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PERT| Military contribution to management science

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PERT: MILITARY CONTRIBUTION TO MANAGEMENT SCIENCE

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Introduction

PERT is an acronym that stands for "Progress Evaluation and Review Technique." The PERT Guide for Management Use[1] defines PERT as "a set of principles, methods, and techniques for effective planning of objective-oriented work thereby establishing a sound basis for effective scheduling, costing, controlling and replanning in the management of programs."

PERT is primarily used for nonrepetitive projects as opposed to continuous production operations. Production managers will not be likely to use PERT for their every-day operations; rather, project or program managers will be the ones to find the proper use of this new management science tool. Applications of this method can be either large or small; however, the larger systems and applications are of more significance.

CPM (Critical Path Method) is another concept having to do with network analysis. CPM was developed in connection with maintenance and construction work, whereas, PERT was developed as an aid to the Polaris Missile system development.

CPM and PERT are both critical path systems. They are basically the same, although they each use somewhat different terminology. The one main difference concerns the problem of uncertainty. CPM

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[1] PERT Guide for Management Use (Washington: U. S. Government Printing Office, 1963), p. 3.

endeavors to determine only the expected times of completion for the project and subprojects. PERT deals more explicitly with uncertainty and estimates variances associated with the expected times of completion. The methodology of these two methods is the same and will be referred to as the basic critical path concept or PERT.

The U. S. Air Force PERT Orientation and Training Center published a report entitled Bibliography: PERT and Other Management Systems and Techniques in 1963.[2] There were 702 works in the field at that time and the growth is rapidly continuing.

Another method of measuring the rapid growth of interest in this field and its voluminous literature is through the listing of acronymic designators and terminology. The Glossary of Management Systems Terminology (Including Acronyms) was prepared by the Air Force and it identifies and defines 118 variations of PERT.[3]

The beginning of scientific management is generally traced back to the early 1900s. Frederick W. Taylor established direct labor standards and costs in relation to the volume of goods produced. Later, standards were set and break-even analysis was used segregating the costs into fixed, variable, and semivariable. The success of these systems was dependent on high volume production of standardized products rather than one-time-through projects with high research and development costs.

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[2]Arch R. Dooley, "Interpretations of PERT," Harvard Business Review, 42(2):162 (March/April 1964).

[3]Ibid.

Henry Gantt, a contemporary of Taylor, developed another technique that is closely related to PERT. Gantt developed his much used Gantt Chart during World War I when he worked with the Army Bureau of Ordnance.[4] His typical chart was comprised of the individual orders placed vertically on the left side of the chart with scheduled completion and actual completion designated by horizontal bars plotted along the horizontal time scale.

The Gantt Chart is widely used today in production planning; however, it is best used in planning for other than development-oriented projects. It is used today in conjunction with PERT project management in two specialized ways. The first is for the overall master planning or schedule phasing where the broad calendar time goals are initially planned and then laid out.

The other use of the Gantt Chart comes after the completion of the PERT analysis. The PERT information is transcribed onto a Gantt Chart for the benefit of executives who are unfamiliar with network analysis.

During World War II, three variations of the early techniques were developed for program planning.[5] The three methods helped to further the development of PERT and are known as: the learning-curve, line-of-balance, and milestone methods. Most production textbooks give a complete coverage of these three techniques for the reader who is interested. The purpose of mentioning these techniques in this

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[4]Robert W. Miller, _Schedule, Cost, and Profit Control with PERT_ (New York: McGraw-Hill, 1963), p. 6.

[5]_Ibid._, p. 7.

paper is to show that they were the result of military needs.

The Goodyear Company developed a graphic management control system in 1941 to handle the growth of new military production plans.[6] The Navy Bureau of Aeronautics used it for procurement during World War II when it became known as the line-of-balance method.

The learning-curve technique was another development of the aircraft industry prior to World War II.[7] This method is best used for projecting costs for a well defined production system since it does not take into account the variability that occurs in limited production situations.

Another military program planning and control system was developed after World War II by the Navy and it is known as the milestone method. This method is simply a refinement of the Gantt Chart. Individual "milestones" are placed within each horizontal bar of the Gantt Chart. These "milestones" are comparable to a PERT event, which is a specific definable accomplishment in a program plan, if they represent a defined point in time. If the constraints that exist in the program are defined and shown, a PERT network could be devised. However, a deeper analytical approach was needed to give validity or predictive quality to the milestone method.

During the 1950s there were many other developments that helped form the foundation for PERT and management science.

Operations research, which is applied decision theory, was first formally recognized as a profession in the first years of World War II.

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[6] Ibid., p. 17.

[7] Ibid., p. 22.

In Britain it was much better received than in the United States where operations research was relatively unwelcome.[8]

The U. S. Air Force used operations research much more extensively than either the Army or Navy during the Second World War. Today, operations research is used by all levels and branches of government and business.

Since operations research began with the military it seems logical that this sector has grown the fastest. Military sectors are beginning to be saturated and the growth area tends to be in the industrial sector.

Another development that aided in the introduction of PERT was the advent of electronic data processing in the middle 1950s.

Military Beginning of PERT

PERT was implemented by the Program Evaluation Branch of the Special Projects Office of the Navy in 1958.[9] Up until that time the Navy had been quite conservative in its approach to operations research.

The Special Projects Office was concerned with the development of the complete weapons system. One group was concerned with the costs of the system and another coordinated the plans.

A schedule for the Polaris Fleet Ballistic Missile program had been made which encompassed hundreds of activities extending into the

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[8]Ellis A. Johnson, "The Long-Range Future of Operational Research," Operations Research, 8(1):1 (Jan-Feb 1960).

[9]D. G. Malcolm et al., "Application of a Technique for Research and Development Program Evaluation," Operations Research, 7(5):647 (Sept-Oct 1959).

future. Many of the activities were compressed into time periods that were not adequate for completion. Other activities were allocated too much time and effort. Since the Polaris program was deemed to be a high priority task it was decided that the progress of the program should be evaluated. Thus, a research team of eight men was chosen to develop a technique for evaluating the Polaris program.

The research team designated the problem as PERT, which stood for the Program Evaluation Research Task. Later this became known as the Program Evaluation and Review Technique. Time limitations forced the team to develop the preliminary model within a period of one month. Therefore, the Polaris program is an excellent example of what can be done in a limited amount of time with an experienced team of operations analysts.

"Project PERT was set up as a three-phase program:[10]

1. To perform an operations-research study leading to the design and feasibility test of an evaluation system.

2. To make pilot application of the system in selected areas, and

3. To implement the system to all applicable parts of the FBM (Fleet Ballistic Missile) program."

The study was restricted to the time area since the Polaris program was quite involved. Today the basic or original PERT has been named PERT/TIME.

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[10] *Ibid.*, p. 648.

Basic Principles of PERT

PERT is a symbol used to represent a set of several concepts. These concepts are:[11] (1) network representation of plans; (2) predictions of time schedules; (3) estimation of uncertainty by using probability of completion approaches, such as the three time estimates which are covered later in this paper, and (4) adaptability of any project to its environment and to circumstances. These concepts taken together form the basic foundation for the management science tool known as PERT.

The PERT concept is built upon the following elements:

1. An event. A specific definable accomplishment in a program plan, recognizable at a particular instant in time. There may be work involved in approaching an event, but the event does not consume time or resources. The event is usually represented by circles or rectangles in the network. The two main types of events are the beginning or predecessor event and the ending or successor event. The beginning event signifies the starting of one or more activities on a network. The event which signifies the completion of one or more activities is called the ending event. Other event terminology is peculiar to the organization making the PERT analysis. Therefore, the event terminology should be placed in an event definition dictionary to avoid confusion.

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[11]American Management Association, PERT: A New Management Planning and Control Technique (New York: American Management Association, 1962), p. 61.

2. An activity. This represents a process, task, procurement cycle, waiting time, or simply a connection between two events in the network. It is represented by an arrow and it is a clearly definable task to which a known quantity of manpower and other resources will be applied. An activity represents an applied effort over a period of time and is bounded by two events referred to as the predecessor and successor events.

3. Time estimates. Elapsed time estimates are made for each activity after all the events and activities have been determined. In order to make advance predictions of this time, it is necessary to estimate. The estimating procedure is one of the most controversial aspects of PERT and one of the basic cornerstones of the PERT technique. There are three time estimates:

a. An optimistic time. The time required to complete the activity if everything goes exceptionally well. This is an unrealistic estimate to the extent that it has no more than one chance in a hundred of being completed within this time.

b. A pessimistic time. The estimated time required for an activity under the most adverse conditions, disregarding catastrophic events unless they are inherent risks in the activity. This is also an unrealistic estimate, representing the worst case of one out of a hundred.

c. A most likely time. The most realistic estimate of the time an activity will take. If this same activity could be repeated independently a number of times this time would be expected to occur the most often.

4. Expected time. The expected time is derived from the calculation of a statistically weighted average time estimate using the three time estimates. The most likely time or mode carries two-thirds of the total weight, while the optimistic times and pessimistic times each carry one-sixth of the total weight. This is the time that divides the total range of probability in half. There is a 50-50 chance that the time required will be earlier or later than the expected time.

5. Spread. This is found by the standard deviation or its squared version (variance) and represents the dispersion of the beta distribution. The beta distribution is represented as follows: $f(t) = K(t-a)^{\alpha}(b-t)^{\gamma}$. K, α, and γ are functions of a, m, and b, and a, m, and b are the three time estimates. The beta distribution may be represented as a normal bell-shaped curve; however, it may be skewed on either side. The amount by which the actual completion date will be earlier or later than the expected time is dependent on the value of the standard deviation. A higher value of the standard deviation will increase the probability that the actual completion time will be earlier or later than the expected time.

6. Network. This is a flow diagram consisting of the activities and events which must be accomplished to reach the program objectives, showing their planned sequences of accomplishment, interdependencies, and interrelationships. The time estimates are calculated and placed on the network.

7. Critical Path. This is the longest path through the network or that particular sequence of events and activities that has the worst (least algebraic) value of slack. Several critical paths may be

identified in a network; however, one will be longer than all the rest. This path determines the length of time required to reach the objective event. If the program is to be shortened, then one or more of the activities along this path must be shortened or eliminated. The application of additional effort anywhere else in the network will be useless unless the critical path is shortened first. If the time required for the actual performance of an activity on the critical path varies from the calculated expected time the variation will be reflected in a one-to-one fashion in the anticipated accomplishment of the objective event, i.e., a one week delay along the critical path will cause a one week delay of the objective event.

8. Slack. Since the critical path is defined as the longest path through the network, then all other events and activities in the network must lie on shorter paths. These paths are referred to as slack paths where there is a surplus of resources of men and facilities, and time to spare.

To measure the amount of slack existing at any one point in the network requires the calculation of two times. They are:

a. Earliest expected date. This is the calendar date on which an event can be expected to occur. The value of this date is determined by summing the calculated expected elapsed times for the activities on the longest path from the starting event up to the event in question.

b. Latest allowable date. This is the latest date on which an event can occur without creating an expected delay in the completion of the program. This value is determined by subtracting the sum of the expected times for activities on the longest path leading back from the objective event to the event in question from the schedule date for the objective event.

Slack for an event is the difference between the latest allowable date and the earliest expected date expressed in weeks. It represents flexibility or a range of time over which an activity can take place without influencing the overall objective.

9. Probability of success. The probability of meeting the expected time for the activity or the objective completion date can be represented as a normal, bell-shaped distribution. The value of the probability of accomplishing the scheduled objective date can be found by subtracting the expected time from the scheduled time and then dividing the difference by the standard deviation. This result is entered into a normal probability distribution table to find the probability of accomplishing the scheduled objective date. By the use of this probability figure it is possible to compare the expected completion date with the uncertainty of it happening. Another probability of success may be obtained by comparing the PERT predicted expected time and its uncertainty with the schedule commitment for the objective event. From this we derive the probability of meeting the schedule.

One of the main objections to the use of PERT, which causes confusion and a great amount of controversy, stems from the significance and proper use of the three time estimates. Although some of the assumptions underlying PERT are questioned on theoretical grounds, they have been proven useful when properly applied. The PERT statistical approach allows for chance variation in the scheduling calculations.

After the three time estimates are obtained, they are considered to be connected in the form of a unimodal probability distribution.[12] The mode is called the most likely time (m). The optimistic time (a) and the pessimistic time (b) may be skewed to either side of "m". The original PERT research team thought that the beta distribution was the closest approximation for the three time estimates. The PERT research team made a mathematical analysis involving an assumption of the relationships between range and standard deviation, and an approximation with respect to the relationship between the mean and the mode in the beta distribution. The research team arrived at the following general formulas:

Expected time (or mean) = $(a + 4m + b)/6$

Standard deviation = $(b - a)/6$

Variance = $([b - a]/6)^2$

Miller[13] believes that the three time estimating approach of PERT constitutes one of its most important features. Uncertainty is brought out in the open where it can be fully evaluated. This evaluation is accomplished by attempting to obtain a measure of the uncertainty involved when we choose the optimistic and pessimistic times. If properly used, this method makes a significant contribution to the establishment of realistic schedules.

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[12]Miller, p. 41.

[13]*Ibid.*, p. 45.

Clark[14] states that each time estimate must be made by a technician who fully understands the performance of the activity. Estimates must be made periodically, formally, and at low cost for thousands of activities. The most likely time estimate that can be used to conceive the time span of a future activity approximates the mode of the distribution.

An estimated expected value and variance are needed from the above information. A distribution is needed of the activity times which has parameters of the mode and the two extremes. The beta distribution fits the activity times quite well; however, it still has a free parameter after its mode and extremes are designated.

A beta distribution is determined if a normal distribution is truncated at ± 2.66. The standard deviation is equal to one-sixth the range which is a fairly good approximation. The mode and the extremes of the beta distribution can be converted into the expected value and variance by computations requiring the solution of a cubic equation. However, this is quite difficult and a close approximation can be obtained by using a simple formula. The expected value is the weighted arithmetic mean of the mode and the midrange, with the mode carrying two-thirds of the total weight. The standard deviation is considered to be one-sixth of the range. Thus, we arrive at the before mentioned formulas for the PERT estimates of the expected value and standard deviation of the activity time.

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[14]Charles E. Clark, "The PERT Model for the Distribution of an Activity Time," Operations Research, 10(3):406 (May-June 1962).

Statisticians will probably continue to argue the handling of the three time estimates. The net error derived from the improper handling of the three time estimates is small when compared with other errors inherent in the critical path calculation.

PERT/COST

The original PERT research team recognized that the network might provide an ideal framework for the development of costs on their complex program. However, they decided to remain with PERT/TIME since they were short of time and anticipated difficulties in implementing their basic PERT.

PERT/COST is fully dependent on PERT/TIME since the networks must be fully developed before the costing phase can be completed. The team used to implement the original PERT/TIME network should be used to establish the costing phase since they have an intimate knowledge of the network.

PERT/COST has two basic objectives:[15] (1) to achieve a realistic original cost estimate, and (2) after the program is authorized to proceed, to achieve a marked improvement in control against the original estimate.

The Department of Defense was instrumental in establishing a uniform PERT/COST system by printing a document entitled DOD/NASA PERT/COST Guide in 1962. This document was printed to satisfy the need of defense and space work companies in establishing a uniform PERT/COST

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[15] Miller, p. 90.

system. After the introduction of PERT/TIME in 1958, most government contractors began to develop their own PERT/COST systems. To benefit government contractors, the Department of Defense, National Aeronautics and Space Administration, Atomic Energy Commission, Federal Aviation Agency, Bureau of the Budget, and other Federal agencies agreed to develop a uniform PERT/COST system for the Federal government. Today the DOD/NASA PERT/COST Guide is the standard for all government contractors.

It is not my intention to cover PERT/COST in any great detail in this paper. I only want to differentiate between PERT/TIME and PERT/COST. When I speak of PERT, I am still referring to the basic PERT or PERT/TIME as it is now known.

Military Uses of PERT

Planning and control of complex, one-time-through programs for the military was marked by very poor performance during the 1950s. These programs were based upon the early techniques of scientific management.

One of the first studies of the above problem was compiled by A. W. Marshall and W. H. Meckling of the RAND Corporation in 1959.[16] The report was entitled Predictability of the Costs, Time, and Success of Development. It covered the cost history of twenty-two major military development programs during the 1950s. Ten of the group were analyzed as to the availability or schedule history of the program.

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[16] Ibid., p. 7.

Marshall and Meckling computed a "factor increase" which was the ratio of the latest available estimate of cumulative average cost of production versus the earliest such estimate available. These estimates were quite difficult to arrive at and probably produced conservative results.

They broke their data into the following groups:[17] fighters, bombers, cargoes and tankers, and missiles. The nine fighter development programs had a mean factor increase of 1.7. The three bomber programs had a mean factor increase of 2.7. The four cargo and tanker projects had a mean factor increase of 1.2 and the six missile projects had a mean factor increase of 4.1. One missile project had a cost factor increase of 7.1; however, the overall average for the study was 2.4. These figures mean that the average increase in costs for the twenty-two major development programs was approximately 140 per cent. The costs were the total escalation costs for any and all reasons from the original estimates.

The ten programs studied for availability or lateness in schedule produced an average time slippage of 2.0 years. This amounts to an extension of development time by one-third to one-half.

Merton J. Peck and Frederic M. Scherer of the Harvard Business School published a book in 1962 entitled The Weapons Acquisition Process: An Economic Analysis.[18] They studied the development cost and time variance factors of twelve weapons programs. Their results correlate highly with the RAND study. The average cost factor increase

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[17] Ibid., p. 8.

[18] Ibid., p. 10.

was 3.2 and the average time factor increase was 1.36. The main difference between the two studies was that the RAND study involved production costs and the Harvard study was concerned with development costs. Another study involving both production and development costs should be made to see what compound effects would occur.

What are the reasons given for these large variances from early time and cost predictions, with their admittedly unfortunate impact on planning and decision making in the national interest? Some of the reasons most commonly advanced are the following:[19]

1. The great difficulty of estimating time and cost for programs with a high degree of technical uncertainty.

2. The built-in 'optimistic bias' resulting from the competitive situation in which such programs are 'sold'. (Both government and industry are involved in this picture, together with the CPFF of Cost-Plus-Fixed-Fee contract.)

3. The lack of clear-cut technical and priority objectives, resulting in a high degree of change in program direction.

4. Problems of management planning and decision making within both industry and government, including the lack of planning and control techniques adequate for the demanding problems of modern program management.

The last reason advanced suggests a need for the introduction of the concept of interdependence of time, cost, and performance variables. This can be accomplished with a PERT Management System.

The complexity and size of military and space programs had mushroomed so much by the early 1960s that it became necessary to multiply original program cost estimates by factors of two to three.[20] To remain within budget limitations, many programs had to be cancelled.

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[19] Ibid., p. 13. [20] Ibid., p. 12.

Dr. Harold Brown, Director of Defense Research and Engineering in 1963, testified before a Congressional Sub-Committee on Military Appropriations that 57 defense programs had been cancelled in the past ten years, on which total funds expended were $6.2 billion.[21]

In 1962 the Department of Defense decided on four approaches to overcome the past problems encountered in project management. They were:[22]

1. Better initial system or program definition, based upon components or building blocks of known feasibility.

2. New cost and schedule estimating practices, i.e., PERT/TIME and PERT/COST analysis prior to the beginning of the development phase.

3. An explicit methodology of Configuration Management for the acquisition phase of a program.

4. New incentive contracting approaches to industry for the acquisition phase of a program.

The Air Force developed the concept of Configuration Management in the late 1950s in order to control the crash programs of the Atlas, Titan, and Minuteman. These ICBM's were all handled on a concurrent basis with overlapping of development, production and site activation necessitated by critical operational readiness dates. Configuration Management involves a formal control procedure for changing the original base-line or preliminary design requirements. Configuration Management is simply a control procedure that begins after the preliminary design requirements have been decided. Control begins with the development stage and continues on through the production, activation, and operational stages.

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[21] Ibid., p. 13. [22] Ibid.

Incentive contracting is the philosophy that is concerned with realistic targets of performance, time and cost. If the contractor achieves all three goals in the execution of a contract he will receive the target profits. The target profits might be a total return of 8 per cent of the total cost of the contract. Contractors who have better performance, time, and cost targets would receive higher than average profits; and those who do not do so well will receive lower profits or possible losses.

From the above four improvements, the concept of interdependence of performance, time, and cost variables for complex, one-time-through programs was formed. Today, the relationship between these three variables has much to do with the success of the whole program.

Program Definition is the first step in the overall PERT Management System. The Department of Defense requires that this concept be used prior to the development and production stage on all programs which fall in the categories of engineering development or operational systems development. The Program Definition phase of the project is concerned with the mission or end use of the project. Program Definition requires additional time and money for the short run, but the Federal government believes that it more than pays for itself in the long run.

Historically, it is evident that the subsystems and components of large systems were designed independently and prior to the major systems themselves. To alleviate the problem of ending up without certain subsystems and then initiating crash development programs for these missing links, the building block approach is now used by the

Department of Defense. The building block approach means to take presently available technology suitable for practical subsystems and build these subsystems into the complete system desired. This method uses the links or blocks to build the chain.

Systems Engineering is another outgrowth of the rapid technological change of the 1950s associated with the onset of large and complex weapon systems.[23] The systems analyst is concerned with the mission effectiveness of the overall weapons system. He is not concerned directly with the problems of detailed development and design of the system and subsystems. He is concerned with optimizing the performance factors of range, payload, and reliability and trading them off against time and cost factors. The range is dependent on how far the target is from the final delivery point. The payload is the explosive power of the missile. The reliability would be dependent on how critical the target is and whether there is any type of backup system to use if the first system should fail.

One of the systems analyst's major problems in today's Cold War era is to determine the penalty costs of our national defense if the new weapons system is not developed in time to deter or meet an enemy threat.

Program Definition and the start of the systems engineering phase begin with the government's statement of the broad goals of the program.[24] These include the primary mission goals and the major performance goals of the program. The environment of the system is also

[23]H. H. Goode and R. E. Machol, Systems Engineering (New York: McGraw-Hill, 1957), p. 1.

[24]Miller, p. 139.

given, i.e., will the system be fired from under water, from the ground, or from the air? At this stage of the program the Federal government is concerned with the overall cost of the program which can be broken down into three elements. They are referred to as "research and development," "investment," and "operating" costs.

Establishment of measures of effectiveness begin after the major goals have been established. These measures are used as an overall test of technical effectiveness later on in the program. Different models are usually constructed using various technical parameters such as reliability and maintainability to establish the "cost-effectiveness ratio" of the system. This ratio is not a set ratio, rather, it depends on the system being studied and the analyst making the study. This concept is analogous to the marketing of a new product. Initially, the effectiveness or value of the system is very low since the investment in development costs cannot be recovered until the system is operational. The system increases in value up to some point in time and then the value decreases as the system becomes obsolete.

The functional analysis of the system can also begin at this time. This phase is concerned with the basic functions performed after the actual system is in use. Since this requires various hardware, design requirements are imposed at this time. The overall system is then broken down into various subsystems. Parametric studies are required to determine the most feasible alternate designs for the various subsystems.

When the systems analyst has narrowed down the various alternatives of the subsystems, he then chooses the preliminary overall system.

The final system, which is the system that will be produced if it is accepted, will probably change from the preliminary overall system since unforeseen difficulties will probably arise.

PERT/TIME is used throughout the complex process of Systems Definition; however, PERT/COST is not usually required at this stage of development of the program.

The Department of Defense begins the Program Definition phase after it determines the program is technologically feasible. Two competing contractors are usually chosen to compete on two equally funded contracts. A good example of this method of contracting is the Supersonic Transport (SST) contract. Lockheed and Boeing are the two equally funded contractors. Systems engineering, PERT analysis based on the preliminary design requirement, and contract negotiations for the development phase make up the Program Definition phase. The three results that may occur at the end of the Program Definition effort are:[25]

1. Program may be cancelled because of an unsatisfactory cost-effectiveness ratio. (The cut-off point for this ratio is not a set figure, rather, it is more of a political and economical decision.)

2. Program Definition phase may be extended to change the preliminary system or other projections.

3. The program may be authorized for development.

If the program is authorized to proceed into the development stage, 18 to 24 months of development will be required before production

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[25]*Ibid.*, p. 151.

can begin.[26] The production phase will probably take another two to three years after the system is developed. Thus, it can be seen that the planned effort, after the conceptual and feasibility phases have been completed, will take approximately five years to complete. However, up until the advent of PERT and systems engineering, the United States took ten years to develop a new weapons system.[27]

The air war problem of the United States is one of the better examples of how the military uses the PERT Management System. Initially, we can state a national goal for the United States such as "to preserve for ourselves and our posterity freedom and the blessings of liberty."[28] Although this is oversimplified, we can assume that national goals change very slowly. Our basic national goals were partially written down in our Constitution and have been expanded and interpreted during the past two centuries.

Next, our national objectives must be considered. One possible national objective out of many might be to remove the threat of militant communism to enhance the survival of ourselves and our national goals. If our national objective is to actually remove the threat of militant communism to the United States, then we must choose between annihilation or attrition. Then we would choose between a policy of aggression or defense. A further breakdown would show strategies of

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[26] Ibid., p. 150.

[27] Charles D. Flage, William H. Huggins, and Robert H. Roy (eds.), Operations Research and Systems Engineering (Baltimore: Johns Hopkins Press, 1960), p. 28.

[28] Donald P. Eckman (ed.), Systems: Research and Design (New York: John Wiley & Sons, 1961), p. 65.

political, economic, or military measures. We would then end up with a strategy for the nation.

The next step would be to determine the tactics which we should use. This would be done with a similar analysis. The decision to wage a small scale tactical war, use an all-out nuclear initial attack, maintain a strong deterrent force, or rely on a superior air defense system would fall under this category.

When the tactics are weighed against one another and against other outside parameters, such as taking into account geopolitics in the theaters where we might have to fight, the problem of choosing a weapons system becomes our next problem. Up until this time the problem would be solved by an operations research group through the use of models, simulation, and gaming. This phase would be called the conceptual or feasibility phase.

The first integrated attempt to study in detail the entire air war problem in all its defensive, offensive, economic, and cultural aspects was conducted by the Operations Research Office.[29]

The weapons needed to complete the total weapons system are defined through the use of the before mentioned Program Definition phase of the planned effort. Design requirements are determined with the aid of systems engineering and the overall PERT Management System. Then comes the development and production phases. Before the aircraft or missile becomes operationally ready it is well on its way to becoming obsolete. Therefore, there is a never ending problem of research and

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[29] Ibid., p. 86.

development in maintaining or trying to maintain an air war superiority over any would-be aggressors.

Some of the heated controversies of the day are concerned with our present day policies affecting our air war capability. The most controversial program is probably the TFX or F-111 program. Others are: the manned bomber (XB-70); Nike-X defense system against ICBM's; aircraft carrier usage, and many other numerous examples. Time will be the final judge as to which basket or baskets we should have carried our eggs (or air war systems) in.

Successful Applications of PERT

PERT has been applied successfully in almost every field of human endeavor. Cost Reduction Through Better Management in the Federal Government was a report published in 1963 by the Bureau of the Budget.[30] The report stated that the principal value of PERT, both time and cost, was as an aid to improved management. The report mentioned several cases of cost reduction and schedule improvement by using PERT. Some of the military implications are as follows:

1. Navy--Has reported a savings of $250,000 out of a total overrun of $850,000 by using PERT/COST. An additional $435,000 of the overrun was reported as a change in contract scope subject to negotiation, in which additional savings might be made.

2. Army--Has found the networking and scheduling aspects of PERT to be most valuable in construction projects. An isolated Pacific

[30]Miller, p. 166.

Isle radar installation project was PERTed. The savings amounted to an estimated $100,000.

3. Air Force--The C-141 program is a good illustration of benefits derived from scheduling with PERT. Three contractors anticipated a delay of 36 weeks in their propulsion area when they integrated their three separate contracts. Through the use of network analysis the delay was reduced from 36 to 8 weeks.

These are but a few of the many savings resulting in the use of the new management science tool called PERT. However, the results are not restricted to the military.

J. W. Pocock of the Booz-Allen Applied Research group made an extensive survey of specific returns of PERT in the commercial area of operations.[31] A 22 per cent time reduction along with a 15 per cent reduction in expediting costs on 47 projects were reported by Catalytic Construction Company. DuPont reported a 37 per cent reduction in downtime, with a saving of more than one million pounds of production in the shutdown of a chemical plant in Louisville. Sun-Maid Growers of California reported a time reduction of 25 per cent and estimated benefits of about $1,000,000 in construction of a plant properly timed to the growing season.

Disadvantages and Problems of PERT

PERT is a refinement of earlier planning and control techniques.

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[31]J. W. Pocock, "PERT As an Analytical Aid for Program Planning --Its Payoffs and Problems," Operations Research, 10(6):900 (Nov-Dec, 1962).

It is not a new management science by itself, however, it is simply a tool to be used in management science. PERT draws heavily on older management control techniques and concepts.

PERT has caused much disappointment since its introduction in 1958. Huge sums of money have been spent on PERT programs before discovering that the PERT approach was not feasible within the context in which its use was planned.

The basic concept of PERT is deceivingly simple. The difficulty arises from the application of PERT to a real life situation. Over-enthusiasm and lack of sufficient experience have caused much of the disappointment that has been encountered.

Management must monitor PERT to a high degree if the anticipated results are to be achieved. Since PERT is a new technique, it must be given much more attention than the older well known and tried techniques. Management must fully understand PERT if they are to determine its feasibility and then continuously monitor it. PERT empires grow and paper work blossoms when management cannot understand or does not try to comprehend this basically simple technique.

Management is often apprehensive to change from their successful static techniques of planning and control to the new dynamic technique of PERT.

PERT cannot be used as a substitute for management decision. PERT is simply an aid to human judgment and a tool to be used for management by exception. Sometimes PERT is thought of as an automatic system which will cure all sorts of problems. This is certainly not true.

PERT has sometimes tended to become an inflexible system. Other management systems have been bent to meet PERT's requirements. This is not the proper application of PERT. Instead, PERT should remain a generalized technique to be adapted to specific needs. Flexibility enables PERT to be implemented as a means to achieve an end.

Treating a project as an integrated whole instead of breaking it into functional or organizational patterns creates another problem. Lines of authority are cut apart at low levels and coordination and cooperation are required of all departments involved. Traditional practices must be changed if PERT is to be used successfully. This problem is caused by the application of PERT and not by the basic technique itself.

Advantages of PERT

PERT was initially regarded as a planning device with its greatest management value concentrated in the initial planning stages of the project. Since PERT's introduction the control and operating values have gradually taken on more importance until they are now the most important aspects. Planning and control with PERT are inseparable. PERT/COST was a normal and almost automatic by-product of PERT/TIME.

One of the first advantages achieved by implementing PERT was the change in management thinking. Management simply wanted to meet a schedule before the advent of PERT. After the advent of PERT, management began to accept uncertainty as a part of the overall system.

The predictive quality of PERT is one of its most talked about advantages. The critical path focuses attention on the major problem areas of the project. Schedule status is constantly obtained and the time required to reach any event in the network can be rapidly evaluated.

PERT contributes to the adoption of positive and unambiguous definitions of program events and activities. Therefore, everyone in the organization is talking the same language.

Integration of planning is accomplished while building the plan into a network by sequencing and relating the different events. Management responsibilities can be designated by studying the interrelationships of the network.

After the project has been networked and analyzed, the expectancies can be readily seen. Management action will be needed if the expectancies are not acceptable.

PERT can be used as a control mechanism in identifying potential trouble spots. PERT is a dynamic reporting process since it can be used to lay the basis for anticipatory management action against trouble spots likely to appear.

Reallocation of resources is another contribution of PERT. Slack areas can be used to trade-off available time and resources to benefit the critical path areas.

PERT results in improved management decision making through the use of simulation and computers. Management alternatives can be fed into a computer instead of trying them on the actual operations. This amounts to quite a sizable cost savings.

Future of PERT

Management has been seeking new techniques to make planning and control more effective for a long time. Today, management, like invention, is no longer a matter of individual effort. Management of space programs, weapons systems, construction projects, and many other various projects are accomplished through large organizations of professional experts. Thus, the complexity of directing and controlling these systems has challenged conventional management techniques.

The objective toward which PERT strives is not a new one. PERT is not the ultimate in planning and control; however, it is a major step in the right direction.

PERT is a significant step forward in integrating management systems encompassing the variables of time, resources, and technical performance. PERT offers a sound basis for defining, scheduling, and completing successfully the prime and supporting objectives of any project through improved planning.

The success of PERT during the development of the Polaris Missile resulted in its proliferation in the military sector of the economy. Today, PERT is a fact of life since it is a requirement in most government contracts.

PERT has snowballed to the private commercial and industrial sector of the economy through the exposure of private industry to military projects requiring PERT. This is the area where PERT will increase the fastest since the military area is becoming saturated.

PERT is now being used for pre-crisis planning. This concerns developing programs that can be used whenever a crisis occurs such as strikes, bad weather happenings, fire or other possible catastrophic events. PERT is used in this way to improve management of the unexpected.

Long range planning, marketing programs, new product introductions, mergers or acquisition programs, and installation of new management control systems are but a few of the future uses of PERT.

Top management will need to be trained in PERT if it is to be fully implemented in today's business activities. Until PERT becomes as common as the bar chart it will be management's responsibility to monitor and control it. Management must understand PERT's capabilities and limitations if they are to experiment with this technique and improve it.

PERT will not be improved until there is a return to the basic concept of simplicity of PERT. The application of PERT needs to be a generalized technique rather than a standardized procedure.

The long run future of PERT will be to act as a catalyst in forming an overall general systems theory for business. PERT is only one of many tools of scientific management needed to extend the field of management science.

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