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ABSTRACT

Two systematic ways of analyzing and planning the components of a program or project, both used extensively by industry and government, are discussed in this paper. The methods are Program Evaluation and Review Technique (PERT) Networks and Critical Path Method (CPM) Arrow Diagrams. The purposes of this paper are (1) to explore the need for systematic planning in education, (2) to compare CPM and PERT both in the past and in the present, (3) to explain the critical rules for developing PERT Networks and CPM Arrow Diagrams, (4) to list the implications for education that may be seen in each of these methods, and (5) to explore the future of systems planning in education. This paper is intended to be used by any educator who wants to improve his or her school district, building, or classroom through effective planning and systematic development of specified objectives. (Author)

PERT AND CPM: A COMPARISON WITH IMPLICATIONS FOR EDUCATION

by

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INTRODUCTION

PERT Networks and CPM Arrow Diagrams are similar in many ways and yet take paths that are often different. Both are systematic ways of analyzing and planning the components of a program or project. Both have been used extensively by industry and government. And finally, both can be used in many ways to improve our educational system.

This paper will (1) explore the need for systematic planning in education, (2) compare CPM and PERT both in the past and in the present, (3) explain the critical rules for developing PERT Networks and CPM Arrow Diagrams, (4) list the implications for education that may be seen in each of these methods, and (5) explore the future of systems planning in education. This paper is intended to be used by any educator who would like to improve his/her school district, building, or classroom through effective planning and systematic development of specified objectives.

THE NEED FOR SYSTEMATIC PLANNING

The need for systematic planning of goals and events has been documented in many fields including government, construction, industry, communication and educational research. Applbaum and Anatol (1971) support this assertion when they state, "Early experimental research in the field of communication proceeded rather inefficiently because the necessary experimental tools for complex behavioral analysis were nonexistent" (p. 368). Applbaum and Anatol go on to say, " . . . (but) little attention has been given to the methods (PERT) advantages for the behavioral sciences." This demonstrates not only a need for the behavioral sciences (e.g., communication, psychology, education) but a serious area of neglect since Desmond Cook and others have written a series of both articles and books relating the use of these methods to the behavioral sciences.

Two other areas (government and industry) have seen the need for systematic planning and have undertaken to fill the gap. Both Horowitz (1967) and Archibald and Villoria (1967) report the development of CPM and PERT almost simultaneously by the government and private industry. The government in the form of the United States Navy developed the early form of PERT in 1958 in order to more efficiently manage and control the Fleet Ballistic Missile Program (FBM) which developed the Polaris missile system. PERT was credited by the Navy with having taken two years off of the successful completion time of this program.

Almost simultaneously in late 1957, a group of engineers from Sperry Rand and Dupont developed what was to become CPM. Their goal was to develop a system for more efficiently designing, constructing and maintaining the physical plants of large industries. Over the years these two forms of systems management have become more and more alike.

CPM AND PERT: PAST AND PRESENT

Figure 1 shows the evolution of the network plan. A superficial analysis of this diagram will show two things. First, both CPM and PERT were preceded by the Gantt bar chart as the major means of systematically managing and monitoring

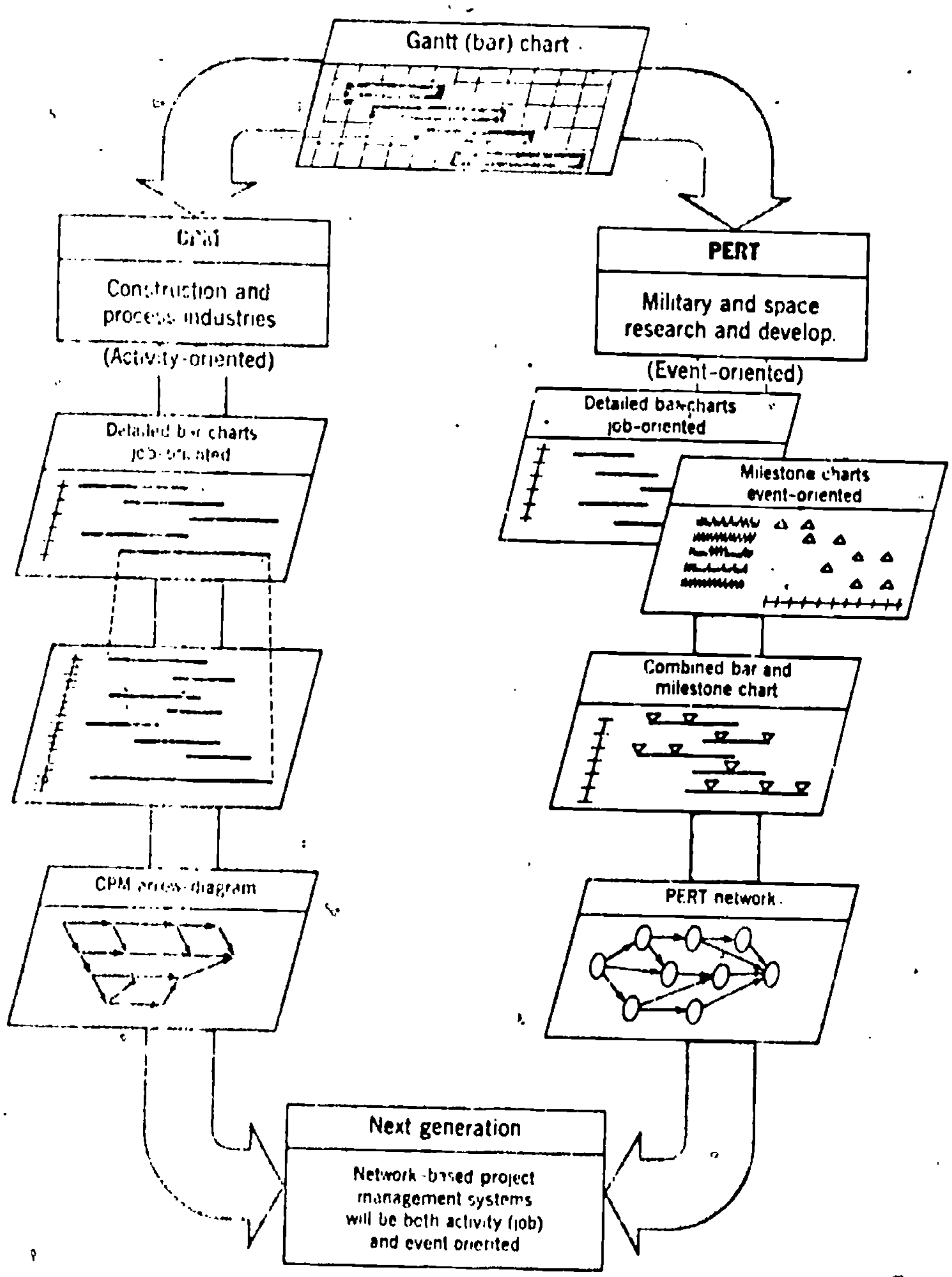

Figure 1. Evolution of the Network Plan

(Archibald and Villoria (1967), p. 15)

projects. Secondly, both systems developed in a similar pattern but with different orientations to the problems they were designed to solve. CPM on one hand developed an activity-oriented approach (and thus an arrow diagram system) while PERT developed an event-oriented approach into a network plan. This distinction between the two has not held up over the years, however. As the two systems have been used and revised and used and revised again, they have become very much the same in terms of significant characteristics. Examination of Tables 1 and 2 makes this change apparent.

Characteristic	PERT	CPM	Different	Similar
1. Based on Logic Network	Yes	Yes		x
2. Emphasis	Event	Activity	x	
3. Time Estimate, Project Time	Yes	Yes		x
4. Method of Estimating Time	3	1	x	
5. Probability	Yes	No	x	
6. Scheduled Event Times	Yes	No	x	
7. Total Float (Slack)	Yes	Yes		x
8. Free Float	No	Yes	x	
9. Negative Float (Slack)	Yes	No	x	
10. Used for Planning New Work	No	Yes	x	
11. Used to Monitor Existing Work	Yes	Yes		x
TOTAL			7	4

Table 1. Early CPM and PERT

(Adapted from O'Brien (1965), p. 105-7)

Characteristic	PERT	CPM	Different	Similar
1. Based on Logic Network	Yes	Yes		x
2. Emphasis	Event and Activity	Activity		x
3. Time Estimate, Project Time	Yes	Yes		x
4. Method of Estimating Time	One or Three	One		x
5. Probability	Yes	No	x	
6. Scheduled Event Times	Yes	Sometimes		x
7. Total Float (Slack)	Yes	Yes		x
8. Free Float	No	No		x
9. Negative Float (Slack)	Yes	Sometimes		x
10. Used for Planning New Work	Yes	Yes		x
11. Used to Monitor Existing Work	Yes	Yes		x
TOTAL			1	10

Table 2. CPM and PERT Today

(Adapted from O'Brien (1965), p. 105-7)

This section, then, has shown that CPM and PERT have developed along different paths to a similar end. O'Brien (1965) has stated that, "PERT and CPM have become essentially the same through usage" (p. 107). This may be overstating the case; however, one can readily see that the two systems have become similar in many ways.

DEVELOPING A PERT NETWORK

The development of a PERT network for monitoring a project follows specific rules. These rules are designed to make the final network logical, accurate and readable.

Rules for Network Construction

A PERT Network consists of a series of arrows (activities) which connect a series of circles or rectangles (events). Arrows may be solid (which indicates an activity that takes time) or dashed--"dummy arrows" (which do not take time and only indicate that one event is dependent upon another).

Rules of Network Logic:

1. Before an activity may begin, all activities preceding it must be completed.
2. Arrows imply logical precedence only. Neither the length of the arrow nor its direction on the diagram have any significance.
3. Any two events may be connected directly by no more than one activity.
4. Event numbers must not be duplicated in a network.
5. Networks may have only one initial event and only one final event.
6. Time estimates for completion of each event are stated on the diagram in common units (e.g., days, hours).

Figure 2 below will be used to illustrate these rules for network planning. In this diagram it should be apparent that event one must be completed prior to beginning activities A, B or C. Also, arrow length and direction are not significant since activity A preceding event two is shorter than activities B or C and yet the time estimate for the completion of

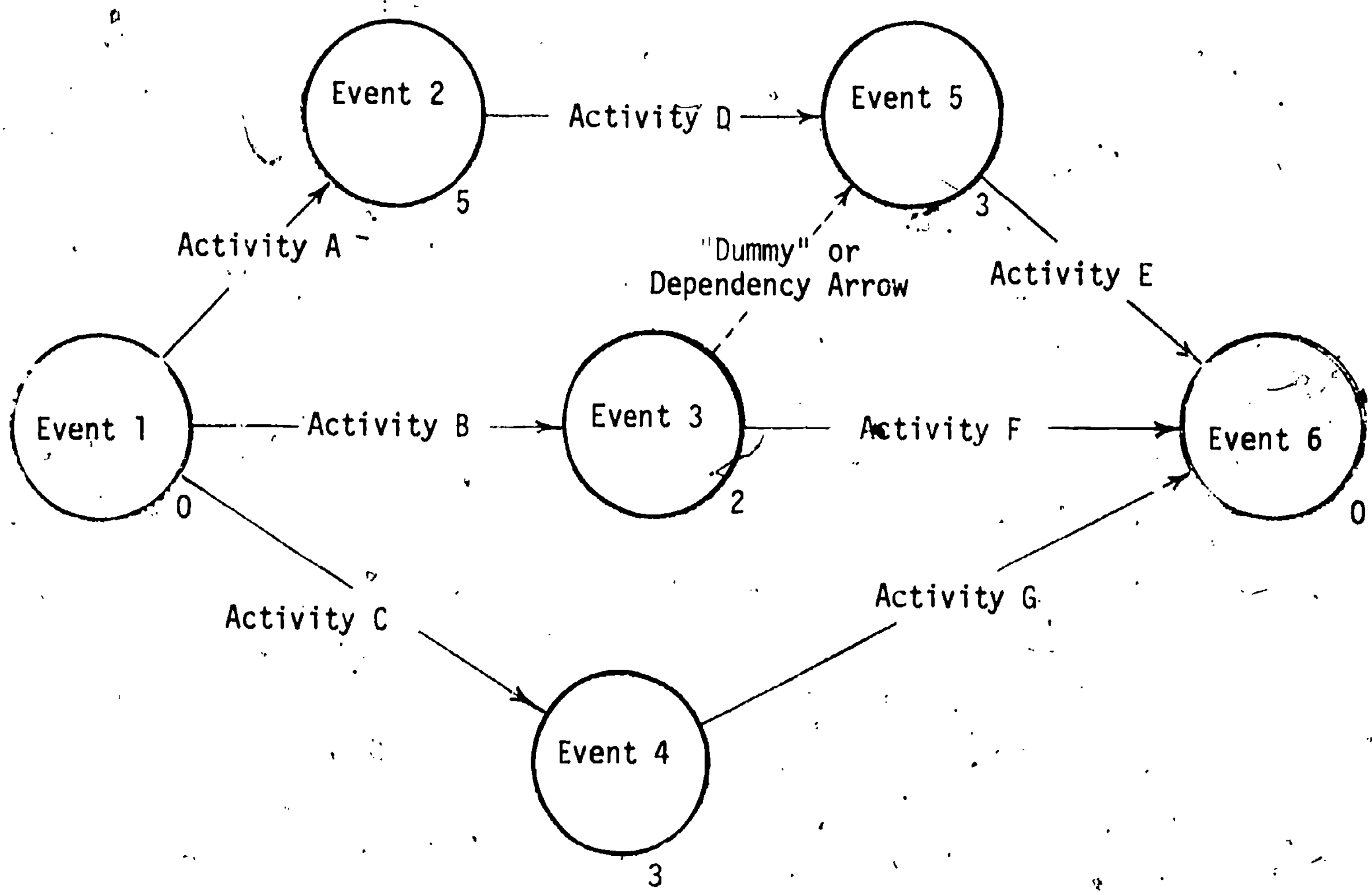

Figure 2. Example PERT Network

event two is considerably longer than for either event three or event four. Rules three and four are appropriately adhered to since events are connected with only one arrow and event numbers are not duplicated. Rule five is satisfied since event one and event six represent starting and finishing events respectively. And, finally rule six is met by the time units stated below and to the right of each event circle.

An additional characteristic of this network not specified in the numbered rules is evident between event three and event five. This arrow is called a "dummy" or dependency arrow and is used to show that the completion of event three must precede the initiation of event five. There is no time factor involved with this arrow. It simply indicates that event five "depends" upon the completion of event three.

Computing Time Estimates

In computing the time estimate for each subgoal (or event) in the PERT network, three time intervals are designated for each task. The first is called the most likely time (m); the second an optimistic estimate (a); and, the third a pessimistic estimate (b). The following formula is then used to compute the expected time (t_e):

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

t_e = expected time
a = optimistic time
m = most likely time
b = pessimistic time

Thus, the optimistic and pessimistic times are taken as the end points of the distribution, and the most likely time as the mode. Finally, a standard deviation equal to one-sixth the range is assumed.

The advantages of this method of obtaining expected time are (1) that the planner obtains probability data which can then be fed into a computer in order to calculate the probability of finishing the project on time and (2) it enables the planner to anticipate and redirect resources to avoid costly delays (Cochran, 1969).

DEVELOPING A CPM ARROW-DIAGRAM

As previously indicated, a CPM arrow diagram is much like a PERT network in terms of construction technique. The rules for construction are very much the same. The major differences center around (1) the usual omission of circles for events (and hence, the orientation toward activities), and (2) the time estimate of the duration of the activity rather than the completion of an event.

The Steps in Drawing Arrow-Diagrams

Horowitz (1967) listed seven basic steps in the planning of a project using an arrow-diagram approach. These steps are:

1. Analyze the project. Determine the individual tasks or operations that are required.
2. Show the sequence of these operations on a chart called an (arrow-diagram).
3. Estimate how long it will take to do each operation.
4. Perform simple computations to locate the critical path (the chain of interdependent operations that determines the duration of the entire project). This step also provides other information that is useful in scheduling the project.

5. Use this information to develop the most economical and efficient schedule for the project.
6. Use the schedule to control and monitor job progress.
7. Revise and update the schedule frequently throughout the execution of the project.

(p. 9-10)

In addition to the above steps in constructing an arrow diagram, Horowitz provides a summary of the rules for arrow diagrams. These rules are:

1. Each operation is shown by a single arrow.
2. The diagram is not drawn to scale.
3. No operation can start until all preceding operations have been completed.
4. Consider the three basic questions:
   a) What jobs must precede this one?
   b) What jobs can follow this one?
   c) What jobs can be done simultaneously?
5. Every operation must have a preceding and a following operation, except the first and last.
6. Use dummies to show the correct dependencies between events and to avoid having more than one operation with the same set of event numbers.
7. Number the (arrow-diagram) in such a way so that the numbers always increase as you go from the start to the finish.
8. Use only one starting event and one ending event.

(p. 20)

Determining the Critical Path

The critical path is that chain of activities or operations whose durations summed determine the overall length of the project.

A change in any activity on the critical path will change the total time or duration of the project. Parallel critical paths may exist but they must have the same total duration and this total time must be longer than any other path. In the arrow diagram below (see Figure 3) the critical path is designated by the double-lined arrows. The reader will notice that the critical path marked is the path which takes the most time from start to finish. Another way to conceptualize the critical path, for a critical operation, is that critical operations along the critical path always have <u>zero total float</u>. In summing the time units for each path, path A has a total duration of 14, path B a total of 23, and path C a total of 22. Thus, it should be obvious that path B (with the longest duration) is the critical path even though the two other paths appear to be longer in the diagram.

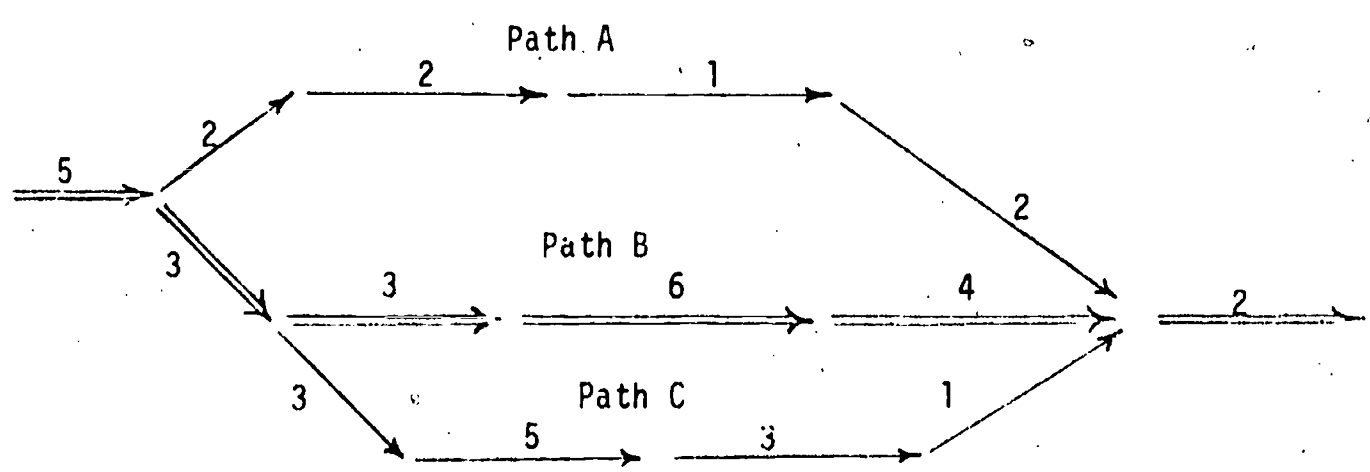

Figure 3. Example Arrow-Diagram

IMPLICATIONS FOR EDUCATION

Cochran (1969) listed experimental research, survey research, historical research, and curriculum projects as the major applications of PERT to education. Applbaum and Anatol (1971) used PERT with communication research planning and declared it to have several (eight) significant advantages. Case (1969) found PERT to be applicable both to educational research and educational evaluation studies. Finally, Garlock (1968) supports the use of PERT systems in application to educational research and curriculum development projects. This support for the use of systematic planning in these areas of education is commendable. However, nowhere in the literature that this author has been able to find is there any mention of using a systematic approach (PERT, CPM or an adaptation) to managing and monitoring the ongoing programs and projects encountered in a public school system. The following three sections will list some of the advantages that might accrue to educators willing to try a systematic approach to administering their programs.

Central Administration

The advantages logically attributable to PERT/CPM based district-wide plans for the central administration are as follows:

1. The creation of a realistic, detailed, easy-to-communicate (to both staff and the community) district-wide plan of operations.
2. The utilization of all possible community and district resources.
3. A procedure that enhances common understanding at all decision-making levels.
4. Reporting procedures that allow for a thorough assessment of the sequence of activities, schedules, and costs.
5. Reporting procedures that assist in forecasting or isolating potential problems.

These advantages and perhaps more can accrue to the school district central administration that employs a systematic approach to managing a school district.

Building Administration

On a smaller but no less important scale, the application of systematic management and monitoring schemes has even more advantages. Among these are:

1. A single network portrayal of all the operations conducted within the auspices of the school.
2. A basis for a unified standard of communication among staff members.
3. A basis for effective utilization of all resources available within and without the school.

4. A means for specifically defining all tasks that need completion.
5. A means to determine where resources should be applied to best achieve the desired objectives.
6. A means for self-correction.

These advantages for the building administrations are applicable not only to projects and curriculum development, but to the ongoing maintenance of the plant, the educational program, the extracurricular activities and all the other programs that a school may be involved in.

Teacher/Student Planning

This area is perhaps potentially the most fruitful area of all. The application of systematic management to the classroom has any number of advantages for enhancing learning (which is, after all, what schools are about). These advantages are listed below:

1. A means of clear communication of goals and objectives to parents as well as students.
2. A means of planning and scheduling activities for individual students.
3. A means of monitoring and reporting individual student progress toward established goals and objectives.
4. A means to assist in identifying potential delays.
5. A means to assist in the effective use of resources available within and without the classroom.

6. A means for permitting data-based decision making in changing student programs.
7. A means for record keeping.
8. A means for simulating alternate plans.

And finally, an advantage that is available at all levels is the fact that the installation of a CPM/PERT system is easy to learn and inexpensive.

THE FUTURE

The future for systematic planning has been projected by Archibald and Villoria (1967). As indicated in Figure 1, the next generation will see network-based plans which will be both activity and event oriented. This in some ways has already occurred. The intermarriage of CPM and PERT has come about in a project specific way. Cochran (1969), for example, shows both activities and events (as in Figure 2 of this paper) in his sample network. The application of computers in large scale operations and the addition of cost and scheduling factors add complexity that is also already here. Thus, the future is with us today. This is not to say that the future will not bring further advances. It is only to say that advances are coming so rapidly that a projection into the future would be virtually guesswork.

In terms of the future of education, however, some things may be said and need to be said. If our educational "system" is to survive (and survive it must) then the present chaotic state and haphazard planning must be interrupted. Currently criticism of our schools is at a peak. Everyone including the communities, the media and many of the nation's leaders are accusing our schools of failing to provide an adequate education. W. James Popham in an article titled, "Getting Damned Tired of Failing" calls for a rational planning model that will reverse this criticism. This author sees the application of PERT/CPM procedures as one step in the right direction. It might quite clearly be one small step for our schools and one giant step for our school children.

GLOSSARY

Activity. An individual element of a project, having a definite beginning and a definite end. An activity always requires a certain amount of time for its accomplishment, and usually requires some kind of resources.

Activity-Oriented Network. A network that emphasizes the activities, rather than the events.

Arrow. A directed line used to show the accomplishment of an operation in the network (arrow) diagram. In most CPM work the length of the arrow has no significance.

Arrow Diagram. A graph showing the sequence and dependencies between the elements of the project. As used in this text, same as network diagram.

Arrow Notation. A form of network diagram used in CPM in which the activities are shown by arrows and the events by the intersections of the arrows (usually shown as circles).

Crash Cost. The minimum direct cost required to complete the operation (or project) in the least possible time (the crash time).

Crash Point. The point on a time-cost curve marking the intersection of the crash cost and crash duration.

Crash Time. (Duration): The shortest time in which it is possible to complete the operation or project, regardless of cost.

Crashing. (1) Shortening an operation by adding additional resources. (2) Shortening a project by shortening the critical operations in such a manner that each resulting schedule is the most economical one possible at that duration. See Least-Cost Scheduling.

Critical Operation. An operation whose duration cannot be increased without increasing completion time of the overall project.

Critical Path. The chain of operations in the network having the longest total duration. The durations of these activities determine the project duration.

Dependency. A relationship between activities such that one cannot start until the other is finished.

Dummy or Dummy Arrow. A fictitious activity, requiring zero time and no resources for its accomplishment, used to show proper network relationships. Dummies are usually shown by dotted lines on the arrow diagram.

Duration. An estimate of how long an operation will take in hours, days, working days, or other time units.

Early Finish. The day an operation will be completed if it is started at its early start time. This is the earliest date on which the operation can be finished.

Early Start. The day preceding the first day an operation can begin.

Event. A point in time that marks the start or completion of one or more operations. Events do not require time or resources.

Event-Oriented Network. A network that emphasizes the events rather than the activities.

Expected Time (t_e). In PERT, the expected time is the weighted average of the optimistic, most likely, and pessimistic times for an activity:

$$T_e = \frac{a + 4m + b}{6}$$

Float Time. A measure of the leeway available in completing an operation. Various kinds of float measure how much the operation can be delayed without affecting other operations, total project completion time, etc. See also Total Float, Free Float, Interfering Float.

Free Float. The amount of time an operation may be delayed without affecting any following operations.

Interfering Float. The difference between total float and free float for any operation. Use of the interfering float does affect subsequent operations.

Latest Finish. The day on which the operation must be completed if the overall project is not to be delayed.

Latest Start Time. The last day on which the operation can begin without delaying the project completion time.

Logic. In CPM, the relationships and dependencies among the activities that make up a project, as shown by the arrow diagram; the planned sequence of work.

Milestone. An important event in a project, such as completion of a major component or phase.

Most Likely Time (m). In PERT, this is the estimator's opinion of the most likely time for completion of the activity. This is what he would give if her were asked for only one time estimate.

Network. See Arrow Diagram.

Operation. Any element of a project having a definite beginning and end and requiring time for completion.

Optimistic Time (a). In PERT, the shortest time in which the activity could be completed if everything goes exceptionally well. The activity has only one chance in a hundred of being completed within the optimistic time.

Optimum Schedule (Duration). That schedule resulting in the smallest total project cost.

PERT (Program Evaluation and Review Technique). A project planning and reporting technique that makes use of the network diagram, and uses a probabilistic approach to determining operation durations.

Pessimistic Time (b). In PERT, the longest time that the activity could possibly take (barring acts of God), if everything goes badly. The eactivity might be expected to exceed this time only once in a hundred times.

Simulation. Testing a proposed course of action by means of a mathematical model.

Slippage. Delay in accomplishing one or more operations.

Total Float. The amount of time an operation may be delayed without affecting the duration of the project.

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Your Name is Not Necessary

PERT/CPM QUIZ

Directions: For the items listed below choose the one best alternative and erase the block on the answer card in the column below the letter of the answer you choose. If your answer is correct an L should appear in the space. If not, continue erasing until you uncover the correct answer.

21. _____ was developed by the U.S. Navy in order to monitor the Polaris Missile Program.

(A) PERT
(B) CPM
(C) Flow Charting
(D) Fault Tree Analysis

22. CPM is

(A) The Critical Path Method
(B) A network approach to Management and Monitoring
(C) Both A and B
(D) Neither A nor B

23. The critical path is

(A) The path that is critical in terms of requiring the most resources
(B) The path that takes the least amount of time to complete.
(C) The path with a total float equal to less than five time units
(D) The path that has zero total slack time.

24. A Dummy or Dependency arrow indicates

(A) Precedence
(B) Resource allocation
(C) Time allocation
(D) All of the above

25. In a PERT or CPM Network

(A) Events are designated by circles
(B) Activities are expressed with arrows
(C) Both A and B
(D) Neither A nor B

26. IN a CPM Network projected time is arrived at

    (A) By using the most-likely time
    (B) Through a three stage estimate
    (C) Through a one or three stage estimate
    (D) In a one stage estimate

27. Computation of $\frac{a+4m+b}{6}$ will result in

    (A) The pessimistic time
    (B) The most-likely time
    (C) The optimistic time
    (D) The expected time

28. CPM was developed by

    (A) Sperry Rand and Dupont
    (B) Lockheed
    (C) Sperry Rand Corporation
    (D) Dupont and the U.S. Navy

29. Which one of the following is NOT a rule for PERT Network Construction

    (A) Before an activity may begin, all activities preceding it must be completed.
    (B) Two events must be connected by one activity
    (C) Networds have only one initial event and only one final event.
    (D) Event numbers must not be duplicated in a network

30. In computing time estimates the optimistic and pessimistic times are taken as the end points of the distribution, and the most-likely time as the

    (A) Mean
    (B) Median
    (C) Mode
    (D) Standard deviation