Subject: CONCEPTS IN PROJECT PLANNING **Credits: 4**

SYLLABUS

Project Planning and scheduling techniques

Introduction, The Specification, Steps, Importance of Project Planning, Planning Schedules and Scope of Prototype and Pilot Projects, Project Planning and Database Issues.

Developing the project network using CPM/PERT

Introduction, History of cpm/pert, Planning, Scheduling & Control, Framework For PERT And CPM, CPM/PERT Network.

Constructing network diagram

Introduction, Network Construction, Constructing a Network Diagram from Work Breakdown Schedule.

AON basics

Introduction, The Workflow, Drawing of Activity Diagram, Examples.

Forward pass and Backward pass

Introduction, Forward Pass, Backward Pass, Calculating and Executing a Forward and Backward Pass, Constructing Forward and Backward Pass Project Management Template, Forward Pass / Backward Pass Calculation.

Advantages and Limitations of CPM/PERT

CPM/PERT, Calculation of Time Estimates In Cpm, Calculations In Network Analysis, Calculation of Expected Time And Variance of APath In Pert, CPM & PERT Weaknesses & Strengths, Advantages of PERT and CPM.

Constructing diagram and computations using precedence diagramming method

Introduction, Example, Sample Precedence Diagramming Method (PDM) Network Diagram, Gantt Charts, Critical Path Method (CPM) Program Evaluation and Review Technique (PERT).

PERT/CPM simulation

Introduction, Description of CPM/PERT, Modification In Cpm/Pert, Simplified Pert Procedure, Reviews, Structure And Elements of Simplified, Algorithm Of Simplified Cpm/Pert.

Reducing project duration

Introduction, Project Audit and Closure, Steps to reduce Project duration, Project Crashing, Conclusion, Project Time-Cost Trade-Off, Activity Time-Cost Relationship.

Suggested Readings:

Project Planning, Scheduling and Control, James P. Lewis, Tata McGraw-Hill
Project Planning and Scheduling, Gregory T. Haugan, Management Concepts

CHAPTER 1

Project Planning and scheduling techniques

Learning Objectives

- To explain about Project Management
- To analyse the Project Governance
- To recognise the role of Project Manager.
- To explain the steps involved in Project Planning.
- To identify key specifications of a Project.

1.1 Introduction

The initial step in project management and planning is to take along a reliable project team. This team should have:

- entrepreneurial spirit,
- experienced leadership,
- governance structure,

as it will guide the project and provide accountability for decision-making. If this is your first project, the people that you and your project manager bring together can make or break your project

1.1.1 Project Governance

As with any multi-million business venture, launching a community wind development effort requires a sound business operations structure. This includes an experienced Chief Executive Officer supported by team members. If you have never presided over an enterprise of this scale, you may want to partner with a veteran project executive to help you steer through major decisions and management issues. Once the project is built, you need to ensure ongoing oversight for:

- Maintenance
- Monitoring
- Operations
- Reporting

on the various financial aspects of the business.

1.1.1.1 Chief Executive Officer

Developing a project is similar to developing a factory plant. It takes a dedicated and diverse team to bring it into production that includes Chief Executive Officer and Board of Directors who will make the project on track. The CEO should have experience in business, preferably in the sector required and should have a strong understanding of the industry and the associated risks and rewards of development. The CEO is instrumental in developing relationships with potential investors and financing institutions. These are relationships that the project will depend on when capital is needed to move forward with development steps. The CEO should have know-how to understand when and how to exercise these relationships to ensure you meet the goals for investment share and return that you set out at the beginning of the project.

1.1.1.2 Board of Directors

The Board of Directors should be diverse, and comprised of members of the community with experience with:

- project,
- politics,
- business management,
- legal issues.

The Board's job is to guide the project toward desired goals by providing input at various stages of project development and giving advice when important decisions must be made involving business planning, finance, and legal issues. Board members should be selected not only for these qualities but also for their ability to make sound business decisions that are not clouded by emotions or local politics. A strong and diverse board will help the project thwart troubles before they develop into substantial problems by drawing on their past experiences with similar endeavors and making difficult decisions when issues do arise. A strong board can also help attract equity to the project, when needed, because investors will have assurance that their money will be used in a responsible way.

1.1.1.3 Project Manager

An efficient project manger acts as the development team leader. He or she should be responsible for making specific decisions and performing definite tasks that are assigned to the proper team members and completed within the timeframe required to meet project deadlines. The project manager should be experienced in development and able to assess the project risks and team member talents. Additionally, this person is responsible for making sure team members exchange needed information in a timely manner. A project manager should communicate well, be organized, and be capable of managing all team members to ensure efficient use of resources and time.

The project manager, in many cases, will be the public face of the project, engaging community members and meeting with officials. He or she will be closely involved in the negotiations for purchase, purchase agreement, and interconnection. An understanding of business metrics, as they pertain to community wind development and local politics, is a must for a well-qualified team leader.

The project manager is often an experienced developer who the project proponent hires. You may wish to hire a project manager who has developed other types of large projects, since the skill sets for developing community wind projects and other generation facilities are similar. The key is to hire someone that you trust, because this person will be primarily responsible for making sure that you and your investors realize your desired return on your investment.

1.1.1.4 Key Consultants

As seen, the right team to execute community development is very important and in that case you should consult with others who have completed similar projects so as to learn about their experiences with specific:

- consultants,
- manufacturers,
- construction companies.

You need to make sure that your project's team of consultants consists of experienced and reliable individuals with whom you have good rapport. Your project will require expertise in areas that include but are not limited to:

- Resource assessment
- Environmental impact studies
- Interconnection design

- Construction management
- Foundation design
- Legal agreements

How many experts you decide to hire for your project will depend on the Board's experience and level of comfort along with the time the Board is willing to devote in each of these areas. If you have little expertise, you may want to hire experts for each of these project development aspects. Some community wind developers may feel qualified to undertake certain tasks themselves.

Resource Assessment

Evaluating and documenting the resource at your site is one of the most important steps in the design of your project. For a commercial-scale project, you will need to conduct extensive on-site data collection and analysis. The data requirements to finance a 50 MW project are often substantially more rigorous than what lenders may require for a 2 MW project. Consulting a meteorologist or wind assessment professional for input on where turbines should be sited is required for some federal grants, and is recommended for sites with complex terrain. A meteorologist or site modeling specialist can confirm the best positions for the equipment and for the project's expected output.

Environmental Impact Studies

For many community projects, an environmental impact assessment is required. Professional scientists that can help in negotiating study protocols and conduct a scientifically sound field survey. A defensible set of environmental studies is important for obtaining permits and community support. Many grants come with requirements for who needs to perform the study and what it must cover. Consulting with local, state, and federal wildlife and environmental agencies will help you to understand what expertise will be required to complete environmental impact studies.

Interconnection Design

The utility of any project interconnects lies on the design and the interconnection system for a particular project, but it may be a good idea to contract with an engineer who is independent of the utility to help design the interconnection system, just to ensure that the utility's plans are within reason, and confirm that the associated costs are realistic. Construction managers are often able to recommend an engineer with interconnection experience.

Construction Management

The construction manager is a critical team member that is responsible for overseeing construction of the project and operating within budget and schedule constraints that may be imposed by power purchase agreements or by expiration of incentives. Ideally, you will be able to hire a local general contractor with previous experience managing wind turbine installations. If not, the manufacturer should be able to recommend one or more high quality construction managers.

Foundation Design

The foundation is a site-specific structure, and it must be properly designed to put up with the substantial loads placed on it by the turbine. A civil engineer will be consulted to conduct soil tests and recommend a foundation design, or to create a new design as the case warrants. Your turbine manufacturer may be able to provide a list of engineers who have previously designed foundations for their turbines.

Legal Assistance

In this case, you have to hire multiple attorneys with different areas of expertise in order to see the project through to fruition. Power purchase agreements, turbine procurement, project financing, land control, and various associated contracts are specialized to the independent power industry. Some attorneys also specialize in permitting and environmental compliance. These parts of a community wind development process must meet industry standards. A community wind project is a multi-million dollar investment and it is worthwhile to consult attorneys experienced in corporate and tax law to make sure that your assets are protected should the project not perform as expected.

1.2 THE SPECIFICATION

Before describing the role and creation of a specification, one need to introduce and explain a reasonably technical term called as numbly, which is a person whose brain is totally numb. In this reference, numb indicates deprived of feeling or the power of unassisted activity; that in general, a numbty requires the stimulation of an electric cattle production so as to even get to the right office in the morning. Communication with numbties is severely in a weak position by the fact that although they think they know what they mean, they hardly ever actually say it, and they never write it down. And the main employment of numbties world-wide is in creating project specifications.

A specification is basically the outline of any project, which is a statement of the problem, not the solution. Normally, the specification contains errors, ambiguities, misunderstandings and enough length to hang around a team. Thus upon the next six months of activity working on wrong project, one must assume that a numbty was the chief of the specification what one received, read, worry, revise and ensure that everyone concerned with the project is working with the same understanding. The outcome of this deliberation should be a written definition of what is required, by when; and this must be agreed by all involved. There are no short-cuts to this; if you fail to spend the time initially, it will cost you far more later on.

The agreement upon a written specification has several benefits:

- the clarity will reveal misunderstandings
- the completeness will remove clashing assumptions
- the rigour of the analysis will depiction technical and practical details which numbties in general gloss over through ignorance or fear
- the agreement forces all concerned to actually read and think about the details

The work on the specification can seen as the first stage of Quality Assurance since you are looking for and countering problems in the very foundation of the project from this perspective creation of the specification clearly merits a large investment of time.

From a purely defensive point of view, the agreed specification also affords ones protection against the numbties that have second thoughts, or new ideas, half way through the project. Once the project is underway, it can lead to change in cost. The existence of a demonstrably-agreed specification enables you to resist or to charge for such changes. Further, people tend to forget what they originally thought; you may need proof that you have been working as instructed.

The places to look for errors in a specification are:

- Global context: Numbties often focus too scarcely on the work of one team and fail to consider how it fits into the larger picture. Some of the work given to someone may actually be undone or duplicated by others. Some of the proposed work may be incompatible with that of others; it might be just plain barmy in the larger context.

- Interfaces: As seen in between a team and both its customers and suppliers, there are interfaces. At these points something gets transferred. Exactly what, how and when should be discussed and agreed from the very beginning. Never assume a common understanding, because you will be wrong. All it takes for your habitual understandings to evaporate is the arrival of one new member, in either of the teams. Define and agree your interfaces and maintain a friendly contact throughout the project.

- Time-scales: Numbties always underestimate the time involved for work. If there are no time-scales in the specification, you can assume that one will be imposed upon you. You must add realistic dates. The detail should include a precise understanding of the extent of any intermediate stages of the task, particularly those which have to be delivered.

- External dependencies: The work may depend upon the others. Make this very clear so that these people too will receive warning of your needs. Highlight the effect that problems with these would have upon your project so that everyone is quite clear about their importance. To be sure, contact these people yourself and ask if they are able to fulfill the assumptions in your specification.

- Resources: Numbty tends to ignore resources. The specification should identify the materials, equipment and manpower which are needed for the project. The agreement should include a commitment by your managers to allocate or to fund them. You should check that the actual numbers are practical and/or correct. If they are omitted, add them - there is bound to be differences in their assumed values.

This seems to make the specification sound like a long document. Each of the above could be a simple sub-heading followed by either bullet points or a table that you are not writing a brochure, you are stating the definition of the project in clear, concise and unambiguous glory.

Of course, the specification may change. If circumstances, or knowledge, changes then the specification will be said as out of date. You should not regard it as cast in stone but rather as a display board where everyone involved can see the current, common understanding of the project. If you change the content everyone must know, but do not hesitate to change it as necessary.

1.2.1 PROVIDING STRUCTURE

Having decided what the specification intends, the next problem is to decide what you and your team actually requires, and how to do it. As a manager, you have to provide some form of framework both to plan and to communicate what needs doing. Without a structure, the work is a series of unrelated tasks which provides little sense of achievement and no feeling of advancement. If the team has no grasp of how individual tasks fit together towards an understood goal, then the work will seem pointless and they will feel only frustration.

To take the planning forward, therefore, one needs to turn the specification into a complete set of tasks with a linking structure. Fortunately, these two requirements are met at the same time since the derivation of such a structure is the simplest method of arriving at a list of tasks.

1.2.1.1 Work Breakdown Structure

Once having a clear understanding of the project, and having eliminated the vagaries of the numbties, one then describe it as a set of simpler separate activities. If any of these are still too complex for anyone to easily organise, one can break them down also into another level of simpler descriptions, and so on until you can manage everything. Thus your one complex project is organised as a set of simple tasks which together achieve the desired result.

The reasoning behind this is that the human brain can only take in and process so much information at one time. To get a real grasp of the project, you have to think about it in pieces rather than trying to process the complexity of its entire details all at once. Thus each level of the project can be understood as the amalgamation of a few simply described smaller units.

In planning any project, one can follow the same simple steps and if an item is too complicated to manage, it becomes a list of simpler items. People call this producing a work breakdown structure to make it sound more formal and impressive. Without following this formal approach you are unlikely to remember all the niggling little details; with this procedure, the details are simply displayed on the final lists.

One common fault is to produce too much detail at the initial planning stage. You should be stop when you have a sufficient description of the activity to provide a clear instruction for the person who will actually do the work, and to have a reasonable estimate for the total time/effort involved. You need the former to allocate the task; you need the latter to finish the planning.

1.2.1.2 Task Allocation

The next stage is a little complex. One has to allocate the tasks to different people in the team and, at the same time, order these tasks so that they are performed in a sensible sequence.

Task allocation is not simply a case of handing out the various tasks on your final lists to the people you have available; it is far more subtle than that. As a manager you have to look far beyond the single project; indeed any individual project can be seen as merely a single step in your team's development. The allocation of tasks should thus be seen as a means of increasing the skills and experience of a team when the project is done, the team should have gained.

In simple terms, consider what each member of your team is capable of and allocate sufficient complexity of tasks to match that. The tasks you allocate are not the ones on your finals lists, they are adapted to better suit the needs of your team's development; tasks are moulded to fit people, which is far more effective than the other way around. For example, if Arthur is to learn something new, the task may be simplified with responsibility given to another to guide and check the work; if Brenda is to develop, sufficient tasks are combined so that her responsibility increases beyond what she has held before, if at all she lacks confidence, then the tasks are broken into smaller units which can be completed frequently.

Sometimes tasks can be grouped and allocated together. For instance, some tasks which are seemingly independent may benefit from being done together since they use common ideas, information, and talents. One person doing them both removes the start-up time for one of them; two people will be able to help each other.

The ordering of the tasks is really quite simple, although one may find that sketching a sequence diagram helps anyone to think it through. Pert charts are the accepted outcome, but sketches will suffice. Getting the details exactly right, however, can be a long and painful process, and often it can be futile. The degree to which you can predict the future is limited, so too should be the detail of your planning. One must have the broad outlines by which to monitor progress, and sufficient detail to assign each task when it needs to be started, but beyond that stop and do something useful instead.

Guesstimation

At the initial planning stage the main idea is to get a realistic estimate of the time involved in the project. One must establish this not only to assist higher management with their planning, but also to protect your team from being expected to do the impossible. The most important technique for achieving this is known as guesstimation. Guesstimating schedules is disreputably difficult but it is helped by two approaches:

- make your guesstimates of the simple tasks at the bottom of the work break down structure and look for the longest path through the sequence diagram
- use the experience from previous projects to improve your guesstimating skills

The consequence to this is that you should keep records in an easily accessible form of all projects as you do them. Part of your final project review should be to update your personal data base of how long various activities take. Managing this planning phase is vital to your success as a manager.

Some people find guesstimating a difficult idea in that if one has no experience of an activity, how can it make a worthwhile estimate? Under such circumstances, how long would it take someone to walk all the way to the top of the Tower? Presuming you have never actually tried this, as one really have very little to go on. Indeed if someone has actually seen one of these buildings, think about the other. Here the job depends upon this, so think carefully. One idea is to start with the number of steps guess that if you can. Notice, you do not have to be right, merely reasonable. Next, consider the sort of pace you could maintain while climbing a flight of steps for a long time. Now imagine yourself at the base of a flight of steps you do know, and estimate:

- how many steps there are

- how long it takes to climb.

To complete, apply a little mathematics. Now examine how confident you are with this estimate. If you won a free flight to Paris or New York and tried it, you would probably be surprised if you climbed to the top in less than half the estimated time and if it took you more than double you would be mildly annoyed. If it took you less than 10^{th} time, or 10 times as long, as one would extremely surprised or annoyed. In fact, one must not believe that what would happen. The point is that from very little experience of the given problem, one can actually come up with a working estimate and one which is far better than no estimate at all when it comes to deriving a schedule. Guesstimating does take a little practice, but it is a very useful skill to develop.

There are two practical problems in guesstimation:

- First, you are simply too optimistic. It is human nature at the beginning of a new project to ignore the difficulties and assume best case scenarios in producing your estimates you must inject a little realism. In practice, you should also build-in a little slack to allow yourself some tolerance against mistakes. This is known as defensive scheduling. Also, if you ultimately deliver ahead of the agreed schedule, you will be loved.

- Secondly, you will be under pressure from senior management to deliver quickly, especially if the project is being sold competitively. Refuse to accept the temptation to rely upon speed as the only selling point, one might for instance, suggest that the criteria of fewer errors, history of adherence to initial schedules, previous customer satisfaction, takes long so one can trust the other quotes.

1.2.2 ESTABLISHING CONTROLS

When the planning phase is over, then the doing phase begins. Once it is in motion, a project acquires a direction and momentum which is totally independent of anything you predicted. If you come to terms with that from the start, you can then enjoy the roller-coaster which follows. To gain some hope, however, one need to establish at the start the means to monitor and to influence the project's progress.

There are two key elements to the control of a project

- milestones
- established means of communication

In this, the milestones are a mechanism to monitor progress; for the team, they are short-term goals which are far more tangible than the foggy, distant completion of the entire project. The milestones maintain the momentum and encourage effort; they allow the team to judge their own progress and to celebrate achievement throughout the project rather than just at its end.

The simplest way to construct milestones is to take the timing information from the work breakdown structure and sequence diagram. When you have guesstimated how long each sub-task will take and have strung them together, you can identify by when each of these tasks will actually be completed. This is simple and effective; however, it lacks creativity.

Another method is to construct more significant milestones. These can be found by identify stages in the development of a project which are recognisable as steps towards the final product. Sometimes these are simply the higher levels of your structure; for instance, the completion of a market evaluation phase. From time to time, one must cut across many parallel activities; for instance, a prototype of the eventual product or a mock-up of the new brochure format.

If you are running parallel activities, this type of milestone is predominantly useful since it provides a means of pulling together the people on disparate activities, and so:

- they all have a shared goal
- their responsibility to each other is emphasised
- each can provide a new viewpoint on the others' work
- the problems to do with combining the different activities that are highlighted and discussed early in the implementation phase of the project
- you have something tangible which senior management and can recognise as progress
- you have something tangible which your team can celebrate and which constitutes a short-term goal in a possibly long-term project
- it provides an excellent opportunity for quality checking and for review

Of course, there are milestones and there are milestones. You will have to be sensitive to any belief that working for some specific milestone is hindering rather than helping the work forward. If this arises then either you have chosen the wrong milestone, or you have failed to communicate how it fits into the broader structure.

Communication is everything. In a project:

- to monitor progress
- to receive early warning of danger
- to promote cooperation
- to motivate through team involvement

all of these rely upon communication. Regular reports are invaluable if you clearly define what information is needed and if you want to teach your team in order to provide it rapidly in an accessible form. Often these reports explain about progressing as per schedule. These can be send back, for while the message is desired the evidence is missing: you need to insist that the team will monitor their own progress with concrete, tangible, measurements and if this is done, the figures should be included in the report. However, the real value of this practice comes when progress is not according to schedule then your communication system is worth all the effort you invested in its planning.

1.2.3 ARTISTRY IN PLANNING

At the planning stage, one can deal with far more than the mere project at hand. One can also shape the overall pattern of team's working using the division and type of activities one assign. For this purpose, ask the team, which must involved in the planning of projects, especially in the lower levels of the work breakdown structure. Not only will they provide information and ideas, but also they will feel ownership in the final plan.

This does not mean that ones projects should be planned by committee rather as manager, planning the project based upon all available experience and creative ideas. As an initial approach, one could attempt the first levels of the work breakdown structure so as to help in communicating the project to the team and then asking for comments. Now using these, the final levels could be refined by the people to whom the tasks will be allocated. However, since the specification is so vital, all the team should vet the penultimate draft.

1.2.3.1 Dangers in review

There are two pitfalls to avoid in project reviews:

- they can be too frequent
- they can be too drastic

The constant drop of new information can lead to a cruel cycle of planning and revising which shakes the team's assurance in any particular version of the plan and which destroys the very stability which the structure was designed to provide. One must decide the balance by picking up a point on the horizon and walking confidently towards it. Decide objectively, and explain beforehand, when the review phases will occur and make this a scheduled milestone in itself.

Even though the situation may have changed since the last review, it is important to recognise the work which has been accomplished during the interim. Initially, one do not want to abandon it since the team will be demotivated feeling that they have achieved nothing. Secondly, this work itself is part of the new situation: it has been done, it should provide a foundation for the next step or at least the basis of a lesson well learnt. Always try to build upon the existing achievements of your team.

1.2.3.2 Testing and Quality

No plan is complete without explicit provision for testing and quality. As a wise manager, you will know that this should be part of each individual phase of the project. This means that no activity is completed until it has passed the defined criteria which establish its quality, and these are best defined at the beginning as part of the planning.

When devising the schedule therefore you must include allocated time for this part of each activity. Thus your question is not only: "how long will it take", but also: "how long will the testing take". By asking both questions together you raise the issue of "how do we know we have done it right" at the very beginning and so the testing is more likely to be done in parallel with the implementation. One can establish this philosophy for the team by including the testing as required cost.

1.2.3.3 Fitness for purpose

Another reason for stating the testing criteria at the beginning is that you can avoid futile quests for perfection. If one has motivated the team well, they will each take pride in their work and want to do the best job possible. Often this shows that polishing ones work until is shines and often this wastes. If it clear at the onset exactly what is needed, then they are more likely to stop when that has been achieved. One needs to avoid generalities and to stipulate boundaries which is not easy but is essential.

The same is also true when choosing the tools or building-blocks of your project. While it might be nice to have use of the most modern versions, or to develop an exact match to your needs; often there is an old/existing version which will serve almost as well and the difference is not worth the time you would need to invest in obtaining or developing the new one. Use what is available whenever possible unless the difference in the new version is worth the time, money and the initial, teething pains.

A linked idea is that one should discourage too much effort on aspects of the project which are idiosyncratic to that one job. In the specification phase, one might try to eliminate these through negotiation with the customer; in the implementation phase which might leave these parts until last. The reason for this advice is that a general piece of work can be tailored to many specific instances thus, if the work is in general form, one will be able to rapidly re-use it for other projects. On the other hand, if one produce something which is cut to fit exactly the specific case, than one may have to repeat the work entirely evenly though the next project which is fairly similar. At the planning phase, a manager should bare in mind the future and the long-term development of the team as well as the requirements of the current project.

1.2.3.4 Fighting for time

As a manager, you have to regulate the pressure and work load which is imposed upon your team; you must protect them from the unreasonable demands of the rest of the company. Once you have arrived at what you consider to be a realistic schedule, fight for it. Never let the outside world deflect you from what you know to be practical. If they impose a deadline upon you which is impossible, clearly state this and give your reasons. You will need to give some room for compromise, however, since a flat no will be seen as obstructive. Since you want to help the company, you should look for alternative positions.

You could offer a prototype service or product at an earlier date. This might, in some cases, be sufficient for the customer to start the next stage of his/her own project on the understanding that your project would be completed at a later date and the final version would then replace the prototype.

The complexity of the product, or the total number of units, might be reduced. This might, in some cases, be sufficient for the customer's immediate needs. Future enhancements or more units would then be the subject of a subsequent negotiation which, one feel, would be likely to succeed since one will have already demonstrates the ability to deliver on time.

You can show on an alternative schedule that the project could be delivered by the deadline if certain (specified) resources are given to you or if other projects are rescheduled. Thus, you provide a clear picture of the situation and a possible solution; it is up to your manager then how he/she proceeds.

1.2.3.5 Planning for error

The most common error in planning is to assume that there will be no errors in the implementation: in effect, the schedule is derived on the basis of "if nothing goes wrong". Of course, recognising that errors will occur is the reason for implementing a monitoring strategy on the project. Thus when the inevitable does happen, one can react and adapt the plan to compensate. However, by carefully considering errors in advance you can make changes to the original plan to enhance its tolerance. Quite simply, the planning should include time where one can stand back from the design and indeed, an excellent way of asking someone's team for the analysis of plan.

One can try to predict where the errors will occur. By examining the activities' list you can usually pinpoint some activities which are risky for instance, those involving new equipment and those which are quite secure for instance, those your team has done often before. The risky areas might then be given a less stringent time-scale actually planning-in time for the mistakes. Another possibility is to apply a different strategy, or more resources, to such activities so as to minimise the disruption. For instance, one could include training or consultancy for new equipment, or might parallel the work with the foundation of a fall-back position.

1.2.3.6 Post-mortem

At the end of any project, one should allocate time to reviewing the lessons and information on both the work itself and the management of that work: an open meeting, with open discussion, with the whole team and all customers and suppliers. If you think that this might be thought a waste of time by your own manager, think of the effect it will have on future communications with your customers and suppliers.

1.2.4 PLANNING FOR THE FUTURE

With all these considerations in merely the "planning" stage of a project, it is perhaps surprising that projects get done at all. In fact projects do get done, but seldom in the predicted manner and often as much by brute force as by careful planning. The point, however, is that this method is non-optimal. Customers feel let down by late delivery, staff are demotivated by constant pressure for impossible goals, corners get cut which harm your reputation, and each project has to overcome the same problems as the last.

With planning, projects can run on time and interact effectively with both customers and suppliers. Everyone involved understands what is wanted and emerging problems are seen long before they cause damage. If you want your projects to run this way then one must invest time in planning.

1.3 Steps

When you're managing a project, planning and scheduling are key to your success. When setting goals, they should be specific, measurable, achievable, realistic and timed. When you plan and schedule your actions, you are taking a huge step toward meeting those requirements. Consider the various techniques that may help you to set up a successful project plan that's simple to follow.

Step 1

Meet with your team to discuss the various elements of the project. Start by setting a goal for the project that's consistent with the SMART goal-setting principle. The goal should be narrowed down to a very specific purpose and you should have a way to gauge your team's progress toward that goal. The goal must also be reasonable and realistic for your small business. Finally, you need to determine a time by which your team must accomplish that goal.

Step 2

Work backwards to determine the steps required to complete the goal you've determined. You can write bullet points or use a project plan template to accomplish this step. Make sure you quote the goal at the top of the written project plan, as well as information about budget requirements, and designate a person as responsible for each point on the plan. You should determine all of these details during your initial meeting.

Step 3

Enter each specific point on your project plan into the project management or calendar software that you use in the course of business, such as Microsoft Outlook, InfoPath or Google Calendar. This scheduling technique is used by many companies because it allows you to set up a reminder system to keep track of your progress on the project. Set a due date for each item on the list of things to accomplish along with a reminder notification.

Step 4

Enter updates for each entry of your project planning schedule as needed. Share access to the project management software or calendar with your team if possible so that each member can stay abreast of the project as well.

1.4 Importance of Project Planning

GIS projects are expensive in terms of both time and money. Municipal GIS and facilities management projects developed by utilities may take a decade or more to bring on-line at a cost of tens or hundreds of millions of dollars. Careful planning at the outset, as well as during the project, can help to avoid costly mistakes. It also provides assurance that a GIS will accomplish it goals on schedule and within budget.

There is an attraction, when a new technology such as GIS become available, to improvise a solution to its use, that is to get started without considering where the project will lead. The greatest danger is that decisions made in haste or on the spur of the moment will have to be reversed later or will prove too costly to implement, meaning a GIS project may have to be abandoned. To avoid disappointing experiences like these, GIS professionals have developed a well-defined planning methodology often referred to as project lifecycle. Lifecycle planning involves setting goals, defining targets, establishing schedules, and estimating budgets for an entire GIS project.

The original impetus for developing effective lifecycle planning was cost containment. For many decades, the rationale for implementing new information technologies was that, in the long run, such projects would reduce the cost of business operations.

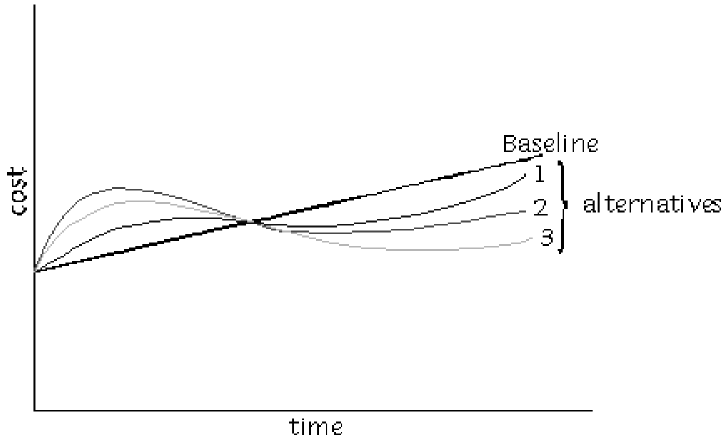


Fig 1.1

This optimistic appraisal of the benefits of information technologies has not borne out in the American economy during the past two decades. In almost all cases, adopting new information technologies has added to the cost of business operations without producing a corresponding increase in traditional measures of labor productivity, as in the following graph.

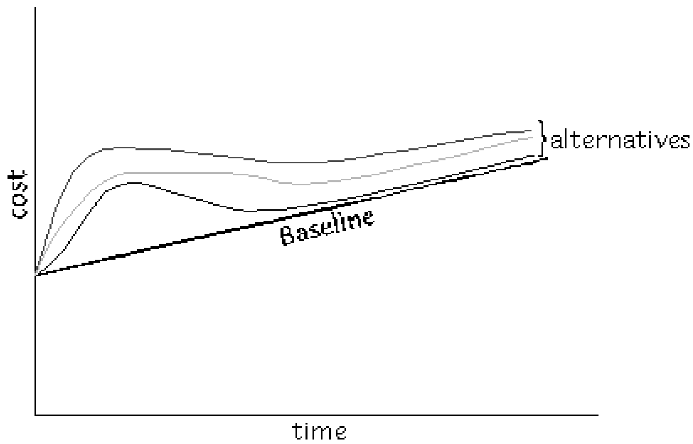


Fig: 1.2

This does not mean that information technologies have been a failure. Rather, these systems allow users to accomplish a greater range of varied and complex tasks, but at a higher cost. Users are not so much doing their previous work at faster speeds, but assuming new tasks offered by the new technologies. Support staff once satisfied with producing in-house documents may now be tempted to get it issued. Cartographers once satisfied with producing discrete utility maps for individual construction projects may be tempted to create an encompassing map and GIS database containing maintenance records for an entire city.

It is generally recognized that, for the foreseeable future, most information technologies projects will have to be justified on the basis of a "do more, pay more" philosophy. This means that effective lifecycle planning is all the more important. In the past, projected existing costs could be used as a baseline against which improvements could be measured. If the cost curve for new information technologies is always above the baseline, then greater care must be exerted in setting goals, establishing targets, and estimating budgets. There is far too great a danger that, in the absence of such checks and balances, a project may grow out of control.

1.5. Planning Schedules and Scope of Prototype and Pilot Projects

There is nothing wrong with being cautious during the process of project planning. Rushing through the procedure exposes an organization to potentially costly mistakes. Large AM/FM projects typically take many years to reach the prototype or pilot stages.

Once a prototype or pilot project has approved, even more time will elapse before full implementation is achieved. Some municipal GIS projects have been underway for over a decade and still have far to go before complete implementation and compilation of a full dataset.

Prototype and pilot projects are kept small, as is indicated in the following table. Remember, prototypes and pilots are intended to demonstrate functions and interfaces. What works best is a carefully selected test area that presents examples of common workflows. Its aerial size of is little consequence in most applications.

1.5.1 Applying the Insights of Project Lifecycle to Research Projects

The concepts of lifecycle planning can be applied to projects of lesser scale and scope, particularly to those pursued in undergraduate and graduate research. This does not mean that every project will move through every step outlined above. Some steps such as benchmarking and system selection may be irrelevant in a setting where the researcher must make do with whatever equipment and software is on hand. But lifecycle planning should not be viewed as a series of boxes on a checklist, it is a process of careful planning and problem solving. It is this process of careful planning that should be emulated regardless of the scope or scale of a project.

This point is not always understood. Some researchers reject the methodology of project planning because it seems overly formal and stringent given their modest research goals. Instead, they improvise a GIS solution. But improvised solutions are always a risk. Attention to the process of careful planning can waylay such risks. Perhaps the essence of this process can be summarized in three points.

- Think ahead to how the GIS will be used, but keep in mind what sources are available.

  Designing an effective GIS involves setting clear goals. The temptation is to rush ahead and begin digitizing and converting data without establishing how the system will be used. Even for small GIS projects, it is wise to engage in a modest functional requirements study. This allows the user to gain an idea of exactly what data sources are required, how they will be processed, and what final products are expected. Without clear-cut goals, there is too great a danger that a project will omit key features or include some that are irrelevant to the final use.

- Exert special care in designing and creating the database.

  Again, it is easy to rush ahead with the creation of a database, and then find later that it has to be reorganized or altered extensively. It is far more economical to get things right the first time. This means that the researcher should chart out exactly how the database is to be organized and to what levels of accuracy and precision. Attention and testing of symbolization and generalization will also pay off good.

- Always develop a prototype or sample database to test the key features of the system.

No matter the size of a project, the researcher should aim to create a prototype first before moving toward full implementation of a GIS. This allows the researcher move through all of the steps of creating and using the system to see that all procedures and algorithms work as expected. The prototype can be a small area or may be confined to one or two of the most critical layers. In either case, testing a prototype is one step that should not be overlooked.

1.6 Project Planning and Database Issues

The project planning cycle outlines a process, but the issues that must be addressed at each stage of this process will vary considerably from organization to organization. Some topics are of critical importance to large municipal, state, and private AM/FM applications, but less so for research applications of limited scope. Among the issues that must be addressed in large GIS projects are:

1.6.1. Security

The security of data is always a concern in large GIS projects. But there is more to security than protecting data from malicious tampering or theft. Security also means that data is protected from system crashes, major catastrophes, and inappropriate uses. As a result, security must be considered at many levels and must anticipate many potential problems. GIS data maintained by government agencies often presents difficult challenges for security. While some sorts of data must be made publicly accessible under open records laws, other types are protected from scrutiny. If both types are maintained within a single system, managing appropriate access can be difficult. Distribution of data across open networks is always a matter of concern.

1.6.2. Documentation

Most major GIS datasets will outlive the people who create them. Unless all the steps involved in coding and creating a dataset are documented, this information will be lost as staff retire or move to new positions. Documentation must begin at the very start of GIS project and continue through its life. It is best, perhaps, to actually assign a permanent staff to documentation to make sure that the necessary information is saved and revised in a timely fashion.

1.6.3. Data Integrity and Accuracy

When mistakes are discovered in a GIS database, there must be a well-defined procedure for their correction. Furthermore, although many users may have to use the information stored in a GIS database, not all of these users should be permitted to make changes. Maintaining the integrity of the different layers of data in a comprehensive GIS database can be a challenging task. A city's water utility may need to look at GIS data about right-of-ways for power and cable utilities, but it should not be allowed to change this data. Responsibility for changing and correcting data in the different layers must be clearly demarcated among different agencies and offices.

1.6.4. Synchronization of Usage

GIS datasets employed in government or by utilities will have many users. One portion of the dataset may be in demand simultaneously by several users as well as by staff charged with updating and adding new information. Making sure that all users have access to current data whenever they need it can be a difficult challenge for GIS design. Uncontrolled usage may be confusing to all users, but the greatest danger is that users may actually find themselves interfering with the project workflow or even undoing one another's work.

1.6.5. Update Responsibility

Some GIS datasets will never be "complete." Cities and utility territories keep growing and changing and the database must be constantly updated to reflect these changes. But these changes occur on varying schedules and at varying speeds. Procedures must be developed to record, check, and enter these changes in the GIS database. Furthermore, it may be important to maintain a record of the original data. In large GIS projects, updating the database may be the responsibility of a full-time staff.

1.6.6. Minimization of Redundancy

In large GIS projects, every byte counts. If a database is maintained for 30-50 years, every blank field and every duplicated byte of information will incur storage costs for the full length of the project. Not only will wasted storage space waste money, it will also slow performance. This is why in large, long-term GIS projects, great attention to devoted to packing data as economically as possible and reducing duplication of information.

1.6.7. Data Independence and Upgrade Paths

A GIS database will almost always outlive the hardware and software that is used to create it. Computer hardware has a useable life of 2-5 years, software is sometimes upgraded several times a year. If a GIS database is totally dependent on a single hardware platform or a single software system, it too will have to be upgraded just as often. Therefore, it is best to create a database that is as independent as possible of hardware and software. Through careful planning and design, data can be transferred as ASCII files or in some metadata or exchange format from system to system. There is nothing worse than having data held in a proprietary vendor-supported format and then finding that the vendor has changed or abandoned that format.

In this way, GIS designers should think ahead to possible upgrade paths for their database. It is notoriously difficult to predict what will happen next in the world of computers and information technology. To minimize possible problems, thought should be given to making the GIS database as independent as possible of the underlying software and hardware.

1.6.8. Privacy

Safeguards on personal privacy have become a great concern over the past decade, particularly with the rise of the internet and web. These concerns arise to two principal situations.

- The first, is hacking into, accidentally release, or inappropriate disclosure of privileged information which can compromise an individual's privacy with respect to medical conditions, financial situation, sexual, political, religious beliefs & values and other privileged personal information.
- The second is the ease with which information and computer technologies permit the creation of information "mosaics" or personal profiles from small pieces of seemingly innocuous, non-confidential data.

Review Questions

1. What is the role of establishing control in Project Planning?
2. What are Project Life Cycle in Project Management?
3. What are GIS Database? Explain its features?
4. Role of GIS in Data Independence?

Discussion Questions

Discuss the key specifications of planning a Project.

Application Exercises

1. If you are a Project Manager, state your role in Project Management?
2. What are the various steps involved in future planning of Projects.
3. State the importance of Project Planning.

CHAPTER 2

Developing the project network using CPM/PERT

Learning Objectives

- To explain about CPM and PERT
- To analyse the network analysis in Project
- To recognise the role of Project network.
- To know about Project completion details.
- To identify length of the Project.

2.1. INTRODUCTION

Basically, CPM stands for Critical Path Method and PERT stands for Programme Evaluation Review Technique are types of project management techniques which have been created out of the need of Western industrial and military establishments to:

- Plan projects
- Schedule projects
- Control complex projects

2.2 History of CPM/PERT

CPM/PERT or Network Analysis as the technique is sometimes called, developed along two parallel streams, one industrial and the other military.

CPM was the discovery of M.R.Walker of E.I.Du Pont de Nemours & Co. and J.E.Kelly of Remington Rand, circa 1957. The computation was designed for the UNIVAC-I computer. The first test was made in 1958, when CPM was applied to the construction of a new chemical plant. In March 1959, the method was applied to maintenance shut-down at the Du Pont works in Louisville, Kentucky. Unproductive time was reduced from 125 to 93 hours.

PERT was devised in 1958 for the POLARIS missile program by the Program Evaluation Branch of the Special Projects office of the U.S.Navy, helped by the Lockheed Missile Systems division and the Consultant firm of Booz-Allen & Hamilton. The calculations were so arranged so that they could be carried out on the IBM Naval Ordinance Research Computer (NORC) at Dahlgren, Virginia.

2.3 Planning, Scheduling & Control

Planning, Scheduling and Control are considered to be basic Managerial functions, and CPM/PERT has been rightfully accorded due importance in the literature on Operations Research and Quantitative Analysis.

Far more than the technical benefits, it was found that PERT/CPM provided a focus around which managers could brain-storm and put their ideas together. It proved to be a great communication medium by which thinkers and planners at one level could communicate their ideas, their doubts and fears to another level. Most important, it became a useful tool for evaluating the performance of individuals and teams.

There are many variations of CPM/PERT which have been useful in planning costs, scheduling manpower and machine time. CPM/PERT can answer the following important questions:

- How long will the entire project take to be completed? What are the risks involved?
- Which are the critical activities or tasks in the project which could delay the entire project if they were not completed on time?
- Is the project on schedule, behind schedule or ahead of schedule?
- If the project has to be finished earlier than planned, what is the best way to do this at the least cost?

2.4 Framework for PERT and CPM

Essentially, there are six steps which are common to both the techniques. The procedure is listed below:

I. Define the Project and all of its significant activities or tasks. The Project should have only a single start activity and a single finish activity.

II. Develop the relationships among the activities. Decide which activities must precede and which must follow others.

III. Draw the "Network" connecting all the activities. Each Activity should have unique event numbers. Dummy arrows are used where required to avoid giving the same numbering to two activities.

IV. Assign time and/or cost estimates to each activity

V. Compute the longest time path through the network. This is called the critical path.

VI. Use the Network to help plan, schedule, monitor and control the project.

The Key Concept used by CPM/PERT is that a small set of activities, which make up the longest path through the activity network control the entire project. If these "critical" activities could be identified and assigned to responsible persons, management resources could be optimally used by concentrating on the few activities which determine the fate of the entire project.

Non-critical activities can be replanned, rescheduled and resources for them can be reallocated flexibly, without affecting the whole project. Five useful questions to ask when preparing an activity network are:

i. Is this a Start Activity?
ii. Is this a Finish Activity?
iii. What Activity Precedes this?
iv. What Activity Follows this?
v. What Activity is Concurrent with this?

Some activities are serially linked. The second activity can begin only after the first activity is completed. In certain cases, the activities are concurrent, because they are independent of each other and can start simultaneously. This is especially the case in organisations which have supervisory resources so that work can be delegated to various departments which will be responsible for the activities and their completion as planned. When work is delegated like this, the need for constant feedback and co-ordination becomes an important senior management pre-occupation.

2.5 CPM/PERT Network

Each activity or sub-project in PERT/CPM Network is represented by an arrow symbol. Each activity is preceded and succeeded by an event, represented as a circle and numbered.

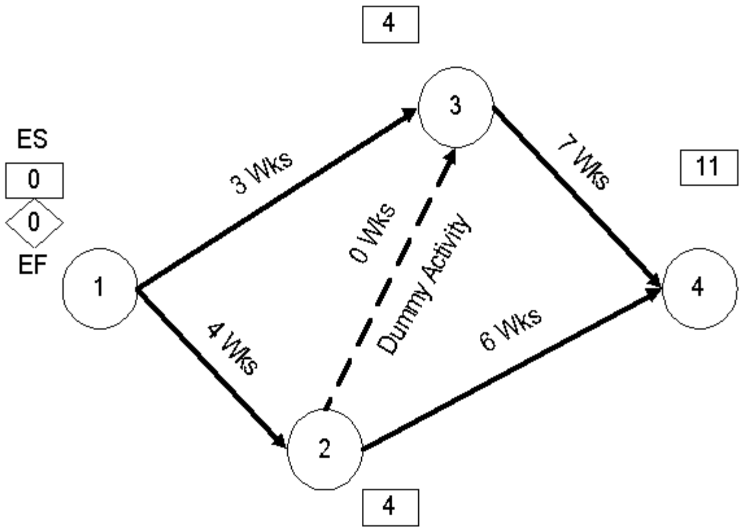


Fig 2.1

At Event 3, we have to evaluate two predecessor activities Activity 1-3 and Activity 2-3, both of which are predecessor activities. Activity 1-3 gives us an Earliest Start of 3 weeks at Event 3. On the other hand, Activity 2-3 also has to be completed before Event 3 can begin. Along this route, the Earliest Start would be 4+0=4. The rule is to take the longer of the two Earliest Starts. So the Earliest Start at event 3 is 4.

Similarly, at Event 4, we find we have to evaluate two predecessor activities - Activity 2-4 and Activity 3-4. Along Activity 2-4, the Earliest Start at Event 4 would be 10 wks, but along Activity 3-4, the Earliest Start at Event 4 would be 11 wks. Since 11 wks is larger than 10 wks, we select it as the Earliest Start at Event 4. We has now found the longest path through the network. It will take 11 weeks along activities 1-2, 2-3 and 3-4. Such is called as Critical Path.

2.5.1 Backward Pass - Latest Finish Time Rule

To make the Backward Pass, we begin at the sink or the final event and work backwards to the first event.

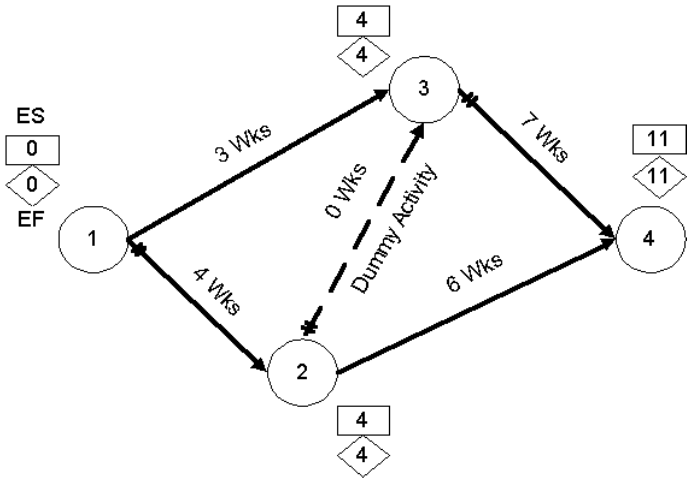


Fig 2.2

At Event 3 there is only one activity, Activity 3-4 in the backward pass, and we find that the value is 11-7 = 4 weeks. However at Event 2 we have to evaluate 2 activities, 2-3 and 2-4. We find that the backward pass through 2-4 gives us a value of 11-6 = 5 while 2-3 gives us 4-0 = 4. We take the smaller value of 4 on the backward pass.

2.5.2 Tabulation & Analysis of Activities

We are now ready to tabulate the various events and calculate the Earliest and Latest Start and Finish times. We are also now ready to compute the SLACK or TOTAL FLOAT, which is defined as the difference between the Latest Start and Earliest Start.

Event	**Duration**(Weeks)	**Earliest Start**	**Earliest Finish**	**Latest Start**	**Latest Finish**	**Total Float**
1-2	4	0	4	0	4	0
2-3	0	4	4	4	4	0
3-4	7	4	11	4	11	0
1-3	3	0	3	1	4	1
2-4	6	4	10	5	11	1

- The Earliest Start is the value in the rectangle near the tail of each activity

- The Earliest Finish is = Earliest Start + Duration
- The Latest Finish is the value in the diamond at the head of each activity
- The Latest Start is = Latest Finish - Duration

There are two important types of Float or Slack. These are Total Float and Free Float.

TOTAL FLOAT is the spare time available when all preceding activities occur at the **earliest** possible times and all succeeding activities occur at the **latest** possible times.

- Total Float = Latest Start - Earliest Start

Activities with zero Total float are on the Critical Path

FREE FLOAT is the spare time available when all preceding activities occur at the **earliest** possible times and all succeeding activities occur at the **earliest** possible times. When an activity has zero Total float, free float will also be zero.

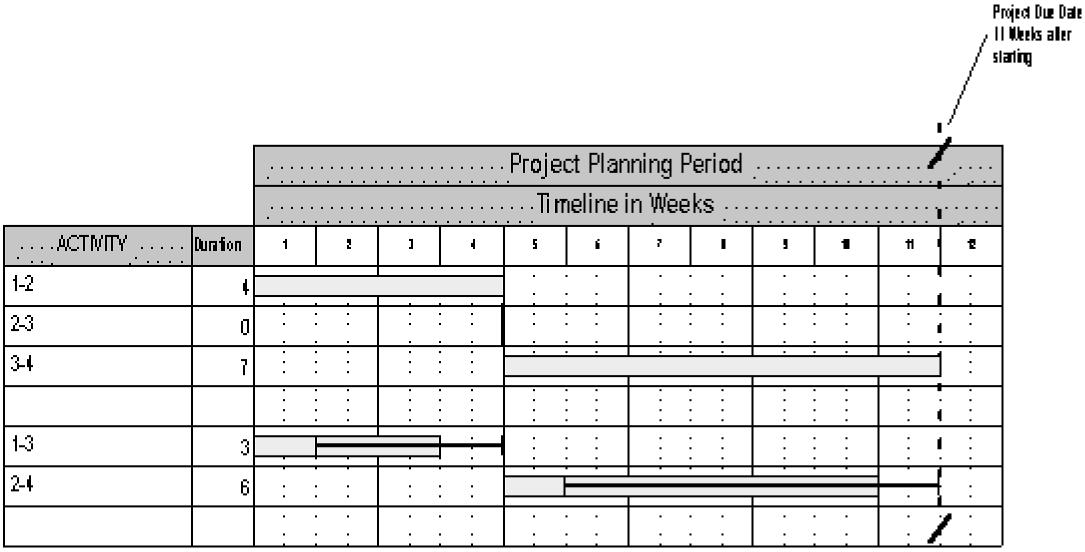
There are various other types of float such as:

- Independent
- Early Free
- Early Interfering
- Late Free
- Late Interfering
- Float

that can also be negative. We shall not go into these situations at present for the sake of simplicity and be concerned only with Total Float for the time being. Having computed the various parameters of each activity, we are now ready to go into the scheduling phase, using a type of bar chart known as the Gantt Chart.

2.5.3 Scheduling of Activities Using a Gantt chart

Once the activities are laid out along a Gantt chart, the concepts of Earliest Start & Finish, Latest Start & Finish and Float will become very obvious.



Activities 1-3 and 2-4 have total float of 1 week each, represented by the solid timeline which begins at the latest start and ends at the latest finish. The difference is the float, which gives us the flexibility to schedule the activity.

For example, we might send the staff on leave during that one week or give them some other work to do. Or we may choose to start the activity slightly later than planned, knowing that we have a week's float in hand. We might even break the activity in the middle for a week and divert the staff for some other work, or declare a National or Festival holiday as required under the National and Festival Holidays Act.

These are some of the examples of the use of float to schedule an activity. Once all the activities that can be scheduled are scheduled to the convenience of the project, normally reflecting resource optimisation measures, we can say that the project has been scheduled.

2.5.3.1. Exercise

A Social Project manager is faced with a project with the following activities:

Activity-id	Activity - Description	Duration
1-2	Social Work Team to live in Village	5 Weeks
1-3	Social Research Team to do survey	12 Weeks

3-4	Analyse results of survey	5 Weeks
2-4	Establish Mother & Child Health Program	14 Weeks
3-5	Establish Rural Credit Programme	15 Weeks
4-5	Carry out Immunisation of Under Fives	4 Weeks

- Draw the arrow diagram, using the helpful numbering of the activities, which suggests the following logic:
- Unless the Social Work team lives in the village, the Mother and Child Health Programme cannot be started due to ignorance and superstition of the villagers
- The Analysis of the survey can obviously be done only after the survey is complete.
- Until rural survey is done, the Rural Credit Programme cannot be started
- Unless Mother and Child Programme is established, the Immunisation of Under Fives cannot be started
- - Calculate the Earliest and Latest Event Times
- - Tabulate and Analyse the Activities
- - Schedule the Project Using a Gantt Chart

2.5.3.2 The PERT Approach

So far we have talked about projects, where there is high certainty about the outcomes of activities. In other words, the cause-effect logic is well known. This is particularly the case in engineering projects. However, in Research & Development projects, or in Social Projects which are defined as "Process Projects", where learning is an important outcome, the cause-effect relationship is not so well established.

In such situations, the PERT approach is useful, because it can accommodate the variation in event completion times, based on an expert’s or an expert committee’s estimates. For each activity, three time estimates are taken

- The Most Optimistic
- The Most Likely
- The Most Pessimistic

The Duration of an activity is calculated using the following formula:

$$t_e = \frac{t_o + 4t_m + t_p}{6}$$

Where:

t_e is the Expected time

t_o is the Optimistic time

t_m is the most probable activity time

t_p is the Pessimistic time

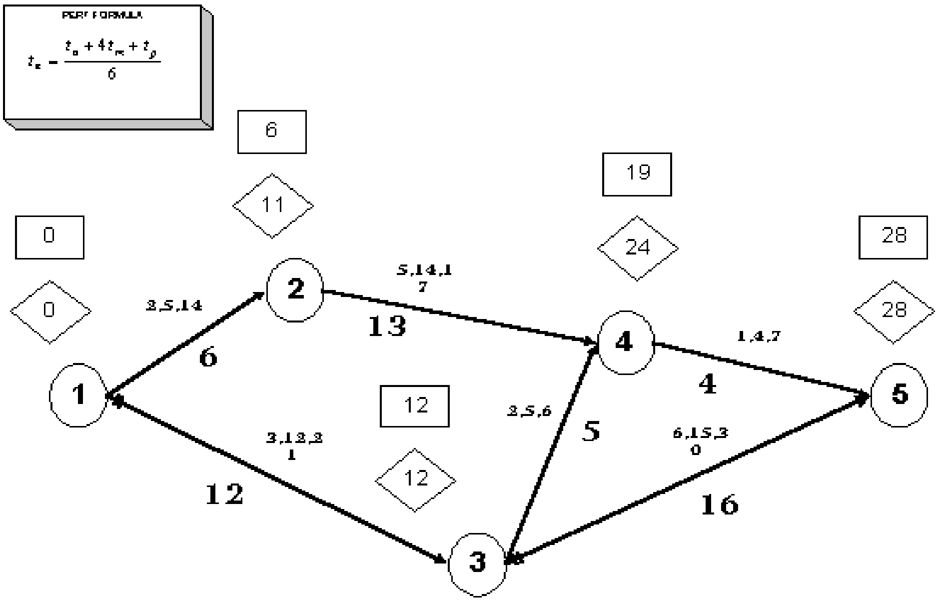
It is not necessary to go into the theory behind the formula. It is enough to know that the weights are based on an approximation of the Beta distribution. The Standard Deviation, which is a good measure of the variability of each activity, is calculated by the rather simplified formula:

$$s_1 = \frac{t_p - t_o}{6}$$

The Variance is the Square of the Standard Deviation.

2.5.3.3 PERT Calculations for Social Project

In our Social Project, the Project Manager is now not so certain that each activity will be completed on the basis of the single estimate he gave. There are many assumptions involved in each estimate, and these assumptions are illustrated in the three-time estimate he would prefer to give to each activity.



In Activity 1-3, the time estimates are 3, 12 and 21. Using our PERT formula, we get:

$$t_e = \frac{3 + (4 \times 12) + 21}{6} = \frac{72}{6} = 12$$

$$s_1 = \frac{(21-3)}{6} = \frac{18}{6} = 3$$

The Standard Deviation (s.d.) for this activity is also calculated using the PERT formula. We calculate the PERT event times and other details as below for each activity:

Event	**t_o**	**t_m**	**t_p**	**t_e**	**ES**	**EF**	**LS**	**LF**	**TF**	**s.d.**	**Var.**
1-3	3	12	21	12	0	12	0	12	0	3	9
3-5	6	15	30	16	12	28	12	28	0	4	16
1-2	2	5	14	6	0	6	5	11	5	2	4
2-4	5	14	17	13	6	19	11	24	5	2	4
3-4	2	5	8	5	12	17	19	24	7	1	1
4-5	1	4	7	4	19	23	24	28	5	1	1

2.5.3.4. Estimating Risk

Having calculated the s.d. and the Variance, we are ready to do some risk analysis. Before that we should be aware of two of the most important assumptions made by PERT.

- The Beta distribution is appropriate for calculation of activity durations.
- Activities are independent, and the time required to complete one activity has no bearing on the completion times of it's successor activities in the network. The validity of this assumption is questionable when we consider that in practice, many activities have dependencies.

2.5.4. Expected Length of a Project

PERT assumes that the expected length of a project is simply the sum of their separate expected lengths. Thus the summation of all the t_e's along the critical path gives us the length of the project. Similarly the variance of a sum of independent activity times is equal to the sum of their individual variances.

In our example, the sum of the variance of the activity times along the critical path, VT is found to be equal to (9+16) = 25.

The square root VT gives us the standard deviation of the project length. So, ST=Ö 25=5. which is higher the standard deviation, the greater the uncertainty that the project will be completed on the due date.

Although the t_e's are randomly distributed, the average or expected project length Te approximately follows a Normal Distribution. Since we have a lot of information about a Normal Distribution, we can make several statistically significant conclusions from these calculations.

A random variable drawn from a Normal Distribution has 0.68 probability of falling within one standard deviation of the distribution average. Therefore, there is a 68% chance that the actual project duration will be within one standard deviation, ST of the estimated average length of the project, t_e.

In our case, the t_e = (12+16) = 28 weeks and the ST = 5 weeks. Assuming t_e to be normally distributed, we can state that there is a probability of 0.68 that the project will be completed within 28 ± 5 weeks, which is to say, between 23 and 33 weeks.

Since it is known that just over 95% (.954) of the area under a Normal Distribution falls within two standard deviations, we can state that the probability that the project will be completed within 28 ± 10 is very high at 0.95.

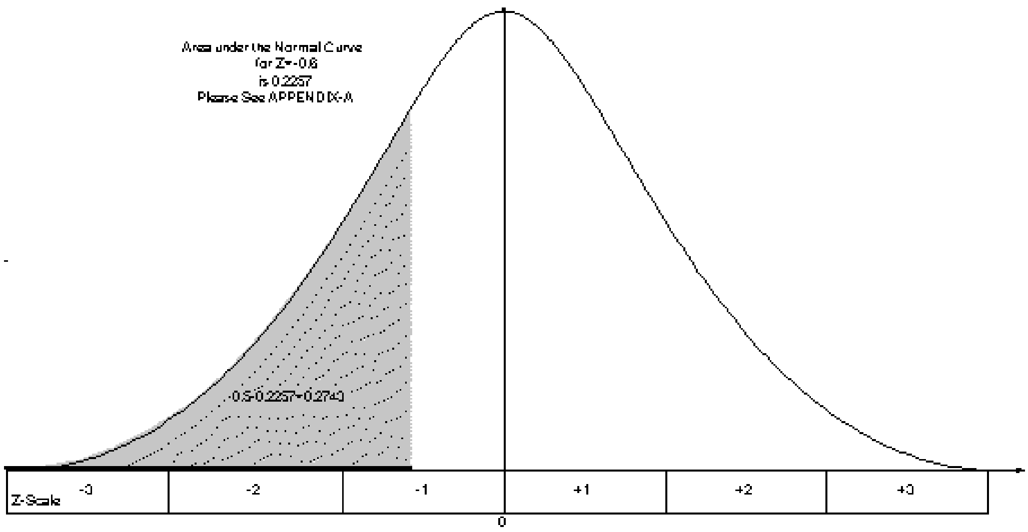
2.5.5. Probability of Project Completion by Due Date

Now, although the project is estimated to be completed within 28 weeks (t_e=28) our Project Director would like to know what is the probability that the project might be completed within 25 weeks (i.e. Due Date or D=25).

For this calculation, use the formula for calculating Z, the number of standard deviations that D is away from t_e.

$$Z = \frac{D - t_e}{S_t} = \frac{25 - 28}{5} = \frac{-3}{5} = -0.6$$

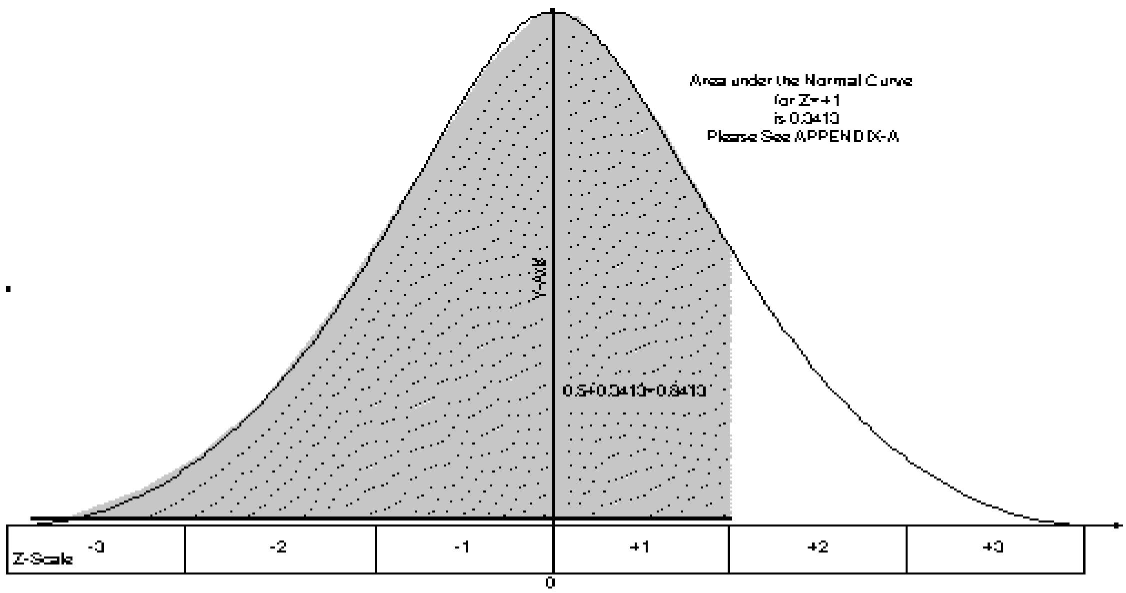
By looking at the extract from a standard normal table, we see that the probability associated with a Z of -0.6 is 0.274. It means that the chance of the project being completed within 25 weeks, instead of the expected 28 weeks is about 2 out of 7.



On the other hand, the probability that the project will be completed within 33 weeks is calculated as follows:

$$Z = \frac{D - t_e}{S_t} = \frac{33 - 28}{5} = \frac{5}{5} = 1$$

The probability associated with Z= +1 is 0.84134. This is a strong probability, and indicates that the odds are 16 to 3 that the project will be completed by the due date.



If the probability of an event is p, the odds for its occurrence are a to b, where:

$$\frac{a}{b} = \frac{p}{1 - p} = \frac{0.84134}{0.15866} \approx \frac{16}{3}$$

Review Questions

5. What is Backward Pass? Explain
6. What is the role of arrow diagram in Project calculations?
7. While calculating the Project details, what will be the probable estimation risk?
8. Probability of Project Completion by Due Date? Discuss

Discussion Questions

Discuss the calculations involved in PERT in a Project.

Application Exercises

4. What is PERT probabilistic approach?
5. Explain CPM and PERT Network in detail?
6. State the framework for CPM/PERT.

CHAPTER 3

Constructing network diagram

Learning Objectives

- To know more about Network diagram.
- To analyse the working of a Project.
- To recognise network diagram for Projects.
- To explain about scheduling computation in Project.
- To identify the rules involved in constructing network diagram of a Project.

3.1 Introduction

A project is a well defined task which has an elabourated beginning and a definable end and requires one or more resources for the completion of its constituent activities, which are interrelated and which must be accomplished to achieve the objectives of the project. Project management is evolved to coordinate and control all project activities in an efficient and cost effective manner. The salient features of a project are:

- A project has identifiable beginning and end points.
- Each project can be broken down into a number of identifiable activities which will consume time and other resources during their completion.
- A project is scheduled to be completed by a target date.
- A project is usually large and complex and has many interrelated activities.
- The execution of the project activities is always subjected to some uncertainties and risks.

The network techniques of project management have developed in an evolutionary way in many years. Up to the end of 18^{th} century, the decision making in general and project management in particular was intuitive and depended primarily on managerial capabilities, experience, judgment and academic background of the managers. It was only in the early of 1900's that the pioneers of scientific management started developing the scientific management techniques. The forerunner to network techniques, the Gantt chart was developed, during World War I, by Henry L Gantt, for the purpose of production scheduling. An example of Gantt chart is shown in Figure 3.1.

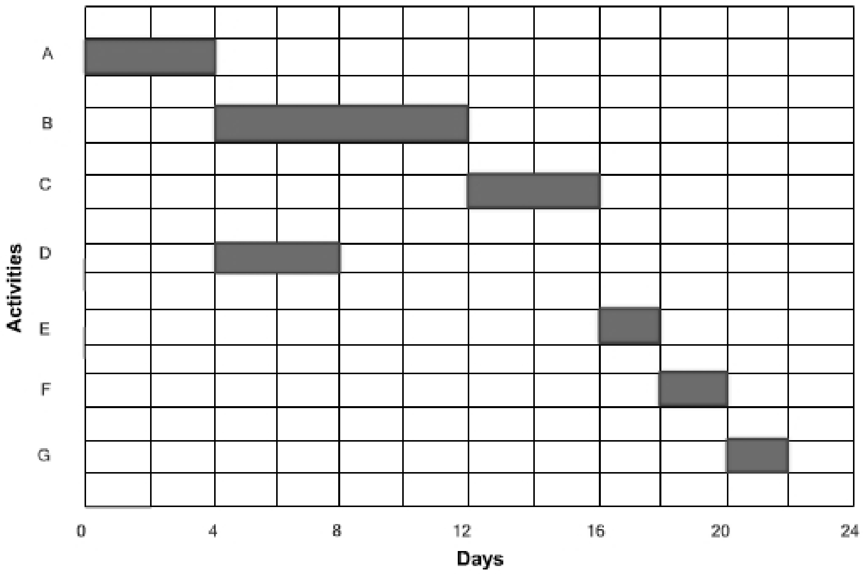


Figure 3.1: Gantt Chart

The Gantt chart was further enhanced to bar chart as shown in figure 3.2, which was used as an important tool in both the project and production scheduling.

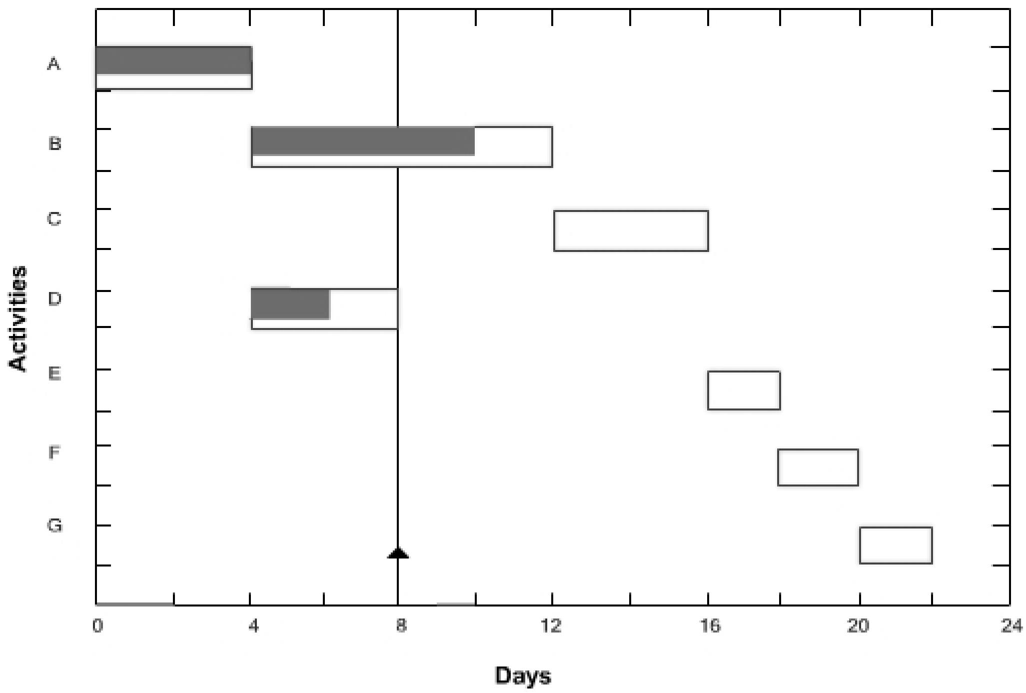


Fig: 3.2 Bar Chart

The bar charts then developed into milestone charts as shown in figure 3.3 and further into network techniques such as CPM and PERT charts.

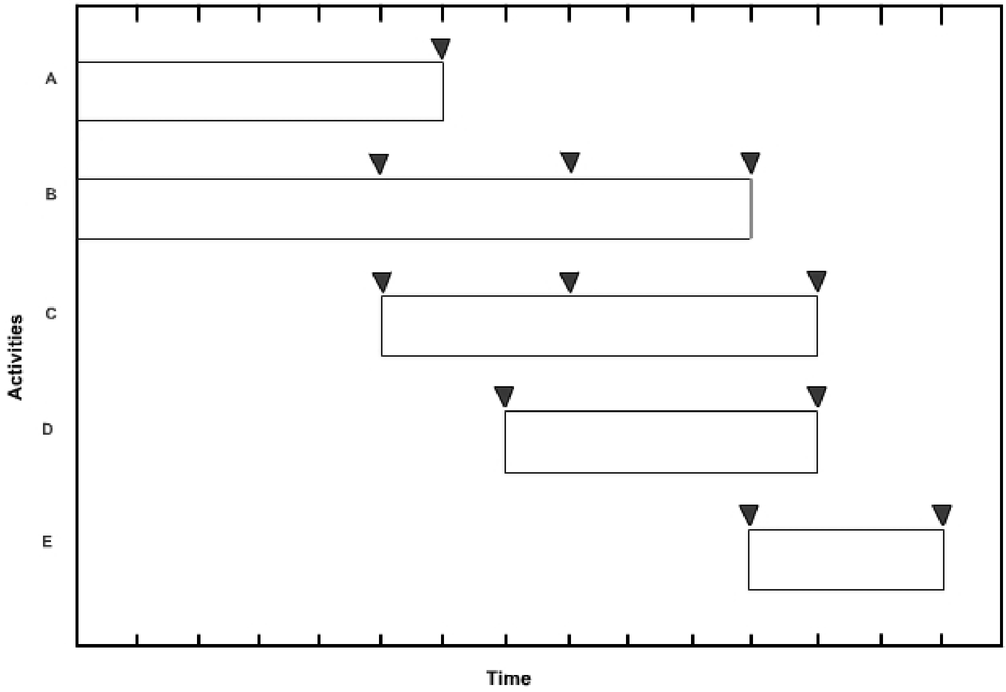


Fig: 3.3 Mile Stone Chart

Creating a network diagram, which is also referred to as a logic diagram, is a easiest and best approach for understanding and visualising how to construct your project. It's a simple concept successfully used in applications outside of project management planning; commonly used in manufacturing industries, as well as service industries requiring mapping and understanding work flows.

In the context of project planning, a network diagram is a sequence of steps (activities), commonly represented by blocks, that are linked together in the logical sequence they need to be carried out. Producing a network diagram follows the completion of your project Work Breakdown Structure. The pile of post-its that you have saved from the WBS exercise gets put to good use in developing a network diagram.

Once the logic diagram has been completed, you have a clearer picture of the required sequence of events and activities for your project. You are able to clearly see the logic rules affecting activities, for example you cannot start building your house foundations until you have first prepared the ground. By including the project team in the development of the network diagram, you obtain a consensus of understanding of how the project should be implemented, at the same time providing a forum for challenging accepted ways of doing things, which may need amending to suit the specific constraints associated with the project at hand.

3.1.1 Example

The following is a very simple example of a network diagram. It's for one of life's important projects - making a cup of tea!

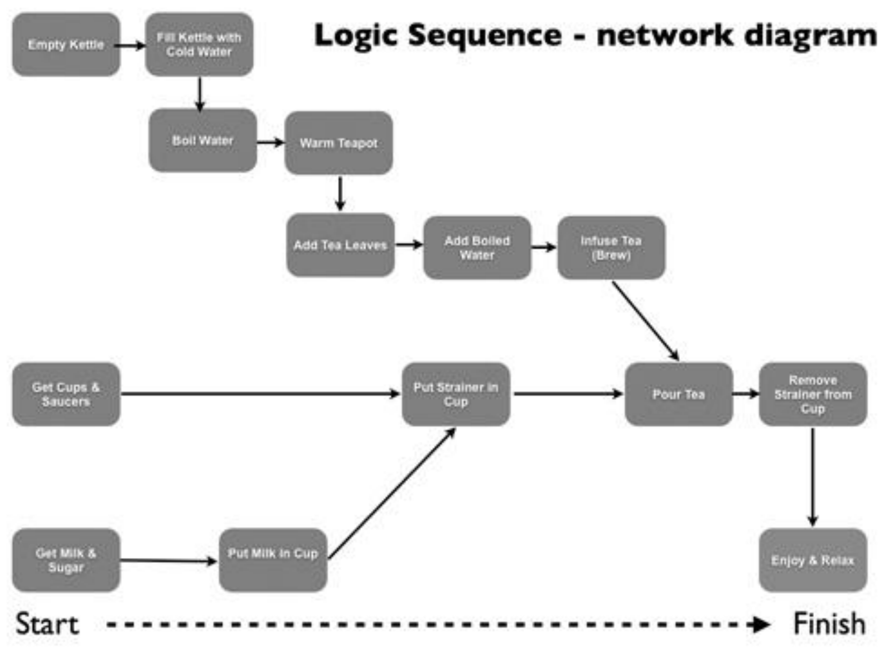


Fig 3.4

A couple things to notice, which will be found in your project network diagrams:

- Parallel work flows: It is the activity which can be started at the same time at the beginning of the tea-making project? Sorting out the kettle and boiling water, getting the cups and saucers as well as collecting the milk and sugar. None of these activities rely on each other at the beginning.
- Logical sequence: in this activity, see how this activity is in the top sequence which is associated with making guidelines, all fit together in a logical sequence. The guidelines cannot be infused until the project is not followed with instructions.

All the logic links in this simple example are referred to as Finish/Start logic links. The succeeding activity cannot start until the preceding activity has finished. You can think of other types of logic links I'm sure. The following are a few examples:

- Start/Start - when one activity starts, another independent activity must start.
- Finish/Finish - two activities must finish at the same time.

- Finish/Start with a lag - the succeeding activity must start some defined time after the preceding activity has finished.
- Start/Start with a lag - when one activity starts, another must also start after a defined time.

Try and stick to Finish/Start logic only, when developing a network diagram. This forces a deeper level of understanding of the events and activities which must be carried out. If the urge is to use some other more complicated form of logic operator, then a good point arises, that why it is required?

This usually happens because something a little more complex or different is going on where a case must be clearly understood. By shifting to a greater level of detail and sticking to Finish/Start logic links, you force the deeper understanding required which benefits all, as well as the project.

More 'complicated' logic operators are generally only used when modeling logic diagrams in project planning software applications, where levels of activity detail may be rolled up. Always follow the rule - have the minimum number of activities needed to properly understand the sequencing. Only add more detail if it benefits the level of understanding or future progress control of the project activity list.

A network diagram communicates the order that activities and events need to take during the implementation of your project. But can soon appear congested and complicated, the larger it gets. Communication in this context is related to understanding. By making things simple will help further in achieving and understanding more effectively.

People will be able to visualise the project sequence if they understand it properly. A very useful tool to aid this process and to provide consistency of understanding within the project team and sponsors is to adopt a Story Boarding approach.

3.2 Network Construction

A network is the graphical representation of the project activities arranged in a logical sequence and depicting all the interrelationships among them. A network consists of activities and events.

3.2.1 Activity

An activity is a physically identifiable part of a project, which consumes both time and resources. Activity is represented by an arrow in a network diagram as shown in figure 3.4.

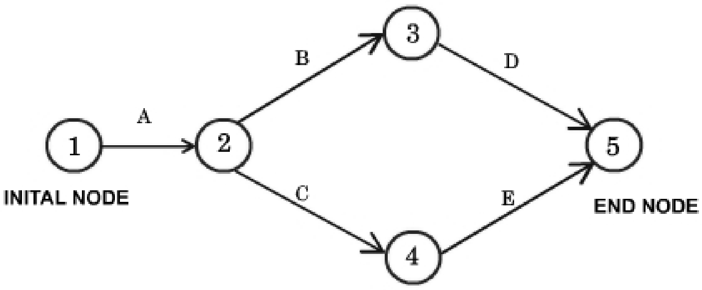
Fig 3.4

The head of an arrow represents the start of activity and the tail of arrow represents its end. Activity description and its estimated completion time are written along the arrow. An activity in the network can be represented by a number of ways:

- by numbers of its head and tail events (i.e. 10-20 etc.),
- by a letter code (i.e. A, B etc.).

All those activities, which must be completed before the start of activity under consideration, are called its predecessor activities. All those activities, which have to follow the activity under consideration, are called its successor activities as shown in figure 3.5.

Figure 3.5: Activity Precedence

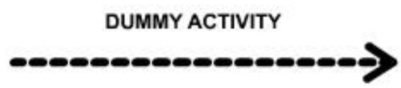


Activity	Immediate Predecessor
A	_
B	A
C	A
D	B
E	C

Activity	Immediate Successor

A	B,C
B	D
C	E

An activity, which is used to maintain the pre-defined precedence relationship only during the construction of the project network, is called a dummy activity. Dummy activity is represented by a dotted arrow and does not consume any time and resource as highlighted in the figure 3.6. An unbroken chain of activities between any two events is called a path.



3.2.2 Event

An event represents the accomplishment of some task. In a network diagram, beginning and ending of an activity are represented as events. Each event is represented as a node in a network diagram. An event does not consume any time or resource. Each network diagram starts with an initial event and ends at a terminal event. Each node is represented by a circle (Figure 3.7) and numbered by using the Fulkerson's Rule.

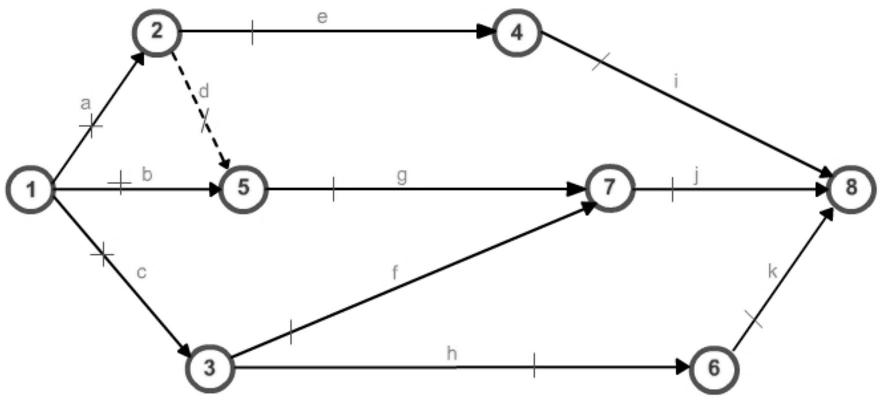
Fig: 3.7 Event Representation

Following steps are involved in the numbering of the nodes:

- The initial event, which has all outgoing arrows and no incoming arrow, is numbered as 1.
- Delete all the arrows coming out from the node just numbered (i.e. 1). This step will create some more nodes (at least one) into initial events. Number these events in ascending order (i.e. 2, 3 etc.).
- Continue the process until the final or terminal node which has all arrows coming in, with no arrow going out, is numbered.

An illustration of Fulkerson's Rule of numbering the events is shown in Figure 3.8.

Figure 3.8: Fulkerson's Rule



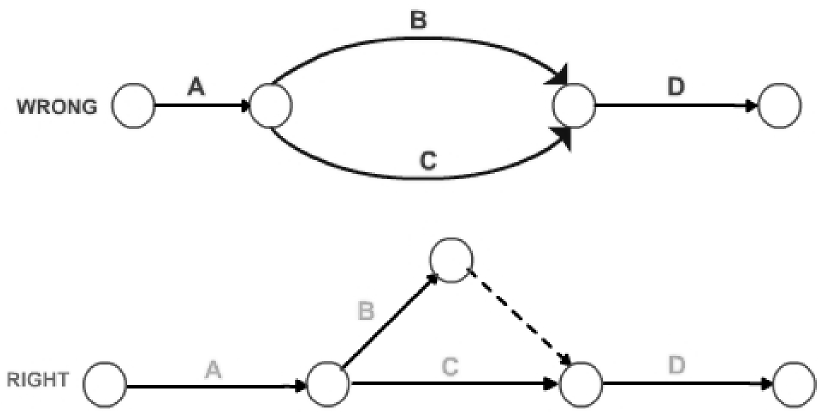
As a recommendation it must be noted that most of the projects are liable for modifications, and hence there should be a scope of adding more events and numbering them without causing any inconsistency in the network. This is achieved by skipping the numbers (i.e. 10, 20, 30…).

3.2.3 Rules for drawing network diagram

Rule 1: Each activity is represented by one and only one arrow in the network.

Rule 2: No two activities can be identified by the same end events (Figure 3.9).

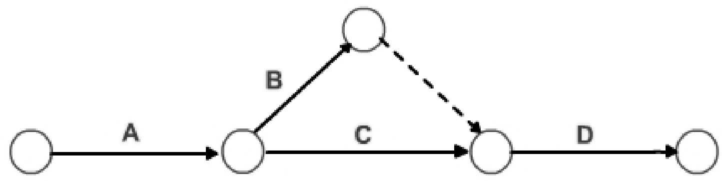
Figure 3.9: Network Preparation



Rule 3: Precedence relationships among all activities must always be maintained.

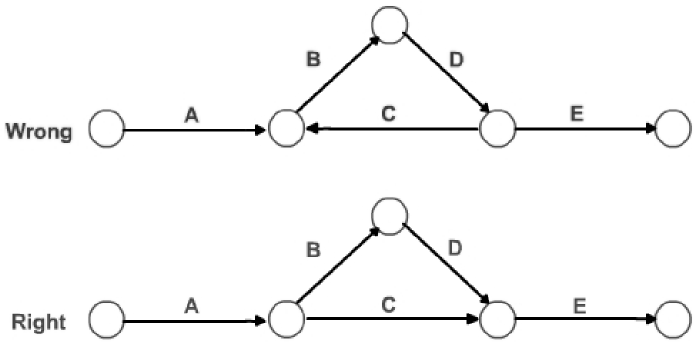
Rule 4: Dummy activities can be used to maintain precedence relationships only when actually required. Their use should be minimized in the network diagram as shown in figure 3.10.

Figure 3.10: Use of Dummy Activities



Rule 5: Looping among the activities must be avoided as described in the figure 3.11.

Figure 3.11: Looping Problem

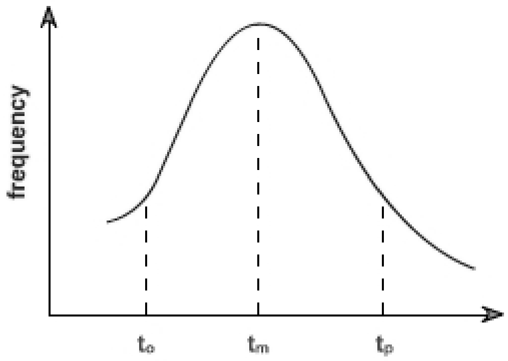


3.2.4 CPM and PERT

The CPM (critical path method) system of networking is used, when the activity time estimates are deterministic in nature. For each activity, a single value of time, required for its execution, is estimated. Time estimates can easily be converted into cost data in this technique. CPM is an activity oriented technique.

The PERT which is called as Project Evaluation and Review Technique is used, when activity time estimates are stochastic in nature. For each activity, three values of time are estimated. Optimistic time (t_o) estimate is the shortest possible time required for the completion of activity. Most likely time (t_m) estimate is the time required for the completion of activity under normal circumstances. Pessimistic time (t_p) estimate is the longest possible time required for the completion of activity. In PERT β-distribution is used to represent these three time estimates as shown in figure 3.12.

Figure 3.12: Time distribution curve



As PERT activities are full of uncertainties, times estimates can not easily be converted in to cost data. PERT is an event oriented technique. In PERT expected time of an activity is determined by using the below given formula:

$$t_e = \frac{(t_o + 4t_m + t_p)}{6}$$

The variance of an activity can be calculated as:

$$\sigma^2 = \left[\frac{(t_p - t_o)}{6}\right]^2$$

3.3 Constructing a Network Diagram from Work Breakdown Schedule

Before scheduling is done, a Work Breakdown Structure (WBS) should be developed. To illustrate how a schedule is constructed from a WBS, we consider a simple job of maintaining the yard around a home. The WBS is shown in Figure 3.13.

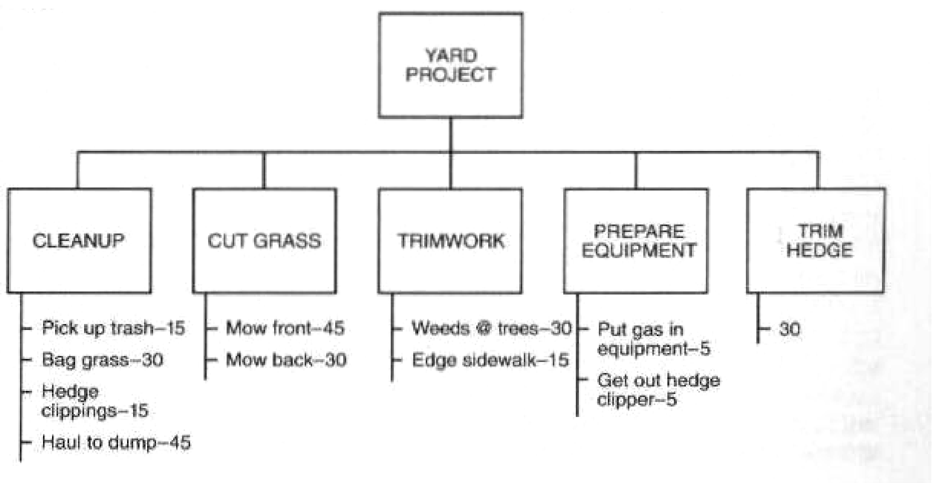


Figure 3.13. Work breakdown structure for yard project.

There are two ways to develop a schedule. One is to begin at the end and work back until you arrive at the beginning. The second method is to start at the beginning and work toward the end. Usually, it is easiest to start at the beginning.

This small project might be thought of as having three phases: preparation, execution, and cleanup. There are three preparation tasks: pick up trash, put gas in equipment, and get out hedge clipper. The cleanup tasks include bagging grass, bundling clippings, and hauling trash to the dump.

There is a basic rule of scheduling so as to design what is logically possible, then deal with resource limitations. In case of yard project, two tasks cannot take place at the same time. On the other hand, if an enlistment is done from the family or neighborhood youth, then parallel paths are possible. The rule suggests that you go ahead and schedule as if it were possible to get help. This is especially important to remember in a work setting, or you will never get a schedule put together. You will be worrying about who will be available to do the work and end up in analysis paralysis.

The next step is to figure 3.13 out how long it will take to do the job. Time estimates for each task are made by using history—remembering how long each activity has taken in the past. Remember, though, that the estimate is valid only for the individual who is going to do the task. If my daughter, who is sixteen, does the lawn mowing using a push mower, it will probably take less time than if my son, who is only twelve, tackles the job.

The first step is to create a work breakdown table. The table will show the name of each task (usually each task is also given a letter code), the duration of the task and what events must be completed before the task can begin. The list the preceding tasks that are only those that immediately precede an individual task, not a list of all the tasks that occurred earlier. As an example for the lawn case a work breakdown table would appear as follows:

TASK	DESCRIPTION	PRECEDING EVENT	DURATION
A	Pick up trash	None	15
B	Put gas in mower	None	5
C	Get hedge clippers	None	5

D	Trim weeds	A and B	45
E	Mow front yard	A and B	12
F	Edge sidewalk	A and B	15
G	Trim hedge	C	30
H	Mow backyard	E	30
I	Bag grass	D, H, F and G	30
J	Bundle Trash	D, H, F and G	15
K	Haul Trash	I and J	45

A network diagram can be drawn from the information in the work breakdown table. D is the task duration and arrows indicate precedence.

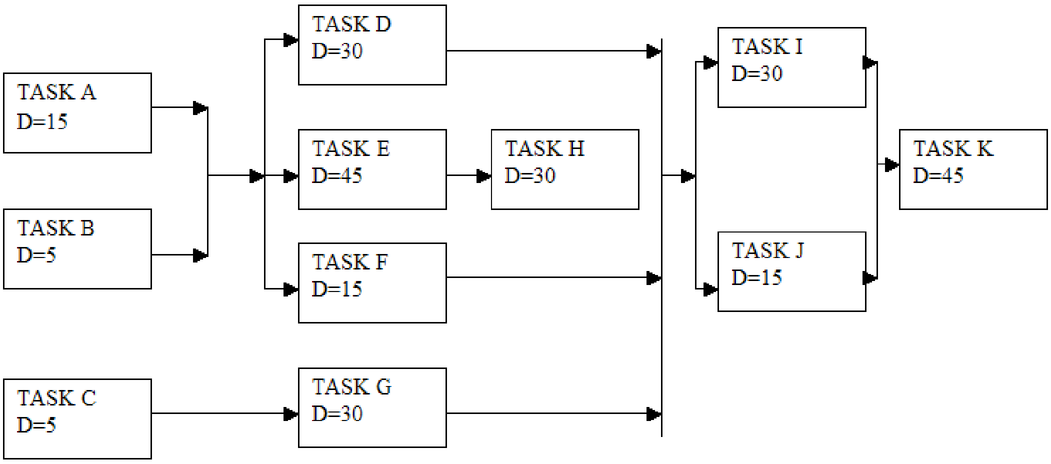


Fig 3.14

3.3.1 Scheduling Computations

Once a suitable network has been drawn, with durations assigned to all activities, it is necessary to determine where the longest path is in the network and whether it will meet the target completion date.

First, consider what we want to know about the project. If it starts at some time zero, we want to know how soon it can be finished. Naturally, in most actual work projects, we have been told when we must be finished; that is, the end date is dictated. Further, the start date for the job is often constrained for some reason: resources won't be available, specs won't be written, or another project won't be finished until that time. Therefore, scheduling usually means trying to fit the between two fixed points in time. Whatever the case, we want to know how long the project will take to complete; if it won't fit into the required time frame, then we will have to do something to shorten its duration.

In the simplest form, computations are made for the network on the assumption that activity durations are exactly as specified. However, activity durations are a function of the level of resources applied to the work, and if that level is not actually available when it comes time to do the work, then the scheduled dates for the task cannot be met. It is for this reason that network computations must ultimately be made with resource limitations in mind. Another way to say this is that resource allocation is necessary to determine what kind of schedule is actually achievable. Failure to consider resources almost always leads to a schedule that cannot be met.

The first step in network computations is to determine the schedule and what kind of latitude is available to shift resources to shorten the project's duration. The ideal situation is one in which unlimited resources are available, so the first computations made for the network are done ignoring resource requirements.

3.3.2 Network Rules and Computation

Three rules are applied to all networks in order to compute network start and finish times.

Rule 1: Before a task can begin, all tasks preceding it must be completed.

Rule 2: Arrows denote which tasks come first.

Rule 3: When two or more activities precede another activity, the earliest time that the final activity can be started is the larger of the durations of the activities preceding it.

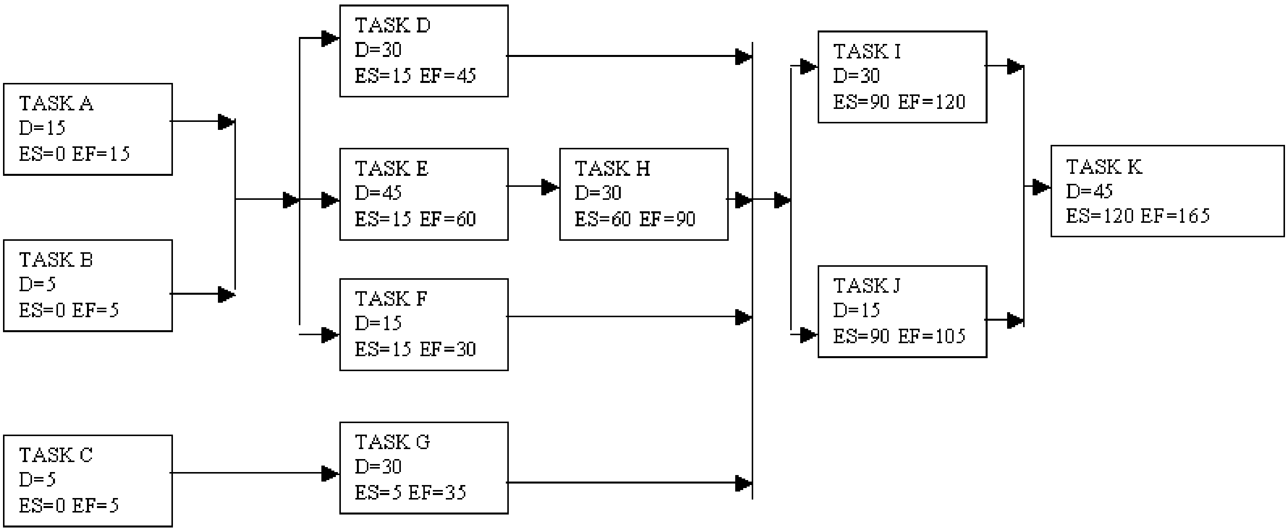
Let's look at an example to clarify what the rules mean. First, let us examine the boxes in the network diagram below used to calculate the schedule. Each box in the network now contains three pieces of information, not just the duration as in the network shown. The box shows:

D=Duration (of the task)

ES=Earliest Start i.e. the earliest time the task can begin, given all preceding tasks are completed

EF=Earliest Finish i.e. the earliest time the task can finish, given the completion of all preceding tasks and the task itself.

Fig 3.15 Network diagram for yard project used for schedule calculations.



Earliest finish of a task equals the earliest start plus the duration of the task or EF= ES +D.

Consider a single activity in the network, such as picking up trash from the yard (TASK A). It has duration of fifteen minutes. Assuming that it starts at time = zero, it can finish as early as fifteen minutes later. We therefore can enter fifteen in the cell labeled EF. Putting gas in the mower and the weed whacker (TASK B) takes only five minutes. The logic of the diagram says that both of these tasks must be completed before we can begin trimming weeds, cutting the front grass, and edging the sidewalk (TASKS D, E and F). The cleanup task takes fifteen minutes, whereas the gas activity takes only five minutes. How soon can the following activities start? Not until the cleanup has been finished, since it is the longest of the preceding activities (rule 3) In fact, then, the Early Finish for cleanup becomes the Early Start for the next three tasks. It will always be true that the_latest Early Finish for the earlier tasks becomes the Early Start for subsequent tasks. That is, the longest path determines how early subsequent tasks can start.

Following this rule, we can fill in Earliest Start times for each task in the network diagram. This diagram shows that the project will take a total of 165 minutes to complete, if all work is conducted exactly as shown. Computer programs do exactly this computation and also convert the times to calendar dates, making quick work of the computations.

The time determined for the end or final task (TASK K) is the earliest finish for the whole project in working time.

The diagram for the PH 453 case study is considerably simpler than this example, but you still must apply the three rules to draw the diagram and figure out the earliest time at which the surveillance project can be completed.

Review Questions

9. What is an Event representation?
10. What are the important features of network diagrams?
11. What do you mean by Finish Start logic Link?
12. What is a Bar Chart representation?

Discussion Questions

Discuss the rules of drawing a network diagram for a particular project? Highlight the steps involved?

Application Exercises

7. Explain Fulkerson's Rule with simple illustration? With the help of any project explain the necessary steps involved in this rule?
8. What is network technique of Project Management?
9. State the Network Rules and Computations.

CHAPTER 4

AON basics

Learning Objectives

- To know more about AON basics.
- To analyse the completion time of certain Project.
- To recognise network diagram for Projects.
- To explain about Workflow in a Project.
- To know more about activity diagram.

4.1 Introduction

Activity-on-node is a project management term that refers to a precedence diagramming method which uses boxes to denote schedule activities. These various boxes or “nodes” are connected from beginning to end with arrows to depict a logical progression of the dependencies between the schedule activities. Each node is coded with a letter or number that correlates to an activity on the project schedule.

Typically, an activity-on-node diagram will be designed to show which activities must be completed in order for other activities to commence. This is referred to as “finish-to-start” precedence – meaning one activity must be finished before the next one can start. In the diagram below, activities A and D must be done so that activity E can begin. It is also possible to create other variations of this type of diagram. For example, a “start-to-start” diagram is one in which a predecessor activity must simply be started rather than fully completed in order for the successor activity to be initiated.

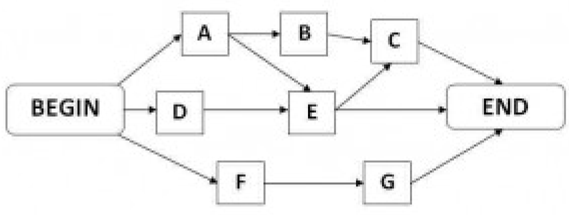


Fig 4.1

An activity-on-node diagram can be used to provide a visual representation of the network logic of an entire project schedule. Or, it can be used for any smaller section of the schedule that lends itself to being represented as having a defined beginning and end. To keep the logic in the diagram simple, it may be most effective to include only critical path schedule activities. The planned start date of each node may also be listed in the diagram legend in accordance with the project management timeline.

4.1.1 Example

We will illustrate network analysis with reference to the following example: suppose that we are going to carry out a minor redesign of a product and its associated packaging. We intend to test market this redesigned product and then revise it in the light of the test market results, finally presenting the results to the Board of the company.

The key question is: How long will it take to complete this project?

After much thought, it is seen that the following list of separate activities together with their associated completion times can result in finding an estimated Project period.

Number	Activity	Completion time (weeks)
1	Redesign product	6
2	Redesign packaging	2
3	Order and receive components for redesigned product	3
4	Order and receive material for redesigned packaging	2
5	Assemble products	4
6	Make up packaging	1
7	Package redesigned product	1
8	Test market redesigned product	6
9	Revise redesigned product	3
10	Revise redesigned packaging	1
11	Present results to the Board	1

It is clear that in constructing this list of activities we must make judgments as to the level of detail to adopt. At one extreme we could have just a single activity "does the project" and at the other extreme we could try to break the project down into hourly activities. The appropriate timescale to adopt grows out of our knowledge of the situation and experience.

Aside from this list of activities we must also prepare a list of precedence relationships indicating activities which, because of the logic of the situation, must be finished before other activities can start e.g. in the above list activity number 1 must be finished before activity number 3 can start.

It is important to note that, for clarity, we try to keep this list to a minimum by specifying only immediate relationships that is relationships involving activities that "occur near to each other in time". For example it is plain that activity 1 must finished before activity 9 can start but these two activities can hardly be said to have an immediate relationship as many other activities after activity 1 must be completed before activity 9 to start. Activities 8 and 9 would be examples of activities that have an immediate relationship and it should be taken care that activity 8 must finished before activity 9.

We see that specifying non-immediate relationships merely complicates the calculations that can be needed to be done as it does not affect the final result. We further see that, in the real-world, the consequences of missing out precedence relationships are much more serious than the consequences of including unnecessary relationships.

Again after much thought it is seen that we can further lists the activities in a logical/chronological order as described in the following list of immediate precedence relationships.

Activity number		Activity number	
1	must be finished before	3	can start
2		4	
3		5	
4		6	
5,6		7	
7		8	
8		9	
8		10	
9,10		11	

The key to constructing this table is, for each activity in turn, to ask the question that "What activities must be finished before this activity can start"

It is clearly seen that:

- activities 1 and 2 do not appear in the right hand column of the above table, this is because there are no activities which must finish before they can start, i.e. both activities 1 and 2 can start immediately
- two activities (5 and 6) must be finished before activity 7 can start
- it is plain from this table that non-immediate precedence relationships (e.g. "activity 1 must be finished before activity 9 can start") need not be included in the list since they can be deduced from the relationships already in the list.

Once we have completed our list of activities and our list of precedence relationships we combine them into a diagram/picture (called a network - which is where the name network analysis comes from). We do this below.

Note first however that we asked the key question above as **How long will it take to complete this project? As seen, all activities has to be** completed at the same time as respecting the precedence relationships.

What would say that:

- could we complete this project in 3 years?
- could we complete this project in 2 weeks?

One answer could be if we first do activity 1, then activity 2, then activity 3, then activity 10, then activity 11. Such an arrangement would be possible here, and can be checked with the precedence relationships, and the project would then take the sum of the activity completion times, 30 weeks.

However could we complete the project in less time? It is clear that logically we need to amend our key question that **what could be the minimum possible time in which we can complete this project?**

4.2 The Workflow

Have you see process flow diagrams? If yes, then activity diagrams take the same shape. Usually there are two main shapes in activity diagrams; boxes and arrows. Boxes of the activity diagram indicate the tasks and the arrows show the relationships. Usually the relationships are the sequences that take place in the activities.

Following is an example activity diagram with tasks in boxes and relationship represented by arrows.

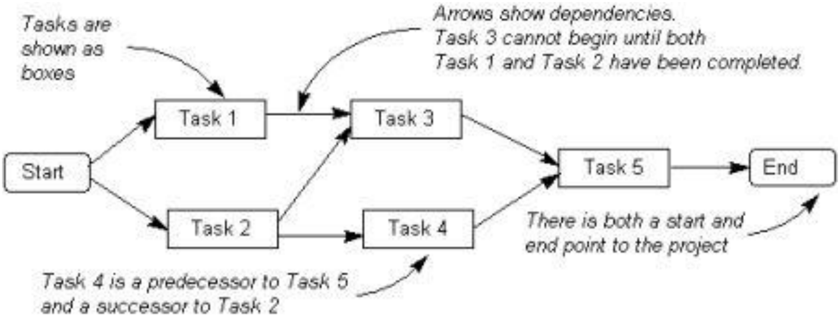


Fig 4.2

This type of activity diagram is also known as activity-on-node diagram. This is due to the fact that all activities (tasks) are shown on the nodes (boxes). Alternatively, there is another way of presenting an activity diagram. This is called activity-on-arrow diagram. In this diagram, activities (tasks) are presented by the arrows.

Compared to activity-on-node diagrams, activity-on-arrow diagrams introduce a little confusion. Therefore, in most instances, people often use activity-on-nodes diagrams. Following is an activity-on-arrow diagram.

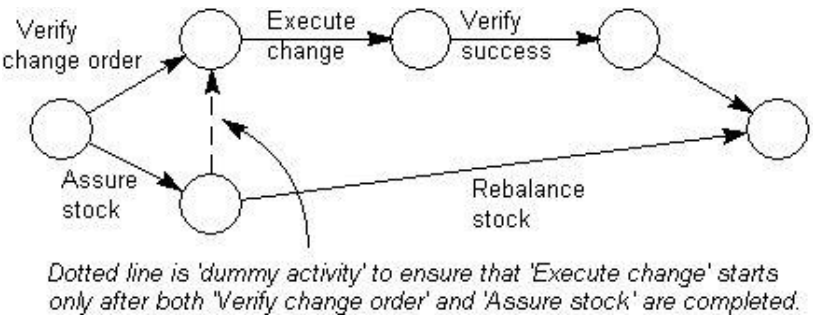


Fig 4.3

4.3 Drawing of Activity Diagram

Creating an activity diagram is easy. You can use a paper-based material such as a post it note or software for this purpose. Regardless of the medium used, the process of creating the activity diagram remains the same.

Following are main steps involved in creating an activity diagram.

Step 1:

First of all, identify the tasks in the project. You can use work Breakdown Structure for this purpose and there is no need to repeat the same. Just use the same tasks breakdown for the activity diagram as well. If you use software for creating the activity diagram to create a box for each activity, then demonstrate all boxes in the same size in order to avoid any confusion. Make sure all your tasks have the same granularity.

Step 2:

You can add more information to the task boxes, such as who is doing the task and the time frames. You can add this information inside the box or can add it somewhere near the box.

Step 3:

Now arrange the boxes in the sequence that they are performed during the project execution. The early tasks will be at the left hand side and the tasks performed at the latter part of the project execution will be at the right hand side. The tasks that can be performed in parallel should be kept parallel to each other. You may have to adjust the sequence a number of times until you get it right. This is why software is an easy tool for creating activity diagrams.

Step 4:

Now, use arrows to join task boxes. These arrows will show the sequence of the tasks. Sometimes, a 'start' and an 'end' box can be added to clearly present the start and the end of the project. To understand what we have done in the above four steps, please refer to the following activity diagram.

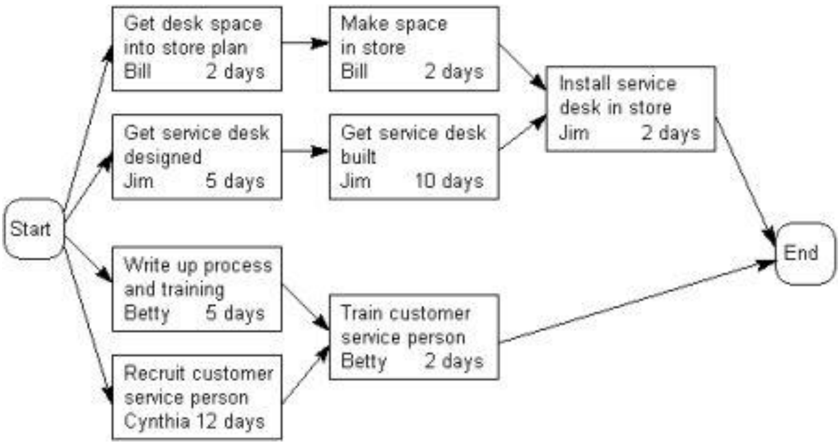


Fig 4.4

4.3.1 Activity

The network diagram is shown below. Note the use of a dummy activity (activity 10, with a completion time of zero) to represent the end of the project. Any nodes (activities) which, in the original network, have no precedence relationships coming out from them must be connected to this dummy activity to ensure that we correctly account for the end of the project. For this problem this means that activities 8 and 9 must be connected to activity 10.

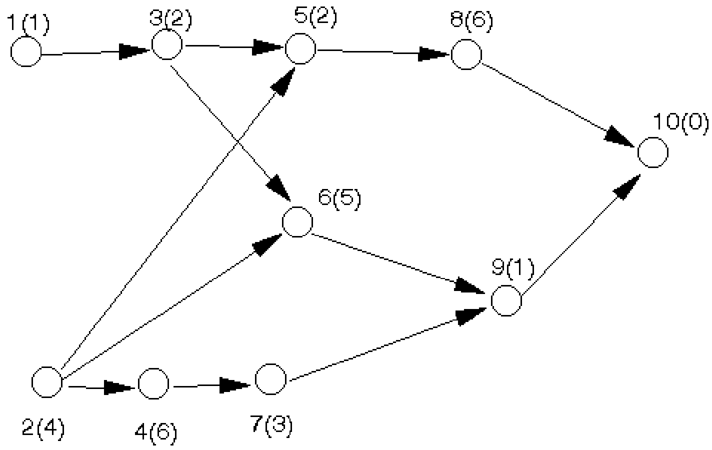


Fig 4.5

E_i is the earliest start time for node i

L_i is the latest start time for node i

T_i is the completion time for activity i

F_i is the float for activity i

We then have the following calculations.

4.3.1.1 Earliest start times

We calculate the values of the E_i (i=1,2,...,10) by going forward, from left to right, in the above network diagram.

$E_1 = 0$ (assuming we start at time zero)

$E_2 = 0$ (assuming we start at time zero)

$E_3 = E_1 + T_1 = 0 + 1 = 1$

$E_4 = E_2 + T_2 = 0 + 4 = 4$

$E_5 = \max[E_3 + T_3, E_2 + T_2] = \max[1 + 2, 0 + 4] = 4$

$E_6 = \max[E_3 + T_3, E_2 + T_2] = \max[1 + 2, 0 + 4] = 4$

$E_7 = E_4 + T_4 = 4 + 6 = 10$

$E_8 = E_5 + T_5 = 4 + 2 = 6$

$E_9 = \max[E_6 + T_6, E_7 + T_7] = \max[4 + 5, 10 + 3] = 13$

$E_{10} = \max[E_8 + T_8, E_9 + T_9] = \max[6 + 6, 13 + 1] = 14$

Hence the minimum overall project completion time is 14 weeks.

4.3.1.2 Latest start times

We calculate the values of the L_i (i=1,2,...,10) by going backward, from right to left, in the network diagram. Hence:

$L_{10} = E_{10} = 14$

$L_9 = L_{10} - T_9 = 14 - 1 = 13$

$L_8 = L_{10} - T_8 = 14 - 6 = 8$

$L_7 = L_9 - T_7 = 13 - 3 = 10$

$L_6 = L_9 - T_6 = 13 - 5 = 8$

$L_5 = L_8 - T_5 = 8 - 2 = 6$

$L_4 = L_7 - T_4 = 10 - 6 = 4$

$L_3 = \min[L_5 - T_3, L_6 - T_3] = \min[6 - 2, 8 - 2] = 4$

$L_2 = \min[L_5 - T_2, L_6 - T_2, L_4 - T_2] = \min[6 - 4, 8 - 4, 4 - 4] = 0$

$L_1 = L_3 - T_1 = 4 - 1 = 3$

Note that as a check all latest times are >=0 at least one activity has a latest start time value of zero.

4.3.1.3 Float

The amount of slack or *float* time F_i available is given by $F_i = L_i - E_i$ which is the amount by which we can increase the time taken to complete activity i without changing (increasing) the overall project completion time. Hence we can form the table below:

Activity	L_i	E_i	Float F_i
1	3	0	3
2	0	0	0
3	4	1	3
4	4	4	0
5	6	4	2
6	8	4	4
7	10	10	0
8	8	6	2
9	13	13	0
10	14	14	0

Any activity with a float of zero is critical.

Hence (ignoring the dummy activity) the critical activities are 2,4,7 and 9 and these form the critical path.

With respect to the changes in completion times:

- Increasing the activity completion time for any activity only affects the overall project completion time if the increase in the completion time is greater than the float for the activity. In this case the increase in the activity completion time for activity 6 is 2 weeks (from 5 weeks to 7 weeks) and the float for activity 6 is 4 weeks so the overall project completion time is unchanged.
- For any activity, cutting the activity completion time only affects the overall project completion time if the activity is critical. In this case activity 8 is not critical and so the overall project completion time is unchanged.

With respect to cutting the completion time for activity 4 (a critical activity) by 3 weeks the completion time for the project will (in general) be changed. The exception to this rule is the case where there are two or more critical paths and there exists a critical path which does not contain the activity whose completion time is being cut.

However we cannot automatically assume the completion time for the project will also fall by 3 weeks. We need to recalculate the earliest times for the network when the activity completion time for activity 4 is 6-3=3 weeks. We get:

$E_1 = 0$ (assuming we start at time zero)
$E_2 = 0$ (assuming we start at time zero)
$E_3 = E_1 + T_1 = 0 + 1 = 1$
$E_4 = E_2 + T_2 = 0 + 4 = 4$
$E_5 = \max[E_3 + T_3, E_2 + T_2] = \max[1 + 2, 0 + 4] = 4$
$E_6 = \max[E_3 + T_3, E_2 + T_2] = \max[1 + 2, 0 + 4] = 4$
$E_7 = E_4 + T_3 = 4 + 3 = 7$
$E_8 = E_5 + T_5 = 4 + 2 = 6$
$E_9 = \max[E_6 + T_6, E_7 + T_7] = \max[4 + 5, 7 + 3] = 10$
$E_{10} = \max[E_8 + T_8, E_9 + T_9] = \max[6 + 6, 10 + 1] = 12$

Hence cutting the activity completion time for activity 4 by 3 weeks, from 6 weeks to 3 weeks, cuts the overall project completion time by 2 weeks, from 14 weeks to 12 weeks. Clearly what has happened here is that the critical path has changed.

Note here that a number of the E_i are unaffected by any change in the completion time of activity 4 (as can be easily seen from the network diagram). In fact only those earliest times "downstream" from activity 4 change. By eye we can see that these downstream activities are just 7, 9 and 10. Using this information we need only have recomputed E_7, E_9 and E_{10} above.

Given the information in the question on the status of the project we can revise the network diagram to that shown below where:

- we remove from the network all completed activities and their corresponding precedence relationships;
- relabel all activities currently in progress with their revised completion times.

This revised network diagram is shown below.

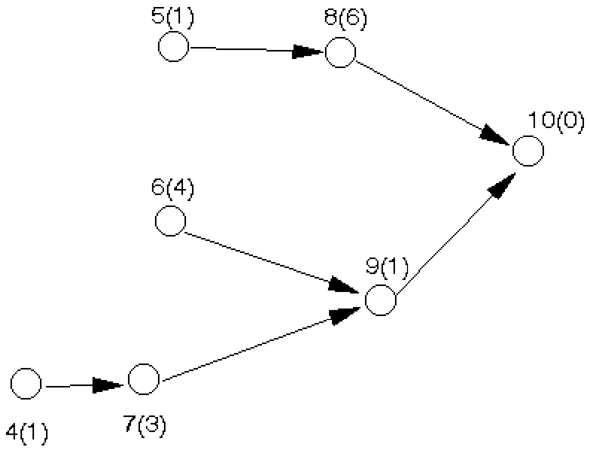


Fig 4.6

We need to recalculate the earliest times for the network shown above to find how long it will take to complete the project. If we do this we find that it will take us 7 weeks to complete the project (with activities 5 and 8 being the critical activities).

As 8 weeks have already elapsed we will complete the entire project in 8+7 = 15 weeks and this compares with the completion time of 14 weeks calculated initially. Hence, at some stage, we have slipped a week and the project is currently a week late.

4.4 Examples

4.4.1 Project consists of 8 activities.

The activity completion times and the precedence relationships are as follows:

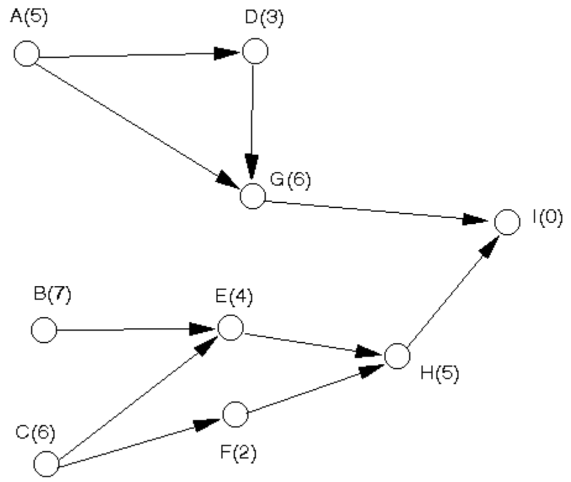
Activity	Completion time (days)	Immediate predecessor activities
A	5	-
B	7	-
C	6	-
D	3	A
E	4	B,C
F	2	C
G	6	A,D
H	5	E,F

- Draw the network diagram.

- Calculate the minimum overall project completion time and identify which activities are critical.
- If activity E is delayed by 3 days how is the project completion time affected?
- If activity F is delayed by 3 days how is the project completion time affected?

Solution

The network diagram is shown below. Note the introduction of a dummy activity I with a duration of zero to represent the end of the project.



Let E_i represent the earliest start time for activity i such that all its preceding activities have been finished. We calculate the values of the E_i (i=A,B,...,I) by going forward, from left to right, in the network diagram.

To ease the notation let T_i be the activity completion time associated with activity i (e.g. T_B = 7). Then the E_i are given by:

$E_A = 0$ (assuming we start at time zero)

$E_B = 0$ (assuming we start at time zero)

$E_C = 0$ (assuming we start at time zero)

$E_D = E_A + T_A = 0 + 5 = 5$

$E_G = \max[E_A + T_A, E_D + T_D] = \max[0 + 5, 5 + 3] = 8$

$E_E = \max[E_B + T_B, E_C + T_C] = \max[0 + 7, 0 + 6] = 7$

$E_F = E_C + T_C = 0 + 6 = 6$

$E_H = \max[E_E + T_E, E_F + T_F] = \max[7 + 4, 6 + 2] = 11$

$E_I = \max[E_G + T_G, E_H + T_H] = \max[8 + 6, 11 + 5] = 16$

Hence the minimum possible completion time for the entire project is 16 days, i.e. 16 days is the minimum time needed to complete *all* the activities. We now need to calculate the latest times for each activity.

Let L_i represent the latest start time we can start activity i and still complete the project in the minimum overall completion time. We calculate the values of the L_i (i=A,B,...,I) by going backward, from right to left, in the network diagram. Hence:

$L_I = 16$

$L_G = L_I - T_G = 16 - 6 = 10$

$L_H = L_I - T_H = 16 - 5 = 11$

$L_D = L_G - T_D = 10 - 3 = 7$

$L_A = \min[L_D - T_A, L_G - T_A] = \min[7 - 5, 10 - 5] = 2$

$L_E = L_H - T_E = 11 - 4 = 7$

$L_F = L_H - T_F = 11 - 2 = 9$

$L_C = \min[L_E - T_C, L_F - T_C] = \min[7 - 6, 9 - 6] = 1$

$L_B = L_E - T_B = 7 - 7 = 0$

Note that as a check all latest times are >=0 at least one activity has a latest start time value of zero.

As we know the earliest start time E_i, and latest start time L_i, for each activity i it is clear that the amount of slack or float time F_i available is given by $F_i = L_i - E_i$ which is the amount by which we can increase the time taken to complete activity i without changing (increasing) the overall project completion time. Hence we can form the table below:

Activity	L_i	E_i	Float F_i
A	2	0	2
B	0	0	0
C	1	0	1
D	7	5	2
E	7	7	0
F	9	6	3
G	10	8	2
H	11	11	0

Any activity with a float of zero is critical. Note here that, as a check, all float values should be >= 0.

Hence the critical activities are B, E and H and the floats for the non-critical activities are given in the table above.

If activity E is delayed by 3 days then as E is critical the project completion time increases by exactly 3 days.

If activity F is delayed by 3 days then as F has a float of 3 days the project completion time is unaffected.

4.4.2 A project consists of 8 activities named A to H.

Construct a network so as to satisfy the scheduling requirements shown in the table below.

Activity	Completion time (days)	Immediate predecessor activities
A	3	-
B	6	A
C	7	A
D	5	A
E	13	B,C
F	8	C,D
G	11	D,F
H	6	G,E

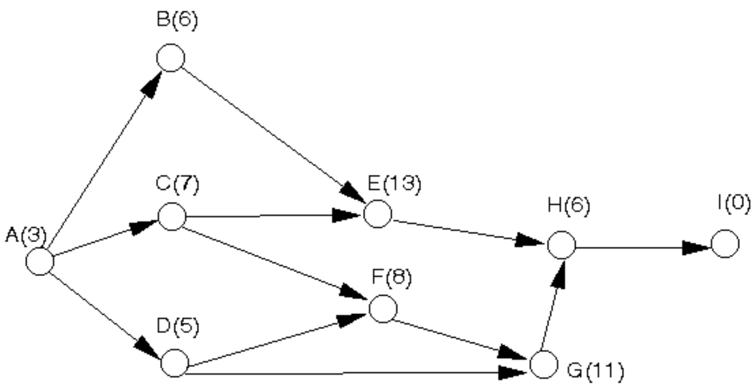
Find the least time required to complete the whole project and identify the critical activities.

How is the project completion time affected if:

- activity F is delayed by 3 days
- activity E is delayed by 7 days
- activity G is finished 7 days early

Solution

The network diagram is shown below. Note the introduction of a dummy activity I with a duration of zero to represent the end of the project.



Let E_i represent the earliest start time for activity i such that all its preceding activities have been finished. We calculate the values of the E_i (i=A,B,...,I) by going forward, from left to right, in the network diagram.

To ease the notation let T_i be the activity completion time associated with activity i (e.g. T_B = 7). Then the E_i are given by:

$E_A = 0$ (assuming we start at time zero)
$E_B = E_A + T_A = 0 + 3 = 3$
$E_C = E_A + T_A = 0 + 3 = 3$
$E_D = E_A + T_A = 0 + 3 = 3$
$E_E = \max[E_B + T_B, E_C + T_C] = \max[3 + 6, 3 + 7] = 10$
$E_F = \max[E_C + T_C, E_D + T_D] = \max[3 + 7, 3 + 5] = 10$
$E_G = \max[E_F + T_F, E_D + T_D] = \max[10 + 8, 3 + 5] = 18$
$E_H = \max[E_E + T_E, E_G + T_G] = \max[10 + 13, 18 + 11] = 29$
$E_I = E_H + T_H = 29 + 6 = 35$

Hence the minimum possible completion time for the entire project is 35 days, i.e. 35 days is the minimum time needed to complete *all* the activities. We now need to calculate the latest times for each activity.

Let L_i represent the latest start time we can start activity i and still complete the project in the minimum overall completion time. We calculate the values of the L_i (i=A,B,...,I) by going backward, from right to left, in the network diagram. Hence:

$L_I = 35$

$L_H = L_I - T_H = 35 - 6 = 29$

$L_G = L_H - T_G = 29 - 11 = 18$

$L_E = L_H - T_E = 29 - 13 = 16$

$L_F = L_G - T_F = 18 - 8 = 10$

$L_B = L_E - T_B = 16 - 6 = 10$

$L_C = \min[L_E - T_C, L_F - T_C] = \min[16 - 7, 10 - 7] = 3$

$L_D = \min[L_F - T_D, L_G - T_D] = \min[10 - 5, 18 - 5] = 5$

$L_A = \min[L_B - T_A, L_C - T_A, L_D - T_A] = \min[10 - 3, 3 - 3, 5 - 3] = 0$

Note that as a check all latest times are >=0 at least one activity has a latest start time value of zero.

As we know the earliest start time E_i, and latest start time L_i, for each activity i it is clear that the amount of slack or float time F_i available is given by $F_i = L_i - E_i$ which is the amount by which we can increase the time taken to complete activity i without changing (increasing) the overall project completion time. Hence we can form the table below:

Activity	L_i	E_i	Float F_i
A	0	0	0
B	10	3	7
C	3	3	0
D	5	3	2
E	16	10	6
F	10	10	0
G	18	18	0
H	29	29	0

Any activity with a float of zero is critical. Note here that, as a check, all float values should be >= 0.

Hence the critical activities are A, C, F, G and H and the floats for the non-critical activities are given in the table above.

If activity F is delayed by 3 days then as F is critical the project completion time increases by exactly 3 days.

If activity E is delayed by 7 days then as E has a float of 6 days the project completion time is affected. The project completion time will increase by exactly (7-6) = 1 day to 36 days.

If activity G is finished 7 days early then as G is a critical activity the overall project completion time will (potentially) be reduced. To see the effect of this change we need to redo the calculation for the earliest times given above but with a completion time for G of 4 days. The only change is in the calculation of E_H and E_I and these now are:

$E_H = \max[E_E + T_E, E_G + T_G] = \max[10 + 13, 18 + 4] = 23$

$E_I = E_H + T_H = 23 + 6 = 29$

Hence the overall project completion time falls to 29 days (a decrease of 6 days).

Review Questions

13. What is AON?
14. What are the activities involved in calculating the required Project time?
15. What do you mean by Earliest Start Time?
16. What is a Latest Start Time?

Discussion Questions

Discuss the rules about the workflow concept in a particular project? Highlight the necessary possibilities?

Application Exercises

10. Explain the process of drawing an Activity diagram?
11. What is an activity completion time? State with an example?
12. Suppose an active is give, so how will you calculate the latest Start Time.

CHAPTER 5

Forward pass and Backward pass

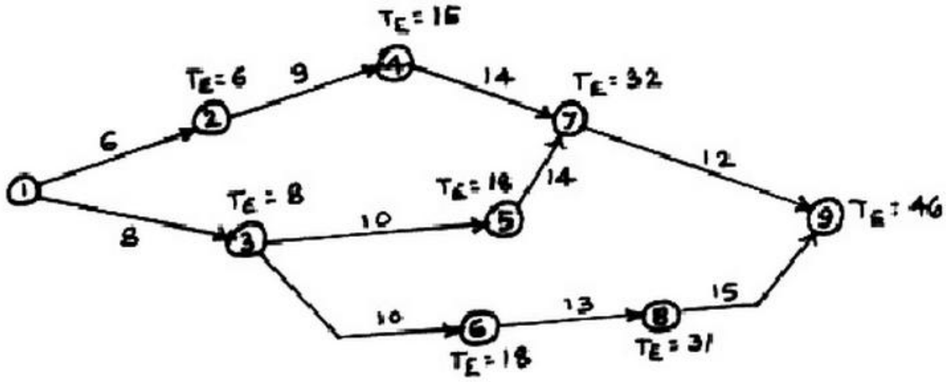
Learning Objectives

- To know more about Forward Pass.
- To analyse the Backward Pass in a Project.
- To recognise Critical Path in a network.
- To explain about allowable occurrence time.
- To know the steps involved in Forward and Backward Pass.

5.1 Introduction

A forward and backward pass is useful for estimating a project's schedule and determining if there is any float time for completing the project. There are two terms related to Critical Path that one may encounter. These are the terms Forward Pass and Backward Pass. These terms are related to ways of determining the early or late start forward pass or early or late finish backward pass for an activity. Forward pass is a technique to move forward through a diagram to calculate activity duration. Backward pass is its opposite.

A network diagram can be built in one of two ways. One approach would be to start from an initial or starting event and build up the events and activities until the end event is reached. In this process the planner asks himself, the questions "what event comes next" and "what events can take place concurrently?" However it is also possible to think backward. This means having the goal in view the planner works backward "if we want to achieve this what should have taken place?" In this manner we can come to the initial event. In practice however we may not strictly adhere to either the forward planning or backward planning but a combination of both the systems may be adopted the network being traversed back and forth several times until it is found satisfactory.



5.1.1 Earliest event time

An event is the beginning or an end of an activity. In a network where each activity is given a duration, we can speak of the time when an event can be said to occur. Consider the network below:

In this network event 1 stands for the beginning of activities 1-2 and 1-3 and we can say that event 1 occurs at time 0. Event 2 represents end of activity 1-2 and the beginning of activity 2-4. Let us assume that the figures shown near the activity is the duration in weeks that the particular activity requires for its execution from beginning to end. Then event 2 can occur at a time equal to 6 weeks. So the event time for event 2 is 6. These event times are shown on top of the nodes. When an event is connected by more than one activity the calculation of event time needs extra care. Consider the event 7 which is connected by two activity paths 1-2, 2-4, 4-7 and 1-3, 3-5 and 5-7.

By choosing the first path 1-2 and 4-7, event 7 can occur at TE = 32 weeks. By definition no event can be a considered reached until all activities leading to it are completed. Therefore event 7 cannot be considered reached until activities 1-3, 3-5 and 5-7 which require longer time for completion are completed. The earliest time for occurrence of event 7 is therefore 32 weeks and not 29 weeks. In other words the earliest time of occurrence of an event is that which is obtained by considering that path which requires the longest time for completion. Consider event 9. There are again two alternative paths for reaching the event 9 : One along 7-9 and the other along 3-6, 6-8and 8-9. The first alternative path requires 44 weeks and the second requires 46 weeks. The longer of these two viz. 46 weeks is therefore the event time of event 9. A simple rube formulated for convenience from the above example.

Firstly evaluate TE T or any event. TE (successor event) = TE (predessor event) + TE(activity). The TE for successor event ± obtained by adding to the event time of predecessor event the time required by the activity connecting the two events.

When there are more than one predecessor event for a successor event the rule is TE(successor event) is the maximum of TE (predecessor)+TE (activity). The TE is shown as indicating that this is obtained by "Forward Pass".

5.1.5 Latest Allowable Occurrence Time

In fig 5.1, we have considered the idea of "Earliest Event Time". Now we consider another idea regarding the estimate of time. The latest time by which an event must occur to keep the project on schedule is called the "Latest allowable occurrence time". This is denoted by TL. To understand this idea, let us assume that it has been agreed to complete a given project within a certain allotted time called the "contractual obligation time". This time refers to the occurrence of the end event. For calculating the latest allowable occurrence time, we have to start from the end event.

Let us assume that 4 is the end event. Now, consider the event 3. The activity 1-4 which itself consumes 19 weeks has to be completed before event 4 can occur. Therefore if the event 4 has to occur at the required time the latest allowable time for event 3 to occur is (45 - 19) =26 weeks.

In a network where an event has more than one predecessor events one has to be more careful. Consider the above network. Let us assume that in this case the earliest event time of the end event and the given project time is the same. (This may not always be the ease. The management may require that the completion time for the project be reduced. However such eases will be discussed later the earliest event times for all the events have been worked out. The latest allowable occurrence time for the project i.e. for the end event to occur is 42 weeks. Now going backwards, consider event 5. The activity 5-6 requires 6 weeks for completion. Therefore the latest occurrence time for event 5 is (42 - 6=) 36 weeks. We see that for event 5, the earliest event time and the latest allowable occurrence time are the same. Now let us go to event 4. The event 4 can be approached in two ways :

i. via 6-4

ii. via 6-5 and 5-4.

Alternatively we see that:

i. will give the latest allowable occurrence time for event 4 as (42-8a=) 34 weeks

ii. will give the latest allowable occurrence time as (36-4=) 32 weeks being the latest allowable occurrence time of event 5minus the duration of activity 5-4.

Thus we now have two latest allowable occurrence times for the event 4 viz. 34 weeks and 32 weeks. For completion of the project in time obviously the earlier of the two times will be necessary and therefore the latest allowable occurrence time for event 4 is 32 weeks.

The first step in the whole process of network planning is of course to draw the network diagram. In order to make use of this diagram for planning this network diagram must now bean analyzed. The analysis of the network diagram will provide data which will enable the planner of the project as well as the project manager to set up a precise schedule for the project and monitor and control its progress. The analysis of the network is relatively simple in principle but involves the performance of many arithmetical calculations. The number of calculations will depend on the size of the network and the amount and type of information required from the analysis. The calculations may be carried out manually or by computer according to circumstances.

5.2 Forward Pass

The term forward pass refers specifically to the essential and critical project management component in which the project team leader (along with the project team in consultation) attempts to determine the early start and early finish dates for all of the uncompleted segments of work for all network activities. There are a number of purposes for he attempted early calculation of the early start dates and early finish dates for the project as well as the early start dates and the early finish dates for all activities that are contained within the project as a whole. Determination of the early start date and early finish date allows for the earliest possible allocation of the resources that may be need for completion of the project and the activities contained within. This refers primarily to the allocation of the project team and the expenditure of their resources, as well as the allocation and expenditures of man hours. Early Start (ES) and Early Finish (EF) use the forward pass technique.

A forward pass is a single part of the Critical Path Method used in project management. Performing a forward pass will generate a numerical value in days for the early start and early finish for each task in the project. Record this visually on a network diagram, helping the Project Manager determine which tasks in the project can experience a delay and still complete on time without jeopardizing the project's current baseline completion date.

5.2.1 Instructions for Calculating ES and EF

a) Assign an ES of zero to each of the initial tasks. Calculate the EF of each initial task by adding the task duration to the ES.

b) Identify the next task on the network diagram starting at the top of the diagram. This task should come right after the initial tasks. The ES of this task will be the EF of the task that precedes it. If multiple tasks precede it, the ES is equal to the longest EF of the immediately proceeding tasks. The EF of this task is equal to the ES plus the duration of the task. Follow this step for each remaining task in the diagram.

c) Calculate the earliest completion by taking the longest EF from the last task in the diagram. If multiple tasks feed into the completion node then the earliest completion is the longest EF of the tasks that feeds into it. Earliest completion tells the project manager what is the best case scenario for finishing the project on time.

To determine the Early Start of an activity, factor in all its dependencies and see its earliest start date. Consider the following simple diagram (durations are in weeks):

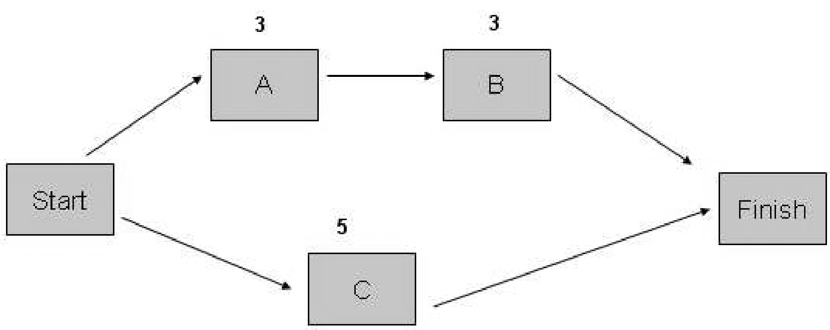


Fig 5.1

The Early Start (ES) for Activity B is 4. Why? B comes after A. A starts on week 1 and finishes on week 3. So the earliest that B can start is week 4. For simplicity, I think of it as: The duration of preceding activity + 1

The Early Finish (EF) is the earliest calculated time an activity can end. In order to find the Early Finish, we see that it is [(ES) for an activity + Activity Duration) – 1]. From the diagram shown in figure 5.1, we can calculate the EF of activity B as [(4 + 3) - 1] = 6. Hence, the EF for Activity B is 6.

Late Start (LS) and Late Finish (LF) use the backward pass technique. You can think of backward pass as calculating backward to see how much an activity may slide without affecting the finish date.

Late Start (LS) is the latest time an activity may begin without delaying the project duration. The simplest way one can compute the LS is adding the float to the activity Early Start. Using the simple diagram above, we know that Activity B is on the critical path, hence has a float of zero. Also, Activity B's ES = 4. Hence, LS = (0 + 4) or 4. Note that if an activity has a float of zero, ES and LS will be the same.

Late Finish (LF) latest time an activity may be completed without delaying the project duration. One can compute LF by LF = (Activity's LS + Activity Duration) - 1. So the LF of Activity B = (4 + 3) - 1 = 6. Note that since activity B has a zero float, EF = LF.

We see that, if the float of the activity is zero, the two starts (ES and LS) and the two finish (EF and LF) are the same. Hence, If float of activity is zero, ES = LS and EF = LF.

5.3 Backward Pass

The calculations of late finish dates and late start dates for the uncompleted portions of all schedule activities is determined by working backwards through the schedule network logic from the project's end date. Subtract the duration from the late finish date of the last activity and add one to get the late start date. This calculation method is called as Backward Pass and this is quite opposite to Forward Pass.

The phrase backward pass was originally used in the field, or more literally on the field, of sport. In one commonly used context, that of American Football, a backward pass is defined as an occurrence in which the quarterback throws the ball to a player that is currently positioned behind the point on the playing surface at which he currently stands, technically a violation of the rules of the sport. In terms of project management, a backward pass also tends to have a negative implication, as it implies lateness. A backward pass in the area of project management refers to the calculation of late finish dates and late start dates for the portions of schedule activities that have not been completed. This is determined by starting at the project's scheduled end date and working backwards through the schedule network logic. The end date may be set by the assigning party, or it may be determined through use of a forward pass.

While doing critical path calculation two Project Management terms (PM) will always come in picture. These are Forward Pass and Backward Pass. These terms are to figure out start and finishing time of an activity and its effect on critical path calculation. Forward Pass is the mechanism to move forward through a diagram to calculate total activity duration. Backward path is other way around.

- Forward pass is used by Early Start (ES) and Early Finish (EF)
- Backward pass is used by Late start (ES) and Late finish (EF)

Let's run through the following diagram to get more clear idea

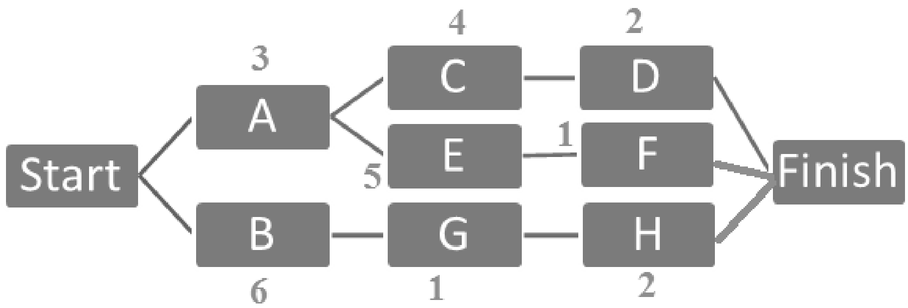


Fig 5.2

Early Start (ES) activity is A as it is scheduled on third day where B is scheduled on sixth day. For the second activity early start day is fourth therefore the activity C and E can be performed in parallel. The reason ES for second activity is day fourth is, activity A will take three days and at earliest C and E can be started in on fourth day. So the logic is "The duration of preceding activity + 1"

Early Finish (EF) is the earliest time that an activity can be finished. To calculate early finish we use (ES for the activity + Activity duration) -1. So we can say that the early finish for activity C is day 17th. The reason is activity C will start on day fourth and will take total four day (fourth, fifth, sixth and seventh). So the earliest time it can finish is on day 7th.

Late Start (LS) is the latest time an activity needs to start without delaying the project. Late start can be calculated by adding float to the activity early start. As per the diagram above we know that activity E has one day float and activity E's ES is 4. So LS for activity C will be 1+4=5. Similarly, we know that activity C is on critical path therefore has zero float and activity C's ES is 4. So LS for activity C will be 0+4=4.

Late Finish (LF) is the latest time an activity can be completed without delaying the project. LF can be calculated by LF = (Activity's LS + Activity Duration) – 1. So the LF of Activity E = (5 + 5) – 1 = 9.

5.4 Calculating and Executing a Forward and Backward Pass

When constructing a project schedule, a project manager can draw upon a score of strategic lessons from the game of football. For example, in wearing the hat of team coach, the project manager has at his fingertips a dynamic playbook of offensive and defensive moves to keep the project on schedule. During the early stages of the game, the project manager's focus is on developing realistic estimates for the project's schedule. The estimation process is accomplished by pulling from one of the early chapters of the playbook two essential plays: the forward pass and the backward pass. Analogous to the two minute drill, the forward pass is the best strategy for quickly driving the ball to the goal line or in the case of a project to the completion date. Each task represents a first down marker and the forward pass pushes the ball along the schedule in the least amount of time.

A forward pass is executed by calculating the early start and the early finish for each task of the project. The early start is the earliest point in time when a task can be started. The early finish is the earliest point in time that a task could be finished. However, sometimes the forward pass is not the best strategy, particularly when the defense rushes the quarterback. In this case, the project manager needs to execute a backward pass to see if there is enough slack time to allow for a different set of plays and still get the project to the goal line before time expires on the clock. In constructing a backward pass, the project manager reverses the process to determine the late start and the late finish for each task in the project and remain in regulation time. The late start date is the latest point in time when a task can be started. The late finish is the latest point in time that task could be finished.

5.5 Constructing Forward and Backward Pass Project Management Template

You can easily constructing a forward and backward pass template in Microsoft Word by following these steps:

- To create the template which is illustrated below and in a downloadable version in the Project Management media gallery, open a Word document and insert an organizational chart.
- Choose the primary color style.
- Create levels to reflect predecessor and successor tasks.
- Fill-in values for each task's early start and early finish. Begin with Task 1 and label the early start (abbreviated ES on the template) as Day 0.
- Add the estimated duration of the task to the early start to calculate the early finish (abbreviated EF on the template).
- Label each successor task's ES as the EF of the predecessor's task.
- Where you have more than one predecessor for a task, use the later EF as the ES for the successor task.
- Fill-in values for each task's late start and late finish. Begin with the last task and label the late finish (LF) with the completion day determined by the forward pass.
- Subtract the duration from the LF to calculate the late start (LS).
- Where you have more than one predecessor for a task, use the later LS as the LF for the predecessor task.

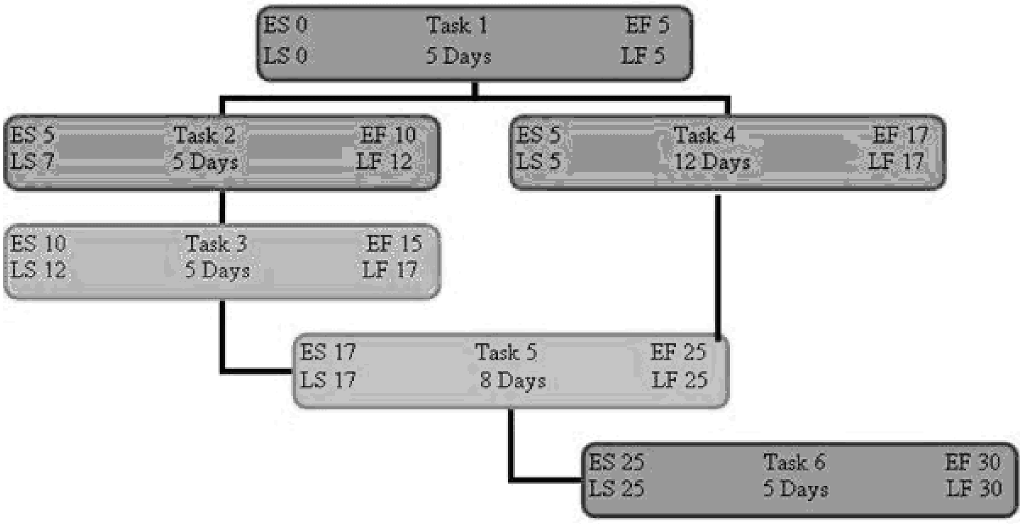


Fig 5.3

Here is an illustration of the forward and backward pass. Notice that the early start and late start begin at the same time (Day 0) and the late start and late finish end at the same time (Day 30), the difference between the early and late finish of any task is called the total slack or float. Remember that even if the project falls behind, the project manager's playbook still has a number of other options to get the schedule back on track.

5.6 Forward Pass / Backward Pass Calculation

Early Start date(ES), Late Start date (LS), Early Finish date (EF), Late Finish date (LF), Free Slack (FS), and Total Slack (TS) of a given set of project activities connected together through different types of relationships such as:

- Start-To-Start
- Finish-To-Start

- Finish-To-Finish

with lag. The project network diagram 5.4 is shown below.

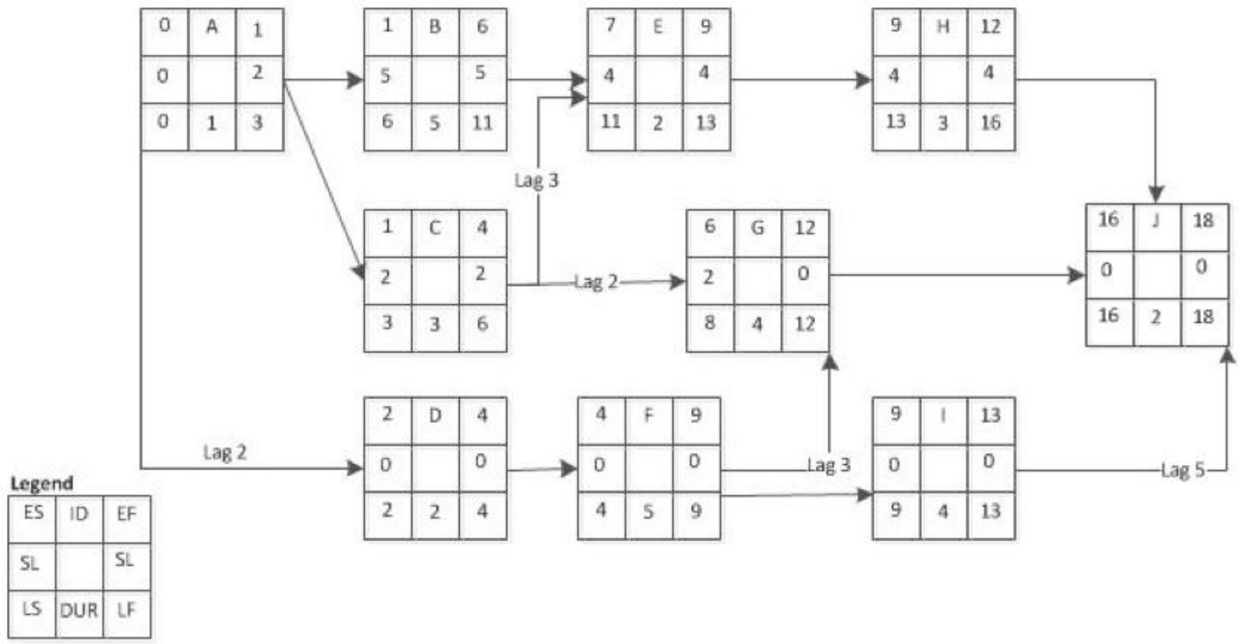


Fig 5.4

Let’s perform Forward Pass to calculate the Early Start date (ES) and Early Finish date (EF) for each task.

First, start with Activity A from left to right. Since Activity A is the first activity and has no predecessor, ES(A) = 0 and EF(A) = Duration(A) + ES(A) = 1 + 0 = 1.

Since Activity A is the sole predecessor for Activity B and since the their relationship is Finish-To-Start, ES(B) = EF(A) = 1. EF(B) = Duration(B) + ES(B) = 5 + 1 = 6.

Since Activity A is the sole predecessor for Activity C and since their relationship is Finish-To-Start, ES(C) = EF(A) = 1. EF(C) = Duration(C) + ES(C) = 3 + 1 = 4.

Since Activity A is the sole predecessor for Activity D and since their relationship is Start-To-Start, activity D can start 2 periods after activity A’s start, ES(D) = ES(A) + lag = 0 + 2 = 2. EF(D) = Duration(D) + ES(D) = 2 + 2 = 4.

Since Activity E has two predecessors (B,C) and since the relationship between E and each of its predecessors is Finish-To-Start, activity E’s Early Start date is the largest of the sum of each of the Early Finish dates of its predecessors and their corresponding lags. Since EF(C) + lag = 4 + 3 = 7 > EF(B) = 6, then ES(E) = EF(C) + lag = 4 + 3 = 7. Thus, EF(E) = Duration(E) + ES(E) = 2 + 7 = 9.

Since Activity D is the sole predecessor for Activity F, ES(F) = EF(D) = 4. EF(F) = Duration(F) + ES(F) = 5 + 4 = 9.

Activity G has two predecessors (C,F). Since the relationship between G and C is Finish-To-Start with lag = 2, then ES(G) = EF(C) + lag = 4 + 2 = 6. Since the relationship between G and F is Finish-To-Finish with lag = 4, then G can only finish 3 periods after F's finish, thus EF(G) = EF(F) + 3 = 9 + 3 = 12.

Since Activity E is the sole predecessor for Activity H and since the relationship is Finish-To-Start, then ES(H) = EF(E) = 9. EF(H) = Duration(H) + ES(H) = 3 + 9 = 12.

Since Activity F is the sole predecessor for Activity I and since the relationship is Finish-To-Start, then ES(I) = EF(F) = 10. EF(I) = Duration(I) + ES(I) = 4 + 10 = 14.

Activity J has three predecessors (H,G,I). Since the relationship between J and I is Finish-To-Finish with lag = 5, then J can only finish 5 periods after I's finish, thus EF(J) = EF(I) + 5 = 13 + 5 = 18. Since the relationship between J and each of its predecessors G and H is Finish-To-Start, the Early Start date of J is the largest of the sum of each of the Early Finish dates of G and H and their corresponding lags. Thus, since EF(G) + lag = 12 + 4 = 16 > EF(H) = 12, then ES(J) = 16.

Now let's perform Backward Pass to compute the Late Start date (LS) and Late Finish date (LF) for each task.

First, start with Activity J (start from last activity and move right to left). Since Activity J is the last activity, LF(J) = EF(J) = 18. LS(J) = LF(J) – Duration(J) = 18 – 2 = 16.

Activity J has three predecessors (H,G,I). Since the relationship between J and I is Finish-To-Finish with lag = 5, then J can only finish 5 periods after I's finish, thus LF(I) = LF(J) – lag = 18 – 5 = 13. Since the relationship between J and each of its predecessors G and H is Finish-To-Start, then LF(H) = LS(J) = 16 and LF(G) = LS(J) – 4 = 16 – 4 = 12. Thus, LS(H) = LF(H) – Duration(H) = 16 – 3 = 13 and LS(G) = LF(G) – Duration(G) = 12 – 4 = 8.

Since Activity E is the sole predecessor for Activity H, LF(E) = LS(H) = 13. LS(E) = LF(E) – Duration(E) = 13 – 2 = 11.

Since the relationship between activity G and its predecessor F is a Finish-To-Finish with lag = 3, and since the relationship between I and its predecessor F is a Finish-To-Start, then LF(F) = LF(G) – 3 = LF(I) = 9.

Since Activity B is the sole predecessor for Activity E, LF(B) = LS(E) = 11. LS(B) = LF(B) – Duration(B) = 11 – 5 = 6.

Since activity C is the predecessor of activities E and G, its Late Finish date is the smallest of the difference of each of the Late Start Dates of activities E and G and their corresponding lags. Since LS(G) – lag = 8 – 2 = 6 < LS(E) – lag = 11 – 3 = 8, then LF(C) = LS(G) – lag = 8 – 2 = 6. Thus, LS(C) = LF(C) – Duration(C) = 6 – 3 = 3.

Since Activity D is the sole predecessor for Activity F, LF(D) = LS(F) = 4. LS(D) = LF(D) – Duration(D) = 4 – 2 = 2.

Since the relationship between activity A and activity D is Start-To-Start, then A can only start 2 periods before the start of activity D, thus LS(A) = LS(D) – 2 =2 – 2 = 0. Since the relationship between activity A and each of its successors is a Finish-To-Start relationship, then the Late Finish date of activity A is the smallest of the Late Start dates of its successors, thus LF(A) = LS(C) = 3.

The slack for the start for each of the activities is computed as follows:

- Slack for the start of A = LS(A) – ES(A) = 0 – 0 = 0.
- Slack for the start of B = LS(B) – ES(B) = 6 – 1 = 5.
- Slack for the start of C = LS(C) – ES(C) = 3 – 1 = 2.
- Slack for the start of D = LS(D) – ES(D) = 2 – 2 = 0.
- Slack for the start of E = LS(E) – ES(E) = 11 – 7 = 4.
- Slack for the start of F = LS(F) – ES(F) = 4 – 4 = 0.
- Slack for the start of G = LS(G) – ES(G) = 8 – 6 = 2.
- Slack for the start of H = LS(H) – ES(H) = 13 – 9 = 4.
- Slack for the start of I = LS(I) – ES(I) = 9 – 9 = 0.
- Slack for the start of J = LS(J) – ES(J) = 16 – 16 = 0.

The slack for the finish of each of the activities is computed as follows:

- Slack for the finish of A = LF(A) – EF(A) = 3 – 1 = 2.

- Slack for the finish of B = LF(B) – EF(B) = 11 – 6 = 5.
- Slack for the finish of C = LF(C) – EF(C) = 6 – 4 = 2.
- Slack for the finish of D = LF(D) – EF(D) = 4 – 4 = 0.
- Slack for the finish of E = LF(E) – EF(E) = 13 – 9 = 4.
- Slack for the finish of F = LF(F) – EF(F) = 9 – 9 = 0.
- Slack for the finish of G = LF(G) – EF(G) = 12 – 12 = 0.
- Slack for the finish of H = LF(H) – EF(H) = 16 – 12 = 4.
- Slack for the finish of I = LF(I) – EF(I) = 13 – 13 = 0.
- Slack for the finish of J = LF(J) – EF(J) = 18 – 18 = 0.

Review Questions

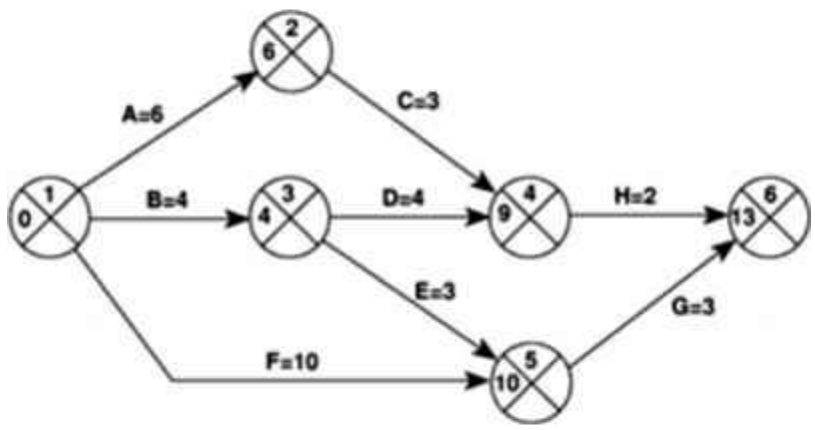
17. What is Forward pass?
18. What are the activities involved in Backward pass?
19. What is the need of Early Start date (ES), Late Start date (LS) and Early Finish date (EF) in a project?
20. What is a Latest Start Time?

Discussion Questions

Consider a project in which you have been involved that experienced unexpected delays. Describe how the project's manager dealt with the delays. Specifically, consider if the delay was due to an activity that was on the project's critical path, if people or resources were diverted from other tasks, or if free float existed in the original schedule. Describe the ultimate effect on the project's completion date?

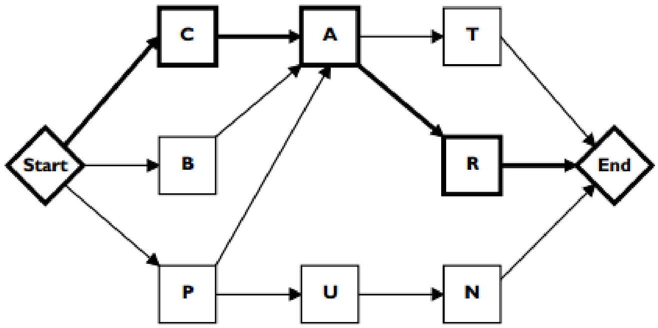
Application Exercises

13. What is the formula for calculating the forward and backward pass for a project using a network diagram?
14. Find the latest even dates from the table and diagram shown below of a backward pass?



Activity	Duration	Earliest	Ixttest	Earliest	Latest	Total
	(weeks)	start (late	start date	finish fate	finish date	fioat
A	6	0	2	6	8	
B	4	0	3	4	7	
C	3	6	8	9	II	
I)	4	4	7	8	II	
E	3	4	7	7	10	
F	10	0	0	10	10	
Ci	3	10	10	13	13	
H	2	9	11	II	13	

15. In the diagram shown, find the Early Finish (EF)?


Start
C
B
P
A
U
T
R
N
End

CHAPTER 6

Advantages and Limitations of CPM/PERT

Learning Objectives

- To know more about CPM/PERT.
- To analyse the Backward Pass in a Project.
- To recognise Critical Path in a network.
- To explain about allowable occurrence time.
- To know the steps involved in Forward and Backward Pass.

6.1 CPM/PERT

THE CPM (CRITICAL PATH METHOD) SYSTEM OF NETWORKING IS USED, WHEN THE ACTIVITY TIME ESTIMATES ARE DETERMINISTIC IN NATURE. FOR EACH ACTIVITY, A SINGLE VALUE OF TIME, REQUIRED FOR ITS EXECUTION, IS ESTIMATED. TIME ESTIMATES CAN EASILY BE CONVERTED INTO COST DATA IN THIS TECHNIQUE. CPM IS AN ACTIVITY ORIENTED TECHNIQUE.

6.1.1 Critical Path Method

The critical path method (CPM) is a project modeling technique developed in the late 1950s by Morgan R. Walker and James E. Kelley, Jr. CPM is commonly used with all forms of projects, such as construction, aerospace and defense, software development, research projects, product development, engineering, and plant maintenance.

CPM involves a diagram of each step of the project, typically represented as letters with lines to each letter to display the sequence in which the project steps take place. A list of activities is required to complete the project and the time (duration) that each activity will take to complete, along with the sequence and dependencies between activities (such as step A has to be finished before moving to step B). Using this information, CPM lays out the longest path of planned activities to the end of the project as well as the earliest and latest that each activity can start and finish without delaying other steps in the project.

Following the pathways created in the CPM diagram between the different steps, the project manager can glean a lot of information about the timing of the project. They can determine which activities in the project need to be completed before others and how long those activities can take before they delay other parts of the project.

They can also determine which set of activities is likely to take the longest. For example, if step A has to be completed before B which has to be completed before moving to C, then this may be the longest series of activities in the project. The longest series of activities in a project is referred to as the "critical path." The critical path is the sequence of project network activities which add up to the longest overall duration. The critical path also tells the project manager the shortest possible time period in which the project can be completed since the timing of the project will be dependent on the completion of the critical path activities.

6.1.2 PERT Chart

A PERT chart (program evaluation review technique) is a form of diagram for CPM that shows activity on an arrow diagram. PERT charts are more simplistic than CPM charts because they simply show the timing of each step of the project and the sequence of the activities.

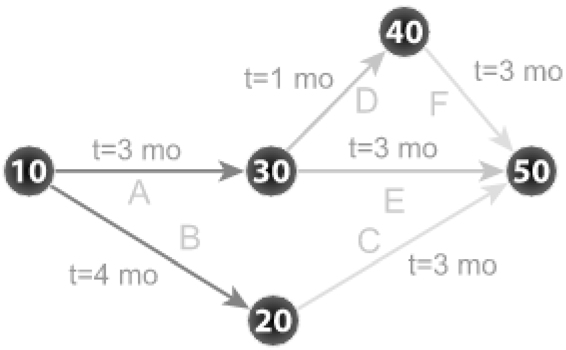


Fig 6.1

The CPM charts are more complex because they show the sequence of steps but also have a diagram around each step that shows the earliest possible time and latest possible time that each activity in the project can be completed (Figure 6.1). The earliest possible times, shown in the CPM chart figure in green are calculated by determining the earliest start times of all activities on the critical path before that activity. The latest possible times are calculated by adding all of the latest possible times of the activities before the critical path. In this CPM chart, the critical path is A-B-C-D-E since that pathway takes the most time to complete of any of the other potential pathways available. The total float time in lime green or TF represents the amount of time flexibility that an activity has between start and end times.

CPM and PERT charts are useful in determining where potential delays may occur in a project and organizing which activities need to come first and in what sequence. This helps project teams organize tasks and make sure that time is managed appropriately for each stage of the project.

THE PERT (PROJECT EVALUATION AND REVIEW TECHNIQUE) TECHNIQUE IS USED, WHEN ACTIVITY TIME ESTIMATES ARE STOCHASTIC IN NATURE. FOR EACH ACTIVITY, THREE VALUES OF TIME (OPTIMISTIC, MOST LIKELY, PESSIMISTIC) ARE ESTIMATED. OPTIMISTIC TIME (T_O) ESTIMATE IS THE SHORTEST POSSIBLE TIME REQUIRED FOR THE COMPLETION OF ACTIVITY. MOST LIKELY TIME (T_M) ESTIMATE IS THE TIME REQUIRED FOR THE COMPLETION OF ACTIVITY UNDER NORMAL CIRCUMSTANCES. PESSIMISTIC TIME (T_P) ESTIMATE IS THE LONGEST POSSIBLE TIME REQUIRED FOR THE COMPLETION OF ACTIVITY. IN PERT B-DISTRIBUTION IS USED TO REPRESENT THESE THREE TIME ESTIMATES (FIGURE 6.1).

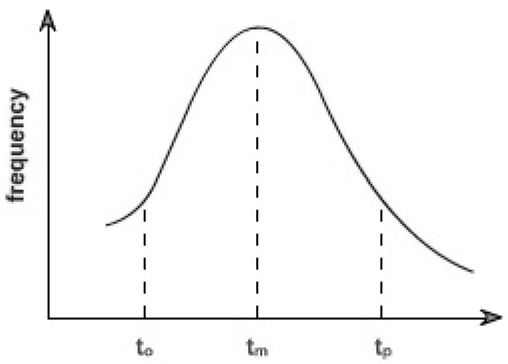


Fig 6.2

AS PERT ACTIVITIES ARE FULL OF UNCERTAINTIES, TIMES ESTIMATES CAN NOT EASILY BE CONVERTED IN TO COST DATA. PERT IS AN EVENT ORIENTED TECHNIQUE. IN PERT EXPECTED TIME OF AN ACTIVITY IS DETERMINED BY USING THE BELOW GIVEN FORMULA:

$$t_e = \frac{(t_o + 4t_m + t_p)}{6}$$

THE VARIANCE OF AN ACTIVITY CAN BE CALCULATED AS:

$$\sigma^2 = \left[\frac{(t_p - t_o)}{6}\right]^2$$

6.2 CALCULATION OF TIME ESTIMATES IN CPM

IN THE PROJECT NETWORK GIVEN IN FIGURE BELOW, ACTIVITIES AND THEIR DURATIONS ARE SPECIFIED AT THE ACTIVITIES. FIND THE CRITICAL PATH AND THE PROJECT DURATION.

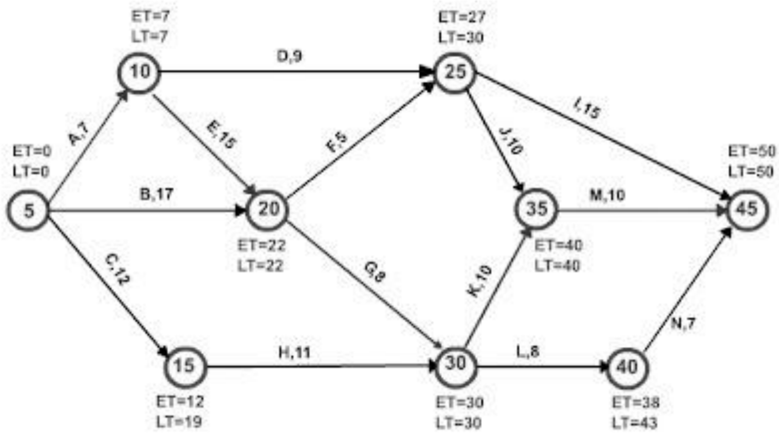


Fig 6.3

6.3 CALCULATIONS IN NETWORK ANALYSIS

THE FOLLOWING CALCULATIONS ARE REQUIRED IN NETWORK ANALYSIS IN ORDER TO PREPARE A SCHEDULE OF THE PROJECT.

a. TOTAL COMPLETION TIME OF THE PROJECT
b. EARLIEST TIME WHEN EACH ACTIVITY CAN START (I.E. EARLIST START TIME)
c. EARLIEST TIME WHEN EACH ACTIVITY CAN FINISH (I.E. EARLIST FINISHED TIME)
d. LATEST TIME WHEN EACH ACTIVITY CAN BE STARTED WITHOUT DELAYING THE PROJECT (I.E. LATEST START TIME)

e. LATEST TIME WHEN EACH ACTIVITY CAN BE FINISHED WITHOUT DELAYING THE PROJECT (I.E. LATEST FINISH TIME)
f. FLOAT ON EACH ACTIVITY (I.E. TIME BY WHICH THE COMPLETION OF AN ACTIVITY CAN BE DELAYED WITHOUT DELAYING THE PROJECT)
g. CRITICAL ACTIVITY AND CRITICAL PATH

THE SYMBOLS USED IN THE CALCULATIONS ARE SHOWN IN TABLE BELOW.

SYMBOL	DESCRIPTION
E_I	EARLIEST OCCURANCE TIME OF EVENT I
L_J	LATEST ALLOWABLE OCCURANCE TIME OF EVENT J
T_E^{I-J}	ESTIMATED COMPLETION TIME OF ACTIVITY (I,J)
$(EST)_{IJ}$	EARLIEST STARTING TIME OF ACTIVITY (I,J)
$(EFT)_{IJ}$	EARLIEST FINISHING TIME OF ACTIVITY (I,J)
$(LST)_{IJ}$	LATEST STARTING TIME OF ACTIVITY (I,J)
$(LFT)_{IJ}$	LATEST FINISHING TIME OF ACTIVITY (I,J)

THE COMPUTATIONS ARE MADE IN FOLLOWING STEPS.

(A) FORWARD PASS COMPUTATIONS:

$$(EST)_{ij} = E_i$$
$$(EFT)_{ij} = \text{Maximum of} \left[(EST)_{ij} + t_E^{ij}\right] \forall \text{ i - j leading into event j}$$

(B) BACKWARD PASS COMPUTATIONS:

$$(LFT)_{ij} = L_j$$
$$(LST)_{ij} = \text{Minimum of} \left[(LFT)_{ij} - t_E^{ij}\right] \forall \text{ i - j emanating from node i}$$

(C) CALCULATION OF SLACK:

EVENT SLACK IS DEFINED AS THE DIFFERENCE BETWEEN THE LATEST EVENT AND EARLIST EVENT TIMES.

SLACK FOR HEAD EVENT = $L_J - E_J$

SLACK FOR TAIL EVENT = $L_I - E_I$

THE CALCULATIONS FOR THE ABOVE TAKEN EXAMPLE NETWORK ARE SUMMARISED BELOW IN THE TABLE.

PREDECESSOR EVENT I	SUCCESSOR EVENT J	T_E^{I-J}	$(EST)_{IJ}$	**$(EFT)_{IJ}$**	**$(LST)_{IJ}$**	**$(LFT)_{IJ}$**	**S(I) SLACK**
5	10	7	0	7	0	7	0
5	15	12	0	12	7	19	-
5	20	17	0	17	5	22	-
10	20	15	7	22	7	22	0
10	25	9	7	16	21	30	-
15	30	11	12	23	19	30	7
20	25	5	22	27	25	30	-
20	30	8	22	30	22	30	0
25	35	10	27	37	30	40	3
25	45	15	27	42	35	50	-
30	35	10	30	40	30	40	0
30	40	8	30	38	35	43	-
35	45	10	40	50	40	50	0
40	45	7	38	45	43	50	5

(D) DETERMINATION OF CRITICAL PATH:

THE SEQUANCE OF CRITICAL ACTIVITIES IN A NETWORK IS CALLED THE CRITICAL PATH. THE ACTIVITIES WITH ZERO SLACK OF HEAD EVENT AND ZERO SLACK FOR TAIL EVENT, ARE CALLED AS CRITITCAL ACTIVITIES. IN THE

TAKEN NETWORK, THE FOLLOWING ACTIVITIES ARE CRITICAL ACTIVITIES: **5 - 10, 10 - 20, 20 - 30, 30 - 35, 35 - 45**. THUS THE CRITICAL PATH IS **A - E - G - K - M**. CRITICAL PATH DURATION IS **7 + 15 + 8 + 10 + 10 = 50**.

6.4 CALCULATION OF EXPECTED TIME AND VARIANCE OF A PATH IN PERT

THE EXPECTED TIME OF A CHAIN OF ACTIVITIES IN SERIES, IS THE SUM OF THEIR EXPECTED TIMES. SIMILARLY THE VARIANCE OF THE PATH, IS THE SUM OF VARIANCES OF ACTIVITIES ON THE PATH. IN FIGURE BELOW, THREE ACTIVITIES A,B AND C ARE CONNECTED IN SERIES, (I.E. FORM A PATH). THEIR TIME ESTIMATES TO-TM-TPARE GIVEN ALONG THE ACTIVITY ARROWS. THE EXPECTED TIME OF THE PATH 1-2-3-4 IS CALCULATED AS:

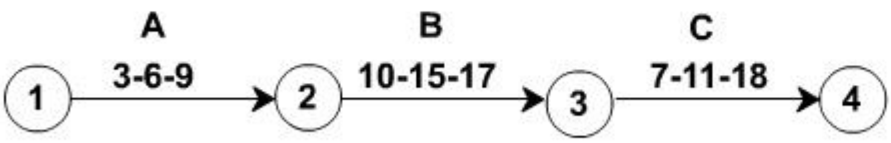


Fig 6.4

$$t_E^{1-2-3-4} = t_E^{1-2} + t_E^{2-3} + t_E^{3-4}$$
$$= \frac{3+4*6+9}{6} + \frac{10+4*15+17}{6} + \frac{7+4*11+18}{6}$$
$$= 6 + 14.5 + 11.5$$
$$= 32$$

t_E could also be computed as

$$t_E^{1-2-3-4} = \frac{\sum t_o + 4\sum t_m + \sum t_p}{6}$$
$$= \frac{(3+10+7)+4(6+15+11)+(9+17+18)}{6}$$
$$= 32$$

The Variance for the path is given by

$$v^{1-2-3-4} = \left(\frac{9-3}{6}\right)^2 + \left(\frac{17-10}{6}\right)^2 + \left(\frac{18-7}{6}\right)^2$$
$$= 1 + (1.17)^2 + (1.83)^2$$
$$= 5.72$$

AS THE LENGTH OF THE PATH, THAT IS THE NUMBER OF ACTIVIES CONNECTED IN SERIES INCREASES,THE VARIANCE OF THE PATH AND HENCE THE UNCERTAINTY OF MEETING THE EXPECTED TIME ALSO INCREASES.

6.3.1 EXAMPLE

IN THE NETWORK OF FIGURE BELOW, THE PERT TIME ESTIMATES OF THE ACTIVITIES ARE WRITTEN ALONG THE ACTIVITY ARROWS IN THE ORDER TO-TM-TP. COMPUTE THE EXPECTED TIME AND VARIANCE FOR EACH ACTIVITY. ALSO COMPUTE THE EXPECTED DURATION AND STANDARD DEVIATION FOR THE FOLLOWING PATHS OF THE NETWORK.

(A) 10-20-50-80-90
(B) 10-30-50-70-90
(C) 10-40-60-80-90

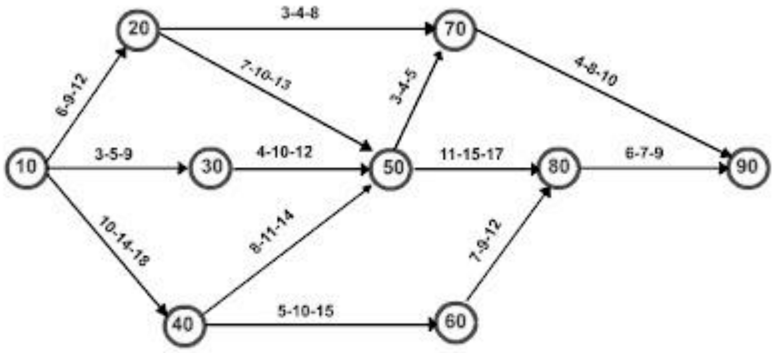


Fig 6.5

THE COMPUTATION OF EXPECTED TIMES AND VARIANCES FOR DIFFERENT ACTIVITIES ARE CARRIED IN A TABLE GIVEN BELOW.

ACTIVITY		TIME ESTIMATES			**EXPECTED TIME**	**VARIANCE**
I	J	T_O	T_M	T_P	T_E	Σ^2
10	20	6	9	12	9.00	1.00
10	30	3	5	9	5.33	1.00

10 40	10 14 18	14.00	1.78
20 50	7 10 13	10.00	1.00
20 70	3 4 8	4.5	0.69
30 50	4 10 12	9.33	1.78
40 50	8 11 14	11.00	1.00
40 60	5 10 15	10.00	2.78
50 70	3 4 5	4.00	0.11
50 80	11 15 17	14.67	1.00
60 80	7 9 12	9.17	0.69
70 90	4 8 10	7.67	1.00
80 90	6 7 9	7.17	0.25

(a) Expected duration and variance of the path 10 - 20 - 50 - 80 - 90

$$\text{Expected time } t_E = t_E^{10-20} + t_E^{20-50} + t_E^{50-80} + t_E^{80-90}$$
$$= 9.00 + 10.00 + 14.67 + 7.17$$
$$= 40.84$$
$$\text{Variance (V)} = V^{10-20} + V^{20-50} + V^{50-80} + V^{80-90}$$
$$= 1.00 + 1.00 + 1.00 + .25$$
$$= 3.25$$
$$\text{Standard deviation } (\sigma) = \sqrt{3.25} = 1.803$$

(b) Expected duration of path : 10 - 30 - 50 - 70 - 90

$$t_E = t_E^{10-30} + t_E^{30-50} + t_E^{50-70} + t_E^{70-90}$$
$$= 5.33 + 9.33 + 4.00 + 7.67$$
$$= 26.33$$
$$\text{Variance (V)} = V^{10-30} + V^{30-50} + V^{50-70} + V^{70-90}$$
$$= 1.00 + 1.78 + 0.11 + 1.00$$
$$= 3.89$$
$$\text{Standard deviation } (\sigma) = \sqrt{3.89} = 1.972$$

(c) Expected duration of path 10 - 40 - 60 - 80 - 90

$$t_E = t_E^{10-40} + t_E^{40-60} + t_E^{60-80} + t_E^{80-90}$$
$$= 14.00 + 10.00 + 9.17 + 7.17$$
$$= 40.34$$
$$\text{Variance (V)} = V^{10-40} + V^{40-60} + V^{60-80} + V^{80-90}$$
$$= 1.78 + 2.78 + .069 + 0.25$$
$$= 5.5$$
$$\text{Standard deviation } (\sigma) = \sqrt{5.5} = 2.345$$

6.4 CPM & PERT Weaknesses & Strengths

Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) help managers to plan the timing of projects involving sequential activities. PERT/CPM charts identify the time required to complete the activities in a project, and the order of the steps. Each activity is assigned an earliest and latest start time and end time. Activities with no slack time are said to lie along the critical path–the path that must stay on time for the project to remain on schedule.

- Expected Completion Time: A strength of PERT/CPM charts is their ability to calculate exactly how long a project will take. PERT/CPM provides managers with a range of time in which the project should be completed, based on the total of all minimum and maximum time limits for all activities. This gives companies a number of advantages, such as the ability to tell customers exactly when their orders will be filled, or to know exactly when to order new supplies. The expected completion time of the project is based on ideal situations, however, and does not take into account the possibility of unforeseen events. The expected completion time of all subsequent activities and the project as a whole can become skewed when things go wrong, which can cause problems if the company has made plans that rely on the timely completion of the project. Another weakness of PERT/CPM is that the technique relies on past data and experience to formulate completion time predictions. New companies may not have any past experience to lean on, putting them at a disadvantage.

- Efficiency: Businesses can share PERT/CPM charts among all key employees, letting employees at each station know exactly when they will be required to begin work processes, where the required inputs will come from, where the outputs must go, and when their task must be completed. This can help dispersed employees to operate efficiently by having a common understanding of the expected work flow. When things go wrong, however, the very thing that encouraged efficiency might suddenly cause confusion. When a project is held up due to an unforeseen circumstance, workers at all subsequent stations must delay their own progress while explaining to subsequent stations' employees why outputs are not flowing.

- Critical Path: The critical path identified in a PERT/CPM chart shows managers which activities are the most time-critical. This allows managers to focus process improvements on the tasks that are most vital to the timely completion of the project. More slack time can be created by reducing the processing time at critical points in the project, or the project schedule can be tightened up for a quicker turnaround. Managers may place too much emphasis on activities along the critical path, however. A weakness of CPM is that it focuses primarily on the time aspect of activities, neglecting other concerns, such as quality and cost control. Focusing too much attention on the critical path can cause managers not to notice possible production improvements in other activities.

6.5 Advantages of PERT and CPM

PERT (Program, or Project, Evaluation and Review Technique) and CPM (Critical Path Method) are specialized project management techniques and scheduling tools that allow managers to plan, manage and control complex tasks and projects. They are jointly referred to as network analysis, networking programming models, and critical path analysis (CPA) techniques, and although they are fundamentally different in their unique characteristics, they are usually used in conjunction with each other. PERT and CPM are used in various industries to effectively plan, organize and monitor project-management related activities.

- Breakdown Projects into Component Tasks: PERT charts are management tools that facilitate effective decision making. They are diagrams that represent the flow of activities through a process, highlight all dependent tasks and events, display the sequence of events from the start of a project to its termination, and highlight the critical path of a project. Activities are represented by boxes, and links between different activities are represented by arrows. A CPM network diagram is activity-oriented, showing the sequence of activities in terms of cost and time. PERT and CPM define projects by specifying their component tasks and activities. A PERT/CPM chart clearly shows relationships and dependencies between different tasks of an activity.

- Forecast and Analyze Possibilities: PERT and CPM are effective forecasting tools and can predict future elements of a process or project. They allow managers to probe and analyze all possibilities, pitfalls, ambiguities and uncertainties. They are used to determine and avoid surprises and minimize wastage. Project managers comprehensively analyze all factors that affect a project and its successful completion in advance, plotting that data clearly in the form of a diagram.

- Focused and Disciplined: PERT and CPM allow managers to focus on critical tasks (those tasks that are essential for the successful completion of a unit, event or task) in order to speed them up. This focus also makes it easier for managers to allocate resources accurately and ensure that they are used effectively.

- PERT and CPM charts facilitate logical structure and discipline in planning, scheduling and monitoring tasks, encouraging detailed and long-ranging project planning.

Improved Communication: PERT and CPM charts and networks improve intra-organizational communication. They graphically represent task and activity relationships between individuals and departments, making it easier to determine individual roles in the completion of a task. PERT and CPM bring together disparate and separate units within an organization, aligning their roles and responsibilities to achieve a common organizational goal. This fosters better working relationships and cohesiveness between various factions.

Review Questions

21. What is Critical Path Method?
22. What is PERT chart?
23. How to calculate time estimation in CPM project?
24. What are the calculations involved in network analysis?

Discussion Questions

For the following data, draw the network diagram, and then crash the activities to find the time-cost trade-off points that the company should want to consider. Start with the plan that has the longest duration?

Activity	Preceding Activity	Time(weeks) Normal Program	Time(weeks) Crash Program	Cost Normal Program	Cost Crash Program
A	-	2	2	5	5
B	A	5	3	11	21
C	A	2	1	7	16
D	B, C	4	2	8	22
E	B	3	2	9	18
F	D, E	3	3	9	9

Application Exercises

16. What is the difference between CPM and PERT?
17. For the following data, draw the network diagram, and then crash the activities to find the time-cost trade-off points that the company should want to consider. Start with the plan that has the longest duration?

Activity	Preceding Activity	Time(weeks) Normal Program	Time(weeks) Crash Program	Cost ($) Normal Program	Cost ($) Crash Program
A	-	2	1	20,000	20,700
B	-	3	1	29,000	33,000
C	A	2	1	25,000	26,100
D	B	4	3	47,000	47,750
E	C	4	2	55,000	57,000
F	C	3	2	29,000	29,500
G	D, E	5	3	79,000	80,800
H	F, G	2	1	15,000	17,900

18. Draw the network diagram for the following problem and indicate a sequence of plans that the company should want to consider in making a time-cost tradeoff. The company is not interested in reducing the project duration below 29 days. Start with the plan that has the longest duration?

Activity	Preceding Activity	Time(days)		Cost ($)	
		Regular Program	Crash Program	Regular Program	Crash Program
A	-	10	9	5,000	5,200
B	-	14	11	3,500	3,950
C	A	8	7	4,000	4,100
D	A	7	2	2,100	3,600
E	B	5	3	2,500	3,000
F	B	10	7	2,250	3,750
G	C	9	9	5,000	5,000
H	D, E	11	9	3,850	5,250
I	G, H	5	3	2,375	3,575

CHAPTER 7

Precedence Diagramming Method

Learning Objectives

- To know more about CPM/PERT.
- To analyse the Backward Pass in a Project.
- To recognise Critical Path in a network.
- To explain about allowable occurrence time.
- To know the steps involved in Forward and Backward Pass.

7.1 Introduction

Precedence Diagram Method (PDM) is a visual representation technique that depicts the activities involved in a project. It is a method of constructing a project schedule network diagram that uses boxes/nodes to represent activities and connects them with arrows that show the dependencies. The Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) techniques are essentially limited to “finish-start” relationships (i.e., activity B cannot start until activity A is completed). PDM was developed subsequent to the PERT/CPM techniques and its function is to permit a more accurate depiction of relationships among various activities.

There are four (4) types of dependencies that you need to be aware of before creating a Precedence Diagram.

- Finish-Start: In this dependency, an activity cannot start before a previous activity has ended. This is the most commonly used dependency.
- Start-Start: In this dependency, there is a defined relationship between the start of activities.
- Finish-Finish: In this dependency, there is a defined relationship between the end dates of activities.
- Start-Finish: In this dependency, there is a defined relationship between the start of one activity and the end date of a successor activity. This dependency is rarely used.

Network scheduling techniques provide managers with a powerful tool for scheduling and controlling their programs/projects. In general, they permit the graphic portrayal of project activities and relationships among the activities. This provides the basis for determining the project's critical path, predicting shortages, and identifying possible reallocation of resources to solve problems. Through the use of readily available software, network schedules are fairly easy to update and rework, thus providing managers with current program/project status information and control over activities and schedules.

7.2 Explanation

Planning the project activities helps us to work out and clearly communicate what we need to do, who needs to do it, and in what order. One of the big reasons that some projects fail is that the list of activities to be undertaken is incomplete or isn't collated into a coherent plan. By first thinking of the products that are needed, it can make this task easier.

Produce the Product Breakdown and agree this as the key milestones and phases with the Sponsor/Project Board. Agree the major tasks required with the project team. Writing each task on a Post-It note can help. This leads to what is sometimes called the Work Breakdown Structure. People with the most knowledge and/or experience should then compile the detailed activity list. i.e. break down each task into its constituent activities e.g.

- Project—produce a new course brochure
- Major Task—check the proofs
- Activity List—check spelling, check layout, check colours, etc
- Establish where any dependencies exist between activities.

Many of the project planning software packages available use the Precedence Diagramming Method. This method plots the tasks to be completed and connects them with arrows that show the dependencies.

Mandatory dependencies are inherent in the work or process e.g. when constructing a new building, building the walls is dependent on laying the foundations. Discretionary dependencies are those defined by the project manager and their team. They should be defined based on best practice or previous experience within the particular area.

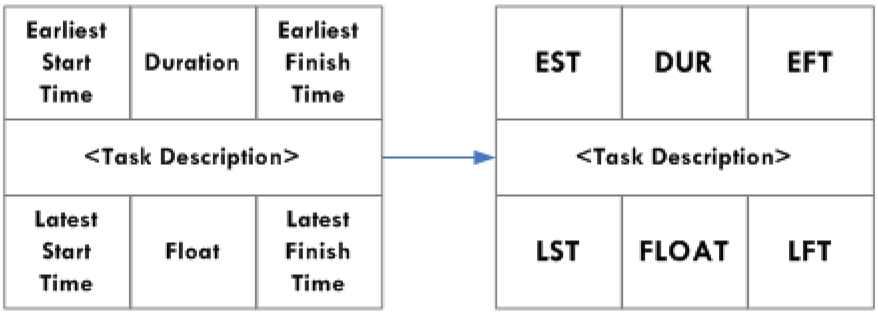
Once the dependencies are agreed they can be mapped into a Precedence Diagram (on PC, on paper, or using post-it notes).

When drawing the precedence diagram the project team needs to decide:

- Which tasks can only be completed after another task
- Which tasks can be done at the same time
- Which tasks don't depend on other tasks at all (e.g. project review meetings)

It can be useful to work backwards when compiling the Precedence Diagram and ask yourself what do we need to have done immediately before this task?

When compiling the diagram you normally represent a task as a box, and link tasks with arrows to show any precedent. There are no loops and at any stage, all preceding tasks must be complete before the following task can begin.



The Precedence Diagram

It is possible to draw these from left to right with the final task on the right, or from top to bottom as many people prefer to work this way. As long as your approach is consistent and understandable by the team, there is no reason why you cannot choose your preferred method.

Once the project activities and any precedences have been identified and agreed, you will need to produce a schedule. As well as scheduling activities you may also need to schedule people, money, materials and equipment. To schedule in detail you will have to establish the following information about each activity:

- The duration (DUR) of each activity – how long it will take to complete.
- The earliest start time (EST) – the earliest an activity can start without interfering with the completion of any preceding activity.
- The latest start time (LST) – the latest an activity can start without interfering with the start of any subsequent activity.
- The earliest finish time (EFT) – the earliest an activity can finish.
- The latest finish time (LFT) – the latest an activity can finish without interfering with the start of any subsequent activity.
- The "float" time of an activity – the time available to perform the activity less the time needed i.e. time available minus activity duration.
- The critical activities are those with zero float. i.e. for a critical activity, EST = LST .

A critical path appears on any precedence diagram (or Gantt Chart) and links tasks which have no float. You should therefore be able to trace a critical path through your project from start to finish.

- Estimate the time required to complete each project activity.
- Calculate the time available to complete each activity.
- Calculate each activity's float, i.e. (LFT – [EST + DUR]).
- Identify the critical path (zero float activities).
- Calculate the total project duration.
- Agree the resources needed and their availability with the Executive/Project Board. Adjust resources and/or schedule if necessary.
- Agree the schedule with the project team and other stakeholders.
- Prepare and publish the project schedule. Using a Gantt chart is one way.

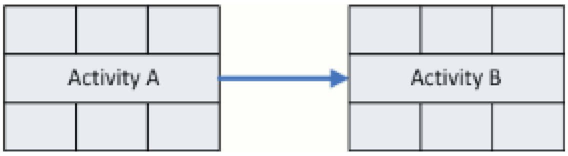
Many times the project duration is not the result of the project manager's estimates or even anyone else's calculations. It can be a deadline set by funders of the project or senior management as a wished for end date, or as a whim. It is only by doing these calculations that you can ascertain whether or not it is feasible to complete the project within the deadline.

Unlike Arrow Diagramming that uses the arrows for activities and nodes for the start and end of activities, Precedence Diagramming places the activity on the nodes and uses arrows between the nodes to show the sequence between each activity. Precedence Diagramming is also called "activity-on-the-node".

To illustrate the Precedence Diagramming method, the illustrations below show several different schedule fragments. You may want to compare notes between the fragments shown here for the Precedence Diagram, and their counterparts in the Arrow Diagramming method.

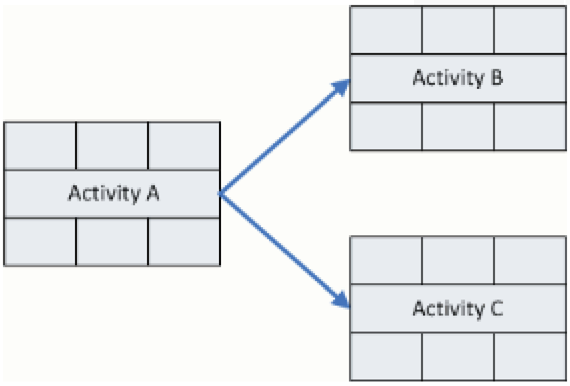
Example 1

Activity	Prior Activity
A	None
B	A



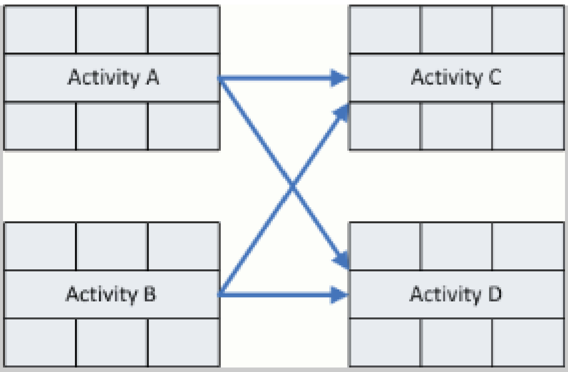
Example 2

Activity	Prior Activity
A	None
B	A
C	A



Example 3

Activity	Prior Activity
A	None
B	None
C	A, B
D	A, B



As described in the section on the Arrow Diagramming method the set of all activities and their related sequence is called a "network".

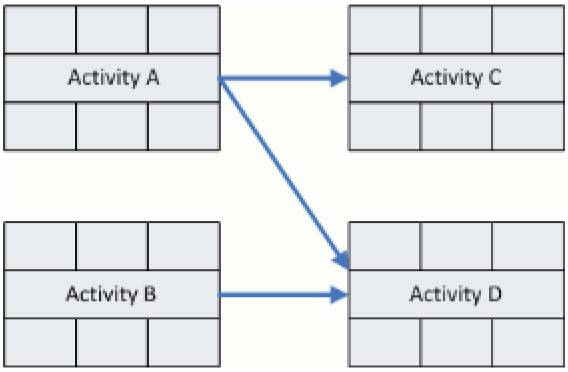
Another item previously covered also bears repeating here. The definition of a project is something with a specific beginning and end. Activities should be included in the network that start and end the project. For most construction contracts these activities related to contractual dates such as the Notice To Proceed and the calculated Contract Completion Date.

Precedence Diagramming separates the definition of activities from their sequence. The activities are of the nodes and the sequence is on the arrows. As a result, the use of dummy logic arrows, required in the Arrow Diagram, is not required in the Precedence Diagram.

Let’s look at a few schedule fragments that caused difficulty for the Arrow Diagram and see what they look like in the Precedence Diagram.

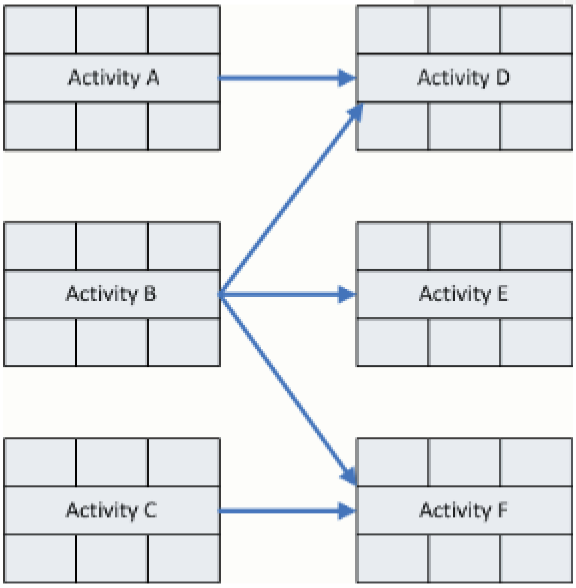
The first example shows how the Precedence Diagram represents a sequence of activities where sets of activities share some, but not all, of the prior activities. In this example, Activity C has a prior of A and Activity B has both A and B as priors.

Activity	Prior Activity
A	None
B	None
C	A
D	A, B



The following sequence of activities also demonstrates the ease with which the Precedence Method is able to represent activities that share different sets of priors. In the Arrow Diagram, the following sequence of activities requires two dummy activities.

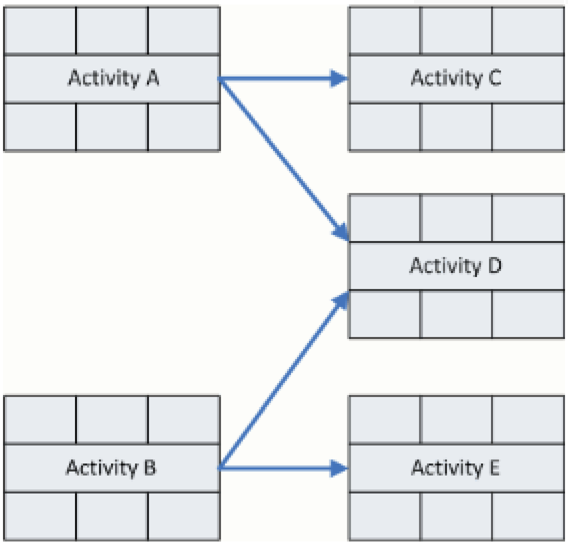
Activity	Prior Activity
A	None
B	None
C	None
D	A, B
E	B
F	B, C



This final example is provided as a reference for you to check against the same activities as shown in the Arrow Diagramming method.

Activity	Prior Activity
A	None

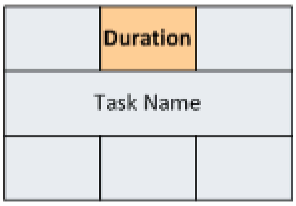
B	None
C	A
D	A, B
E	B



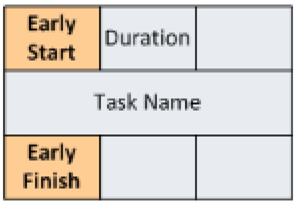
Another implication of separating activity definition from sequence, as is done by the activity-on-the-node schedule, is that the numbering dummies are not needed as they are for activity-on-the-arrow schedules.

7.2.1 Forward pass notation

The goal of the forward pass is to determine the earliest time that an event could take place. For example, what is the earliest that a project or activity might be started and finished?
To show the data on the forward pass, two additional elements are added to the precedence diagram picture. The first element is the duration of each activity. The duration of the activity should be shown in the center of an activity's node.



The second elements added to a Precedence Diagram for the forward pass are the "Early Time" boxes. The Early Time boxes are placed within the activity node. There are no standards for the placement of these Early Time boxes, therefore, a legend must be provided with a Precedence Diagram to show where these Early Time boxes are placed. Early Time boxes are typically placed in one of two locations. The first is on the left-hand side of the activity node. The second is in the top left and right corners of the activity box. The CPM tutor will use the convention shown in the diagram below.



These Early Time boxes refer to the Early Start and Early Finish of each activity. Unlike the "event times" of the arrow diagram, which are attributes of nodes, the Early Times of the Precedence Diagram are activity-specific.

Review Questions

25. What is Critical Path Method?
26. What is PERT chart?
27. How to calculate time estimation in CPM project?
28. What are the calculations involved in network analysis?

Discussion Questions

For the following data, draw the network diagram, and then crash the activities to find the time-cost trade-off points that the company should want to consider. Start with the plan that has the longest duration?

Activity	Preceding Activity	Time(weeks)		Cost	
		Normal Program	Crash Program	Normal Program	Crash Program
A	-	2	2	5	5
B	A	5	3	11	21
C	A	2	1	7	16
D	B, C	4	2	8	22
E	B	3	2	9	18
F	D, E	3	3	9	9

Application Exercises

19. What is the difference between CPM and PERT?
20. For the following data, draw the network diagram, and then crash the activities to find the time-cost trade-off points that the company should want to consider. Start with the plan that has the longest duration?

Activity	Preceding Activity	Time(weeks)		Cost ($)	
		Normal Program	Crash Program	Normal Program	Crash Program
A	-	2	1	20,000	20,700
B	-	3	1	29,000	33,000
C	A	2	1	25,000	26,100
D	B	4	3	47,000	47,750
E	C	4	2	55,000	57,000
F	C	3	2	29,000	29,500
G	D, E	5	3	79,000	80,800
H	F, G	2	1	15,000	17,900

21. Draw the network diagram for the following problem and indicate a sequence of plans that the company should want to consider in making a time-cost tradeoff. The company is not interested in reducing the project duration below 29 days. Start with the plan that has the longest duration?

Activity	Preceding Activity	Time(days)		Cost ($)	
		Regular Program	Crash Program	Regular Program	Crash Program
A	-	10	9	5,000	5,200
B	-	14	11	3,500	3,950
C	A	8	7	4,000	4,100
D	A	7	2	2,100	3,600
E	B	5	3	2,500	3,000
F	B	10	7	2,250	3,750
G	C	9	9	5,000	5,000

H	D, E	11	9	3,850	5,250
I	G, H	5	3	2,375	3,575

CHAPTER 8

Constructing diagram and computations using precedence diagramming method

Learning Objectives

- To explain about Project Planning.
- To analyse the precedence diagram method.
- To recognise the idea of forward pass.
- To explain how to use Gantt Chart.
- To identify the benefits of using critical path method.

8.1 Introduction

The precedence diagram method is an approach to project planning and scheduling that relies on a visual representation of activities and their relationships. This method can be used to create a clear, logical schedule that will flow appropriately to keep tasks on deadline. Some planners manually create a precedence diagram, while others may use software with this capability. Project planning software can have additional features, like tie-ins with forms and other materials to make the document interactive for the benefit of users.

One element in the precedence diagram method is the creation of nodes, representing activities. Each node is a box, with a notation about the kind of activity it represents. The nodes can be linked by arrows to illustrate their relationships. Some are isolated, and can be done at any time, without dependence on other activities as part of the project. These can be less important for planning, as they do not hinge upon or have the potential to hold up other events.

Other nodes can be performed at the same time and make multitasking available. These nodes provide a high degree of flexibility for schedule planning. Nodes with a high priority are those which require the completion of other tasks, or which need to be finished to allow other tasks to precede. For example, a home needs a foundation before other construction activities can start. In the precedence diagram method, the foundation would take priority in the scheduling for the site.

It may be necessary to move nodes around to better illustrate and encapsulate their relationships to each other. Software can be useful for this, as it makes it easy to move components of the planning as necessary. Working on a whiteboard or other easily configurable surface while drafting a plan with the precedence diagram method can be advised, as drawing, redrawing, erasing, and moving nodes can be time consuming and irritating.

At the finish, a designer using the precedence diagram method should have a clear representation of what needs to happen to complete a project, and when it needs to happen. This information can help with the development of a schedule, as well as a project timeline to provide information about when clients can expect completion. The method permits companies to start organizing in advance to prepare for critical events, like stages of a project that could potentially hold up the whole project; thus, for example, a construction company can order supplies ahead of time to avoid a situation where workers stand around with nothing to do because a critical component is missing.

A precedence diagram shown in fig 8.1 is a graphical method of depicting the sequence of activities in a project. It is represented as a network of arrows and nodes where the nodes represent activities and the arrows indicate dependencies between activities. The diagram also depicts the duration of each task and time lags between the starts and finishes of related tasks.

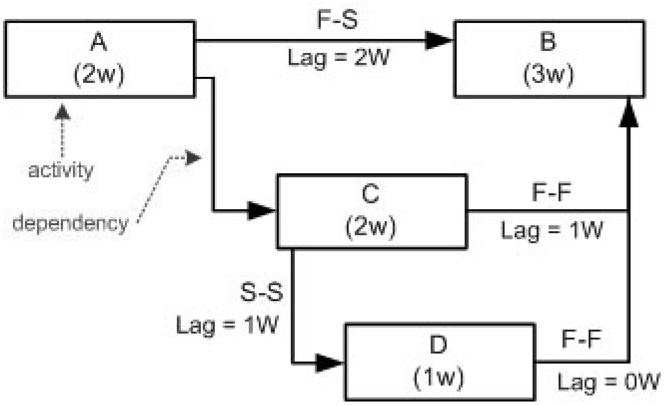


Fig 8.1 Precedence Diagram

The precedence diagram method supports the modelling of the following types of dependencies between activities:

Finish-to-start (F-S)	The predecessor activity must be completely finished before the successor activity can start. A time lag may be specified between the finish of the

predecessor activity and the start of the successor activity. Example: The start of Task B must be delayed two weeks after the finish of task A.

Start-to-start (S-S) — Two activities may start together. A time lag may be specified between the start of one activity and the start of the other. Example: Task D must start one week after the start of task C

Finish-to-finish (F-F) — Two activities must finish together. A time lag may be specified between the finish of one activity and the finish of the other. Examples:
Task C must be completed one week before the completion of task B. Task D must be completed at the same time as task B.

8.2 Example

In the example activity Preceded by Duration as shown in the table

Activity	Preceded by	Duration
A	—	4
B	A	3
C	A	2
D	C	5
E	B,D	2

8.2.1- Forward Pass (calculating Earliest Start and Earliest Finish)

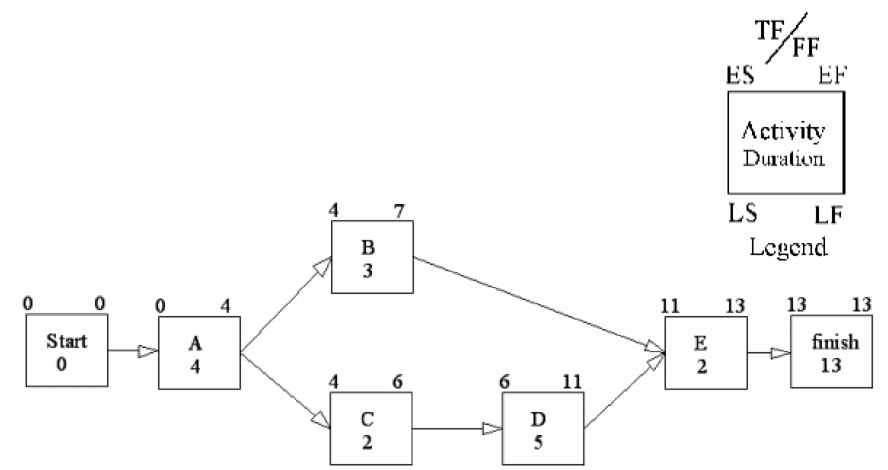


Fig 8.2

8.2.2- Backward Pass (calculating Latest Start and Latest Finish)

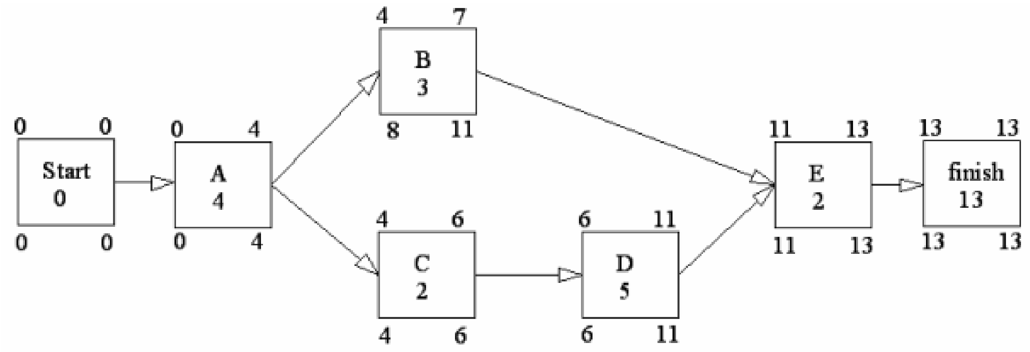


Fig 8.3

8.2.3- Float calculation (calculating Total Float and Free Float)

Activity Total Float (TF) = Activity LS –Activity ES = Activity LF –Activity EF

Free Float (FF) = min. ES of Activity's successors – Activity EF

Activity A

TF = LS- ES = 0 – 0 = 0

FFi = ESj – Efi = 4 – 4 = 0

Activity B

TF = LS- ES = 8 – 4 = 4

FFi = ESj – Efi = 11 – 7 = 4

Activity C

TF = LS- ES = 4 – 4 = 0

FFi = ESj – Efi = 6 – 6 = 0

Similarly you can calculate floats for the other activities.

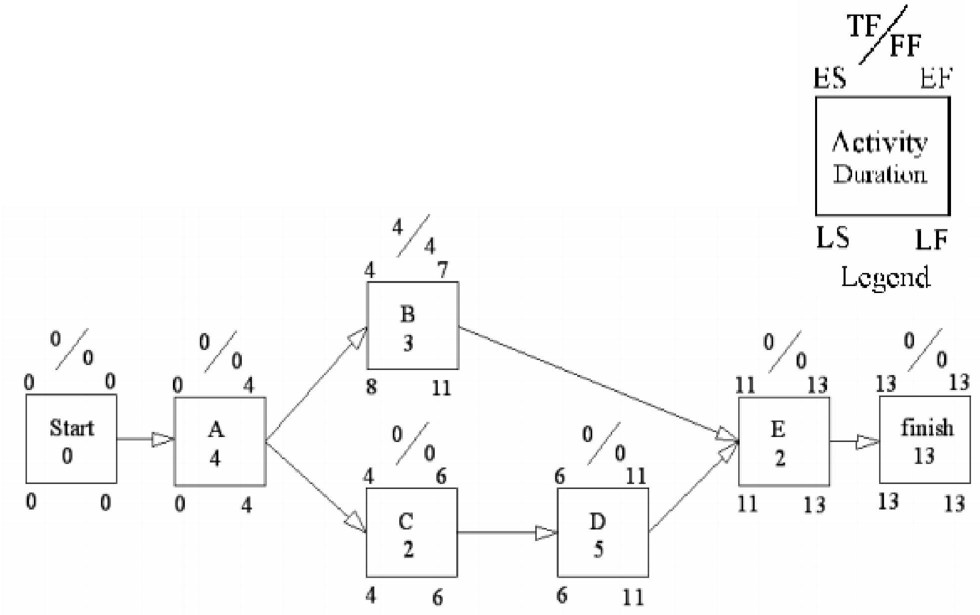


Fig 8.4

8.3 Sample Precedence Diagramming Method (PDM) Network Diagram

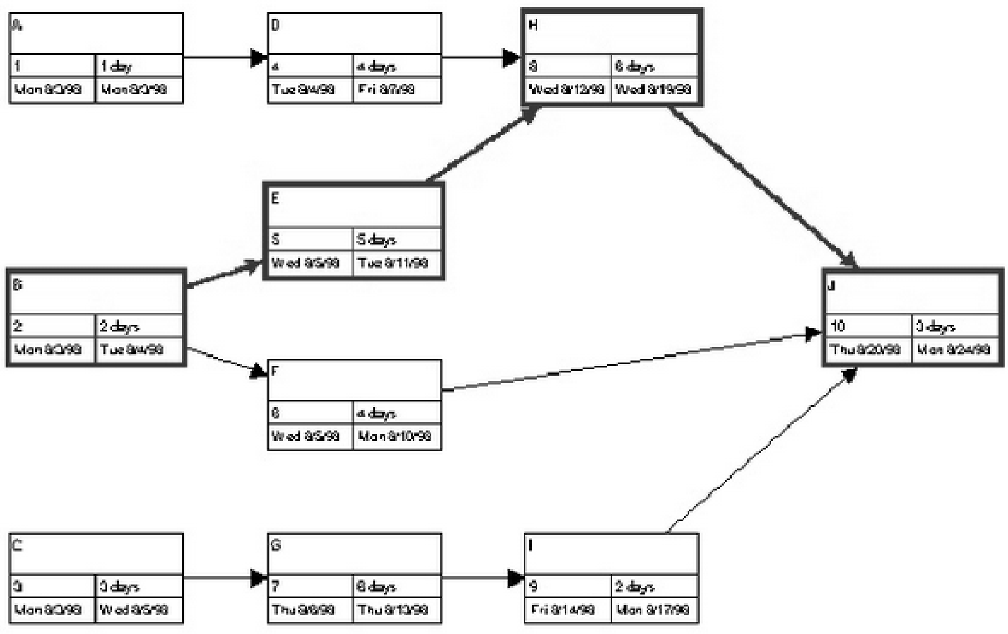


Fig 8.5

8.3.1 Activity Duration Estimating

- After defining activities and determining their sequence, the next step in time management is duration estimating
- Duration includes the actual amount of time worked on an activity plus elapsed time

- People doing the work should help create estimates, and an expert should review them

8.3.2 Forward and Backward Pass

To place the network on a timetable, you must make time and duration computations for the entire project. These computations establish the critical path and provide the start and finish dates for each activity. Each activity in the network can be associated with four time values:

0 Early start (ES)- Earliest time an activity may be started;

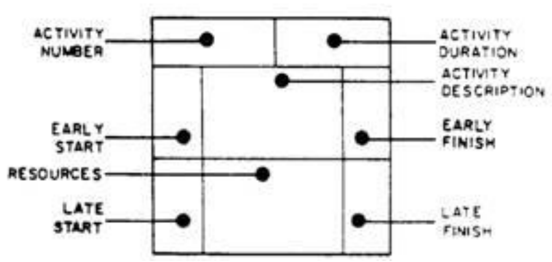


Figure 8.6.-Information for a precedence activity.

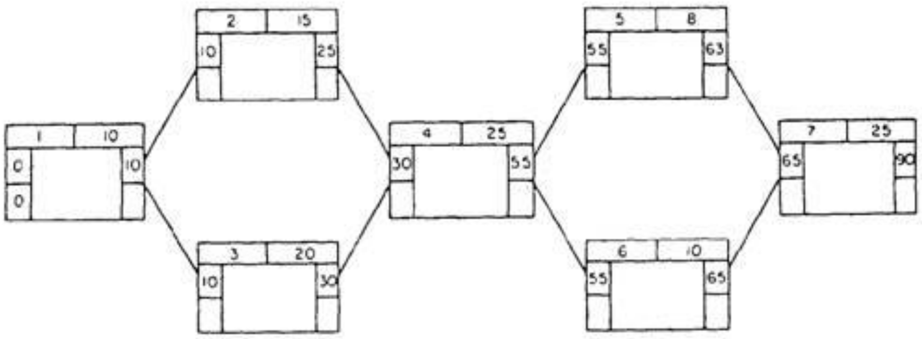


Figure 8.7.-Example of forward-pass calculations.

- Early finish (EF)- Earliest time an activity may be finished;
- Late start (LS)- Latest time an activity may be started and still remain on schedule;
- Late finish (LF)- Latest time an activity may be finished and still remain on schedule.

The main objective of forward-pass computations is to determine the duration of the network. The forward pass establishes the early start and finish of each activity and determines the longest path through the network.

The common procedure for calculating the project duration is to add activity durations successively, as shown in figure 8.7, along chains of activities until a merge is found. At the merge, the largest sum entering the activity is taken at the start of succeeding activities. The addition continues to the next point of merger, and the step is repeated. The formula for forward-pass calculations is as follows:

ES = EF of preceding activity EF = ES + activity duration

The backward-pass computations provide the latest possible start and finish times that may take place without altering the network relationships. These values are obtained by starting the calculations at the last activity in the network and working backward, subtracting the succeeding duration of an activity from the early finish of the activity being calculated. When a "burst" of activities emanating from the same activity is encountered, each path is calculated. The smallest or multiple values is recorded as the late finish.

The backward pass is the opposite of the forward pass. During the forward pass, the early start is added to the activity duration to become the early finish of that activity. During the backward pass, the activity duration is subtracted from the late finish to provide the late start time of that activity. This late start time then becomes the late finish of the next activity within the backward flow of the diagram.

LS = LF - activity duration

Figure 8.8 shows a network with forward- and backward-pass calculations entered.

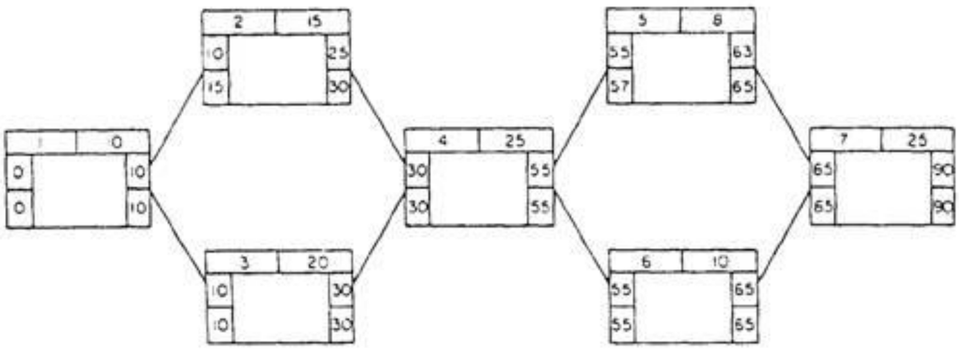
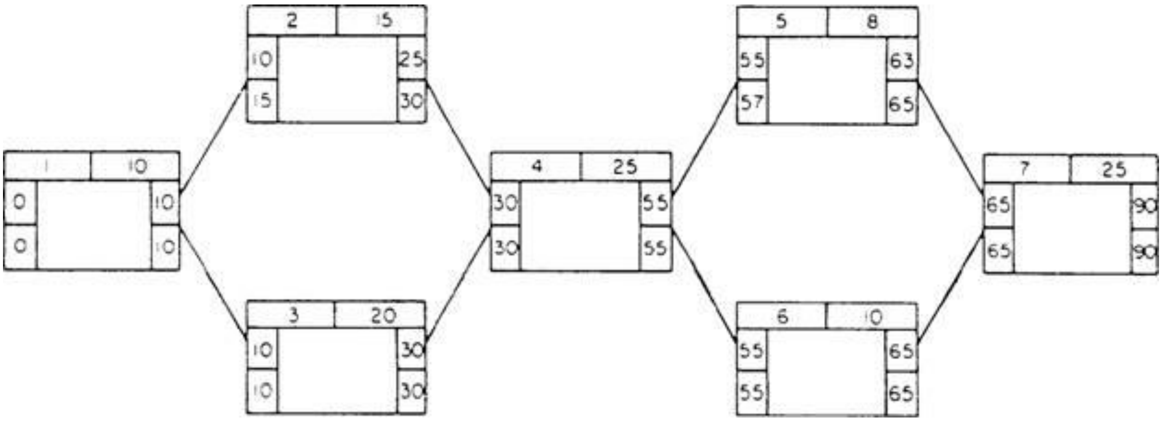


Figure 8.8.-Example of forward- and backward-pass calculations.



ACTIVITY	DUR	ES	EF	LS	LF	FF	TF	
1	10	0	10	0	10	0	0	CRITICAL
2	15	10	25	15	30	5	5	
3	20	10	30	10	30	0	0	CRITICAL
4	25	30	55	30	55	0	0	CRITICAL
5	8	55	63	57	65	2	2	
6	10	55	65	55	65	0	0	CRITICAL
7	25	65	90	65	90	0	0	CRITICAL

Figure 8.9.-PDM network with total and free float calculations.

The free and total floats times are the amount of scheduled leeway allowed for a network activity, and are referred to as float or slack. For each activity, it is possible to calculate two float values from the results of the forward and backward passes.

TOTAL FLOAT.-

The accumulative time span in which the completion of all activities may occur and not delay the termination date of the project is the total float. If the amount of total float is exceeded for any activity, the project end date extends to equal the exceeded amount of the total float.

Calculating the total float consists of subtracting the earliest finish (EF) date from the latest finish (LF) date, that is:

Total float = LF- EF

FREE FLOAT.-

The time span in which the completion of an activity may occur and not delay the finish of the projector the start of a successor activity is the free float. If this value is exceeded, it may not affect the project end date but will affect the start of succeeding, dependent activities.

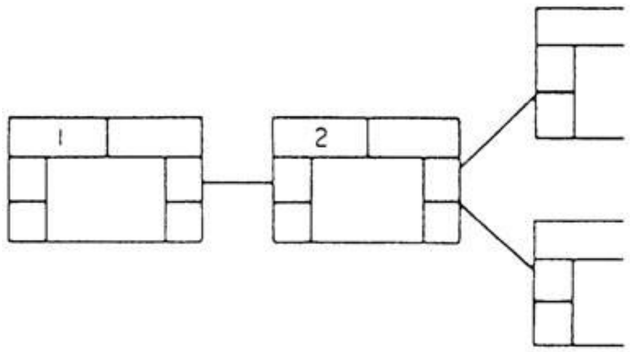


Figure 8.10.-Independent activity.

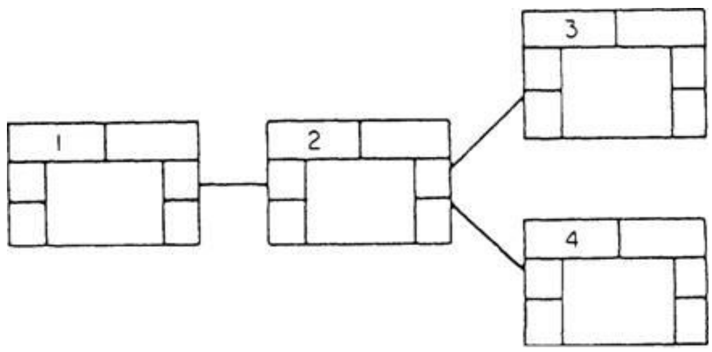


Figure 8.11-Dependent activity.

Calculating the free float consists of subtracting the earliest start (ES) date from the latest start (LS) date, or:

Free float = LS - ES

Figure 8.11 is an example of an activity-on-node precedence diagramming method (PDM) network with total and free float calculations completed.

INDEPENDENT ACTIVITY

An independent activity is an activity that is not dependent upon another activity to start. Activity 1, diagramed in figure 8.12, is an example of an independent activity.

DEPENDENT ACTIVITY

A dependent activity is an activity that is dependent upon one or more preceding activities being completed before it can start. The relationship in figure that states that the start of Activity 2 is dependent upon the finish of Activity 1.

Frequently, an activity cannot start until two or more activities have been completed. This appears in the diagram as a merge or junction. In figure, Activities 3 and 4 must be completed before the start of Activity 5.

8.3.3 Schedule Development

- Uses results of the other time management processes to determine the start and end date of project activities
- Ultimate goal is to create a realistic project schedule that provides a basis for monitoring project progress
- Important tools and techniques include Gantt charts, PERT analysis, and critical path analysis

8.4 Gantt Charts

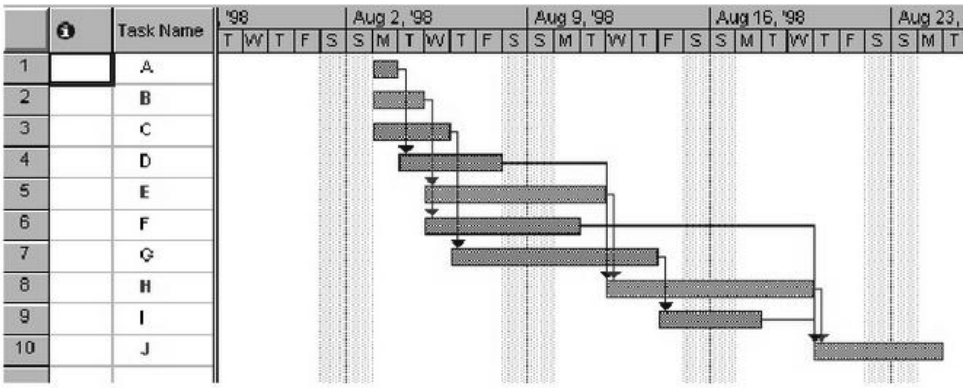
A Gantt Chart, or Project Chart, is used extensively by project managers and other people involved in scheduling. While it is similar to a timeline in that it deals with time and events, the format and purpose of a Gantt Chart is very different. The Gantt Chart is a table with one task for each row and time in the columns. The unit of time chosen depends on the length and detail of the product, but some common units are weeks, quarters, months, and years. Usually there is a column at the left listing the tasks, then columns for start date, end date, and duration, followed by the columns for time. Each task has a bar extending across the time columns, representing the duration of the task. Milestones and critical path lines may also be used to add further detail to the chart. Milestones are important checkpoints or deadlines represented by small symbols in the time columns. Critical path lines connect task bars to indicate a dependence of one task upon another's completion or commencement.

Gantt charts provide a standard format for displaying project schedule information by listing project activities and their corresponding start and finish dates in a calendar format. A Gantt chart is a chart that describes a project schedule. The horizontal axis of that chart is time. The vertical axis is occupied with different tasks.

The chart consists of bars, with each bar representing a task. The location of the bars on the horizontal axis is coordinated with the task timing. The bar starts at the time the task starts, and it ends at the time the task ends. Since we locate different tasks in a different vertical position but keep the same horizontal axis for all the tasks, we can see the relative timing of the tasks, and we can also define what tasks should be done before other tasks.

Symbols include:

- A black diamond: milestones or significant events on a project with zero duration
- Thick black bars: summary tasks
- Lighter horizontal bars: tasks
- Arrows: dependencies between tasks



8.4.1 Best Practices

A Gantt chart is a powerful and preferred visual reporting device used for conveying a project's schedule. A typical Gantt chart graphically displays the work breakdown, total duration needed to complete tasks, as well as %completion. The Gantt chart itself will not display level of effort, and is not an effective planning tool on its own. Today, Gantt Charts may be integrated with other spreadsheet-type reporting devices that convey additional information related to project planning. Furthermore, Gantt Charts are often enhanced with functionality that includes the identification of relationships between tasks, and the ability to dynamically change task attributes.

- Identify the purpose. First choose the process or project to be detailed on the Gantt chart.
- Create a timeline. Decide when the entire process will begin and when it must be completed. Now decide how to divide the increments of time for the duration of the project. Create a table with a column for each of the dates and increments you have decided to use and place them inside in chronological order.

- List tasks. Determine how many tasks there are in the process. Make a row for each and place the name of each task in its cell on the left side of the chart.
- Create progress bars. Now create a progress bar for each of the tasks. A progress bar is simply a horizontal bar that should be in line with the task name it represents and should begin beneath its start date and end beneath its end date (thus indicating the time at which the task will be in progress). Do this for each task. Some may overlap, meaning that they are occurring at the same time.
- Add critical paths. Use lines to connect a task to another if they are dependent on each other. If the completion of one task will trigger the beginning of another, draw a line from the end of the first to the beginning of the second with an arrow pointing to the second to show that it can begin after the first is finished.
- Add milestone markers. Choose a symbol to represent milestones, that is, major events that either have a large part in the process or must be completed before progress can continue. Place them on the chart beneath the date or time when they occur.
- Additional labeling. If there is anything else you wish to label you may do it now, whether you need to label who is in charge of each activity, or note the cost of each task. Fill in any information you find critical.
- Do not deviate. Use the Gantt Chart to maintain the schedule, and update it occasionally during the project.

8.4.2 Gantt charts to improve time management

This chart enables us to better understand the complexity and demands of our tasks. Let’s assume we need to prepare a report and present it to our boss. In our to-do list, we might find a simple definition of a task: “present project x to the boss”. Since we have two weeks until the deadline, we might think that this task belongs to Quadrant 2 (from the Priority Matrix above) because it is an important but not urgent task. Using the Gantt chart will tell us that there are some subtasks hidden under that task, and some of these subtasks are urgent and important.

Let’s start with a work breakdown structure (WBS). WBS is a tree structure that defines the different parts of what we are trying to achieve. It can be a product, a contact, a project, or even a task.

The task called “present project x to the boss” consists of a few subtasks: prepare general structure of the report (one day), collect data (two days), write a draft (one day), get feedback from colleagues (three days), update the draft to a final report (one day), send a document to the boss, set a time for presentation and finally, the presentation. Looking at the Gantt chart, we can see that we need at least eight work days before we can send a document to our boss. Since our deadline is in two weeks, we'd better start on step one as soon as possible because, if we don’t, in two days we will be in the urgent and important zone. We will end up working in a stress mode that will yield poor quality of life and a low level report.

8.5 Critical Path Method (CPM)

The critical path method (CPM) is a way of breaking complex projects into lists of activities, and determining which are critical to keeping a project on schedule. Developed in the 1950s, this method was used for complicated government and private industry programs that were running behind schedule for undetermined reasons. A critical path as defined by the method as a series of events, called activities, which must be completed in the correct order and on time.

Construction or other projects can contain thousands of separate activities that occur before a job is done. Drawings must be made, a construction site must be prepared, and many other events must occur even before construction begins. During construction, foundations and building framework must be completed before the interior work can start. Some activities can occur at the same time, but some must wait until previous activities are completed. All of these assumptions are used in the critical path method.

Calculations of critical path timing can be done manually, but can be quite difficult due to the many interactions of activities. An easier way to create a CPM is using a computer spreadsheet program. Since the late 20th century, commercial software has existed that will create critical path method results from manually entered activity information. CPM is a project network analysis technique used to predict total project duration. A critical path for a project is the series of activities that determines the earliest time
by which the project can be completed. The critical path is the longest path through the network diagram and has the least amount of slack or float.

Developing a CPM report requires the use of assumptions, because a project typically has not started when the report is created. A project manager or programmer begins the process by listing all known activities from start to finish. Activities are given constraints if any exist, which may be an earliest calendar date an activity can start, or the latest date one can finish. These date constraints keep activities from moving around in the model, and constrained activities are often part of the critical path.

Along with any fixed calendar constraints, all activities must be given an estimated duration, or the days or weeks needed to finish. An activity may have a long duration, such as putting up building steel or finishing the interior that may cause the critical path to be affected. Software programs available for critical path method modeling will show when an activity has extended past an estimated time. Activity durations can also affect the critical path if they take longer than an estimated project time allows. These results are summarized in the software report when all data have been inserted.

Another function of critical path method software is determining how people are used. Each activity can have a resource, a person or group, assigned to it. An activity normally includes the resource name and how much of their time as a percentage is needed for the activity. Reports can show when a resource is needed more than they are available; for example, employees that are needed for 150% of their allotted time. These constraints allow project managers to shift resources as needed to prevent under- or over-use of personnel during a project.

Complex projects can have cost estimates included in the CPM report. Activities can be listed with an estimated cost to complete and any additional cost if the activity is delayed or extends past the due date. Changes in the critical path resulting in delays or project extensions will have a visible effect on total project cost.

Commercial CPM software is often useful because it can easily show changes in the critical path for real-time activity data. When an activity changes by date or duration, a project manager can input changes into the project schedule and immediately see effects on total project and critical path schedules, resources, and costs. A critical path method will provide the most accurate results by regularly inputting data for a project as it continues, and changing activity dates and durations to actual dates and completion times.

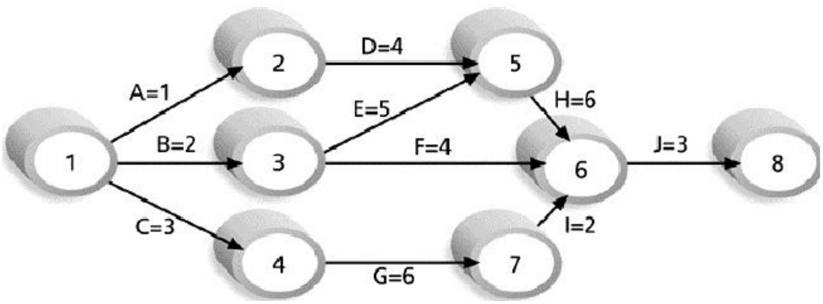
8.5.1 Finding the Critical Path

• First develop an accurate project network diagram

• Add the durations for all activities on each path through the project network diagram

• The longest path is the critical path

8.5.2 Determining the Critical Path



Path 1:	A-D-H-J	Length = 1+4+6+3 = 14 days
Path 2:	**B-E-H-J**	**Length = 2+5+6+3 = 16 days**
Path 3:	B-F-J	Length = 2+4+3 = 9 days
Path 4:	C-G-I-J	Length = 3+6+2+3 = 14 days

Since the critical path is the longest path through the network diagram, Path 2, B-E-H-J, is the critical path for Project X.

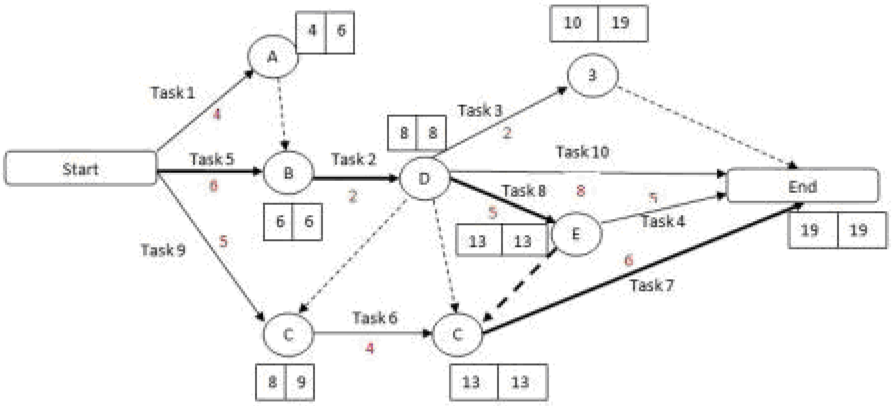
Critical path is the sequential activities from start to the end of a project. Although many projects have only one critical path, some projects may have more than one critical path depending on the flow logic used in the project.

If there is a delay in any of the activities under the critical path, there will be a delay of the project deliverables. Most of the times, if such delay is occurred, project acceleration or re-sequencing is done in order to achieve the deadlines.

Critical path method is based on mathematical calculations and it is used for scheduling project activities. This method was first introduced in 1950s as a joint venture between Remington Rand Corporation and DuPont Corporation.

The initial critical path method was used for managing plant maintenance projects. Although the original method was developed for construction work, this method can be used for any project where there are interdependent activities.

In the critical path method, the critical activities of a program or a project are identified. These are the activities that have a direct impact on the completion date of the project.



8.5.3 Key Steps in Critical Path Method

Let's have a look at how critical path method is used in practice. The process of using critical path method in project planning phase has six steps.

Step 1: Activity specification

You can use the Work Breakdown Structure (WBS) to identify the activities involved in the project. This is the main input for the critical path method. In activity specification, only the higher-level activities are selected for critical path method. When detailed activities are used, the critical path method may become too complex to manage and maintain.

Step 2: Activity sequence establishment

In this step, the correct activity sequence is established. For that, you need to ask three questions for each task of your list.

- Which tasks should take place before this task happens.
- Which tasks should be completed at the same time as this task.
- Which tasks should happen immediately after this task.

Step 3: Network diagram

Once the activity sequence is correctly identified, the network diagram can be drawn as shown in figure. Although the early diagrams were drawn on paper, there is a number of computer software, such as Primavera, for this purpose nowadays.

Step 4: Estimates for each activity

This could be a direct input from the WBS based estimation sheet. Most of the companies use 3-point estimation method or COCOMO based (function points based) estimation methods for tasks estimation. You can use such estimation information for this step of the process.

Step 5: Identification of the critical path

For this, you need to determine four parameters of each activity of the network.

- Earliest start time (ES) - The earliest time an activity can start once the previous dependent activities are over.
- Earliest finish time (EF) - ES + activity duration.
- Latest finish time (LF) - The latest time an activity can finish without delaying the project.
- Latest start time (LS) - LF - activity duration.

The float time for an activity is the time between the earliest (ES) and the latest (LS) start time or between the earliest (EF) and latest (LF) finish times. During the float time, an activity can be delayed without delaying the project finish date.

The critical path is the longest path of the network diagram. The activities in the critical path have an effect on the deadline of the project. If an activity of this path is delayed, the project will be delayed. In case if the project management needs to accelerate the project, the times for critical path activities should be reduced.

Step 6: Critical path diagram to show project progresses

Critical path diagram is a live artifact. Therefore, this diagram should be updated with actual values once the task is completed. This gives more realistic figure for the deadline and the project management can know whether they are on track regarding the deliverables.

8.5.4 Advantages of Critical Path Method

Following are advantages of critical path methods.

- Offers a visual representation of the project activities.
- Presents the time to complete the tasks and the overall project.
- Tracking of critical activities.

8.6 Program Evaluation and Review Technique (PERT)

8.6.1 Introduction

PERT is a network analysis technique used to estimate project duration when there is a high degree of uncertainty about the individual activity duration estimates. PERT uses probabilistic time estimates based on using optimistic, most likely, and pessimistic estimates of activity durations

The Program Evaluation and Review Technique (PERT) is a widely used method for planning and coordinating large-scale projects. As Harold Kerzner explained in his book Project Management, "PERT is basically a management planning and control tool. It can be considered as a road map for a particular program or project in which all of the major elements (events) have been completely identified, together with their corresponding interrelations'. PERT charts are often constructed from back to front because, for many projects, the end date is fixed and the contractor has front-end flexibility." A basic element of PERT-style planning is to identify critical activities on which others depend. The technique is often referred to as PERT/CPM, the CPM standing for "critical path method."

PERT was developed during the 1950s through the efforts of the U.S. Navy and some of its contractors working on the Polaris missile project. Concerned about the growing nuclear arsenal of the Soviet Union, the U.S. government wanted to complete the Polaris project as quickly as possible. The Navy used PERT to coordinate the efforts of some 3,000 contractors involved with the project. Experts credited PERT with shortening the project duration by two years. Since then, all government contractors have been required to use PERT or a similar project analysis technique for all major government contracts.

8.6.2 Network Diagrams

The chief feature of PERT analysis is a network diagram that provides a visual depiction of the major project activities and the sequence in which they must be completed. Activities are defined as distinct steps toward completion of the project that consume either time or resources. The network diagram consists of arrows and nodes and can be organized using one of two different conventions. The arrows represent activities in the activity-on-arrow convention, while the nodes represent activities in the activity-on-node convention. For each activity, managers provide an estimate of the time required to complete it.

The sequence of activities leading from the starting point of the diagram to the finishing point of the diagram is called a path. The amount of time required to complete the work involved in any path can be figured by adding up the estimated times of all activities along that path. The path with the longest total time is then called the "critical path," hence the term CPM. The critical path is the most important part of the diagram for managers: it determines the completion date of the project. Delays in completing activities along the critical path necessitate an extension of the final deadline for the project. If a manager hopes to shorten the time required to complete the project, he or she must focus on finding ways to reduce the time involved in activities along the critical path.

The time estimates managers provide for the various activities comprising a project involve different degrees of certainty. When time estimates can be made with a high degree of certainty, they are called deterministic estimates. When they are subject to variation, they are called probabilistic estimates. In using the probabilistic approach, managers provide three estimates for each activity: an optimistic or best case estimate; a pessimistic or worst case estimate; and the most likely estimate. Statistical methods can be used to describe the extent of variability in these estimates, and thus the degree of uncertainty in the time provided for each activity. Computing the standard deviation of each path provides a probabilistic estimate of the time required to complete the overall project.

8.6.3 PERT Analysis

Managers can obtain a great deal of information by analyzing network diagrams of projects. For example, network diagrams show the sequence of activities involved in a project. From this sequence, managers can determine which activities must take place before others can begin, and which can occur independently of one another. Managers can also gain valuable insight by examining paths other than the critical path. Since these paths require less time to complete, they can often accommodate slippage without affecting the project completion time. The difference between the length of a given path and the length of the critical path is known as slack. Knowing where slack is located helps managers to allocate scarce resources and direct their efforts to control activities.

For complex problems involving hundreds of activities, computers are used to create and analyze the project networks. The project information input into the computer includes the earliest start time for each activity, earliest finish time for each activity, latest start time for each activity, and latest finish time for each activity without delaying the project completion. From these values, a computer algorithm can determine the expected project duration and the activities located on the critical path. Managers can use this information to determine where project time can be shortened by injecting additional resources, like workers or equipment. Needless to say, the solution of the algorithm is easy for the computer, but the resulting information will only be as good as the estimates originally made. Thus PERT depends on good estimates and sometimes inspired guesses.

PERT offers a number of advantages to managers. For example, it forces them to organize and quantify project information and provides them with a graphic display of the project. It also helps them to identify which activities are critical to the project completion time and should be watched closely, and which activities involve slack time and can be delayed without affecting the project completion time. The chief disadvantages of PERT lie in the nature of reality. Complex systems and plans, with many suppliers and channels of supply involved, sometimes make it difficult to predict precisely what will happen. The technique works best in well-understood engineering projects where sufficient experience exists to predict tasks accurately in advance.

Review Questions

29. Why is the importance of precedence diagram method?
30. Explain PDM network with total and free float calculations?

31. What are the benefits of using Gantt Charts?
32. What is Critical Path Method?

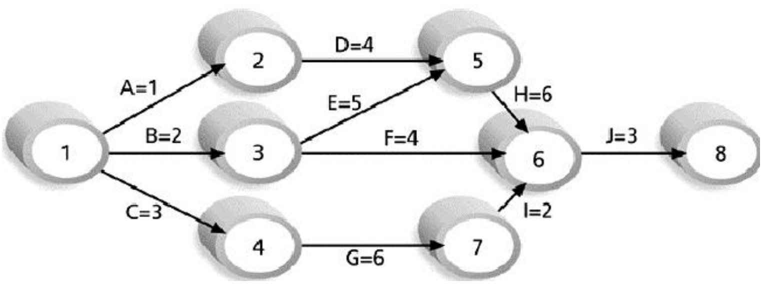
Discussion Questions

Draw PDM and calculate activities times and floats. Determine the critical path.

Activity	Preceded by	Duration
A	—	8
B	—	4
C	A,B	3
D	A,B	8
E	A,B	5
F	C,D,E	5

Application Exercises

22. Estimate the main advantage of PERT Analysis?
23. What does Program Evaluation and Review Technique (PERT) mean?
24. Find the Critical Path in the figure shown.



CHAPTER 9 – PERT/CPM simulation

Learning Objectives

- To explain about PERT simulation.
- To analyse CPM simulation.
- To recognise the modification of CPM.
- To explain Three-Stage ABC Sim Algorithm.
- To identify simplification of PERT procedures.

9.1 Introduction

Formal stochastic simulation study has been recognized as a remedy for the shortcomings inherent to classic critical path method, project evaluation and review technique analysis. An accurate and efficient method of identifying critical activities is essential for conducting PERT simulation. This discusses the derivation of a PERT simulation models which in corporate the discrete event modeling approach and a simplified critical activity identification method. This has been done in an attempt to overcome the limitations and enhance the computing efficiency of classic CPM/PERT analysis. A case study was conducted to validate the developed model and compare it to classic CPM/PERT analysis. The developed model showed marked enhancement in analyzing the risk of project schedule over run and determination of activity criticality. In addition, the beta distribution and its subjective fitting methods are discussed to complement the PERT simulation model. This new solution to CPM network analysis can provide project management with a convenient tool to asses alternative scenarios based on computer simulation and risk analysis.

Planning and analyzing the operations comprising a large scale engineering project generally require accurate estimates of selected numerical characteristics of the input processes for those operations. Whether the project management system is based on a network model velocity diagrams, line of balance diagrams or simulation models, the validity of the systems performance measures depends directly on the quality of the estimates of the input characteristics. In the planning phase of an engineering project a first cut simulation model of the project typically involves uniform or triangular distributions for activity times to reflect the moderler`s uncertainly about the duration those activities as well as inherent variability in the time required to perform repetitions of those activities. In a wide diversity of construction simulation studies, it is often necessary to represent a particular sequence of simulation inputs as independent random variables taken from a common underlying probability distribution and fixed the main objective of simulation input modeling is to approximate this distribution accurately and with a minimum of computational effort. A key element in making computer simulation accessible to construction practitioners is the automation of the complex statistical and numerical techniques required to achieve the desired accuracy within a simulation experiment. The classic critical path method (CPM) has been widely used for network analysis and project planning in industry and in academe ever since its invention in the 1950s.Project evaluation and eview technique (PERT) was originally oriented to the time elements of a project and used probabilistic time estimates to aid in determining the probability that a project could be completed by a given data. Both techniques identify a project critical path, activities that cannot be delayed and slack activities that can be delayed without lengthening the project completion time. Deterministic CPM is easy to use for the purpose of project control. However, lack of flexibility and uncertainly considerations limit its effectiveness.

Most industry professionals view such as analytical method as potentially hemming them into a fixed definition or performance. This “Straight jacket” based on theoretical assumptions such as the estimated normal activity duration and project completion time is not attractive to practitioners who are used to incorporating personal experience and the ever-changing actual conditions into their decision making. This reflects the early reaction to CPM scheduling. Most professionals were against its use as CPM was viewed as enforcing arbitrary or unattainable goals. PERT, which can be thought of as an improvement to CPM that incorporates uncertainly and risk analysis, still proves baffling to practitioners because of its underlying theoretical assumptions? Based on the central limit theorem of statistics, the classic CPM/PERT analysis takes into account the uncertainly of activity duration or costs to analyze the overrun risk of the project schedule or cost. However, the PERT calculated mean project time is always an underestimate of the true project mean.

This bias in the mean estimate is called the “merge event bias”. Abuja give a thorough analysis and theoretical explanation of the PERT drawbacks and argue that the solution to the PERT`s inherent problems is to conduct the network analysis through a formal stochastic simulation study. In such a study, the true properties of the activity duration distributions (including all of its statistical descriptors such as mean and variance) are used, and the concept of activity criticality rather than path criticality is used to overcome most of the PERT shortfalls. To perform PERT analysis through simulation, two relevant issues need to be studied carefully. They are:

(1) how to determine the critical path;

(2) how to model activity duration statistically.

9.2. Description of CPM/PERT

9.2.1 Description of CPM

The CPM analysis is activity oriented as shown:

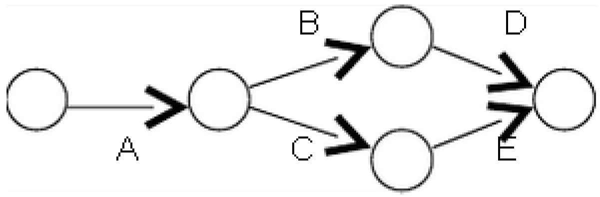


Fig: 9.1

No allowance is made for the uncertainties in the duration of time involved. In CPM, times are related to costs. The activities are represented by arrows that are logically connected in order of the sequence of operations. The beginning and the end of each arrow is attached to nodes that symbolize the events and are numbered in some logical order. These exists only one time estimate for each activity. After finalising the network, the next step is to estimate the time required for the completion of each activity of the network. Probabilistic approach estimates optimistic time, likely time. Pessimistic time as in PERT is a deterministic approach as the time required for activity. In probabilistic approach, the time estimates of the activity has greater range and hence greater uncertainly. In deterministic approach, the range of variation is very narrow, and we approach towards a more deterministic model.

The earliest event time of event j can be measured by

TE^{j} = maximum of ($T^{i}E + tE^{ij}$)

Where

$T^{j}E$ is the earliest time for event j

TE^{i} is the earliest time for event i

t^{ij} is the duration for job i – j.

TL is latest allowable occurrence time which is the latest time by which an event must be completed to keep the project on schedule.

TL^i = minimum of (TL^j – t^{ij})

where
TL^i =latest allowable occurrence time of event i.
TL^j = latest allowable occurrence time of event j
t^{ij} = duration for job i – j.

From this, the slack is measured and then “critical path” connects those events for which the earliest and latest times are the same i.e. slack time is zero is draw.

9.2.2 Description of PERT

PERT was originated by U.S. Navy in 1958 as a tool for scheduling the development of a complete weapons system. The technique considers a project to be an acyclic network of events and activities. The duration of a project is determined by a system flow plan in which the duration of each task has an expected value and a variance. The critical path includes a sequence of activities that cannot be delayed without jeopardy to the entire project. PERT can be used to estimate the probability of completing either a project or individual activities by any specified time. It is also possible to determine the time duration corresponding to a given probability. The first step in applying PERT is to diagram the project network, where each are represents an activity and each node symbolizes an event, as in Fig. 9.1. Alternatively, each node can Symbolize an activity.

The second step is to designate three time estimates for each task:

- optimistic (a)
- pessimistic (b)
- most likely (m)

Small probabilities are associated -with a and b. In the original PERT, a is the minimum duration of an activity; the probability of a shorter duration is zero. Similarly, b is the maximum duration; the probability that the duration will be less than or equal to b is 100%, No assumption is made about the position of m relative to a and b. In statistical terms, a and b are the extreme ends of a hypothetical distribution of duration times. The mode of the distribution is m. To accommodate flexibility in the positions of these parameters, the beta distribution is used, as shown in Fig. 9.2. The beta distribution is useful for describing empirical data and can be either symmetric or skew. The third step is to compute the expected value and variance of the duration of each activity in the project network. The mean of a beta distribution is a cubic equation. The PERT equation for the mean [(l)] is a linear approximation to this

$$Te = (a + 4m + b)/6 \qquad (1)$$

Where
Te = expected duration of an activity.

As shown the equation (1) is exact when m is equal to the mode, which occurs when a and b are symmetrical about m. In unimodel probability distributions, the standard deviation of the distribution is equal to approximately one-sixth of the range. With 100% of the possible durations bound by a and b, the estimated variance of the duration is as follows: σ2100 (Te) = $[(b - a)/6]^2$ (2)

Where
σ^2= variance of the activity duration.

Moder and Rodgers argues that the exact endpoints of the range of the duration are impossible to define. Their alternative is to define a and b as the 5% and 95% thresholds of the range, respectively. Then, the variance is as follows:

$$\sigma_2^{90}(Te) = [(b - a)/3.2]^2 \qquad (3)$$

Perry and Greig, alternatively, use 3.25 in the denominator of equation (3), rather than 3.2. They argue that subjective probability distributions tend to be rounded rather than peaked. The denominator of 3.25 is more appropriate for platykurtic, bell-shaped curves. Moder and Rodgers' result seems to be cited more frequently in the literature, though. The fourth step is to order the activities sequentially, from the beginning to the end of the project, in a tabular format, listing the optimistic, pessimistic, most likely, and expected durations and the variances. Fifth, forward and backward passes through the network are performed to identify the critical path, just as in the widely used critical path method. The central limit theorem is then applied as follows: The distribution of the sum of the expected durations of the activities along the critical path is approximately normal, particularly as the number of activities increases. The expected duration of each sum is equal to the sum of the expected durations. Similarly, the variance of each sum is the sum of the variances. These applications of the central limit theorem enable the computation of project duration probabilities using the deviations from a zero mean of the standard normal variable (Z). These probabilities can be critical in making financial decisions about the viability of a project.

9.3 MODIFICATION IN CPM/PERT

9.3.1 Modification of CPM :

CPM is widely used for scheduling and planning in construction. Although it lacks the capability to address the dynamic and random nature of construction operations, the activity – based approach for modeling construction projects has been widely accepted in the industry. A new simulation method, namely an activity-based construction modeling and simulation method, is to be explored. ABC consists of modeling and simulation functions addressing the specific needs of constructions.

9.3.1.1 Fundamentals of Construction Operation:

An activity consumes both time & resources to be constructed. Construction progress is achieved by constructing activities in the real time sequence. Therefore, activity and resource constitute the two fundamental components of a construction operation. Activities are the basic elements that ABC-sim directly deals with during a simulation experiment. The dynamic behavior of a construction process is portrayed by detailing the changes of the state of activities.

The ABC-sim algorithm involves three stages:

(1) select activity for construction

(2) Advance simulation

(3) release simulation entitles.

The process as

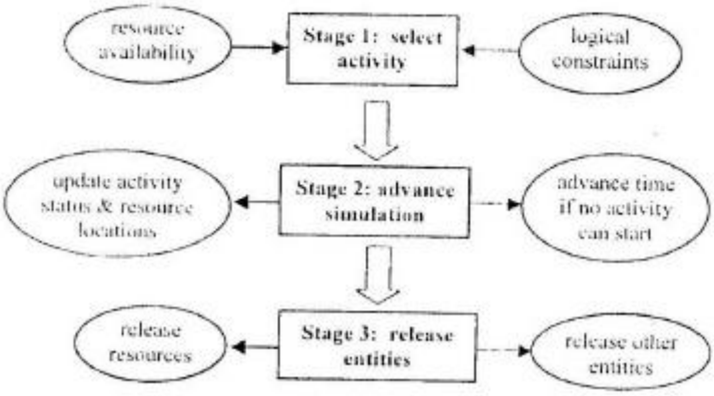


Fig. 9.2.Three-Stage ABC- Sim Algorithm

Stage 1: Select activity.

All activities are equally checked against their logical and resource requirements. If an activity meets all conditions for start, it is selected into the feasibility activity set, and the early start time of an activity is calculated as follows:

$t_1(i)$ = max.{resource_available_timej},jϵ (required _resources)......(1)

$t_2(i)$ = max.{ Finish(l)},lϵ (dependent_activities)..............................(2)

t(i) = max.{ $t_1(i)$,$t_2(i)$} ....(3)

Where $t_1(i)$ = earliest available time of resources for activity i;

$t_2(i)$ = earliest allowed time of logical dependents;

t(i) = early start time of activity i.

The activity with the minimum early start time is then selected for construction, as in (4). {(tk) – min(t(i)}, iϵ (Feasible-activity set) ....(4)

Stage 2: Advance Simulation:

If no activity can be scheduled for start, the simulation time TNOW is advanced to the time when an activity can start and go to Stage 3. If an activity is selected, the activity status is updated to active, and the start time of the activity is set to the current simulation time

TNOW as in equation (5)

T(k) = TNOW ....(5)

Required resources are then allocated to the activity from one of the two sources:

(1) The activity itself

(2) Resource pools

An activity may hold available resources by either initialization or release from its immediate preceding activities. If the activity does not have sufficient resources, the outstanding units are allocated from resource pools. The allocated resources are then updated with the current activity number as their new location, i.e. RL(j) = k……………… (6)

Where

RL(k) = location of resource j;

k = current activity.

Then, the completion time of activity k is scheduled as in equation (7)

Finish(k) = Start(k) + Duration(k) …………………………………(7)

Where

Duration (k) = duration of activity k.

It can be a constant value or any random distribution.

Stage 3: Release Entities

After the completion of an activity, the involved resource entities are released to one of the three locations:

(1) Resource pool;

(2) Its following activities;

(3) Remain at the current activity.

If a resource is needed by its immediate following activity, it is released to the following activity; otherwise, it is released to the resource pools if a resource pools exists; otherwise, it remains at the current activity. The released resources are updated with the new available time and locations, mathematically

Resource – available – time (j) = Finish(k)...(8)

$$RL(j) = \begin{cases} O, \text{ the resource pool} \\ l, \text{ the immediate following activity} \\ k, \text{ the current activity} \end{cases} \qquad \ldots\ldots\ldots.(9)$$

where

RL(j) = new location of resource j.

Processing entities, if there are any, are identified and released at this stage to activate the immediate following activities. It should be mentioned that the simulation algorithm must be implemented to a computer program because a practical numeric simulation experiment can only be conducted on a computer. The implemented program can then run the ABC model and it provides simulation results on the construction process. As a user, to experiment with an ABC model is to execute a command or click a button.

9.3.2 Modification to PERT

Numerous authors have developed modifications to PERT, including the adjustments to equation (2) and criticality indexes. Some authors have, as is done in the present paper, modified PERT's time estimates. Troutt replaces the mode with the median in equation (1). He states that this produces a good estimate of the mean regardless of the probability distribution assumed. Three time estimates are still required, however, Izuchukwu dolph, lauetar. Finally, Lau state that the estimation of all three of PERT's time estimates is subject to ambiguity. They replace a, m, and b with sets of either five or seven quintiles (the 0.25 quantile, for example, is greater than 25% of the numbers in the distribution). The estimation of quantile is argued as being more straightforward than the estimation of modes and extreme values. Their method has merit, but the number of time estimates required, is increased from three to five or seven.

9.4 SIMPLIFIED PERT PROCEDURE

The proposed simplification of PERT is to reduce the number of time estimates required .for each task from three to two. This reduction decreases both the level of effort needed to apply PERT and the required knowledge of activity durations. To retain a probabilistic procedure, the time estimates must be inputs to determining the expected value and variance of an activity duration. The only choice is to assume that the distribution of a duration is symmetric, i.e., normal, rather than beta. A unique normal distribution is defined by any given pair of mean and standard deviation values. Thus, a unique normal distribution can be defined by any two points on one side of the curve, and the other elements of the PERT technique remain the same. Given that Izuchukwu uses a and b in his procedure, the question remains as to which of a, m, and b to use in the

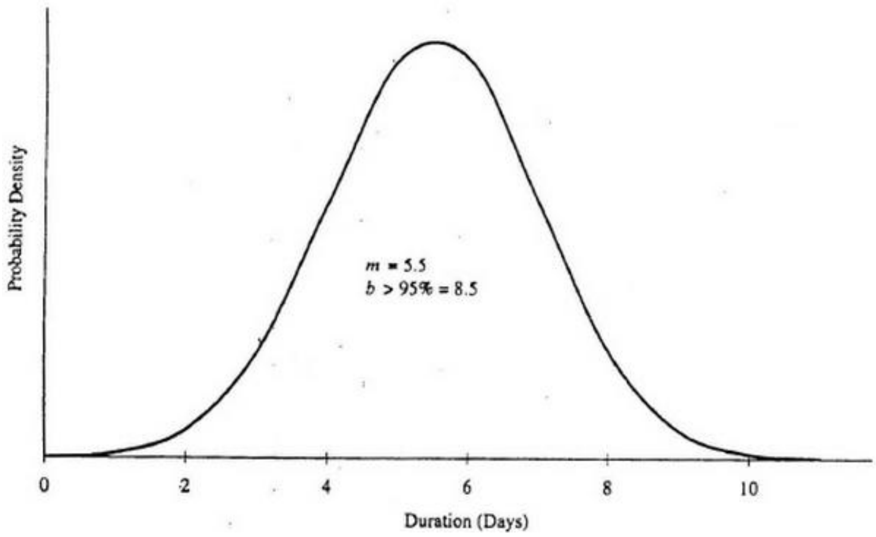


Fig 9.3

new, simplified procedure. Moder reports that most time estimates are on the optimistic side, resulting in actual project durations being longer than those forecasts. This finding is congruous with Izuchukwu's on the closeness of m to a. Hence, relying on a and m only may result in optimistic time estimates. The more conservative approach is to use m and b. Here, m, the mode, is equal to the mean, since the distribution is symmetric. The expected duration of an activity in simplified PERT can be determined as follows:

Te=m ……………………………………………………..…..(4)

where

(Te) = expected duration.

The two variances can be computed as follows:

The standard normal variable, Z, is equal to 3.44 when b is the upper bound on 100% of all durations, and is 1.645 when b is greater than 95%of the durations.

$Z=(b-m)/\sigma$,

so $\sigma2100(Te) = [(b - m)/3.44]^2$ …………………………………(5)

$\sigma_2{}^{90}(Te) = [(b - m)/1.645]^2$ ………………………………………(6)

In choosing between equations (5) and (6) for the variance, it is recognized that the normal distribution is not bound on either end. Hence, b as the upper limit on 100% of the durations would be, by definition, infinite. Equation (6), therefore, is preferable. The remainder of the simplified PERT procedure is the same as that of conventional PERT. Hence, the merge event bias problem is not explicitly corrected.

9.5 Reviews

In classic CPM analysis earliest start time ES, latest start time LS. earliest finish time EF, latest finish time LF, and total float TF must be documented for every activity. The criticality of an activity can be decided based on TF. Tile classic CPM analysis is straightforward and effective for simple, small-scale CPM networks. However, when facing complex, large-scale CPM networks with a great number of nodes and activities, the classic CPM algorithm becomes cumbersome and inefficient for two reasons.

- First, the duration for all the activities must be tracked and stored during the forward pass calculation to conduct the ensuing backward pass calculations.
- Second, live time attributes (ES, EF, LS, LF, and TF) must be calculated prior to determining the criticality of an activity.

A real project may consist of hundreds of distinct activities. To expose the implicit schedule risk of each activity and of the whole project, the simulation may need to be run hundreds of times. It is only in recent years, with the dramatic upgrading of computer technology, that such CPM-based risk analysis tools appeared in the market. The major software includes Risk + by Project Gear and Monte Carlo,

Pritsker presented an approach to PERT simulation in which the backward pass is processed as a "reversed" forward pass. To have the same time duration for backward and forward passes for each activity of the network, a separate random stream number is used to generate the duration for each activity. As per approach still falls into the category of the classic CPM in that the activity criticality is determined based on the TF of an activity. Pritsker pointed out that after a sufficient number of simulation runs, a ranking of the activities by high value of average slack (TF) time becomes a possible method for ordering the activities that can be delayed. A more appropriate ranking is based on the ratio of the average slack time to the standard deviation of activity duration. A higher ratio value indicates that there less likelihood that the average slack time will he exceeded due to the value of the basic variability inherent in the performance of the activity. A low ratio value indicates there is little leeway in the start time for the activity. The above analysis demands some in-depth knowledge of statistics and is not easy for the common practitioner to use. Pritsker et al's final conclusion was that "there is a large positive correlation between the ranking of critical activities based on the ratio of average slack (TF) to activity duration standard deviation and the criticality index." Criticality index for an activity in a percentage term is defined as the number of simulation runs in which the activity is critical, divided by the total number of simulation runs.

As presented, a PERT simulation approach uses CYCLONE. By performing non cyclic simulation in CYCLONE, the forward pass calculation was solved and the statistics for total project completion time were obtained; these were the average project completion time recorded by a COUNTER node of CYCLONE. However, Halpin and Riggs pointed out that "a somewhat troublesome aspect in the interpretation of any computer simulation of a network regards the critical path." They identified the statistics of the waiting times of entities converging at a merge node in the CPM network as a good indication of activity criticality; the lower the average waiting' time, the more critical the activity. The limitation of this CPM is that the "amount of time an entity had to wait in a QUEUE node before being processed by the following COMBI activity" is actually the local slack or free float in CPM terminology. According the CPM analysis, the condition required for an activity to be deemed critical is for the TF value to be equal to 0. As in the classic CPM, determination of TF for each activity requires the backward pass calculation.

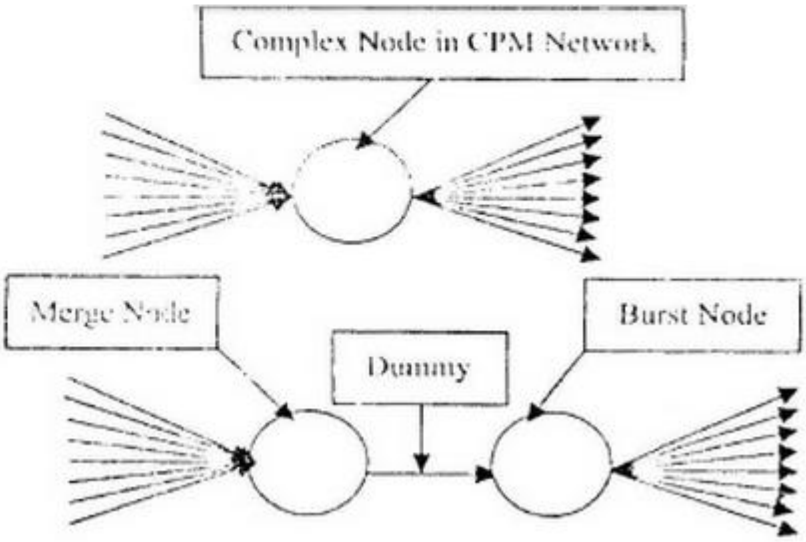


Fig: 9.4 Processing Complex Nodes

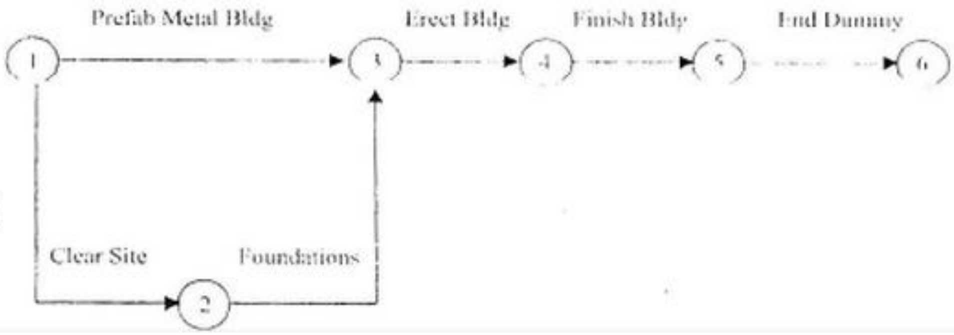


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Fig 9.5 CPM Network for Sample Network

9.6. STRUCTURE AND ELEMENTS OF SIMPLIFIED

The simplified CPM/PBRT simulation follows the convention of the classic CPM network, which is built using the activity- on-arrow structure. The network is constructed with two basic elements that are interconnected by arrows: these are the merge node and the burst node. In the proposed model, a merge node is strictly defined as a node with two or more incoming branches and only one outgoing branch, and a burst node is defined as a node with only one incoming branch and two or more outgoing branches. If a node has only one incoming branch and only one outgoing branch, its treatedasa burst node for the sake of simplicity in calculation, because no attribute needs to be tracked and determined in the calculation for a burst node.

If a node has more than two incoming branches and more than two outgoing branches, as is often encountered in the CPM network, it must be changed into a merge node and a burst node by adding one dummy activity between nodes as shown. Only one terminal node is allowed to exist in a network to earmark the finish milestone of the whole project. A dummy activity (zero duration) is added to link the last node of the CPM network to a terminal node, as shown. As long as a node has no preceding activities or incoming branches, it is defined as an origin node. The following rules apply to the origin node:

- A network may have more than one origin node.
- At a particular control moment when the prerequisite activities of a merge node or a burst node are all completed, the merge node or burst node mutates into an origin node dynamically.
- An origin node is closely associated with a control time at which moment the origin node releases a simulation entity. At the planning stage, the control time may be set to zero or to the expected project commencement date in the future. During the execution stage, the control time may be set to the current time or calendar date.

9.7. ALGORITHM OF SIMPLIFIED CPM/PERT

9.7.1 Discrete Event Modeling:

A Discrete Event Modeling A discrete event simulation system consists of discrete entities that occupy discrete states that will change over time. The simplified CPM/PERT simulation takes the discrete event modeling approach. An entity is an object that is created at the start of simulation, processed in the simulation model, and terminated at the end of simulation. The states and behaviors of an entity within the model will he explicitly tracked as simulation proceeds such as "Start activity ij" and "Finish activity ij". The entity persists in a state for a defined period of time; for instance, "Being processed by activity ij" state is maintained for the duration of activity ij. The time at which the entity changes its state is known as an event. For instance, "Arriving at a simple burst node" event changes the entity state from "Being processed by the previous activity" to "Being processed by next activity”. The complex logic constraining an event can be defined as a set of prerequisite conditions. For instant, the “Departing from a merge node” event will not occur unless all entities have arrived from the incoming branches. An activity or arrow in the network always begins with a “Departing from a node” event and ends with an “Arriving at a node” event.

9.7.1.1 Forward Pass Calculation:

The algorithm of the simplified CPM/PERT simulation for computing simulation event times on the forward pass can be summarized as follows:

1) At the control time of an origin node, entities are created. The number of entities created is equal to the number of branches emanating from the origin node.
2) Starting from the origin node, entities travel along the forward direction of the network (usually from left to right) until arriving at a merging node I that has N converging branches (N≥ 2).
3) When N entities all arrive at merge node I, N entities will be batched into one entity.
4) The batched entity wills immediately bare leased from node I and travel along the network path until arriving at another merge node.
5) Steps 3 and 4 will be repeated until an entity arrives at the terminal node, at which point the entity is terminated.

It should be noted that calculation only occurs at all the merge nodes and the terminal node in the CPM network, as is discussed next. If the merge node I has N converging branches (N≥ 2), then 2N variables are needed to capture the entity arrival times AT and entity waiting times WT of the N branches. One extra variable is used to capture the departure time of the batched entity released from the merge node. Therefore, 2N + 1 variables suffice to keep track of all the event time information associated with a merge node. The calculations are given in the following formulas. Notice that k corresponds to the k^{th} converging branch at the merge node I, k = 1, 2,...,N.

The remainder of this section outlines the computations that take place during simulation.

Entity Arrival time (AT):

To calculate AT on a given branch, to cases must be differentiated:

1. If the entity is released from a origin node (i.e., if incoming branch k can be traced back directly to an origin node without any other merge node in its way) then AT at merge node I from branch k can be calculated as shown.

AT(k)=Control Time + Path Dur (k).. (1)

where

AT(k) = arrival time of the entity coming from branchk Control Time = control time of the origin node;

Path Dur (k) = sum of activity duration along the path from merge node I to the origin node.

2.If the entity is released from a merge node (i.e., if incoming branch k can be traced back to previous merge node J that is closest to current merge node I in the network), AT at merge node I from branch k can be calculated as shown

AT(k) = DT(J) + Path Dur (k)...(2)

where

AT(k) = arrival time of the entity coming from branch DT(J)= departure time of the entity from merge node J Path Dur (k) = sum of activity duration along the path from current merge node I to previous merge node J.

DT from Merge Node: The DT of the batched entity from merge node I depends on AT from all the converging branches, dictated by

DT(I) = AT(c)...............,,…,,,,,,,,,,,,,,,,,,,,,,,,,,......... (3)

where

DT(I) = entity departure time from merge node I

c corresponds to the incoming branch that gives the maximum AT from Steps 1 and 2, in other words, the entity from incoming branch c arrives last.

WT at Merge Node:

WT(k) = DT(I) - AT(k)... (4)

Where

WT (k) = waiting time of the entity coming from branchk

AT(k) = arrival time of the entity coming from branch k.

DT(I) = batched entity departure time from merge node I.

Once the above event times are all determined on a merge node, the same process is repeated on every other merge node in the network until the terminal node is reached. The total project completion time is equal to AT the terminal node as given by project completion time = AT(end dummy)...................................... ………......................... (5)

9.7.1.2 Backward Passing Processing

The simplified CPM/PERT simulation algorithm is a streamlined network, analysis method, which is reflected in the backward pass calculation. It is unnecessary to calculate LS, LF, and TF of each activity to determine activity criticality. Further, unlike an approach, no simulation entity is involved in the backward pass. The backward pass calculation can be treated as a post processing of the PERT simulation. In the backward pass calculation, four steps are followed:

1. Associated a CI variable of “byte type” (i.e., 1 or 0) with each branch or activity CIij = 1 or 0

Where

I = activity start node;

J= end node;

CIij = 1 indicates activity I-J being critical, 0 being noncritical.

2.Initialize CI for the end dummy activity with 1.

3.Next, apply the following two critically rules along the backward path (usually from right to left in the CPM network)

- Rule 1 (applicable to a merge node): If the emanating branch of a merge node has a CI value equal to I, then the CI value is set to 1 only for the converging branch that is associated with the zero WT: for the other converging branches are set to 0. The WT is calculated in the forward pass.
- Rule 2 (applicable to a burst node): If the sum of the CI values for all the emanating branches of a burst node is equal to zero, then the incoming branch must have a CI

value of zero; otherwise, the CI value of the incoming branch is 1. Rule 2 is also applicable to a burst node that has only one outgoing branch.

4. Rules 1 and 2 are applicable in the backward direction until the origin nodes are reached. Once the backward path processing of one simulation run is completed, it is easy to detect all critical activities, which are distinctly marked by the CI value of 1.

Review Questions

33. Describe the role and application of PERT/CPM for project scheduling?
34. Develop a complete project schedule?
35. Compute the critical path, the project completion time and its variance?
36. Compute the project completion time given a certain level of probability?

Discussion Questions

Define a project in terms of activities such that a network representation can be developed.

Application Exercises

25. Convert optimistic, most likely and pessimistic time estimates into expected activity time estimates?
26. Compute the probability of the project being completed by a specific time.
27. Find the least expensive way to shorten the duration of a project to meet a target completion date.

CHAPTER 10

Reducing project duration

Learning Objectives

- To explain the methods to produce project duration that minimize project cost.
- To analyse direct and indirect project cost including a description of the basic types of schedules.
- To discuss the reasons for the need to reduce project duration.
- To examine time reduction method of expediting or buying time along the critical path.
- To identify time-cost relationships for project activity duration.

10.1 Introduction

The need for reducing the project duration occurs for many reasons such as imposed duration dates, time-to-market considerations, incentive contracts, key resource needs, high overhead costs, or simply unforeseen delays. These situations are very common in practice and are known as cost-time trade-off decisions. This chapter presented a logical, formal process for assessing the implications of situations that involve shortening the project duration. Crashing the project duration increases the risk of being late. How far to reduce the project duration from the normal time toward the optimum depends on the sensitivity of the project network. A sensitive network is one that has several critical or near-critical paths. Great care should be taken when shortening sensitive networks to avoid increasing project risks. Conversely, insensitive networks represent opportunities for potentially large project cost savings by eliminating some overhead costs with little downside risk.

Alternative strategies for reducing project time were discussed within the context of whether or not the project is resource limited. Project acceleration typically comes at a cost of either spending money for more resources or compromising the scope of the project. If the latter is the case, then it is essential that all relevant stakeholders be consulted so that everyone accepts the changes that have to be made. One other key point is the difference in implementing time-reducing activities in the midst of project execution versus incorporating them into the project plan. You typically have far fewer options once the project is underway than before it begins. This is especially true if you want to take advantage of the new scheduling methodologies such as fast-tracking and critical-chain. Time spent up front considering alternatives and developing contingency plans will lead to time savings in the end.

For numerous reasons, projects fall behind. However, project managers do have different options in crashing or reducing the project duration. Some include adding additional staffing or resources, outsourcing, and adding overtime.

Constructing a project-cost duration graph identifies costs to reduce project time with the focus of getting the project completed sooner. Project cost reduction alternatives also exist as do time reduction techniques. Some examples include project scope reduction, outsourcing, and identifying tasks that customers can do themselves.

An important, but unfortunately sometimes overlooked, step includes project auditing. Auditing allows a company to incorporate best practices and continuous improvement techniques for project management. The actual process includes the phases of initiation and staffing, data collection and analysis, and reporting.

Many times, projects fall behind the promised date, and a conflict of time versus cost arises. Project managers must decide or determine what factor supersedes the other or realize how to balance the two in the best interest of the project. Another factor comprised for time includes quality. “The project duration time is set while the project is in its “concept” phase before or without any detailed scheduling of all the activities in the project”. Without carefully creating a detailed plan of the project, the project duration cannot have an accurate forecast.

Some reasons to reduce the project duration include an imposed date created by a key stakeholder, on-time market demands due to global competition and technological advances, incentive contracts for completing the project before schedule, and making up for unforeseen delays.

Different options exist to crash or shorten project time as defined by Clifford Gray of the Project Management textbook. The most common method includes assigning additional staff and equipment to the project activities. Additions cannot occur too late in the project; otherwise, the project duration can potentially drag out longer than anticipated. Next, outsourcing or subcontracting can occur. This option allows the project to access experienced professionals.

Experience in key areas can help reduce times and increase the quality of work. Another option includes adding overtime. Even though this alternative is an easier choice, the project manager must consider the additional costs and potential employee burnout involved. Establishing a core team that is dedicated to the project includes the fourth option. A core team enables speed and focus for the project. Project managers also have the option to perform activities twice. The first completion of the activity occurs as a quick and sloppy solution. The second completion occurs the right way. Fast-tracking includes a method where critical activity completion occurs parallel rather than sequentially. Critical-chain involves a method that prioritizes the project activities to incorporate rapid project completion through long-term commitments. “Probably the most common response for meeting unattainable deadlines is to reduce or scale back the scope of the project”. For example, project managers can choose to reduce the number of features for a new product or service. Managers must not lose the value the project results offer. A re-examination of the requirements can help keep or even improve the project values and increase the speed while reducing costs. The final option includes reducing the quality of the product. Managers should evaluate this alternative very carefully as the wrong decision could essentially cause project failure.

A project-cost duration graph represents an identification of costs to reduce project time so that comparison acknowledgement occurs with the benefits of getting the project completed sooner. Constructing a project-cost duration graph involved three major steps as defined by Clifford Gray.

- Find total direct costs for selected project durations
- Find total indirect costs for selected project durations
- Sum direct and indirect costs for these selected durations

The first step usually involves the most difficulty. The central concern is to decide which activities to shorten and how far to carry the shortening process. Project managers need to identify critical activities they can shorten with the least increase in cost per time. Indirect costs are usually easily obtainable from the accounting department.

Managers should assess other factors besides cost evaluation when choosing a method for project time reduction.

a) First, activity timing needs consideration.
b) Second, the impact on employee morale and motivation needs evaluation.
c) Finally, project managers should consider the potential risk involved.

As options exist for reducing project duration, they also exist for cost reduction as defined by Clifford Gary. First, a reduction for project scope not only gains additional time but also produces cost savings. Another option includes having owners take more responsibility. Managers should identify tasks that customer can do themselves. Third, outsourcing parts of the project or the entire project can create cost savings. Finally, communicating with team members can produce ideas on cost savings. Members can brainstorm and introduce savings.

10.1.1 Techniques

There are many techniques on how you can reduce project duration that you can adapt in managing your business.

10.1.1.1 Project monitoring

Never leave your business project unchecked. Always monitor the process in every step and every activity. In this way, you can have updates about what is going on in every task and check whether these are conducted on time based on the schedule, having delays, or are they accomplished earlier than has been planned. From there, you can make a decision on the next steps or what actions to take.

10.1.1.2 Eliminate unnecessary steps

Project plans can never be perfect. There are times when even if the project is already rolling out, you find some steps that are no longer necessary but was included in the plan to make a certain result. You can leave out this step that is no longer necessary and move on to the next one. This will help you complete the project in a shorter time than was planned.

10.1.1.3 Simultaneous work

In many projects, there can be activities or steps that can be done simultaneously without having significant negative effects to the others. Identify these activities that can be done at the same time but still produce the same results for your project. You can greatly shorten the time frame of your project in the process.

10.1.1.4 Faster methods

There are many approaches or methods to doing things. If you can find faster methods for an activity or a step to accomplish the same result, incorporate this into the process. For example, if you have planned that one person can do each activity in the process, you can re-examine which of these activities can be done by two or more persons. This can help you reduce the duration of the project than you have originally set out because there will be more hands to do the work and the time to complete that task will be reduced.

In essence, you can adapt alternative measures to each step or activity of your project that has a direct effect to the time frame of the tasks. You can always make some adjustments while the project is on going or make the alternative steps as part of the plan. It can also be a back up plan at the beginning of the process in case there is a need to finish the project earlier than the original plan.

10.2 Project Audit and Closure

Mistakes will occur throughout a project; however, if carefully assessed, errors can introduce what to do or not to due for future business processes. The project audit and report are instruments for supporting continuous improvement and quality management. In order to incorporate best practices for project management, the business must evaluate past failures and successes. Companies that thoroughly audit their projects, lead in their field.

The project audit process consists of more than status reports. Other factors the audit offers as defined by Clifford Gray that include the following.

- Reason to why project was selected
- Reassessment of the project’s role in organizational policies
- Organizational culture check to ensure facilitation of project implementation type
- Assessment if project team is functioning well and staffed appropriately

Project audits can act as both reactive and proactive forces for project managers. Conducting audits while in the process of a project initiates proactive responses. Conducting audits after the fact allows PM's to approach future projects with improved processes.

Before conducting a project audit, the steps outlines will help ensure a successful assessment.

- Keep the mindset that the audit is not a witch hunt
- Focus on project issues not the individuals performing them
- Auditing should impose minimal threat to employees and efforts of sensitivity should be made
- Data accuracy should be verifiable
- Senior management should openly support project audits and provide the team with maximum access to audit needs
- Audit objectives include learning from mistakes and conserving value
- Audit process should be quick
- Audit leaders have access to senior management above project managers

The actual auditing process falls into three steps. First, the initiation and staffing phase occurs, with results dependent on the organization. This step works well as an automatic process in removing perceptions of a witch-hunt approach. Characteristics possessed by the audit leader include no direct involvement in the project, respect for stakeholders, willingness to listen, reporting without fear, having the best interest of the organization for decision-making, and experience and expertise in the organization or industry. Data collection and analysis stem from two auditing perspectives including organizational and the project team views. Organization views help determine such questions as the organizational culture correctness, sufficient management support, intended project accomplishment, identification of appropriate risks, and adequate staffing during and after the project. Project team views answer such factors as appropriateness of plans and control systems, over or under budget and schedule numbers, adequate stakeholder communication, and sufficient access to organizational resources. The third step includes reporting to capture changes needed and lessons learned.

The report serves as a training instrument for project managers of future projects. A general outline for the reporting process includes the following:

- Classification of project
- Analysis of information gathered
- Recommendations
- Lessons learned
- Appendix

Conducting project audits involves an important aspect of project management. When done on a consistent basis, audits can lead to significant improvements in the processes and techniques that organizations use to complete projects. Once projects are in the closing process, different forms of closure exist. First, the most common form occurs when the project is simply completed; this is the normal condition. The premature circumstance occurs with early project completion through elimination of certain parts of the project. Next, the perpetual condition occurs when the project becomes continuous due to required changes; thus seeming never-ending. The fourth project type includes the failed project where the project fails due to different reasons. The final project condition, changed priority, includes projects that incorporate revised priorities to reflect changes in organizational direction.

Project closure includes the five main activities as:

- Receive delivery acceptance from the customer
- Shut down resources and release to new uses
- Reassign project team members
- Close accounts and verify payment for all bills
- Evaluate the project team, members, and manager through such methods as performance reviews

Project managers must learn to balance time, cost, and quality. Often, the project time or duration becomes longer than desired. Managers can take different steps to reduce the project duration. Some options include adding additional staffing or resources, outsourcing, adding overtime, establishing a core team, performing activities twice, creating a critical chain, reducing the project scope, and reducing the quality of the product or service. Managers should assess activity timing, employee morale, and potential risks along with cost evaluation when choosing the method for project time reduction. Mistakes will occur throughout a project; however, with careful assessment, PM’s can introduce continuous improvement and best practices. The proactive process of auditing includes initiation and staffing, data collection and analysis, and reporting. The reporting step allows future projects to have a training instrument to ensure for a more successful outcome.

10.3 Steps to reduce Project duration

Step 1:

Keep track of how time is used and eliminate time wasters. When working on your next project, set a timer for everything you do to complete a given project. Track not only your steps in project completion, but also your activities that are not project-related, but take time away from the project. For example, keep track of the time you use getting snacks or returning unrelated phone calls. At the end of the project, add up the numbers and cut or modify unnecessary steps that are taking up your time. For example, perhaps you've spent a total of two hours over a course of a month walking back and forth to the copy room to get more paper. To solve this problem, ask the office manager to stock your drawer with copy paper. While things like getting snacks may not be able to be eliminated, modify them by bringing snacks to your desk or designating snack break times for yourself.

Step 2

Create an agenda or system to follow when working on projects. Make weekly or daily task lists, including detailed items to do; cross off each task as you accomplish it. This will not only allow you to feel good about getting something done, but will ensure that you are working on projects even when you are stumped. Putting even the smallest details -- such as printing and stapling reports -- on the agenda will also prevent you from underestimating how long some of the most mundane, low-level tasks take to be resolved.

Step 3

Understand how you work best. Try working in a few different environments, with music on and without music, and while multi-tasking and without multi-tasking. Think about which environment feels more comfortable to you, and compare the work you got done in each. Try to reproduce the same environment for every task. For example, if you work best in the early morning, try to dedicate your mornings at work to working on projects. Leave the afternoons for meetings when you are talking about ideas rather than accomplishing them.

Step 4

Collaborate and delegate. Work with others, and split up the project into parts by strengths. This way, people who are weak in a particular area do not have to spend days completing a project when someone who is strong in that area could have had it done in hours. Discuss strengths and weaknesses in the office or in your project teams so that you know who to contact about helping you with your project.

Step 5

Let others know you are working on an important project, and cut out time wasted using technology such as social networking, testing and emailing. While these technologies are fun to use and may even help you communicate important business information, you don't have to use them during time that has been allotted for working on a project. Tell people that you are generally working during a certain part of the day, and explain that you will have technology turned off, but that you will be happy to get back to this technology later in the day or the following day. However, always make sure there is a way for others to get in contact with you, should there be an emergency. For example, you may want to keep your office phone on.

10.4 Project Crashing

No project is implemented in isolation. Events happening around the project may affect its progress. A nation-wide strike, an un-expected calamity or an abrupt economic change may bring the project to a grinding halt. Even if everything goes well, the sponsors may be tempted to enter the market early. In all cases, the project manager plays a vital role in shortening the project schedule. To start with, a manager should study fast-tracking or shift to an advanced technology. If nothing helps, more resources can be introduced for an early completion. Since it would invariably result in more costs, a manager must find out if, within the same time-frame, the costs could be brought lower than the crash-cost limit. This has been explained by Crashing Techniques through an example of a Yacht Project.

In crashing, the time is reduced by increasing resources. But the sequence is not disturbed. For example, a project involves raising a boundary wall in 16 days and moving machinery crates in 8 days, the total duration being 24 days. By engaging more workers and excavators, the boundary wall can be made in 12 days and machinery shifted in 4 days, reducing total time to 16 days.

In fast tracking, shifting of machinery would start when boundary is only partially complete, usually 2/3, and the entire job would be completed in 16 days without incurring extra cost. But it would increase risk to a certain degree. It is like drinking coffee or using mobile phone while driving in a fast lane.

To sum up, crashing involve time and cost trade off without any change in sequence of activities or task-dependencies. On the other hand, fast tracking does not increase costs but increases the risk as many jobs are done in parallel rather sequentially.

10.4.1 CRASHING

10.4.1.1 FIRST CRASH

As stated above, we can crash C by 8 days for which would have to incur an extra Rs.4,000 (8 days @ Rs.500 per day). After the crash, we re-draw the network.

10.4.1.2 SECOND CRASH

A glance at the revised network would reveal that total time under the path A- C has reduced to 9 but B, on the other path, has time duration of 12 days. As critical path is the longest path, total time duration has only reduced to 12. Since our crash time is 10 days, we would now reduce B by two days.

10.4.2 UN-CRASHING

For technological reasons, it is not possible to shorten the duration below the crash limit of 10 days even by spending more money or resources. But we can review the situation and reduce the crash cost to some extent. This is done through un-crashing.

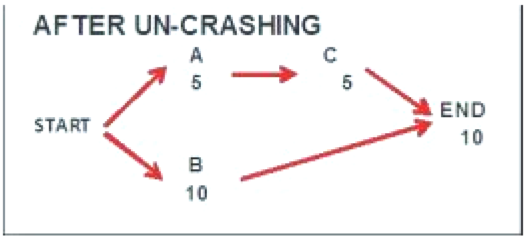

Fig 10.1

After second crash, we observed that path A&C had duration of 9 days. If we can increase any activity by one day, we would still be under the permissible limit of 10 days. As a rule, an activity with the highest per-day cost should be un-crashed. In this case, however, only C can be uncrushed for one day as the other A has never been crashed. By doing so, we would make all paths as critical paths. Total cost would now be Rs.39,100 as under.

10.4.2.1 Task splitting

The aim here is to take a large task and to split it down into two or more smaller tasks each of which could start ahead of the completion of the previous one. This can happen more often than you think.

In an ideal world the work break down structure will already go down to the lowest available task. If this were the case there would be no tasks to split and every task precedence would be sorted. When you examine a task and split it you are not adding more resource merely adjusting the overlap of the individual smaller tasks.
In addition, when you modify the start times of the individual smaller tasks the overall duration of the original task remains the same.

There are a few things to consider when choosing a task to split and how to do it most efficiently.

- The task you are considering for 'splitting' must be on the critical path otherwise you cannot reduce the overall project duration.
- Tasks after splitting should not all run in series.
- The tasks after splitting cannot use the same resource at the same time.

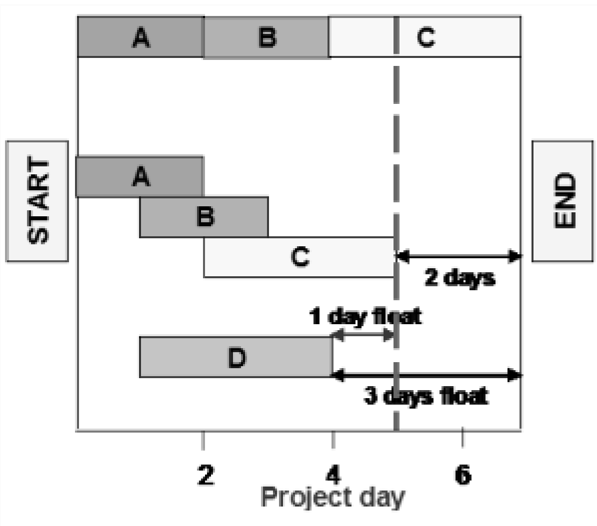

Fig: 10.2

If we look at the simple example in the diagram we have a single task shown as ‘A’ ‘B’, and ‘C’ in one block at the top. This single task is also critical as it goes from beginning to end. We can split these into the individual tasks ‘A’ ‘B’, and ‘C’. Having considered these activities very carefully we decide that task ‘B’ can start 1 day after task ‘A’ has begun. Similarly, task ‘C’ can begin 1 day after the start of task ‘B’. If we adopt this new structure then the critical path still ends at the end of task ‘C’ but it is now shortened by 2 days. Notice that the durations of tasks ‘A’ ‘B’, and ‘C’ have not changed. Also, within the schedule we have task ‘D’. This task originally had a total float of 3 days. Due to the reduction in the overall project time its float has been cut to 1 day.

Note that when the schedule is more complex you will need to take other aspects into consideration. The original critical path will be shortened but there is no guarantee that it will remain the critical path. Indeed, if the float of a task is less than the original critical path reduction that task will become critical. For example, if we have:

A task ‘X’ with total float = 16 days
Project reduction = 20 days
The total float of task ‘X’ becomes 16 – 20 = 0 days
Note that it can’t be -4 days. Once a task gets to total float = zero it is on the critical path.

10.4.2.1 Critical path

- Be wary when dealing with critical paths. There may be more than one. If there is more than one and you carry out task splitting on only one task of one of the serious paths then the overall project duration will not change as it will be governed by the remaining critical path.
- In this case if you want to reduce the overall project you must carry our task splitting on two tasks. One from each critical path. The path that is shortened the least will remain as the critical path.
- Once you have done this once you will need to recalculate the critical path before deciding on the next pair of tasks to split.

When you have split any tasks, particularly a pair in two critical paths makes sure that the 3 point rule considered above has not been broken before going through the cycle again.

10.4.3 Criteria for Selecting Activities to Crash:

There are several characteristics that mark or highlight an activity that exists on the Critical Path as a better candidate for crashing.

1. Must be on the Critical Path. Crashing noncritical activities that already have slack only buys more slack and doesn't shorten the project duration. Only critical path activities drive the project and crashing them will shorten the project duration.
2. Precedes multiple activities. When an activity bottlenecks numerous succeeding activities, it is a great candidate to shorten. Once this activity is shortened, it allows the multiple activities to begin.
3. Long duration. An activity that has a long duration offers more potential time gain from crashing it.
4. Lower cost per period gained. Activities that cost less to crash are preferred. These include those requiring lower paid, lower skilled workers or other resources that are otherwise sitting idle.
5. Early in the project, if you fail in crashing the activity and it takes longer than planned, it is still early in the project. Thus you still have recovery time. Also, typically demand on resources early in the project is lower than other times, and they should be readily available.
6. Labor-intensive. When an activity is low skill labor intensive, it is easy to add people to help complete the project early. When an activity requires high skills to complete, it may be hard to find qualified individuals who are capable of completing the task.
7. Subject to common problems. Try to pick activities that are subject to higher probability of common problems. Shortening the duration lowers the exposure time and lessens the chances of having a problem.

10.4.4 Steps in Project Crashing:

1. Compute the crash cost per time period. If crash costs are linear over time:

Crash cost per period = (Crash cost – Normal cost) / (Normal time – Crash time)

2. Using current activity times find the critical path and identify the critical activities

3. If there is only one critical path, then select the activity on this critical path that (a) can still be crashed, and (b) has the smallest crash cost per period. If there is more than one critical path, then select one activity from each critical path such that

(a) Each selected activity can still be crashed, and

(b) The total crash cost of all selected activities is the smallest. Note that a single activity may be common to more than one critical path.

4. Update all activity times.

5. Cease crashing when

- The target completion time is reached
- The crash cost exceeds the penalty cost

If not, return to Step 2.

10.5 Conclusion

Whether it's small or large, complex or simple, every project has risk. It's our job as managers to do our best to not only minimize the risk in our projects but to minimize it as soon as we can. In this article, you'll learn a simple four-step approach for doing just that.

10.5.1 Inventory

The first step to managing the risk of a project is to inventory the situation. That is, identify all of the risks that you think are possible in the project. The inventory should include all internal factors for the project such as resource changes, assumption failures, and sponsor availability. It should also include all external factors such as a change in company direction or a change of technology direction. Most of all, however, it should include the things that are new in the project. If the project is working with a new technology, is using a new development methodology, or even if there are new, relatively unknown team members, these need to be listed as potential risks to the project.

The purpose of the inventory phase isn't to classify the risk or identify its importance. That step happens later. The goal is to collect all the risks. If you mix in the process of evaluating the risk you'll find that you won't get a complete inventory of the potential risks for the project. Staying focused on capturing risks is essential to the process.

10.5.2 Evaluate

Once you have a complete list of potential risks, it's time to evaluate them. Each risk should be evaluated based both on its probability and on the impact that it would cause if it happens. The loss of a key team member may have a low probability; however, the impact to the project can be great.

Some people struggle with the evaluation step because both of the numbers, percentage and impact, are guesses. They recognize that even subtle changes in the values for these numbers can have a huge impact on the total risk of the project. However, in general, the objective here isn't to come up with a single number that represents each risk. The objective is to develop a framework for evaluating the various risks against one another. Although precision in the estimating process is useful it's not essential.

The other factor to evaluate when looking at a risk is its duration as how long that it can have a potential impact on the project. For instance, the loss of a subject matter expert early in the project is a risk because their input is still needed. However, later in the project they may not have much input and therefore aren't a risk if they leave. The risk of a functional analyst leaving is greatest in the initial phases of the project when they are intensively interacting with the customer. Later on in the project, the loss of the functional analyst has a smaller potential impact for the project.

In order to get a consistent number for all of the risks, multiply the probability which should be per interval of duration by the impact and finally multiply that by the duration. The resulting number is a single number, a risk quotient, which can be used to prioritize risks within the project. For instance, if the probability of the risk happening in a given week is 10%, the number of weeks the risk may happen is 10 weeks, and the impact is 1000, the overall risk is 1000. (.10*10*1000 = 1000)

10.5.3 Prioritize

Now that you have a single risk quotient for the various risks, it's possible to prioritize the risks for the project. It can give you a clear vision of what the risks are and which ones you'll ultimately need to be concerned about. This is also a part of the process that typically helps validate the estimates made above. For instance, if your greatest risk is personnel turnover you may want to more objectively evaluate the probability. If the average person stays at your organization for three years you can assume a probability of them leaving in a given week is 1/156 (3x52 weeks/year) which is a 0.00641 percent chance.

10.5.4 Control and mitigate

Once the risks are prioritized you can go through the list and identify which risks are controllable, which risks are things that can be mitigated, and which risks must be accepted. For instance, the risk of loosing key personnel can be mitigated by providing completion bonuses or even just monitoring their happiness more closely. Technical risks can be controlled by moving them forward in the project so that they are proven out nearly immediately.

In general, the fastest way to reduce the overall risk quotient for a project is to tackle the controllable risks early in the project. The more quickly that you are able to validate the risk associated with an item the more quickly the risk is no longer a risk (so its probability can be zeroed out.) Focusing on controllable risks won't completely eliminate risk but it will quickly cut it down.

The next step is to develop mitigation strategies for those risks that can’t be controlled. Completion bonuses are a routine way that organizations which are closing down operations mitigate the risk that the people participating will leave before the project is ready to let them go.

Not every mitigation strategy needs to involve money. Simply getting a verbal, personal commitment to finish the project is often enough to further reduce the probability that a person will leave during the project. Most people value their own sense of self worth and they believe that their ability to meet their personal commitments is a part of the admirable part of their self.

10.6 Project Time-Cost Trade-Off

10.6.1 Introduction

We have seen that the duration of activities discussed as either fixed or random numbers with known characteristics. However, activity durations can often vary depending upon the type and amount of resources that are applied. Assigning more workers to a particular activity will normally result in a shorter duration. Greater speed may result in higher costs and lower quality, however. In this section, we shall consider the impacts of time and cost trade-offs in activities.

Reducing both construction projects' cost and time is critical in today's market-driven economy. This relationship between construction projects' time and cost is called time-cost trade-off decisions, which has been investigated extensively in the construction management literature. Time-cost trade-off decisions are complex and require selection of appropriate construction method for each project task. Time-cost trade-off, in fact, is an important management tool for overcoming one of the critical path method limitations of being unable to bring the project schedule to a specified duration.

10.6.2 Time-Cost Trade-Off

The objective of the time-cost trade-off analysis is to reduce the original project duration, determined form the critical path analysis, to meet a specific deadline, with the least cost. In addition to that it might be necessary to finish the project in a specific time to:

- Finish the project in a predefined deadline date.
- Recover early delays.
- Avoid liquidated damages.
- Free key resources early for other projects.
- Avoid adverse weather conditions that might affect productivity.
- Receive an early completion-bonus.
- Improve project cash flow

Reducing project duration can be done by adjusting overlaps between activities or by reducing activities' duration. What is the reason for an increase in direct cost as the activity duration is reduced? A simple case arises in the use of overtime work. By scheduling weekend or evening work, the completion time for an activity as measured in calendar days will be reduced.

However, extra wages must be paid for such overtime work, so the cost will increase. Also, overtime work is more prone to accidents and quality problems that must be corrected, so costs may increase. The activity duration can be reduced by one of the following actions:

- Applying multiple-shifts work.
- Working extended hours (over time).
- Offering incentive payments to increase the productivity.
- Working on week ends and holidays.
- Using additional resources.

10.7 Activity Time-Cost Relationship

In general, there is a trade-off between the time and the direct cost to complete an activity; the less expensive the resources, the larger duration they take to complete an activity. Shortening the duration on an activity will normally increase its direct cost which comprises: the cost of labor, equipment, and material. It should never be assumed that the quantity of resources deployed and the task duration are inversely related. Thus one should never automatically assume that the work that can be done by one man in 16 weeks can actually be done by 16 men in one week. A simple representation of the possible relationship between the duration of an activity and its direct costs appears in Figure 10.3.

Considering only this activity in isolation and without reference to the project completion deadline, a manager would choose a duration which implies minimum direct cost, called the normal duration. At the other extreme, a manager might choose to complete the activity in the minimum possible time, called crashed duration, but at a maximum cost. The linear relationship shown in the Figure 10.3 between these two points implies that any intermediate duration could also be chosen. It is possible that some intermediate point may represent the ideal or optimal trade-off between time and cost for this activity. The slope of the line connecting the normal point (lower point) and the crash point is called the cost slope of the activity. The slope of this line can be calculated mathematically by knowing the coordinates of the normal and crash points.

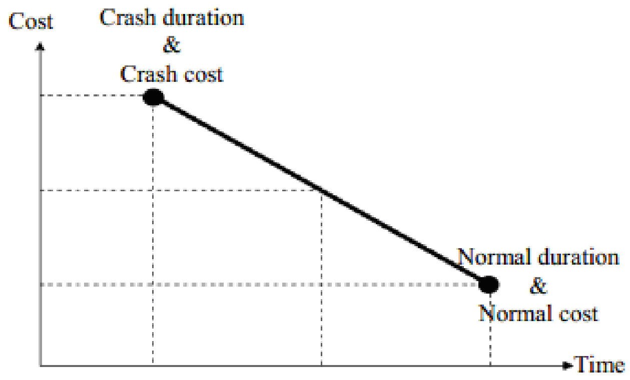

Fig 10.3 Illustration of linear time/cost trade off

Cost slope = crash cost – normal cost / normal duration – crash duration

As shown in Figures 10.3, 10.4, and 10.5, the least direct cost required to complete an activity is called the normal cost (minimum cost), and the corresponding duration is called the normal duration. The shortest possible duration required for completing the activity is called the crash duration, and the corresponding cost is called the crash cost. Normally, a planner starts his/her estimation and scheduling process by assuming the least costly option.

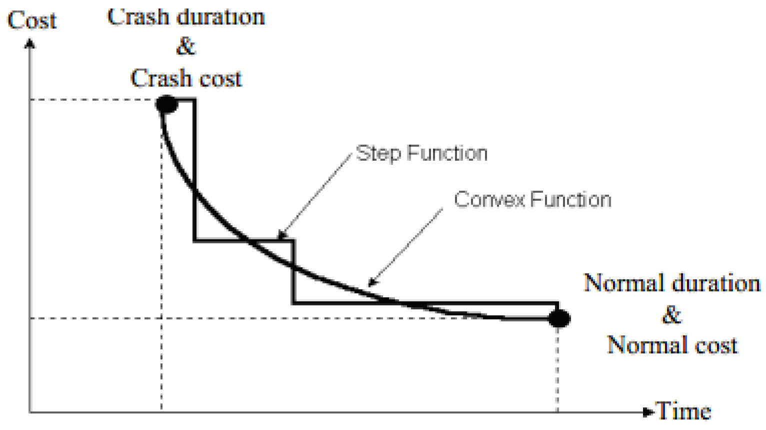

Fig 10.4: Illustration of non linear time/cost trade off

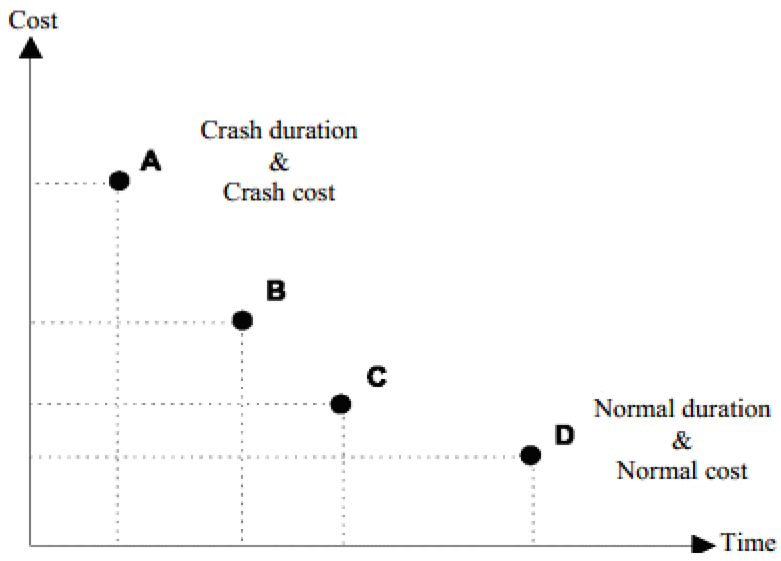

Fig 10.5: Illustration of discrete time/cost trade off

Review Questions

37. What are five common reasons for crashing a project?
38. Why is scheduling overtime a popular choice for getting projects back on schedule? What are the potential problems for relying on this option?
39. Identify four indirect costs you might find on a moderately complex project. Why are these costs classified as indirect?
40. How do you choose the tasks to reduce the project duration?

Discussion Questions

A subcontractor has the task of erecting 8400 square meter of metal scaffolds. The contractor can use several crews with various costs. It is expected that the production will vary with the crew size as given below:

Estimated daily production (square meter)	Crew size (men)	Crew formation
166	5	1 scaffold set, 2 labors, 2 carpenter, 1 foreman
204	6	2 scaffold set, 3 labors, 2 carpenter, 1 foreman
230	7	2 scaffold set, 3 labors, 3 carpenter, 1 foreman

Application Exercises

28. Explain time-cost relationships for project activity duration as well as cost slope computations and comparisons?
29. Explain the direct and indirect project cost including a description of the basic types of schedules relative to the relationships of project duration and total project costs.
30. What are the advantages and disadvantages of reducing project scope to accelerate a project? What can be done to reduce the disadvantages?