

PERT AS A TOOL FOR
BUILDING CONTRACTORS

by

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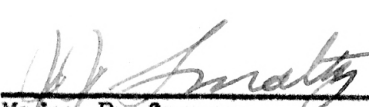
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INTRODUCTION

Program Evaluation and Review Technique (PERT) is a powerful management tool developed in recent years. It has created much interest and received much widespread publicity ever since its development, especially within the construction and defense industries.

It is a method of planning, replanning and progress evaluation in order to control a program more accurately and effectively. This technique was first developed during 1958 at the Navy Special Projects office by a project team which studied the application of statistical and mathematical methods to the planning, evaluation and control of research development (R&D effort). Basically PERT consists of the following elements.

1. Project analysis and charting
2. Time estimates
3. Computation and report writing
4. Review, control and updating

When PERT is used properly, the results can be truly significant.

Through its use we have a means of achieving accuracy in the planning and control of activities. Areas of a project that require remedial decisions can be detected and proper use of three major factors, time, resources, and technical performance can be achieved. PERT adds advantages by providing a method for establishing a network of a program. Events can be depicted and their relationships are expressed in activities or jobs with three time estimates over the network.

Construction and engineering are moving into a new era of accuracy and efficiency. Bidding on critical requirements has become very important due to competition. PERT with the use of electronic data processing machines and other rapid calculating systems helps to accelerate the required results and increase the accuracy of information for the contractor.

PERT has been and is presently under continued development and modification. However it will take much creative thinking, development and experience to invest it with the full usefulness of which it appears to be capable.

History and Progress

Program Evaluation Review Technique (PERT) was originated in the Special Projects Office (SP) of the Bureau of Ordnance in January 1958. The project team was organized to study the application of statistical and mathematical methods to the planning, evaluation, and control of a Research and Development Program involving a series of tasks scheduled in logical sequence and leading to a final objective. This included the research and development of improved methods for the planning and control of the complex and far-reaching program developing the Fleet Ballistic Missile (FBM). The result of this study is called "PERT" (15).

Thus PERT was an outgrowth of military needs for better coordination and closer scheduling of complex defense programs. As a result of this program many millions of dollars were saved and the first operational units were available a year and a half ahead of the original schedule.

Since that time, PERT has spread rapidly through the United States defense and space industry. Currently almost every major government and military agency concerned with space programs is utilizing the technique. Also large industrial contractors are currently utilizing PERT extensively. Small businesses wishing to participate in national defense programs find it increasingly necessary to develop a PERT capability if they wish to be competitive in this field.

At about the same time the Navy was developing PERT the Du Pont Company, concerned with the increasing costs and time required to bring new products from research to production, initiated a study which resulted in a similar technique known as Critical Path Method (CPM).

Many variations of these techniques are in different stages of development or application, such as the Task Reporting and Current Evaluation (TRACE), Resource Allocation and Multi-Project Scheduling (RAMPS), Scheduling and Control by Automated Network Systems (SCANS), the Program Reliability Information System for Managements (PRISM), and some thirty-odd additional systems (11). These in the main are the offspring of the two basic systems, PERT and CPM. They have been developed for a specific company, industry, or branch of government to meet a specific need of that organization.

What is PERT?

The Program Evaluation and Review Technique is a management control tool for defining, integrating, and interrelating what must be done to accomplish program objectives on time. PERT is a statistical technique.

Through its use, areas of a project that require remedial decisions can be detected and the effect of trade-offs among the three basic factors--time, resources and technical performance can be determined. One of the major advantages of PERT is that it provides a method for establishing a network of a program. Each event is depicted and its relationship to the others expressed. PERT uses time as the common denominator to reflect planned resource application and performance specifications. It also provides:

1. Aids in planning and scheduling a program.
2. Better communication.
3. Continuous, timely progress reports, identifying potential problem areas where action may be required.
4. A simulation of the effects of alternate decision under consideration and an opportunity to study their effect upon the program deadlines prior to its accomplishment.
5. Probability of successfully meeting deadlines.

Briefly the PERT system is a management control tool which reflects the complex interrelationships of a large number of activities. The activities make up one integrated network of events and their completion leads to the end objective of the system.

Some Features of the PERT System

Before entering into the theoretical aspects of the PERT system it is worthwhile to look at some prominent features of PERT. Some of the important ones are described below: (12)

1. Specific events, which must occur in the process of attaining the final objective are selected. These events must be both meaningful to the development plan and of a definite, recognizable nature and each must be a point in TIME. It is known that plans will change and hence some or all of the events will change during the course of time. However at any point in time a definite future plan exists. It is this plan that is typified by the set of events that are the specified accomplishment. In a building construction program, for example there are many hundred or thousand events according to its size which must be accomplished before the completion of the entire building. An event does not necessarily imply the completion of a piece of hardware; it may be the completion of the foundation work or even the receipt of money necessary for subsequent activity to begin. In other words all known constraints either administrative, physical or technical are included in the selection of events.

2. The planned events are linked graphically so as to portray the interdependencies among them. The chosen events comprise a set of accomplishments, each of which will exist at a given point in time as the culmination of one or more activities. The activities are the links between events.

3. The next important feature is the estimation of the times necessary to move from event to event together with a measure of uncertainties involved. The time estimates are obtained from the technical personnel within the contractor establishments directly charged with the accomplishment of the activities. The evaluation system deals with the future and the future is uncertain. PERT is designed to estimate this uncertainty. It is done by choosing three estimates of the time necessary to perform each activity from

a technical man familiar with the activity. The three time estimates are:

- a) Optimistic time
- b) Most likely time
- c) Pessimistic time

PERT estimates the future on the basis of informed judgements. The correctness of the judgement depends on the validity of the authoritative estimates. Uncertainty will tend to be high and validity low when events in the remote future are estimated. Improvements will be obtained as events come closer to present.

4. The system is so designed that current progress information may be obtained at any point in time and in a form subject to ready interpretation.

5. A measure of the uncertainty (probability) associated with the accomplishment of events is determined by using statistical methods.

Advantages of PERT

PERT application to a large program gives the manager information which he may use for better planning and decision making within the time available to him. Because of time limitation, or lack of information, or both, managers are often unable to evaluate alternate courses of action in advance. For example a building contractor may not be able to know what particular activity will hold him back in the continuation of the construction program. Therefore, by use of PERT, decisions can be made with knowledge of the overall consequence or effect upon specific objectives.

A major advantage of PERT comes from the adaptability of its concept (6). Although it was first developed and adapted for a particular weapons systems,

it has been widely used in many industrial applications: the installation of a new computer, the new-product process, construction and maintenance activities, mining operations, and highway construction are a few examples. Another feature is that one can compute and evaluate the effect of alternate decisions under consideration upon any subsystem as well as their impact upon the overall objectives.

For large systems characterized by many complex interrelationships the PERT system provides a means of better management. Efficient operation of any evaluation system is dependent upon the timely receipt, analysis, and use of accurate information. The procedures outlined are designed to obtain the necessary information rapidly and with minimum effort.

Functions of PERT

With the aid of a computer, PERT gives the current reports, the current validity of approved plans, and schedules the progress to date compared with the program objectives and outlook for meeting ultimate objectives on TIME. More specifically it performs the following functions.

1. It generally shows the sequence and interrelationship of significant finite events in the plan to achieve and objectives in the planned program.
2. It measures the relative probability for accomplishing the activities in the flow network. These are recorded on the basis of experienced estimates of time and range of time necessary to complete the activity.
3. It unites network and time data to provide the combined impact of such data on capacity to meet program deadlines.
4. It pinpoints, on the one hand the activities for which criticalness may require remedial decisions and on the other hand, activities for which

surplus time exists and where some delay will not affect any change in meeting the end objective deadline.

5. It computes the current probability for meeting scheduled completion dates, based on the comparison of current expectation with scheduled dates.

6. It provides a summary picture of total progress and progress outlook on a continuous basis.

PERT NETWORK DEVELOPMENT

The first step in developing a PERT network is to define the program objectives. This is accomplished by the analysis of the total work and by identification of the functional areas. The different functions and the components of the program should be clarified by detailed statements that describe the events which will make the final objective.

The next step is a work plan which expresses the technical approach and a time scale for the entire program. The time scale shows when large work groups are involved and the extent to which one depends upon another. The development of the network from the basic steps will occur next.

Basically the PERT network is the development of the bar chart, presumably derived from a Gantt chart (3). It is still widely used, serves to plan the occurrence of entire phases of tasks in series and parallel groups over a time period as shown in Fig. 1.

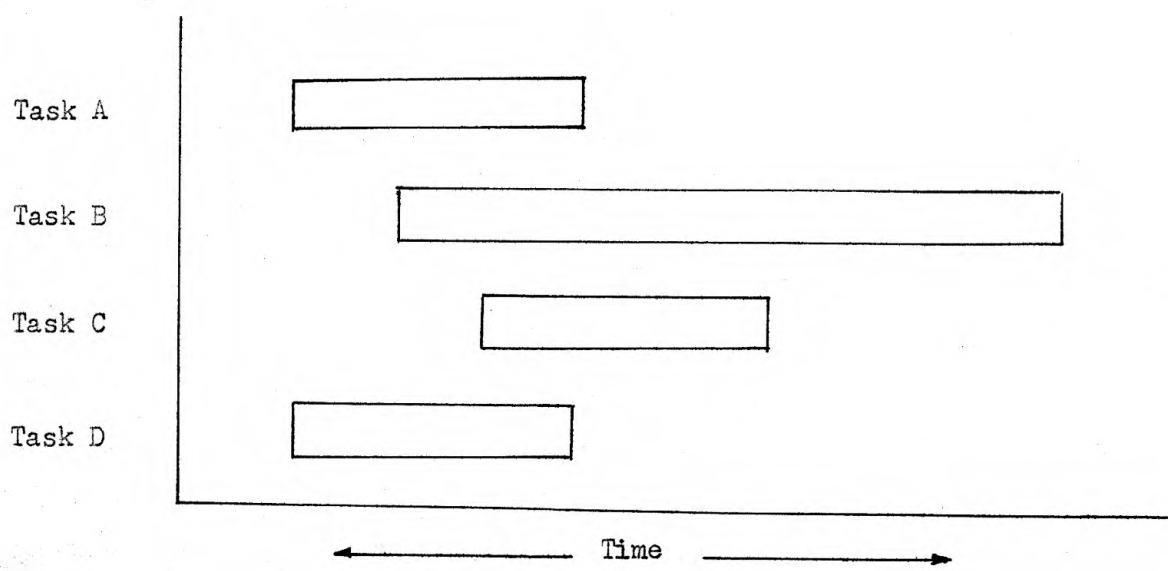


Fig. 1. Program bar chart.

From the simple bar chart a "milestone chart" is derived which indicates significant event accomplishment as shown in Fig. 2.

Both of these networks tie together interdependences between tasks and significant events. Series and parallel lines shown indicate the inter-relationship constraints between events and tasks as shown in Fig. 3.

At this point the activity network is developed. It is the pictorial representation of the events which take place in the program. In the milestone chart, the events are shown in blocks. For PERT network it can be depicted by blocks or circles and these are connected by arrows which represent the activities necessary to achieve the events. The network is the basic planning tool of the PERT technique. It consists of those milestones that must be accomplished under the approved plan of any program and therefore is the actual procedure to be followed.

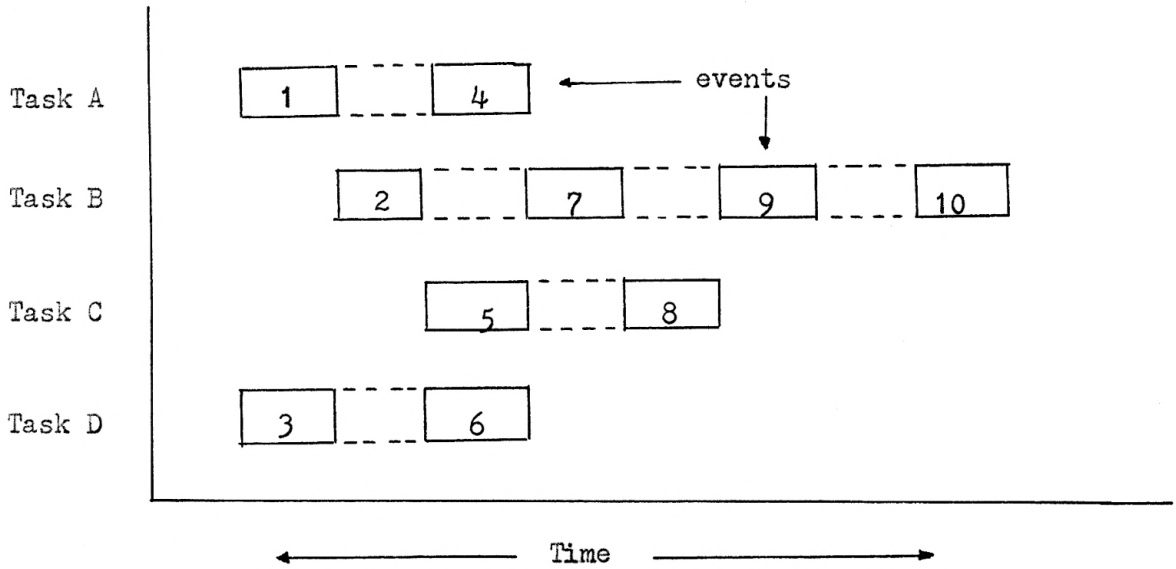


Fig. 2. Milestone chart.

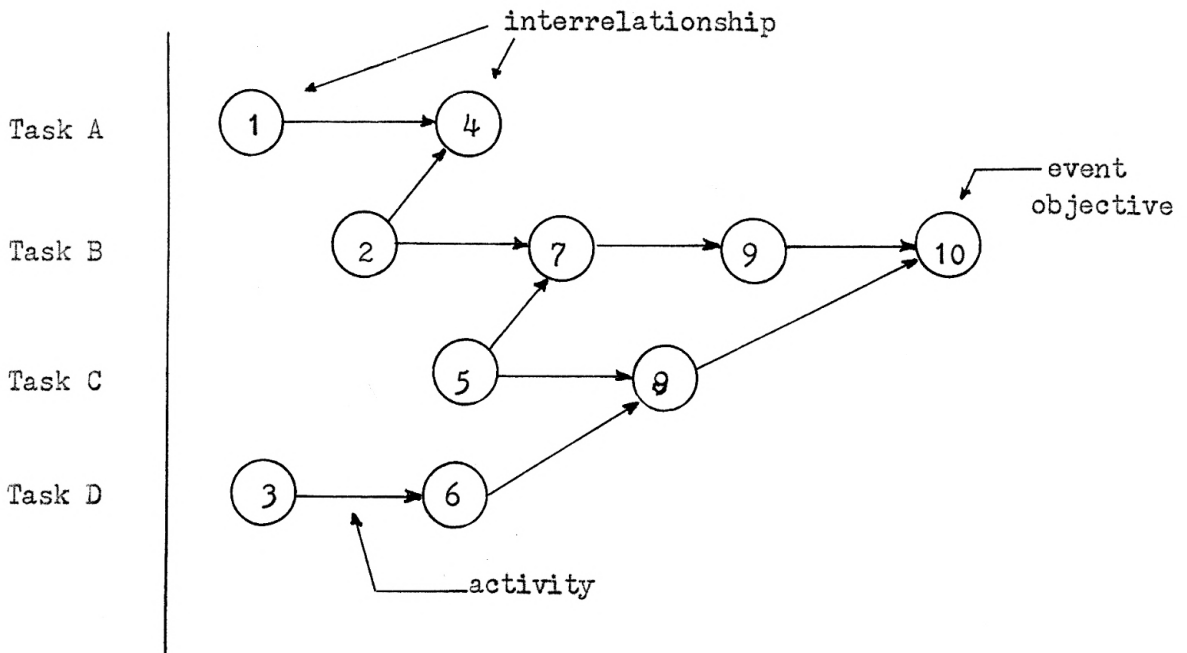


Fig. 3. PERT network.

A team approach is the effective method to develop a detailed network. This should be developed at the level where the work is to be performed. The size of the team depends upon the size of the program in question. And the areas of representation in the team depends on the type of program. For example, for the manufacture of a product, the representatives are included from engineering, quality control, manufacturing, reliability, purchasing and specialists from other functional areas. The team evolves the best plan for completing a project and the leader must be thoroughly familiar with the planning requirements established. According to the size of the program the detailed network must be broken down into smaller networks of activities and events to reduce the complexity of a very large network.

For very complicated networks where the planning could become hazy and confused, experience has shown that the backward approach is good up to a point. It means to start with an end objective and then work backward in developing the network. The basic line for the network is a starting point or the first event in the network. It must be dated and numbered.

Events are marked and joined together by activity lines. A most important factor is to have executives of functional areas on hand together with PERT specialists when the network is being developed, for it is the user's plan and represents how they intend to fulfill commitments.

Upon completion of the network, the events are numbered, responsibilities are assigned to the activities, interface activities with other tasks are shown, and three time estimates for each activity are obtained from those assigned or having the responsibility for each activity. The network is recorded and then may be processed either manually or by an electronic computer depending upon the complexity. Necessary replanning is done by the team if the critical path (that is the longest path in the network) indicates

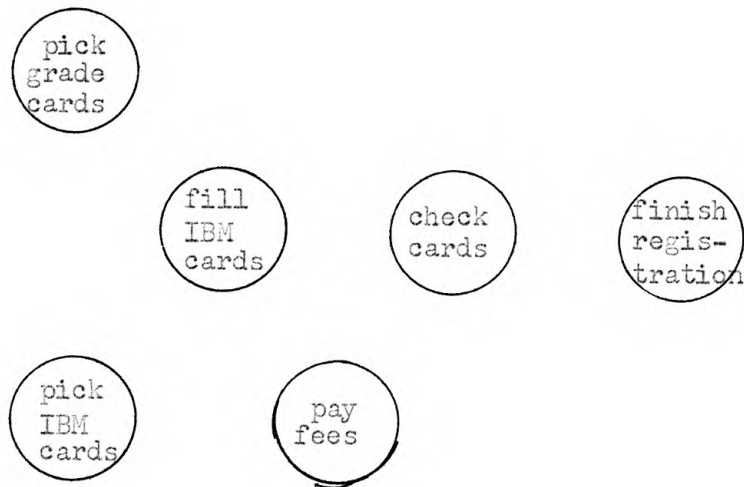
that too much time is required in attaining the end objectives. This may involve a change in the length of time to accomplish an event or change in the objective.

Events

The flow plan consists of events that can be established as points in time when a decision is made. It should be recognizable as a particular instant in time. A further definition of an event is "the start or completion of a task; not the actual performance of that task." Events, therefore, do not require time or resources. The event is shown on the network as a circle, square or other geometric symbol and description or numbers are written therein for easy identification.

Events should be sequenced according to technical requirements. For example, if two events are assemble and inspect, the event number 1 will be assemble which will precede inspection event number 2. For best results more attention should be given in detail to areas where probability of program delay is greatest. In detailing a network the exact interrelationship of events that leads to completion must be known and the time between two events should be related to the degree of control desired.

Descriptions of each event are placed on the flow chart as the example, shown in Fig. 4. After all events have been placed on the chart, identification numbers are assigned to each event.



Clearly defined events include such items as the issuance of task outlines, the approval of final drawings, the completion of final designs, or the completion of procurement. A satisfactory event must be (1) positive, specific, tangible and meaningful to the project, (2) definitely distinguishable at a specific point in time; and (3) really understood by all concerned with the project.

Activities

The events on the PERT network are connected by activity lines represented by arrows. An arrow connects two successive events. An activity cannot be started until its preceding event has been accomplished. A succeeding event to an activity cannot be accomplished until the activity is complete.

Qualified personnel acquainted with the area of the project to be analyzed should assist in determination of the interconnection of events. They should be aware of the over-all planning of the area covered in the

flow chart so as to indicate the appropriate connections.

For example, in the network of Fig. 3, it is expected that events numbered 9 and 10 are related and that event number 9 will have to be reached before event number 10 can be accomplished. Events number 9 and 10 are so related and interdependent that unless 9 is completed the activity between them cannot be started. Furthermore it will be impossible to reach the point in time represented by 10 until the activity represented by the arrow between them is completed. More specifically: painting cannot be done until door is installed, installing of door cannot begin until the hinges are fixed and so on.

The activity connecting events start at time "C" or time "now" and work toward the extreme right until each event is properly related to all the other events either directly or indirectly. This should be done with minimum of "cross over" lines or "backtracking".

Time Estimates

To complete the network, the elapsed time necessary to complete an activity in a specified manner must be estimated. The same person who determines the activity between events should also provide those estimates of elapsed time for performance of the activity. He should have full knowledge of a "fixed resources mix" available to him and should be capable of performing the activity. More realistic evaluations could be made if three estimates for each activity were obtained. This practice was developed to help the personnel who make the estimate, to overcome their built-in knowledge and prejudices of the existing schedules, and to provide more information concerning the inherent difficulties and variability in the

activity being estimated. Consequently, three time estimates for each activity are selected and defined as follows:

1. Optimistic Time - The first estimate is an "optimistic" one, in that it gives the best or shortest time. It is designated by the letter "a". There is little hope in completing the activity in less than the optimistic time. If the activity were repeated 100 times, this would be the best time of the 100 time operation with a probability of 1/100.

2. Most Likely Time - It is designated by the letter "m" and the one that would occur most often if the activity was repeated under exactly the same conditions, 100 times. If many knowledgeable people were asked for the most likely time, the value given most often would form the most likely time estimate.

3. Pessimistic Time - It is the longest time that the activity would take and is designated by the letter "b". Or it is the worst time in the 100 times operation with a probability of 1/100.

Time estimates should be entered on the flow charts along the arrows to which they apply. Further the three time estimates should be based on elapsed calendar time, (days, weeks or months including holidays) rather than upon work days which may or may not represent a standard 40 hour week.

To obtain satisfactory time estimates a number of requirements must be fulfilled. For that the estimates should:

1. Be reported in weeks and tenths of weeks being based on elapsed time estimates.
2. Be made on the premise that the activity lies on the critical path.
3. Be based on presently available man power and resources.
4. Relate to all resource applications: number, skill, and talent of the personnel required; facilities; equipment; material and so forth.

5. Be made only by the individual who is assigned the work responsibility or by an individual who is capable of doing that work.

6. Be entered above each activity line to which they apply.

A completed PERT network with all time estimates would appear as in Fig. 5. It is to be noted that the events are numbered after the completion of time estimates. It is to be done randomly or reviewed sequentially for accuracy and reasonableness. At IBM, they use the random numbering system, because of its ease of application. For a network to be effective the sequence of events should be checked for logical planning.*

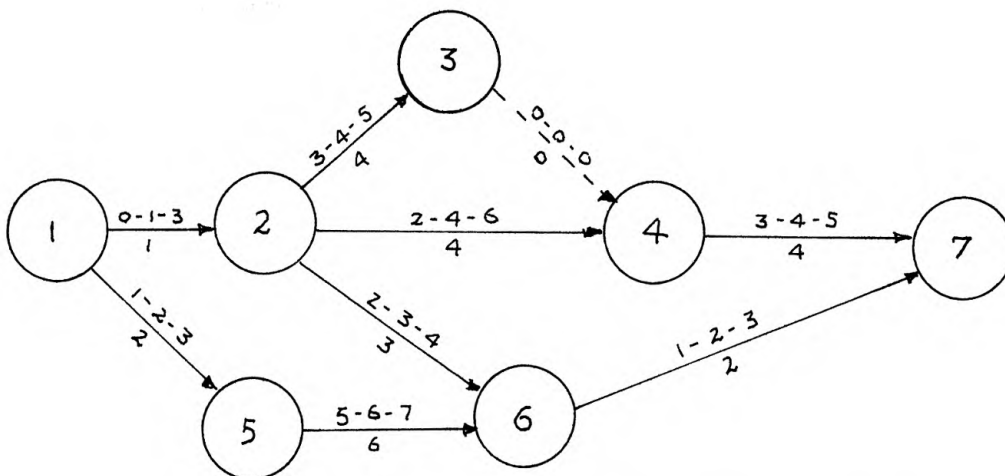


Fig. 5. Sample completed PERT network.

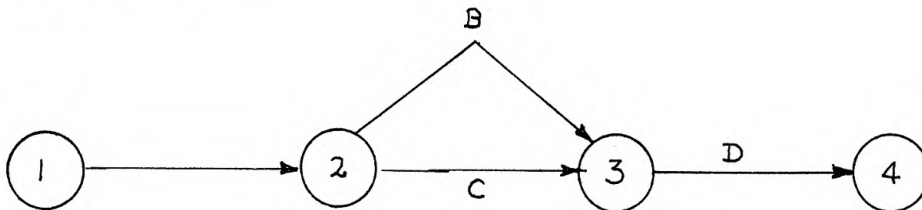
Dummy Activities

A dummy activity is an arrow on a network showing the dependent relationship between two activities, but does not represent actual work

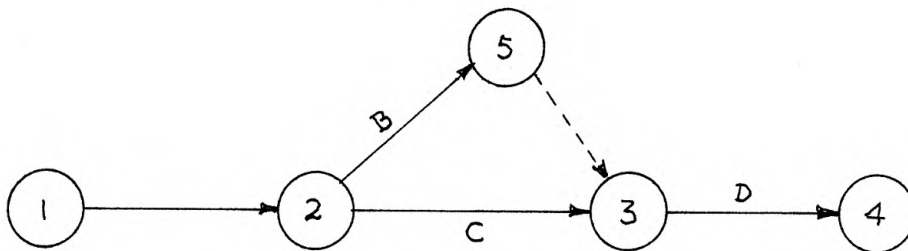
*Leonard P. Hartung, PERT: A New Management Planning and Control Technique, p. 107.

effort. In the PERT network shown in Fig. 5, activity between 3 and 4 is a dummy one. These dummy activities usually will not take any elapsed time. So the time for the above activity between events 3 and 4 has assigned as zero. Dummy activities are also used to show proper sequencing of dependent activities where two activities have the same preceding event and are done in parallel fashion. The following illustration explains the use of a dummy activity to clarify their proper interdependent relationship.

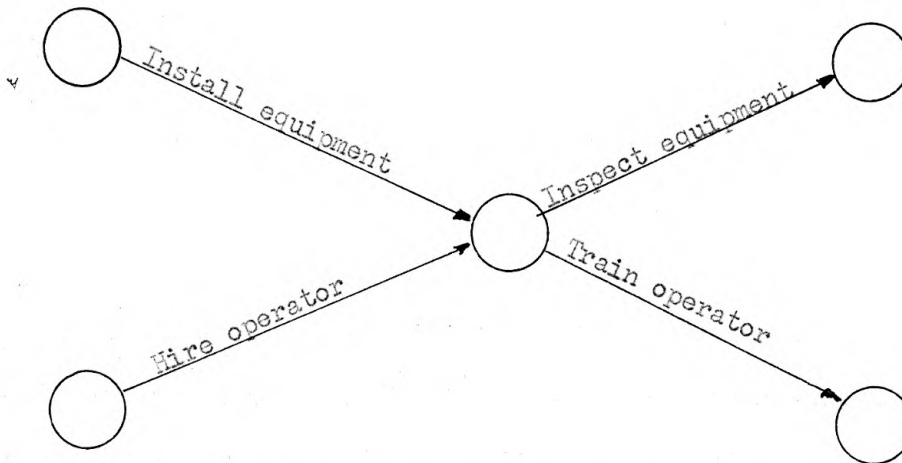
Dummy Restraint. (11)



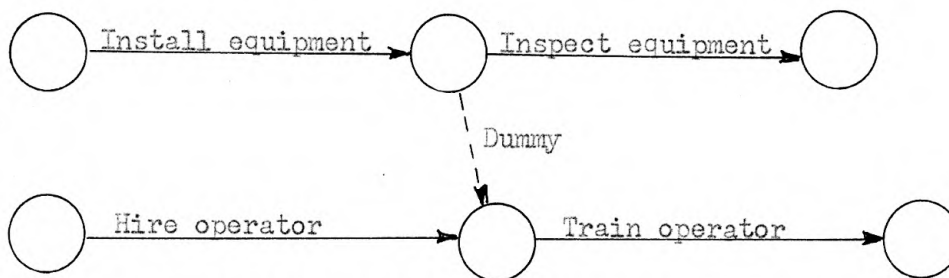
Condition: Two or more jobs begin and end at the same event.



Correction: Because "B" and "C" would be identified by the same numbers, an extra event number is needed to keep them separate. A "dummy" is inserted to do this.



Condition: This shows the hiring of the operator unnecessarily holding up the inspection activity.



Correction: To keep dependency relationships clear, a dummy constraint is added. Thus by using the "dummy constraint" the network does not show a false dependency relationship between hiring the operator and inspecting the equipment.

PERT NETWORK COMPUTATION

Time Distribution Estimation

The three time estimation described earlier are graphically portrayed in the top line of Fig. 6. An activity is started and its completion is estimated at some future point in time. Thus the points "a", "m" and "b" correspond respectively to the optimistic, most likely and pessimistic

estimates. The lower portion of the illustration represents the probability distribution of the time involved in performing the activity. This curve is assumed to have only one peak, the most likely time for completion. Thus the point "m" is representative of the most probable time. Similarly, it is assumed that there is relatively little chance that either the optimistic or pessimistic estimates will be realized. Hence, small probabilities are associated with the points "a" and "b". No assumption is made about the position of the point "m" relative to "a" and "b". It may take any position between the two extremes, depending entirely on the estimator's judgement.

Finish of Event

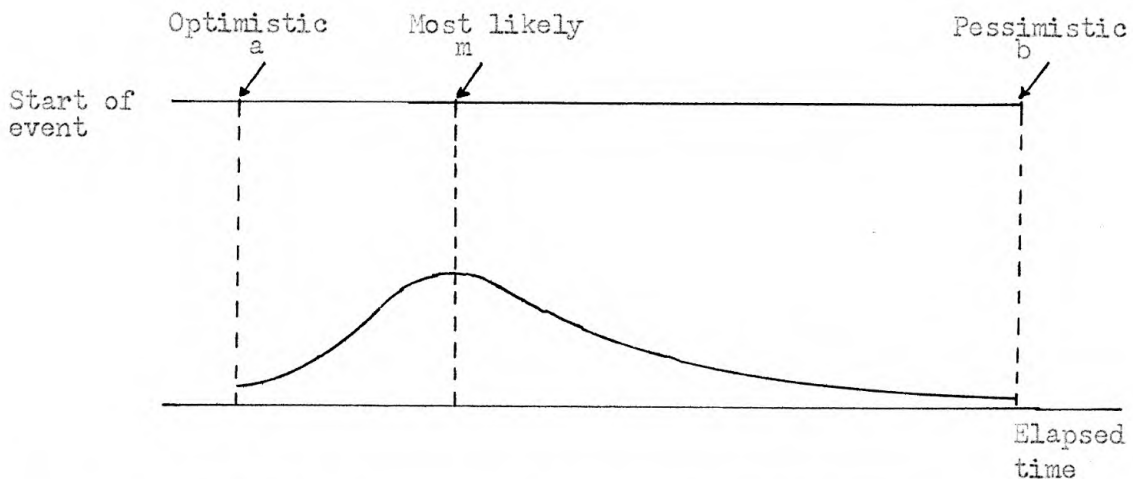


Fig. 6. Theoretical frequency distribution of performance times.

Expected Value (mean), t_e and Variance, t_e^2 of the
Time Interval between Events

In order to make statistical inferences about the times at which the future events will be accomplished, it is necessary to typify intervals between adjacent events with their expected values and variances. The

expected value is a statistical term that corresponds to "average" or "mean". The variance is a term that is descriptive of the uncertainty and should be relatively small.

Mathematical investigation of the various distribution types yields the equation for mean and variance as:

$$\text{Mean } t_e = \frac{a + 4m + b}{6}$$

$$\text{Variance } \sigma^2 t_e = \frac{(b - a)^2}{6}, \text{ where } a, m, \text{ and } b \text{ are optimistic,}$$

most likely and pessimistic time respectively. The detailed derivation of the above formulas are beyond the scope of this report and hence omitted.

The three time estimates are obtained for each activity. From the three elapsed time estimates, mean time t_e and its associated variance, t_e^2 are computed for each activity.

Computation of the Expected Time (T_E) (6)

Calculated expected time T_E is obtained by accumulating t_e for the activities preceding the event of the network starting from the base line. Sums of activity mean time t_e are determined for all possible paths leading to the event. For example in Fig. (6), t_e between events 8 and 44 is two weeks. This is added to T_E (56) for event 8 to obtain T_E 58 for event 44.

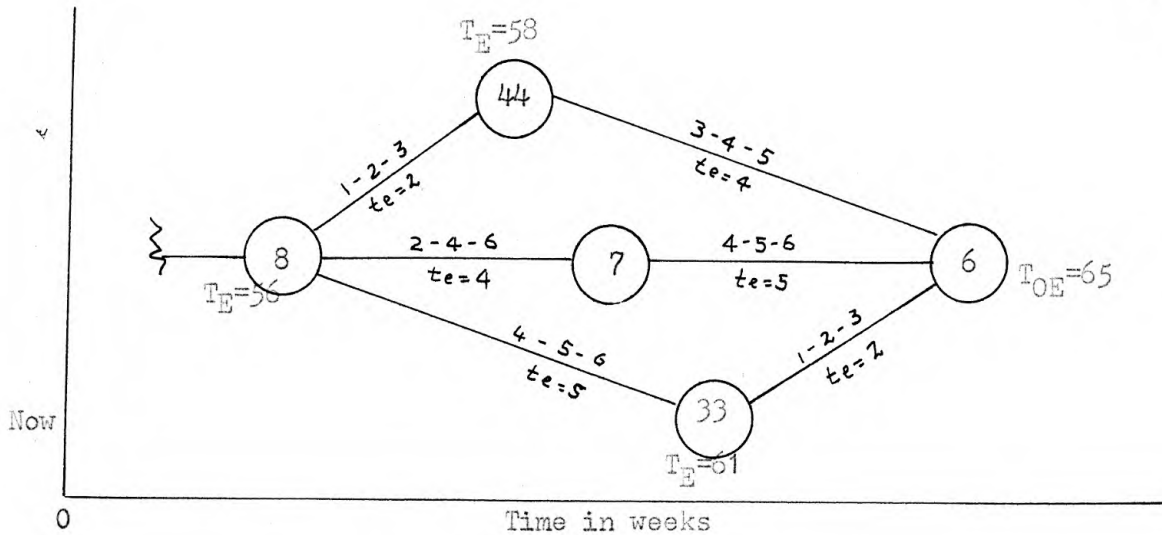


Fig. (6). Calculated t_e and calculated T_E .

Similarly T_E for 7 is obtained by adding $t_e=4$ to $T_E=56$ to give T_E equal to 60. The completion of event 6, the end objective will thus be 65 weeks after the project is begun. The t_e for activity connecting events 8 and 33 is five weeks. Thus added to 56 (T_E for event 8), gives 61 (T_E for event 33). Since the greatest of the three T_E 's computed for event 6 is 65, it is the value of T_{OE} (expected time for the completion of the objective event).

Computation of Latest Allowable Time (T_L) (6)

The latest allowable time is found by fixing the objective event at some future date and working backwards through the earlier events. The latest time for an event exists in the form of a distribution in terms of its expectation (mean) and variance. The same applies to earliest time as discussed later. The latest allowable time for an event is located at a point such that, if the following events are accomplished according to anticipations, the objective will then be completed precisely on the desired date.

The latest allowable time is calculated conversely to T_E . Activity mean times are cumulatively subtracted from a scheduled date, or T_{OE} when date has not been fixed along the various paths between a given event and the objective event. T_L is selected as the smallest of the possible values thus obtained.

For example, in Fig. 7, set T_L of event 6, the end objective equal to T_E of event 6 and work backwards through the network.

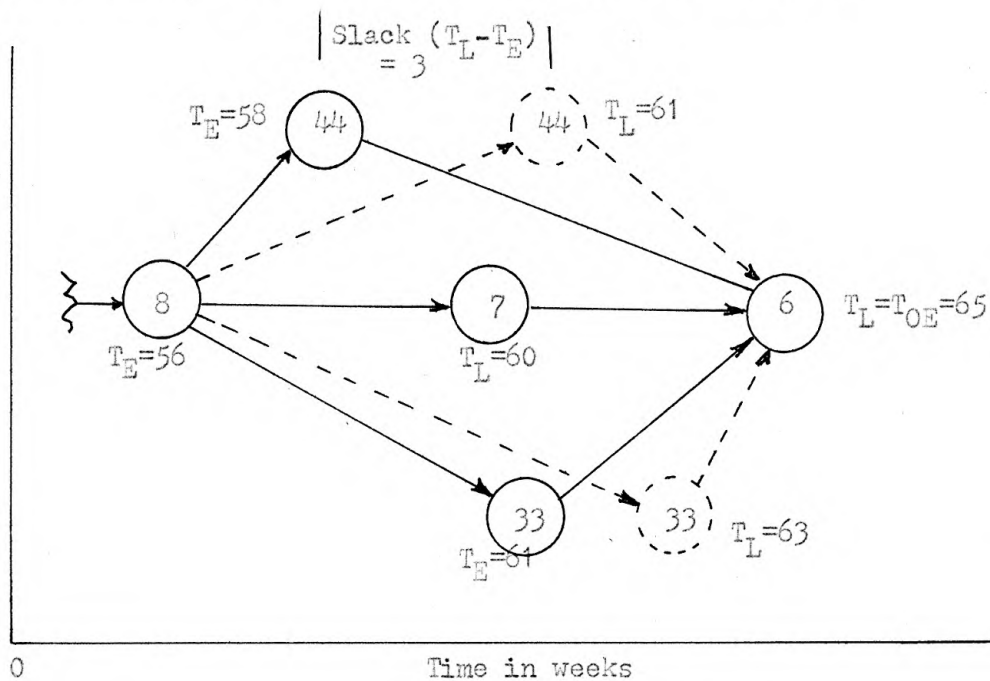


Fig. (7). Calculated T_L .

For the activity connecting events 44 and 6, the value of t_o is four weeks. Subtracted this four from T_L for event 6 gives a T_L at event 44 equal to 61 weeks.

For the activity connecting events 7 and 6, the value of t_o is two weeks. This subtracted from T_L of event 6 gives a T_L at event 33 equal to 63 weeks.

Similarly t_0 for activity connecting events 8 and 44 is two weeks. This subtracted from T_L for event 44, gives a T_L at event 8 equal to 59 weeks. T_L is calculated for event 8 by considering the activity connecting events 8 and 7 and 33. The t_0 for the (8 and 7) is four weeks; this subtracted from the T_L for event 8 equals to 56 weeks. This being the smallest of the three T_L 's computed for event 8, is selected as the T_L for event 8.

Computation of Slack

Slack is one of the important attributes of PERT. With its aid the management can find out whether a program is on, ahead of, or behind schedule. Slack is the difference between the expected time T_E and the latest allowable completion time T_L for each event. It is the amount of time an event can be delayed without affecting the schedule, and it indicates those areas where manpower and/or funds can be shifted to a more critical area of the network if necessary.

The formula for slack is $T_L - T_E$. For events 8, 7, and 6 the value of slack is zero, referring to Fig. (7). Events having zero slack are called critical events since any delay in activities between them could cause an increase in the T_E for the end objective, event 6.

Event 44 has three week's slack and event 33 has two weeks slack. It shows that its connecting activities could take up to three weeks and two weeks respectively longer than expected and not delay the completion of event 6.

Negative, Zero and Positive Slack

By grouping activities according to amount of slack several paths will be defined which vary in their criticalness. It is possible to have two or more critical paths.

Criticalness is measured in times of negative, zero or positive slack. As an example it is illustrated in the following network.

Condition: The activity 8 - 9 and 9 - 10, has taken as the critical path and thereby its slack is equal to zero.

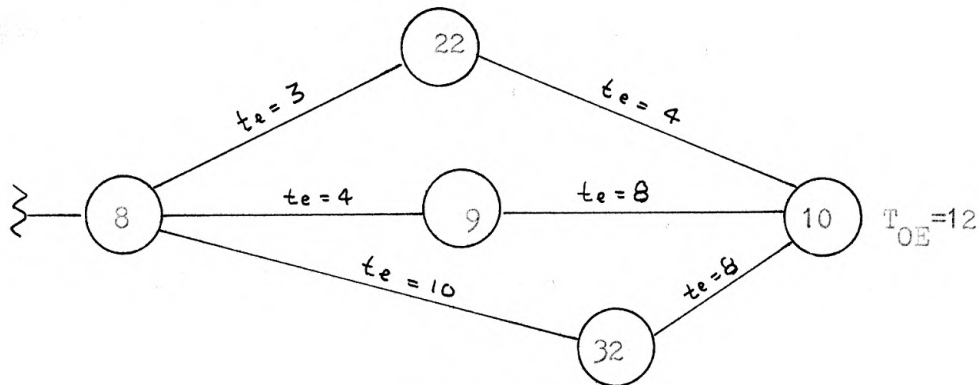


Fig. 8.

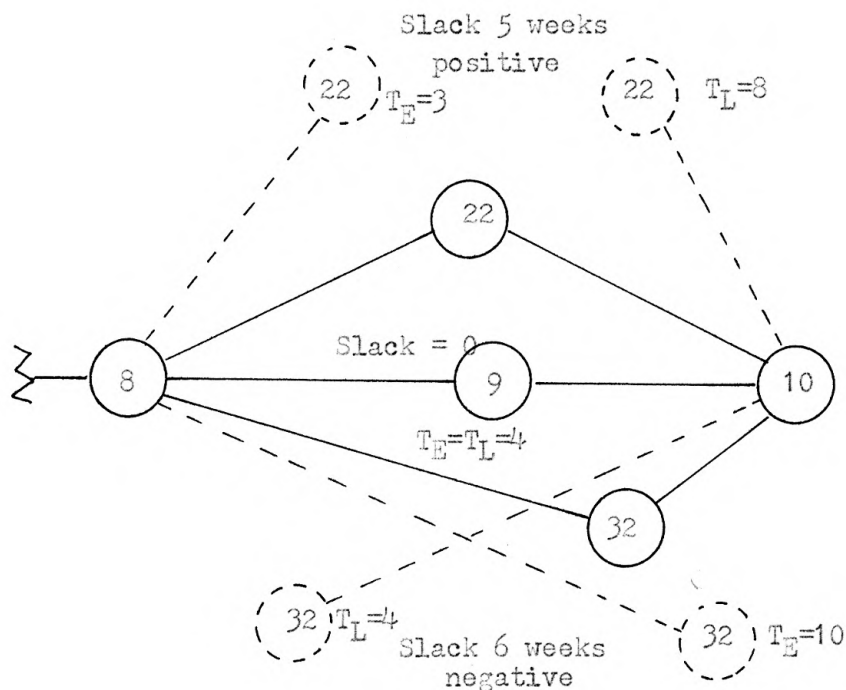


Fig. 9.

Positive slack indicates an ahead-of-schedule condition while negative slack indicates a behind the schedule condition, and zero slack indicates an on-schedule condition with a probability of 1/2. Negative slack occurs when the total activity mean time along a path is greater than the time available to meet program requirements.

Critical Path

After the project is in network form and it contains all of the "expected elapsed time" estimates for each activity, the next step is to determine the total amount of time required to complete the project. This is determined by tracing each path on the network, adding up the elapsed times of the activities, and marking the path which takes the longest elapsed time. This longest path is the "Critical Path", since the project cannot possibly be completed until this path is completed. The activities on this path are, in turn, the critical activities of the project and any delay in their completion would result in a stretching out of the project.

APPLICATION OF PERT

Government and commercial organizations have utilized PERT in many ways. But the most common usage is in the estimating, bidding and controlling of projects. These are the important items faced by the building contractor. With its application, contractors found that estimation can be made in a more logical manner, giving insight into the reasons for, and behind the schedule estimates.

Firms which have been employing this technique are in a preferred position. It allows them to remain competitive and ahead of "uninformed bidders" due to this powerful tool. As a defensive tool this technique has been used by many contractors to defend their stand on schedule and cost on their projects due to change in work scope.

PERT can be applied on smaller projects as well as large complex projects. A hand method of organizing the pertinent information and calculating elapsed time can be effectively used on smaller projects. However there are many different types of high speed computers available which are used to process and calculate data. These computers are able to process thousands of project data and produce very meaningful information in a very short time. For large complex projects, however, the use of computers results in a substantial savings in time and cost.

One of the main problems facing a building contractor is to meet the deadline for the completion of a project. Any contractor knows that there are a certain number of jobs that directly affect the completion time of a project. A delay in the completion of one of these jobs will hold up the entire project. These critical spots are identified by PERT before a delay occurs and could be corrected. Depending upon which system is utilized, non-computer or computer, the completion of a total project, or just one task within the project can be indicated in terms of elapsed days, weeks, months, etc., from the beginning of the project. It can also be indicated as a specific calendar date, such as January 1, 1964. This system can reveal what date the project is expected to be completed. If a scheduled date is already imposed on a given project, an indication is given about that project which reveals a point in time when the project must start or end in order to accomplish the goals within planned and scheduled limitations.

Delays and changes in a construction project are common occurrence. It may be due to adverse weather, lack of man power, shortage of materials and the inability of suppliers and related contractors to meet their obligations to the project. Similarly an unanticipated variable, such as a strike can come about and delay the project completion. Also there occur many on the job delays. The PERT network and knowledge of critical activities and slack activities allows project management to evaluate the delays and give correction as required. This can be in the form of denying a request for additional rental equipment since the request was received on activities which do not lie along the most critical path.

HOW PERT WORKS - A SAMPLE CASE

The following simplified step by step analysis of a hypothetical plan may provide a better idea how the PERT system aids in solving future problems before they arise.

The network consists of nine events making thirteen activities or jobs and two dummy activities. An IBM 1620 program written by John C. Patton and Frank H. White of IBM corporation was used to calculate the mean time duration t_e , and other timings which are shown in the print out sheet of IBM 1620 computer on the following page (9).

Figure 10 shows the initial network showing "a", "m", and "b" assigned to each job. PERT program is then used to analyze the project network to yield the following information.

The mean time duration $t_e = \frac{a+4m+b}{6}$, is shown in Fig. 11. It is the probable mean duration time for each job based on the three time estimates.

I	J		A	M	B	ES	EF	LS	LF	TF	FF
1	2	11.00	8	10	18		11.00	00000	11.00	0000*	00000
2	3	6.17	4	6	9	11.00	17.17	17.82	23.99	6.82	00000
3	9	10.67	8	10	16	17.17	27.84	27.49	38.16	10.32	10.32
1	6	7.33	5	7	11		7.33		12.00	4.67	00000
6	5	5.33	3	5	9	7.33	12.66	12.00	17.33	4.67	4.67
2	5	6.33	4	6	10	11.00	17.33	11.00	17.33	0000*	00000
5	4	12.33	8	12	18	17.33	29.66	17.33	2 .66	0000*	00000
3	4	5.67	4	5	10	17.17	22.84	23.99	29.66	6.82	6.82
4	9	8.50	6	8	13	29.66	38.16	29.66	38.16	0000*	00000
6	7	11.50	8	11	17	7.33	18.83	13.00	24.50	5.67	00000
5	7					17.33	17.33	24.50	24.50	7.17	1.50
7	4	4.50	3	4	8	18.83	23.33	25.16	29.66	6.33	6.33
7	8	7.33	5	7	11	18.83	26.16	24.50	31.83	5.67	3.50
4	8					29.66	29.66	31.83	31.83	2.17	00000
8	9	6.33	4	6	10	29.66	35.99	31.83	38.16	2.17	2.17

PROJECT COMPLETION 38.16 PROJECT SLACK 00000
I - Beginning of the activity J - End of the activity

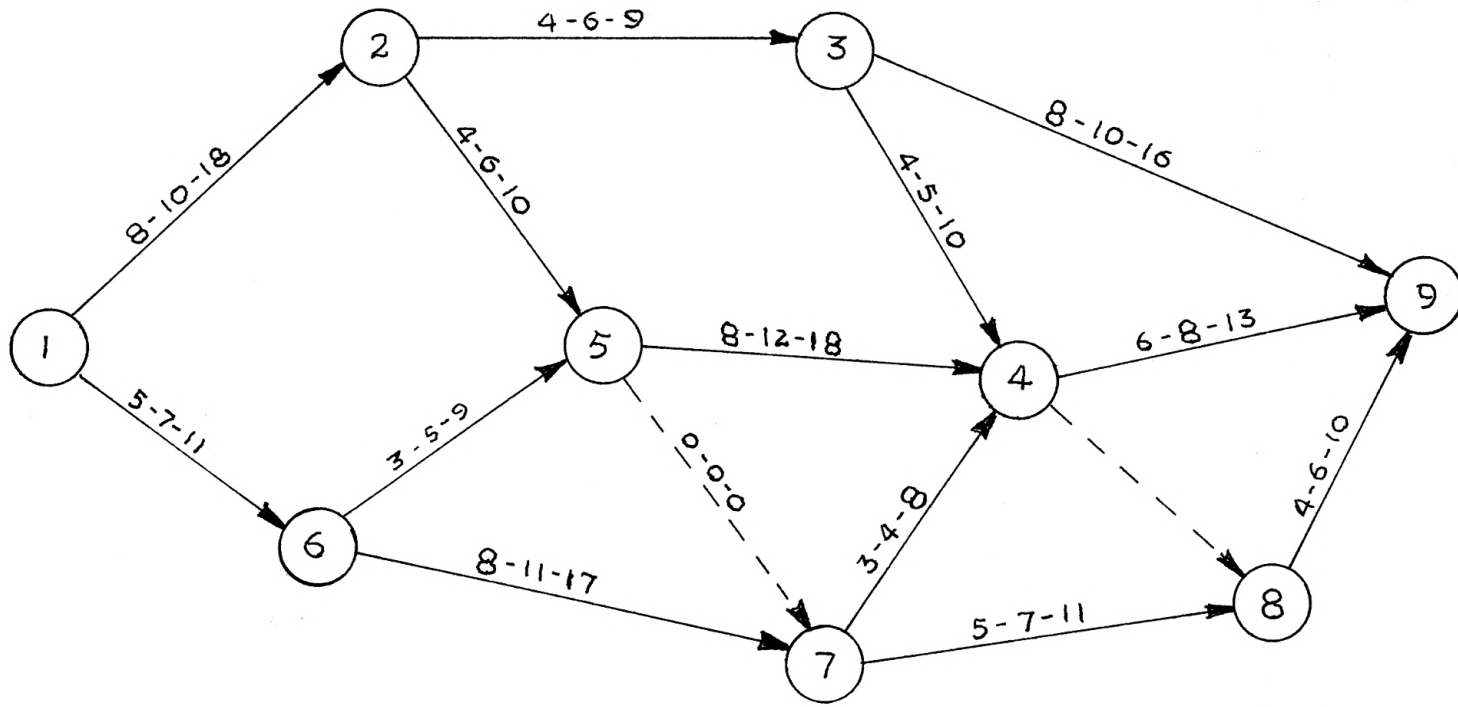


Fig. 10.

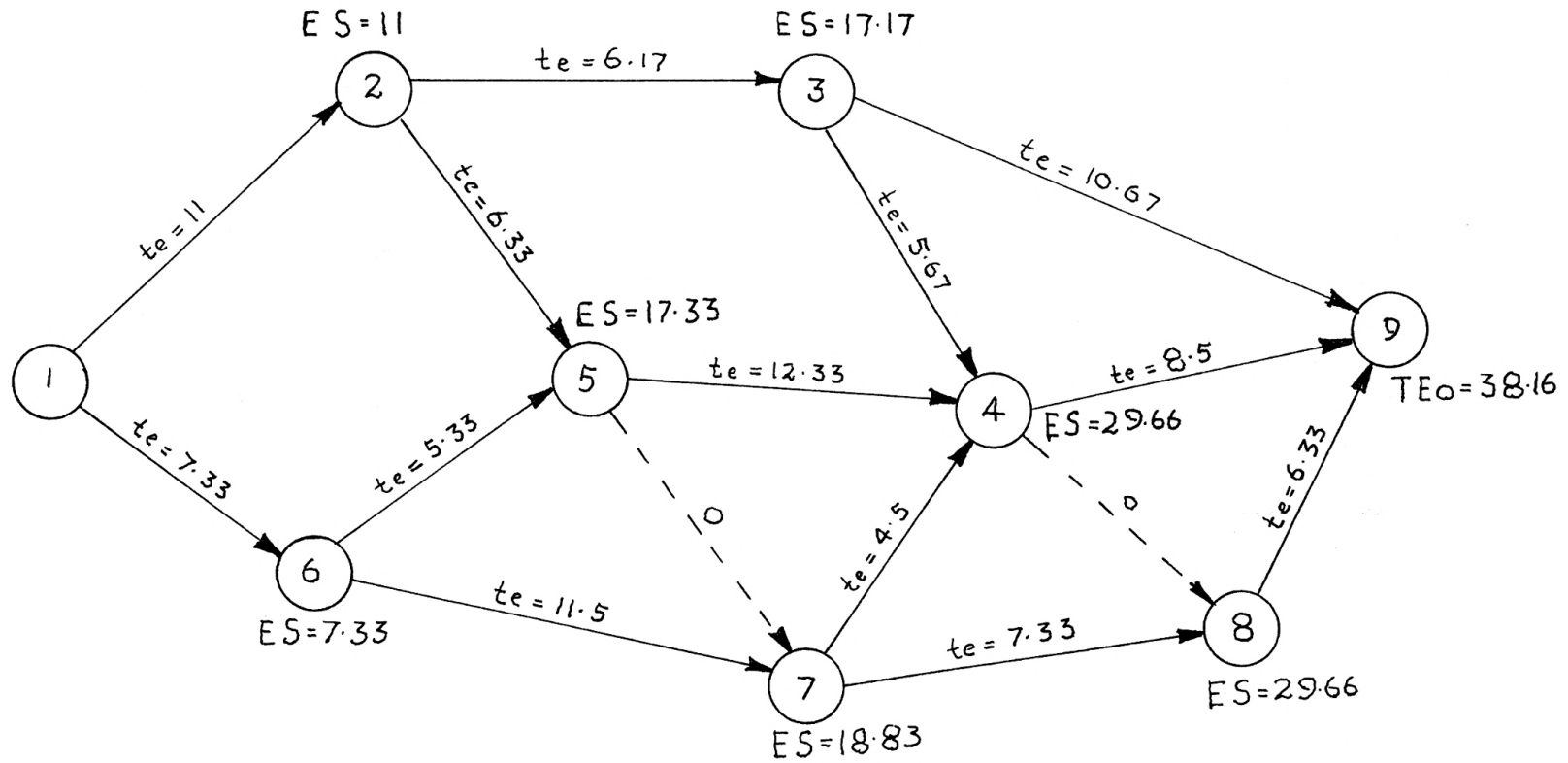


Fig. 11. (ES) Earliest Start Time.

ES - Earliest Start Time. This is the earliest time that a job may be started and assume minimum project completion time. This is computed by summing the t_e 's, for all jobs along a path leading to the tail node or event of the job or activity. Each path is summed up and the largest is set equal to ES. Summation is performed starting from the first node. Here the event node is referred to the earliest start time of all jobs of the tail node.

ES for jobs (3,9) and (3,4) is 17.17 weeks.

EF - Earliest Finish Time. It is the earliest time a job may be completed. This is achieved by adding the job's mean time (t_e), along the longest path, to the value of ES for that job. This is the expected completed time for that job represented by its head node event number. When several jobs join together at a node there will be more than one early finish time, i.e., one for each job.

LF - Latest Finish Time. The latest time that a job may be finished and still complete the project within the specified project completion time (TE_0). It is shown in Fig. 13. In this case $TE_0=38.16$. LF is computed by starting at the last node and working towards the first node. To find LF for job (8) going from right to left (8,9), just subtract t_e (6.33) from TE_0 (38.16)

$$LF(8) = TE_0 - t_e(8,9)$$

$$= 38.16 - 6.33$$

$$LF(8) = 31.83$$

When several jobs come together at a node, going from right to left; jobs (4,9) and (4,8) join at node 4. LF is computed for each path and the smallest of the values of LF is assigned to the node 4.

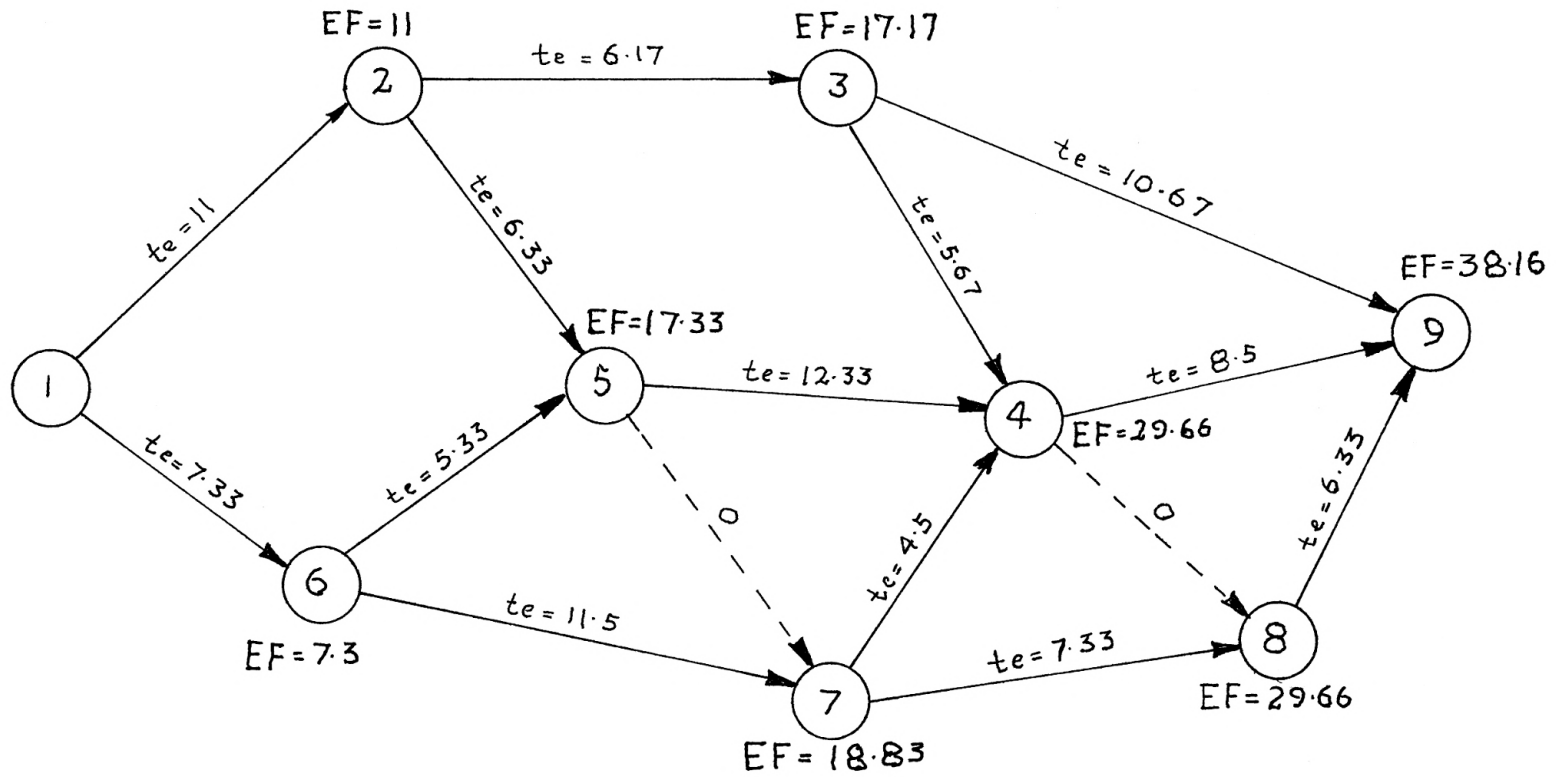


Fig. 12. (EF) Earliest Finish Time.

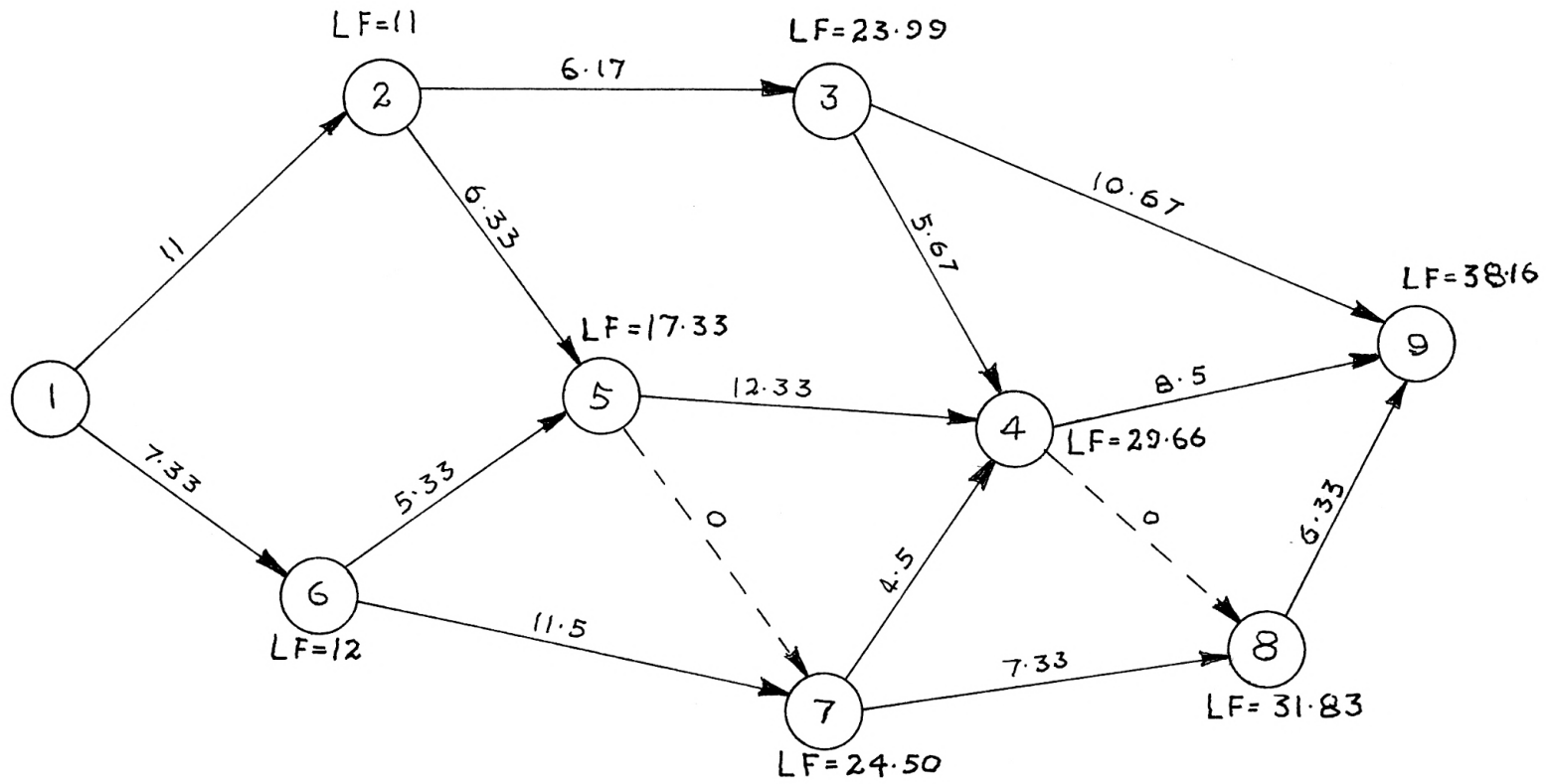


Fig. 13. (LF) Latest Finish Time.

$$\begin{aligned} LF(3,4); (5,4); (7,4) &= LF(9) - t_e(4,9) \\ &= 38.16 - 8.5 \end{aligned}$$

$$LF(4) = 29.66$$

$$\begin{aligned} LF(3,4); (5,4); (7,4) &= LF(8) - t_e(4,8) \\ &= 31.83 - 0.00 \end{aligned}$$

$$LF(4) = 31.83$$

Here the smallest value is 29.66 weeks, hence it is the LF for (4).

This is continued until LF for the first jobs are found.

LS - Latest Start Time. This is the time that a job may start and complete in the specified time TE_0 . It is shown in Fig. 14. LS is calculated by starting from the last node and subtracting t_e from its LF.

$$\begin{aligned} LS \text{ for job } (2,3) &= LF(3) - t_e(2,3) \\ &= 23.99 - 6.17 \end{aligned}$$

$$LS(2,3) = 17.82$$

LS is associated with the tail node of the given job. There may be several paths starting with one node and thereby exist several LS for that node. The smallest of all the LS is assigned to that node. Going back again for the LS of node (2),

$$LS \text{ for job } (2,3) = 17.82 \text{ (from above)}$$

$$\begin{aligned} LS \text{ for job } (2,5) &= LF(5) - t_e(2,5) \\ &= 17.33 - 6.33 \end{aligned}$$

LS(2,5) = 11, this being the smallest it is taken as the LS of (2).

TF - Total Float Time. It is the difference between LS and ES for a job. TF represents the total float or slack allowed in beginning a job. It is the length of time that the start of a job may be delayed without changing the minimum project completion time.

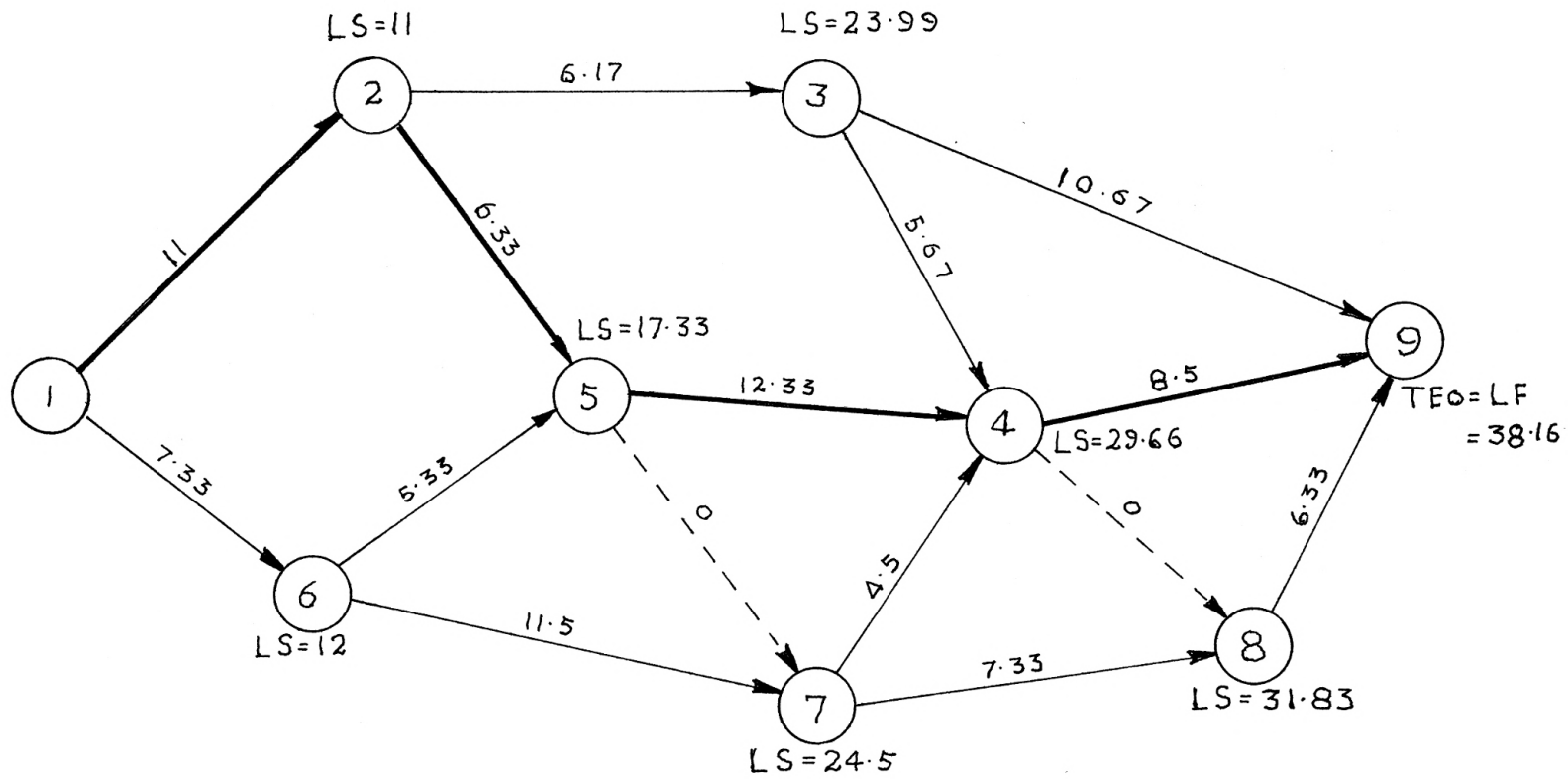


Fig. 14. (LS) Latest Start Time.

Total float may be positive, which indicates that the job may start with a delay. If an allowable completion time is assigned which is less than the minimum project completion time then the free float may be negative. It is the indication that the job is behind schedule.

When Total Float Time is zero, the job must be started at early start time if the project is to be completed in minimum time. In the print out sheet of the computer, zero slacks are indicated by an asterisk (*).

FF - Free Float Time. This is the length of time that the start of a job may be delayed without changing ES for another job.

In the example the expected completed time is 38.16 weeks. The critical path for this project is shown as thick line on Fig. 14. They are the events starting at 1 and following the path 1-2-5-4-9. It indicates that the job in this path should be completed in the mean time of each job to meet the expected time of 38.16 weeks, and thus meet the deadline of the project. Suppose the contractor wants to finish the project two weeks earlier than the expected time, i.e., within 36.16 weeks. To meet this new deadline two weeks must be reduced from the jobs on the critical path. Then recompute all the timings for all the events as before and arrive at the new expected completion time. This may change the critical path to some other path and then attention must be given to that path.

By using the method of rescheduling, replanning becomes a continuous part of the PERT program. By reducing the time additional man power, material, and money may be required to carry on the project. But experience shows that the increase in dollar expenditure will be off-set by a saving in meeting the schedule time and thereby eliminating penalties for not meeting the deadline of the project.

EXAMPLE OF AN APPLICATION OF PERT TO BUILDING
CONSTRUCTION SCHEDULING

To show how PERT helps a contractor in scheduling the construction program, the author collected data from The Green Construction Company, Manhattan, Kansas during the summer of 1963. They were the contractors for constructing the Jardine Terrace Apartments for Kansas State University. There were five buildings under their contract. Two of the buildings, Y and X, were due to be completed by August 31, 1963. The contractor wanted to know what jobs were critical and how the scheduling could be done to meet the deadline effectively. More than half of the construction work was over at the time the author started collecting the data. Masonry, wall framing, roofing, etc. were over. However many more jobs were to be completed before the entire construction could be finished.

The initial step was the determination of jobs that were to be finished and collection of data. The jobs were divided into different categories according to type such as wood working, hardware installation, electrical equipment installation, etc. Those different types of jobs were carried out by sub-contractors. Time for the jobs were then estimated according to weeks. The contractor supplied three time estimates, optimistic, most likely and pessimistic, for each job based on his previous experience and consultation with sub-contractors.

On the basis of this estimated data, a PERT network was developed. The different timings were punched on cards, and using the PERT program as explained earlier, these were fed into the IBM 1620 computer. The output gave different timings of each job such as earliest start, earliest finish, latest start, latest finish, slack and the critical path of the projects

was determined. Checking with the contractor, it was learned that some of the jobs shown in the critical path were not necessarily critical. Because the time estimates for some of the jobs supplied by the company were incorrect, hence the input data was incorrect. Also sub-contractors would put more men on certain jobs, therefore, they were finished much earlier than expected. Some of the jobs were left unfinished due to lack of men. However the network also showed a completion date much later than the expected deadline.

Some changes in duration of job time estimates were obviously necessary to make the completion date coincide with the deadline. The different jobs were then revised and new times were estimated. Some of the jobs were combined and some other larger ones were split into smaller ones. This gave more control and definiteness in estimating time. On the basis of this new estimate another network was developed. The critical path and different times for each jobs were obtained by the same method explained earlier. This again gave the contractor a better insight into the tight and troubled spots. More emphasis was put on these jobs in the form of more workmen. Delays to start certain jobs because of waiting for the previous work to be completed was one of the critical problems. There was then one month left for meeting the completion date. To overcome the difficulty encountered earlier and to meet the deadline, the remaining jobs were broken into smaller ones and their estimated times were calculated in hours. The listings of the jobs are shown in the following pages of the computer print out sheet. When there were twenty days left for the buildings to be completed, a new time estimate and a PERT network was developed, which is shown in Appendix 1.

PERT CONSTRUCTION PROBLEM, BUILDINGS Y AND X
 JARDINE TERRACE AUGUST 8 1963
 PROBLEMS IN INDUSTRIAL ENGINEERING

EMMANUEL G PALLATH

I	J	TE	A	M	B		ES	EF	LS	LF	TF	FF
110	111	0000				DUMMY	10800	10800	14400	14400	03600	03600
	100	2000				DUMMY			7200	07200	07200	00000
	200	30800	0700	0800	0900	SWITCH PLATES	00000	00800	07200	08000	07200	00000
	300	40800	0700	0800	0900	SWITCH PLATES	00800	01600	08000	08800	07200	00000
	404	70000				DUMMY	01600	01600	08800	08800	07200	03200
	100	50000				DUMMY			7200	07200	07200	00000
	500	60800	0700	0800	0900	LAYFELT	0000	800	07200	08000	07200	00000
	600	90000				DUMMY	00800	00800	08000	08000	07200	00800
	100	70000				DUMMY			5600	05600	05600	00000
	700	80800	0700	0800	0900	FIELD TILE	00000	00800	05600	06400	05600	00000
	800	90800	0700	0800	0900	FIELD TILE	00800	01600	07200	08000	06400	00000
	901	00800	0700	0800	0900	FIELD TILE	01600	02400	08000	08800	06400	00000
	100	110800	0700	0800	0900	FIELD TILE	02400	03200	08800	09600	06400	00000
	110	120800	0700	0800	0900	FIELD TILE	03200	04000	09600	10400	06400	00000
	120	180800	0700	0800	0900	FIELD TILE	04000	04800	10400	11200	06400	00000
	80	130000				DUMMY	00800	00800	06400	06400	05600	00000
	130	140800	0700	0800	0900	TILE EDGES	00800	01600	06400	07200	05600	00000
	140	150800	0700	0800	0900	TILE EDGES	01600	02400	07200	08000	05600	00000
	150	160800	0700	0800	0900	TILE EDGES	02400	03200	08800	09600	06400	00000
	160	170800	0700	0800	0900	TILE EDGES	03200	04000	09600	10400	06400	00000
	170	180800	0700	0800	0900	TILE EDGES	04000	04800	10400	11200	06400	00000
	10	190000				DUMMY			5600	05600	05600	00000
	190	200800	0700	0800	0900	BASE SHOE	00000	00800	05600	06400	05600	00000
	200	210800	0700	0800	0900	BASE SHOE	00800	01600	07200	08000	06400	00000
	140	210000				DUMMY	01600	01600	08000	08000	06400	00000
	210	220800	0700	0800	0900	BASE SHOE	01600	02400	08000	08800	06400	00000
	220	230800	0700	0800	0900	BASE SHOE	02400	03200	08800	09600	06400	00000
	230	240800	0700	0800	0900	BASE SHOE	03200	04000	09600	10400	06400	00000
	170	240000				DUMMY	04000	04000	10400	10400	06400	00000
	240	250800	0700	0800	0900	BASE SHOE	04000	04800	10400	11200	06400	00000

180250000			DUMMY	04800	04800	11200	11200	06400	00000
250260800	0700	0800	0900	BASE SHCE	04800	05600	11200	12000	06400
180260800	0700	0800	0900	TILE EDGES	04800	05600	11200	12000	06400
260270800	0700	0800	0900	BASE SHCE	05600	06400	12000	12800	06400
200280000			DUMMY	00800	00800	06400	06400	05600	00000
280290800	0700	0800	0900	HANG LAV	00800	01600	06400	07200	05600
290300800	0700	0800	0900	HANG LAV	01600	02400	07200	08000	05600
150300000			DUMMY	02400	02400	08000	08000	05600	00000
300310800	0700	0800	0900	HANG LAV	02400	03200	08000	08800	05600
310320000			HANG LAV	03200	03200	08800	08800	05600	00000
103300000			DUMMY			5600	05600	05600	00000
330340800	0700	0800	0900	THRESHOLDS	00000	00800	05600	06400	05600
340350800	0700	0800	0900	THRESHOLDS	00800	01600	06400	07200	05600
350360800	0700	0800	0900	THRESHOLDS	01600	02400	07200	08000	05600
360370800	0700	0800	0900	THRESHOLDS	02400	03200	08000	08800	05600
103800000			DUMMY			6400	06400	06400	00000
380390800	0700	0800	0900	HANG DOORS	00000	00800	06400	07200	06400
390350000			DUMMY	00800	00800	07200	07200	06400	00800
390400800	0700	0800	0900	HANG DOORS	00800	01600	07200	08000	06400
400360000			DUMMY	01600	01600	08000	08000	06400	00800
104100000			DUMMY			4000	04000	04000	00000
410420800	0700	0800	0900	ADDITIONAL PAINT	00000	00800	04000	04800	04000
420430800	0700	0800	0900	ADDITIONAL PAINT	00800	01600	04800	05600	04000
430440800	0700	0800	0900	ADDITIONAL PAINT	01600	02400	05600	06400	04000
440450800	0700	0800	0900	ADDITIONAL PAINT	02400	03200	06400	07200	04000
450460800	0700	0800	0900	ADDITIONAL PAINT	03200	04000	07200	08000	04000
460470800	0700	0800	0900	ADDITIONAL PAINT	04000	04800	08000	08800	04000
370470000			DUMMY	03200	03200	08800	08800	05600	01600
470480800	0700	0800	0900	ADDITIONAL PAINT	04800	05600	08800	09600	04000
480490800	0700	0800	0900	ADDITIONAL PAINT	05600	06400	09600	10400	04000
490500800	0700	0800	0900	ADDITIONAL PAINT	06400	07200	10400	11200	04000
500510800	0700	0800	0900	ADDITIONAL PAINT	07200	08000	11200	12000	04000
510520800	0700	0800	0900	ADDITIONAL PAINT	08000	08800	12000	12800	04000
270520000			DUMMY	06400	06400	12800	12800	06400	02400
520530800	0700	0800	0900	ADDITIONAL PAINT	08800	09600	12800	13600	04000
105400000			DUMMY						*00000
540550800	0700	0800	0900	SET CLOSET TSNK	00000	00800	00000	00800	0000*

55	056	0800	0700	0800	0900	SET CLOSET TANK	00800	01600	00800	01600	0000*	00000
56	057	0800	0700	0800	0900	SET CLOSET TANK	01600	02400	04000	04800	02400	00000
57	058	0800	0700	0800	0900	SET CLOSET TANK	02400	03200	04800	05600	02400	00000
58	059	0800	0700	0800	0900	SET CLOSET TANK	03200	04000	05600	06400	02400	00000
59	060	0800	0700	0800	0900	SET CLOSET TANK	04000	04800	06400	07200	02400	00000
60	061	0800	0700	0800	0900	SET CLOSET TANK	04800	05600	07200	08000	02400	00000
61	062	0800	0700	0800	0900	SET CLOSET TANK	05600	06400	08000	08800	02400	00000
56	063	0000				DUMMY	01600	01600	01600	01600	0000*	00000
55	063	0000				DUMMY	00800	00800	01600	01600	00800	00800
63	064	0800	0700	0800	0900	PLUMBING AND GAS	01600	02400	01600	02400	0000*	00000
64	065	0800	0700	0800	0900	PLUMBING AND GAS	02400	03200	02400	03200	0000*	00000
65	066	0800	0700	0800	0900	PLUMBING AND GAS	03200	04000	03200	04000	0000*	00000
66	067	0800	0700	0800	0900	PLUMBING AND GAS	04000	04800	06400	07200	02400	00000
67	068	0800	0700	0800	0900	PLUMBING AND GAS	04800	05600	07200	08000	02400	00000
68	069	0800	0700	0800	0900	PLUMBING AND GAS	05600	06400	08000	08800	02400	00000
32	069	0000				DUMMY	03200	03200	08800	08800	05600	03200
69	070	0800	0700	0800	0900	PLUMBING AND GAS	06400	07200	08800	09600	02400	00000
70	071	0800	0700	0800	0900	PLUMBING AND GAS	07200	08000	09600	10400	02400	00000
71	072	0800	0700	0800	0900	PLUMBING AND GAS	08000	08800	10400	11200	02400	00000
72	073	0800	0700	0800	0900	PLUMBING AND GAS	08800	09600	11200	12000	02400	00000
73	074	0800	0700	0800	0900	PLUMBING AND GAS	09600	10400	12000	12800	02400	00000
74	075	0800	0700	0800	0900	PLUMBING AND GAS	10400	11200	12800	13600	02400	00000
65	076	0000				DUMMY	03200	03200	04000	04000	00800	00800
66	076	0000				DUMMY	04000	04000	04000	04000	0000*	00000
76	077	0800	0700	0800	0900	CLEAN FIXTURES	04000	04800	04000	04800	0000*	00000
77	078	0800	0700	0800	0900	CLEAN FIXTURES	04800	05600	05600	06400	00800	00000
78	079	0800	0700	0800	0900	CLEAN FIXTURES	05600	06400	06400	07200	00800	00000
79	080	0800	0700	0800	0900	CLEAN FIXTURES	06400	07200	07200	08000	00800	00000
80	081	0800	0700	0800	0900	CLEAN FIXTURES	07200	08000	08000	08800	00800	00000
62	081	0000				DUMMY	06400	06400	08800	08800	02400	01600
81	082	0800	0700	0800	0900	CLEAN FIXTURES	08000	08800	08800	09600	00800	00000
82	083	0800	0700	0800	0900	CLEAN FIXTURES	08800	09600	09600	10400	00800	00000
83	084	0800	0700	0800	0900	CLEAN FIXTURES	09600	10400	10400	11200	00800	00000
84	085	0000				DUMMY	10400	10400	11200	11200	00800	00000
85	086	0800	0700	0800	0900	WASH WINDOWS	10400	11200	11200	12000	00800	00000
85	086	0800	0700	0800	0900	WASH WINDOWS	10400	11200	11200	12000	00800	00000
86	087	0800	0700	0800	0900	WASH WINDOWS	11200	12000	12000	12800	00800	00000

870880800	070008000900	WASH WINDOWS	12000	12800	12800	13600	00800	00000
881110800	070008000900	WASH WINDOWS	12800	13600	13600	14400	00800	00800
770890000		DUMMY	04800	04800	04800	04800	00000	*00000
890900800	070008000900	FINAL PICK UP AND	CH04800	05600	04800	05600	00000	*00000
900910800	070008000900	FINAL PICK UP AND	CH05600	06400	05600	06400	00000	*00000
910920800	070008000900	FINAL PICK UP AND	CH06400	07200	06400	07200	00000	*00000
920930800	070008000900	FINAL PICK UP AND	CH07200	08000	07200	08000	00000	*00000
930940800	070008000900	FINAL PICK UP AND	CH08000	08800	08000	08800	00000	*00000
940950800	070008000900	FINAL PICK UP AND	CH08800	09600	08800	09600	00000	*00000
700950000		DUMMY	07200	07200	09600	09600	02400	02400
810950000		DUMMY	08000	08000	09600	09600	01600	01600
950960800	070008000900	FINAL PICK UP AND	CH09600	10400	09600	10400	00000	*00000
960970800	070008000900	FINAL PICK UP AND	CH10400	11200	10400	11200	00000	*00000
970980800	070008000900	FINAL PICK UP AND	CH11200	12000	11200	12000	00000	*00000
980990800	070008000900	FINAL PICK UP AND	CH12000	12800	12000	12800	00000	*00000
991000800	070008000900	FINAL PICK UP AND	CH12800	13600	12800	13600	00000	*00000
751000000		DUMMY	11200	11200	13600	13600	02400	02400
531000000		DUMMY	09600	09600	13600	13600	04000	04000
1001110800	070008000900	FINAL PICK UP AND	CH13600	14400	13600	14400	00000	*00000
110100000		DUMMY			3200	03200	03200	00000
1011022800	270028002900	SIDE WALKS	00000	02800	03200	06000	03200	00000
1021032800	270028002900	SIDE WALKS	02800	05600	06000	08800	03200	00000
1031042800	270028002900	SIDE WALKS	05600	08400	08800	11600	03200	00000
1041052800	270028002900	SIDE WALKS	08400	11200	11600	14400	03200	00000
1051110000		DUMMY	11200	11200	14400	14400	03200	03200
1021060000		DUMMY	02800	02800	06400	06400	03600	00000
1061072000	190020002100	FINAL GRADE	02800	04800	06400	08400	03600	00000
1071082000	190020002100	FINAL GRADE	04800	06800	08400	10400	03600	00000
1081092000	190020002100	FINAL GRADE	06800	08800	10400	12400	03600	00000
1091102000	190020002100	FINAL GRADE	08800	10800	12400	14400	03600	00000
1101110000		DUMMY	10800	10800	14400	14400	03600	03600
-PROJECT COST	00000000	PROJECT COMPLETION	14400		PROJECT SLACK	00000		

The network shown in Appendix 1 includes jobs for both buildings Y and X. The network dates are shown at the top and scaled according to eight hour days. The jobs are divided into eight hours each and drawn to scale under each date. One advantage in doing this is that by looking at a particular day, one can see the exact progress of the project, how much is finished and how much more needs to be completed.

The computer print out sheet showed different timings for each job and the critical path. It showed that the setting of closet tanks for buildings Y and X was critical and should be completed on August 6 and 7. After that plumbing and gas fittings for building Y showed critical from August 8 to 13. The final pick up and clean up remained critical for both buildings Y and X from August 14 to 29. The final deadline of the buildings to be finished was on August 30. By following the network and finishing each job according to the time estimates, all the jobs would be completed by August 29, a day earlier than the expected deadline. The contractor followed the schedule according to the network, concentrating on the critical path to see that each job was finished within the mean time. The non-critical jobs were carried on parallel to the critical jobs, but with less rush since they had slack time. Without using any overtime the construction was completed a day earlier than the final date of completion. It was because the network gave up-to-date construction conditions with a high degree of control.

CONCLUSION

In conclusion, it can be said that PERT offers a new and almost necessary tool for building contractors. PERT exposes the way jobs are planned, estimated, bid, and controlled. The success or failure of the application of the technique lies in the hands of individuals who plan and do their jobs.

The basic technique of network development is unfamiliar to most contractors. It is, however, only an extension of the bar chart invariably used by all in the construction industry. PERT is unique in its capability for properly considering, recognizing and providing assistance with the most important problem in construction projects - uncertainty.

PERT allows the readjustment to give a schedule with up to date conditions and a high degree of control. The planning of the network diagram technique should be reviewed during construction. Also activity sequence can be adjusted according to the review of the network. In short PERT could provide a better control in the following areas:

1. Overtime: With PERT, it is possible to see where overtime effort can most effectively be applied to shorten the over-all schedule.
2. Elimination: Certain portions of the first planned work may be eliminated.
3. Parallel Efforts: Activities which normally would be carried out in series may be scheduled for accomplishment in parallel.

Many firms make intense investigation and large investments to determine and purchase the best tool to use for their business. Due to the need for better management and tighter control, many contracting firms are using PERT as a tool to keep them competitive and ahead in today's fast market.

The cost of applying PERT will depend on the size and complexity of the project. By using experienced program planning personnel and PERT, highly successful results will be achieved. However it should be remembered that the results and impact of PERT still depend upon man and his decisions.

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REFERENCES

- (1) Albertson, Leland C. "CPM Construction Scheduling, Access Road to Fort Riley, Kansas." *Mid-West Contractor*, April 10, 1963, 1121: 19-21.
- (2) Bonchonsky, Joseph. "PERT's Place in Subcontracting." *Aerospace Management*, January 1962, p. 48-50.
- (3) Boulanger, David G. "Program Evaluation and Review Technique.....A Case Study Application With Analysis." *Advanced Management*, July-August 1961, 26:7-12.
- (4) Doyle, G. A. "Modern Management Systems--Their Impact on Construction Contractors." *Constructor*, July 1962, p. 28-31.
- (5) Freeman, Milton L. "The Critical Path Method." *Western Construction*, May 1962, p. 56-58.
- (6) General Information Manual PERT.....a Dynamic Project Planning and Control Method, IBM Data Processing Division, White Plains, New York.
- (7) MacNew, Tom. "NASA's Plans for PERT." *Aerospace Management*, December 1961, p. 24-28.
- (8) NASA PERT and Companion Cost System. Handbook, Washington: National Aeronautics and Space Administration, October 30, 1962.
- (9) Patton, John C. and Frank H. White. 1620 PERT (Program Evaluation and Review Technique), IBM 1620 General Program Library, File Number 10.3.006, 1220 19th Street N.W., Washington 6, D.C.
- (10) Pearlman, Jerome. "Engineering Program Planning and Control Through the Use of PERT." *IRE Transactions on Engineering Management*, December 1960, EM-7:125-134.
- (11) PERT/CRITICAL PATH, An Introduction to the Newest in Management Tools, Analicin, California: Charles W. Adams Associates Inc.
- (12) PERT Data Processing Plan Handbook for Techniques, Department of the Navy, Bureau of Naval Weapons, Special Project Office; Washington: Government Printing Office, November 1960.
- (13) PERT Instruction Manual and Systems and Procedures for the Program Evaluation System, Department of the Navy, Bureau of Naval Weapons, Washington: Government Printing Office.
- (14) PERT Summary Report, Phase I, Department of the Navy, Bureau of Naval Weapons, Special Projects Office; Washington: Government Printing Office, July 1958.

- (15) PERT Summary Report, Phase II, Department of the Navy, Bureau of Naval Weapons, Special Projects Office; Washington: Government Printing Office, September 1958.
- (16) Stilian, Gabriel and others. PERT A New Management Planning and Control Technique. New York: American Management Association.
- (17) Summary Minutes for Meeting of Contractor PERT Reporting Personnel (8-9 June 1960 and 14-15 July 1960), Department of the Navy, Bureau of Naval Weapons, Washington: Government Printing Office, November 1960.
- (18) The Critical Path Method as Applied to Construction. New York: Associated General Contractors of America, March 1963.
- (19) Thompson, Van B. "PERT Pro and Con about the Technique." Data Processing, October 1961, 3:4-44.
- (20) White, Glenn L. "An Introduction to Computerized CPM." The Constructor, April 1963, 53-55, 63-64.

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APPENDIX I

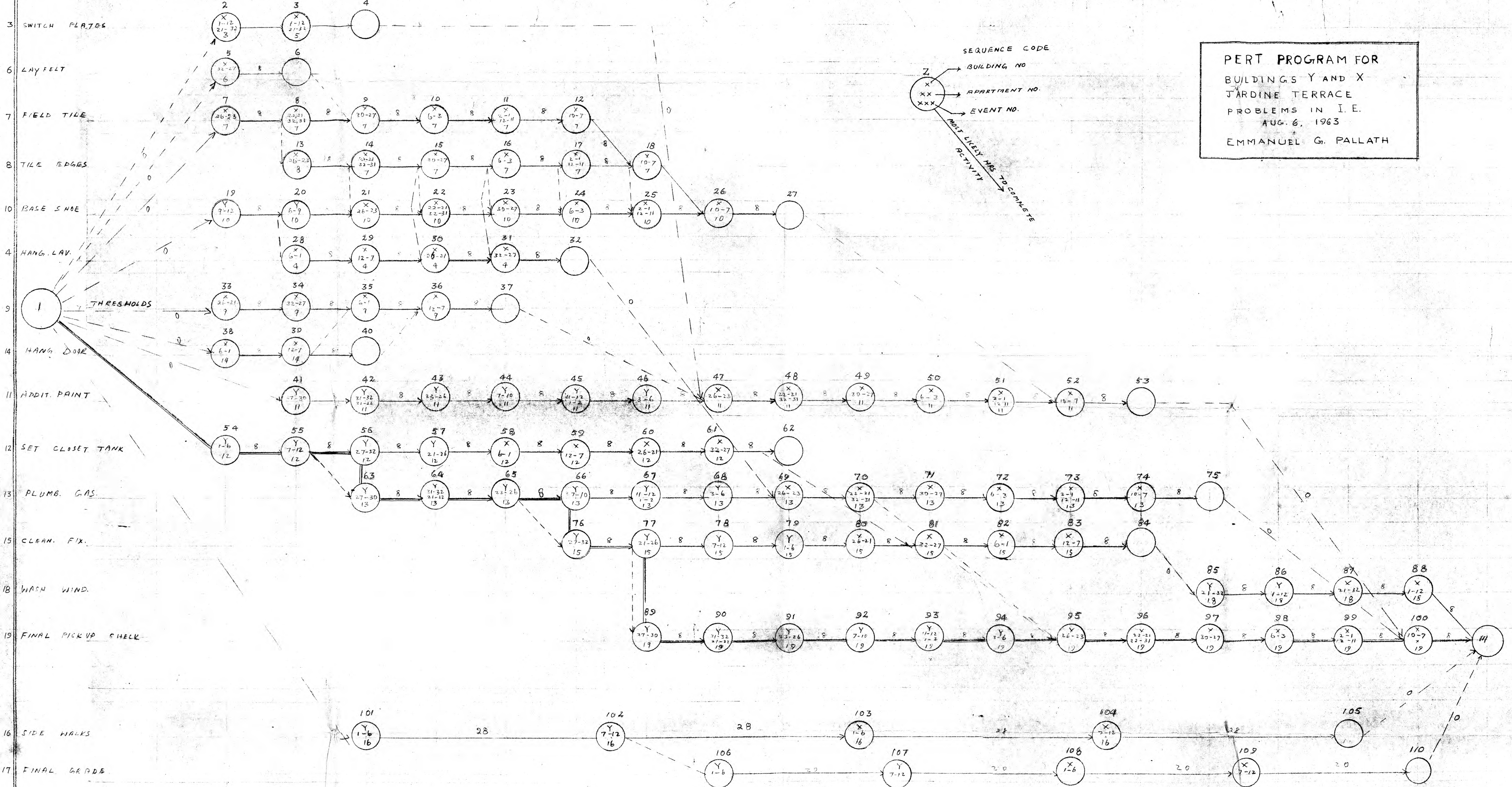
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EVENT



PERT PROGRAM FOR
BUILDINGS Y AND X
JARDINE TERRACE
PROBLEMS IN I.E.
AUG. 6, 1963
EMMANUEL G. PALLATH

PERT AS A TOOL FOR
BUILDING CONTRACTORS

by

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B. Sc. (Physics) University of Madras, India, 1958
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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
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Program Evaluation and Review Technique (PERT) is a recently developed management tool. It is a method of planning, replanning, and progressive re-evaluation in order to control a program more accurately and effectively. PERT was first developed in 1958 by the U.S. Navy's Special Project office (SP), to study the application of statistical and mathematical methods to the planning, evaluation, and control of a particular weapons system. Today it has been widely used in many industrial applications.

Through its use, areas of a project that require remedial decisions can be detected and the effect of trade offs among the three basic factors - time, resources, and technical performance can be determined.

The first step in the PERT is the development of a program network. The network is comprised of "events" and "activities". An event represents a specified program accomplishment at a particular instant in time. An activity represents the time and resources which are necessary to go from one event to the next. On the network events are connected by activity lines represented by arrows. They are sequenced on the network in a logical fashion: an activity cannot be started until its preceding event has been accomplished and a succeeding event to an activity cannot be accomplished until the activity is complete.

Three time estimates are made for each activity of the network. They are namely, the optimistic time "a", the most likely time "m", and the pessimistic time "b". These elapsed time figures are estimated by the person or persons most familiar with the activity involved. For the purpose of computation and reporting, the three time estimates are reduced to a single expected time (t_e). It is calculated using the formula, $t_e = \frac{a+4m+b}{6}$. The

expected time of all the activities are added up on each path of the network and marked. The path which has the longest time is called the "critical path", since the project cannot possibly be completed until this path is completed.

To show how the PERT works, a hypothetical sample case with step by step analysis is explained. An IBM 1620 PERT program was used to calculate mean time duration t_e , other timings and the critical path. The details are shown in the computer print out sheet.

PERT has been utilized by Government and commercial organizations. But the most common usage is in the estimating, bidding, and controlling of projects.

The major objective of PERT is to provide the contractor with an accurate picture of current and future activities necessary to accomplish a job in the shortest desired time, at the least corresponding cost, and with the most efficient use of manpower and equipment. Due to the need for better management and tighter control, today, many contracting firms are using PERT as a powerful tool to keep them competitive and ahead in today's fast market.