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Use of CPM in Systems Installations

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PERT and Critical Path Method techniques, although most closely associated with construction scheduling, can profitably be applied elsewhere. This article describes how CPM was used to schedule installation of an electronic computer —

USE OF CPM IN SYSTEMS INSTALLATIONS

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A number of network analysis techniques have been developed in recent years to aid management in planning, scheduling, and controlling complex projects. Among them are CPM (Critical Path Method), PERT (Program Evaluation and Review Technique), and PERT/Cost.

The best known applications of these techniques so far have been in research and development management and in construction scheduling. They are suitable, however, under appropriate circumstances, for a wide variety of other uses. Among the most interesting of these—for consultants and systems analysts—is the control of systems projects. This article presents some criteria for deciding when a systems project would benefit from the use of network analysis and illustrates the method by means of a simplified case study of the use of CPM to plan and control the installation of a computer-based information system.[1]

Early successful applications of network analysis techniques possessed the following characteristics: (1) The problem involved new proposals, nonrepetitive jobs, or projects of long duration. (2) There were elements of unusual complexity, either because of the presence of many unknowns or because of the massive proportions of the job. (3) Management was pri-

[1] The basics of network analysis have been discussed in many books and articles and are not covered here. The reader who is completely unfamiliar with these techniques is referred to two previous articles in MANAGEMENT SERVICES, "PERT/Cost—The Challenge" by Don T. DeCoster, May-June '64, p. 13, and "PERT/Cost: Its Values and Limitations" by Peter P. Schoderbek, January-February '66, p. 29. CPM differs from PERT in only minor respects.

marily concerned with the functions of planning, scheduling, costing, resource allocation, and accountability.

Criteria too narrow?

Many systems projects, admittedly, do not have all these characteristics. Yet such projects would benefit from the use of network analysis techniques if a broader set of criteria were applied, namely, that: (1) There is a goal to be achieved that can be defined in terms of a specific objective event. (2) There is a required completion date to meet this objective event. (3) There are numerous identifiable and mutually dependent tasks that must be accomplished in a proper sequence before the objective can be reached. (4) Estimates of time and cost can be established for these tasks. (5) Resources may be moved from one job to another in order to affect the intermediate completion dates of tasks.

Measure the problems involved in the installation of a computer and the conversion to a new system against these broader criteria for a network approach. In many cases they match well enough to suggest that a systems project to install a computer is a likely candidate for the application of critical path methods.

The objective event in this project is the cut-out of the old system. This cut-out is generally to be completed by a certain date to achieve management's payback goals.

To identify a specific task in the project essentially requires knowing when the task can begin and when it must end. Even though systems development is a continuous operation, the completion of flow charts is an identifiable task necessary for the next step in the project, in this case, the writing of programs.

Interdependence and a sequence requirement among individual tasks are also evident in a computer installation program since the cut-over to new systems depends upon completion of debugging of programs. Debugging cannot be done until programing is completed. Programing cannot be completed until new systems are designed. The effective design of new systems requires an analysis of system requirements—and so on back through the entire project.

Estimating time and cost

The ability to identify individual tasks implies that the time to accomplish each task can be estimated. Experience with such installations usually makes reasonably accurate time estimates possible. Furthermore, since the specific talents needed to perform each task in an installation can be clearly recognized on the basis of related experience, associated cost estimates can also be established.

The final criterion for the appropriateness of the network approach is the transferability of resources from one job to another to ensure completion of the critical tasks on time. Many tasks in a computer installation and systems conversion program are of the type that can be accelerated by the addition of more manpower.

Advantages of CPM

The principal remaining question is this: What benefits could be derived by applying CPM?

Installation of a computer system can be subdivided into a number of individual and distinct tasks necessary to the final cut-out of the old system(s). Varying approaches and varying levels of effort in terms of number of personnel assigned and hours worked may be used to complete each job.

Cost considerations might make it seem desirable for each task to be performed at its lowest possible direct cost so that the entire project may be completed at the lowest total cost. Direct costs are minimized by avoiding use of overtime, temporary personnel, and the like.

There are, however, other costs associated with project completion —such as overhead, imputed costs of inefficiencies in the old system, and the extension of the payback period—that may make project scheduling for least direct cost unattractive. Unlike direct costs, these costs tend to rise with duration of the project.

Thus, time becomes a key variable. All cost elements connected with project performance must be considered in order to establish the best plan of action. Logically, there is some balance between cost and time that offers the best solution.

Systematic approach essential

To reach this balance is not a simple problem. A "cut and try" approach to find a reasonable balance of cost and timing is seldom feasible because the numerous tasks in a computer installation program rarely form successive links in a single chain of events through the project.

In any computer installation project there is normally a complex network of concurrent, overlapping, and interrelated tasks cutting across numerous departmental lines and functional responsibilities, particularly if the system is intended to meet the varied needs of the different management elements in an organization. Without a systematic method for choosing

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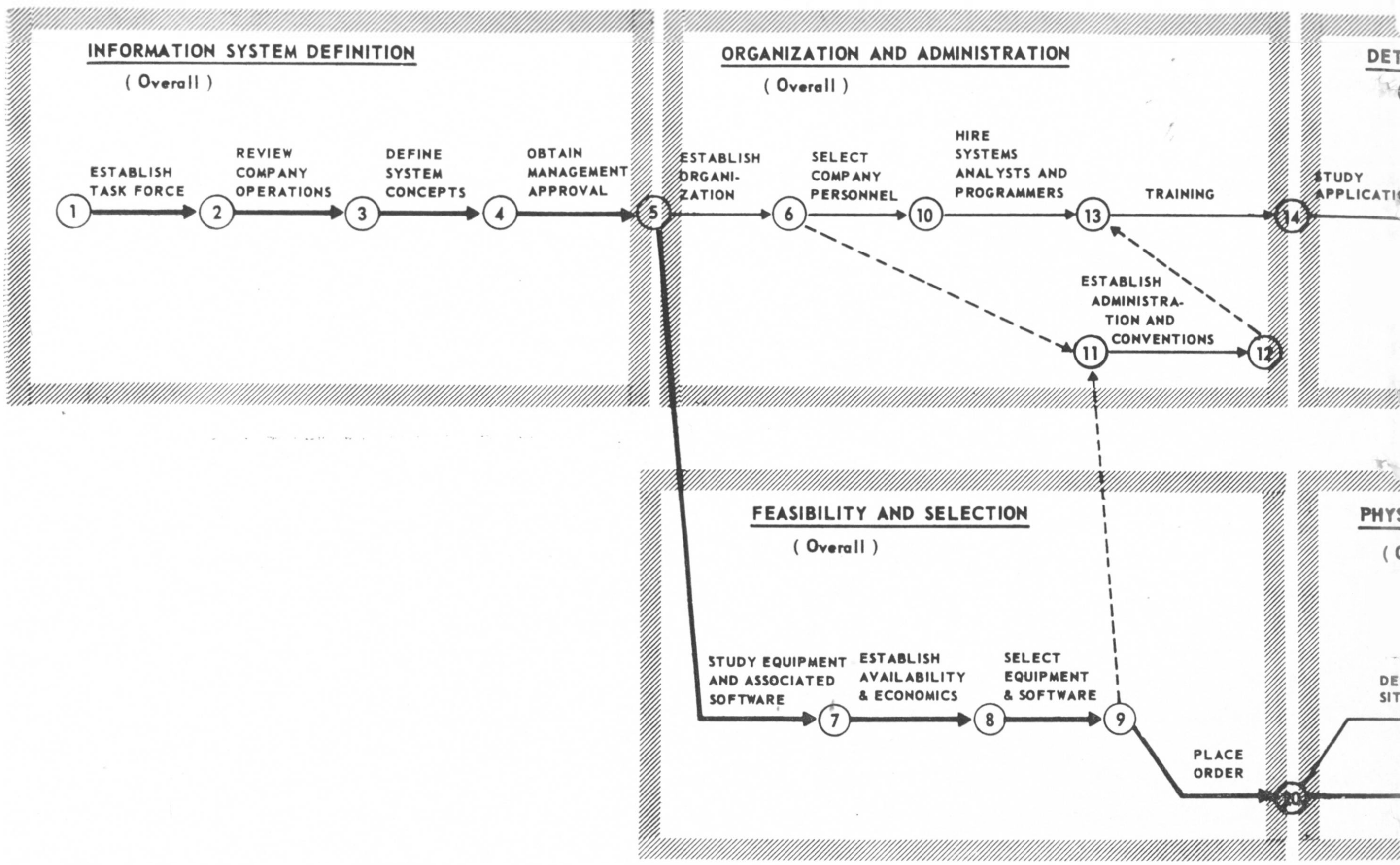


NETWORK DIAGRAM OF COMPUTER SYSTEM INSTALLATION AND CONVERSION

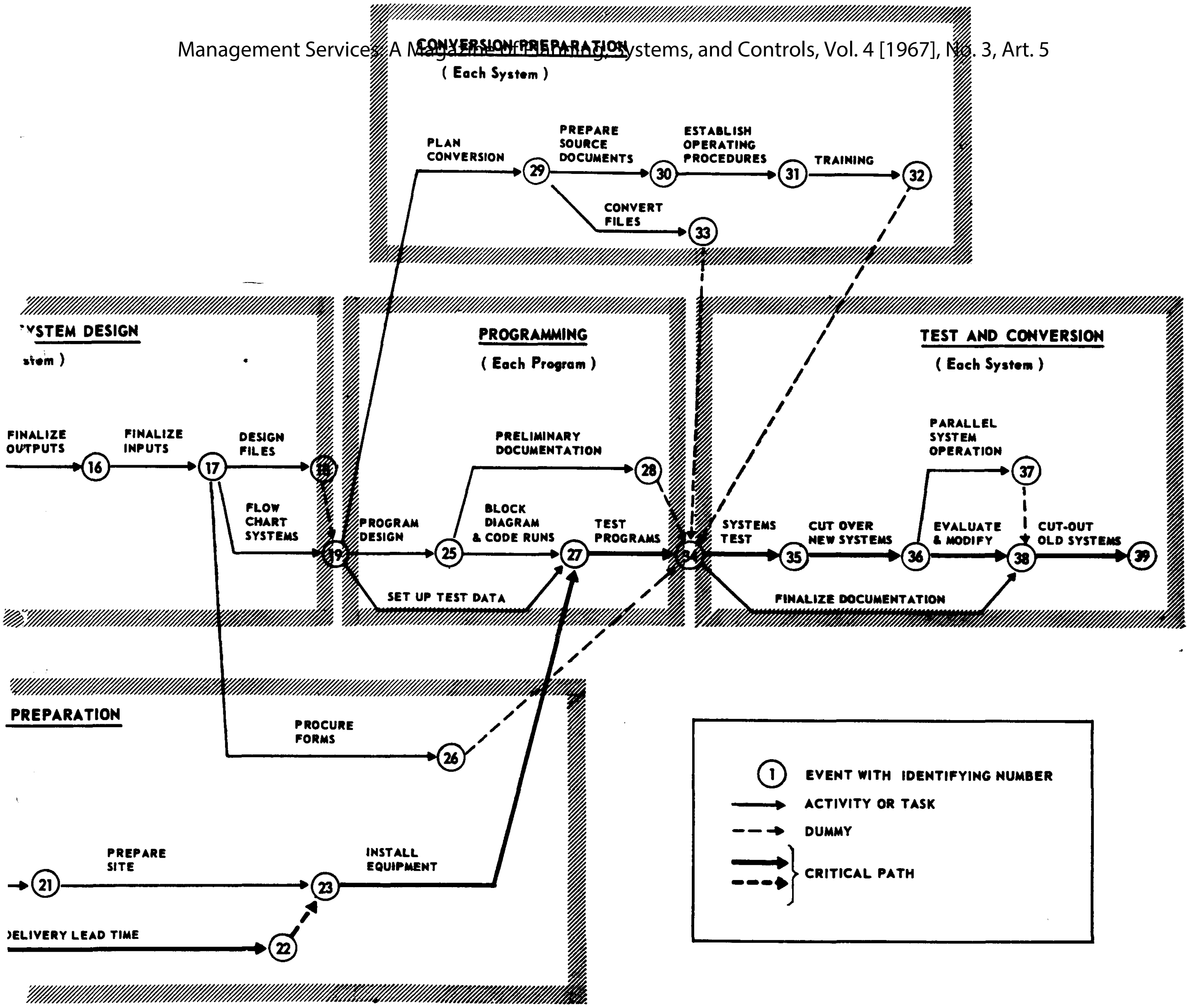
FIGURE I

among alternative ways of performing the required project tasks, it is unlikely that a "best" or even a logical plan will be developed. The critical path method offers such a systematic approach, as the following case study illustrates.

Case background

The company that is the subject of this case study had made reasonable advances in the development of systems—both manual and those utilizing existing electronic data processing facilities—to serve the needs of individual functions. These systems for inventory control, cost accounting, budgetary control, and the like reflected specialized uses of information flow, data handling, work procedures, and analysis methods primarily aimed at doing specific tasks in a consistent and more efficient manner. However, because the design and implementation of these systems had been performed piecemeal, they failed to encompass the complete spectrum of management and operating needs and did not represent the best use of electronic data processing equipment.

The company's executives attributed its lack of continued growth and its inability to attain increased profits largely to these limitations of the existing systems. They believed that an integrated system was needed to synthesize the information requirements of all functions of the company and facilitate decisions that would be rapid and responsive to changing conditions and that would opti-



mize overall organization goals rather than those of any particular part of the organization. Clearly, the complexity and data processing requirements of such a system would necessitate the use of new or additional electronic computer equipment.

In the early stages of organizing this project it became apparent that a well-defined work program and a detailed timetable were essential to timely implementation of the system and establishment of meaningful bench marks for progress reviews. Critical path methods were selected as the means of developing this schedule, of pinpointing responsibilities, and of providing a basis for progress reporting.

Network diagram

The first step was to prepare a list of the individual tasks required to accomplish the installation and conversion. The level of detail had to be sufficient to identify points where specific interrelationships occurred and to permit monitoring and control of significant segments of work.[2] This task list was represented as a network or arrow diagram, graphically depicting the sequence and dependencies of the activities making up the overall project (see Figure 1 above).

Three basic questions were asked

[2] To illustrate the concepts of CPM, a gross oversimplification of the project will be used. Each of the tasks represented in the example was, in fact, composed of many individual steps.

as each task was entered on a diagram worksheet:

1. What task or tasks must immediately follow this task?

2. What task or tasks must be completed to permit the start of this task?

3. What tasks may be performed concurrent with this task?

Answers to these questions indicated where the breakdown of activities was not sufficient. Missing activities became apparent. Eventually a network evolved.

A time estimate was subsequently assigned to each task. A project plan was then developed to establish (1) the earliest date by which complete cut-out of the old systems could be accomplished; (2) those tasks whose completion times governed project duration; (3) the amount of leeway or "float" that each non-critical task had; and (4) the impact of variations in completing any given task on the overall project or on succeeding tasks.

Four conventions governed

The following conventions were used:

1. Each task, defined as the effort required to accomplish a specific task measured in terms of elapsed time, was represented by an arrow. The length of the arrow was governed by convenience and clarity; it did not represent importance, duration, or start or finish times of the task. The direction of the arrow indicated precedence only with the arrowhead signifying completion of the task.

2. Arrow junctions, shown as circles, were called events or nodes. An event was a real point in time signaling the start or completion of a task; it did not, however, itself represent elapsed time.

3. Events were numbered so that each task had a distinct pair of numbers; the initial or origin event was always lower than the terminal event.[3]

4. If one task took precedence over another and there was no task relating them, a "dummy" activity, represented by a broken arrow and requiring no time or cost, was inserted to maintain the precedence. Tasks 6-11, 9-11, 26-34, etc., have been inserted to maintain proper precedences.

5. On a CPM network only one event (number 1) could have no predecessor tasks and only one event (number 39) could have no successor tasks.

The development of a network is, in itself, a useful product of CPM in project planning for the following reasons:

1. The discipline required to construct a network diagram necessitates a thorough understanding of the project scope.

2. It provides a basis for communication; it is easily read and understood.

3. Alternative strategies and/or objectives can be evaluated.

4. It reduces the hazards of leaving out tasks that should be considered in the project.

5. It provides a basis for pinpointing responsibilities.

6. It permits rapid orientation for new personnel assigned to the project.

A time estimate was subsequently assigned to each task. These estimates represented the elapsed time needed to accomplish the task at the lowest direct cost under average performance standards and the usual assignment of manpower. A project plan and schedule was then developed to establish (1) the earliest date by which the complete cut-out of the old systems could be accomplished; (2) those tasks whose completion times governed the overall project duration; (3) the amount of leeway or "float" that each noncritical task had; and (4) the impact of variations in completing any given task or the addition of tasks on the overall project or on succeeding tasks.

The information depicted in the network diagram was put in tabular form as shown in Figure 2 on page 35. To determine the earliest finish date for the total project, the earliest finish time for each task was calculated. The earliest

[3] The value of this numbering is that it facilitates ease of computation on a manual basis, even for fairly large projects. The numbering procedure is a specific requirement for computer utilization.

[4] Actually, the company developed a CPM computer program as discussed later in this paper. For purposes of simplification, the analysis will be outlined as if done on a manual basis.

TASK DESCRIPTION	EVENT initial	EVENT terminal	DURAT'N (work days)	EARLIEST start	EARLIEST finish	LATEST start	LATEST finish	FLOAT total	FLOAT free
Establish task force	1	2	10	0	10	0	10	0 •	0
Review company operations	2	3	90	10	100	10	100	0 •	0
Define system concepts	3	4	30	100	130	100	130	0 •	0
Obtain management approval	4	5	8	130	138	130	138	0 •	0
Establish project organization	5	6	10	138	148	153	163	15	0
Select company personnel	6	10	10	148	158	163	173	15	0
Hire personnel	10	13	25	158	183	173	198	15	10
Dummy	6	11	0	148	148	183	183	35	30
Study equipment & software	5	7	15	138	153	138	153	0 •	0
Establish economics & availability	7	8	15	153	168	153	168	0 •	0
Select equipment & software	8	9	10	168	178	168	178	0 •	0
Dummy	9	11	0	178	178	183	183	5	0
Establish conventions	11	12	15	178	193	183	198	5	0
Dummy	12	13	0	193	193	198	198	5	0
Train personnel	13	14	30	193	223	198	228	5	0
Order equipment	9	20	5	178	183	178	183	0 •	0
Delivery lead time	20	22	180	183	363	183	363	0 •	0
Dummy	22	23	0	363	363	363	363	0 •	0
Design equipment site	20	21	25	183	208	318	343	35	0
Prepare site	21	23	20	208	228	343	363	135	135
Install equipment	23	27	5	363	368	363	368	0 •	0
Test programs	27	34	45	368	413	368	413	0 •	0
Dummy	28	34	0	373	373	413	413	40	40
Dummy	26	34	0	323	323	413	413	90	90
Plan conversion	19	29	10	318	328	348	358	30	0
Convert files	29	33	45	328	373	368	413	40	0
Dummy	33	34	0	373	373	413	413	40	40
Prepare source documents	29	30	15	328	343	358	373	30	0
Establish procedures	30	31	20	343	363	373	393	30	0
Training	31	32	20	363	383	393	413	30	0
Dummy	32	34	0	383	383	413	413	30	30
Systems test	34	35	45	413	458	413	458	0 •	0
Cut over to new systems	35	36	30	458	488	458	488	0 •	0
Evaluate systems	36	38	20	488	508	543	563	55	55
Parallel system operation	36	37	75	488	563	488	563	0 •	0
Dummy	37	38	0	563	563	563	563	0 •	0
Finalize documentation	34	38	30	488	518	533	563	55	55
Cut-out old systems	38	39	2	563	565	563	565	0 •	0

• *DENOTES CRITICAL TASK*

DETERMINATION OF CRITICAL TASKS, TIME BOUNDARIES, AND SLACK

FIGURE 2

finish for any task is determined by the longest sequence leading up to that task and cannot be calculated until all finish times of preceding tasks have been computed. The starting point then, must be those tasks with no precedent tasks, e.g., "Establish task force" (1-2).

The earliest that Task 1-2 could be finished was 10 days after the project got under way. For all following tasks, the earliest finish is equal to its duration plus the largest of the immediately preceding earliest finishes. "Review company operations" (2-3), for instance, was the sum of its duration, 90 days, and the earliest completion of 10 days for its only preceding task 1-2, totaling 100 days.

Task 27-34, on the other hand, had three tasks preceding it, namely 19-27, 25-27 and 23-27. Its earliest finish was equal to its duration of 45 days plus the largest of the earliest finishes for 19-27 (328th day), 25-27 (363rd day) and 23-27 (368th day), namely, the 413th day (45 + 368).

Overall duration determined

The earliest finish for the entire project was determined to be 565 work days. (This, of course, represented many more man-days since the time estimates were based on "normal" assignments of manpower to each task.) To establish which tasks governed the total duration, the latest finish time for each task was calculated. The latest finish of any task was defined as the latest possible time it could be completed without prolonging the overall project beyond its earliest completion of 565 days. If there was no difference between the earliest and latest finish times of a task, no leeway or float existed on that task, and therefore it was critical.

The latest finish times were determined by proceeding backwards from the final event to the beginning event. For any given task, the latest finish time was calculated by subtracting the sum of the longest sequence of tasks following that task. The starting point, therefore, had to be the task (38-39) with no successor, its latest finish obviously equal to the overall project duration. The latest finish for Task 34-38 was 563 days, the latest finish for Task 38-39 (565th day) less the 2-day duration of Task 38-39. Not so obvious was the latest finish of Task 4-5, which was the smaller of the following: latest finish of Task 5-7 (153rd day) less the duration of Task 5-7 (15 days), or the 138th day, or latest finish of Task 5-6 (163rd day) less the duration of Task 5-6 (10 days), or the 153rd day.

The quantitative measure of leeway or "float" of each task was determined by subtracting the earliest finish from the latest finish. This float was the number of days that the task could be delayed beyond its earliest finish without extending the installation and conversion beyond 565 days. In the table shown in Figure 2 those tasks with zero float represent the sequence of activities through the project which governed the overall project duration, i.e., the critical path (heavy line in Figure 1).

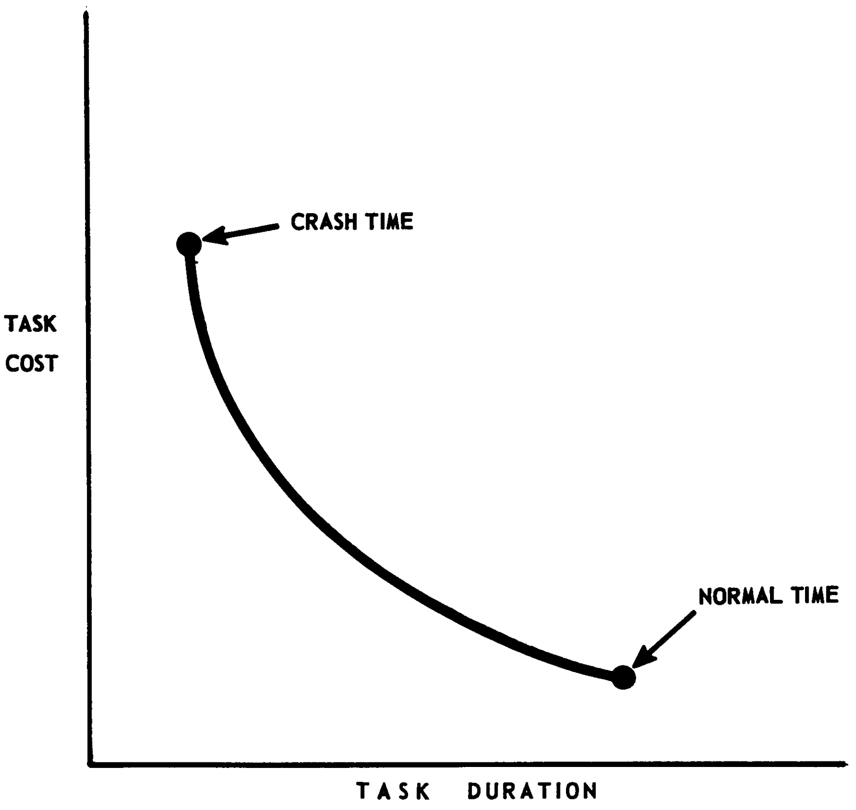
The ability to identify these critical (and near critical) tasks provided the project leader with a basis for management by exception. Potential bottlenecks were pinpointed at the outset to allow preparation of corrective measures. The seriousness of delay in these tasks was now measurable and provided a framework for directing follow-up and expediting action where it was truly required and could do the most good.

Other considerations

Management was interested in evaluating the effect on the total duration of alternative allocations of effort and assignment of personnel. The information provided from the calculation of float was just as valuable as the identification of the critical path for evalu-

FIGURE 3

TIME-COST RELATIONSHIP



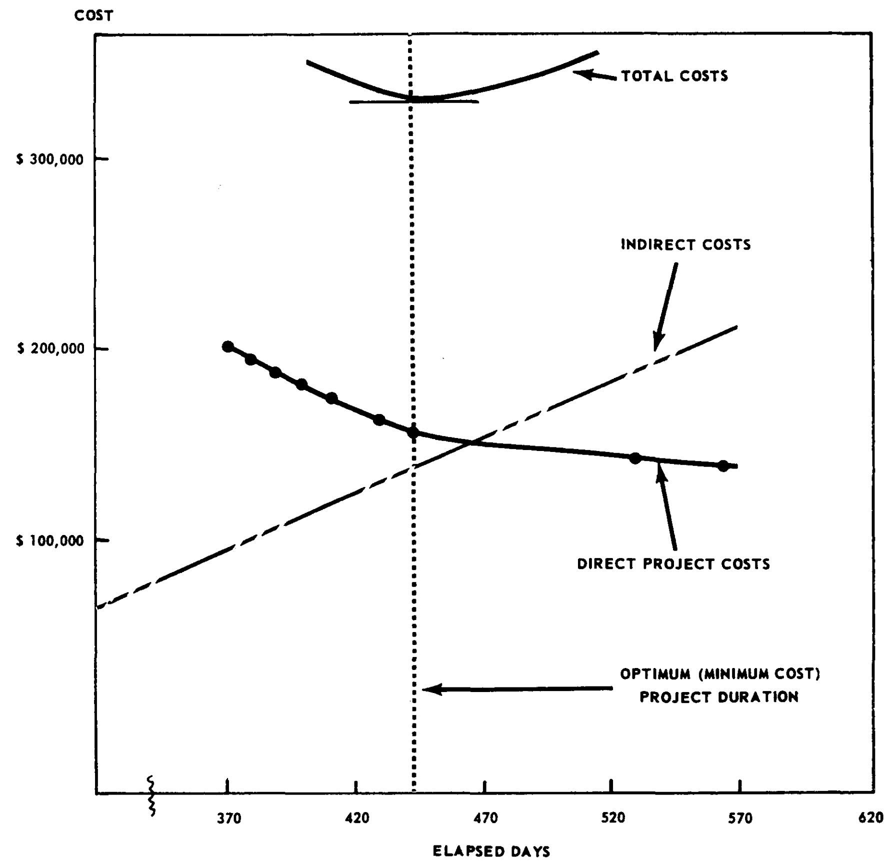
. . . provided the project leader with a basis for management by exception.

ation of such courses of action.

As an example, in Figure 2 Tasks 9-11, 11-12, 12-13 and 13-14 each has 5 days of float. These four tasks require 45 days duration; there are 50 days available to accomplish them (earliest start on the 178th day to the latest finish on the 228 day). Thus, when these are considered as a series of tasks, there are only 5 days of total float available. If any one of these tasks required or was scheduled to use its 5 days of float, the remaining tasks would become critical. This illustrates that total float is associated with a path which may include more than a single task and which may flow in and out of the critical path or be completely independent of the critical path. The total float will be equal for each activity on that path, and if one activity is delayed or prolonged, the float available for the succeeding activities is reduced by an amount equal to the delay.

Free float, on the other hand, is associated with a single task. It represents the time available to accomplish the single task less the time required for the task assuming all preceding jobs have been completed by their earliest finish times and all succeeding tasks will start at their earliest start times. In Figure 2, an example of free float is found on Task 10-13. The earliest start of the following task (13-14) is the 193rd day less the earliest finish of Task 10-13 (183rd day), which gives Task 10-13 free float of 10 days.

This extension of the analysis demonstrated to management how float could be used to select those activities that could be delayed (as a result of an alternative plan but without changing the overall duration) most effectively. Total float indicated the amount of time certain tasks could be delayed without detrimental effect on the project duration. Here, however,



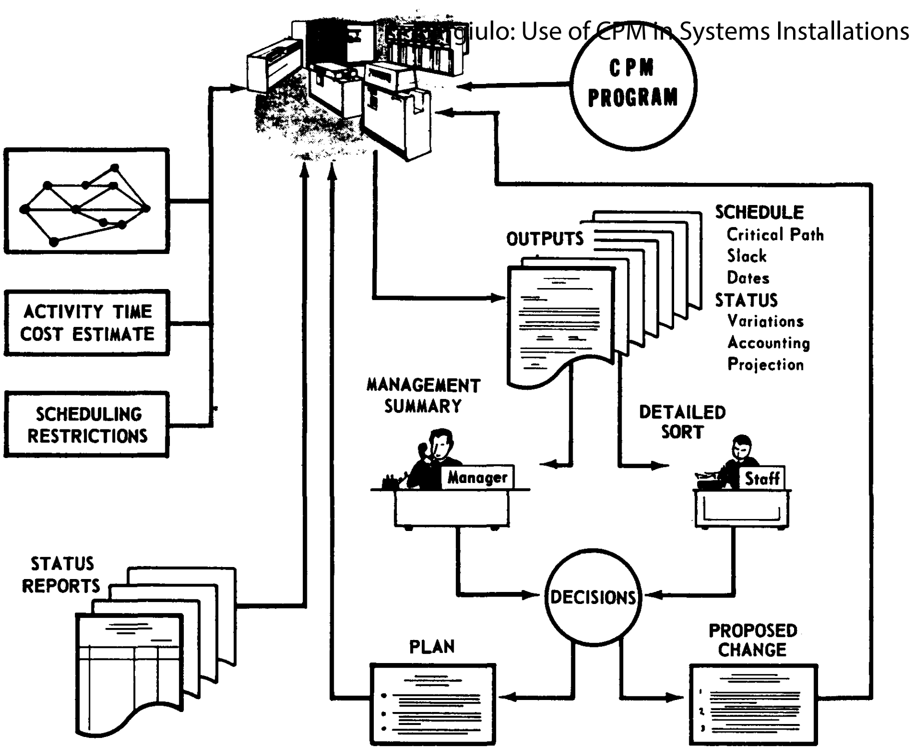
PROJECT COST VERSUS PROJECT DURATION

FIGURE 4

the start time of succeeding steps would be affected, and the results of the delay could be meaningfully considered. Free float indicated the amount of time a task could be delayed without affecting any other task. Essentially, float acts as a measuring rod for good project management. Those activities with zero float are critical and require special management attention; those with positive float have greater flexibility in relationship to start times and durations.

The analysis to this point had been limited to the time required to complete the installation and conversion. As a means of evaluating even further ways of compressing the schedule, the analysis was extended to consider time-cost relationship, as shown in Figure 3 on page 36. The initial schedule was based on completing each task at the "normal" time representing the lowest direct cost. To expedite the completion of a task, the deployment of additional resources was considered, and the corresponding increase in cost was determined. At a "crash" point, the task duration could not be reduced further. Any attempt to expedite the completion date would only result in higher cost without a concomitant decrease in time.

The computer installation and conversion carried out with all tasks completed at "normal" times had an overall duration of 565 working days. The project's direct cost was computed by totaling all task costs. Since many tasks could be completed sooner with corresponding increases in cost as shown in Figure 3, additional schedules



CRITICAL PATH METHOD COMPUTER-BASED SYSTEM

FIGURE 5

were generated. This was done by considering the critical tasks in a stepwise fashion, selecting in sequence those tasks with the least cost incremental increase per unit of time decrease. The range of overall project durations versus direct costs could be viewed as depicted in Figure 4 on page 37.

The reduction of the project from an all-normal basis to a crash-time basis results in increased direct costs required to accomplish the time reduction. As the duration is shortened, however, indirect costs (overhead, penalty for delay, etc.) are reduced since they vary directly with the length of the project. The sum of these two costs for any project duration equals the total project cost (curve). The lowest or minimum cost point on the total cost curve represents an optimum project duration.

Computer-based CPM system

The challenges in developing a useful CPM system are (1) to provide a continuous stream of timely and meaningful reports for management evaluation and (2) to extend the basic technique further into the management decision area. The larger the project (such as the installation of a total information system) the more difficult it is to meet the first objective on a manual basis. The second objective can best be achieved by utilizing the simulation facility of a computer program.

Figure 5 on this page depicts the cycle of a computer-based system for critical path analysis. A typical CPM program performs the following functions: (1) It performs the mathematical analysis of the network. (2) It synthesizes network and time data to indicate the relation to program deadlines on a calendar basis. (3) It compares current estimates against scheduled dates and indicates bottlenecks. (4) It provides a wide variety of summaries of progress and the outlook for future progress. (5) It rapidly computes the effects of alternative courses of action including manpower leveling and time-cost trade-offs.

More specifically, the cycle shown in Figure 5 begins with computer inputs (diagrams, time and cost estimates, and other scheduling objectives or restrictions) from the company function responsible for meeting a project end objective. The initial output reports require analysis and comprehensive management review. Alternate courses of action may be proposed, entered into the flow, and analyzed and the effects reported back.

Once a plan is settled upon, input of project status enters the system, enabling the computer to develop control reports at any level of detail and frequency. Typically, these reports may be listed as follows: (1) in event number sequence, (2) by paths of criticality, (3) in chronological order of expected completion date, (4) by department, and (5) by functional responsibility.

Systems projects possess all the characteristics of size and complexity which require good scheduling and tight control for effective implementation. The CPM, as outlined in this article, is a useful tool for meeting these needs.

The integrated project plan resulting from the development of a network and critical path analysis provides a clear delineation and understanding of the interfacing of functional responsibilities in executing the plan. With time and cost data tied directly to a plan and schedule clearly understood by all concerned, a uniform method of status reporting can be put into effect to display these data in as much detail and as frequently as needed for various levels of management. Management's ability to exercise co-ordinating and control responsibility is greatly enhanced by the network representation of the significant and controllable tasks in the plan, knowledge of the critical tasks to which greatest attention must be directed, and the means for measuring the consequences of variances from plan on a timely and meaningful basis for effective corrective action.