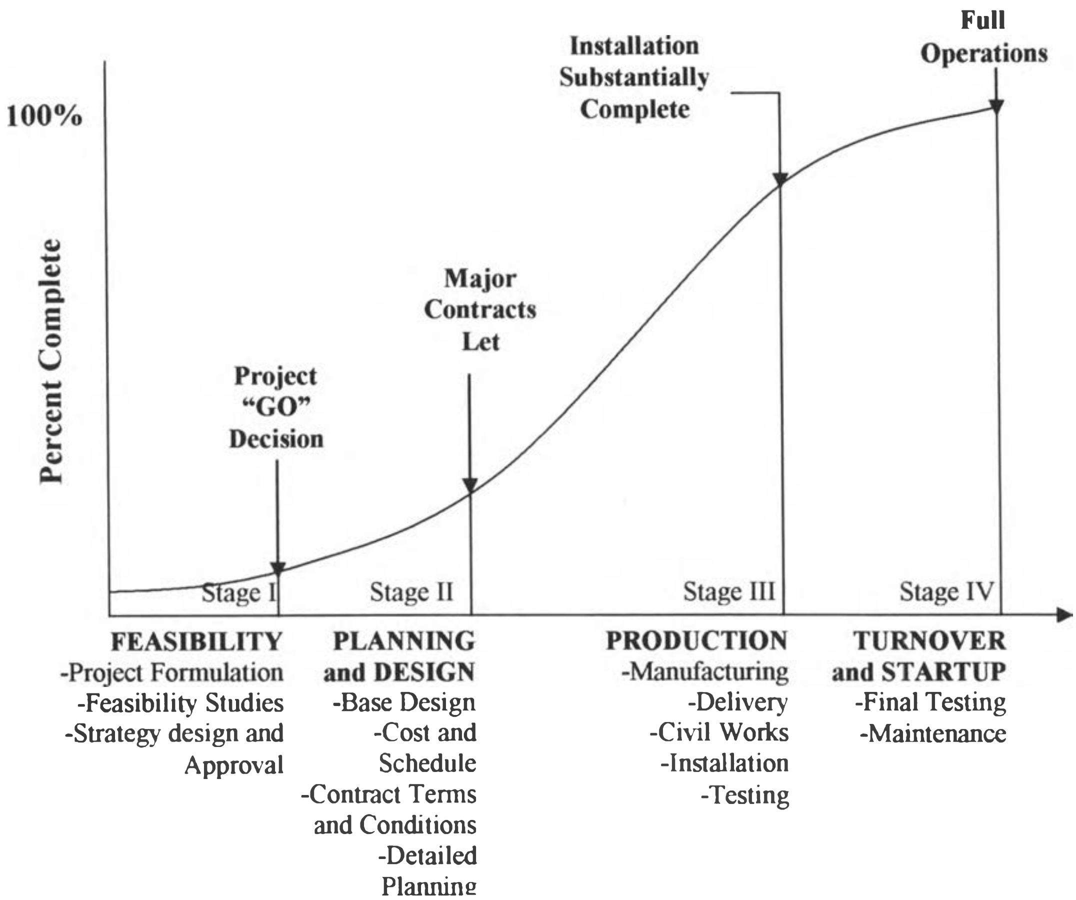

Figure 2.2 Example of Project Life Cycle for Construction Project

In this section only the general ideas of what each phase means and involves will be discussed. The detailed discussion will be in later sections.

- Feasibility – This phase is mostly involve paper and office work which involves many people from engineers to management. The feasibility phase includes project formulation, feasibility studies, and strategies design and approval. At the end of this phase, a decision of go or no-go is made.
- Planning and Design – This phase probably means the heart of the project because successful project requires careful planning. The planning and design phase includes base design, cost and schedule, contract terms and conditions, and detailed planning. At the end of this phase major contracts are let.
- Production – This phase should be directly link from the planning and design, however some changes might occur that could alter the schedule and the company

should be ready to handle the situations. The production phase includes manufacturing, delivery, civil works, installation, and testing. At the end of this phase, the installation or construction is substantially completed.

- Turnover and Startup – The final phase is wrapping up the work and handing over, the effort of this level is much lower than that in production phase. The turnover and startup phase includes final testing and maintenance. At the end of this phase, the facility is in full operations.

2.5 Project Processes

According to Duncan (1996, 28) each phase in the life cycle consists of number of processes that come together. The relationship between these processed can be shown in the figure where arrows represent flow of documents and documentable items.

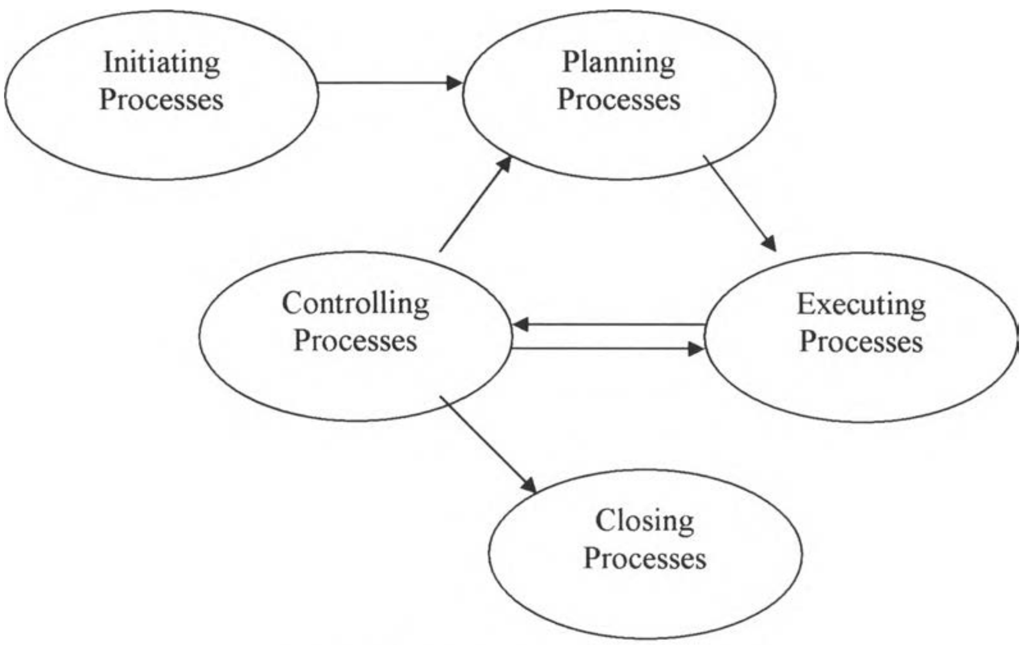

Figure 2.3 Typical Project Processes

2.5.1 Initiating Processes

It is important to repeat the initiation process at the beginning of each phase in order to keep the goal of the project focused. Other than that initiating process will set up and guide the team through the phase.

2.5.2 Planning Processes

The planning processes are important in project management and it is our research focus. The process divides into core processes and facilitating processes. The core processes include scope planning, resource planning, cost estimating, schedule development, project plan development, and etc. The facilitating processes include quality planning, organizational planning, procurement planning, and etc. The topic of our research is implementing information system in project management and in the planning process, this is one are where information system can be used very effectively.

2.5.3 Executing Processes

The executing processes include the core processes and facilitating processes as in planning processes. The only core process in executing processes is project plan execution, however the facilitating processes play important role in helping the execution to achieve targets. Examples of facilitating processes are scope verification, quality assurance, team development, information distribution, solicitation, source selection, and contract administration.

2.5.4 Controlling Processes

The objective of the controlling processes is to measure project performance whether it is keeping up with the plan or not. The controlling processes also consist of core processes and facilitating processes. The core processes are Performance reporting and overall change control. The facilitating processes are scope change control, schedule control, cost control, quality control, and risk response control.

2.5.5 Closing Processes

The closing processes consist of contract close-out and administrative closure.

2.6 Project Management Knowledge Areas

In this section of project management knowledge areas, some of the topics, namely project planning, scheduling, and resource allocation, that related to our research will be discussed. The information presented in this section is mainly the overview and what are required in each step, such as inputs. Probably the most useful information is tools and techniques required in each step in which will be taken and apply to the case company in chapter 4.

According to Duncan (1996, 37), he divides the project management into many different areas namely:

- Project Integration Management
- Project Scope Management
- Project Time Management
- Project Cost Management
- Project Quality Management
- Project Human Resource Management
- Project Communications Management
- Project Risk Management
- Project Procurement Management

The project integration management, project time management, and project cost management are directly related to our topic of project planning, scheduling, and control. Special attention should be paid to project plan development (project integration management), schedule development (project time management), and resource planning (project cost management).

2.7 Project Integration Management

Project integration management includes processes required to ensure that every elements of the project are coordinated properly (Duncan, 1996). The three main processes in the project integration management are:

- Project Plan Development
- Project Plan Execution
- Overall Change Control

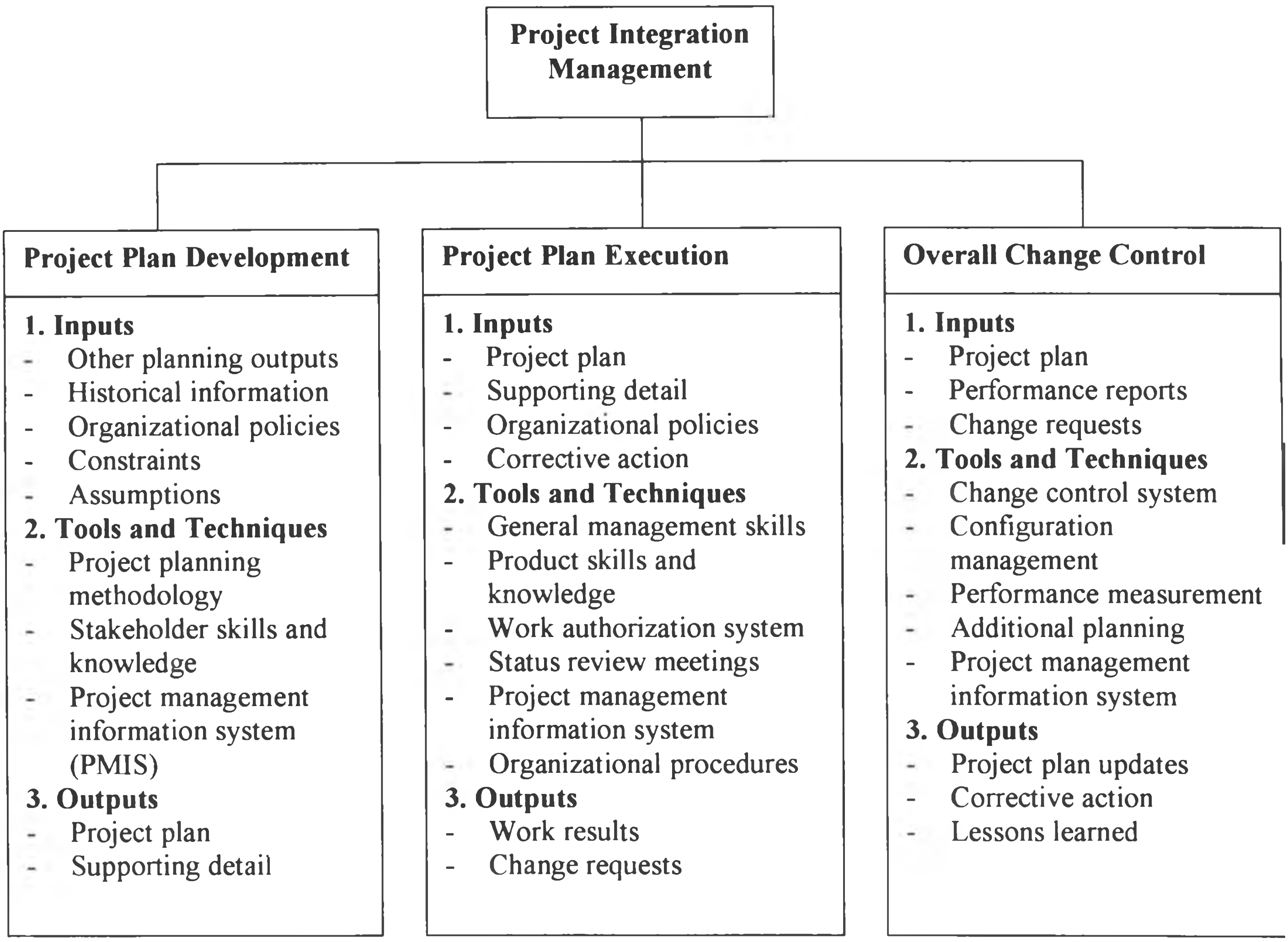

Figure 2.4 Project Integration Management Overview

2.7.1 Project Plan Development

The purpose for project plan development is to use the outputs from other planning processes to create a guide for project execution and project control. The use of the project plan is to (Duncan, 1996):

- Guide project execution
- Document project planning assumptions.
- Document project planning decisions regarding alternatives chosen.

- Facilitate communication among stakeholders.
- Define key management reviews as to content, extent, and timing.
- Provide a baseline for progress measurement and project control.

2.7.1.1 Inputs to Project Plan Development

The inputs to project plan development mean what is needed to develop a project plan. In this case, there are:

1) Other planning outputs – as discussed earlier, these include outputs from scope planning, scope definition, activity definition, resource planning, cost estimating, etc.
2) Historical information – the use of historical information also benefits the planning process.
3) Organizational policies – organizational policies are different form company to company, therefore they must be taken into consideration while planning the project. These policies may include but not limited to quality management, personnel administration, and financial controls.
4) Constraints – constraints such as predefined budget or contractual provisions must be considered while planning.
5) Assumptions – a company might require to make some assumptions while develop a plan but they have to keep in mind that assumptions generally involve a degree of risk.

2.7.1.2 Tools and Techniques for Project Plan Development

Tools and techniques that generally use in project plan development include:

1) Project planning methodology – a structured approach used to guide the project team in developing a project plan. This is what will be developed in this research, a project planning methodology for mechanical and electrical installation for water treatment plant. The tools used in project planning methodology include from project management software to facilitated start-up meeting.

2) Stakeholder skills and knowledge – The skills and knowledge of stakeholders can be used as a tool to help in project plan development. The problem could be how to get the stakeholders to contribute effectively.
3) Project management information system (PMIS) – a project management information system consists of tools and techniques that are used to gather information from other processes. The project management information system is not only used in the planning process but it is usually applied throughout the project. The PMIS will also be focused on during system design.

2.7.1.3 Outputs from Project Plan Development

The output from project plan development is definitely a project plan and also there is supporting detail. A project plan is a formal, approved document that is used to manage and control project execution (Duncan, 1996). However, it has to be kept in mind that the project plan is not definite and can be changed overtime according to circumstances. Supporting detail is mostly other documents that are generated from the development process that can be used facilitate the execution process.

2.7.2 Project Plan Execution

Project plan execution is the process of carrying out the project plan and majority of the budget will be spent in this process.

2.7.2.1 Inputs to Project Plan Execution

The project plan execution uses the project plan and supporting detail that were developed from project plan development process. It also uses the organizational policies and corrective action.

2.7.2.2 Tools and Techniques for Project Plan Execution

The tools and techniques use in the project plan execution is general management skills such as leadership, communicating, and negotiating are basis for successful project execution. Other tools and techniques include product skills and knowledge which the project team must have. Work authorization system ensures the work is done in the right time and order. Status review meeting is another way to communicate and update information in the project team. Organizational procedures must be followed and lastly project management information system must be applied.

2.7.2.3 Outputs from Project Plan Execution

The outputs from project plan execution are the work results and change requests. The information on work results is collected in order to put into performance reporting process. The change requests are generated as the work is done. The change could be scope modification to cost or schedule change, and etc.

2.7.3 Overall Change Control

Overall change control is concerned with:

- Influencing the factors that create changes to ensure that those changes are beneficial
- Determining that the change has occurred
- Managing the changes as they occur.

2.7.3.1 Inputs to Overall Change Control

There are three important inputs to overall change control. First is project plan which provides a baseline in which the changes will be controlled. Second is performance report which identifies issues that could cause problems in the future. Last is change requests which generated from project plan execution process.

2.7.3.2 Tools and Techniques for Overall Change Control

A change control system which is a formal, documented procedures that defines the steps in which the project documents may change will be used. Performance measurement is also used to determine how effective the change is and additional planning may be needed as the plan may have changed according to the changes.

2.7.3.3 Outputs from Overall Change Control

The outputs from overall change control includes project plan updates which is the modification of the original project plan. Corrective action which suggests what needs to be corrected in order to bring the future project performance in line with the project plan. Lastly is the lesson learned from the changes which can be used in the future project as historical information.

2.8 Theory on Project Planning

Many authors have discussed how important of planning in project management, but it does not matter how good a plan is if it has not been put into work. Therefore, a good planning should be plans that can translate to hard work and a successful completion of the project (Meredith and Mantel, 2000).

According to Meredith and Mantel (2000, 182), the primary purpose of planning is to establish a set of directions so that the project team knows what must be done, when it must be done, and what resources to use in order to successfully produce the deliverables. The deliverables in this case include the product or service required by the client or contractor, time and cost to complete the project to client or contractor's satisfaction, and the plan must be designed so that the project outcomes meet with the firm's objective. The plan should be adjustable because the nature or scope of work could change at any time during the life of project. Lastly, a plan must include ways of controlling the work it prescribes.

2.8.1 Initial Project Coordination

Initial project coordination, or project launch meeting, is set up so that senior management can inform the rest of the company of what is the firm's intent in taking on the project, outline the scope of project, and describe the project's desired results. Those who run the meeting should first define the scope of the project. This is to set everybody up and make sure they are on the same page before the project started. The launch meeting is considered to be successful if those who lead the meeting can get their points across.

The outcome of the initial project coordination should be that:

1) Technical scope is established, however it is not definite and can be changed.
2) Basic areas of performance responsibility are assigned and accepted by participants.
3) Estimated budgets and schedules are generated by those in charge.

By the next meeting, those who have had responsibility in the areas should prepare a preliminary plan which contains descriptions of the required tasks and estimates of the budgets and schedules. These preliminary plans are gathered together by project manager to compose a composite plan. Any change to composite plan must be made by processing a formal change order. When all the changes have been made, then this composite plan becomes a master or baseline plan.

As initial project coordination concerns with all departments, every department should at least send a representative to attend the meeting. The meeting should probably be lead by project manager while senior management should be presented to observe the meeting.

2.8.2 Outside Clients

If the project involves producing product or service for outside clients or contractors, then clients' or contractors' permission needs to be obtained before any changes made to the specification. This is important during the initial meeting because the scope or nature of work can be changed during the process of planning. It is basically the same thing for letting people involve in the areas know if a change takes place in the project, clients or contractors deserve the same rights.

The most common problem faced with outside clients is that marketing team promises something that engineering team may not know how to produce on a schedule that manufacturing team may be unable to meet. This is a result of lack of involvement of all departments. The solution to this problem is concurrent engineering or multifunctional team during the planning process. The use of concurrent engineering or multifunctional team in planning process will help reduce problems in the earlier phase, hence it could save the company both time and money.

2.8.3 Project Elements

The process of developing project plan different from company to company. The elements of the project are also varies depend on the type of project, however the common elements for project plan are:

- Overview – overview contains a short summary of objectives and scope of the project. It is directed to top management, as in executive summary, and contains statement of the goals of the project, how it is related to the firm's objectives, managerial structure that will be used in the project, and a list of milestone in the project schedule.
- Objectives – this is a more detailed version of general goals already stated in the overview. The objectives should include profit, competitive aims, and technical goals.
- General Approach – general approach includes both the managerial and technical approaches to the project. The managerial approach discusses some procedures that might be different from the normal procedure for the firm. Technical approach discusses how the available technologies apply to the project.
- Contractual Aspects – this section is very important because it is related to contract. Things that should be include in this section include complete list and description of reporting documents, customer-supplied resources, liaison arrangements, project review and cancellation procedures, etc.
- Schedules – this section outlines the schedules and lists of milestone events. The estimated time, obtained by those who responsible for the tasks, should also be listed for each task. This information will be used to develop project master schedule.
- Resources – resources generally mean two things; budget and cost monitoring and control procedures. The capital and expenses requirements are listed by task, and therefore composed a *project budget*. Cost monitoring and control procedures are used for non-routine elements such as special machines, test equipment, laboratory usage or construction, etc.
- Personnel – personnel section describes the requirements for the personnel needed in the project. Special skills, types of training, recruiting problems, and other related topics should be listed here in this section. Because personnel is directly

related to project budget, it is wise to include personnel in project schedule so it is known when the personnel are needed and in what numbers.

- Evaluation Methods – the project should be evaluated against some standards and this section includes procedures for monitoring, collecting, storing, and evaluating the history of the project.
- Potential Problems – this section lists the potential problems that could happen in the project. Examples of difficulty are subcontractor default, technical failure, strikes, bad weather, tight deadlines, resource limitations, and etc. The potential problems should not only list the potential difficulties but they can predict when these problems likely to occur and contingency plan should be developed in preparation for these events.

As stated earlier, the above project elements are just the guidelines of what should be included in the project plan. Different firms might add more elements as they see appropriated.

2.8.4 The Action Plan

In a project, it needs to be known exactly what to be done, by whom, and when. In order to do that, action plan needs to be created. Meredith and Mantel (2000, 193) propose a method which called a *hierarchical planning system* or *even planning process*. The summary of even planning process is first define major activities and list these as Level 1. The number of activities in level one should be between 2 – 20. Then break each item in Level 1 into 2 – 20 tasks, which they will be called Level 2. Then the process goes on until it reaches the detailed tasks at a level that are well understood. This way the activities can be broken down and create action plan with project objectives set clearly.

2.8.5 The Work Breakdown Structure and Linear Responsibility Charts

Work breakdown structure is a map of the project in which it identifies work elements, integrate project with the current organization, and establish a basis for control (Gray and Larson, 2002). Work breakdown structure or WBS can exist in many forms. The one that is most common is that generated by project management software such as

Microsoft Project. This type of WBS often appears as an outline with the Level 1 tasks listed on the left with subtasks indented. Other type of WBS could show the organizational elements associated with specific categories of tasks.

Meredith and Mantel (2000, 203) give general steps in designing and using the WBS. Depending on the size and complexity of the project, some steps might be skipped, combined, extended, or handled differently.

1) Using information from action plan, list the tasks in finer details. Continue until all the tasks or work packages can be individually planned, budgeted, scheduled, monitored, and controlled.
2) For each work packaged, identify the data relevant to WBS such as vendors, durations, equipments, materials, labors, special specifications, etc. Also personnel and organizations responsible for each task should be listed. The *linear responsibility chart* or *responsibility matrix* can be helpful because it helps project manager to track who is responsible for what task and who must report to whom. A simple responsibility matrix is shown below (Roman, 1986):

Task	**Bob**	**Cherryl**	**David**
A	P		S
B	S	P	S
C			P

P, primary responsibility; S, secondary responsibility

Figure 2.5 Simple Responsibility Matrix

3) All information on each package or task should be reviewed by those responsible for doing or supporting the work to ensure accuracy. Resource requirements, schedules, and subtask relationships can now be added up to the next higher level. At the top most level, there are a summary of the project budget and an estimate of duration of each work element.
4) For the purpose of pricing proposal or determining profit and loss, the total project budget should consist of four elements: direct budget from each task, indirect cost budget for the project, a reserve for unexpected situations, and residual which includes the profit derived from the project.

5) *Project master schedule* can be generated from schedule information and milestone events. The master schedule can also contain contractual commitments, key interfaces and sequencing, keystone events, and progress reports.
6) As the project moves along, the project manager should monitor each task and the resource usage planned against actual. While the project runs over budget, the performance maybe farther along than expected. On the other hand, the project budget might be as planned or lower, but the actual progress may be less than planned.
7) A project schedule may be subjected to the same comparisons as the project budget. Actual progress is compared to schedule progress by work element, task, package, and complete project to identify the problem. Once the problem has been identified, additional resources may be brought in to expedite those tasks behind schedule. These added funds could come from the budget reserve or from other tasks that are ahead of schedule.

The above listed items 1 – 5 focus on the WBS as a planning tool, while item 6 and 7 show how WBS can be used as a monitoring and controlling tool for the project. However, it is important that the WBS should be designed with the specific uses in mind in order to take the full advantage of it.

There is no clear problem in the project planning process of the case company, however the guidelines discussed above can be applied to improve the efficiency of the process. The initial project coordination is being practiced regularly in the company for every new project. For outside clients, the company is operated under contract basis, therefore every task or process needs to be according to specifications. The bidding documents that the company provides during the bidding process also cover and consider all of the project elements discussed above. The action plan and the work breakdown structure seem to share a lot in common; they both involve defining work packages and tasks. The company is familiar with creating WBS for a project, however the responsibility chart is somewhat new to the company.

To illustrate the point and set an example, an example of responsibility matrix has been generated. The items in activity list are the most common which are often components of many areas. The matrix shows the list of activity on the left and people who are responsible on the top.

Activity	Managing Director	Project Manager	Construction Manager	Mechanical Engineer	Electrical Engineer	QA/QC	Safety Officer	Procurement	Accountant
Shop drawings	5	6	2	1	1	3	5		
S/C supplied materials	5	6	2	1	1			3	5
Installation of equipment	5	5	6	1	1	2	3		
Fabricate/install steelwork	5	5	6	1	1	2	3		
Testing & Inspection	5	5	6	1	1	3	4		
Painting	5	5	6	1	1	2	4		
Other									
Pipework fabrication & installation :	5	6	6	1	1	2	3		
Fabrication Drawings	5	6	6	1	1	4			
S/C supplied materials	5	6	6	1	1	4		3	5
Fabrication of Spools	5	5	6	1	1	2	4		
Installation of Pipework	5	5	6	1	1	2	3		
Hydrotest/ precommissioning	5	5	6	1	1	2	4		
Insulation	5	5	6	1	1	3	4		

1 Actual responsibility 4 May be consulted
2 General supervision 5 Must be notified
3 Must be consulted 6 Final Approval

Figure 2.6 Example of Responsibility Matrix from the Project

The matrix shows information about each activity, the person who is responsible, and all of the people who are related to the activity. However, this is only a simple example. According to Meredith and Mantel (2000, 204), a real responsibility chart can be as large as 30 pages and covering up to 116 major activities.

2.9 Project Time Management

Project time management includes the processes required so that the project is completed in a timely manner. The project time management consists of:

- Activity definition which identifies what activities must be performed in order to produce project deliverables.
- Activity sequencing which identifies the how each activity interacts and dependants.
- Activity duration estimating which determines how long each activity requires.
- Schedule development which analyze activity sequences, activity duration, and resource requirements to create project schedule.
- Schedule control which controls the changes to project schedule.

2.9.1 Activity Definition

Activity definition involves identifying and documenting what are the specific activities that need to be performed in order to achieve the project deliverables and objectives.

2.9.1.1 Inputs to Activity Definition

1) Work breakdown structure is the primary inputs to activity definition.
2) Scope statement – the project justification and the project objectives contained in scope statement must be kept in mind during activity definition process.
3) Historical information, constraints, and assumptions must all be considered while defining project activities.

2.9.1.2 Tools and Techniques for Activity Definition

1) Decomposition – decomposition is a process of dividing project elements into smaller, more manageable components in order to provide better management and control.

2) Templates – an activity list from previous project may be used as a template for the next project.

2.9.1.3 Outputs from Activity Definition

1) Activity list – activity list contains all the activities involve which will be performed to complete the project.
2) Supporting detail – all supporting detail must be documented and organized as to facilitate project management process.
3) Work breakdown structure updates – the work breakdown structure must be updated if some activities or items are found missing during the activity definition process.

2.9.2 Activity Sequencing

Activity sequencing involves sequencing activity because some activities interact and depend on others. Activity sequencing is important so that a development of schedule can be more effective. Project management software is often used in sequencing activity on a large project.

2.9.2.1 Inputs to Activity Sequencing

1) Activity list – the activity list generated from activity definition will be used because activity needs to be sequenced together.
2) Product description – the definition of product is important so that the activity can be sequenced with the final product in mind.
3) Mandatory, discretionary, and external dependencies – these are the dependencies in which the project team must follow. Mandatory dependencies are the physical dependencies of activity. Discretionary dependencies are mostly defined by the project team. External dependencies are the relationship between project activities and non-project activities such as waiting for product or service from outside product or service provider.
4) Constraints and assumptions – constraints and assumptions also have to be taken into account while sequencing the activity.

2.9.2.2 Tools and Techniques for Activity Sequencing

1) Precedence diagramming method (PDM) – this is a sequencing method using nodes to represent activities and connect them with arrows that indicate dependencies. Example of precedence diagram is shown below.

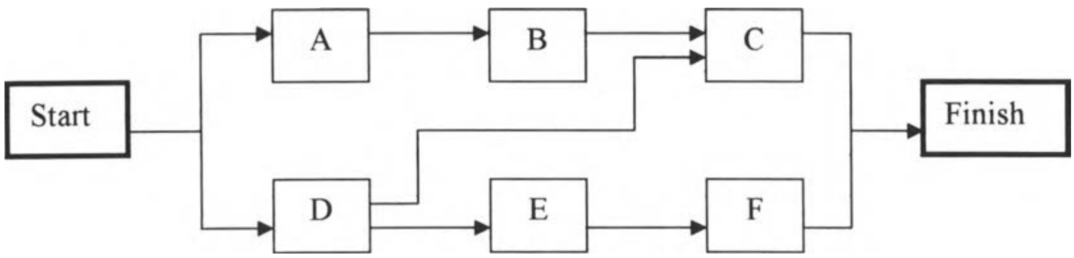

Figure 2.7 Example of Precedence Diagram

In the figure, this is called activity-on-node (AON) and this method is used by most of the project management software. There are four types of dependencies or precedence in PDM. The most commonly used type is finish-to-start.

- Finish-to-start – first activity must finish before the second can start
- Finish-to-finish – first activity must finish before the second can finish
- Start-to-start – first activity must start before the second can start
- Start-to-finish – first activity must start before the second can finish

2) Arrow diagramming method (ADM) – This method constructs a network diagram using arrows to represent activities and nodes to show dependencies. This is also called activity-on-arrow (AOA), which is not widely used as PDM but it is still an application of choice in some industry. The example of ADM is shown below.

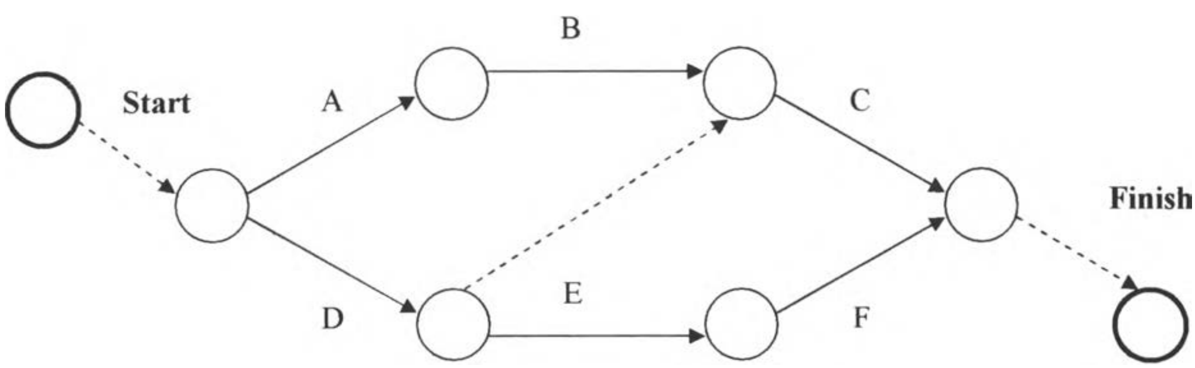

Figure 2.8 Example of Arrow Diagram

3) Conditional diagramming methods – In some case, there might be loops or conditional branches which can not be mapped on PDM or ADM, therefore GERT (Graphical Evaluation and Review Technique) or System Dynamics models must be used.
4) Network templates – a network template can be used to expedite the project network diagrams preparation.

2.9.2.3 Outputs from Activity Sequencing

1) Project network diagram – at the end of activity sequencing process, a project network diagram will be generated. A project network diagram is a schematic drawing showing the dependencies of the activities. It may look like the above two examples.
2) Activity list update – as for activity definition generates an updated WBS, activity sequencing also does the same.

2.9.3 Activity Duration Estimating

The activity duration estimating involves estimating how long each activity should take to complete. This must be done by a person or a team that most familiar with the nature of such activity.

2.9.3.1 Inputs to Activity Duration Estimating

1) Activity list, constraints, and assumptions – these are the three that have already been discussed.
2) Resource requirements – in order to estimate the activity duration, one must know how much resource is assigned to such activity. The more resource, the shorter the time it takes to complete an activity.
3) Resource capabilities – not only how much resource is assigned to an activity, it is also a matter of the quality of those resources that will play a role in determining the duration of such activity.
4) Historical information – the use of historical information can be divided into three major categories. First, old project files which are the records of previous projects and can be used in estimating. Second, commercial duration estimating database

such as how long does it take concrete to cure and how long does it take for government officer to come down and inspect and so on. Third, project team knowledge which uses the knowledge of members of the team who have estimated the activity before.

2.9.3.2 Tools and Techniques for Activity Duration Estimating

1) Expert judgment – expert judgment such as consultants or industry groups should be used wherever possible, however a number of factors could affect the estimates. Therefore, the unexpected should be prepared for.
2) Analogous estimating – analogous estimating or top-down estimating uses the information from previous similar activity as a basis for estimation where information available is limited. This is also considered to be a type of expert judgment because the person who prepares the analogous estimating needs to have the required expertise.
3) Simulation – simulation involves calculating multiple durations with different assumptions. The most common use is Monte Carlo Analysis which a distribution of probable results for each activity is defined then used to calculate that of the total project.

2.9.3.3 Outputs from Activity Duration Estimating

1) Activity duration estimates – activity duration estimates are quantitative assessment of the possibility of work periods that will be required to complete an activity. Good activity duration estimates should include the range of possible results or uncertainty.
2) Basis of estimates – the assumptions made during the estimate must be documented.
3) Activity list updates – as discusses in activity definition and activity sequencing.

2.9.4 Schedule Development

Schedule development determines the start and the finish date of the project. The process is often iterated because the schedule has to be modified according to the duration estimating and cost estimating.

2.9.4.1 Inputs to Schedule Development

1) Project network diagram, activity duration estimates, and resource requirements – the first two are developed in the earlier processes with the resource requirements already determined in the project.
2) Resource pool description – resource pool description involves knowing what resources will be available at what time and in what patterns is crucial for schedule development.
3) Calendars – project and resource calendars are important because it has to be known what are the working days and what are not, so schedule can be developed accordingly.
4) Constraints – there are two major constraints for schedule development:
   - Imposed dates are the dates that set by customer or project sponsor in which they require certain deliverables to be delivered.
   - Key events or major milestones are the same as imposed dates but the customer or project sponsor this time request the deliverables.
5) Assumption – as in previous processes, some assumptions needed to be made during the schedule development.
6) Leads and lags – leads and lags need to be taken into account. It is clearly visible in the procurement process where it may take a long time for materials to be delivered which affect the schedule.

2.9.4.2 Tools and Techniques for Schedule Development

1) Mathematical analysis – this is the basis for calculating the project early start and finish date for each activity, however it does not take resource pool limitations into account. The results are indication of time periods in which each activity should be scheduled given resource limitations and other constraints. Some of the mathematical analysis techniques are:

- Critical Path Method (CPM) – CPM calculates early and late start and finish date each activity based on specified network logic and a single duration estimate.
- Graphical Evaluation and Review Technique (GERT) – GERT allows flexibility in network logic and activity duration estimates.
- Program Evaluation and Review Technique (PERT) – PERT uses sequential network logic and a weighted average duration estimate to calculate project duration.

2) Duration compression – duration compression is a special case for mathematical analysis that looks for way to shorten the project schedule to meet the imposed dates or other schedule objectives. Example of the techniques are:
    - Crashing – cost and schedule trade-offs are both taken into account to determine the greatest amount of compression with the lease incremental in cost
    - Fast tracking – fast tracking is doing the activity in parallel that would normally be done in sequence. Fast tracking often results in rework and generates more risk.
3) Simulation – as discussed in activity duration estimating, simulation is to calculate multiple durations with different assumptions.
4) Resource leveling heuristics – while mathematical analysis generates a preliminary schedule in which more resources are required in a certain time period than available, resource leveling heuristics such as allocating resources to critical path activities first can be applied to produce a schedule that reflects such constraints.
5) Project management software – project management software is widely used today because it helps in mathematical analysis and resource leveling which expedites the schedule development process.

2.9.4.3 Outputs from Schedule Development

1) Project schedule – the project schedule includes at lease a planned start and expected finish dates for each activity. The schedule remains preliminary until

resource assignments have been confirmed. The project schedule can be presented in many forms such as summary form (master schedule), project network diagram, Gantt charts (most often used), milestone charts, and time-scaled network diagrams.

2) Supporting detail – supporting detail is a document of all assumptions and constraints made during the development process. For a construction project, additional detail could be resource histograms, cash flow projections, and order and delivery schedules.
3) Schedule management plan – schedule management plan defines how to manage schedule should a change occurred.
4) Resource requirement updates – the resource leveling and activity list updates may effect the estimates of resource requirements.

2.9.5 Schedule Control

The purposes of schedule control are:

- Influencing the factors that create schedule change to ensure that the changes are beneficial.
- Determining that the schedule has changed.
- Managing the actual changes as they occur.

2.9.5.1 Inputs to Schedule Control

1) Project schedule, schedule management plan, and change requests – these are the things that have been mentioned earlier and are the inputs to schedule control.
2) Performance reports – performance reports provide information on schedule performance such as which planned dates have been met and have not.

2.9.5.2 Tools and Techniques to Schedule Control

1) Schedule change control system – the system defines the procedures of how the schedule should be changed. The schedule change control should be implemented together with overall change control system.

2) Performance measurement – a performance measurement is needed in order to verify and assess the magnitude of the variations.
3) Additional planning – as the project might not go as plan, activity duration estimates, modified activity sequences, or analysis of alternative schedules may need to be revised.
4) Project management software – the project management software can help in schedule control because it has the ability to track planned dates with actual dates and to forecast the effects of schedule changes whether real or potential.

2.9.5.3 Outputs from Schedule Control

1) Schedule updates – a schedule update is any modifications to the schedule information that used to manage the project.
2) Corrective action – corrective action is anything done to bring expected future schedule performance into line with project plan.
3) Lessons learned – the causes of variances and reasons behind corrective actions are example of what should be documented for future reference.

2.10 Theory on Project Scheduling

Second aspect that involves our research topic is project scheduling. In creating schedule, there are many techniques available to use. Some techniques that will be discussed in this section are the Program Evaluation and Review Technique (PERT), the Critical Path Method (CPM), with the following will be discussed briefly Gantt charts, Precedence Diagramming and the Graphical Evaluation and Review Technique (GERT).

From the previous chapter, it has been mentioned that the main problem for the case company is that they do not use project management tools and techniques correctly and to full capabilities. The techniques such as PERT or CPM could help the company reduces costs and that is the focus of this section.

A schedule is the conversion of a project action plan into an operating timetable (Meredith and Mantel, 2000). A schedule is a major tool in project management because it serves as a basis for monitoring and controlling project.

The basic approach for scheduling techniques is to create a network of all activities to show their relationships. The benefits for the network are:

- It is a consistent framework for planning, scheduling, monitoring, and controlling the project.
- The network shows the relationship and interdependence of tasks, work packages, and work elements.
- It identifies the time when specific individuals must be available to do the assigned task.
- It helps ensuring communications take place between departments and functions.
- It determines the project expected completion date.
- It identifies critical activities which can not be delayed.
- It also identifies the slack activities which can be delayed without penalty. The resources for slack activities also can be borrowed to use in other activities.
- It identifies the start dates for the tasks so the project stays on schedule.
- It determines resource or timing conflicts in which activities must be re-scheduled to avoid them.
- It also identifies if some tasks need to be run in parallel in order to achieve completion date.
- By showing task dependencies, it relieves some interpersonal conflict.
- It also provides an estimate of the probability of project completion date.

2.10.1 Network Techniques: PERT and CPM

The use of network techniques such as PERT and CPM is a common approach to project scheduling. Meredith and Mantel (2000, 307) state that the Program Evaluation and Review Techniques was developed by the U.S. Navy in cooperation with Booz-Allen Hamilton and the Lockheed Corporation for the Polaris missile/submarine project in 1958. The Critical Path Method was developed by DuPont, Inc., during the same period.

The usage of these two techniques are different however it can be adapted to suit the industry. PERT is commonly used in R&D project and it is more common to find PERT on development project rather than research project, while CPM has been widely used in construction project. On the application side, Meredith and Mantel (2000, 307) states that PERT and CPM are very similar so that they discuss t(% two together. Nevertheless, PERT was originally designed to look at the time element of projects and used probabilistic activity time period to determine the probability of project finishing on some given date. CPM, on the other hand, used deterministic activity time estimates and was designed to control both time and cost of the project. But both of PERT and CPM identifies a project critical path, activities which can not be delayed, and slack, activities that can be delayed without affecting the project completion time. Meredith and Mantel (2000, 307) then conclude that the use of PERT and CPM is very similar and interchangeable.

The use of network scheduling techniques, such as PERT or CPM, introduces a significantly lower probability of cost and schedule overruns (Meredith and Mantel, 2000). It also seems that it is becoming more and more common for project managers will use these techniques since the project management software packages are inexpensive and becoming more and more user-friendly.

2.10.1.1 Constructing a Network

To transform a project plan into a network, the activities in the project and what its predecessors (and/or successors) must be known. An activity can be

1) It may have a successor(s) but no predecessor(s), activity that starts the network
2) It may have a predecessor(s) but no successor(s), activity that ends the network
3) It may have both predecessor(s) and successor(s), activity in the middle.

Example of the sequential of activities is shown below in activity-on-arrow (AOA) format (Meredith and Mantel, 2000).

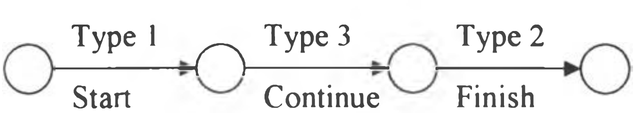

Figure 2.9 Example of Activity-On-Arrow Network

There are two types of network drawing. AOA (activity-on-arrow) is shown above where arrows represent activities and nodes represent events. The other format is AON (activity-on-node) where nodes represent activities and arrows represent the precedence relationships. When constructing a network, first activity time must be considered. The table below lists the activities, their most likely completion times, and preceding activities. The table also shows the optimistic and pessimistic time for each activity.

Table 2.1 Example of Activity Time

Activity	**Optimistic Time**	**Most Time**	**Likely Pessimistic Time**	**Immediate Predecessor Activities**
A	10	22	22	-
B	20	20	20	-
C	4	10	16	-
D	2	14	32	a
E	8	8	20	b,c
F	8	14	20	b,c
G	4	4	4	b,c
H	2	12	16	c
I	6	16	38	g,h
J	2	8	14	d,e

In constructing a network, start by finding the activities which have no predecessors, in this case **a**, **b**, and **c**. Therefore, **a**, **b** and **c** can start from a starting node. Now look for activities that require **a**, **b**, or **c** as predecessors, they are **e**, **f**, **g**, and **h**. Then, **j** which requires **d** and **e** and **i** which requires **g** and **h** can be drawn. The project network is shown in the figure below.

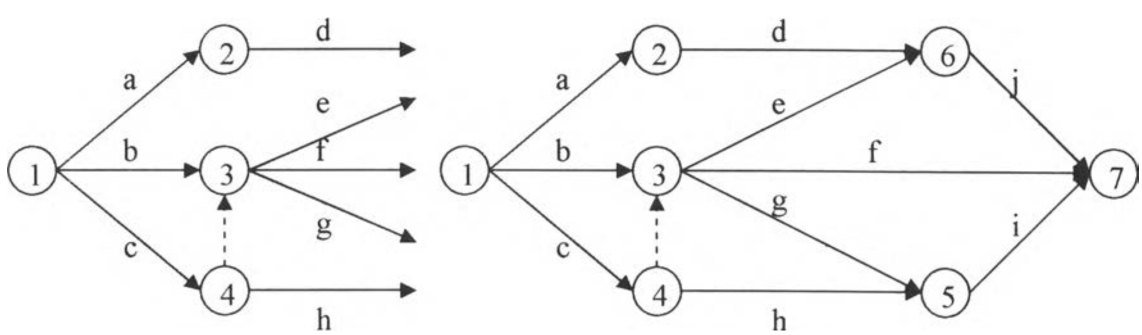

Figure 2.10 Example of How to Construct a Network and Finished Network

2.10.1.2 Calculating Activity Times

The three times, optimistic, pessimistic, and most likely) given in the table will be used to calculate the activity time. Assuming that activity time can be represented by a statistical distribution. The most likely time, *m*, is the mode for the distribution. Optimistic time, *a*, is chosen by the project manager so that the activity time will be *a* or greater about 99 percent of the time. Pessimistic time, *b*, is chosen so that activity time will be *b* or less more than 99 percent of the time. This way, the expected time, TE can be found.

$$TE = (a + 4m + b)/6$$

where;

a = optimistic time estimate,

b = pessimistic time estimate,

m = most likely time estimate.

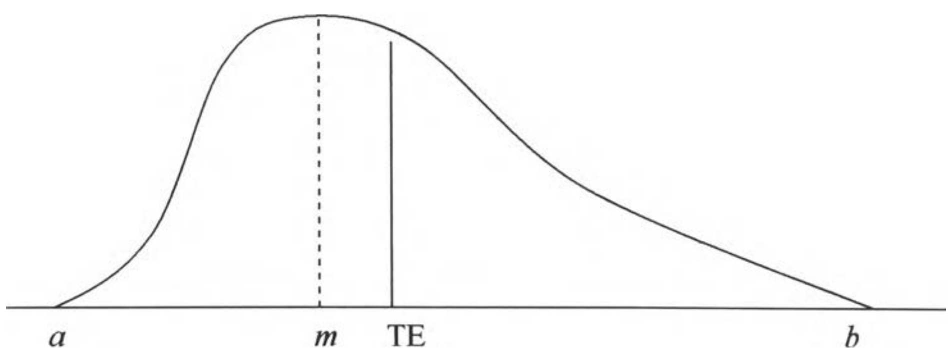

Figure 2.11 Graph Showing Time Estimate for an Activity

The uncertainty for the duration of each activity, the variance σ^2, can also be calculated by;

$$\sigma^2 = ((b - a)/6)^2$$

and the standard deviation, σ, given by;

$$\sigma = \sqrt{\sigma^2}$$

The calculated expected time, variance, and standard deviation are shown in the table below.

Table 2.2 Expected Time, Variance, and Standard Deviation for Activity

Activity	Expected Time, TE	Variance, σ^2	Standard deviation, σ
a	20	4	2
b	20	0	0
c	10	4	2
d	15	25	5
e	10	4	2
f	14	4	2
g	4	0	0
h	11	5.4	2.32
I	18	28.4	5.33
j	8	4	2

Meredith and Mantel (2000, 328) suggests that an Excel template can be created to find the expected times, variances, and standard deviation associated with a series of three-time estimates for PERT and CPM networks. However, most project management software will not accept three time estimates but a large majority of software will exchange information with the spreadsheet software. Therefore, entering the three-time estimate to find the expected time in Excel and the expected time can be used as deterministic time in project management software to find project's critical path and time.

2.10.1.3 Critical Path and Time

When the total time for the project is needed to be known, the network is listed the expected activity time and variance next to it. From the network that was created earlier, it becomes:

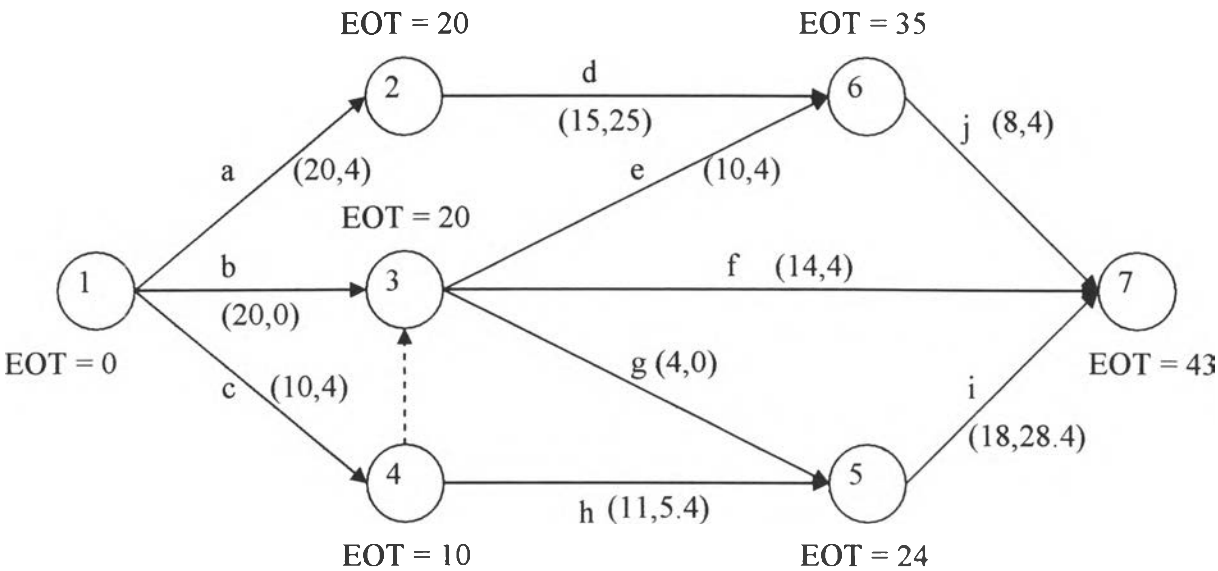

Figure 2.12 Example of Network Showing Activity Duration and Total Time

The total time it takes to complete the project can be found by EOT, earliest occurrence time. Assuming the activity time is in day and start at day 0, EOT at event 1 is, therefore, 0. Activity *a*, *b*, and *c* can all start at the same time since they do not have any predecessors. Hence, it takes 20 days to reach event 2, 20 days to reach event 3, and 10 days to reach event 4. It can be seen that event 3 requires both activity *b* and *c* to be completed, therefore, the EOT of 3 is equal to the longer activity time which is 20 from activity *b*. Now keep going in the same way for the rest of the network. Event 5 requires the completion of *g* and *h*, and the longer path is from event 3 (EOT = 20) + g (4 days), EOT at event 5 becomes 24. Event 6 requires the completion of activity *d* and *e* and the longer path is from event 2 through *d*, therefore EOT at 6 equals 35. Finally, event 7 requires the completion of activity *i*and *j*, the longer path is from event 6 through activity *i*, and EOT at 7 becomes 43. To summarize the activity paths leading to event 7, there are 8 paths as follow:

a-d-j = 20 + 15 + 8 = 43 days

b-e-j = 20 + 10 + 8 = 38 days

b-f = 20 + 14 = 34 days

b-g-i = 20 + 4 + 18 = 42 days

c-dummy-e-j = 10 + 0 + 10 + 8 = 28 days

c-dummy-f = 10 + 0 + 14 = 24 days

c-dummy-g-i = 10 + 0 + 4 + 18 = 32 days

c-h-i = 10 + 11 + 18 = 39 days

The shortest possible time to complete the project is the longest path, or **a-d-j**, which is 43 days. Therefore, 43 is the *critical time* of the network and **a-d-j** is the *critical path*.

This is only a simplified example of network diagram. In real life, drawing a network diagram can be quite a task because the number of activities in large project can be hundreds or thousands. This is the reason why the use of project management software can come in handy, because most project management software contains the option of drawing network diagram.

2.10.1.4 Slack

In the above section, the *critical path* and *critical time* can be found by using the method of earliest starting times (EST). In this section, another method called latest possible starting time (LST) is discussed. To find the LST, take activity *i* as an example.

Activity *i* takes 18 days to completed and the project has a critical time of 43 days, therefore activity I must not start later than day 25, which is LST for *i*. But activity *i* can not start until event 5 has occurred, hence LOT for event 5 is 25 days. The difference between LST and EST for an activity is called slack or float. For activity *i*, it must not start later than day 25, but it could be start as early as day 24, therefore it has a slack of one day. With this method, all activities in critical path have zero slack which means they can not be delayed without causing delay to the entire project. The table below summarizes the LOT, EOT, and slack for each event and LST, EST, and slack for each activity.

Table 2.3 Table Showing Slack for Event and Activity

Event	LOT	EOT	Slack
1	0	0	0
2	20	20	0
3	21	20	1
4	14	10	4
5	25	24	1
6	35	35	0
7	43	43	0

Activity	LST	EST	Slack
a	0	0	0
b	1	0	1
c	4	0	4
d	20	20	0
e	25	20	5
f	29	20	9
g	21	20	1
h	14	10	4
I	25	24	1
J	35	35	0

The benefit of knowing the slack is that project manager can allocate the resources to those activities that have no or little slack first.

2.10.2 Gantt Charts

Gantt chart was developed by Henry L. Gantt around 1917 (Meredith and Mantel, 2000). Gantt chart shows the planned and actual progress against a horizontal timescale and it can be helpful in expediting, sequencing, and reallocating resources among tasks. The advantages for Gantt chart include the ease of understanding and it is easily constructed. Because the Gantt chart is easy to read, it is often mounted on the wall of the project office so that everyone can see the progress. The Gantt chart can be constructed from both PERT/CPM network and the WBS, that is why it is easy to construct. However, there are disadvantages which are it requires frequent updates but it is always the case for other scheduling and control devices and Gantt chart needs to be accompanied by PERT/CPM network to interpret what appears beyond the chart or to compensate for the lateness.

The way to construct a Gantt chart is that the activity is often listed in alphanumerical order on the vertical axis while on the horizontal axis is a time scale. The duration of each activity is shown with light line or hollow bars for planned activity time and heavy lines or filled-in bars for actual progress. The chart often shows the scheduled and achieved milestones on the horizontal timescale. Most project management software will generate the Gantt charts with the customization options.

2.10.3 Precedence Diagramming

Precedence diagramming is one of the extensions to PERT and CPM, because PERT and CPM do not allow leads and lags which are often the case in construction project. Some common restrictions are:

- Activity B must not start before activity A has been in progress for at least two days.

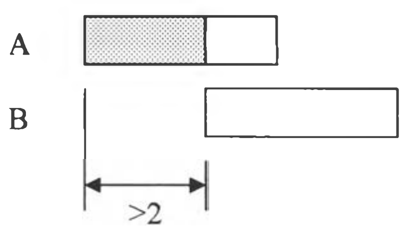

Figure 2.13 Precedence Diagramming Case A

- Activity A must be completed three days before activity B can be finished.

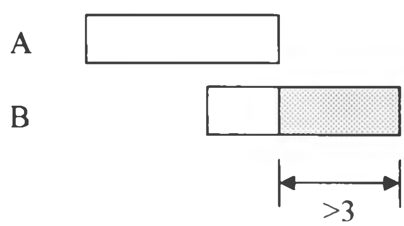

Figure 2.14 Precedence Diagramming Case B

- Activity B can not begin before four days after activity A is completed.

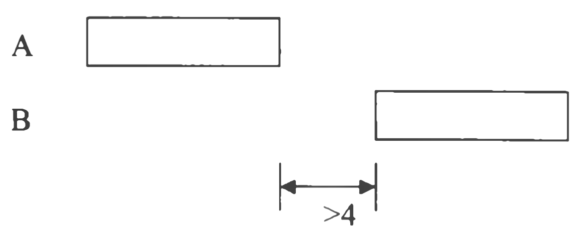

Figure 2.15 Precedence Diagramming Case C

- Activity B can not be finished before eight days from the start of activity A.

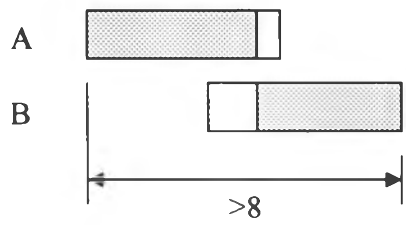

Figure 2.16 Precedence Diagramming Case D

In precedence diagramming, critical path of the network may go backward which increasing the activity time may reduce the project completion time. This is called *reverse critical*. This happens when critical path enters the completion of activity through a finish constraint (Figure 2.14 or 2.16), continues through activity, and leaves through a start constraint (Figure 2.13 or 2.15).

2.10.4 GERT

The Graphical Evaluation and Review Techniques (GERT) in a modeling network developed to deal with a more complex model that PERT and CPM can handle (Meredith and Mantel, 2000). GERT combines signal flowgraph theory, probabilistic networks, PERT/CPM, and decision trees together in one framework. The components of GERT consist of logical nodes and directed arcs (or branches) with two parameters: the probability that a given arc is taken (or realized) and the distribution function describing the time required by the activity. Evaluation of a GERT network will result in the probability of each node being realized and the elapsed time between all nodes.

2.11 Project Cost Management

Project cost management includes the processes required to ensure that the project is completed within the approved budget. The overview of major processes is:

- Resource planning – determining what resources (people, equipment, and materials) and of what quantities are needed to perform project activities.

- Cost estimating – an estimation of costs of resources needed to complete the project activities.
- Cost budgeting – allocating overall cost estimate to individual work items.
- Cost control – controlling the changes to project budget.

2.11.1 Resource planning

Resource planning determines what resources (people, equipment, and materials) and of what quantities are needed to perform project activities. It is closely linked with cost estimating which will be discussed later.

2.11.1.1 Inputs to Resource Planning

1) Work breakdown structure – WBS is the primary input to resource planning because it identifies the project elements that will need resources.
2) Historical information – historical information such as what resources are needed for such activity in the past can be useful.
3) Scope statement – project justifications and project objectives which are contained in scope statement should be kept in mind while planning resources.
4) Resource pool description – resource pool description is important because the company needs to know what resources are available for resource planning.
5) Organizational policies – staffing and rental or purchase of supplies and equipment policies are examples of what should be considered during resource planning.

2.11.1.2 Tools and Techniques for Resource Planning

1) Expert judgment – expert judgment seems to be the only tool available to help in resource planning. Sources of experts include:
   - Other units within the performing organization
   - Consultants
   - Professional and technical associations
   - Industry groups

2) Alternatives identification – alternatives identification is a term used for any techniques used to generate alternative to the project. The most common use techniques are brainstorming and lateral thinking.

2.11.1.3 Outputs to Resource Planning

1) Resource requirements – the resource requirements determine what type of resources are required and in what quantities for each element of the work breakdown structure. These resources will be obtained through staff acquisition or procurement.

2.11.2 Cost Estimating

Cost estimating involves developing an estimate of the costs of the resources needed to complete project activities. However, there is a different between cost estimating and pricing because cost estimating is only one consideration in many for pricing.

2.11.2.1 Inputs to Cost Estimating

1) Work breakdown structure, resource requirements, and activity duration estimates – these are the outputs from previous processes that will be used in cost estimating.
2) Resource rates – those who prepare the cost estimates should know the unit rates for all labors and equipments. If the rate is not known, then it must be estimated.
3) Historical information – historical information can be used in cost estimating. This includes old information from previous projects, commercial cost estimating databases, and knowledge of project team members.
4) Chart of accounts – chart of accounts is used to report financial information in its general ledger.

2.11.2.2 Tools and Techniques for Cost Estimating

1) Analogous estimating – as discussed earlier, analogous estimating uses actual cost of previous similar project as a basis for estimating. The analogous estimating is less costly than other techniques, but it is also less accurate.
2) Parametric modeling – parametric modeling involves using project characteristics or parameters in a mathematical model to predict project costs.
3) Bottom-up estimating – bottom-up estimating estimates the cost of individual work items then summarizing up to get the project total.
4) Computerized tools – Project management software and spreadsheets are often used in cost estimating because they can simplify the tools described above and facilitate consideration of costing alternatives.

2.11.2.3 Outputs from Cost Estimating

1) Cost estimates – cost estimates are quantitative assessments of what the costs of the resources needed to complete the project. The cost estimates include, but not limited to, labor, materials, supplies, and special categories such as inflation allowance or cash reserve.
2) Supporting detail – supporting detail such as the scope of work estimated, basis for the estimate, assumptions, and range should be documented.
3) Cost management plan – cost management plan describes how cost variances should be managed.

2.11.3 Cost Budgeting

Cost budgeting involves allocating the overall cost estimates to each item in order to create a cost baseline to measure project performance.

2.11.3.1 Inputs to Cost Budgeting

Cost budgeting uses information from previous processes such as cost estimates, work breakdown structure, and project schedule where WBS defines what the cost should be allocated to and project schedule defines when.

2.11.3.2 Tools and Techniques for Cost Budgeting

Cost budgeting uses the same tools as described in cost estimating tools and techniques.

2.11.3.3 Outputs from Cost Budgeting

A cost baseline will be developed in cost budgeting. A cost baseline is a time-phased budget that is used to measure cost performance of the project and it is normally shown in the form of an S-curve.

2.11.4 Cost Control

The purposes of cost control include:

- Monitoring cost performance to detect variances from plan.
- Ensuring the changes are recorded accurately in the cost baseline.
- Prevent incorrect, inappropriate, or unauthorized change to cost baseline.
- Informing stakeholders of authorized changes.

2.11.4.1 Inputs to Cost Control

1) Cost baseline, cost management plan, and change requests – these provide inputs for cost control.
2) Performance reports – allow the project team to see which budgets have been met and which have not.

2.11.4.2 Tools and Techniques for Cost Control

1) Cost change control system – cost change control system defines procedures by which cost baseline may be changed.
2) Performance measurement – performance measurement helps identify the magnitude of the variances that occur and tool such as earned value analysis can be useful for cost control.
3) Additional planning – should a project not running as plan, a new or revised cost estimates should be made.

4) Computerized tools – project management software and spreadsheets are often used to help with the process because they can track actual costs against planned costs and also forecast the effect of cost changes.

2.11.4.3 Outputs from Cost Control

1) Revised cost estimates – revised cost estimates are modifications to the cost information that used to manage the project.
2) Budget updates – budget updates are a special case for cost estimates. They are changes to an approved cost baseline which will only be revised if the scope has changed.
3) Corrective action – corrective action is what must be done to bring the project performance inline with the plan.
4) Estimate at completion – estimate at completion or EAC is a forecast of total project costs based on project performance. The most common techniques are:
   - EAC = Actuals to date plus the remaining project budget modified by a performance factor.
   - EAC = Actuals to date plus a new estimate for all remaining work.
   - EAC = Actuals to date plus remaining budget.
5) Lessons learned – as always, lessons learned from the process should be documented for future reference.

2.12 Theory on Resource Allocation

While project scheduling deals with allocating time among project activities, resource allocation deals with allocating physical resources, such as labor-hours, machine-hours, computing hours, etc. However, problem of allocating and scarce resource are what firms usually encounter in the project.

This section will look at trade-offs between time and other resources, resource allocation for single and multiple projects, relationship between resource loading and leveling, and approaches to solve allocation problem such as Critical Path Method (CPM), constrained resource diagramming and scheduling, etc.

2.12.1 Critical Path Method – Project Crashing

The difference for CPM and PERT is that CPM includes a way of relating project schedule to the level of physical resources allocated to the project. This allows the project manager to make a trade-off between time and cost and vice versa. Normally, two time/cost combinations are specified in CPM, they are *normal times* which is the same as *m* time estimate in PERT and *crash times* which is a result of an attempt to expedite the activity by application of additional resources.

Example of crashing a project taken from Meredith and Mantel (2000, 365) is shown below.

Activity	Precedence	Duration, Days (normal, crash)	Cost (normal, crash)
A	-	3,2	$40,80
B	a	2,1	20,80
C	a	2,2	20,20
d*	a	4,1	30,120
e**	b	3,1	10,80

* Partial crashing allowed

** Partial crashing not allowed

Figure 2.17 Example of Project Crashing and its Associated Costs

First, a cost/time slope for each activity that can be crashed must be computed. The slope can be found by:

$$\text{slope} = \frac{\text{crash cost} - \text{normal cost}}{\text{crash time} - \text{normal time}}$$

The slope shows cost per day for crashing a project and negative slope means as time required for the task increased, the cost is increased. For activity *a*, the slope is:

$$\text{slope } a = \frac{80-40}{3-2} = -40$$

$$\text{slope } b = \frac{80-20}{2-1} = -60$$

$$\text{slope } c = 0$$

$$\text{slope } d = \frac{120 - 30}{4 - 1} = -30$$

$$\text{slope } e = \frac{80 - 10}{1} = -70 \text{ (2 days crash)}$$

The slope calculation shows that activity c can not be crashed and activity e can not be partially crashed. This information will be used and calculate the cost of project with crashing.

Normal Schedule

8 days, $120

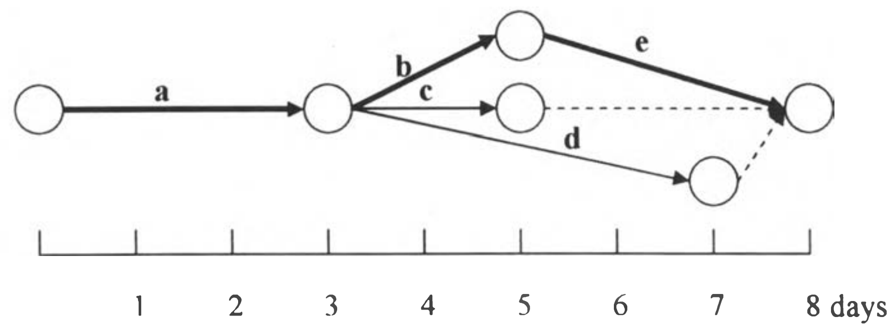

Figure 2.18 Normal Schedule without Crashing

From the figure, this is a normal network drawn in AOA representation with **a-b-e** as the critical path. The normal time is 8 days and the cost is $120. Suppose the company wants to crash the project for one day, it needs to crash the activity that is in the critical path. It has a choice of crashing **a**, **b,** or **e** but which is the lowest cost. From the slope of activity, crashing **a** costs 40, while crashing **b** costs 60 per day, **e** could also be crashed for 70 (2 days) which makes **a-d-dummy** becomes the critical path. But the lowest cost is crashing **a**, therefore the company chooses to crash activity **a**. The network then becomes 7-day schedule with the cost of $160.

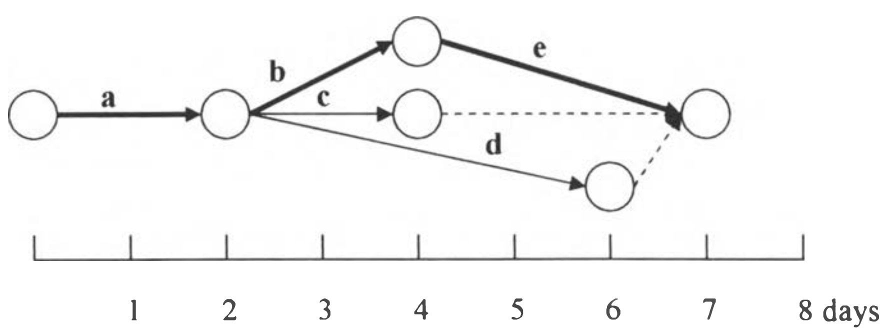

Figure 2.19 Schedule with 1 day Crashing

Suppose the project needs to be crashed for 2 days. From the normal network, there are two choices, first is to crash **a** and **b** and second is to crash **e**. Crashing **a** and **b** costs 100 while crashing **e** costs 70. But if **e** is crashed, then either **a** or **d** must be crashed because the duration of the project is still 7-day due to **a-d-dummy** becomes the critical path. In this case, **d** is chosen to be crashed because it is cheaper and the total cost becomes 100. The two options generated the same result, therefore either can be chosen. The first figure shows a network after crashing **a** and **b**, while the second shows a network after crashing **e** and **d**. The network becomes 6-day with a cost of $220.

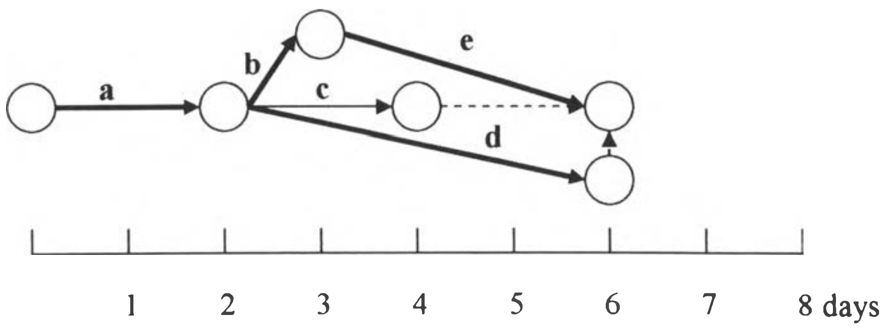

Figure 2.20 Schedule with 2 day Crashing

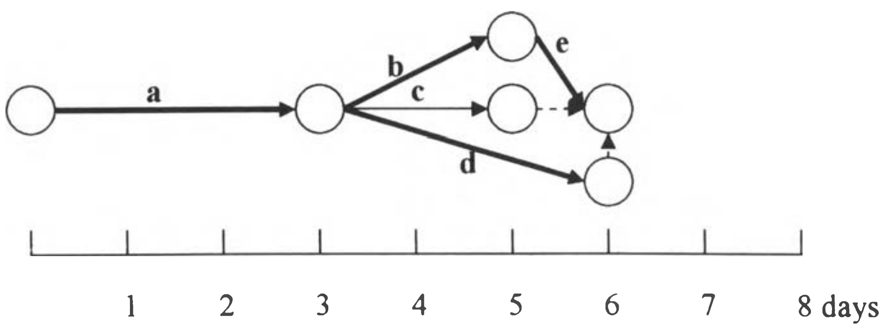

Figure 2.21 Schedule with 3 day Crashing

Suppose the project needs to be crashed by three days. From the original network and critical path, **e** must be crashed and either **a** or **b** for another day. Choose **a** because the cost is lower. Then **d** must also be crashed by one day and the total cost of crashing becomes 70 + 40 + 30 = 140. The network becomes 5-day with a cost of $260.

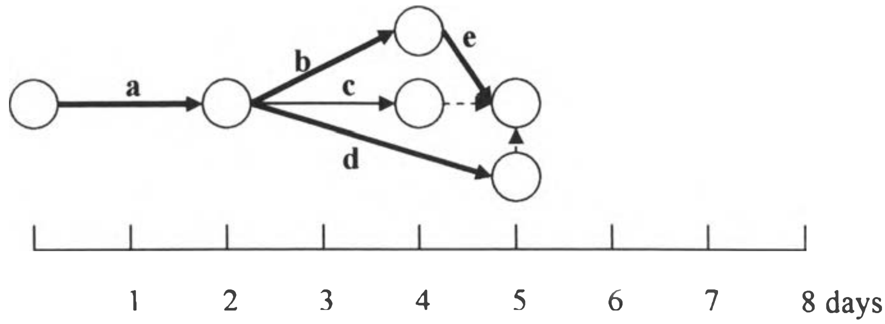

Figure 2.22 Schedule with 4 day Crashing

Lastly, suppose the project needs to be crashed by four days. From the 5-day schedule, **a-b-e** and **a-d-dummy** are both critical paths. **b** and **d** can be crashed for one day to make it a 4-day schedule. The total cost of project becomes \$350.

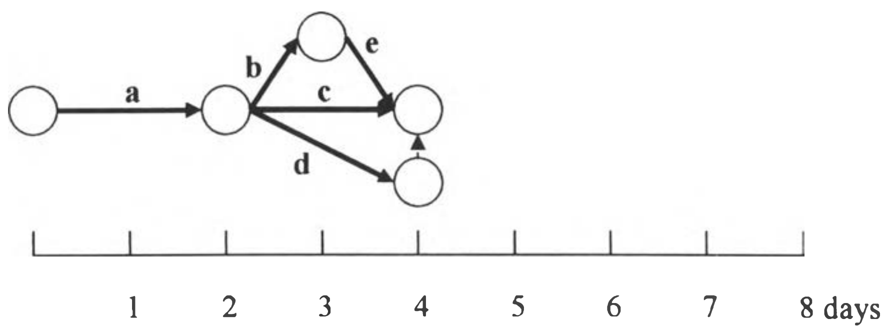

Figure 2.23 Schedule with 5 day Crashing

So now all activities are critical, **a-b-e** and **a-c** can not be crashed any further. This is not an all-crash time schedule because **d** can still be crashed for another day but since the network can not be reduced any further the duration of 4-day is the same.

With all the information above, a cost-duration history which is a graph represents the relationship between cost and the duration of the project can be generated. The cost-duration history can be presented to the senior management or clients, so they can understand the trade-off between time and cost if they want to speed up the project. The cost-duration chart is shown below.

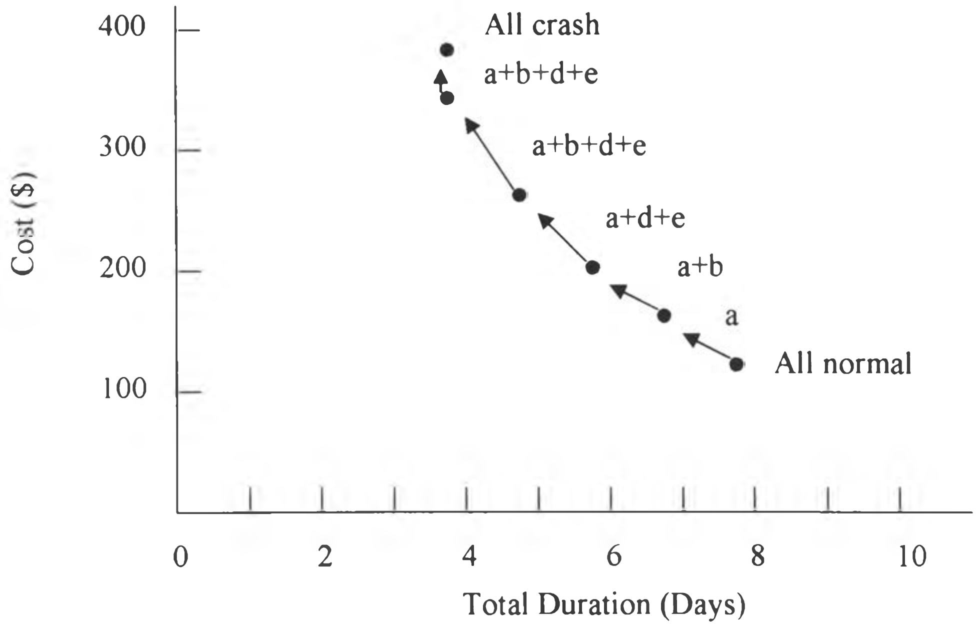

Figure 2.24 Cost versus Duration Comparison of Crashing a Project

Shown above is the CPM cost-duration history which summarizes all the crashes that have been experimented.

2.12.2 Resource Allocation Problem

The resource problem is not limited to time limited, there is also a problem of resource limited. Time limited is when the project must be finished by a certain time and using as few resources as possible. Resource limited is when the project must be finished as soon as possible with limited resources available or some level of resource constraints. A project might vary between these two extremes of time or resource limited. Meredith and Mantel (2000, 372) states that there is another variable to a project that is specifications. The three variables must not be fixed at the same time, otherwise the project manager has lost all the possible trade-offs required to complete the project. Another constraint in a project is known as system-constrained. System-constrained tasks require a fixed amount of time and known quantities of resources. An example of a system-constrained task is a process of waiting for concrete to cure. The only thing that can be prepared for system-constrained task is make sure that the needed resources are available.

2.12.3 Resource Loading

Resource loading means the amount of resources that a schedule requires during a specific point in time. Resource loading only gives firms a rough idea of how much resources is required by projects. After looking at the resource loading, the project manager will be able to determine which resource is overloaded and which is not. The advantage of knowing this is that project manager can plan in advance and ensure that the required resources, in the required amounts, are available when and where they are needed. The method of showing resource loading could be done by modify a PERT/CPM diagram to show resource requirements against time or a modified Gantt chart, but a modified PERT/CPM is more helpful in showing slacks.

2.12.4 Resource Leveling

Resource leveling is one of the methods of dealing with resource allocation problems. After doing resource loading, the company will have an overall picture of the usage of resources. There may be times when the resource usage is low and times when the usage is very high. Resource leveling will attempt to solve these problems by minimizing the variation of resource loading in a time period by shifting tasks within their slack allowances. The purpose for doing this is to create a smoother distribution of resource usage.

There are four major advantages to smoothing the resource usage. First, the project will not have to be closely managed if resource usage is level. This means resource leveling helps reduce the hassle of dealing with ordering materials. Second, if resource usage is level, just-in-time (JIT) could be implemented in the company without having to worry about wrong delivered quantity. This can be done because the quantity required by the project will be pretty much constant overtime, therefore it is easier for the suppliers to receive and supply constant orders over a period of time. Third, if the resource is people then leveling could improve morale which reduces problems in the personnel and pay-roll offices. Fourth, leveling the resource can also help leveling the costs which is a benefit for cost control. From a cost perspective, Meredith and Mantel (2000, 376) states that leveling employment throughout project or task is most important. By knowing when and how many labors needed in advance, the company will be able to control the costs of hiring and layoff. Sometime it is worth it to sacrifice some extra wages for the high costs of hiring and layoff.

The process of resource leveling can be done by hand if the resource use and the project are not too big. But for larger networks and multiple resources, computer-aided leveling is considered to be a mandatory tool.

2.12.5 Constrained Resource Scheduling

Constrained resource scheduling deals with minimizing the resource usage in a project while still achieving various completion dates or minimizing completion time while using only specified limited resources.

There are two main approaches to constrained allocation problems, they are heuristics and optimization methods. The two approaches have different goals, heuristic method looks for better solutions, while optimization looks for the best solution but it is far more limited on large problems.

2.12.5.1 Heuristic Methods

There are two reasons why heuristics are being used today. First, they seem to be the only method that can handle large, nonlinear, complex problems that are commonly found in the real world. Second, the schedules generated by heuristics are good enough for most purposes, even thought they are not the optimal. Nowadays, many different computer programs can handle large problems and also simulate many different results so project manager can choose which one is the best.

2.12.5.2 Optimization Methods

Optimization methods are divided into two categories: mathematical programming (linear programming for the most part) and enumeration. In 1960's, linear programming improved from being able to handle three resources and 15 activities to four resources and 55 activities. However, at that time linear programming did not have the ability to solve larger problems. In the late 1960s and early 1970s, a limited number of enumeration techniques using tree search and branch and bound methods were able to handle problem with five resources and 200 activities (Meredith and Mantel, 2000). At present, linear programming has been improved so that they can handle more complex problems.

2.12.6 Multiproject Scheduling and Resource Allocation

Multiproject scheduling and resource allocation is much more complicated than that of a single project. There are two approaches to mulitproject scheduling and resource allocation. First, treat them as they were each element of a single large project. Second, considered each project independently. Meredith and Mantel (2000, 389) states that there are three important parameters which will determine the effectiveness of scheduling. They are schedule slippage, resource utilization, and in-process inventory. The firm or project manager must determine which criterion is most suitable to the situation.

- Schedule slippage – schedule slippage means the time past project due date or delivery date when the project is completed. Schedule slippage often results in penalty costs, reduce profits, slippage to other projects, loss of goodwill, etc. Schedule slippage is normally considered to be most important criterion.
- Resource utilization – resource utilization is very important in industrial firm because the cost of making resources available is very expensive. Though a perfect resource allocation is not attainable, the company needs to find a system that smoothes out the peaks and valleys of resource usage as much as possible.
- In-process inventory – in-process inventory concerns with the amount of work waiting to be processed due to shortage of resource(s). The project manager must make a trade-off decision normally between the in-process inventory and the cost of the resources, usually capital equipment.

It is not possible to optimize all three criteria at the same time, therefore the project manager or a firm must make a decision of which criterion is most suitable. Then, use that criterion to evaluate its various scheduling and resource allocation options.

Some examples of various types of multiproject scheduling and resource allocation techniques will be examined.

2.12.6.1 Mathematical Programming

Mathematical programming can be used to obtain optimal solutions to some of multiproject scheduling problems. The three most common objectives for mathematical programming are:

1) Minimum total throughput time for all projects (time in the shop)
2) Minimum total completion time for all projects
3) Minimum total lateness or lateness penalty for all projects

The following constraints needed to be met by constraint equations.

- Limited resources
- Precedence relationships among activities
- Activity-splitting possibilities
- Project and activity due dates
- Substitution of resources to assign to specified activities
- Concurrent and non-concurrent activity performance requirements

The disadvantage for mathematical programming is extremely difficult and computationally expensive when dealing with large problems.

2.12.6.2 Heuristic Techniques

Heuristics have been the choice for dealing with the resource-constrained multiproject scheduling problem because the difficulties with the analytical formulation of realistic problems. Most of the heuristic-based procedures are commercially available for computers.

- Resource Scheduling Method – In calculating activity priority, the precedence is given to that activity with minimum value of d_{ij} where

  d_{ij} = increase in project duration resulting when activity **j** follows activity **i**.

  $= \text{Max}\ [0; (EFT_i - LST_j)]$

  where

  EFT_i = early finish time of activity **i**

  LST_j = latest start time of activity **j**

  The comparison is made in pairs among the activities in the conflict set.

- Minimum Late Finish Time – This rule assigns priorities to activities on the basis on activity finish time as determined by PERT/CPM. The earliest late finishers are scheduled first.
- Greatest Resource Demand – This rule assigns priorities on the basis of resource requirements, with higher priorities given to those with greater demands on resources. The priority can be calculated by

  Priority = $d_j \Sigma^{m}_{i=1} r_{ij}$

  where

  d_j = duration of activity **j**

  r_{ij} = per period requirement of resource **i** by activity **j**

  m = number of resource types

  Resource requirements must be stated in the common terms, usually dollars. This greatest resource demand aims to give priority to potential resource bottleneck activities.
- Greatest Resource Utilization – This rule gives priority to the combination of activities that results in maximum resource utilization or minimum idle resources during each scheduling period. The rule is implemented by solving 0-1 integer programming problem.
- Most Possible Jobs – This rule gives priority to a set of activities that results in the greatest number of activities being scheduled in any period. The rule is also implemented by solving 0-1 integer programming problem.

2.13 Conclusion

This chapter discussed the theories and review literatures that are related to the research. Firstly, the chapter talks about the basics of project management. Then, the chapter further discusses the project management knowledge areas, focusing on project planning, project scheduling, and resource allocation, which include theoretical tools and techniques which are currently and widely used today. Some of these tools and techniques will be used to apply and solve the problems of the case company in which will be discussed in the chapter 4.