A CONSIDERATION AND ANALYSIS OF SIGNIFICANT CONCEPTS AND TECHNIQUES IN SCHEDULING THEORY

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PREFACE

There have been tremendous strides made in the development of scientific management and of management skills. This can be observed in the advancements being made in new scheduling techniques; beginning with the significant early developments of Henry Laurence Gantt and his followers to the formulation, within the last few years, of one of the most important concepts in scheduling theory, the management-information-systems approach to executive decision making. PERT is one of many management information and control systems which follow this approach--and one of the most valuable.

It has been established that some of the concepts that are elements of PERT apply to simple, short-range problems as well as to the more complicated problems which PERT has usually been associated with. Hence, this report emphasizes the methodology and concepts of systems which may not be considered by technicians to be "pure" PERT technique. The important thing is that the executive in business has available an effective method of making a profit for his company by doing a better job. This report attempts to initiate to the reader recent developments in this direction.

I wish to thank Professor Stan Aaronson and Dr. Richard Weeks for their valuable assistance both in their excellent instruction and as my report advisers. I am deeply indebted to Dr. Wayne A. Meinhart for excellent instruction in both undergraduate and graduate schools; scholar-

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CHAPTER I

INTRODUCTION

The purpose of this paper is to survey the history of scheduling in order to present the techniques that have been used and the ones that are unique today.

The first part of the paper deals with the Gantt chart and the significance it has upon management decisions. Scientists and engineers have used it for decades; as a result, it is always customary to start with Henry Laurence Gantt when tracing the history of network scheduling.

The bulk of the paper consists of PERT techniques that have been used in planning and controlling scheduling problems. The Gantt chart is far outdated, thus, the new devices discussed center around PERT and its value to management. Chapter III discusses the origination of PERT, the planning involved in PERT, and the milestones and keypoints necessary for the development of the PERT system. Chapter IV brings out the various new techniques used such as PERT/Time, PERT/Cost, and PERT/Reliability. These tools are advantageous for the perpetuity of operations. Chapter V features the Critical Path Method and discusses the differences in this method and PERT. A time-cost analysis is established and its significance to the CPM system is evaluated. Chapter VI is an informative part of the paper in which a few applications and extensions are discussed. For instance, the application of PERT in industrial areas, armed forces and extensions into probability theory are viewed and credited with its enhancement within these areas.

Chapter VIII is the conclusion. An evaluation of PERT is considered in order to define the necessary requirements for a profitable PERT system. In other words, evaluating the rate of return to the cost of PERT is important when allocating resources within the organization.

The implication of the study is that for some time managers have been deficient in a universal management information systems. Therefore, it is essential that they be cognizant of all new techniques such as PERT so that eventually a generalized system for planning and control might be developed.

CHAPTER II

DEVELOPMENT OF THE GANTT CHART

In 1917, H. L. Gantt had installed several of his methods in various factories. Mr. Gantt was acting as a consultant in production, first at the Frankford Arsenal, and then in the Ordinance department at Washington, D.C.

Because of the large orders that had been placed with manufacturing plants for the production of arms and munitions, quantities had risen from hundreds to millions; and it became impossible to schedule and control production with the various tables being used. Thus, the Gantt Chart was developed.[1]

Advantages of the Gantt Chart

Management is concerned almost entirely with the future. A task of management is to decide on policies and to take action in accordance with the policies which will bring about a desired goal. Management must know when events take place or at the rate those events are accomplished--the relationship of facts to time must be made clear.

A plan is necessary when using a Gantt chart. The plan can be recorded on a chart where it can be seen by individuals who are to perform the tasks and can be clearly understood not only by the executives

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[1]Wallace Clark, The Gantt Chart (New York, 1922), p. 1.

but by their subordinates as well. The Gantt chart compares what is done with what was done--it keeps the scheduler informed on a charted plan and its execution. Time is saved by the executive because each time a figure is received he does not need to compare it with past records and decide whether it is good or bad. This comparison has already been determined by the executive when he recorded the figures on the chart. Thus, the manager is left free to study the trends and take corrective action as warranted on the chart.[2]

In attempting to predict and control, the Gantt chart emphasizes the reasons why performance falls short of the plan and thus fixes responsibility for the success and failure of a plan. A significant relationship with time is brought out so that it becomes possible for the executive to foresee future happenings with considerable accuracy.

Application of the Gantt Chart

In order to determine the application and use of the Gantt charts, it is necessary to group the charts in three general classes:[3]

1. Man and Machine Record Charts
2. Layout and Load Charts
3. Progress Charts

In the Man and Machine Record Charts, Gantt developed a mechanism to show the relationship between what is done and what should be done by a man or a machine. The disparity which results from the actual and the possible accomplishment is called idle time; in other words, the

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[2]Ibid., p. 3.

[3]Ibid., p. 17.

neglect to make any use of time or a proper use of it. From the Machine Record Chart time is shown when the various machines are not in use. The Man Record Chart illustrates whether or not a man makes proper use of his working hours and, if not, indicates why. The reasons for idleness are emphasized on the Man and Machine Record Charts, which imply that certain procedures should be taken sometime in advance in order to maintain maximum usage of man and machine.

The Layout Chart is a procedure for planning work in order to avoid idleness of men and equipment and to maintain the balance of work in the order of its importance. This chart shows the amount of work, in hours or days, ahead of a plant or any part of a plant.

The Progress Chart is Gantt's mechanism to promote work by showing a comparison of accomplishments with the plan and the reasons for failure to live up to that plan. These three general classes of Gantt charts simplify a complex situation or problem and point corrective adjustment in the right direction.[4]

The value and adaptability of these charts have through time been recognized by all progressive engineers. In his book, Organizing for Work,[5] Gantt quoted a letter which shows the broad applicability of his chart. The letter was dated December, 1917, and was written by Dean Herman Schneider of the University of Cincinnati to General C. B. Wheeler, Chief of Ordinance. Referring to the Gantt charts in use in the Ordinance department, he said:[6]

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[4]Robert G. Provost, "The Contribution of Henry Laurence Gantt," The Journal of Industrial Engineering (January-February, 1961), p. 62.

[5]Ibid., p. 63.

[6]Clark, pp. 18-19.

> Each production section has production and progress chart systems. . . . The charts give a picture of progress of the whole Ordinance program including lags and the causes therefore. Combined in one office and kept up to date, they would show the requirements as to workers, . . . materials, transportation, accessory machinery, and all the factors which make or break the program.
>
> . . . . Finally, these charts assembled in one clearing office would give the data necessary in order to make the whole program of war production move with fair uniformity, without disastrous competition and with the justice to the workers.

About seven months after Dean Schneider's letter, Colonel John T. Thompson began using Gantt charts in his Small Arms Division.

Another engineer, Walter N. Polakov, in a paper on "Principles of Industrial Philosophy" presented at the Annual Meeting of the American Society of Mechanical Engineers, December 1920, said:[7]

> The achievement of Gantt offers a means of measuring the human or social efficiency of industry. . . . Gantt's method has made it possible to ascertain the cause of the diseased industry just as a blood analysis established the cause of malaria. While the latter made the completion of the Panama Canal possible, the former will transform industry from servitude into a creative service and its pensioners into respectable members of the community.
>
> Unlike statistical diagrams, curve records, and similar static forms of presenting facts of the past (Gantt) charts . . . are kinetic, moving, and project through time the integral elements of service rendered in the past toward the goal in the future.

Summary

It is rather evident that to Gantt the total picture was one of optimizing a complete system which consisted of men, machines, and mate-

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[7]Ibid., p. 21.

rials so as to secure the maximum output. Each of his major contributions, so often listed, was not an isolated fact with no common connection, but part of an over-all concept of scientific management. Gantt may well have been the man, more than any other, responsible for the over-all theory of logistics which coordinated the efforts of industry and the military in both great wars.[8]

In any case, it may well be that from these teachings and from his own personal characteristics the man formulated an over-all theory of scheduling, which is, in reality, a philosophy. It may be expressed as a fact in industry that output must be maximized by the minimization of internal friction caused by loss of communication and time. Technically, all this can be expressed by using rate/quota plotted against time as a simple but highly effective information device. Gantt was primarily a methodologist whose great contribution was method rather than technique.

As a result of the efforts of Gantt's successors, scheduling methods and techniques have been developed which have far more practical application than the Gantt chart. In the following chapters these new devices will be discussed.

[8]Provost, p. 65.

CHAPTER III

AN INTRODUCTION TO PERT

It is essential to understand that network theory is not a new concept. Scientists and engineers have been using it for centuries, but it is customary today when tracing the history of network theory, particularly PERT, to start with Henry Laurence Gantt. This does not mean there is nothing new in the PERT system. On the contrary, new, original techniques have been added continually throughout the development of PERT.

Origination of PERT

PERT is a mixture of new ideas and proven experience. For example, the three time estimates of PERT are a new concept. These time estimates have put realism into the Research and Development schedules. This is perhaps PERT's major contribution to management planning. A major advance was made when a method to show the uncertainty of future R & D schedules was developed. Before PERT, R & D people were requested to pick a specific point in time, several years ahead, when they were going to invent something. Now, they are asked to estimate the probability of completing a job by a particular time.

One of the major reasons network theory has become so popular is the fact that so many people recognize the technique. The project engineer does not see anything revolutionary in networking because he has always thought in those same well ordered, interdependent terms while planning his programs. He has been trained to orderly thinking. For this reason, many experienced project engineers do not understand all the fuss being made about PERT.

On the other hand, the industrial engineers believe they invented network theory, and to some degree this is correct. PERT is related in many ways to the industrial engineer's process flow chart.[9]

Some mathematicians have recognized the topological approach in the PERT network. The mathematics of PERT alone have been subject of many papers and debates.[10]

In 1956 the Navy Special Project Office began to scan around for ideas on management control: within the Navy, in private industry, and in the Air Force ballistic missile program. The United States Navy began to use PERT in the management of the Polaris program early in 1959. The United States Air Force's interest in the technique also dates from this period, although Air Force use of PERT did not start until late 1959.

Applications of PERT

The primary, most basic, and singularly important record in a weapon system development program is undoubtedly the scheduling record. All other records stem from this one. Schedule records are of value in the domains of planning and control; and it is essential that both functions be given adequate consideration. Slippages, overruns, and overcomplica-

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[9]D. G. Malcolm, et al., "Application of a Technique for Research and Development Program Evaluation," Operations Research (September-October, 1959), p. 646.

[10]Ibid., p. 648.

tion are but a few of the myriad of program problems that have their beginning in the planning stage. PERT is primarily a tool of planning and as such makes its greatest contribution at that stage.

PERT forces logical thought. It compels program planners to recognize the relationship of the parts to the whole; because of this, PERT is a natural as a weapon-system planning tool. However, it is certainly not limited to this use. In fact, whenever anything must be planned and is of sufficient complexity to warrant being put on a piece of paper, PERT provides a better way to do it.[11]

Summary

In a large project which requires computerization of the PERT data, the project manager--after a new network has been satisfactorily drawn, reworked, and received his approval--will be better off if he does not use it again until he must replan in whole or in part. He should let PERT reports or PERT derived reports do the control job. A PERT network is like a map; once the route is drawn, we can more easily follow progress against a check list of key points or milestones. Many operating managers become frustrated and disillusioned with PERT because staff people try to force them to use the network as a series of progress reports. It is true that in some instances project engineers do like to use the network as a progress-reporting or recording tool since it is more akin to blueprints than machine-prepared reports. But, this is a matter of preference and certainly should not be rigidly determined. Using the network

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[11]Raoul J. Freeman, "Quantitative Methods in R & D Management," _California Management Review_.

to follow the progress of a large program is the exception and not the rule.

CHAPTER IV

VARIOUS TECHNIQUES OF PERT

During the past several years, a number of significant developments in management methods have occurred. These new management methods show promise of becoming an important competitive element in industry as well as valuable contributors to defense programs. A company's success or failure may stem directly from its ability to understand quickly and utilize effectively these new concepts in daily operations and planning. Techniques such as PERT/Time, PERT/Cost, PERT/Reliability, are examples of these new tools.

There are three main reasons why these new methods are desirable and useful to management. First, there is a continuing need to improve efficiency of operations through quicker, more responsive, and more integrated controls and, especially, to see tangible results from the investment in data processing. Second, management wishes to improve its ability to identify problems in advance by looking ahead rather than relying in the main on approaches that discover deviations from plan after the fact and then attempt to prevent recurrences in the future. Third, in coping with the R & D process, management in both the military and industry are faced with the necessity of reducing the time and cost of development programs. The company that can more quickly turn the fruits of R & D efforts into useful and desired products can gain market initiative.[12]

Experts in the field of aviation often speak of "generations" of missiles having a greater range or other operational capability than the preceding ones. The same concept has been applied to PERT in a series of stages. The first stage of PERT tackled the problem of time in development programs. Second and third stages of PERT are concerned with costs and reliability.

PERT/Time

In the PERT/Time approach, a development program is first portrayed graphically as a network of interrelated activities necessary to achieve prescribed events. Events are shown as squares, circles, or rectangles in the diagram and activities as the connecting arrows. The critical path is the longest path through a particular program. It is this part of the program that management is most anxious to determine, shorten, and monitor.[13]

The relationship of network approach of PERT and traditional Gantt charting is worth commenting on. In Gantt charting, no dependency or interconnection between activities is shown, and coordinate functions and precedent relationships are not shown. These are of major significance in large R & D programs where many activities must be performed concurrently and coordinated properly. Planning for these points and

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[12]A. Astrachan, "Better Plans Come from the Study of the Anatomy of an Engineering Job," Business Week (March 21, 1959), p. 64.

[13]David G. Boulanger, "Program Evaluation and Review Techniques," Advanced Management (July-August, 1961), p. 9.

utilizing the resulting plan in monitoring make it more nearly possible to "create on schedule." The use of the network is thus a significant innovation in the body of industrial engineering techniques.

The next step in the PERT process is to obtain elapsed time estimates for each activity in the network from engineers responsible for their completion. The three estimates--optimistic, most likely, and pessimistic--obtained for each activity represent the range of time which can be expected. They are, in turn, transformed into a probability statement indicating the chances of the activity taking different lengths of time to be achieved.[14]

The flow plan and time estimates are then fed into a computer which sorts out the longest path from all possible paths. All other paths to an event are said to have slack in them, and they represent areas where resources may possibly be reallocated. The path having zero slack is, therefore, the critical path.[15] Thus, PERT aids management by exception because it tells the manager where slips are likely to occur and what their magnitude may be. It also indicates where slack exists in the program and is a guide for reallocating some of the resources to reduce the total program time. This identification of slack areas also tells the manager where not to buy attractive time reduction opportunities.

Another feature of PERT is the possibility of simulating a change. The manager can introduce a synthetic time reduction and find out what would happen to the total program as a result. Changes often do not

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[14]Ibid., p. 10.

[15]A. Charnes and W. W. Cooper, "A Network Interpretation and a Directed Subdual Algarithm for Critical Path Scheduling," The Journal of Industrial Engineering (July-August 1962), p. 215.

bring about a time reduction in the program and have to be rejected. In addition, many displays are possible from the data available in the PERT computer files. A variety of reports can be adapted to individual management needs and preferences. It is highly important for management to specify what it wants out of the computer and not vice versa. It frequently happens that the computer facility can see many possibilities of analyses and outputs of interest to it, which merely complicate the situation and make it difficult for management to see the real simplicity of the PERT technique.[16]

A management systems-design function is being established in many companies to serve as sort of a buffer between management and the computer facility. The specialists in this function know the needs of management and are also able to communicate effectively with the computer experts. The role of the systems designer is becoming better recognized as the need for improved management controls is realized in companies. Many requests for proposals which are issued by military organizations require that the management controls which are to be employed be set forth in the proposal. As a result, systems designers are now free to choose appropriate types of organizations, reporting channels, information gathering techniques, and computer programs for evaluating alternatives at decision points.

PERT/Cost

Early in the original PERT research, it was deemed impractical on two counts to cope simultaneously with all three variables (time, cost,

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[16]Boulanger, p. 10.

and performance) in a computer model. First, related cost and time data on activities not experienced before are almost impossible to obtain with any degree of accuracy. Further on cost and time for different degrees of the item's performance are even more difficult to obtain. Second, even if the data were obtainable, roughly twenty times the amount required by the basic PERT system would be necessary. Therefore, it was reasoned that if an integrated time-cost performance approach were taken at the outset, the cost and data problem would hinder acceptance by the potential user of the system. Because time was of the essence in the Polaris project, the Navy decided to tackle the time variable first and go on to costs after the information channels had been established.[17]

There are a number of ways costs can be assigned to activities. A range of possible costs can be applied to each activity, or a single cost for each one of the time estimates in PERT can be made. Moreover, we must decide whether to use a single cost, or a direct cost, or a total cost. PERT applications have generally applied direct man-hour costs, either in man hours or dollars, to the activity showing the department code for the man. In many cases, the individual man is identified, especially where highly skilled personnel are a scarce commodity in great demand.

There is a problem in making PERT cost data compatible with fiscal practices already in effect. Planned activities often cut across the orderly monthly accounting periods. It is possible to convert from PERT activities to financial planning and accounting by knowing the rate of expenditure, but it is not possible to work in the other directions in

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[17]Department of Defense. DOD and NASA Guide, PERT Cost System Design, June 1962, p. 4.

the absence of a PERT diagram. In other words, PERT costs should be considered an input to current accounting systems. The following output reports can be made available by a PERT/Cost system:[18]

* * * Expected manpower needs by skill, month, and department.

* * * Individual man loading by month.

* * * Expected project direct costs by skill, month, and department.

* * * Regular PERT/Time outputs: slack areas, critical paths, expected calendar time, and impact prediction.

PERT costs and budgeted costs may not always agree. PERT costs will usually be lower and displaced in time because of the fact that all direct work may not be easily identified with networked activities.

After the first PERT cost outputs are available and management has used them in improving utilization and balancing the work load, other opportunities to reallocate resources to activities or to apply new resources will appear. The effect of these in regard to the over-all schedule, or time objective, may be easily evaluated by a simulated change, with the increment costs known. The effectiveness can be measured in terms of time reduction to be achieved. In the course of planning any project, there will be peaks and valleys in the requirements for services of individual skills and individuals in particular. Where knowledge of this can be ascertained in advance, the time may be scheduled for other productive work that the company has available or desires to do--such as a directed research effort. In addition, this is a good project control device for management.

The normal PERT/Cost uses are a single estimate of price for a sin-

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[18] National Aeronautics and Space Administration. _NASA PERT and Companion Cost System Handbook_. Washington, D.C., October 1962, pp. 11-18.

gle time schedule. The time-cost option of PERT takes into consideration the possibilities of (1) saving time by increasing cost or (2) saving cost by increasing time. The advantages of this information are obvious. For example, a contractor may wish to cut his time and therefore his profits on a project to enable him to bid on another project or if the contractor faces a business lull he may wish to lower cost by extending the completion date of the project.[19]

The time-cost option alters PERT Cost System to include three alternative plans. These plans vary in time, cost, and risk. The alternatives are:[20]

1. Most Efficient Plan - The network plan which will meet the technical requirements of the project through the most efficient uses of resources. This plan is usually characterized by low cost, long time, and low risk.

2. Direct Date Plan - The network plan developed to meet the technical requirements of the project by the target date in the contract. This plan is usually characterized by the average cost, time and risk for the project.

3. Shortest Time Plan - The network plan which will meet the technical requirements of the project in the shortest time. This plan is usually characterized by higher cost, shorter time and higher risk.

The selection of one alternative as being the best of the alternate items depends upon the importance of each of the elements of variation (cost, time, and risk) as compared with others.

Much of the process of preparing the three optional plans is incorporated into the development of the directed date plan, which is the normal PERT/Cost Plan. Usually the initial work on the Directed Date

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[19]National Aeronautics and Space Administration. NASA PERT and Facilities Project Management, Washington, D.C., March, 1965, p. 3.

[20]Ibid., p. 11.

Plan results in a Most Efficient Plan which must be compressed in total time.

PERT/Reliability

There are two general approaches towards a greater reliability of PERT. The first approach attempts to put a numerical value on the expected operational reliability of the end item: by measurement or test, a number indicates how many times out of how many trials an item will perform a program. The second approach entails trying to increase reliability by use of the development plan. This is done by monitoring the program to see that there is compliance with the basic specifications, the design, reliability-test procedures, acceptance-test procedures, and so forth. Thus, the theory is that the proper compliance with these reliability tests will result in a more reliable product. The (RMI) is known as the reliability maturity index. (RMI) is an extension of PERT which encompasses the average of two ratings: the (TQE) technical quality evaluation and the (SCE) schedule compliance evaluation. For each reliability event, the two ratings are computed in order to determine the (RMI).[21]

(TQI) is an independent audit of the reliability-events to determine whether the required information has been adequately supplied. This audit is prepared by an engineer as he evaluates an activity that has culminated in a reliability event.

The (SCE) provides planning, scheduling, reporting, and monitoring

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[21]AMA Management Report. PERT: A New Management Planning and Control Technique. American Management Association (New York, 1962), p. 23.

functions of (RMI). Two different SCE rating values are calculated for each assembly and its lower items: a relative composite rating and a cumulative composite rating. The relative composite rating is derived by totaling the actual number of reliability events completed as of the report's date and dividing by the number of reliability events scheduled to have been completed by that date. The cumulative composite rating is computed by totaling the actual number of reliability-events completed as of the report's date and then dividing by the number of reliability events scheduled for the total program.

These two approaches can enhance the reliability of PERT, if the events are handled and the limitations given adequate consideration. The ratios are not used in a dynamic sense, but these are point-in-time ratios, which evaluate reliability in the present situation.

Summary

The PERT techniques mentioned in this chapter have been well explored, but there is still a great future in the exploration of PERT/Time, PERT/Cost, and PERT/Reliability techniques. Therefore, it is essential that management maintain its perception of PERT and the methods it has to offer to planning and operations.

CHAPTER V

THE CRITICAL PATH METHOD

The accelerated pace of today's modern technology demands an equally modern advancement in project management and the means of making sound decisions. In many project activities involving the engineering, construction, and maintenance of today's facilities and installations, the critical path method (CPM) is a powerful management tool that has been used with rewarding results. It integrates all of the factors or building blocks of a project: manpower, money, time, materials, and equipment. It allows management to develop a balanced, optimum, time-cost schedule, which assures timeliness and a minimum use of resources and which provides a true vehicle for management by exception.

PERT contains probabilities for the estimate of job duration, which CPM lacks. However, PERT lacks CPM's cost-time function, which is important in maintaining complete project control. There are two fundamental ways CPM differs from the traditional methods:[22]

> * * * Planning is separated from scheduling. Planning consists of determining what tasks must be performed to complete a project and what the order of their performance should be. Scheduling is an act of translating the plan into a timetable.
>
> * * * Time and costs are directly related. This indicates that the minimum costs and related time of an activity in a

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[22]J. S. Sayer, J. E. Kelly, and Morgan R. Walker, "Critical Path Scheduling," <u>Factory</u>, July 1960, p. 75.

project can be shortened at some sacrifice in cost.

Planning the Process

The critical path scheduling technique starts with arrow diagramming which incorporates all elements of a project. Operations, methods, and resources (time, money, manpower, equipment, and material) plus imposed conditions (design, delivery, approval, budget, completion date) are molded into a coordinate plan and model. Each activity, task, or operation is represented as an arrow, and each arrow indicates the existence of a task.

The arrows interconnect to show the sequence in which the tasks will be performed. The process develops a network in which three basic questions are asked and answered about each arrow:[23]

* * * What must be done before we can start this activity?

* * * What can be done concurrently?

* * * What must immediately follow this activity?

Only those activities immediately related to the one at hand are considered. This way, the process will not become buried when diagramming complex jobs. With a thorough knowledge of the job, only these three questions need be answered to develop a complete network which will serve as a plan for the project.

Time-Cost Analysis

Once the plan is established and the arrow diagram correctly depicts the logical sequential relationship between project activities, time and

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[23] Ibid., p. 76.

cost estimates must be made for all activities in the project to determine project duration, costs, and schedule.

There is a direct relation between the time and cost of any activity. This relationship takes into account the manpower, money, and methods used, and the efficiency achieved. There is an optimum way to do a task. When one deviates from this way, sacrifices in cost are made. If a task is dragged out, cost can increase and schedule can be protracted. Therefore, for each activity a time-cost curve would be beneficial. However, the CPM network does not require such a curve for each activity in a project (because sufficient data are generally not available).[24]

As an alternative two points are estimated:

. . . Normal Point which is the normal cost defined as the minimum activity cost, and the related minimum time is defined as normal time.

. . . Crash Point which is the crash time defined as the minimum possible time to perform the activity, and the related cost is defined as the crash cost.

A linear relationship between these two points is generally sufficient to produce acceptable results comparable to the accuracy of the data input.

With this information available for each activity in the project, CPM can be utilized to process the data. Objective information is derived which gives a number of schedules showing the earliest and latest starting and completion times for each activity and their related costs, along with a number of project-completion times ranging from normal to crash with their related lowest cost.

All critical activities are identified, and they make up the criti-

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[24]AMA Management Report, p. 150.

cal path. These activities will have but one starting and finishing time. Delay in any one of them will hold up the completion of the total project. The critical path of a project is the connected sequence of activities that forms the paths of the longest duration. All the remaining activities in the project can be classified as non-critical. These can suffer a considerable amount of time delay in the earliest start and completion time without affecting the project-completion date. The amount of time delay permissible is called "float."[25]

Having ascertained both the activities on the critical path and the amount of float available for the non-critical activities, those managing the project can control them with much greater assurance. They can concentrate their efforts on the critical jobs with complete knowledge of the effect of any changes in the over-all schedule.

Since the duration of any project is dependent on the time required to complete the various activities, it is possible to have a range of durations depending on the selected time needed to perform each activity. This selection of duration also incorporates specific related activity costs. As a result, for each project duration there is a different project cost. In any project a tremendous number of possibilities exist for combining the various activity times and costs. The mathematical algorithms formulated for CPM do this and produce only the lowest possible cost for each project duration. This computation involves complex mathematical analysis, but the theory can be summarized in terms of the following operations:[26]

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[25]Ibid., p. 151.

[26]Sayer, p. 77.

. . . A normal or minimum cost for project duration is computed.

. . . With the minimum cost schedule established, the next step is to seek and compress activities on the critical path that have the smallest change in cost per unit of time saved and consequently cost the least to expedite. A new schedule is then prepared showing the activities that have been compressed to some values between the normal and crash durations.

Summary

The compression of activities along the critical path can result in making other activities critical and producing different critical paths. Further compression must then consider activities along more than the original critical path. The results produce a series of schedules, each establishing the earliest and latest start and completion times as well as floats for all activities on the project. The critical path is identified, and the associated cost for each activity and for the over-all project for each schedule is provided. The cost for each schedule is the minimum for its related project duration.

CHAPTER VI

APPLICATION AND EXTENSIONS OF PERT

Many people wonder exactly where PERT can be used. They ask whether it is better on small jobs or big jobs. The answer is that there is no restriction on the size of the project. Various firms have implemented the PERT system on small development jobs of $10,000 and less as well as on multi-million dollar programs. Therefore, the impression that PERT and its derivatives are useful only in large, one-time development programs should be dispelled.

Industrial Applications of PERT

In industrial areas, networking has been found useful in small jobs of 5000 to 20,000 man hours. Several users have stated that the very discipline involved in such planning has prevented many errors. The approach has been utilized in areas such as the following:[27]

* * * Installation of new computers
* * * The shelter program in civil defense
* * * The new product process
* * * Construction and maintenance of activities
* * * The financial forecasting process
* * * Mining operations
* * * Real estate development programs
* * * Highway construction
* * * Cost control
* * * Documentation control
* * * Value engineering

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[27] AMA Management Report, p. 26.

It is clear that a network can be and should be used as a dynamic control mechanism. This requires that top management have versatile characteristics enabling them to cope with new technological changes: For instance, the direction and control of major weapons systems programs at General Precision is vested in a program manager, who is fully responsible for establishing and exercising technical and administrative control over the entire program.

Application of PERT for Ballistic Missile
Modification Programs

The Norton Air Force Base is headquarters for the San Bernardino Air Material Area (SBAMA) which is part of the Air Force Logistics command. SBAMA provides world-wide maintenance, supply, transportation and procurement support for the Atlas, Titan and Thor Ballistic Missiles and for liquid rocket engines.[28]

A PERT management center was established at SBAMA in order to control and direct all activities. Involved in this program are several hundred Air Force and contractor personnel. Daily status reports of engineering changes are received via datafax and telephone at the SBAMA PERT center from missile sites undergoing modification. This information is analyzed, and the PERT network is updated for each missile. Critical path calculations are made daily and the resulting information is used by management for evaluation, control and predictive purposes.

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[28]Donald E. Newnham et al., "A PERT Control Center for Management of Major Ballistic Missile Modification Programs," The Journal of Industrial Engineering, January-February, 1961, p. 274.

The Navy and PERT Application

The theory of PERT originated with the Program Evaluation Branch of the Special Projects Office of the Navy. The Special Projects Office was concerned with plans for the development of a complete weapons system. The Program Evaluation Branch of the Plans and Programs Division was assigned the task of estimating progress to date of the complete system. The objective was the attainment of specifically designated operational capabilities at times some years in the future. A schedule for the system development was at hand, encompassing thousands of activities extending years into the future. This schedule had been set up partially to conform to time deadlines set in light of an urgent requirement for the completed weapon system. This forced activities to be compressed into uncomfortably short time intervals. Slippage of scheduled dates sometimes occurred. As the Program Evaluation Branch studied the slippages and prospect of future slippages, it appeared that the capacity to predict future progress was more limited than desired. Thus, a study was made of current practice in the evaluation of progress of huge development programs in order to educe some technique with more reliable predictive power. As a result, the project evaluation research team developed the problem known as PERT (Program Evaluation and Review Technique).[29]

Since the implementation of PERT by the Special Projects Office in 1958, scores of organizations have developed interest in PERT. Several are studying the applicability of PERT in other time consuming operations.

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[29]Malcolm, p. 647.

PERT Probability Statements

Program Evaluation and Review Technique has been developed and implemented as a device for planning and evaluating the progress of research and development programs. Probability theory is used in PERT to calculate a measure of uncertainty in meeting scheduled dates. The computed probabilities can then be used by technical management personnel to aid their judgment in evaluating the validity of proposed and established schedules for accomplishing program objectives. Probability within the PERT system shows that the mechanics of activities can increase or decrease the computed probabilities, depending upon whether the scheduled date for an event is later or earlier in time than the expected date. In other words, given an activity or sequence of activities that terminate in an objective event for which the schedule date has been set, it is desired to investigate the effect of these activities on the computed probability for meeting the scheduled date of the objective event.[30]

For example, utilizing the variance which is computed in PERT schedules, it is possible to estimate the probability of actually meeting scheduled dates. Figure 1 shows the last few events wherein event No. 20 was scheduled at $To_s = 82$ weeks. The expected time analysis, however, indicated $To_e = 92$ weeks with variance $\sigma^2 Te = 38$.[31]

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[30] Thomas L. Nealy, "Activity Subdivision and PERT Probability Statements," <u>Operations Research</u>, May-June 1961, p. 341.

[31] Malcolm, p. 658.

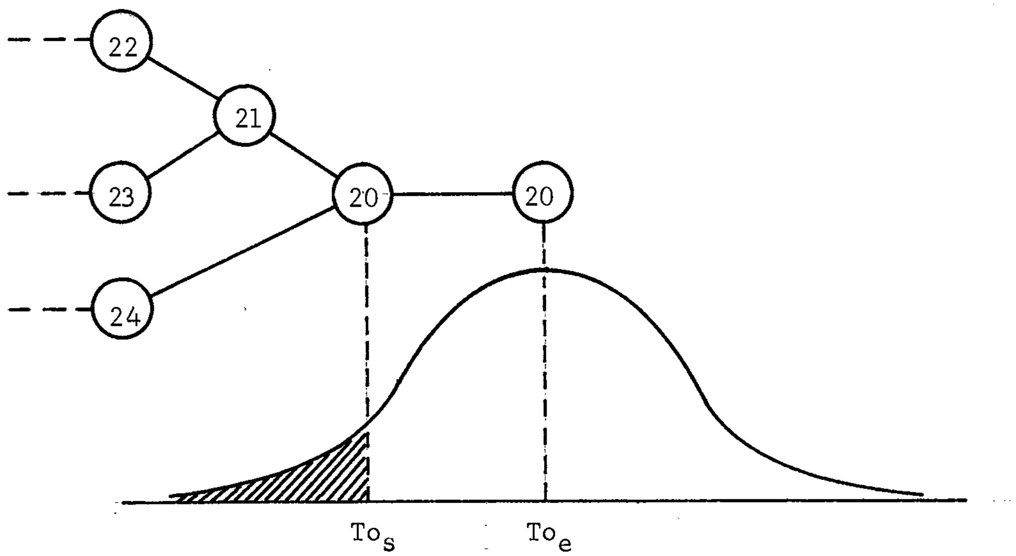

Figure 1

Utilizing the central-limit theorem, it may be assumed that the probability distribution of times for accomplishing an event can be closely approximated with the normal probability density. The probability that event No. 21 will have occurred by time To_s is represented in Figure 2 by the shaded area under the curve. This was determined by equation 1, and using the normal curve tables to educe the probability.

Equation 1

$$\frac{To_s - To_e}{\sigma_{Te}} = \frac{82 - 92}{\sqrt{38}} = 1.6$$

$P(To_s) = .05$

Where probabilities assume low values it is reasonable to assume that the schedule is in jeopardy. High values indicate the opposite--that the schedule appears feasible and likely to be met. For instance, $P(To_s)$ the probability of meeting the scheduled date To_s is .05. Therefore, it is reasonable to suggest that the schedule is in danger.

Summary

The application and extension of PERT techniques are unlimited. Only a few were mentioned in this chapter with the intention of demonstrating the important areas where PERT has been used.

Numerous firms today are finding more problems to which PERT is applicable. Therefore, it is necessary for managers to be aware of current material available so that their current competitive positions can be enhanced.

CHAPTER VII

CONCLUSION

Managerial evaluation of an operating program is admittedly one of the most important yet most difficult tasks that an executive faces. Many approach this task by using an unsystematic method which determines only whether a particular program should be continued or abandoned. PERT as a management information and decision-making system should be evaluated just like any other initial investment or continuous operating expenditure in a company.

Corporate officers must look at the total company operation and evaluate all programs with the board of directors and stockholders in mind. In fact, the function of top management is to allocate the money that is available to it to (1) those functions that are necessary for the continuance of growth of sales, (2) the protection and generation of profits, margins, and (3) the reduction of costs in order to optimize the profits of the company as a whole not only on a short range basis but also from a long-range point of view.[32]

Each department within a company should concentrate on total objectives as they affect stockholders, employees, and the general public. The PERT system has often been introduced into a firm without relating

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[32]PERT Coordinating Group, PERT Guide for Management Use, Washington, D.C., June 1963, p. 40.

it to these objectives--that is, without comparing the cost of PERT with the benefits derived from it. Unless PERT proves its value there is no justification for adding it to the other activities of the organization.

The significant aspect of a network analysis system is the planning and control that it makes possible--not the methods used in collecting and processing information.

In many instances, those individuals who are responsible for decision making are able to see what is going to happen visually--by reviewing PERT information--even before the reports that identify problem areas are formally used. This is the strength of PERT. The many elements of the PERT system--the planning sessions, the reporting system, the evaluation sessions--point the way to sound decision making.

It is entirely possible that management may eventually accept a PERT approach for the development of a universal management information system--one that will give the individual executive a formalized, meaningful approach to the integrated and precise management of those functions for which he is responsible. The PERT system can be used to design a production line or a production process for the "manufacturer" such as:

* * * A market research study, in marketing
* * * A design for a new product, in R & D
* * * A conversion project or an equipment installation, in manufacturing
* * * A computer installation, in finance
* * * An office move, in administrative area
* * * A manpower analysis, in personnel

The only danger is to become so involved in the mechanics of PERT as to overlook its great promise for the planning and control of a manager's work.

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Scope and Method of Study: This report has been undertaken to illustrate some of the concepts and elements of scheduling techniques. The Gantt chart is discussed only with the intention of mentioning its previous significance to managers as a scheduling device. PERT (Program Evaluation and Review Technique) is discussed relative to its potentialities for wide-scale application as a management tool. PERT has offered a new approach to executive decision making in the development of techniques for information and control systems. These techniques are organized in general form throughout the paper. The materials used in the study are chiefly library periodicals and books dealing with PERT techniques and their applications and supplements from the National Aeronautics and Space Administration.

Findings and Conclusions: PERT scheduling techniques, representing a new and significant decision-making tool for executive management, are in the embryonic stage of development. It will take much creative thinking, much development and much company experience to invest it with the full usefulness and potential application of which it now appears to be capable. This report has emphasized the methodology and concepts of PERT systems, with the intention of providing the reader with a framework for the further development of scheduling theory. PERT/Time, PERT/Cost, PERT/Reliability, and Critical Path are discussed relative to their methodology and applications and their significance to the manager in developing decision making rules which are in tune with scheduling policies.

ADVISER'S APPROVAL Richard P. Weeks