PERT/CPM Control of Construction and Maintenance Projects

Edmund J. Ayres
International Salt Company
Clarks Summit, Pennsylvania

ABSTRACT

Program Evaluation and Review Technique/Critical Path Method (PERT/CPM) is a planning and control technique performed on a predetermined set of ordered activities which must be accomplished to complete a job. The "network" is the heart of the system. The evaluation of the network gives the expected completion date and the probability of meeting the date. As a modern scheduling tool PERT/CPM is used by most large companies and, as such is probably the most popular method employed today.

This presentation briefly reviews the origins of PERT/CPM and describes in somewhat more detail the network technique. An evaluation of the techniques' advantages and disadvantages compared with other techniques and several practical recommendations in its use are provided. The fundamentals of project planning including the responsibilities of the owner which cannot be delegated to others and the need for, and how to insure the active participation of those outside the company such as architects, contractors and vendors are set forth.

The need for disciplined planning and scheduling are discussed as well as the advantages and problems which may be anticipated in the use of PERT/CPM technique. The approach presented here is based on the practical aspects of planning and implementing PERT/CPM and touches in the briefest manner only on the use of computers.

PERT/CPM is as simple as any current technique and makes it possible not only to know the exact schedule, but to be able to control the various project activities on a daily basis. Presented here, is a practical and easily understood method of using PERT/CPM so it can be efficiently implemented and become an effective planning and scheduling tool. Without adequate planning and scheduling there is no management control of a project.

INTRODUCTION

Today's rising cost of labor and materials, coupled with the demands for increased production and plant expansion, have forced most large companies to seek new and better methods of project management. Inadequate planning and scheduling on both new construction and major maintenance projects result in production losses which are most always economically far out of proportion to the direct labor and material cost of the project itself.

When properly applied, Program Evaluation and Review Technique/Critical Path Method (PERT/CPM) or simply "network scheduling" is, I believe, a major advance in the continuing development of project planning and scheduling. The standard method of scheduling, displaying, and reviewing progress has for many years been the bar chart method.

In applying the bar chart approach to planning and scheduling, it has always been difficult to measure progress against a bar that represents a long time period. It has also been impossible to indicate on the bar chart the dependencies that govern the planning and the scheduled development for a project. The insertion of "milestones," although an improvement providing more detailed control, still neglected the interrelationship and dependencies between milestones. The next logical step to overcome this deficiency was to diagram the sequence relationships between the milestones or events in a project.

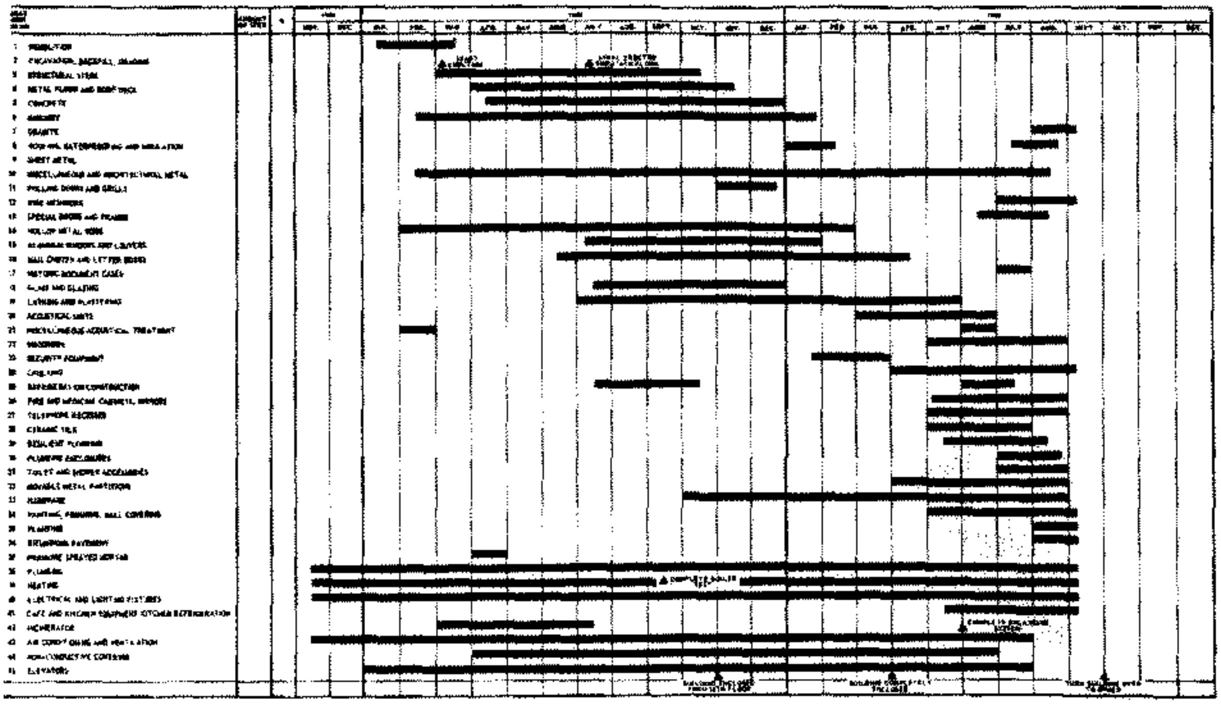

Figure 1. Bar chart schedule for a typical office building project.

ıe basis for what is presently referred to as the ⁄vork system was created in two parallel lopments: a DuPont chemical plant renova- project and the U.S. Navy's Fleet Ballistic Mis- ɔroject.

uPont, during the late 1950's was interested in ing a way to schedule major renovation and ıtenance projects so that a minimum amount ɔroduction was lost. With a team from the ⁄ac Division of Remington Rand Company, Du- t developed a project planning and scheduling nique, based on network analysis, which came ɔe known as the critical path method, abbrevi- CPM. CPM was applied by DuPont personnel ı great success. By using this technique, they ıd that they saved a considerable amount of ıey as a result of reduced downtime.

.t about the same time, the Navy Department faced with the problem of overseeing the large, ıplex, and extremely important Fleet Ballistic ɜile project—the now famous Polaris Project. problem was complicated because most of the k was new and there were several levels of sub- tractors working within the many divisions of job. The Navy sought a way to calculate or lict the effect of one part of the project on ɜlopments in all other parts. The object was the ıtion of trouble spots early enough to take appropriate action, and to make most effective use of the available time and resources.

The U.S. Navy Special Projects Office, Lockheed Aircraft Company, and Booz Allen & Hamilton developed, in January of 1958, a technique they called Program Evaluation and Review Technique—PERT. This was a technique that produced a schedule for a project along with a statistical probability of meeting the schedule and then evaluated and reviewed the progress of the project against this schedule. The Navy implemented the PERT system with much success on the Polaris project.

Both PERT and CPM utilize the same basic concept, that is, the use of network analysis to plan and schedule projects. The early differences between PERT and CPM have, to a large extent, disappeared and the term "network system" is becoming widely used. The network system uses the features of PERT and CPM, as well as some new refinements in the continuing process of project time and cost control.

FUNDAMENTALS OF PROJECT PLANNING

In order to appreciate the planning and management advantages of the network approach it is necessary to examine some of the factors which affect construction today. The most significant of these may be summarized as follows:

- The continued increase in plant expansion and new construction.
- The increasing cost of materials, equipment and labor, both skilled and unskilled.
- The long lead time required for the fabrication and delivery of many materials and types of equipment.

The tempo of construction activity has been accelerating rapidly. Shortages of skilled labor are already evident in many parts of the country, and will likely intensify in the months ahead. In order to obtain realistic bid figures and intelligent planning for a project, a company must provide the contractor with a concise plan outlining exactly what areas of construction require special attention and what the company schedule for completion is. Failure on the part of the company to convey to the contractor a plan indicating its needs will frequently result in efforts being expended in areas where they will do the least benefit to the overall completion of the project.

RESPONSIBILITIES OF THE COMPANY

Responsibilities. A company may delegate responsibility for specific parts of a project to organizations outside the company—architects, suppliers or contractors. However, the company initiating the project must assume responsibility for its successful conduct. The planning and management of the various segments and their proper integration to the overall project can only be determined by the company. The larger the project, the more complex become the problems of defining the relationship between the various segments, the greater the need for adequate planning, realistic schedules and performance requirements.

Let's consider the responsibilities which the company must assume and which cannot be delegated:

DEFINE THE PROJECT OBJECTIVES

ARRANGE PROJECT FINANCING

APPROVE FINAL PLANS AND SPECIFICATIONS

OVERSEE CONSTRUCTION PROGRESS

INTEGRATE CONSTRUCTION WITH NORMAL OPERATIONS

INTEGRATE UTILITY REVAMPING OR EXPANSION

DETERMINE EQUIPMENT NEEDS

ORDER AND SCHEDULE SHIPMENT OF EQUIPMENT

PROVIDE FOR DELIVERY AND INSTALLATION OF EQUIPMENT

DEVELOP POLICIES AND PROCEDURES

HIRE AND TRAIN PERSONNEL

SCHEDULE STARTUP

ADJUST TO OPERATING LEVEL (DEBUG)

It is because of this broad array of responsibilities that the company must take a well defined hand in planning and management of a project.

Participation of vendors and contractors. In order to have a meaningful network it is necessary that those vendors supplying the components for the project and the contractors charged with the responsibility for erection and installation provide scheduling information consistent with the PERT/CPM system in use by the company. It should be pointed out to these contributing organizations that a logical and meaningful schedule is to their advantage as well as to the company's. All competent organizations plan their work thoroughly. The user merely wishes to profit by their planning and to establish a realistic schedule from which the progress during the course of the project can be monitored.

In analyzing any project, it becomes readily apparent that the failure of any of the contributing vendors or contractors to perform on schedule will result not only in undue delay by subsequent contractors, but will cause a corresponding delay in the overall completion of the project. The most successful method to insure the active and continued participation on the part of contractors and vendors is to insert the PERT/CPM specifications in the contract bid packages, requests for quotations on equipment and in actual purchase orders executed. These specifications should be tailored to suit the magnitude and priority of these contracts or purchases. They should not impose unnecessary and burdensome scheduling or reporting on the part of the contributing parties.

FUNDAMENTALS OF THE PERT/CPM APPROACH

The heart of the PERT/CPM method of project management is the "network."

The network. A very simplified PERT/CPM network is shown in Figure 2. It is essentially an advanced concept of a flow chart, or drawing of the steps necessary to accomplish a given objective or task. It presents the logical sequence of work to be performed for the duration of the project.

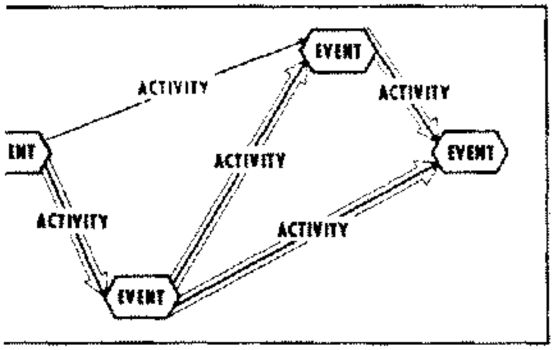

Figure 2. Pert/critical path network.

PERT/CPM network has three basic compo- -EVENTS, ACTIVITIES AND RELATION- S.

event. A milestone is a clearly identifiable in time which marks the beginning or com- n of a specific task in the project. The event e either a decision point or a physical accom- nent point. It can represent the start or com- n of a physical or mental task. In the ified network shown in Figure 2, the start might represent the start of steel erection on ain floor and the end event may represent the letion of steel erection on that floor.

tivity. This is another basic component of the ork. It is the physical or mental work required een two events which must be accomplished e the following event can occur. Activities are cterized by people using resources over a d of time to accomplish a stated objective. An ty is depicted in the network by a line or connecting events. The length of each activ- ne is arbitrary and bears no relation to the length of the activity it represents.

lationships. Combining events and activities in etwork serves the purpose of depicting rela- hips between the basic tasks involved in the ct. The network then is made up of a number ents, related to each other by activities, and ically shows the total plan for the project. network starts with a single beginning event, nds into any number of events or activity , and is completed with a single end event h represents the project goal. The requirement all activities be linked to a single start event a single end event assures that each activity be thoroughly evaluated in terms of its rela- hip to the start and end of the total project For example, in Figure 2, the uppermost event has two activities, both of which must be accomplished before the event itself occurs. It is evident that the managers of these two activities must coordinate their work, for they have a com- mon responsibility in attaining the event. All key relationships are depicted in this manner in the net- work.

Resource allocation. Since each activity involves work to be done, it follows that each activity must have at its disposal an allocation of resources. Thus, back of each activity in the network, and tailored to the work in that activity, is an alloca- tion of manpower, material and equipment.

Activity times. Because an activity typically rep- resents work, each activity on the network has a time value. The time values are based on the *elapsed* time needed to accomplish an activity. For example, if four man weeks of effort are required to perform a task, but the effort is expended over a six week period, six weeks is the elapsed time for the activity.

Network paths. A network path is a series of logically, sequentially related events and activities leading from the start event through the network to the end event. Network paths are further de- fined as being critical, semi-critical or slack paths. (Fig. 3)

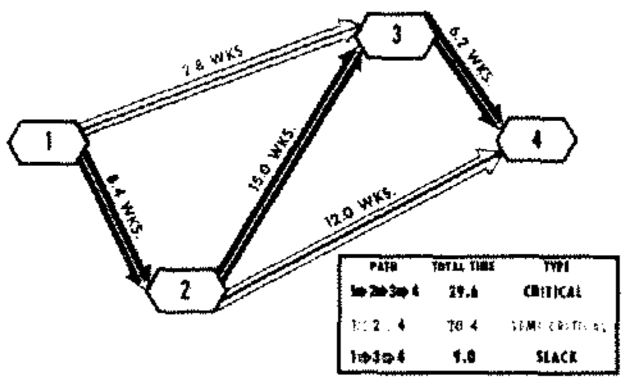

Figure 3. The critical path.

The critical path. The critical path is a series of sequentially related events and activities that re- quire the longest *elapsed* time for completion. Any delay in the activities in this path will delay the completion of the project. Typically, no more than five to ten percent of all the activities of a project will fall on the critical path, and hence will control the project. The critical path provides the best possible means of "management by exception," for the events and activities on the critical path are those which must receive particular attention and control.

Semi-critical paths. These paths may be described as being close to the critical path in terms of elapsed time required for completion. They can become critical as the project progresses and should receive almost the same degree of attention as the critical path.

Slack paths. Are those which are short in comparison to the critical path and are, therefore, unlikely to become critical without unusual slippage in the schedule.

In the network system, every possible path through the network is evaluated and assigned a numerical value which represents its degree of criticality. This value is called *slack* and is the difference between the scheduled duration of the project and the total elapsed time of the path being considered. Slack may be positive negative, or zero.

- A path is *positive* if the total time along the path is *less* than the scheduled project duration.
- A path is *negative* if the total time along the path *exceeds* the scheduled project duration.
- A path has *zero* slack if the total time along the path *coincides* with the scheduled project duration.

The arithmetic that is used to produce the PERT/CPM schedule is relatively simple and can be done manually. Most projects require no more than 200 to 400 activities and can be handled on a manual basis. The PERT/CPM approach, however, is not limited to manual calculations–it is tailored for computer operations. Therefore, the larger and more complex project involving thousands of activities are quite easily adapted to computer resolutions. This eliminates the laborious manual calculations on the larger projects and thus reduces the possibility of error. Schedules can be produced rapidly and are, therefore, current allowing the user to react quickly and economically to developments in the project.

NETWORK DEVELOPMENT

The development of a PERT/CPM network should begin as soon as a project is conceived. The level of detail will increase as more information becomes available concerning the project; however, the early attempt to develop a network will serve to identify the specific information needed first.

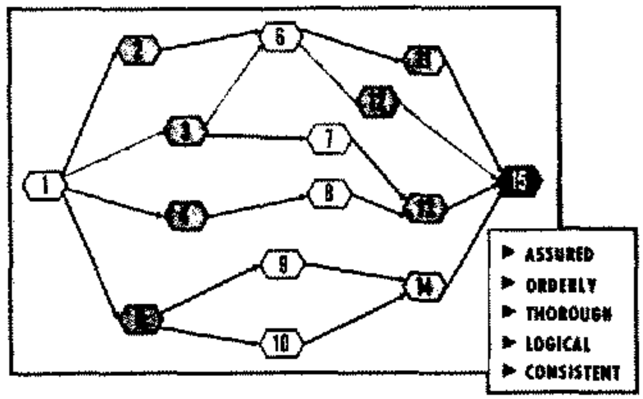

Figure 4. Building the plan.

The network should be implemented in three basic phases:

1. THE PLANNING PHASE
2. THE SCHEDULING PHASE
3. THE CONTROL-MONITOR PHASE

Planning phase. The first step in developing the PERT/CPM network is to define clearly the project objectives. These objectives should be stated as specifically and quantitatively as possible and written out so that all the participants in the project are aware of them and have a common goal in mind. The accomplishment of the project objective is depicted in the network as the end event. Because the network system welcomes a high level of detail, the user can break the project into as many activities as necessary to accurately and meaningfully describe it. In the planning phase, all the necessary input information–the data that PERT/CPM manipulates–is developed. The planning phase provides the opportunity to simulate the project on paper. By doing a competent job of planning, knowledge of the job, and insights into its problems are obtained. This results in the ability to take remedial action before becoming involved in costly and time consuming on-site revisions. In using other methods such as bar charting, these problems are not usually evident until the job has been completed.

In developing the initial or skeleton network it is often desirable to start with the end event in the project and work backward through the network, asking three questions at each event along the way:

1. What events and activities must be accomplished before this event can occur?

What events and activities must be accomplished after this event?

What events and activities can be accomplished concurrently?

iis initial or skeleton network is used to de-) the basic configuration and logic of the final ork, as well as to advance the project planning e next level of detail.

hen the detail network is complete, it should :viewed to assure that all the significant events been included and the network represents a)lete and logical plan for the project.

ith the development and review of the detail 'ork, more of the initial planning values of T/CPM become apparent. An obvious benefit ɔre thorough planning. It is impossible to build and network showing relationships and interionships unless everyone does his planning job 'ully.

ıe network technique also makes for consist-)lanning and more effective communication. In tructing a network, each participant has the : approach in terms of defining events and de- ing the activities involved. It brings all the par- ants to a common understanding of the total : plan, their own individual areas of responsi- y and how their particular jobs are related to rs.

:heduling phase. In the scheduling phase, the t information produced in the planning phase ed to produce a schedule. You will notice that planning phase has been separated from the duling phase. One must finish planning of the ɔefore a realistic schedule can be produced. All ıctivities must be defined before the durations e) can be incorporated. As the schedule is pro- :d, the critical, semi-critical and slack paths are loped.

ɔntrol-monitor phase. Because of PERT/CPM bility, this is probably the most valuable of the : phases. Relatively little effort is involved on ɔart of the user; possibly thirty percent of the [effort expended in his effective use of PERT/ [. In this phase, the user is able to maintain a ıre of the overall status of the project in gen- and the current activities in particular. Be- e PERT/CPM deals with actual job conditions is constantly looking ahead, problem areas are tified well in advance, allowing sufficient time valuate these problem areas and to take reme- action. As a result, lost time and additional on the project are minimized.

OBTAINING TIME ESTIMATES

When the detail and logic of the network have been established and reviewed, time estimates are assigned to each activity. It is important that these time estimates be made by the person who determined the need for the activity in the network and who has the responsibility for doing the work that it represents.

Avoiding biased estimates. Time estimates should be obtained by skipping around the network at random. If the time estimates are made following a specific path, there is a tendency to add up the times mentally and see the critical and semi-critical paths. This results in a tendency towards overoptimism in the time estimates of activities along these paths.

Recording the time estimates. The most efficient method of recording time estimates is to write them directly on the network diagram. This assures a more clear understanding of the activity involved and minimizes the likelihood that an activity will be overlooked.

It is important to emphasize that the time estimates given should reflect the judgment and experience of the contributor, based on presently known facts. On this basis, the contributor should be willing and able to abide by the estimate unless there is a change in the scope of the work or a change in the allocated resources.

Defining resources. For each activity the PERT/ Critical Path analyst should record on the network the resources on which the time estimate was based (the level of resources in terms of manpower assigned, shifts worked per day and days worked per week).

Supervisory review of the time estimates. While the time estimates are based on the experience and judgment of the individual contributor, the estimate should be reviewed by the project manager. It is essential that the project manager have confidence in the data being used as a planning and control tool for the project. It is not intended that the project manager "second guess" his subordinates or subcontractors. However, he may be aware of some future commitments or changes in resources that would affect the time estimate given.

After the time estimates have been established and reviewed, they should remain firm unless there is a change in the scope of the work or a change in the allocated resources.

NETWORK CALCULATIONS

Performing the PERT/Critical Path calculations manually. Small networks of approximately 100 to 400 events can be processed readily by hand. Occasions may arise, even with larger networks, when it will be desirable to calculate a critical path quickly, without a computer run. Described here is an efficient hand computation procedure for single time estimate PERT/Critical Path which is essentially the same procedure as that built into the computer programs.

Numbering the events. Events should preferably be numbered sequentially. Sequential numbering means that the predecessor event of an activity always has a lower number than the successor event of the same activity. Figure 5 is numbered sequentially. Sequential numbering is, however, not absolutely necessary—it is simply a convenience. The hand computation procedure will work with any event numbering system, including random numbering.

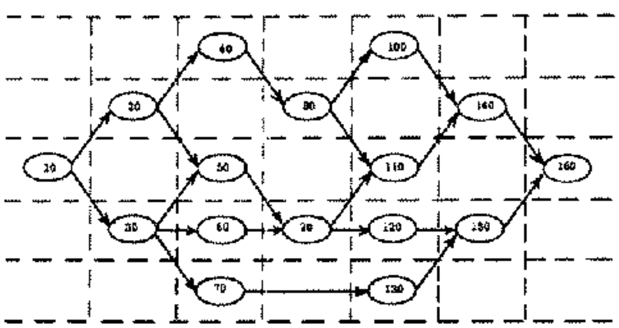

Figure 5. Method for Easy Location of Event Numbers.

The manual job calendar. The first step in the manual calculations of the activity schedule is to generate a job date calendar blank such as the one shown in Figure 6. This blank calendar should include the months for the period covering the entire life of the project. After completion of the calendar blank, the standard holidays and other non-work days should be masked. Job day one should then be inserted in the appropriate month and day of the month on which the project will be started. From this point all job working days are sequentially numbered starting from job day one and continuing on through the life of the project, and preferably exceeding the acticipated project completion date by some time period to be selected by the PERT analyst (Fig. 7).

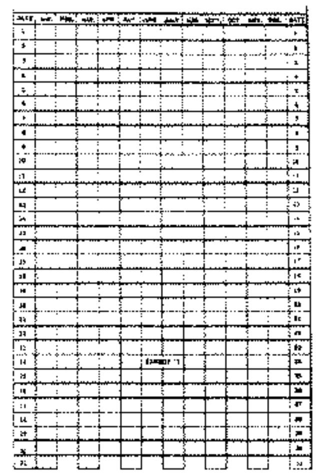

Figure 6. Working day calendar—conversion table.

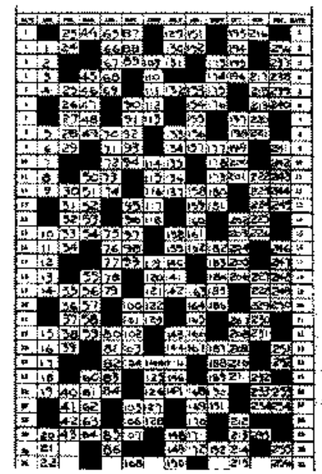

Figure 7. Working day calendar—conversion table.

You will note that by masking the standard holidays and other non-work days, it is possible to generate a calendar for a five, six, or seven day week. It should be noted here that the same approach can be taken on an hourly, weekly, or monthly basis depending on the particular project under consideration. The time required to generate the appropriate job calendar is insignificant compared to the benefits derived during the course of the project.

Calculating the earliest expected time (Te). Figure 8 shows a simple seventeen activity network. The numbers indicated *beneath* the activities

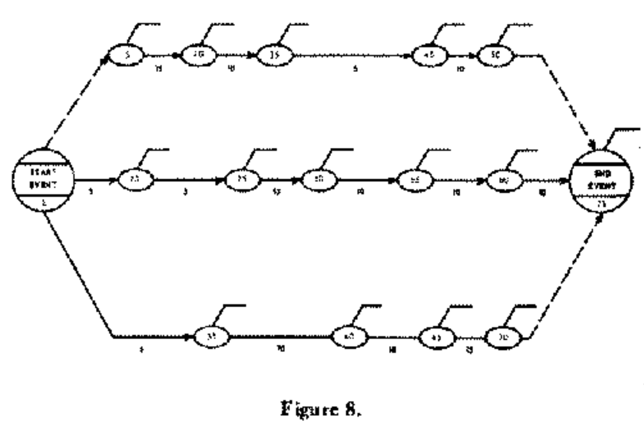

Figure 8.

lect the duration of these activities. The first ective is to establish the earliest expected time the completion of all activities and, in turn, the liest expected time for the completion of the ject. Considering the three paths through this work we find the following:

- Path 1-5-10-15-45-50-75 has a total duration of 40 days.
- Path 1-20-25-30-55-60-75 has a total duration of 50 days.
- Path 1-35-40-65-70-75 has a total duration of 45 days.

e longest path through this network is obviously 0-25-30-55-60-75 which has a total duration of days. Therefore, the duration of this project or earliest possible completion would be on job 50.

Earliest expected time. The sum of the activity es along the longest path from the beginning of network to the event in question, or end event, lefined as the earliest expected time. The adjec- "earliest" indicates that it is assumed all activ- s are started as early as possible regardless of the ount of slack they may have. In this discussion, earliest expected times are assumed to be ex- ssed in days from the start of the project. Most nputer programs calculate these times in terms calendar dates.

Calculating the latest allowable time. If you will er to Figure 9, you will observe that the earliest ected completion time for each of the events the network has been inserted below the time icator line. In addition, the "latest allowable e" has been inserted above the time indicator . The latest allowable time was arrived at in the owing fashion: Having established the earliest

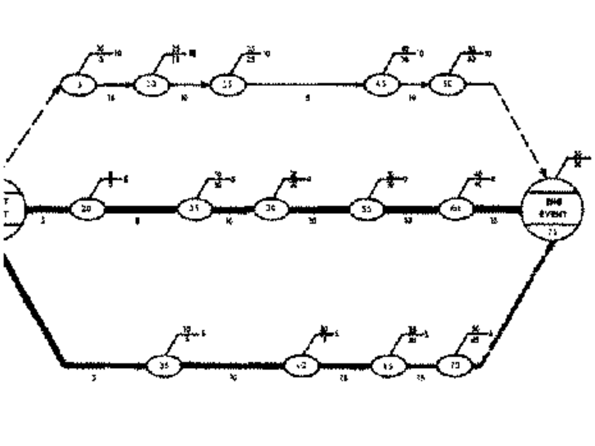

Figure 9.

completion as job day 50 and indicating this figure as the earliest completion at event 75, we now insert job 50 as the latest allowable time for completion above the time indicator at event 75. By proceeding in reverse order through the network, *deducting* the activity durations from the *latest* allowable time along each given path, we arrive at the latest allowable completion for each event in the network. You will note that activity 50-75 is drawn as a dotted line; this indicates a "dummy" activity. A dummy activity denotes a technical restraint but does not require the use of any resources. The duration for a dummy activity is always *zero*. Therefore, by taking the latest allowable completion of 50 days shown at event 75 and deducting zero duration for activity 50-75, we find that the latest allowable completion for event 50 will be job day 50. The Figure 10 shown immediately to the right of the job day indicator from event 50 indicates that there are 10 days of slack relative to the project completion if all the activities along this path are started and completed by their earliest date. You will find this is typical throughout the network. The earliest expected completion is shown below the time indicator, the latest allowable completion is shown above the time indicator and the amount of slack or criticality is placed immediately to the right of the time indicator at every event in the network.

The slack for each successor event should be calculated by means of the following formula:

Slack = latest allowable completion (TL) - minus - earliest expected completion (Te).

Identifying the critical path. The critical path is defined as the sequence of activities which have the least amount of slack. If you again refer to Figure 9, you will find that the critical path falls through events 1-20-25-30-55-60-75, which has a slack of zero indicated at each event along this path. The sub-critical path is found to fall through 1-35-40-65-70-75 which has a slack of five days indicated and the slack path is found to be 1-5-10-15-45-50-75, which has a slack of 10 days.

When an event has two or more preceding activities, the *latest early completion* will govern. If you will refer now to Figure 10, you will find that an additional technical restraint or dummy activity has been inserted from event 15 to event 30. The insertion of this single dummy restraint has generated an additional path through the network for our consideration. This path can be defined as events 1-5-10-15-30-55-60-75. In order to

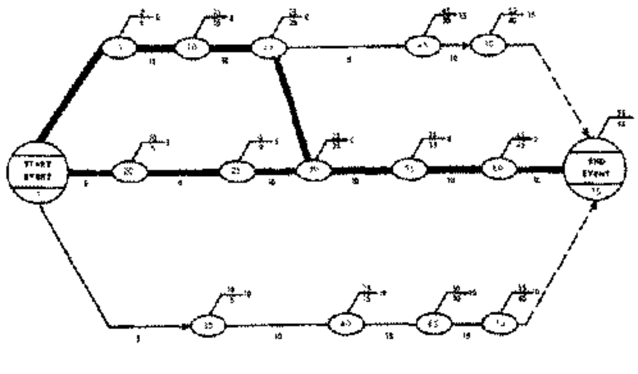

Figure 10.

determine the earliest completion for event 50, it is necessary to evaluate both activities preceding event 50, 15-50 and 25-50. Although activity 25-50 could conceivably be completed as early as job day 20, it is also evident that event 15 cannot complete any earlier than job day 25. Therefore, the earliest possible completion for event 30 would be job day 25. Proceeding through the subsequent activities 30-55, 55-60, 60-75, we find that we have arrived at a new early completion date which is indicated as job day 55 beneath the time indicator at event 75.

You will notice that the introduction of this single dummy restraint has had a multiple effect on the project schedule:

- First, it has shifted the critical path from activities 1-20, 20-25, 25-30 to activities 1-5, 5-10, 10-15, 15-30.
- Second, it has changed the earliest possible completion for the project from job day 50 to job day 55.
- Third, it has changed the earliest expected completion for events 30, 55 and 60.
- Fourth, it has changed the degree of criticality or slack for events 45, 50, 35, 40, 65 and 70.

If you recall, it was stated that the development of the logic of the network precedes the generation of a schedule. One of the major reasons for this procedure now becomes obvious. Changes in logic require a corresponding change in schedule. It should also be pointed out in considering the sample network, that if any activity duration had been omitted, it would have been impossible to arrive at an early completion date for the project and, in turn, latest allowable date.

If you will now refer to Figure 11, where we have interjected an additional dummy restraint from event 30 to event 40, you will notice that the

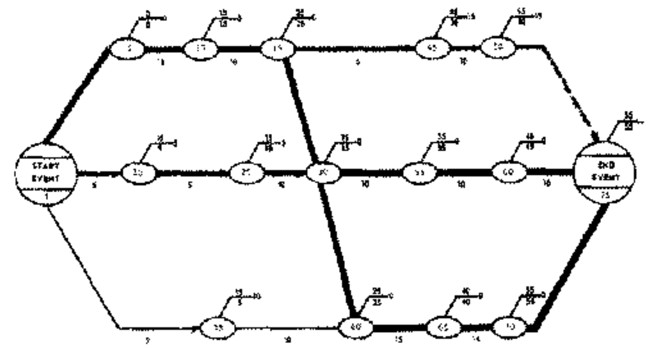

Figure 11.

critical path has again shifted, only this time we have two critical paths. Both indicate zero slack. This further indicates that any change in logic will require a proper analysis of the network to reflect the corresponding changes in the schedule. These simple examples also amplify points discussed earlier, such as:

- A comparatively small number of activities constitute the critical path and therefore govern the life of the project.
- Paths which are subcritical can frequently shift to the critical path.
- The importance of completing the logic and analyzing the network prior to the generation of a schedule.

Networks of 1 to 400 activities can be processed in this manner without difficulty. However, when expanding into larger and more complex networks, which may involve 200 to 2,000 activities, the use of a computer becomes necessary in order to provide *timely and accurate* schedules.

Now let's consider the conversion from job days to calendar days. If we refer to Figure 7 and the job calendar shown previously, we can now convert job days to calendar days. Let's select any event in the network, as an example, event 30 which has a late completion of job day 25 and an early completion of job day 25. If you now refer to the job calendar and locate job day 25 in the columns, you will find that this corresponds to the 5th day of

February. Now let's take our end event which ›ccurs on job day 55. If we again check the calendar, we will find that job day 55 falls on the 18th of March. The selection of these random events is done to show that once the job days have been identified, it is a simple matter to convert them to calendar dates without the need of calculating calendar dates for all events or activities in the network. This is of considerable advantage when working manually on a working network.

The computations and conversions described above are the same as those which a computer performs for all activities in the network in a matter of seconds. The computer, in addition to performing the calculations, produces this information in the form of reports as requested.

The smaller networks of up to 400 activities or less are best handled by using a working copy of the network with the job days and significant calendar dates indicated on this working copy. It will not only provide the people involved a constant and clear picture of the overall plan, but will also reflect up-to-date progress through the life of the project.

The larger networks of several thousand activities are handled by computers in order to keep the data timely and up to date. However, even on computerized networks, it will frequently be to your advantage to be able to convert portions of the network to a manual operation in order to evaluate proposed changes in logic and their effect on the schedule.

PERT/CPM SCHEDULING FOR MAINTENANCE PROJECTS

The use of PERT/CPM for plant maintenance type of projects is undoubtedly one of the most beneficial and most easily implemented uses of PERT today. Almost all major maintenance projects within a plant require some down time involving lost production. This loss of production is most always economically out of proportion to the direct labor and material cost in this type of operation. The primary purpose here is to perform the required maintenance in the shortest possible time in order to resume normal production as early as possible.

The application of PERT/CPM on maintenance type of projects is always direct, simple, and less involved than any other application. The people participating in the project are most always in-house personnel. In those rare instances when outside contractors are required, they in turn would be working under the direct supervision of in-house personnel. In addition, the actual maintenance work is generally completed in a matter of hours. This eliminates the need for progress reporting or the need of a computer. The use of the network right on the site and the marking of this network as the project progresses is the best possible method of monitoring a project of this nature. The network, in addition to providing an overall picture of this maintenance project, indicates the responsibility for each and every activity, its sequence of performance and its effect on the overall completion.

As in most projects, which are PERTed, most of the work is performed during the planning stage; in maintenance projects this would account for approximately 95%, the remaining 5% in monitoring the actual network as the work progresses. The greatest advantage here is in allowing the project personnel to simulate this maintenance shutdown before the actual work starts. This, as usual, provides many advantages. It allows sufficient time to identify possible problem areas, this in turn will help project personnel select alternate courses of action. This is rarely possible once the work is in progress. The advanced planning performed during this simulation of the project insures that the components required will be on hand in sufficient time. It insures the proper and utmost use of the personnel available. It will provide an accurate timetable, hour by hour, by which plant personnel can determine how accurately they are meeting their predetermined schedule and return to production.

The network used during these maintenance projects also serves an additional function. Beside providing an accurate and detailed plan of the shutdown, it will provide, upon completion of the project, an accurate record of the problems encountered, the actual durations of the activities performed, and can therefore be used as a guide on future projects of a similar nature.

REQUIREMENTS FOR THE EFFECTIVE USE OF PERT/CPM

PERT is not a perfect technique; it should not be so represented. The basic concept of PERT is logical and easily understood and has therefore achieved a high degree of acceptance. The significant problems of PERT are almost entirely concerned with its application, rather than the mechanics of the technique.

The simplicity of the PERT concept can be deceptive and can lead one to underestimate the caliber of individual required and the extent of training needed for the effective application of PERT/CPM.

PERT/CPM should be kept as simple as possible, consistent with the scope of the project under consideration. Network planning should be defined only to the point where practical results can be obtained. Too much networking and detail defeats the basic advantages of the method; the technique begins to run the personnel on the project instead of the personnel running the project. It is pointless to detail a network outlining thousands of activities where hundreds would be adequate.

Sufficient time must be allowed to develop a comprehensive network, keeping in mind that the major portion of the project planning is being done at the start, while there is some flexibility in choosing alternative plans. Supervisory time, as the project progresses, is minimized by directing the supervisor's attention to those areas where his efforts and decisions are required. PERT/CPM also identifies potential problem areas well ahead of their actual occurrence so that crisis decisions can be avoided.

Securing realistic time estimates is often difficult when a new work area is involved and little company experience exists. This problem, however, exists regardless of the approach used to scheduling, whether it be PERT/CPM or Gantt charting.

It should be recognized that the network accuracy reflects the best thinking of those planning the work. It is always possible that a revised network would more accurately reflect the project plan and that a better plan could be developed. However, this problem basically comes down to the fact that PERT is no better than the people who provide the input to affect the approach. This problem merely emphasizes the need that the most capable people be assigned to conduct the planning and analysis and construction of the network.

Networks should be neat and legible because they are the graphic representation of project tasks and decision points indicating who should communicate with one another on the project and when communication should take place. The network delineates responsibilities in areas needing coordination and as a result, responsible individuals on each part of the project must acquire a uniform understanding of the total project through this depiction of the network. This helps clarify the communications process.

Care must be exercised in the administration of resources. Efficiency is largely measured by how well a company utilizes its resources. Here, PERT can make a major contribution. This is largely

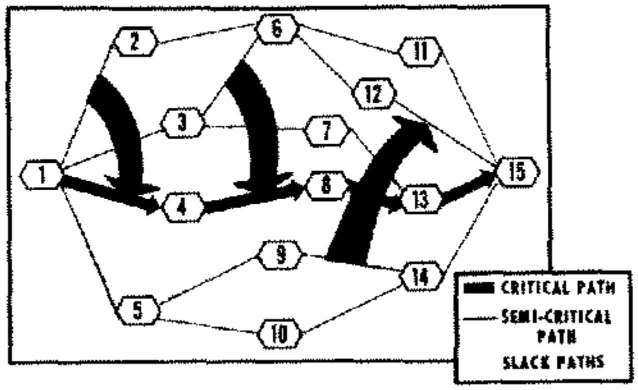

Figure 12. Trade-off of resources.

accomplished through trade-offs. Paths through the network are made up of accumulations of resources of the activities on each path. Paths shorter in time than the critical path—slack paths—may have resources which can possible be applied to the critical path to shorten it. This is termed "trade-off of resources." Carefully planned and carefully rationalized resource trade-offs can substantially affect the end result of the project. When the resource trade-offs have been exhausted, the company may elect to use premium time in order to maintain the project schedule. PERT's ability to keep management attention focused on the critical path, which governs the life of the project, makes it quite evident where the premium time will have the most effect and thereby minimize additional cost.

CONCLUSIONS

We have found PERT/CPM contributed significantly to the success of both major construction and maintenance projects, ranging in scope from the design and erection of our Cleveland Refinery and Warehouse to the complete refurbishing of our Koeppe Hoist. It has provided us with an effective method of planning and scheduling which is thorough, logical and consistent. Projects have continually been completed on or ahead of schedule with a corresponding savings in cost and a minimum of production lost.

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