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USE OF NETWORK ANALYSIS FOR THE PLANNING, DESIGN AND ADMINISTRATION OF CONSTRUCTION PROJECTS

TECHNICAL REPORT NO. 55
OF THE BRAB/FEDERAL CONSTRUCTION COUNCIL

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FOREWORD

This report is concerned with the use of network analysis techniques in connection with construction activities. It is based upon personal interviews with knowledgeable individuals in both Government and private industry as well as upon an extensive review of published books and articles on the subject.

The study, conducted for the Federal Construction Council by the BRAB Staff, was undertaken to provide background material for a future FCC task group charged with developing specific recommendations regarding the employment of network analysis techniques for Government construction operations.

This report has been reviewed and approved by the Federal Construction Council.

BRAB gratefully acknowledges the cooperation and assistance of the many individuals who provided the information presented herein.

Robinson Newcomb, Chairman
Building Research Advisory Board

I
INTRODUCTION

Objectives

The objectives of this study were to determine first, the current state of the art of network analysis techniques; second, the applicability of such techniques to construction activities in general and to the construction activities of Government agencies in particular; and third, the extent to which such techniques have been used to date and the results obtained.

Scope

This report describes first, how network analysis techniques relate to the management of the building process; second, how these techniques have been applied in the management of the process; third, what problems have been associated with such applications; and fourth, what additional techniques or procedures might be used to enhance the application of network analysis techniques to the building process of the future.

Conduct of Study

The information presented in this report was derived from three sources: An extensive review of the current literature to determine what network analysis techniques are available, how these techniques are relatable to construction activities, who has applied these techniques, and what were the results (the literature reviewed is listed in the BIBLIOGRAPHY); interviews with responsible individuals in various Government agencies to determine more specifically the experience of the agencies with network analysis techniques (the individuals interviewed are listed in APPENDIX D); interviews with recognized systems analysis and engineering experts and real property managers in the private sector of the construction industry.

II
FINDINGS AND CONCLUSIONS

Findings

1. A variety of network analysis techniques are available for use in support of the management functions of planning, allocating, scheduling, and controlling resources in the planning, design, construction, and maintenance phases of the building process.

2. All available network analysis techniques are either CPM[1]-or PERT[2]-based and are predicated upon:

   a. The development of a network diagram comprised of arrows (each arrow representing one of the various planned tasks leading to the end objective of a project), nodes (each node representing a point in time at which a decision to start or stop a task takes place), and time estimates (each estimate representing a judgment on the amount of time required to complete a task, given the availability and employment of specific personnel, financial and material resources).

   b. The initial and iterative identification of the series of tasks that determine the shortest period of time in which a project can be accomplished and of the latest time at which all other tasks can be started without extending the shortest time required for the entire project.

3. Some available network analysis techniques have provisions for additionally incorporating resource estimates (each estimate representing a judgment on the amount of men and/or money required to complete a task) in the development of the network diagram as well as in the initial and iterative analysis of the diagram; most of these extensions of technique accommodate only resource estimates that either are invariable with respect to the time duration of a task or the

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[1] Critical Path Method.

[2] Program Evaluation and Review Technique.

over-all project or are linearly variable with respect to the time duration of a task or the over-all project.[1]

4. Among the participants in the building process currently using network analysis techniques are large industrial organizations having continuing multi-plant building programs, large real estate developers having continuing long-range development programs, state and municipal government agencies having major highway, utility, and school development programs, and, at the Federal level, the Corps of Engineers, the Naval Facilities Engineering Command, the Directorate of Civil Engineering (USAF), the Atomic Energy Commission, the National Aeronautics and Space Administration, and the Public Buildings Service; very few contracting, designing-contracting, or design firms make general use of such techniques in managing their own operations.

5. When network analysis techniques are used in connection with managing the building process, they are most often used in connection with managing the construction phase of the building process for a single facility, seldom in connection with managing all phases of the process for a single facility, and rarely in connection with managing any phase of the process for a multiplicity of concurrent facilities.

6. The most frequently used techniques are essentially CPM and PERT, and only project and task time factors are managed; sometimes, techniques incorporating provisions for task- and project-costs are used, but use is seldom made of techniques incorporating provisions for personnel and material resources.

7. Although many users of network analysis techniques in conjunction with managing building process activities are prone to cite isolated cost- or time-savings achieved, such savings are generally not directly attributable to the use of these techniques; the most probable benefits of such usage are:

    a. Increasing the rigorousness with which projects are planned and controlled.

    b. Minimizing the damaging effects on project cost or time due to changed conditions that seem inevitably to occur in the building process.

8. The major problems cited by users of network analysis techniques are:

    a. Securing realistic estimates of time and other resource requirements.

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[1]With the exception of a few techniques developed by some Federal agencies (e.g., NASA PERT/COST), these extensions of the basic CPM and PERT techniques and the programs for applying these techniques generally are proprietary products of data processing and management or engineering consulting organizations.

b. Obtaining acceptance and use by operating and management personnel.

c. Developing a clear logical network at the correct level of detail.

d. Making modifications due to changes in conditions.

9. Network analysis techniques are not now more widely used in the building process because:

a. The models and techniques are not yet fully developed in regard to accommodating resources other than time.

b. The participants are not yet generally aware of operations research and econometric concepts.

c. The participants in the building process have not evolved a coordinated, economical method for transmitting relevant, timely, and accurate information to meet the needs of all participants in the process.

d. The individual participants in the process have not yet unified the process.

Conclusions

1. The ever increasing demand for productivity in the building process is engendering ever greater use of scientific methods in conjunction with the management of the building process.

2. Currently available network analysis techniques provide a substantial methodological framework around which other analytical techniques can be grouped to advance measurably the effectiveness of building process management.

3. Currently available network analysis techniques are sufficiently developed for use by a Federal agency to manage strategically and operationally, the time requirements of its entire building process or specific phases of the process performed within the agency as well as to control the time required for specific phases of the building process (e.g., design and construction) performed outside the agency.

4. Currently available network analysis techniques are insufficiently developed for use by a Federal agency to manage resources other than time (e.g., cost) unless the involvement of the other resource is directly variable with time.

5. There is immediate need for further study by a task group focused on improving the capability of the Federal agencies to use network

analysis techniques in conjunction with controlling those phases of the building process performed outside the agencies; specifically, study is needed to determine:

a. What information and level of detail is needed by the agencies to monitor satisfactorily the progress of the work performed by non-agency personnel; i.e., to answer such questions as: For what kinds of projects should the techniques be used by outside contractors? How should the activities within a project be reported; should, for example, the time duration of reported activities be limited by the elapsed time between regular, periodic field inspections? Should estimates of construction costs be associated with the performance of each activity?

b. How to specify and obtain from the outside contractor the information and level of detail needed by the agency; i.e., to answer such questions as: Who is responsible for developing the network? On what basis will the acceptability of contractor-submitted networks be judged? Under what conditions, how, and by whom will the network be revised during the progress of the project?

c. What costs should be reasonably incurred by the agency in obtaining the needed information and level of detail; i.e., to answer such questions as: What costs will the contractor incur in providing the required information? Should the agency provide data processing services for the contractor? What means of investigation should be pursued to reduce the contractor's cost of submitting the information? Do benefits justify cost?

d. How to control the project using network analysis techniques; i.e., to answer such questions as: Does the agency have the "right" to insist that all activities start at their scheduled early-start times (who "owns" the float)? Can the agency or the contractor change the original network or its scheduled times (who "owns" the schedule)? What training should be given to agency and/or contractor personnel concerning the use of the techniques?

III
DISCUSSION

Network analysis techniques are a set of formal procedures for investigating the cause and effect relations that exist among the interconnected activities of a system. Two of the more widely known techniques are the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT). The building process--the planning, designing, construction, and maintenance of buildings and structures--can be viewed as such a system of interconnected activities. These techniques, therefore, are useful to managers of the process for developing alternative schemes for accomplishing the activities of the process as well as for organizing and controlling the accomplishment of the activities according to the dictates of the selected scheme.

Managers of the building process concurrently function at two distinct levels, the strategic and the operational. At the strategic level, managers are concerned with all organizational objectives and seek to plan, allocate, schedule, and control organizational resources (men, money, material, and time) in order to accomplish all the objectives (projects) of the organization. For example, the District Engineer of a Corps of Engineers district, the Post Engineer of a military base, the head of the design division at the district or base level, the head of the structural engineering branch at the district or base level--all have responsibility for so managing organizational resources that all projects within their purview are efficiently and effectively accomplished. At the operational level, managers are concerned with particular organizational objectives and with the efficient and effective accomplishment of each individual project within their purview.

At both the strategic and the operational levels, projects are the means by which managers operate. At the strategic level, projects are continuous (i.e., there is continual concern about planning, allocating, scheduling, and controlling resources as individual objectives are accomplished and new ones added). At the operational level projects are limited (i.e., there is basically a definable beginning and a definable end to each project). Nonetheless, both types of projects consist of a number of interconnected activities which utilize resources and which must be performed under imposed internal and external constraints. Both types of projects are amenable to management's use of network analysis for planning and controlling their accomplishment.[1]

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[1] Currently, however, such techniques are rarely used in the building process in conjunction with projects at the strategic level.

Principles

By 1956, the theories and applications of operations research in regard to industrial problems had been advanced to rather sophisticated lengths.[1] Nonetheless, operations research still suffered from two drawbacks. On the one hand, no real industrial problem could be attacked by application of just one operations research technique; a real industrial production problem, for example, generally required the iterative application of a series of techniques--a costly and time-consuming process. On the other hand, even when the analyses were performed and the resulting recommended operational plans implemented, problems again arose because management did not have techniques for the timely evaluation of the performance of the recommended plan nor for the timely correction of deviations from the plan.

In 1956, the E.I. duPont de Nemours Company established a task force to study the possible application of operations research techniques to the company's engineering functions; the first area to be considered was the company's planning and scheduling of construction projects. By late 1957, the task force had developed a new technique--then known as the Kelley-Walker method or the Critical Path Planning and Scheduling Technique (CPPS) and now known as CPM.

In 1958, the new technique was tried twice by the company under controlled conditions. In the first trial, the company assigned a test (CPM) planning team and a normal planning team to plan the construction of a $10 million chemical plant in Louisville. In this trial, both teams expended the same effort in originally planning the schedule, but when the schedule had to be revised to accommodate design changes, the normal planning team spent four times as much effort in rescheduling as did the CPM team. In the second trial, CPM was applied to scheduling an equipment "turnaround" (process stopped, and equipment shut down, purged, and serviced,) that had been done many times before; application of CPM resulted in a schedule that saved approximately 25 percent of the "turnaround" time.[2]

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[1] See Appendix A for a brief discussion of the history and methodology of operations research.

[2] These duPont trials are about the only examples of controlled experimental applications of CPM. They are reported in James E. Kelley, Jr. and Morgan R. Walker, "Critical Path Planning and Scheduling, "Proceedings of the Eastern Joint Computer Conference, December 1-3, 1959. The significance of the first trial should not be overlooked. The effectiveness of management is measured in terms of actual accomplishments versus required objectives. A key factor in obtaining results equal to or exceeding objectives is management's ability to respond in time to changed conditions that somehow modify the internal or external constraints that affect the project. This factor assumes major importance in administration of the building process. The extended time scale of

Early in 1958, before the duPont trials were completed, the Special Projects Office (SPO), Bureau of Ordnance, U. S. Department of the Navy, began the development of a new technique to monitor and control the activities of several thousand contractors and agencies working on the Polaris missile program for which SPO had over-all management responsibility. By mid-1958, a theoretical basis for the technique was outlined and a method of application was proposed. By late 1958, the technique--Program Evaluation and Review Technique (PERT)--was imposed on the Polaris contractors,[1] and the Navy credits the technique with helping to complete Polaris ahead of schedule.

CPM and PERT, though developed independently for different purposes--the former for planning and scheduling and the latter for monitoring and controlling--share an essential basic notion. Both employ network diagrams to present graphically the logic of a plan for accomplishing a project.

As illustrated in Figure 1,[2] a network comprises arrows, each arrow representing one of the various planned tasks (activities) leading to the end objective, and nodes, each node representing an event (a point in

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the process (four years from preliminary planning to beneficial occupancy is not unusual for major private or public facilities) readily admits restraint modifications throughout the process due to economic, sociological, or technological occurrences or changes. The imprecise nature of the data available at the time of planning concerning actual conditions that will prevail at the time of construction engenders changes in the design and construction steps. And, of course, the vagaries of weather and the suddenly-discovered nature of the subsurface at the construction site also generate changes in that step of the process. Thus, although many users of network analysis techniques in conjunction with building process activities are prone to cite isolated cost or time-savings achieved, in the final analysis the real benefit of using these techniques may well be in minimizing the damaging effects on project cost or time due to changed conditions that seem to inevitably occur in the building process.

[1]The final report on the development of PERT is contained in the U. S. Bureau of Naval Weapons, Special Projects Office, Department of the Navy, PERT Summary Report Phase 2, (Washington: U. S. Government Printing Office, September 1958).

[2]Again, attention must be called to the fact that the project illustrated in Figure 1 could be either a strategic- or operational-level project. On the one hand, the project diagramed at the top of the figure could represent a strategic-level-project--a Post Engineer's scheme to accomplish all the planning, designing, and supervising of construction that must be accomplished by his organization (in a particular time period or to meet a particular mobilization objective), or an architect-engineer's scheme to accomplish all the design work required of his organization in a particular time period, or a contractor's scheme for bidding

time at which a decision to start or stop an activity takes place). Each arrow starts (i.e., has its tail) at one event and ends (i.e., has its head) at another event; several arrows may start at the same event (indicating that the activities can be undertaken concurrently on one decision to proceed) and several arrows may end at the same event (indicating that all these activities must be accomplished before the next decision can be made).[1]

If the discipline followed in preparing the CPM or PERT network (the "arrow diagram" as it is popularly called) is rigorous, the resulting diagram is a tight sequence of dependent events and activities that fully reveals the interrelationships and constraints in the plan. This diagram or, more precisely, the preparation of this diagram (showing only events and activities at this stage) can be a powerful device to aid management in accomplishing its project planning function.

Associated with each arrow, of course, is the expenditure of resources such as time, labor, and materials; no resource expenditures are associated with nodes.

In the original CPM and PERT developments, the only resource considered was time. In CPM, time was handled deterministically; i.e., associated with each activity was the one best estimate of the time required to accomplish each activity. In PERT, time was handled probabilistically; i.e., associated with each activity were pessimistic, optimistic, and most likely time estimates which were used to derive statistically a scheduled event time and its standard deviation and to gauge the probability of the activity being accomplished within the scheduled event time.

The process of superimposing the time estimates, derived deterministically or probabilistically, on the diagram can be a valuable aid to management's scheduling function. The resulting diagram (activities, events, and times) can provide management with a suitable technique for evaluating the impact of any actual deviations from the schedule on the over-all project effectiveness as measured by the project's expected completion time.

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for and constructing projects during a particular time period. On the other hand, the diagramed project could represent an operational-level project--a Post Engineer's scheme for planning, designing, and supervising construction of a barracks, an architect-engineer's scheme for designing the barracks, or a contractor's scheme for building the barracks.

The diagram at the bottom of the figure is in all instances an operational-level project, being either a specific project to be accomplished within a strategic-level project, or a specific task to be accomplished within an operational-level project.

[1] It is not intended to pursue here the considerations and mechanics of developing a network, this topic is amply covered in the public documents, books, reports, and articles listed in the BIBLIOGRAPHY.

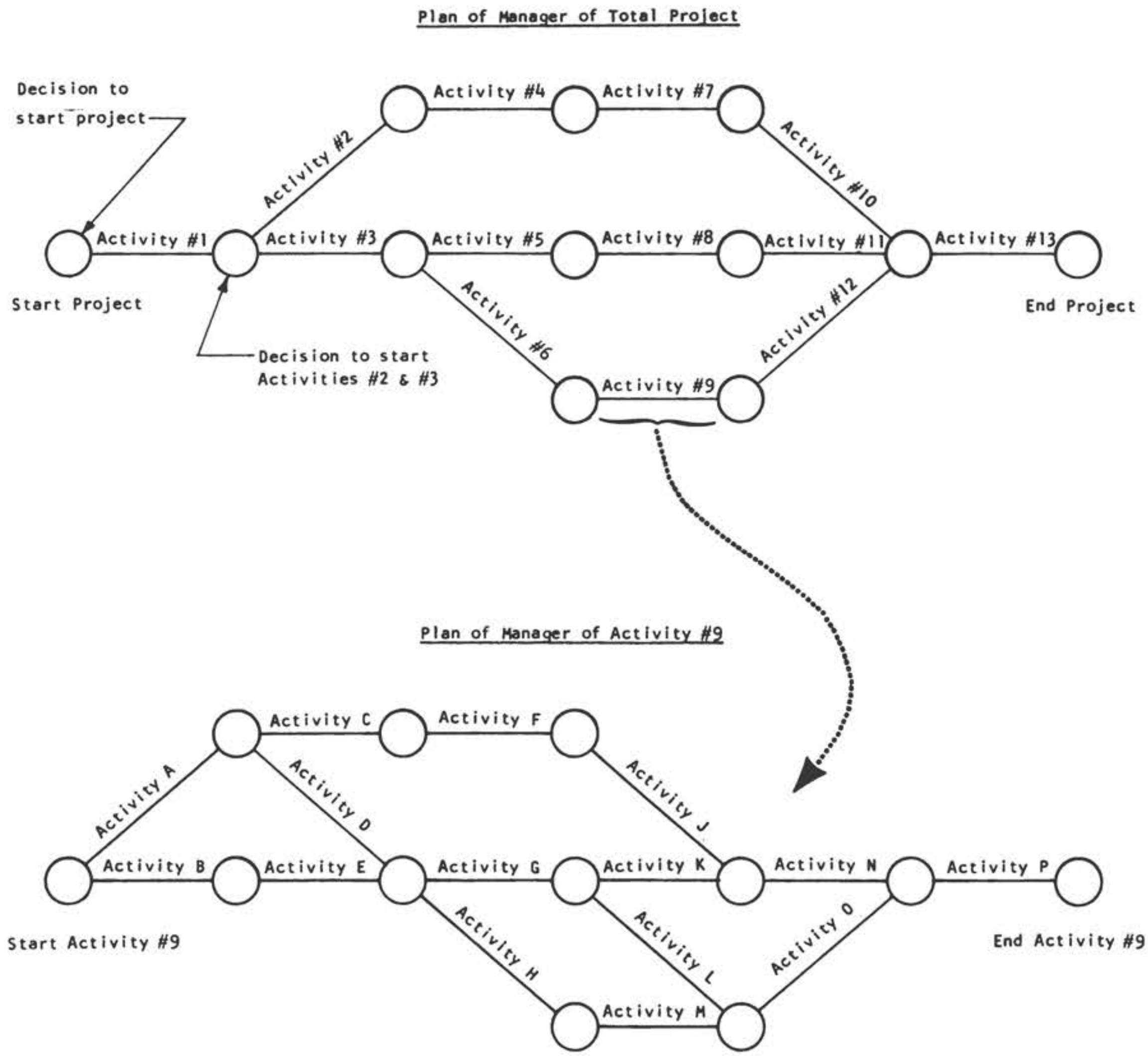

Figure 1. Network Diagram of Plan to Accomplish a Project

However, project management is concerned with more than determining an orderly sequence of events and the amount of time required to complete the project. Management comprises, in sequential order,

a. planning - the determination of requirements upon project resources and their necessary order of commitment in the various operations that must be performed to achieve the project objectives,

b. allocation - the determination of the proper distribution of available resources among all the activities in order to minimize some measure of over-all project effectiveness (e.g., expected cost or time) or to maximize some measure of over-all project effectiveness (e.g., expected profit),

c. scheduling - the determination of the proper timetable for committing resources to project activities within the limits of the internal and external constraints,

d. controlling - the systematic determination of actual deviations from the desired timetable, the evaluation of the impact of the deviations on some measure of over-all project effectiveness (e.g., expected cost, time, or profit), and the iteration of the preceding steps to develop a new schedule to minimize or maximize the expected impact of the deviations on some measure of over-all project effectiveness.

Comparing the potential usefulness of CPM and PERT described earlier to the above list of functions comprising management, it can be noted that the original CPM and PERT techniques can be used only to measure project effectiveness in terms of expected time and they do not, by themselves, readily permit allocation of or accounting for other resources.

In the years since 1958, a wide variety of governmental and private organizations have expended considerable effort to modify or augment the basic CPM and PERT techniques so that other resources could be handled and other measures of project effectiveness employed. With the exception of a few techniques developed by some Federal agencies (e.g., the National Aeronautics and Space Administration's PERT/COST), the computer programs for these extensions of the basic CPM and PERT techniques are proprietary products of data processing and management or engineering consulting organizations. Among the more widely publicized techniques are: Multiple Allocation Plan (MAP), Least-Cost Estimating and Scheduling System (LESS), Resource Allocation and Multi-Project Scheduling (RAMPS), Minimum Cost Expediting (MCX), and Resource Planning and Scheduling Method (RPSM). All of them seek, by one device or another, to append one or more operations research processes to the basic CPM and PERT techniques to accomplish the desired modification or augmentation.[1]

Practice

1. Users

   Even though one of the techniques, CPM, was spawned in the context of the building process, network analysis techniques are not now widely used in the management of the building process. This is so even though the literature, of which but a fraction is cited in the BIBLIOGRAPHY, is replete with books and articles describing the methods and extolling their utility, and is full of articles relating applications and accrued benefits.

   Among private owners/users/managers of real property, the techniques seem to be used mainly by large industrial organizations having continuing multi-plant building programs and by large real estate developers having continuing long-range development programs. At the state and local government level, usage is confined mainly to organizations with highway development responsibilities, although some agencies with major utility and school development programs also use these methods. Among the agencies interviewed at the Federal level, the methods are used by the Corps of Engineers (CE), the Naval Facilities Engineering Command (NFEC), the Air Force's Directorate of Civil Engineering (D/CE), the Atomic Energy Commission (AEC), the National Aeronautics and Space Administration (NASA), and the Public Buildings Service (PBS).

   Among the contractors, CPM- and PERT-based methods seem to be largely used by contractors whose work principally comprises construction of facilities for the foregoing owners/users/managers. Although one recent survey of 500 randomly selected architectural, engineering, contracting, and designing-contracting firms indicates that about 70 percent of the designing-contracting firms in the sample use CPM or PERT and that about 45 percent of the contracting firms use these methods,[2] over-all it is suspected that a much smaller percentage of the universe of contracting and designing-contracting firms use these methods.

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[1] As the title of this sub-section suggests, the list of such "new" techniques is already long and seems to grow longer daily. It includes such acronyms as CPS, PEP, TOPS, CRAM, SCANS, COMET, PROMPT, and PROMOCOM. However, many of these "new" techniques are really different methods of receiving information from a computer (e.g., calendar-phased progress reports) rather than true extensions of network techniques.

[2] H. M. Priluck, "CPM Studied-Conceptions and Misconceptions of a New Tool," Building Construction, December, 1964, pp. 45-46.

Among the professions, such methods again seem to be largely used only by those firms whose work principally comprises design and supervision of construction of facilities for the aforementioned owners/users/managers. That same survey indicates that about 25 percent of the engineers and 17 percent of the architects included in the survey use CPM- and PERT-based methods.[1] Again, however, it is suspected that, over-all, less than 5 percent of the universe of design firms employ such methods in managing their own operations.

2. Applications

From the foregoing, it should not be assumed that these "users" employ network techniques for all management functions (strategic and operational) throughout the entire building process; such is distinctly not the case.

Among the Federal agencies interviewed, only NASA routinely uses these techniques at both the strategic and operational levels. At the strategic level, the agency utilizes "master networks" that encompass the entire building process for all facilities supporting particular research and development programs; the agency, however, does not develop a "master network" that encompasses the agency's total construction responsibilities. At the operational level, the agency uses network techniques for managing the over-all building process as well as the separate phases of the process for individual facilities, but, generally speaking, the design phase of the process for a particular facility is not so managed.[2] As for management of resources, at both the strategic and operational levels, the agency seeks only to plan, allocate, schedule, and control time and costs with network techniques.

One Federal agency interviewed, NFEC, routinely uses these techniques at the operational level for managing the over-all building process (excluding the planning phase) as well as the design and construction phase of the building process for major individual facilities (those facilities exceeding $100,000 in construction costs, having critical completion times, or involving advanced technologies).[3] As for the management of resources, NFEC, seeks only to manage time with network techniques.

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[1] ibid

[2] The design phase for most NASA facilities is usually performed outside the agency, either privately or by other governmental agencies. The agency does not routinely require or even suggest that the design organization use network techniques to manage this phase of the process.

[3] However, it is quite unusual for NFEC to require the design phase to be managed by network techniques if the design phase is performed outside the agency by a private organization.

The remainder of the Federal agencies interviewed that use network techniques generally only use CPM- and PERT-based methods at the operational level for managing the construction phase of individual projects. AEC selectively uses network techniques to plan, control, and schedule time for the construction phase of new facilities, and time, plus in some instances manpower, for maintenance work.[1] PBS requires the techniques to be used in the management of the construction phase of any new facility having contract costs in excess of $1 million or of any remodeled facility having contracts costs in excess of $500,000. CE generally requires the techniques to be used in the management of the construction phase of any Army facility having either contract costs in excess of $100,000 or critical completion times, and requires the techniques to be used in the management of the construction phase of all Air Force and NASA facilities for which CE has construction responsibility. D/CE generally requires the techniques to be used in the management of the construction phase of all facilities. For the most part, these agencies seek only to manage time and cost with network techniques.

There are exceptions to the foregoing generalities, however, such as CE's use (at both strategic and operational levels) of an over-all PERT system for the facilities involved in the NIKE X program, and its use (at the operational level) of CPM/PERT in the planning and design phases of projects in the Arkansas River Development program. Another exception is D/CE's use (at the strategic level) of CPM/PERT for managing multi-shop maintenance projects at the base level, its use (at the operational level) of CPM to manage the entire building process for project TURN-KEY in Southeast Asia, and its use (at the strategic level) of a PERT-system by Pacific Air Force Headquarters to monitor the complete funding, designing, and construction phases of all facilities constructed in the Southeast Asia area.[2] In most of these cases, the only resource being managed is time.

Table 1 summarizes the routine Federal agency usage of network analysis techniques in connection with managing the building process.

[1] AEC has also experimented, in a limited way, with use of network techniques for controlling resources other than time and manpower.

[2] The Pacific Air Force system was found to be too sophisticated to be of practical value, and its use was discontinued within a year; a principal problem was that the volume of data required by the system exceeded the capabilities of the available data transmission facilities.

TABLE 1

SUMMARY OF ROUTINE FEDERAL AGENCY USE OF NETWORK ANALYSIS TECHNIQUES IN CONNECTION WITH MANAGEMENT OF THE BUILDING PROCESS

For Management of	Agency					
	AEC	CE	D/CE	NASA	NFEC	PBS
1. Strategic Level						
Over-all building process				X		
Planning phase						
Design phase						
Construction phase						
2. Operational Level						
Over-all building process				X	X	
Planning phase				X		
Design phase					X	
Construction phase	X*	X	X	X	X	X

*AEC selectively uses network analysis techniques in connection with management of the building process.

Among the private and state- and local-government owners/users/managers of real property, the use of CPM- and PERT-based methods is generally confined to the operational level, and the techniques are usually only used for monitoring the time and cost of the construction phase of the building process for individual facilities. Some large private industrial owners/users/managers and real estate developers, however, use the techniques at the operational level to plan, schedule, and control the entire building process for individual facilities; a very few attempt to use the techniques at the strategic level.

Among contractor organizations, CPM- and PERT-based methods are principally used at the operational level for planning the execution of individual projects. Generally speaking, few contractors utilize network techniques for the actual allocating, scheduling, and controlling functions of management; when they do use the techniques for these purposes, only time and cost are typically managed.

Among professional design organizations, CPM- and PERT-based methods are principally used at the operational level either to plan the design stages of individual projects or, on behalf of the owner, to monitor contractor's progress in constructing a particular facility. Extremely few organizations use the techniques for the actual allocating, scheduling, or controlling functions of management.

3. Cost and Benefits

The cost of implementing network techniques to manage all resources at either the strategic or operational levels, or at both levels, is unknown because such degrees of implementation have not yet been achieved in either public or private organizations. In Federal agencies this cost similarly is unknown because the relevant data are not separately identified in the accounts of the using organizations.[1] However, in the private sectors, there are some indications that the cost of implementing CPM- or PERT-methods at the operational level to manage time, money, and men for facilities in the $1- to $10-million range is about as shown in Table 2. It is not known to what extent this cost adds to, subtracts from, replaces other costs associated within the management of the process. In the planning and allocation functions, approximately one-third of the cost is associated with data processing; in the other functions, data processing accounts for approximately two-thirds of the costs. Generally, the costs range appreciably higher for intermittent use of these techniques.

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[1]At the same time, it must also be noted that the costs associated with "conventional" management of the building process have not been identified either, and thus it would not be possible in any event to develop a true cost-benefit analysis of the management functions.

TABLE 2

COST OF CPM AND PERT METHODS AS A PERCENTAGE OF TOTAL CONSTRUCTION COSTS

Building Process Phase	Management Function				
	Planning	Allocating	Scheduling	Controlling	Total
Planning	0.10	0.10	0.05	0.10	0.35
Design	0.10	0.10	0.05	0.10	0.35
Construction	0.30	0.20	0.10	0.30	0.90
TOTAL	0.50	0.40	0.20	0.50	1.60

Despite the aforementioned lack of cost data, there appears to be a wide-spread concensus among users that have attempted to integrate these methods into their over-all operations that the methods have a beneficial effect on operations. For the most part, such concensus is built on faith--faith that rigorous planning leads to better scheduling and rigorous controlling leads to better performance. To some degree, that faith is supported by numerous, albeit isolated, instances of reduced project completion times and costs. Perhaps, considering the uncertainness of the building process, the faith is really supported by the number of projects completed on time and for the scheduled cost.

4. Problems

The basic concepts of CPM- or PERT-based methods are logical and can be easily understood by managers of any or all phases of the building process at either the strategic or operational levels. However, the simplicity of these concepts belies the difficulties of their implementation. From the point of view of the current users of network techniques, the major problems, in order of importance, are:

a. securing realistic estimates of time and other resource requirements,

b. obtaining acceptance and use by operating and management personnel,

c. developing a clear, logical plan at the correct level of detail,

d. making modifications due to changed conditions.

The problems, although vexatious in any management scheme, are particularly emphasized by an attempt to implement total management methods such as CPM- or PERT-based methods at either the strategic or operational level.

Although not generally appreciated by many users of network techniques, the first and third problems are closely related. If estimates of the resources (men, money, materiel, or time) required to perform an activity in all the ways the activity can be performed are not realistic, then logical, alternative plans for accomplishing the project cannot be developed and evaluated, and the plan finally used for controlling the project is very apt to mislead the project manager[1] and contribute further to operating and management personnel's resistance to using the techniques.

Management's problem of dealing with estimates of resources other than time at either the strategic or the operational level is complicated by the fact that existing computer programs for CPM- and PERT-based methods generally can be utilized only to find an optimum economic schedule if the project's economy is almost linearly dependent on time of completion; i.e., if the mathematical expressions for the relationships among men, money, materiel, and time for all activities encompassed in the project are linear equations or can be reasonably approximated by linear equations. Although such linearity often can be assumed for preliminary planning purposes at either the strategic or operational level, seldom is such an assumption reasonable for the detailed planning, scheduling, allocating, and controlling functions of management at either the strategic or operational level. Most often, the expressions--if they have been developed--are second- or higher-order polynomial and step or other discontinuous equations, most of which presently cannot be routinely handled by computers in conjunction with network computations, and all of which are next to impossible to accommodate efficiently by manual methods.

The problem of obtaining wider acceptance and use of CPM- and PERT-based methods at all levels of management and operations in the building process stems to a large degree from the natural reluctance of people and organizations to accept and effect changes. However, the problem is aggravated by the six- or seven-year history of well-intentioned, but over-zealous efforts to promote network techniques as being fully exploitable in the management of the building process, when, in fact the techniques are not yet ready for such full exploitation, partly because of the inadequacy of the methods to handle the resource concerns of management at either the strategic or operational levels, and partly because the building process at the operational level is a disjointed process in which the participants on

[1]A very simple example of this situation is developed in Appendix B.

a particular project tend to suffer one another rather than to support one another.

With the exception of the owner/user/manager participants in the process, such as the Federal agencies, there is presently no great desire on the part of the other participants in the process to want to be so intimately inter-locked in an over-all operational scheme as is necessary to exploit these management methods throughout the building process at the operational level.

Consequently, it appears that, in the near term, if the Federal agencies wish to use network techniques to plan and control at the operational level the over-all building process or any separate phase of the process, the network techniques used should either be compatible with conventional management techniques employed by the other participants involved in the process or else a specific system should be specified for use by the other participants, with added remuneration provided.

The experience of the Federal agencies interviewed, as well as information received in other informal conversations, indicate that this issue is the crux of the matter to which any further study should be addressed. Among the agencies using network analysis techniques, practice varies from encouraging contractor usage of network techniques (but accepting "normal" contractor progress reports) to the agency's furnishing the contractor with a stipulated network schedule. In more than half of the agencies, it was acknowledged that, of the construction contracts let that required contractor usage of network techniques, there was, at best, poor, and, at worst, deceptive use made of these techniques in substantially more than half of the construction projects involved.

The foregoing situation is in part explainable. On the one hand, the contractor, who is profit-oriented, is aware that the costs ascribed to each activity on the submitted network schedule are valid only if the activity is performed in exactly the manner planned and in exactly the amount of time stipulated, and that the available techniques (particularly the computer programs generally available) do not permit him properly to assess the impact on profits due to changes which are inevitably necessitated. Moreover, if the contractor uses the techniques at the operational level for every project independently, he is in the schizophrenic position of producing optimum schedules for each project when in fact he wants an optimum schedule for all projects. On the other hand, the contracting officer of the Federal agency (or his representative), who is cost-and time-oriented, is aware that estimates of time and cost ascribed to each activity on the submitted schedule are not precise, and that the available techniques do not permit him to assess properly the impact on total cost or time of the project due to either the errors associated with the estimates or to changes. The end result is that both the contractor and the contracting officer frequently ignore the initially submitted network schedule, and, more often than not, take no pains to revise the submitted network (not just the time and cost estimates) as changes occur.

Thus, one facet of a further task group study should be to determine what level of detail is needed to satisfactorily plan and monitor the over-all program, how to specify and obtain that level of detail from the other participants, and what costs should be reasonably incurred for this detail. Another facet of the study should be to determine how to control the project using network analysis techniques and should seek to answer such questions as:

a. Does the owner/user/manager have the "right" to insist that all activities start at their scheduled early-start times (or who "owns" the "float")?

b. Can the owner/user/manager or the contractor change the original network and its scheduled times (or who "owns" the schedule)?

These and similar questions already are plaguing governmental and private owners/users/managers.

Potential

Given the foregoing, somewhat less than enthusiastic, appraisal of the current value of and the problems associated with the use of CPM- and PERT-based methods in the management of the building process, it is reasonable to question whether such methods will have a valid function in the building process of the future.

The answer to such a question must be affirmative in recognition of the demand for increased productivity in the building process that is voiced each year in ever greater measure by the building industry and by informed outsiders. There are, after all, only four basic ways to increase productivity, and one of these, increasing the efficiency of the building process operations, requires improving the management of the building process at the strategic and operational levels.

Certainly one means of improving management is improving the array of techniques available for management functions. The use of existing network analysis techniques and other methods of operations research in the management of the building process is a start in this direction.

But much needs to be accomplished. The models and techniques are not yet fully developed. The participants in the building process are not yet generally aware of operations research and econometric concepts. The participants in the building process have not yet evolved a coordinated, economical method for transmitting relevant, timely, and accurate information to meet the needs of all participants in the process. The individual participants in the building process have not yet unified the process.

But the indications are that these events will occur. Then network analysis techniques will provide a most effective skeleton for planning, allocating, scheduling, and controlling the building process at the strategic and operational levels.

APPENDIX A

SCIENTIFIC MANAGEMENT METHODS

Almost from the dawn of history, man has engaged in construction; for something like three or four thousand years, man has engaged in the building process. Throughout almost all of that time, management, not only of the building process but of all other industrial activity, was largely "rule with a big stick."

As might be expected, at the time of the industrial revolution some reasoned inquiry into the problems of management took place;[1] however, such early efforts prior to the mid-nineteenth century were rather isolated happenings, and they did not have any direct, measurable impact on the industrial situation at the time.

During the period 1882 to 1912, the movement towards the scientific study of business management began; the work of F.W. Taylor, L.L. Gantt, F.B. and L.M. Gilbreth,[2] and others did have direct impact on industrial activity, and, in fact, form the basis of much of modern industrial engineering in particular, and modern management in general.

As management functions grew, or more precisely, as division of managerial functions increased, there emerged more and more applied scientific and engineering disciplines to support individual managerial functions, until by, say, the end of World War II, the array of "scientific" arguments that could be mustered for and against a proposed course of action seemed almost to exhaust management's ability to determine the best

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[1]Perhaps the earliest published work was that of Charles Babbage (1792-1891), Lucasian Professor of Mathematics at the University of Cambridge (England). His book, The Economy of Machinery and Manufacturers (1832), is noted in H.B. Maynard (Ed.), Industrial Engineering Handbook, (New York: McGraw-Hill Book Company, Inc., 1956), p. 1-10.

[2]See, for example, Frederick Winslow Taylor, Scientific Management (New York: Harper & Brothers, 1947). This volume contains reprints of Taylor's Shop Management (1903) and Principles of Scientific Management (1912). Also see Wallace Clark, The Gantt Chart, (New York: The Ronald Press Co., 1922). Also see F.B. and L.M. Gilbreth, "Process Charts: First Steps in Finding the One Best Way to Do the Work," Paper presented at the Annual Meeting of ASME, New York, Dec. 5-9, 1921.

strategy for the over-all organization. To support the functions of the top executive, the new "discipline" of operations research was employed.

Operations research, as a name, dates back to 1940. Its initial development took place in a military context in England during World War II and was quickly accepted in the same context in the United States. After the War, operations research was quickly tried and widely accepted in business, industrial, and civil government functions in England; the trial and acceptance of operations research was slower in the United States, but, by 1951, operations research was rather widely accepted in an industrial context in this country.[1]

Operations research is generally considered to be the application of scientific methods, techniques, and tools[2] to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to the problems. Usually, it is performed by a team whose individual members have been drawn from different scientific and engineering disciplines, and its performance comprises the following major phases:

a. Formulating the problem of the system
b. Constructing a mathematical model to represent the system
c. Deriving a solution from the model
d. Testing the model and the solution derived from it
e. Establishing controls over the solution
f. Recommending the method of implementating the solution.

Because operations research has enjoyed rather wide-spread industrial acceptance and because industrial problems tend to be recurring problems within general categories, it is not too surprising to find that the mathematical models and the other techniques and tools of operations research are generally classified in the literature according to the type of process to which they are applicable. These classifications are:

a. Inventory processes
b. Allocation processes
c. Waiting-time processes
d. Replacement processes
e. Competitive processes.

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[1] For a brief history of operations research, see Florence N. Trefethens, "A History of Operations Research," in Joseph F. McCloskey and Florence N. Trefethens (Ed.), Operations Research for Management, (Baltimore: The Johns Hopkins Press, 1954).

[2] "Methods," "techniques," and "tools," are usually carefully differentiated among the practitioners. To the practitioner, calculus is a "tool," using calculus to find an optimum value in a mathematical model is a "technique," and the plan to use a model to find the optimum system is a "method."

The inventory process involves the decision of how many (or much) to produce (or purchase) and/or the decision of when to produce (or purchase). Models of this process generally consider balancing inventory carrying costs against order setup costs, delay costs, and/or costs associated with changing levels of production. Some of the general techniques applicable to these problems are linear, dynamic, and quadratic programming.[1]

The allocation process involved the decision of how to distribute resources (men, money, material, machinery, time, facilities) among a number of activities to be performed when there are alternative ways of performing each activity and there are insufficient resources for performing each activity in the most effective way. Models of this process generally consider the assignment of resources among activities on the basis of the activity's effectiveness in employing resources, the amount of resources to be committed, and the schedule of resource commitments. The most prominent general technique applicable to these problems is linear programming, with its special solution techniques--simplex and transportation.[2]

The waiting-time process involved the decision of how to service units which require service at one or more service points. Models of this process generally consider the arrival pattern of units, the waiting required of the units and/or the service points, and the costs associated with these times. Three techniques, individually or collectively, are principally applied to these problems: Queuing theory for problems involving determining the number of service points required and the time of arrivals,[3] sequencing theory for problems involving determining the order in which units should be serviced,[4] and line-balancing theory for problems involving determining how to group the service activities into a sequence of servicing points.[5]

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[1] The developments up to about 1952 are summarized in T.M. Whitin, The Theory of Inventory Management, (Princeton: Princeton University Press, 1953).

[2] The basic applications are developed in Tjalling C. Koopmans (Ed.), Activity Analysis of Production and Allocation, (New York: John Wiley & Sons, 1951).

[3] See, for example, B. D. Marshall, Jr., "Queuing Theory," in Joseph F. McCloskey and Florence N. Trefethens (Eds.), Operations Research for Management, (Baltimore: The Johns Hopkins Press, 1954).

[4] See, for example, S.M. Johnson, "Optimal Two-and Three-Stage Production Schedules with Setup Times Included." Naval Research Logistics Quarterly, Vol. 1, No. 1 (March, 1954), pp. 61-68.

[5] See, for example, Melvin E. Salveson, "The Assembly Line Balancing Problem," The Journal of Industrial Engineering, Vol. 6, No. 3 (May-June 1955), pp. 18-25.

The replacement process involves the decision of when to replace resources that deteriorate or become obsolete or the decision, for items that fail, of which items to replace and according to what schedule. Models of this process, when the concern is deterioration or obsolescence, generally consider the cost of new resources, the cost of maintaining the efficiency of the old, and the cost of loss of efficiency; there is, however, no generalized model that is applicable. Models of this process, when the concern is failure, generally consider the cost of the resource, the cost of replacement, and the cost associated with failure; again, there is no general model that is applicable. For both types of replacement models, the techniques employed are those of engineering economy, heavily supplemented, in the case of failure considerations, with probability theory.[1]

The competitive process is associated with problems wherein the efficiency of a decision by one party can be decreased by the decision of another party. Two broad sub-classes of this process are (1) games, wherein the number of players, the rules for play, a set of end conditions, and the benefits associated with each end condition are specified, and (2) bids, which differ from games in that the number of players is not known, the "moves" are unlimited, and the benefits associated with each end condition can only be estimated. The basic set of techniques applicable to the former class is the theory of games;[2] techniques for the latter class are in their infancy and have not yet fully evolved into a theory of bidding.[3]

Despite these general classifications of models or theories according to the industrial processes to which they have been applied, there is nothing restrictive about the classifications. For example, if the solution of the problems of an inventory process requires consideration of delivery or supply times, one of the models associated with the waiting-time process (e.g., queuing theory) might be used. Furthermore, inventory models may be applicable to problems of cash, working capital, or personnel.

Thus, it is not difficult to envision the use of an array of the foregoing operations research models in conjunction with the initial

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[1] General treatment of these problems will be found in any good textbook on engineering economy; see, for example, Eugene L. Grant and W. Grant Ireson, Principles of Engineering Economy, (New York: The Ronald Press Co., 1960).

[2] The mathematical treatment of games became of interest after the publication of J. Von Neumann and O. Morgenstern, Theory of Games and Economic Behavior, (Princeton: Princeton University Press, 1944).

[3] Nonetheless, some techniques are available; see, for example, Marvin Gates, "Bidding Strategies and Probabilities," Journal of the Construction Division, ASCE, Vol. 93, No. CO1, March 1967, pp.75-107.

development of a network diagram in order to define the most favorable plan for executing an individual project that properly allocates resources among all the activities of the project while satisfying the resource demands of all concurrent processes.

APPENDIX B

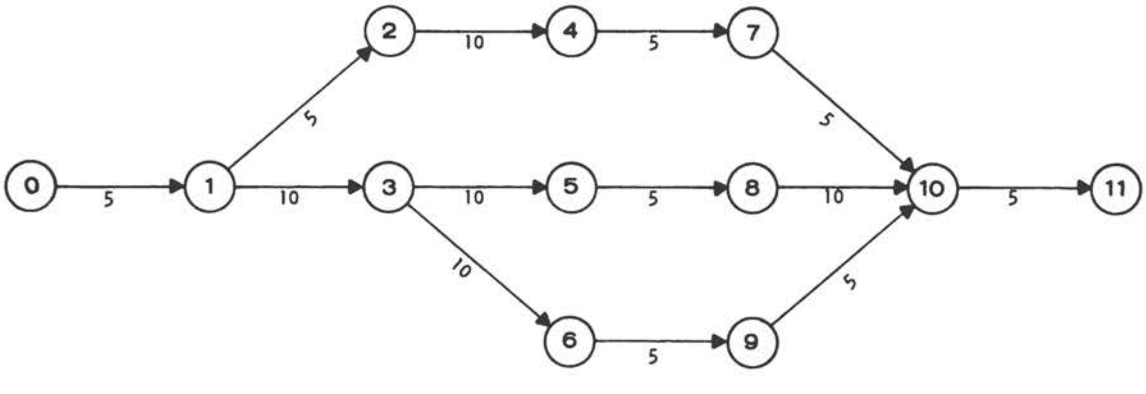
THE SIGNIFICANCE OF ESTIMATES IN THE DEVELOPMENT AND USE OF NETWORKS

Shown in Figure 2 is a manager's plan for scheduling and controlling a project; the project could be the entire building process for a facility or any one of the phases of the building process. The network at the top of the figure comprises 13 activities (arrows) linking 11 nodes (events). Note that after activity (0-1) is accomplished, two series of activities can be pursued concurrently for a period of time and that after activity (1-3) is finished, three series of activities can be pursued for a period of time. Note also that the last activity (10-11) cannot be undertaken until three prior activities (7-10, 8-10, and 9-10). are finished. Directly below each activity is a number indicating the time duration for each activity; the number represents the manager's estimate of the time required for each activity based on certain quantities of other resources (men, machines, materiel, and money) being employed.

In the table below the network diagram, the manager's basis for scheduling the project is given. This comprises the time required for each activity (t), the earliest time each activity can be started after the initiation of the project (ES), the latest time each activity can be started after the start of the project without increasing the minimum length of time of the over-all project (LS), and the amount of "float" (delay) that each activity can incur without increasing the minimum over-all time for the project (F). This basis is shown in bar chart form to the right of the table. Based on the manager's estimates of time duration for each activity, the minimum project time is 45 time units and the attainment of this minimum project time is dependent on activities on the critical path being started at their ES time and on other activities being started no later than their LS time.

Suppose now that the manager's estimates are randomly in error by one time unit, one unit over on some activities and one unit under on others. With the aid of a table of random numbers, one time unit was randomly added and subtracted to each of the manager's estimates. Of the many possibilities tried, one result is shown in Figure 3.

At the top of Figure 3, the network is the same as shown in Figure 2, except that the time duration for activities is different; the time units shown in this figure are the <u>actual</u> time durations required for



Activity	t	ES	LS	F
0 - 1	5	0	0	0*
1 - 2	5	5	15	10
1 - 3	10	5	5	0*
2 - 4	10	10	20	10
3 - 5	10	15	15	0*
3 - 6	10	15	20	5
4 - 7	5	15	30	15
5 - 8	5	25	25	0*
6 - 9	5	25	30	5
7 - 10	5	20	35	15
8 - 10	10	30	30	0*
9 - 10	5	30	35	5
10 - 11	5	40	40	0*

* Critical Path Activities

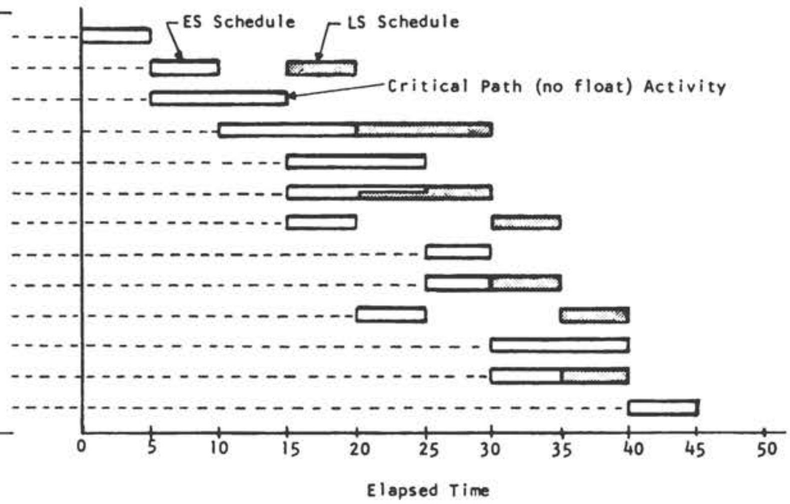
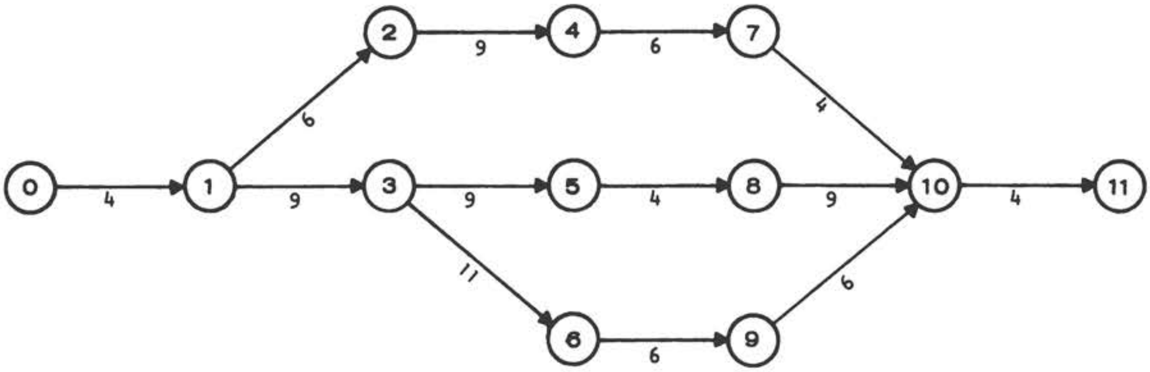
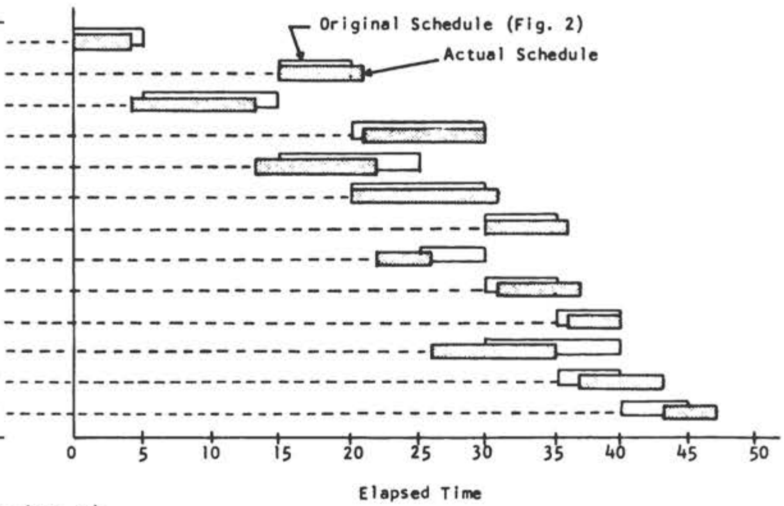


Figure 2. Manager's Plan for Scheduling and Controlling a Project



Activity	t	ES†	LS†	F
0 - 1	4	0	0	(0)*
1 - 2	6	4	11	7
1 - 3	9	4	4	(0)*
2 - 4	9	10	17	7
3 - 5	9	13	14	1*
3 - 6	11	13	13	(0)*
4 - 7	6	19	26	7
5 - 8	4	22	23	1*
6 - 9	6	24	24	(0)*
7 - 10	4	25	32	7
8 - 10	9	26	27	1*
9 - 10	6	30	30	(0)*
10 - 11	4	36	36	(0)*



† With Actual Critical Path
( ) Actual Critical Path Activities
* Estimated Critical Path Activities (Fig. 2)

Figure 3. Effect of Time Estimate Errors on Manager's Plan

each activity, in contrast to the manager's estimated time duration shown in Figure 2. In the table below the network diagram is the basis for scheduling the project according to the actual time duration of activities; it should be noted that the project could actually be completed in 40 time units (instead of the manager's estimate of 45 time units) and that the activities lying on the critical path (activities having zero float) are not identical with the activities the manager believes are on the critical path (designated by an asterisk in column "F" of the table in Figure 3).

If the manager, relying on the original time estimates, schedules critical activities to start at the earliest opportunity and non-critical activities to start at the originally computed late-start times, then, as shown in the bar chart in Figure 3, not only is the manager unable to capitalize on the potential shortening of the over-all project (i.e., using 40 time units instead of 45), but also the manager will be penalized by an excessive over-all project time (i.e., using 47 time units instead of 45). To make matters worse, judging from the simulated reports of progress, which are based on the manager's estimates of activity durations and shown in Table 3, the manager will believe the project is on schedule for the first 15 time units, will waste resources during the next 15 time units trying to make up a onetime unit overrun on non-critical activities, and will be powerless in the final third of the project to "save" the project.

TABLE 3

SIMULATED PROGRESS REPORT

Report Date	Critical Path to Completion	Expected Completion Date
5	1-3, 3-5, 5-8, 8-10, 10-11	45
10	1-3, 3-5, 5-8, 8-10, 10-11	45
15	3-5, 5-8, 8-10, 10-11	45
20	2-4, 4-7, 7-10, 10-11	46
25	2-4, 4-7, 7-10, 10-11	46
30	3-6, 6-9, 9-10, 10-11	46
35	6-9, 9-10, 10-11	46
40	9-10, 10-11	47
45	10-11	47

Given the foregoing accuracy of estimates, then it can be argued that, whereas the detail shown in the network might have been necessary for the manager's planning properly the project's execution, the detail is excessive for the manager's scheduling and controlling of the project. A more meaningful scheduling and controlling network, in this case, might have been confined to groups of activities with estimated times around 10 time units; it would be similar in concept but different in detail. Thus, the user's problem of determining correct level of detail in the network is rather dependent on the user's ability to estimate the quantities of time and other resources needed.[1]

[1] In actual practice, this type of estimating difficulty is mitigated somewhat by the manager's application of the rule-of-thumb--always start activities at the earliest-start times. Thus, with or without CPM or PERT methods, one generally finds the owner/user/manager pushing the general contractor to work on everything that can be worked, and the general contractor similarly pushing subcontractors.

APPENDIX C

BIBLIOGRAPHY

Public Documents

U.S. Department of Defense and the National Aeronautics and Space Administration. DOD and NASA Guide PERT/COST Systems Design. June, 1962.

U.S. Department of the Army, Office of the Chief of Engineers. Network Analysis System, Regulation ER No. 1-1-11. March 15, 1963.

U.S. Department of the Air Force, Air Force Systems Command, Aeronautical Systems Division. AFSC PERT Policies and Procedures Handbook. January 5, 1962.

_____. AFSC PERT/Time System Description Manual. June 1963.

U.S. Department of the Navy, Bureau of Naval Weapons, Special Projects Office. PERT Summary Report - Phase II. September, 1958.

_____. Instruction Manual and Systems and Procedures for PERT. 1960.

_____. An Introduction to PERT. May 16, 1960.

_____. Proceedings of the PERT Coordination Task Group Meeting at Lockheed Missile Space Division, Palo Alto, California. August, 1960.

_____. An Introduction to the PERT/COST System for Integrated Project Management. 1961.

_____. An Introduction to the PERT/COST System. October 15, 1961.

_____. Common Problems Associated with Implementation and Operation of the PERT/COST System, PERT Coordinating Group Technical Paper No. 1. April 30, 1964.

U.S. Executive Office of the President, Bureau of the Budget. "New Approaches for Managing Complex Programs," Cost Reduction Through Better Management in the Federal Government. April 24, 1963, pp. 37-47.

U.S. National Aeronautics and Space Administration, Office of Programs. NASA PERT and Companion Cost System. October 30, 1962.

_____. NASA PERT In Facilities Project Management. March 1965.

Books

Antill, James M. and Woodhead, Ronald W. Critical Path Methods in Construction Practice. New York: John Wiley & Sons, 1965.

Baker, Bruce and Eris, Rene L. An Introduction to PERT/CPM. Homewood: R.D. Irwin, 1964.

Battersby, Albert. Network Analysis for Planning and Scheduling. New York: The Macmillan Co., 1964.

Bock, Robert H. and Holstein, William K. Production Planning and Control. Columbus: C.E. Merrill Books, 1963.

Clark, Wallace. The Gantt Chart. New York: The Ronald Press Co., 1922.

Deatherage, George E. Construction Scheduling and Control. New York: McGraw-Hill Book Co., 1965.

Dooley, Arch R. Operations Planning and Control. New York: John Wiley & Sons, 1964.

Evarts, Harry F. Introduction to PERT. Boston: Allyn and Bacon, 1964.

Fuller, Don. Organizing, Planning and Scheduling for Engineering Operations, 1962.

Grant, Eugene L. and Ireson, W. Grant. Principles of Engineering Economy. New York: The Ronald Press Co., 1960.

Koopmans, Tjalling C. (Ed.). Activity Analysis of Production and Allocation. New York: John Wiley & Sons, 1951.

Lambourn, Simon. Network Analysis in Project Management. London: Industrial and Commercial Techniques Ltd., 1965.

Levin, Richard I. Planning and Control with PERT/CPM. New York: McGraw-Hill Book Co., 1966.

Martino, Rocco L. Project Management and Control, Vol. 1 - Finding the Critical Path. New York: American Management Association Inc., 1964.

_____. Project Management and Control, Vol. II - Applied Operational Planning. New York: American Management Association, Inc., 1964.

_____. Project Management and Control, Vol. III - Allocating and Scheduling Resources. New York: American Management Association, Inc., 1965.

Maynard, Harold B. (Ed.). Industrial Engineering Handbook. New York: McGraw-Hill Book Co., 1956.

McCloskey, Joseph F. and Trefethens, Florence N. Operations Research for Management. Baltimore: The Johns Hopkins Press, 1954.

Miller, Robert Wallace. Schedule, Cost, and Profit Control with PERT. New York: McGraw-Hill Book Co., 1963.

Moder, Joseph J. and Phillips, Cecil R. Project Management with CPM and PERT. New York: Reinhold Publishing Corp., 1964.

O'Brien, James Jerome. CPM in Construction Management. New York: McGraw-Hill Book Co., 1965.

Riggs, James L. and Heath, Charles O. Guide to Cost Reduction through Critical Path Scheduling. Englewood Cliffs: Prentice-Hall, Inc., 1966.

Shaffer, Louis Richard, Rither, J.B., and Meyer, W. Lyle. The Critical Path Method. New York: McGraw-Hill Book Co., 1965.

Smith, Kenneth Menzies. A Practical Guide to Network Planning. London: British Institute of Management, 1965.

Stires, David and Murphy, Maurice. PERT and CPM. Boston: Industrial Education Institute, 1962.

Taylor, Frederick Winslow. Scientific Management. New York: Harper & Brothers, 1947.

Von Neumann, John and Morgenstern, Oskar. Theory of Games and Economic Behavior. Princeton: Princeton University Press, 1944.

Whitin, T.M. The Theory of Inventory Management. Princeton: Princeton University Press, 1953.

Reports

Associated General Contractors of America. CPM In Construction. A Report prepared by the Associated General Contractors of America, Washington: 1965.

_____. The Critical Path Method As Applied to Construction. A Report to the Forty-Fourth Annual Convention of the Associated General Contractors of America, New York City, March 4-7, 1963, prepared by Members of the Associated General Contractors of America. Washington: 1963.

Booz-Allen & Hamilton, Inc. New Uses and Management Implications of PERT. A Report prepared by Booz-Allen & Hamilton, Inc., Chicago: 1964.

Breitenberger, Ernst. Development Projects as Stochastic Processes, Technical Memo K-33/59. A Report prepared by the U.S. Naval Weapons Laboratory, Dahlgren: December, 1959.

Burch, W.D. and LaMaster, C.H. Critical Path Method for Scheduling the Transuranium Processing Plant: An Appraisal. A Report for the U.S. Atomic Energy Commission, prepared by the Oak Ridge National Laboratory. Operated by Union Carbide Corporation, Oak Ridge: March, 1966.

Calahan, D.A. Linear Network Analysis and Realization Digital Computer Programs: An Instruction Manual. A Report prepared by the College of Engineering, University of Illinois, Urbana: February, 1965.

CPM Systems, Inc. Introduction to CPM. A Report prepared by CPM Systems, Inc., California: September, 1964.

Fondahl, John W. A Non-Computer Approach to the Critical Path Method for the Construction Industry. A Report prepared for the U.S. Bureau of Yards and Docks by the Department of Civil Engineering, Stanford University, California: 1962.

Fulkerson, D.R. A Network Flow Computation for Project Cost Curves. Publication No. P-1947 A Report prepared by the Rand Corporation, California: March, 1960.

General Electric Company. Complete Data Processing Services for the Construction Industry. A Report prepared by the General Electric Company, Arizona.

_____. GE-225 Application Critical Path Method Program. A Report prepared by the General Electric Company, Arizona: 1962.

_____. PROMOCOM Highlights. A Report prepared by the General Electric Company, Arizona: 1963.

Hunter, Thomas C. Critical Path Program. A Report prepared by the International Business Machines Corporation Headquarters.

International Business Machines Corporation. 1130 Project Control System Application Description. A Report prepared by the International Business Machines Corporation. New York: 1966.

Jellinger, Thomas C. Advanced Techniques in Constructed Scheduling. A Report prepared by the Iowa Engineering Experiment Station, Iowa State University of Science and Technology, Iowa: 1963.

Kelley, James E., Jr. Computers and Operations Research In Road Building. Proceedings of the Symposium on Operations Research, Computers, and Management Decisions, Case Institute of Technology, January 31 and February 1 & 2, 1957.

_____. and Walker, Morgan R. Critical Path Planning and Scheduling. Proceedings of the Eastern Joint Computer Conference. December: 1959, pp. 160-173.

Preston, E.S. & Associates, Ltd. A Manual For Applying the Critical Path Method to Highway Department Engineering and Administration. A Report prepared by E.S. Preston & Associates, Ltd., Washington, D. C. and Ohio: 1963.

White, Glenn L. Company. Complete Project Management - The GLWCo. Project Time and Cost Control System. A Report prepared by the Glenn L. White Company, Washington: 1965.

Papers

Callaway, Hilda W. Making Practical Use of PERT/COST. A Paper presented to the PERT/COST Management Course, American Management Association, New York, New York: January 28, 1965.

Getz, C.W. PERT in Perspective. A Paper presented to the Society of Automotive Engineers. Paper No. 557A, New York: 1962.

Gilbreth, F.B. and L.M. Process Charts: First Steps in Finding the One Best Way to Do the Work. A Paper presented at the Annual Meeting of ASME, New York: December 5-9, 1921.

Martino, Rocco L. Resource Allocation and Scheduling--An Introduction to M.A.P. A Paper presented to the 8th Annual Meeting of the American Association of Cost Engineers, New York: June, 1964.

Meyer, W. Lyle and Shaffer, Louis R. Extending CPM for Multi-Form Project Time-Cost Curves. A Paper presented to the 8th Annual Meeting of the American Association of Cost Engineers, New York: June, 1964.

Naimoli, Vincent J. PERT/COST Systems in Chemical Construction Projects. A Paper presented to the American Society of Mechanical Engineers Annual Winter Meeting. November 29-December 4, 1964.

Swim, R.K. Graphic PERT/COST Milestone Reporting. A Paper presented to the Society of Automotive Engineers. Paper No. 576D, New York: 1962.

Tebo, K.M. PERT - A Technique for Management. A Paper presented to the Society of Automotive Engineers. Paper No. 557D, New York: 1962.

Waldren, A.J. The Use of PERT in Scheduling Manufacturing Operations. A Paper presented to the Society of Automotive Engineers. Paper No. 658A, New York: 1963.

Articles

Anshen, Melvin, Holt, Charles C., Modigliani, Franco, Muth, John F. and Simon, Herbert A. "Mathematics for Production Scheduling," Harvard Business Review, Vol. 36, No. 2 (March-April, 1958), pp. 51-58.

Anzelon, George J. "CPM or PERT - What's the Difference?" The Constructor, Vol. 45, No. 5 (May, 1963), pp. 23-24 and 45.

Aras, Restan M. and Surkis, Julius. "PERT and CPM Techniques in Project Management," Journal of the Construction Division, ASCE, Vol. 90, No. CO1 (May, 1964), pp. 1-25.

Archibald, Russell D. "PERT and the Role of the Computer," Computers and Automation, Vol. 12, No. 7 (July, 1963), pp.26-30.

_____. and Villoria, Richard L. "Product Planning and Evaluation," Mechanical Engineering, Vol. 86, No. 6 (June, 1964), pp.48-51.

Baker, Bruce N. "Making PERT Work," Space/Aeronautics, Vol. 37, No.3 (March, 1962), pp.58-60.

Barker, Paul V. "CPM-Its Effect on the Building Team," Building Construction, (October, 1963), pp.39-40.

Barmby, John G. "The Applicability of PERT as a Management Tool," Transactions on Engineering Management, IRE, Vol. EM9, No. 3 (September, 1962), pp.130-131.

Beckwith, R.E. "A Cost Control Extension of the PERT System," Transactions on Engineering Management, IRE, Vol. EM9, No. 4 (December, 1962), pp.147-149.

Bennion, Edward G. "Econometrics for Management," Harvard Business Review, Vol. 39, No. 2 (March-April, 1961), pp. 100-112.

Berman, Herbert. "CPM and the Architect," AIA Journal, Vol. 41, No. 2 (February, 1964), pp. 55-62.

_____. "The Critical Path Method for Project Planning and Control," The Constructor, Vol. 43, No. 9 (September, 1961), pp. 24-29.

Beutel, Morris L. "Computer Estimates Costs, Saves Time, Money," Engineering News-Record, Vol. 170, No. 9 (February 28, 1963), pp. 26-30.

_____. "New Computer Program and New Report Form Improve Scheduling," Engineering News-Record, Vol. 174, No. 13 (April 1, 1965), pp. 20-22.

Boehm, George A. W. "Helping the Executive to Make up His Mind," Fortune, Vol. 65, No. 4 (April, 1962), pp. 128-131, 218, 222, & 224.

Bonchonsky, Joseph. "PERT's Place in Subcontracting," Aerospace Management, Vol. 5, No. 1 (January, 1962), pp. 48-50.

Boulanger, David G. "Managing a PERT Program," Machine Design, Vol. 34, No. 27 (November 22, 1962), pp. 130-132.

Boverie, Richard T. "The Practicalities of PERT," Transactions on Engineering Management, IRE, Vol. EM10, No. 1 (March, 1963), pp. 3-6.

Bradford, Guy,Jr. "CPM-An Introduction," Building Construction, (February, 1964), pp. 36-38.

Brown, Robert G. "Less Risk in Inventory Estimates," Harvard Business Review, Vol. 37, No. 4 (July-August, 1959), pp. 104-116.

Butcher, William S. "Dynamic Programming for Project Cost-Time Curves," Journal of the Construction Division, ASCE, Vol. 93, No. CO1 (March, 1967), pp. 59-73.

Caplan, Basil. "New Ideas Simplify Building Schedule," Engineering and Contract Record, Vol. 75, No. 4 (April, 1962), pp.60-61.

Christensen, Borger M. "Network Models for Project Scheduling, Part 1 - Planning Phase," Machine Design, Vol. 34, No. 11 (May 10, 1962), pp. 114-118.

_____. "Network Models for Project Scheduling, Part II - Preliminary Scheduling Phase," Machine Design, Vol. 34, No. 12 (May 24, 1962), pp. 173-177.

_____. "Network Models for Project Scheduling, Part III - Advanced Scheduling Phase," Machine Design, Vol. 34, No. 13 (June 7, 1962), pp. 132-138.

_____. "Network Models for Project Scheduling, Part IV - Preparation of Network Model," Machine Design, Vol. 34, No. 15 (June 21, 1962), pp. 155-160.

_____. "Network Models for Project Scheduling, Part V - Preparing Computer Data," Machine Design, Vol. 34, No. 16 (July 5, 1962), pp. 105-111.

_____. "Network Models for Project Scheduling, Part VI - Choosing A Plan," Machine Design, Vol. 34, No. 17 (July 19, 1962), pp. 136-140.

Clarke, Roderick W. "Activity Costing - Key to Progress in Critical Path Analysis," Transactions on Engineering Management, IRE, Vol. EM9, No. 3 (September, 1962), pp. 132-136.

Consinuke, Walter. "The Critical Path Technique for Planning and Scheduling," Chemical Engineering, Vol. 69, No. 13 (June 25, 1965), pp. 113-118.

Dombrow, Rodger T. "How to Meet Your Construction Deadline," School Management, Vol. 7, No. 7 (July, 1963), pp. 99-103.

Dooley, Arch R. "Interpretations of PERT," Harvard Business Review, Vol. 42, No. 2 (March-April, 1964), pp. 160-162 and 165-168.

Douglas, Damon G., Jr. "CPM Helps General, Subs, and Suppliers Talk Same Scheduling Language," The Constructor, Vol. 44, No. 12 (December, 1962), pp. 31-33.

Doyle, G.A. "Modern Management Systems - Their Impact on Construction Contractors, " The Constructor, Vol. 44, No. 7 (July, 1962), pp. 28-31 & 48.

Edmonds, William F. "Critical Path Planning," Consulting Engineer, Vol. 15, No. 2 (February, 1962), pp. 84-89.

Fazar, Willard. "Program Evaluation and Review Technique," The American Statistician, Vol. 13, No. 2 (April, 1959), p. 10.

Fondahl, John W. "Can Contractors' Own Personnel Apply CPM Without Computers? - Part I," The Constructor, Vol. 43, No. 11 (November, 1961), pp. 56-60.

_____. "Can Contractors' Own Personnel Apply CPM Without Computers? - Part II," The Constructor, Vol. 43, No. 12 (December, 1961), pp. 30-34.

Freeman, Milton L. "The Critical Path Method," Western Construction, Vol. 37, No. 5 (May, 1962), pp. 56-58.

Fulkerson, D.R. "A Network Flow Computation for Project Cost Curves," Management Science, Vol. 7, No. 2 (January, 1961), pp. 167-178.

_____. "Expected Critical Path Lengths in PERT Networks," Operations Research, Vol. 10, No. 6 (November-December, 1962), pp. 808-817.

Galbreath, Robert V. "Computer Program for Leveling Resource Usage," Journal of the Construction Division, ASCE, Vol. 91, No. CO1 (May, 1965), pp. 107-124.

Gates, Marvin. "Bidding Strategies and Probabilities," Journal of the Construction Division, ASCE, Vol. 93, No. CO1 (March, 1967), pp. 75-107.

Giffler, B. "Scheduling General Production Systems Using Schedule Algebra," Naval Research Logistics Quarterly, Vol. 10, No. 3 (September, 1963), pp. 237-255.

Gleason, William J., Jr. and Ranieri, Joseph J. "First Five Years of the Critical Path Method," The Journal of the Construction Division, ASCE, Vol. 90, No. CO1, pp. 27-36.

Goodkind, Donald. "CPM is Here to Stay - Experiences in the Use of CPM on Construction Projects," Pacific Building and Engineer, Vol. 69, No. 2 (February, 1963), pp. 54 and 56.

_____. "The Critical Path Method and the Computer," Contractors and Engineers, Vol. 59, No. 1 (January, 1962), pp. 106-108.

Gustafson, P.G. "PERT/PEP/CPM," The Navy Civil Engineer, Vol. 3, No. 7 (July, 1962), pp. 14-15 and 27.

Hansen, Bob J. "The Use of PERT in Construction Management," The Constructor, Vol. 44, No. 1 (January, 1962), pp. 28-30.

Healy, Thomas L. "Activity Subdivision and PERT Probability Statements," Operations Research, Vol. 9, No. 3 (May-June, 1961), pp. 341-350.

Hickey, Edgar B. "Critical Path Scheduling - A New Construction Tool," The Navy Civil Engineer, Vol. 3, No. 1 (January, 1962), pp. 12-15 and 50.

Hoffmier, Joseph B. "Non-Computer CPM: It's Feasible Even on Some Large Projects," The Constructor, Vol. 44, No. 12 (December, 1962), pp. 28-31.

Hogatt, H.G. "Making CPM Work," Civil Engineering, Vol. 37, No. 3 (March, 1967), pp. 62-64.

Horowitz, Joseph. "CPM and the Mechanical Contractor - Part I," Heating, Piping and Air Conditioning, Vol. 38, No. 1 (January, 1966), pp. 117-121.

_____. "CPM and the Mechanical Contractor - Part II," Heating, Piping and Air Conditioning, Vol. 38, No. 2 (February, 1966), pp. 115-120.

_____. "CPM and the Mechanical Contractor - Part III," Heating, Piping and Air Conditioning, Vol. 38, No. 3 (March, 1966), pp. 121-125.

Howard, Burl W. "CPM as Complete Project Management," Journal of the Construction Division, ASCE, Vol. 91, No. CO1 (May, 1965), pp. 99-106.

Jeanes, R.E. "The Critical Path Method - Application to the Whole Building Process," The Builder (London), Vol. 205, No. 6286 (November 8, 1963), pp. 957-963.

Johnson, Sidney M. "Optimal Two-and Three-Stage Production Schedules with Setup Times Included," Naval Research Logistics Quarterly, Vol. 1, No. 1 (March, 1954), pp. 61-68.

Kavanagh, Thomas C. and Johnson, Sidney M. "Maintenance - The Systems Approach," Civil Engineering, Vol. 36, No. 7 (July, 1966), pp. 31-33.

Keim, Paul R. "More on CPM - Don't Specify Machine Methodology - A letter to the Editor," The Constructor, Vol. 45, No. 5 (May, 1963), p. 16.

Kelley, James E., Jr. "Critical Path Planning and Scheduling: Mathematical Basis," Operations Research, Vol. 9, No. 3 (May-June, 1961), pp. 296-320.

_____. "Parametric Programming and the Primal-Dual Algorith," Operations Research, Vol. 7, No. 3 (May-June, 1959), pp. 327-334.

_____. Wilson, Louis D., and Berman, Herbert. "Using Critical Path Programming," Automation, Vol. 9, No. 11 (November, 1962), pp. 90-95.

Kem, Richard S. "Construction Scheduling with CPM," Military Engineer, Vol. 54, No. 362 (November-December, 1962), pp. 423-426.

Klass, P.J. "PERT/PEP Management Tool Use Grows," Aviation Week, (November 28, 1960), pp. 85 and 88-91.

Kochanski, S.L. "Critical Path Techniques - An Appraisal," The Engineer, (London), Vol. 215, No. 5592 (March 29, 1963), pp. 559-562.

_____. "Critical Paths and True Productivity," Engineering, (London), (July 3, 1964), pp. 2-3.

LaPorta, Rocca A. "CPM Computer Scheduling and Management of High-Rise Construction," Building Construction, (October, 1963), pp. 43-46.

_____. "CPM - Can It Add a New Dimension to An Old Feud?" Building Construction, (December, 1964), pp. 56-60.

_____. "CPM - Status Symbol or Breadwinner?" Building Construction, (April, 1964), pp. 51-57.

Pearlmen, Jerome. "Engineering Program Planning and Control Through the Use Of PERT," Transactions on Engineering Management, IRE, Vol. EM7, No. 4 (December, 1960), pp. 125-134.

Peterson, Russel J. "CPM Helps an A-E Consultant Schedule Engineering Manpower," Engineering News-Record, Vol. 170, No. 26 (June 27, 1963), pp. 22-25.

_____. "Critical Path Scheduling for Construction Jobs," Civil Engineering, Vol. 32, No. 8 (August, 1962), pp. 44-47.

Peurifoy, R.L. "CPM as Project Control Tool - Here's Brushup on Fundamentals," Roads and Streets, Vol. 107, No. 12 (December, 1964) pp. 56-57, 62 and 67.

Pocock, J.W. "PERT On An Analytical Bid for Program Planning - Its Payoff and Problems," Operations Research, Vol. 10, No. 6 (November-December, 1962), pp. 893-903.

Priluck, Herbert M. "CPM Studied - Conceptions and Misconceptions of a New Tool," Building Construction, (December, 1965), pp. 37-46.

Reeves, Eric. "Critical Path Speeds Refinery Revamp." Canadian Chemical Processing, Vol. 44, No. 10 (October, 1960), pp. 74-79.

Royer, King. "CPM - It is Not Planning," Building Construction, (October, 1963), pp. 41-42.

Salveson, Melvin E. "On A Quantitative Method in Production Planning and Scheduling," Econometrica, Vol. 20, No. 4 (October, 1952), pp. 554-590.

_____. "The Assembly Line Balancing Problem," The Journal of Industrial Engineering, Vol. 6, No. 3 (May-June, 1955), pp. 18-25

Sampsell, David F. "A Graphical PERT Analog." Military Engineer, Vol. 55, No. 367 (September-October, 1963), pp. 321-324.

Sando, Francis A. "CPM - What Factors Determine Its Success? - Part I," Architectural Record, Vol. 135, No. 4 (April, 1964), pp. 211-216.

_____. "CPM - What Factors Determine Its Success? - Part II," Architectural Record, Vol. 135, No. 5 (May, 1964), pp. 202-204.

Sayer, J.S. Kelley, James E., Jr., and Walker, Morgan R. "Critical Path Scheduling," Factory, Vol. 118, No. 7 (July, 1960), pp. 74-78.

Schureman, L.R. "Critical Path As A Job Scheduling and Control Aid," Roads and Streets, Vol. 105, No. 6 (June, 1962), pp. 66-68 and 70.

_____. "Developing a Critical Path Network," Western Construction, Vol. 37, No. 7 (July, 1962), pp. 73-74 and 78.

_____. "The Building Construction Industry and the Computer," Building Construction, (July, 1964), pp. 36-39.

Sobczak, Thomas V. "A Look at Network Planning," Transactions on Engineering Management, IRE, Vol. EM9, No. 3 (September, 1962), pp. 113-116.

_____. "A Statistical Analysis of the General Characteristics of a PERT Technician," Transactions on Engineering Management, IRE, Vol. EM10, No. 1 (March, 1963), pp. 25-29.

Stinchcum, W.R. "Scheduling and Controlling Design Work," The Navy Civil Engineer, Vol. 3, No. 12 (December, 1962), pp. 16-19.

Szuprowicz, Bohdan O. "Choosing a Critical Path Scheduling Program," Engineering News-Record, Vcl. 172, No. 23 (June 8, 1964), pp. 78-80.

Tiner, W.D. "The Many Faces of CPM," Building Construction, (February, 1964), pp. 47-50.

White, Glenn L. "An Introduction to Computerized CPM," The Constructor, Vol. 45, No. 4 (April, 1963), pp. 53-55 and 63-64.

_____. "Complete Project Management," The NAHB Journal of Home Building, Vol. 18, No. 2 (February, 1964), pp. 32-35.

_____. "Computerized Project Network Analysis," The Military Engineer, Vol. 55, No. 366 (July-August, 1963), pp. 236-239.

_____. "New Approach to CPM Gives Prompt Solutions to Difficult Problems," The Constructor, Vol. 46, No. 5 (May, 1964), pp. 27-29.

Zahler, Charles W. "Use of Critical Path Techniques," Journal of the Structural Division, ASCE, Vol. 89, No. ST4 (August, 1963), pp. 151-160.

Periodicals

The Architects Journal (London), Vol. 136, No. 24 (December 12, 1962), pp. 1329-1332. "Computers in Building - PERT and CPM."

Architectural and Engineering News, Vol. 7, No. 3 (March, 1965), pp. 40, 42-44, and 47-49. "CPM With and Without Computers."

Aviation Week, December 19, 1960, p. 29, "AMC is Developing Program Control Plan."

The Builder (London), Vol. 205, No. 6286 (November 8, 1963), p. 963. "Critical Path Analysis of the Management of Construction Projects - A Discussion by the Institute of Civil Engineers' Engineering Management Group."

Building Construction, October, 1963, pp. 47-49. "CPM - Think PERT/CPM Says Pachen."

_____. October, 1963, pp. 50-52. "CPM and Logistics Too."

_____. October, 1964, p. 71. "More Uses Found for PERT."

Business Week, No. 1542 (March 21, 1959), pp. 60-66. "Better Plans Come from Study of Anatomy of Engineering Jobs."

_____. No. 1714 (July 7, 1962), pp. 104-106. "Shortcut for Project Planning - PERT/COST Is Hottest New Tool in Space-Age Research and Development."

The Constructor, Vol. 45, No. 3 (March, 1963), pp. 29-31. "Arizona Contractor Applies Computer CPM to All Jobs Large and Small, for Time and Cost Control."

_____. Vol. 45, No. 5 (May, 1963), pp. 25-26. "CPM Ranks High in Haas and Haynie's Arsenal of Management Weapons."

_____. Vol. 44, No. 12 (December, 1962), pp. 26-27 and 30-31. "Survey Shows: Corps of Engineers Has A Deep and Growing Interest in Critical Path Scheduling."

Engineering News-Record, Vol. 166, No. 4 (January 26, 1961), pp. 25-27. "Perini Corporation Pioneers CPM: New Tool for Management."

_____. Vol. 167, No. 10 (September 7, 1961), pp. 68-69. "Missile-Base Builder Wins Profit With Paper."

_____. Vol. 168, No. 26 (June 28, 1962), pp. 19-20. "Builders Bone Up On Critical Path."

_____. Vol. 169, No. 6 (August 9, 1962), pp. 42-44. "CPM Enthusiasts Claim Bonus Benefits."

_____. Vol. 169, No. 11 (September 13, 1962), pp. 58-61. "Unusual Job, Unusually Managed."

_____. Vol. 169, No. 23 (December 6, 1962), pp. 19-21. "CPM Moves Into the Specifications."

_____. Vol. 169, No. 23 (December 6, 1962), p. 92. "Bye-Bye Bar Chart - An Editorial."

_____. Vol. 170, No. 2 (January 10, 1963), pp. 38-40. "CPM Cuts Construction Time on Floor Slabs."

_____. Vol. 170, No. 4 (January 24, 1963), p. 37. "How and Where to Learn to Use CPM."

_____. Vol. 170, No. 11 (March 14, 1963), pp. 19-21, "CPM Stars at the AGC Convention."

_____. Vol. 171, No. 20 (November 14, 1963), p. 105. "Device Expedites CPM Scheduling."

_____. Vol. 174, No. 11 (March 18, 1965), p. 53. "Don't Fight Computers, Join Them."

_____. Vol. 174, No. 13 (April 1, 1965), pp. 38-39. "Construction Company Expands With the Help of A Computer."

_____. Vol. 174, No. 18 (May 6, 1965), pp. 32-33. "Contractors Shift from Arrow Precedence Diagrams for CPM."

_____. Vol. 177, No. 16 (October 13, 1966), pp. 221-222. "CPM Gets Baptism By Fire."

House and Home, Vol. 27, No. 5 (May, 1964), pp. 128-134. "How Computered CPM Saves Money."

NAHB Journal of Homebuilding, Vol. 18, No. 2 (February, 1964), pp. 28-31 "Computerized CPM Puts You In the Drivers' Seat."

_____. Vol. 18, No. 2 (February, 1964), pp. 26-27. "Electric Brains Can Help You Manage, Build and Market Better."

Oil and Gas Journal, Vol. 58, No. 23 (June, 1960), p. 78. "Critical Path Planning Means More Economical Turnarounds."

School Management, Vol. 7, No. 7 (July, 1963), pp. 104-105, 138, 141, 143 and 145. "How CPM Works for A School District."

APPENDIX D

FEDERAL AGENCY INTERVIEWS

Office of the Chief of Engineers, Department of the Army

O. Struve--Operations Division, Directorate of Civil Works

T. Blankinship--Engineering Division, Directorate of Civil Works

H. Richardson--Construction Division, Directorate of Military Construction

Naval Facilities Engineering Command, Department of the Navy

J. Rhodes--Systems Division, Directorate of Programs and Comptroller

Directorate of Civil Engineering, Department of the Air Force

R. Brandon--Plans and Control Division

Bureau of Reclamation, Department of the Interior

C. Palmetier--Construction Division, Office of the Chief Engineer

H. Halliday--Business Management Division, Office of the Chief Engineer

G. Powell--Business Management Division, Office of the Chief Engineer

D. Raitt--Business Management Division, Office of the Chief Engineer

Atomic Energy Commission

W. Palmer

H. Callaway

[1] Interviews were conducted in late summer of 1966, with some supplementary information obtained in early summer of 1968.

National Aeronautics and Space Administration

J. McNicholas--Office of Administration

J. Sollohab--Construction Division

Public Buildings Service, General Services Administration

W. Dominy--Construction Division

Veterans Administration

L. Schweickart