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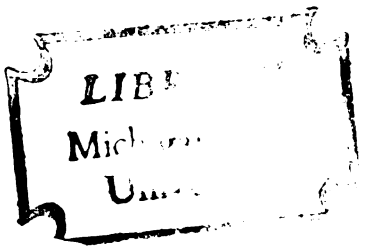

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THE MANAGEMENT OF PROJECTS--AN EXAMINATION OF THE STATE OF THE ART AS REPRESENTED BY CURRENT LITERATURE

presented by

Francis Marion Webster, Jr.

has been accepted towards fulfillment
of the requirements for

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Major professor

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THE MANAGEMENT OF PROJECTS--AN EXAMINATION OF THE STATE OF THE ART AS REPRESENTED BY CURRENT LITERATURE

By

Francis Marion Webster, Jr.

A DISSERTATION

Submitted to
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1978

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ABSTRACT

THE MANAGEMENT OF PROJECTS--AN EXAMINATION OF THE STATE OF THE ART AS REPRESENTED BY CURRENT LITERATURE

By

Francis Marion Webster, Jr.

Experience in teaching, designing, and applying network based systems to the management of a wide variety of projects made evident the inadequacies of the literature. The purpose of this study was to assess the state-of-the-art of project management literature with special emphasis on identifying gaps, conflicts, and deficiencies.

To assure comprehensiveness of the study, a framework for analysis was developed which gave overall direction to the study. It focused attention on the activity, the basic building block of projects, and on the many variables which affect the performance of projects.

A definition of "project" was developed which clearly distinguishes this type of work from other types and yet includes work efforts which have been excluded by previous definitions. Five modes of arranging work efforts were identified--craft, project, job shop, mass production, and continuous flow process. Rationales

were presented for this paradigm based on economics, organization behavior, and schedule/control practices. In addition, twelve loci of responsibility for projects were identified which gave breadth to the concept of projects.

A conceptual model of an activity was developed using the dimensions of time, resource application rate, and technical performance. It was pointed out that micro economics is based on volume production and is therefore not applicable to projects. Some of the relationships which should be incorporated in project economics were presented. An analytical model of an activity was developed which is consistent with the conceptual model, compatible with project practices, incorporates capabilities of the major techniques, and requires reasonable data input.

The characteristics of projects were examined including type, phase, stage of the management process, magnitude, and complexity. The graphic notation used in network representation of projects was reviewed and some advantages shown for the activity-on-node approach. No hard research was found to support these claims. Some additional relationship notations were suggested. Some types of problems were identified which are not easily handled by current capabilities including the drafting room scheduling problem, dispatching problem, and problems such as the acquisition of land parcels in urban renewal. The dynamics of the human resource were explored to show how they add to the uncertainties of projects. The unique relationships associated with the technical

performance dimension were examined, highlighting the need for research into the nature of an activity at a micro level.

The concept of criticality conventionally incorporated in such systems was shown to be myopic at best. Other concepts of criticality were suggested. Other factors affecting project performance were examined at individual participant, organizational, and environmental levels. It was shown that very little is known about the nature of project participants in general and about project managers and their superiors in particular. Training available for project managers was shown to be inadequate at best and methods for their selection no better.

The tools available to assist in managing projects were shown to be far more numerous than is suggested by the literature. The emphasis in the last two decades on network techniques has resulted in the other tools being largely ignored. Major deficiencies were identified in existing techniques and in understandings of how to apply them in the larger managerial sense.

The major product of this effort was the identification of some one hundred research and/or development efforts which could contribute to the closing of gaps, reconciling conflicts, and correcting deficiencies identified in this study.

Projects are an essential and unique approach to productive work efforts. There is a need for more study and understanding of projects and for the development of better tools and guidance for their management.

DEDICATION

To my parents who taught me to reach for the limits of my capabilities;

To my wife who encouraged and helped me to pursue a dream; and

To my children who endured these years.

ACKNOWLEDGMENTS

I wish to express my thanks to the members of my committee; my adviser, Dr. Richard Gonzalez for his encouragement and willingness to allow deviation from tradition; to Dr. Bruce Coleman particularly for his concern for editorial quality; and especially to Dr. John R. Adams, Lt. Colonel, USAF, Air Force Institute of Technology, for his insightful challenging of conceptual and technical material contained herein.

I am grateful for the consideration given me by Dr. Richard T. Nyerges, Chairman of the Department of Management, and later by Dr. John A. Larson, Dean, School of Management, University of Michigan, Flint, which permitted me to complete this research and writing.

A number of people were kind enough to grant interviews which added information and insight to this endeavor and others provided encouragement to persevere.

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LIST OF SYMBOLS, ABBREVIATIONS, OR NOMENCLATURE

a	optimistic duration estimate for an activity as used in PERT
b	pessimistic duration estimate for an activity as used in PERT
m	most likely duration estimate for an activity as used in PERT
t_e	expected duration estimate for an activity as used in PERT
AMETA	Army Management Engineering Training Agency
AOA	Activity-on-Arrow notation for network diagrams
AON	Activity-on-Node notation for network diagrams
BOM	Bill of Materials
CPM	Critical Path Method (Time-Cost Trade-off)
CPPS	Critical Path Planning System (Time-Cost Trade-off)
CPT	Critical Path Technique--the simplest of critical path--network based techniques
DART	Daily Automatic Rescheduling Technique
DOD	Department of Defense
GERT	Graphic Evaluation and Review Technique
LOB	Line of Balance Technique
NASA	National Aeronautics and Space Agency
PERT	Program Evaluation and Review Technique
PERT/COST	PERT with cost
PMI	Project Management Institute
RAMPS	Resource Allocation and Multiple Project Scheduling
RMI	Reliability Maturity Index
SPO	System Program Office
WBS	Work Breakdown Structure

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CHAPTER I

INTRODUCTION

The Problem

Project management has received much attention in the last three decades, partially as the result of the development of network-based techniques to aid in managing projects and partially as the result of the increasing size of projects. Many articles and numerous books have been written on various aspects of managing projects. Nevertheless, it is the thesis of the present study that substantial gaps, significant conflicts, and important deficiencies still exist in the literature, and numerous shortcomings remain in the techniques and systems that have been promoted for managing such work.

Such basics as operational definitions of terms are still deficient for clearly distinguishing project-type work from other forms of human endeavor. As an example, Steiner and Ryan (1968) define a project based on Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) statements as follows:

> A project is concerned with the article below the interface (between a governmental agency and the organization that produces an article); it encompasses the production of an identifiable non-repetitive item, large or small in scope, under conditions of technical uncertainty, and to be completed at a specific time (p. 7).

While this definition is appropriate for the purposes of their book and intended audience, it has important deficiencies as a general definition of a project. By implication, this definition indicates that a project must involve the government as a customer, must concern a single item, and must have a degree of technical uncertainty associated with it. This limited definition would exclude such work efforts as the building of two or more houses for a private individual or firm, while possibly including the job shop environment or the efforts of an individual craftsman or professional.

Cleland and King (1975) provide the following definition of a project:

> Project--A combination of human and non-human resources pulled together in a temporary organization to achieve a specific purpose (p. 184).

This broad definition fails to uniquely distinguish project endeavors from other forms of work arrangement except on the permanence dimension. Definitions of projects have not yet been developed which uniquely identify a set of tasks as a project, and at the same time preclude that set of tasks from being identified as job shop or any other class of work efforts. It is necessary to have precise working definitions if there is to be a cohesive theory concerning projects and their management as distinguished from theories concerning other types of work efforts and their management.

Furthermore, the literature on project management suggests that only two techniques exist for managing project work--Gantt

charts and networking techniques. George (1968), makes references to work-types throughout history. Much of the work involving large numbers of people working together was project oriented. For example, "Solomon . . . managed construction projects and the Egyptians constructed pyramids . . . (over twenty year) periods" (p. 4). Thus, project work substantially preceded the development of both the Gantt chart and modern networking techniques. It is also evident that much project work continues to be successfully managed with the aid of much less sophisticated tools. A thorough analysis of projects should discuss other techniques applicable to their management.

The importance of project oriented work in our society is made more clear when all management work is viewed as a continuum of work efforts. One end of the continuum is represented by steady-state work efforts. The epitome of this is the oil refinery or the automobile assembly plant. Successful, efficient, day-to-day operation is dependent upon constant work assignments and flows of materials. Perturbations to such a system, such as an interruption in the flow of materials, a breakdown of equipment, or a labor strike, principally place demands on the skill of management to return the system to steady state operations. Generally, the operation of steady-state efforts, once routinized, is relegated to lower level managerial personnel.

On the other end of the continuum is the management of change. Much of this work can be viewed as project type work. It

is typical of military systems development, major construction efforts, and much of middle and upper management's work. Typical endeavors include new product development, new facilities planning, modification of existing facilities, annual budget development, and new marketing program development. These endeavors place high demands on the skill of management to conceptualize future products of the efforts, to visualize the actions necessary to create that product, and to mobilize the resources which can, often with limited guidance, take those actions in a timely manner.

When viewed in this broader context of managing change, the importance of projects in our society takes on a new meaning. They are not limited to stereotyped projects such as the Polaris Missile Weapons System development or manned lunar missions. Nor do they involve only those work efforts to which network based techniques can be applied, or to which the matrix organizational concept, popular in project management literature, can be employed. Nevertheless, reading the current literature leaves the impression that these special efforts constitute essentially the total realm of "project management."

Projects, as considered in this study, vary from relatively small work efforts involving two or more persons to multi-billion dollar work efforts involving thousands of persons. They include building a house as well as constructing a major stadium or launching a lunar mission. The definition developed in Chapter II encompasses this broader concept of projects.

In his article analyzing the pros and cons of Project Evaluation and Review Technique (PERT), Pocock (1962) made some predictions of trends of the future for PERT in particular and the managing of projects in general. Among them was the prediction of the development of a "central theory or theme" (p. 902). Fifteen years later two articles appeared questioning the promises of Pocock. Dunne, Ewart, and Nanney (1977) asked, What Happened to PERT? Ryan (1977) used PERT and capital budgeting to support his thesis that, Management Practice and Research [are] Poles Apart. Clearly, the prediction by Pocock is yet to be realized. Much work is required to gain a better understanding of PERT, of other network-based techniques, of other tools applicable to the management of projects, and, indeed, of the nature of projects and project-type work efforts.

The Study

Status of Research and Literature

An extensive review of the literature on the management of projects reveals only a few classes of books and articles. There are many "how-to-do-it" books and articles on managing projects in the construction industry, in the aerospace industry, on data processing and systems management efforts, and in a few other such specific areas. There are several books and many articles on the mathematics, data processing, and technical issues associated with the design of network based systems for managing projects. The

most popular books in this latter class tend to promote the "systems concept" or explicate the mathematics of the techniques. The book by Cleland and King (1975) is an example of the former and the one by Wiest and Levy (1977) is an example of the latter. There are articles and books on such associated aspects of managing projects as evaluation and selection of projects, specifications and proposal writing, bidding procedures, configuration management, management of engineering and scientific personnel, matrix management, and cost control techniques. Nowhere, however, was substantive work found which concentrated on integrating the concepts of project management across industry or function or on identifying the management principles and theories specifically applicable to this type of work effort.

Purpose of Study

Viewing the literature from a more distant perspective, there appear to be a number of deficiencies in the current theories specifically applicable to the management of projects. The literature is fragmented in terms of subjects and sources. There is a lack of a comprehensive framework for considering projects as a significant form of work effort. There is no comprehensive model of an activity or concept of the project within which it exists. Rather, most articles on techniques begin with a statement of a few assumptions essential to that technique with no support for the realism of the assumptions, and most literature on managing

projects focuses on only a single type of project without specifying its particular characteristics.

Pocock (1962) predicted a bright future for the development of techniques and for a general theory of managing projects. If this prediction is to become fact, it is essential that these deficiencies be identified and eliminated and a more comprehensive theory of managing projects be evolved as a basis for further developments.

The overall objective of this study was to assess the state-of-the-art of managing projects. Specific emphasis was placed on identifying gaps, conflicts, and deficiencies in the current literature and reported research on managing projects. It was expected that the final results would include more questions than answers. Indeed, the important result of this study was the identification of research tasks that should be undertaken to provide the basis for a comprehensive theory of managing projects. Essential to the achievement of this overall objective were several intermediate objectives including the development of (1) a framework for analysis suitable for a general review and critical analysis of the literature, (2) the definition of "project," and (3) the development of a comprehensive understanding of "projects" and the basic entity of which they are composed, the activity.

Approach and Methodology

The approach and methodology used in this study was a combination of deductive and inductive reasoning based on both the

literature and practical experience. In a sense, the approach can be viewed as a series of mini-studies, each designed to establish the basis for a succeeding one. In several instances, concepts, approaches, or techniques were suggested which seem to have merit for correcting some of the deficiencies identified. In each case they are considered tentative until appropriate indepth research is conducted to confirm, reject, or improve upon them. Similarly, a number of "needs" were identified in terms of techniques, features of techniques or systems, or system concepts which experience has suggested may be of value. Again, confirmation of the existence of these needs, and the justification for their development, is recommended.

The target literature considered was that which pertains to the management of projects. Specifically excluded, without implying lack of importance or relevance to the success of projects, is that literature concerning the economic evaluation, selection, and justification of projects. This material is generally discussed under research and development project selection, engineering project justification, or investment analysis. Also excluded was literature dealing primarily with the specific technology underlying the various project efforts. Examples of this literature range from research techniques for the R & D laboratory to construction and industrial engineering technology. Rather, the concern of this study was with the problems of managing the use of such techniques and technology in the conduct of the work of a project; managing the people who employ the techniques and technology; and the planning, executing, and controlling of the work involved in the project.

In addition, no attempt was made to repeat evaluations which have already been made. For example, certain authors have been recognized as having adequately critiqued specific areas such as the underlying assumptions of PERT. Where such work has been done, it is reported in summary. However, where such critiques have overlooked key aspects or otherwise appear deficient, such deficiencies are noted. Where appropriate to support the analysis and development of concepts, models, or other ideas, literature from outside that on managing projects was incorporated.

A Framework for Analysis

A study of the state-of-the-art in any field requires a frame of reference with certain qualities. Three qualities were considered necessary for this study. The framework must be comprehensive in that it must encompass at least the essential material contained in existing literature and extend across industries and functions. It must be analytical in nature so that it will reveal gaps in the knowledge of projects and their management not adequately dealt with in existing references. Finally, it must be systematic so that individual concepts fit into a larger scheme that permits syntheses of ideas.

Existing Frameworks

A number of books were received to determine how various authors structured their discussions of projects and the tools for managing projects. Only a few basic structures were found. The

most frequent was the "how-to-do-it" structure which essentially proceeds from the definition of the project to planning, estimating, calculating, scheduling (both time-cost trade-off and resource analysis), controlling time and cost, and taking corrective action. This could also be called the "system documentation approach." A second approach emphasizes the mathematics of the network based techniques. These range from requiring no mathematical background to requiring at least a knowledge of calculus. A third was the reporting of observed practices of project managers and project organizations. They are oriented to single industries and are experiential rather than experimentally based. The fourth approach was essentially promoting an organizational concept, whether it be the systems concept, task forces, or matrix management.

Each approach is limited in one or more ways. The mathematical approach could be considered comprehensive in its applicability to a variety of industries and functions, and analytical in that it is based on the relevant theory underlying the techniques. It is lacking in comprehensiveness as to the role of people, to management systems, to societal issues, and even to detailed consideration of the activities and projects with which it is concerned. The report of current practices on projects is limited to a rather narrow industry scope as are the "how-to-do-it" books specializing in the aerospace, construction, and computer systems development industries as well as other industries and functions. The organizational approach emphasizes behavioral issues independent of the management information system and decision and control techniques employed.

In none of these is there really an attempt to analytically understand projects, their management, and the factors affecting them in a comprehensive manner. Accordingly therefore, a need exists to integrate the material contained in these and similar references in a comprehensive manner which will tend to identify the gaps in knowledge as well as clarify what is understood.

Proposed Framework

The following framework, illustrated in Figure I-1, A Framework for Analysis, was the basis for the comprehensive review of the literature and critical analysis of its content. In the following sections this framework is discussed briefly starting at the micro and progressing to a macro level. In the Framework for Analysis, the project is shown as a set of interrelated activities portrayed in typical network fashion using activity-on-the-node notation. This notation identifies the activity as the basic building block of a project. The arrows simply show the relationship between the activities.

Definitions

Definitions are required of the basic entities which are the subject of this study. The definitions must be applicable across industries, functions, and techniques. They must include the essential concepts and conditions of existing definitions. They must be consistent with a comprehensive taxonomy of work efforts and the differences in production scheduling and control concepts

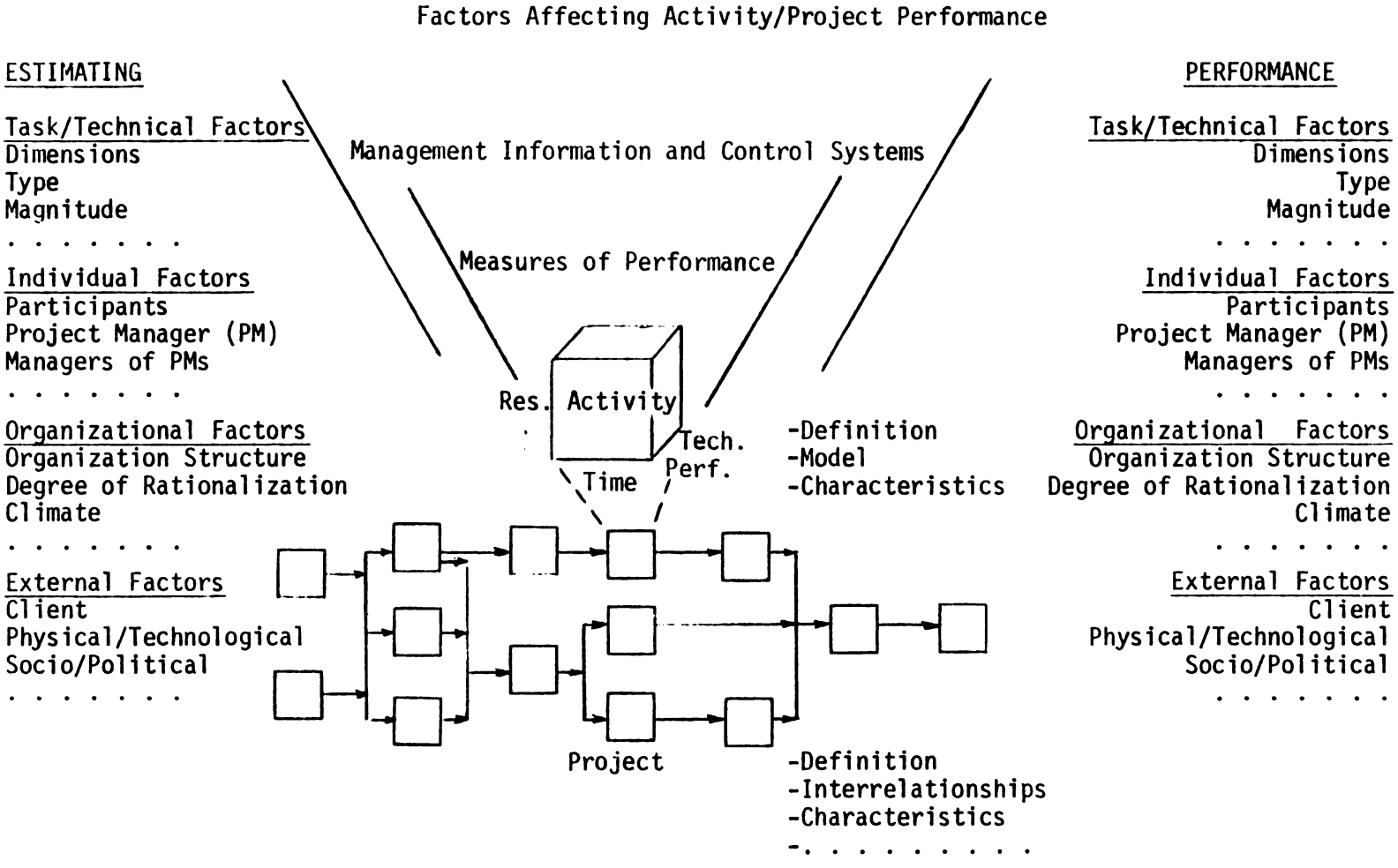


Figure I-1.--A Framework for Analysis.

applied to these type of work efforts. It must also be consistent with the variety of ways of organizing for the accomplishment of projects. The resulting definitions are:

> Project--A unique, technologically determined sequence of purposeful, usually non-repetitive activities; involving the coordination of multiple, heterogeneous human and non-human resources representing a significant proportion of the performing organization's capacity; operating on an inter-related set of items; accomplishment of which will result in the achievement of a specified set of objectives for one or a few units of output and termination of that work effort; with primary managerial emphasis placed on timely accomplishment of the work effort as a whole (as compared to the managerial emphasis on other modes of work).
>
> Activity--a finite operation (physical or mental) performed on an item (concrete or abstract) to achieve certain specified technical objectives requiring the lapse of time and, generally, the use of resources.

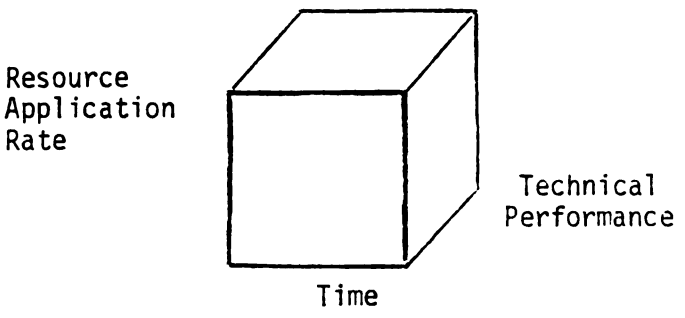
The derivation and justification of these definitions are the subject of Chapter II, Definition of "Project."

Activity Considerations

The essential entity of which all projects are composed is the activity. The activity is shown isolated from the project and having certain dimensions. This implies that these dimensions are measurable, can be stated before the fact as specifications of the

results expected from the performance of the activity, and that the efforts required to achieve these results can be estimated. The listing of the characteristics of activities on the left under "Estimating" and on the right under "Performance" implies that there may be a difference between these two sets of measurements. This implies some variability and uncertainty associated with the activity in estimating or performing, or both.

Given this conceptualization of an activity, it is important to explore the specific characteristics of an activity which account for its variability and uncertainty. This exploration includes an understanding of the economics of the activity. While the developers of PERT recognized time, resources, and technical performance, the more common conceptualization is time, cost, and resources. The conceptual model used in this analysis relies on the time, resource application rate, and technical performance dimensions. Thus an activity is seen as a polyhedron, the volume of which is representative of the cost of performing that activity.



Clearly, this relationship requires that resource application rate be stated in terms of cost per unit of time. The resource application rate varies with the technical performance required. Considering cost as a function of only one of these dimensions at a time, it is assumed that the function is convex (has a single minimum) for both time and resources and exponential (constantly increasing) for technical performance.

There are other aspects of an activity which must be considered. For example, there are different types of activities within a project and across projects. Their characteristics vary, including such things as the degree of uncertainty and their susceptibility to being "managed." The level of detail in planning has implications for estimating the work content and communicating the technical performance requirements and technology assumed, on the amount and location of coordinating responsibilities, and on the number of activities, to name only a few. The level of detail also affects the potential degree of repetitiveness of activities in and between projects. Certainly, if examined at a sufficiently minute level, the variety of human work elements approaches a finite list, albeit possibly a lengthy one. The criticality of an activity within the project would seem to have an impact on its performance, the "management attention" it gets, and the allocation of resources to it.

In Chapter III, The Activity, these considerations are examined and the conceptual model of an activity is analyzed in

detail. The current feasibility of incorporating various aspects of this conceptual model into a comprehensive technique and management system were assessed. Those aspects which were judged to exceed reasonable current practicability were dropped in order to develop a comprehensive analytical model of an activity which could have immediate utility.

Project Considerations

More generally an activity exists in the larger context of a set of interrelated activities which, if they are consistent with the proposed definition, constitutes a project. The dependency relationships that exist between the activities in the set may affect the estimating, scheduling, and performance of the activity. Such dependencies are generally thought of in terms of technological precedence. Dependencies may also exist on the other dimensions, i.e., resources and technical performance. All these relationships need to be understood in depth to gain a thorough understanding of the activity and of the project.

There are other characteristics of projects such as type, phases, magnitude, complexity, relationship to current state-of-the-art of technology and progress on the project. There are important characteristics associated with the project which may have effects on its estimation and performance. Some of these are internal to the project organization and include the nature and behavior of the individual participants and the nature and behavioral tendencies of

the organization performing the project. Other characteristics are external to the project but definitely have an impact on its performance. These considerations are discussed in Chapter IV, Projects.

Management Tools and Systems

A major factor affecting the planning and performance of a project is the type of management tools and systems that are used. If there are different types, phases, magnitudes, etc., of projects, there may be different management tools and systems applicable to managing different projects. Much of the literature on projects to date has dealt with a limited set of the tools available. The range of tools recognized to be applicable to managing projects must be expanded and examined in considerable detail.

Chapter V, Tools for Managing Projects, examines these considerations. Existing evaluations of some of the techniques and their features are examined to assess their accuracy and usefulness, and to determine the adequacy of the framework for such evaluations. Some improvements are suggested and some needs are identified which are apparently not being met currently. The reports of costs and savings associated with the use of the tools are evaluated. Finally, the prospects for integrating the best features from the range of tools available are considered.

Finally, in Chapter VI, Summary and Recommendations, the major gaps, conflicts, and deficiencies of knowledge necessary for the development of a comprehensive theory of projects and effective tools are summarized along with recommendations for research aimed at

correcting these conditions. Alternative strategies for resolving these deficiencies are considered and an approach is recommended which would provide early returns on the most significant problems and yet provide a logical pattern for relating relevant research. A specific network plan is provided for guidance of much of the recommended research and development.

Testing the Framework

In the introduction to this section certain criteria were established for this framework to meet. The following examines the framework vis-a-vis each criterion to demonstrate that they have been met.

Comprehensiveness

While the current study certainly cannot go into the detail incorporated in the books cited in the review, it is reasonable to consider the material and, especially, the gaps and deficiencies that exist in this and other literature. The books on techniques by Wiest and Levy (1977) and Elmaghrably (1977) are incorporated under the heading of Management Information and Control Systems. The documentation of field studies by Steiner and Ryan (1968) and Sayles and Chandler (1971) are incorporated throughout the framework. The contents of these books have been reviewed against the framework and a logical "home" found for each concept.

The Cleland and King (1975) and Archibald (1976) books have several thrusts, each of which is incorporated. The first of these

emphasizes "systems analysis." In part this is incorporated in Management Information and Control Systems as it relates directly to their design and the techniques that should be employed in specific circumstances. It also deals with organization design emphasizing the matrix concept. Cleland and King deal explicitly, although rather generally, with techniques, procedures, and system design concepts especially applicable to projects. Finally, they emphasize the aerospace industry and the high-technology projects typical of that industry. Archibald goes into more detail on procedures and systems design and formal organizational considerations specifically for high-technology aerospace projects. All of these subjects are adequately incorporated in the proposed framework.

The contents of the three books on the construction industry and the one on computer system development have been reviewed against the proposed framework and a "home" found for each concept except for certain subjects such as economic justification and technology of construction which are beyond the scope of the current study.

Finally, the contents of the book by Bass (1975) on task forces has been checked against the framework and all concepts are incorporated except for the discussion on economic development which is more directly relevant to project evaluation and selection than to planning and execution and was not within the scope of this study.

Analytical

The framework is progressive in a general systems sense. The framework first considers the activity as a unique entity and then in the context of a project, in different phases of a project, and in different types of projects. Then the scope is expanded to incorporate the individual participants in the project. Basically, at this level the framework is independent of the organization within which the individual exists. Next, the organization and its characteristics are considered, expanding to include the "federation" concept of Sayles and Chandler (1971). Finally, the view is expanded to include external considerations within which the project must operate including the socio/political environment. Management information and control systems, a major topic in much of this literature, is incorporated as a separate subject. This seems to meet the analytical criterion in that it tends to draw attention to gaps in knowledge of projects and their management.

Systematic

Finally, the systematic nature of the framework provides the basis for the synthesis of ideas, concepts, knowledge, techniques, and practices into a comprehensive and comprehendable whole.

Based on the above "testing" it was concluded that the framework was sufficiently comprehensive, analytical, and systematic for the purposes of this study.

CHAPTER II

DEFINITION OF "PROJECT"

Introduction

A review of literature in several areas of management revealed that although there is frequent mention of projects, there is a tendency either to assume that the reader understands what is meant by "project" or the discussion implies a rather narrow view of the concept. For example, some books deal primarily with DOD/NASA procurement and therefore approach the subject from that point of view. Others give examples such as construction, ship building, research and development, and the like.

Bartels (1970) gives as his first and second axioms of a metatheory that "a theory proceeds from a concept of its subject and should be consistent with it," and "theory is built upon basic concepts derived from the concept of the subject and from related scientific disciplines" (pp. 6-7). Therefore, if a theory of projects and their management is ever to be developed an adequate definition of the subject must be the basis for that theory.

An adequate definition must meet certain necessary and sufficient conditions. It is necessary that it be detailed and explicit enough to uniquely identify a work effort as a project as opposed to any other mode of arranging work. On the other hand,

it should not be so constraining as to exclude work efforts that are legitimately considered projects. It should be operationally precise so that it might, for example, be the basis for programming a computer simulation. It should be conceptually consistent with applicable general theory such as economics, and encompass the theory of techniques that are useful in dealing with the subject. Finally, it should be consistent with and useful in dealing with reality.

To develop such a definition of project, it was necessary to examine the literature to determine exactly what is implied by the word "project" and how this concept fits into the general field of managing different types of work efforts. To accomplish this the taxonomy of work efforts was examined particularly as presented in production/operations management texts. The management of projects was considered as one part of a continuum of management technologies applicable to managing work efforts. The scheduling and control concepts applicable to each of these management technologies were compared. Finally, alternative approaches to managing project type work efforts were explored. While examination of other taxonomies may have been relevant to the development of a definition of the word "project," they were not suggested by either the framework or the analysis reported in this chapter to be necessary to meet the criteria for an adequate definition as discussed above.

From these taxonomies, definitions of "project" and "activity" were developed to uniquely categorize any work effort into the project class or some other class. This definition of "project" was then

"tested" by comparing it with definitions by other authors; by considering its ability to differentiate between modes for managing work efforts; by analyzing its applicability in practice; and by considering if it is sufficiently explicit to facilitate computer simulation.

Analysis of Taxonomies

Work Efforts

An examination of texts on production and operations management disclosed limited and inconsistent taxonomies of work efforts. Emphasis was on job shops with some discussion of assembly line balancing and project scheduling. Little if any mention was found of either craft or continuous flow process modes. Often, the project mode was characterized as being relatively insignificant.

Two frameworks from organization behavior research provide insight into the relationship between the work and the manner in which it is performed. Woodward (1965) identified nine classes of work on a technology continuum as follows:

Unit and Small Batch	1. Units to customer requirements 2. Prototypes 3. Large equipment or stages 4. Small batches to customer order
Large Batch and Mass	5. Large batches 6. Large batches on assembly lines 7. Mass production
Process	8. Intermittent production of chemicals in multi-purpose plants 9. Continuous flow production of liquids, gases, and crystalline substances

The other framework is that of Perrow (1970) which uses the dimensions of "exceptions" versus "search analyzable" to form a matrix on which various types of work are characterized. Perrow defines these two dimensions as follows:

> Exceptions--"the variability of the stimuli presented to an individual--the variety of problems which may lead to search behavior."

In a footnote, he adds . . .

> Note that, in industrial firms, this is not necessarily a distinction between a great or small variety of products. Automobile firms produce an amazing variety of models and a staggering variety of parts, but there are not novel situations requiring search behavior (except in the design and engineering of model changes).
>
> Search Analyzable--the degree to which stimuli are converted into responses based on "experience, judgement, knack, wisdom, intuition" versus reliance on "manuals, computers, or clerks who have the requisite information and programs."

Also in a footnote, . . .

> Note also that the difference between analyzable or routine search and unanalyzable search procedures is not necessarily the same as the distinction between technologically advanced and technologically backward industries (p. 77).

Using these two dimensions, Perrow describes the resulting quadrants as craft, nonroutine, engineering, and routine (p. 78).

Search (responses based on)	Exceptions (Stimuli): Few	Exceptions (Stimuli): Many
Unanalyzable	Craft	Nonroutine
Analyzable	Routine	Engineering

Figure II-1.--Perrow Framework

Perrow's "search" dimension is analogous to Simon's (1960) dimension of "types of decision." Simon distinguishes the types of decisions as:

> Programmed:
> Routine, repetitive decisions
> Organization develops specific processes for handling them
> Nonprogrammed:
> One-shot, ill-structured, novel, policy decisions
> Handled by general problem solving process (p. 8).

Perrow further elaborates on his paradigm by placing more suggestive examples of types of work efforts on this same matrix (p. 83).

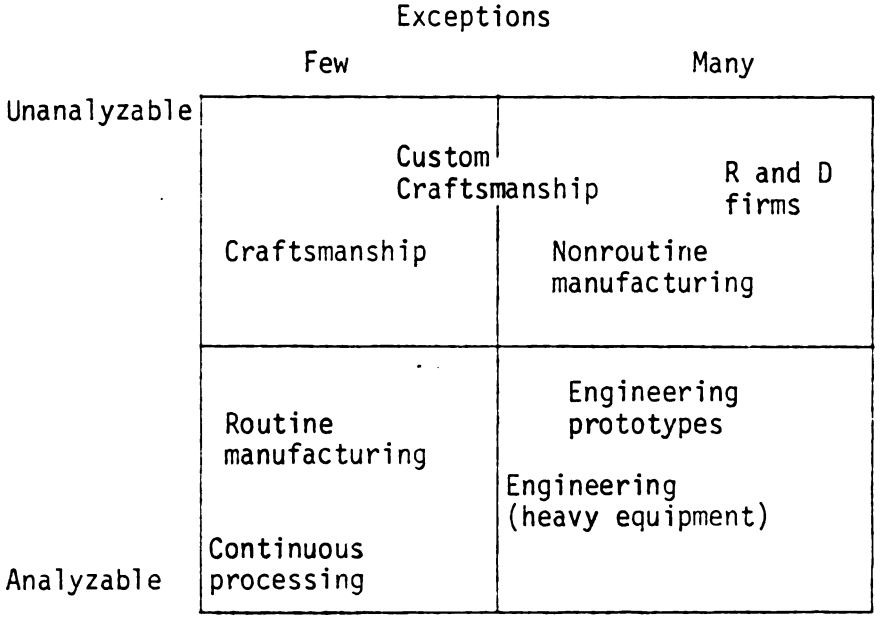


Figure II-2.--Perrow Framework Expanded.

The Perrow paradigm was carried a step further by using the Woodward continuum to suggest the similarities between the two and

to suggest some additional categories which might make the Woodward analysis more complete (see Figure II-3). The areas encompassed by the various categories overlap, again stressing the existence of alternatives in organizing the productive efforts.

As noted by Perrow, research and development exists in the upper right quadrant. A finer breakdown is suggested showing basic and applied research and then development. In addition, craft is included as was done by Perrow and art added in the upper left quadrant. In adding art in this fashion, it was necessary to distinguish between technical stimuli versus artistic stimuli perceived by the artist. Although the artist experiments with materials, such experimentation seems less a scientific search for knowledge than a pragmatic search for effect. Finally, "small batches to customer order" has been shown somewhat closer to the center of the diagram than Perrow showed "non-routine manufacturing," and "prototype" is shown extending over a larger area. The justification for this is that all of this area is characterized by essentially one-of-a-kind production. If the prototype is a clay model of a proposed new car, its production involves a large degree of the artist's skills. If the description of the item to be produced is coming from R and D, it may be produced essentially by the "craft" approach. If it comes from engineering areas where designing is less than an exact science, such as die design, there may be a considerable element of the craftsman's skill involved.

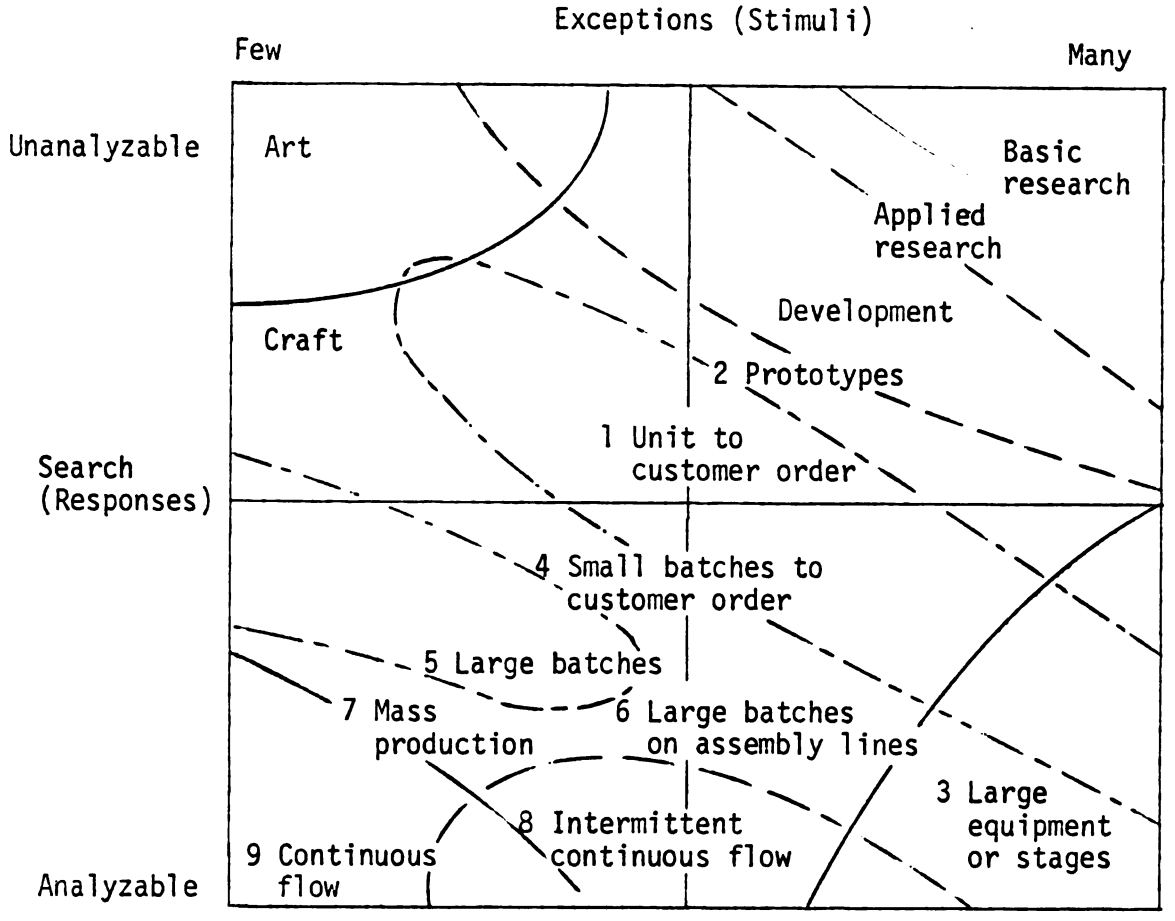


Figure II-3.--Perrow and Woodward Models Combined.

Note: Numbered items are those originally specified by Woodward.

In an effort to understand the implications of such an analysis, several other dimensions were considered. For example, volume is a major factor in determining the most economic technology to use for a specific work effort. It became clear, however, that volume as measured in units is closely related to the diagonal going from the

upper right corner to the lower left corner with volume generally increasing in that direction. Thus, it was incorporated in the Perrow model implicitly. Likewise, the maturity of the technology of an industry is also roughly on the same diagonal. Several other dimensions were examined but in nearly every case, the variable considered could be mapped into either the "exceptions," "search," "volume," or "maturity of technology" variables.

One variable does seem to offer some understanding beyond these four dimensions--magnitude of the effort. Magnitude is clearly different from volume. For example, model plastic cars are produced at approximately the same or larger volume as full size cars, yet the magnitudes of the efforts are quite different. Also, the construction of a major dam produces only one unit, but the magnitude is substantially greater than building a dam for a farm pond. Just how to measure magnitude, i.e., dollars, number of people involved, project duration, etc., is unclear at this time and what it implies can be only partially understood. For example, the demands placed on management information systems by an effort of large magnitude are certainly different than for an effort of small magnitude. Also, there is some evidence that the behavior of workers as well as their attitudes are a function of the magnitude of the project. These phenomena are relatively clear in the differences between the "mom and pop" procery store and the supermarket chain, or between the automobile customizing shop and the automobile manufacturer. Magnitude of effort does seem to offer some insights and may be a promising variable for further research.

The implication for the current study is that the modified Perrow matrix offers some insight into the applicability of the project concept as a way of arranging work efforts. This is suggested in Figure II-4. Again, the variables "volume" and magnitude" become evident as factors in arranging the efforts.

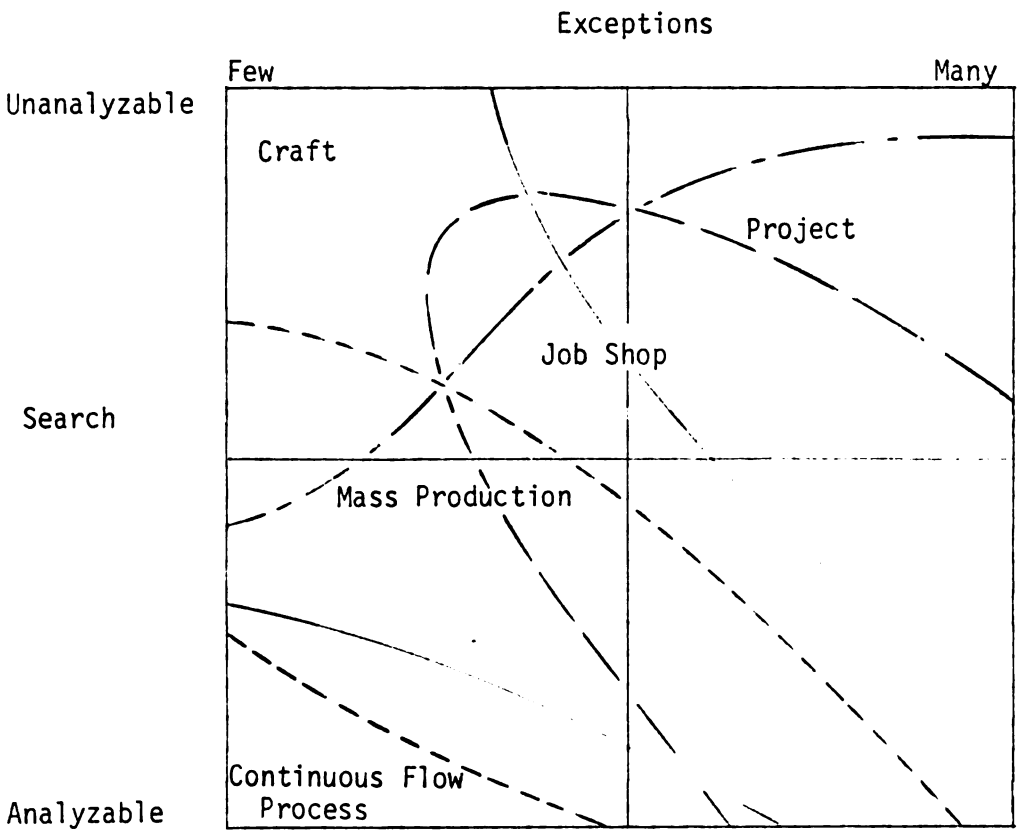


Figure II-4.--Modes of Work Arrangement.

From this brief analysis of the work by Woodward and Perrow it can be seen that there is definitely a class of work which can either be called "project type work" or, alternatively, can be said to be amenable to management by "project methodology." The analysis fails to show what is popularly considered a major segment of a modern society's productive efforts, namely maintenance and service. Alternatively, these classifications may be adequately handled by the five classes of work efforts included in Figure II-4. For example, medical care services are provided in all five work modes. The individualized treatment that one receives from the family doctor is essentially in the craft mode. It is characterized by a one to one relationship and, although some of the tasks are delegated to nurses and office workers, none of the tasks they perform require skills that the doctor does not have. Rather, these skills are somewhat less demanding and can be performed by one with less training than is required of the doctor.

If a patient has a problem which the doctor cannot solve in the normal office call relationship, the relationship is often moved to what is comparable to the project mode. The patient is sent to an X-ray laboratory, another laboratory for chemistry or tissue analysis, perhaps a specialist, and sometimes to others. In this case, skills not available to the doctor are brought into play and some of these steps may be performed in aprallel.

Many organizations today offer, as a benefit to their management personnel, an annual physical examination. Generally, these are conducted in a clinic type of facility which operates in the job shop

mode. The patient moves from one department to the next, often being in a queue for some time at each of then.

Anyone who has taken a physical for military service will recall having gone through an assembly line type of processing. Persons confined to a cardiac care ward are monitored in a manner similar to monitoring a continuous flow process.

Other examples of maintenance and service efforts could be cited such as the repair of railroad box cars in the job shop and assembly line modes, repair of appliances in the craft and job shop modes, etc. The discussion seems adequate to make the point that the five modes of arranging work efforts offer insights into maintenance and service that may add clarity to their understanding as opposed to treating them as separate and apart from manufacturing and other forms of productive efforts.

Management Technologies

The concept of "management technologies" may be a somewhat unusual notion. It is not totally unfamiliar as Woodward classified the nine types of work she identified on a technology continuum. A common concept in capital expenditure evaluation is the fixed versus variable cost curve relationships of various technologies as a function of volume. Buffa (1975) discusses this under "Estimating and Process Selection" (pp. 225-8) using a lathe operation as an example. The typical graph of this relationship is shown in Figure II-5.

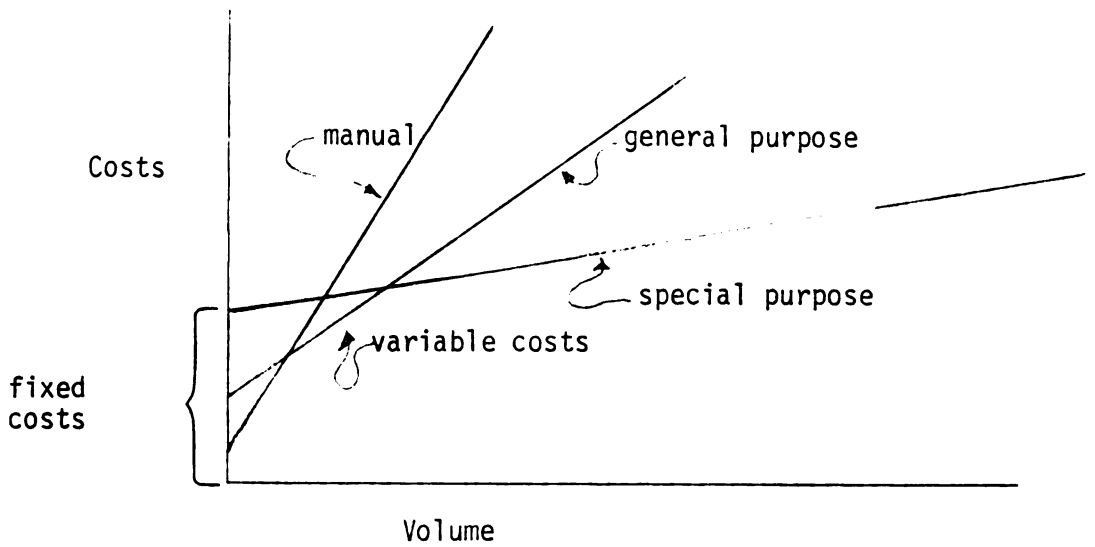


Figure II-5.--Fixed Versus Variable Costs for Alternate Processes.

As volume increases, pressure could be expected to develop for an organization to move to the "higher order technology," which by implication means more automation and more capital intensive technology. This tendency is recognized by Moore and Jablonski (1969) for the manufacturing technology when they state that:

> If any of the products reach large volume, the company will probably change to continuous production for them even though the rest of the factory stays on intermittent production (p. 20).

Furthermore, under their discussion of continuous production they state that:

> Automation was largely a continuation of the long time trend toward more mechanization whenever mass production was possible (p. 23).

The graph as presented in Figure II-5 can be converted to the form shown in Figure II-6 to help understand the relationship

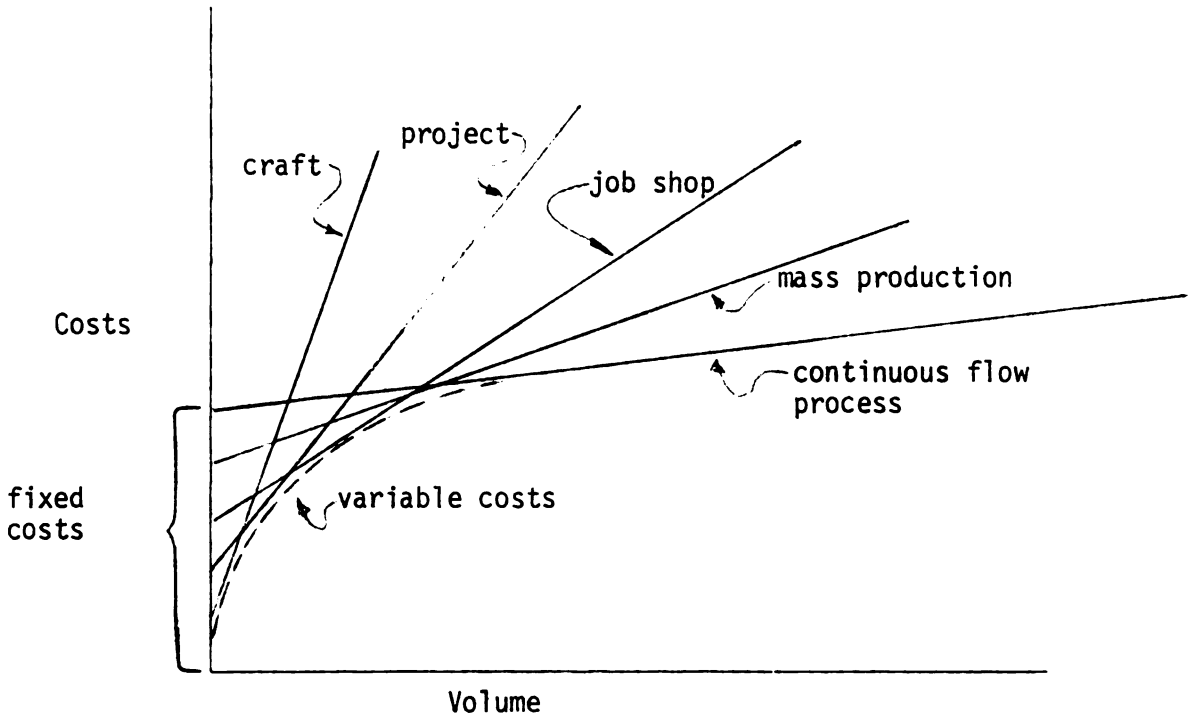


Figure II-6.--Fixed Versus Variable Costs for Alternative Modes for Arranging Work Efforts.

between various approaches to arranging work efforts. The craft mode is comparable to manual methods, project and job shop modes are different levels of general purpose methods, and mass production line and process flow modes are different levels of special purpose methods. It is clear that the fixed costs of the craft mode are very low while the variable costs are quite high. At the other extreme, the flow process mode has very high fixed costs and much lower variable costs.

While volume is shown as the variable on the abscissa, the relevant variable is some combination of volume and magnitude of the effort, as discussed previously. Craft and project efforts are usually

associated with one or only a few units of output. The larger the magnitude of the effort (without comparable extension of the time allowed) the more likely, if not necessary, it is that the work will be done in the project mode. By implication, this means more people involved, which in turn means there will be communications required. The larger the number of people, the more important that these communications be documented. Also, the larger the magnitude of the job the greater the cost of errors, both in the project phase and in later operations phases.

What factors contribute to the shape of these management technology cost curves? First, considering the craft approach, little or no supervision is provided, design and specifications may be a meager sketch with general comments as to the performance requirements, no routing instructions are required, and generally no organizational policies or procedures are written. All of these factors which are not present at this level would be fixed costs for the organization which must have them. The skilled craftsman is expected to have knowledge of accepted trade procedures, practices, and standards and therefore commands a higher rate of pay per unit of output produced.

A project, using more and varied resources, requires more supervision to provide the coordination and communication that becomes necessary. It is not unusual for project work, as opposed to craft work, to be planned and detailed by persons other than the performer of the work. A building is generally designed by an architect with the help of various engineers, and is built by

carpenters, masons, riggers, and others. The craftsman, on the other hand, may conceptualize the house and construct it without any detailed plans or specifications. This is possible for he does not have to communicate his concept of the end product to anyone else. As the number of people involved in the work increases, it is necessary to coordinate and control their activities. It is unlikely that a nuclear power generating station could be built without formal plans and communication. This requires management systems and procedures as well as the supervisors to use them.

A job shop is generally considered to be a somewhat more permanent facility. The variety and number of units processed is also generally greater. Being arranged by function, it is necessary to determine the sequence in which the various operations are to be performed and provide instructions to the operator, i.e., routings and processing instructions. This introduces at least one more person into the management process, the one who prepares the routings and processing instructions. Generally, another person is involved in scheduling and controlling production for the entire organization. Thus, more and more discretion is taken from the operator who must perform the work. Also, additional staff functions are frequently introduced. Functions such as personnel and quality control also exist in the larger project type organizations, and so are probably more associated with the total number of people in the organization. The proliferation of persons with portions of the total responsibility creates an even greater need for written policies, procedures, and instructions--capital investments which are essentially fixed costs

chargeable against future production. Furthermore, these staff functions do not vary in size directly with the amount of work being performed by the organization. Thus, the zero-volume fixed cost level is increased. As the volume for a given item or family of items increases, the assembly line becomes advantageous. The skills required by individual operators generally decrease and often the first line supervisor is concerned primarily with training, discipline, and local material expediting. Additional levels of supervision are often required as well as increased functionalization of management tasks. So, in addition to the even higher capital costs, the zero-volume operating costs are higher.

Typically, the technology of the work is incorporated into the facilities of the flow process shop to a higher degree than any of the rest. Often the operator is really a monitor of the operation, assuring that it is within specified control limits but, more importantly, with the skills to bring it back into control when it varies or to react quickly in case of an emergency. Thus, the training and experience requirements are greater and backup in the form of supervisors well trained on this facility is a necessity. Often the facilities are designed in such a way as to require the same compliment of operating personnel regardless of volume. Thus, fixed operating costs are the highest of the five modes. Even though the rate of pay for the operators and supervisors may be somewhat higher than for the mass production shop, the smaller numbers of them and the increased volume result in a lower variable cost per unit.

In the same manner as for the fixed versus variable costs analysis for alternative processes, the promise of lower unit costs creates a pressure on the organization to increase volume and move to the more specialized technologies. This gives a rationale for both Burns and Stalker's (1961) organic versus mechanistic continuum and to Perrow's claim that there is a tendency to move towards mechanistic organizational approaches, on this continuum and thus to bureacratization.

Another pressure towards routinization stems from the need for predictability. In the small organization, representatives to the external environment know from personal experience the capabilities of their organization and can make performance and delivery commitments based on this personal knowledge. The larger the organization, the less reliance can be placed on personal knowledge and the more routine and written policies and procedures must be relied upon. Thus, routinization and bureaucratization may be an operational necessity in addition to economically desirable as volume and/or magnitude increases.

It is now reasonable to consider another level of complexity in that the conventional capital equipment technology breakeven analysis can be combined with the breakeven concept for management technologies. Thus, it is possible to conceive of a three dimensional system with volume on the x axis, magnitude of the effort on the y axis, and cost on the z axis. It would seem that the capital equipment technology would tend to be a function of the volume of production while the management technology would be a function of

the magnitude of the effort. The interaction of these, it would seem, would lead to a family of cost surfaces for each combination. Consistent with Woodward's work, it would seem reasonable to expect that the areas of dominance in this system would be where the management and capital equipment technologies are appropriately matched. Ideally, the organization would operate at this dominant point. As the organization experiences growth (or decline) it becomes important for it to adapt to the then dominant combination. Failure to do so puts the organization at a competitive disadvantage with respect to those organizations that have properly adapted. The general shape of the surfaces in this system is difficult to conceptualize at this time. Although it is not essential to the furtherance of the current study, it would seem fruitful to conduct research to better understand these relationships. For example, as will be discussed more fully in a later section, the project office of a major weapons system acquisition moves through several stages of organizational form over the life cycle of the project. Perhaps the logic of this metamorphosis could be discovered using this conceptualization.

Using this conceptualization of modes for arranging work efforts viewed as management technologies, a rationale is provided for the relationships between the various modes. The modes have economic, communications, and perhaps other rationales to relate them one to another. While the above discussion implies pure forms for each mode, it must be realized that in reality such pure forms may not exist except in the most primitive situations. In any organization

there is probably some work being performed in each of at least two modes. Much of the executive's work is performed in a craft mode, i.e., that which he does alone or in a one-on-one relationship with another person. A considerable amount is probably done in the project mode, i.e., that which involves other participants, each of whom contributes unique skills and knowledge, and which is a unique effort having an easily identifiable beginning and ending. Much accounting and personnel work probably resembles job shop technology but, for personnel if volume of hiring is sufficiently high the processing is frequently set up as a temporary assembly line. However, the craft mode is still a major factor in both accounting and personnel. Due to the uneven evolution of an organization in moving from craft to a higher order mode and considering finer gradations of the scale, the set of dominant points on the system described could easily be seen as essentially a continuous surface. This may be a more realistic view due to the tendency in practice to use hybrids of these different modes.

Comparison of Scheduling/Control Practices

Analysis of the five major modes of work arrangement indicates considerable similarities between flow process and mass production and between job shops and projects. The craft mode has some characteristics in common with both job shops and projects but also has several unique characteristics. Comparison of the scheduling and control practices in each of these modes reveals significant differences in approach.

Flow Process Mode

Looking first at the flow process mode, the most obvious characteristic is that the technology of the process is designed into the hardware. It has an operating capacity range which cannot be changed significantly in the short run. Generally, flow process industries are capital intensive and therefore a major objective is to maximize capital efficiency. Constraints on this are the relatively long term commitments to input flows, maximum capacity of the process, and purchase commitments and storage capacity for the outputs. The major uncertainty associated with this industry is the market demand and much attention is given to "managing" that demand. The major variables in the short run are mix of products produced and some adjustment of volume. For example, the mix of a refinery is adjusted to produce a higher volume of heating oil in the winter and gasoline in the summer. This is accomplished by some adjustments in flows but primarily by the adjustment of set points on process controllers. These adjustments are determined by process engineers rather than by the operators. Changes are made rather infrequently. Since all of the inputs are essentially homogeneous, there is no sequencing problem, at least to the extent that it occurs in other forms of work organization. Sometimes there is sequencing in terms of color, viscosity, width, etc., to minimize cleanup, changes in feed stock, or tool changing between runs. As a result of these characteristics of flow processes, the job of production scheduling and control is primarily the assurance of an

uninterrupted flow of inputs, maintaining accurate material balances, and making adjustments to flow rates and controller set points.

Mass Production Mode

Mass production is often characterized as a synthesis process such as the assembly of automobiles. Once a unit is dispatched through the system, it flows continuously through on a first come-first served basis. However, due to the potential disruption of operations, a unit is not started down the line until all components are available that are required to complete the unit. Because commitments are made for the inputs of parts to the assembly line some months in advance, the variation in volume and mix is quite limited. Mass production operations also perform analytical processes such as the dismantling of railroad cars on a moving line prior to their reconstruction.

Generally, mass production operations are labor intensive relative to flow process operations, although the introduction of robots, etc., are changing this. Therefore, a major objective in the short run is to maximize labor utilization. In the long run there is more interest in maximizing capital efficiency. To provide more flexibility in sequencing products on the line, it is desirable to have an inventory of orders from which the day's production can be selected. On a mixed model line, especially with variable options, the units are sequenced in such a way as to not overload any work station on the line.

Major variables in production scheduling and control in the intermediate range are the number of employees and the job assignments for them as well as the number of jigs, fixtures, and tools provided. In the somewhat shorter range, some volume changes can be made as well as adjustments to mix. In the short run, the major variables are the number of hours that are worked and the lead time in delivering the product ordered. A major activity of production control is the constant monitoring of material receipts and even shipments from vendors to insure that the materials are in fact available as planned.

Craft Mode

At the other end of the continuum, craft types of endeavors tend to use first come-first served rules. For example, maintenance and service organizations tend to respond to calls for service in that manner. If the urgency is not great, some attempt may be made to group units of the same type or some geographical location to minimize set-up costs, travel, or some other such variable. Except for emergency services, the medical and legal professions tend to schedule to an appointments calendar and force clients to wait if they schedule too tightly. Retail operations tend to separate customers into queues according to the number or types of items or transactions. Nevertheless, service is then on a first come-first served basis. Demand in this area tends to be relatively uncertain as exemplified by the demand for services in the emergency room of a hospital. Therefore, there is a tendency to have more

capacity than is required to service average demand if the service cannot be delayed. On the other hand, as exemplified by that portion of the services of dentists and optometrists which can be classified as non-critical, the tendency is to inventory clients by scheduling them well into the future. Clearly, such a capability implies certain relationships between supply and demand for the services. Since these types of efforts are largely one-on-one relationships, the major variables include price (to modify demand for the services), the hours worked by the craftsman, and the inventory of clients awaiting service. The major activities of production scheduling and control are making appointments and scheduling of hours and persons.

Job Shop Mode

Job shops tend to have the greatest variety in forms but can be categorized roughly into two classes, those producing a standard product line and those producing one-off or single batch to customer order. The major differences between these two are in the routing and the steps necessary to maintain current status of orders. The standard product line shop uses routings that are consistent from one batch of the same product to the next. In the one-off shop the routings have to be developed for each order.

Job shops tend to be intermediate in terms of capital versus labor intensity. Therefore, the general objective is to minimize the combined costs. The variable that is more prevalent in job shops than in other modes is set-up costs. Set-up costs can be

minimized by careful sequencing of jobs and by increasing the batch size on a single set-up. Because job shops are characteristically organized by type of function or equipment, it is important to consider the balance of the load on each of these departments or pieces of equipment. The typical job shop maintains inventory of the most commonly used items but must also obtain materials unique to the specific job. An important technological difference between job shops and projects is the extent of parallel processing. In the job shop, processing of a unit tends to be strictly sequential. On the project there may be many things happening at the same time.

The major variables in production scheduling and control for the job shop are the number of pieces of equipment in the long run; the number of employees hired, the delivery dates committed to on new orders, the amount of work accepted, and the amount of work subcontracted in the intermediate run; and the number of hours worked, and which orders are going to be late in the short run.

Project Mode

Projects tend to be fewer in quantity but larger in magnitude as compared to the capacity of the organization actually performing the work. Generally the materials required for a project are unique to the specific project and very little is inventoried except for the period between delivery and installation. Essentially the routing of each job is ad hoc with some standard operating procedures applying for certain tasks.

Another difference between projects and job shops is the extent of use of leased equipment. Often the organization performing the project performs a variety of jobs. Except for very limited areas, the intensity of equipment usage would be low if they owned it. Therefore there is a tendency to lease a larger proportion of the equipment that is used or to subcontract for the required services. For this reason, it is desirable to schedule in such a way as to get all preceding work accomplished prior to bringing in that equipment so the equipment can be used intensively while on the scene and then released. For example, on a construction project, if a heavy duty crane is required for a few activities, it would be desirable to get all work preceding those activities completed to free-up the work requiring that crane. In that manner the time that it is required can be minimized along with the associated rental costs.

There exist some decision rules comparable to those for job shops based on dynamic loading of machines so that work is dispatched properly to achieve such objectives. Project activities are generally scheduled first in accordance with technological precedence, then by least amount of slack, by use and availability of resources, and then by other criteria depending upon the goals of the organization or the project.

A major objective in project type work is minimum delivery time for the finished product. Some of the reasons for minimizing time are loss of production from the finished end item, interest on the money invested in the project to date, and deterioration of the

work in place if not completed or at least protected. Scheduling varies in complexity depending upon the intensity of application of resources. Whereas the job shop eases the strain of scheduling by providing in-process inventories, the project is often scheduled with minimum in-process inventories. Therefore, the coordination of resources is much more demanding.

A major part of the effort in production scheduling and control is the revision of schedules and plans required to adjust to the exigencies of the situation. The major variables in production scheduling and control include the amount of detailed planning that is done, the number of employees brought onto the job, the number of hours worked, the amount and type of equipment that is rented, and the amount and type of work that is subcontracted. Often the project manager is deeply involved in these decisions. In the short run, the major variables are the specific activities on which to work and the allocation of labor, materials, equipment, space, and sometimes energy to those activities.

If any one thing is clear from examining the differences in production scheduling and control for projects vis-a-vis that for other modes of work, it is that there is a great deal of overlap, especially with job shops, but also with craft types of efforts. On the other hand, some characteristic differences can be discerned. One difference that is reasonably vivid is that projects are often spatially separated with the equipment and labor moving to the site of the project whereas job shop operations tend to be relatively close spatially and the work moves to the equipment. This is not

a clean distinction as can be seen by business systems design and computerization, which are generally considered projects but have the work typically moving to the analyst or programmer.

There also tends to be a perceived difference in the relationship of activity time versus in-process storage for projects as compared to operations times versus in-process storage for the typical job shop. Various authors report ratios of 5% to 10% of total in-system time for job shops being used for operations and 90% to 95% being delay between processes. Although no reference was found in the literature to such a measure for projects, experience would suggest that, except for other reasons, the object being worked upon in a project does not wait for the next processing operation for anywhere near this amount of time.

Some of the reasons why the object being worked upon may be delayed between processing steps in projects are:

1. De-coupling the scheduling of trades or subcontractors.
2. Accumulation of work requiring common resources.
3. Awaiting delivery of materials that are late.
4. Subcontractors accepting more work than they can reasonably accomplish and therefore not performing in a timely manner.
5. Occasional usage of a scarce resource such as a heavily loaded computer upon which time can be obtained only infrequently.

Some of the reasons for minimizing delay on projects are:

1. Generally, the project is not undertaken unless there is a need, often urgent, for the results of the efforts.
2. The duration of a project, accompanied by the steady build-up of the investment in the project, leads to an increasing actual or implied interest cost on the investment.
3. Return on the investment in a project cannot (normally) begin to be realized until the project is substantially completed.
4. Delays in project completion can result in deterioration of that work which is completed or can result in a relearning of what has been done such as in computer programming.
5. Delays in project completion can result in loss of competitive advantage and postponement of gain from money spent in research and development of a new product or process.

It is not meant to imply that these characteristics are unique to projects as compared to any other mode of work but to simply note differences in degree of emphasis on projects as compared to the other modes. Both differences and similarities between project type efforts and other modes have been demonstrated. These will be used to assist in developing an operational definition of project.

Organizational Approaches to Managing Projects

Perrow (1968) described project management as a "concept of decentralization and centralization at the same time" (p. 47). The rationale for this statement is that, while on the one hand the chief executive is delegating responsibility and authority for that project to the project manager, he is at the same time centralizing responsibility in the project manager that may have otherwise been shared by the various functional department heads involved in that project.

Several authors have contributed to the understanding of this process in general including Burns and Stalker's (1961) mechanistic versus organic organizational forms and Lawrence and Lorsch's (1969) study of the role of the integrator in resolving conflicts between departments. Several other authors have discussed specific organizational approaches for accomplishing project type work. These include Davis (1962), Cleland (1966), and Steiner and Ryan (1968). Their typologies are shown in Table II-1, Typologies of Project Organizational Approaches.

The organizational approaches to managing projects cited in Table II-1 are only a few of the many which are available. They are apparently derived primarily from experiences in the defense and aerospace industries. In the broader perspective of projects of the current study, recognizing that projects range from the very small first assignment given the new employee to the "mega-buck" nuclear power plant, it is important to consider additional

TABLE II-1.--Typologies of Project Organizational Approaches.

Responsibility/Authority	Davis	Cleland	Steiner and Ryan
Expedite per schedule and provide a center of communications	Expediter	Assistant to	Influence
Above plus authority to make schedule changes and release budgeted monies	Coordinator		
Full range of management responsibilities and authority except that the people who work on the project are permanently assigned to functional departments for day-to-day supervision	Confederation Manager	Matrix	Matrix
All persons working on the project report to the project general manager in all respects for the duration of their assignment to the project	General Manager		Pure

organizational alternatives. This will provide a more comprehensive base from which to derive a definition of project. Furthermore, a more complete listing of approaches may assist managers in understanding the pros and cons of these alternatives. For example, one seemingly sophisticated manager was disturbed because of the lack of success of his attempts to use the matrix approach in managing an urban planning department. Closer examination revealed that he had really not delegated either the appropriate responsibility or authority to his "project managers." Furthermore, the job descriptions for the functional managers had not been modified from those used under the previous functional organization. The discussion that follows would have been helpful in assisting him to understand what was happening. Each of the approaches enumerated have been observed in practice with varying degrees of success on different types of projects.

Alternative Loci of Project Responsibility

Assistant to--This is the weakest form of project manager and has only communications responsibility. In practice, the assistant may, through personal characteristics, instructions by his superior to others working on the project, or simply by judicious use of his direct channel to the executive, actually achieve the status of expediter, coordinator, or even matrix project manager. This form is often found where the executive is unwilling, for whatever reason, to delegate responsibility and authority yet cannot attend to all the details himself.

Expediter--He is responsible for expediting per schedule and providing a center for communications. If the executive requires regular reports of status as compared to schedule, a person in this position can be very effective.

Coordinator--This is consistent with Davis (1962) in which the individual has responsibility for communications and expediting per schedule, plus the authority to make schedule changes and to release budgeted monies. The schedule change authority may be somewhat limited but does give this person some "bargaining power" with the performer. Also, control over release of money adds to his "bargaining power" but only if there are effective budgeting and work authorization procedures.

Manager--This is the matrix concept that was of primary concern to Cleland and King (1975). As they pointed out, it can be implemented in a variety of manners with, not only differences in responsibilities and authorities, but also differences in the amount of support staff provided the project manager. This can vary from no staff to a minimal staff to a rather complete staff.

General Manager--This is the project general manager concept of Davis (1962) in which all of the resources necessary to perform the project are under the complete control of the project manager. This approach is frequently used to accomplish a project in the absolute shortest time possible, i.e., in an emergency or crisis, or where the magnitude of the project warrants.

Chief Executive Officer--This occurs most frequently in the small firm, especially on its first significant job. It also happens

in the larger firm when one job is of overwhelming importance to the organization or a somewhat lesser job gets into trouble. The management of a project by the chief executive officer is mentioned only briefly in the literature, primarily with the caveat that it can only be effective for relatively small or single purposed firms. A major problem with this arrangement is that it draws the attention of the chief executive away from his broader and longer range responsibilities, some of which cannot be delegated effectively. He then gives too little attention to those responsibilities until they become critical at which time he may be forced to reverse his allocation of time to the detriment of the project.

Deputy Executive Officer--This represents a splitting of the chief executive's duties between the maintenance of the organization as a whole vis-a-vis the day-to-day operating responsibilities associated with managing projects. This often occurs in small to medium size construction firms and undoubtedly in other types of firms.

Key Function Manager--This approach involves assigning responsibility for managing the project to that functional manager having the dominant role or interest in the project. This frequently occurs in plant expansion or process improvement projects where the plant manager assigns overall responsibility to the production manager and the other managers provide support. While it is effective in assigning responsibility to a single individual, and generally to the one with the most at stake if not the most technical

expertise, there is a serious problem associated with it. Often the designated manager feels a pressure to "have his own house in order" before bringing full pressure to bear on the other functional managers. For example, if activities for which the "key function" manager is responsible are behind schedule, he is in a handicapped position to persuade the other department managers to expedite activities for which they are responsible.

Task Force of Managers--In this approach a committee is formed of key people from the functional areas based on the involvement of the function or special expertise of the individuals. These people may be partially or totally relieved of their regular responsibilities for the duration of the project. Frequently, the task force of managers will be employed when a particularly critical issue is involved which must be handled at a high level, for example a major acquisition or critical union negotiations. Often in such projects the chief executive officer is very closely associated with the effort but often depends on the members of the task force to organize their own efforts. Often it is propitious for the chief executive to avoid direct involvement until a critical point is reached, although he may be involved behind the scenes. One problem that frequently occurs is that the managers are not relieved of their functional responsibility and as a result one or the other, or both, responsibilities are not performed as well as they should be.

Management Committee--This varies from the task force of managers in that the members of the management committee become

strictly decision makers with staff members of various functions performing the detail work to support the committee's deliberations. Although the committee may have a chairman, the responsibility for project accomplishment is more dispersed in this form than for any of the above. A major difficulty with this approach is the extent of political maneuvering between the members of the committee. This often leaves the workers without firm direction, or even worse, provides them with two or more sets of directions depending upon the desires of different coalitions or members within the management committee.

Craftsman--This approach has been observed frequently in systems and procedures and computer programming types of operations and in some engineering assignments. A single person is assigned responsibility for managing and performing a significant effort. It is also a way of introducing a new member into the organization. It is not unusual for the recent college graduate to be given an assignment that requires minimum interaction with others in the organization. If successfully completed, it is often followed by assignments involving progressively more responsibility and interaction and coordination of other people. Although it is easy to supervise, it also tends to take longer to accomplish any given effort due to the limitation of resources brought to bear. Note that this limitation of resources is not only in quantity, but also in the degree of expertise that can be brought to bear by a single individual. Thus, the project may take longer to accomplish and the results be of less quality than possible.

Consultant/Contractor--In this case the responsibility for the project is turned over, in very large measure, to someone who is hired only for the duration of the project. The amount of responsibility and authority delegated to the consultant/contractor varies over the full range of the above alternatives. In addition, three basic subforms can be recognized. One, the consultant/contractor only performs the work while a representative of the client acts more as project manager. Two, the consultant/contractor only managers the effort, bringing special expertise and/or an outsider's point of view to bear. Often in this role he is able to assist in resolving some political conflicts which could not be accomplished nearly as well by the insider. Three, the consultant/contractor may manage and perform at least a major share of the work if not perform a complete "turnkey" job.

The consultant/contractor approach has considerable merit, especially for a "lean" organization. Occasionally, an organization will have to undertake a project which, if they were to attempt to do it internally, would require more effort than is available within the organization or would require expertise beyond that normally required in their regular operations. Small organizations often call on a consultant to analyze their data processing requirements and assist them in making a decision or an architect/contractor may be called in to design and construct a building. These may result from both a manpower and skill limitation. In this event, the consultant contractor may very well manage and perform all of the work. This has grown in popularity in the construction industry

in recent years where the design/build contractor agrees to provide a structure which meets certain specifications at a fixed price.

Another alternative is that the consultant would essentially manage the effort with members of the organization performing most of the work, such as data gathering, flow charting, etc. This also has grown in popularity in recent years in the construction industry where it is known as construction management. It has been implemented in two basic forms. In the "manage only" form the construction manager does no construction work but devotes full time to the management of all of the others involved. In the manage and perform mode, the construction manager may take full responsibility for a turnkey job. There are several references in the construction management area. Foxhall (1972) points out that the construction manager has broader responsibilities in the design and delivery of the project itself within the client's budget. He identifies two phases. The first phase has to do with defining the cost-quality relationships of the architectural and engineering design options. The second phase (which usually overlaps the first in time but not in function) is a control method for schedule and contract management. This approach has become particularly popular in recent years of rather high inflation rates. Due to the fact that design and construction phases can be overlapped so much, savings can be achieved by much earlier completion of the project and the avoidance of escalation of costs due to inflation.

Finally, the client may choose to manage the effort himself, calling in the consultant/contractor to perform specific parts of

the job. In this case the consultant/contractor has no overall project management responsibility and is really no different than any of the other outside participants in the project.

From this analysis of loci of project responsibility, it can be seen that the specific organizational approach is not an essential characteristic in the definition of a project.

In the above analysis, five basic modes for arranging work efforts were identified among which is the project mode. Rationale for the existence for these modes was provided as well as for the evolution from one to the next. Production scheduling and control practices were examined for each of the five modes and distinct differences found. Finally, the organizational approaches normally considered in the literature were expanded upon to show at least twelve loci of responsibility for managing projects. Each of these analyses provided insights into the nature of projects as a type of work effort necessary for developing a general definition of "project."

Proposed Definition

The point of departure for the development of a general definition of "project" was Norden's (1960) definition of a developmental project:

> a finite sequence of purposeful, temporally ordered activities, operating on a homogenous set of problem elements, to meet a specified set of objectives representing an increment of technological advance (p. 41).

A more general definition of a project can be achieved by modifying it to the following:

> A project is a finite technologically determined sequence of purposeful activities, operating on an interrelated set of items, accomplishment of which will result in the achievement of a specified set of objectives and the termination of the work efforts.

Note that "sequence of activities" as used here does not imply a strictly linear sequence in time.

While Norden did not define an activity except in a mathematical sense, the following would correspond to his concept. "An activity is an operation performed on an item requiring the lapse of time, and, generally, the use of resources." This definition is consistent with the graphic notation used in Program Evaluation and Review Technique (PERT) and Critical Path Planning System (CPPS) as originally developed. By using the activity-on-node notation with the delay feature the definition could be modified to: "An activity is an operation performed on an item requiring the lapse of time and the use of resources." Norden stated that a set of items is composed of elements of the end product, or sub-divisions thereof, each of which has at least one technological interdependence point in common with another element. A corollary of this is that for every activity performed on the items in a homogeneous set, there is at least one interdependence point that connects it to some other activity performed on another item in the set.

The substitution of "interrelated" for "homogeneous" seems to more accurately convey the meaning as derived from Norden's discussion. That is, the elements are interrelated in that they will eventually be combined into a deliverable end item contracturally if not physically. The inclusion of "technologically determined"

sequence emphasizes that there is a minimal interrelationship between activities which is determined by the technology of the end product and each of its elements. There are also alternative relationships between activities determined by the specific technology chosen for the activities to operate on the items. There is generally more than one method for performing an operation on an item. Therefore, the activities included in a specific project plan, and their sequential relationship, are the result of decisions as to the methods to be employed and the technology of these methods. Occasionally, more than one method will be pursued to reduce uncertainty, with the results of the best, or first successful, method actually being incorporated in the end product. Also, the addition of "technologically determined" sequence plus the requirement that an activity must have a duration, precludes the necessity of the words "temporally ordered."

Careful examination of these definitions revealed that nothing in them uniquely distinguishes the project from work performed by other means, i.e., job shop or craftsman mode. It would seem that the primary distinction between project and craft modes would be the degree to which multiple resources are employed. In general, craftsmen are lone individuals performing work requiring a high degree of skill, experience, and judgment. While more than one individual may be involved, their efforts are either not differentiated or they provide support services to the craftsman. Therefore, it seems that to specify that "multiple, heterogeneous

resources" are used is sufficient to distinguish the project from the craft mode.

As to the difference, a major distinction between a project and a job shop seems to be the difference in the magnitude of the effort as compared to the capacity of the organization actually performing the work. Generally, a job shop processes a relatively large number of jobs in a year, each one requiring a small fraction of the total resources of the shop. An organization working in the project mode tends to work on relatively few jobs during the year; many extend over several years. Each project thus uses a relatively large proportion of the organization's resources.

Furthermore, it seems that a project is usually viewed as a whole entity and progress is measured on that entity. The emphasis in a job shop is on the work station and the length of the in-process queue before that work station. That is, in the job shop emphasis seems to be on the status of the system (the job shop) while emphasis on projects is on the status of the job as a whole. This is not to argue that job shops do not know the status of a particular job; it is simply a matter of emphasis.

Another distinguishing characteristic of projects as compared to other forms of work effort is the low unit volume. Generally, a project results in a single unit of production--a building, a dam, a report, a fund collection, etc. Even for a multi-unit housing development, the project is the "development" as opposed to a multiple of single units because of common facilities such as streets, utilities, etc.

Finally, generally included in any discussion of project management is the notion that the project is unique; that it has never been done before and is not expected to be done again in the same manner. Careful analysis of many projects reveals that a large proportion of activities are performed with considerable frequency. A construction firm may pour concrete on every project it undertakes. However, conditions change from one project to another bringing with them new problems to be solved or different mixes of problems than have been dealt with before. Furthermore, the sequence in which certain activities are performed may vary substantially from job to job. With a few exceptions, such as a multi-floor building, the activities are not repeated. Even when repeated, they are generally repeated in a relatively long sequence with other activities. This contrasts with the batch type job shop or the mass production shop where the intent is to perform the same activities, often many thousands of times, in the process of producing a large unit volume of product. Also, the activities in a project are generally described at a macro level of detail while the work elements in a mass production shop are described at a micro level. This results in some uncertainty as to the precise method, work content, and point of completion of the activity and therefore uncertainty as to the actual duration required to perform the project activity. Thus, in comparison to the job shop and other high volume modes, the project activities are usually non-repetitive.

This relationship of work units in a mass production environment as opposed to a project environment can be visualized more

precisely by the following relationship. An activity is a unit of work performed by an organizational entity i.e., a group or possibly a person. Each person in that group fills a job, i.e., has a continuing responsibility for performing a specified set of tasks. Each task can be detailed as a set of work elements, i.e., rather small, unvarying units of work. Each work element can be further detailed as a set of micro motions as identified by Gilbreth's Therbligs or the basic motions of Methods-Time-Measurement, or other such predetermined time standards system.

The previous definition can now be expanded by modifying and incorporating these considerations, Project--a unique, technologically determined sequence of purposeful, usually non-repretitive activities; involving the coordination of multiple, heterogeneous human and non-human resources representing a significant proportion of the performing organization's capacity; operating on an interrelated set of items; accomplishment of which will result in the achievement of a specified set of objectives for one or a few units of output and termination of that work effort; with primary managerial emphasis placed on timely accomplishment of the work effort as a whole (as compared to the managerial emphasis for other modes of work).

To be consistent with the three dimensions of an activity as discussed by Malcolm et al. (1959), it is necessary to modify the definition of an activity to incorporate the technical performance dimension. Activity--a finite operation (physical or mental) performed on an item (concrete or abstract) to achieve specific

technical performance objectives requiring the lapse of time and, generally, the use of resources. This definition does not preclude a specific activity from being considered a project by a subset of the performing organization. Such an activity when treated as a project would normally be called a sub-project. Thus, these definitions are recursive in a manner similar to comparable concepts in systems theory.

From these definitions we can derive some characteristics of the planning and control system required to manage projects. First, it must be able to represent the entire project as one integrated whole and show the technological relationships between the activities. It must be able to account for multiple units of different resources and, if the organization is to be cost effective, assist in assuring the effective use of those resources. It must permit efficient identification of the activities. Since they are non-repetitive, it must recognize that the time and resource estimates are imprecise and deal with them accordingly.

While this definition does seem to provide the essential criteria for uniquely identifying a project, there is considerable overlap in the ways that certain work can be organized. Therefore, two nearly identical work efforts may well be performed in different modes due to factors inherent in the performing organization, requirements of the client, socio-economic differences, etc. As is true of the technological breakeven curve, there are conditions under which the costs would be the same for two different modes.

Away from that point, however, in the long run it could be expected that one or the other would dominate.

Also, as was pointed out in the discussion of management technologies earlier, the existence of any mode of organizing work efforts in its pure form is rare. Rather, the tendency is to "upgrade" the mode of selected parts of the operation. Thus, where a set of repetitive activities appear in a project, we would expect those to be performed in the job shop (or mass production) mode. The greater the number of such sets, the more a project will resemble a job shop (or mass production shop).

Testing the Definition

If the proposed definition is adequate, it must contain the essential criteria to uniquely identify a set of tasks as a project and, at the same time, preclude them from being identified as a job shop or any other mode of work effort. Also, it must include the essential aspects of definitions that have been provided in the literature.

Comparison with Other Definitions

Consider the definitions cited from the literature first. The proposed definition is consistent with Gavett's (1968, p. 13) in all but one respect; the resources being brought to the job. It is argued that this is not a necessary condition but simply one which occurs frequently in certain types of projects. The construction of a Saturn booster was managed as a project yet to some

extent it was done in job shop fashion as far as location was concerned. Similarly, the design of a building is a project which may take place in a number of locations at the same time when considering the work of architects; structural engineers; heating, ventilating, and air conditioning engineers; electrical engineers; and others.

Steiner and Ryan (1968, p. 7) derive their definition from government systems procurement and imply that the government must be involved. This precludes projects by private industry; clearly an unnecessary restriction. Although conditions of technical uncertainty are often involved in the types of projects with which they were concerned, it is not true of all projects. For example, construction of a standard house on a well understood lot does not really involve technical uncertainty even though other uncertainties may be involved, such as weather. Finally, although time of completion is critical, it is often a variable and is often allowed to vary for the benefit of cost or performance. Emphasis on timely accomplishment seems to be a more appropriate statement.

Cleland and King (1975, p. 184) emphasize "human and non-human" resources. Human resources are included specifically to preclude purely mechanistic systems and to draw attention to the vagaries of human behavior. Non-human has been incorporated to recognize that availability of cranes, trucks, computer time, and other such resources when needed is often as vital to timely accomplishment as are human resources. Cleland and King's incorporation of "temporary organization" places emphasis on the

organization as opposed to the work itself. This would seemingly preclude identification of successive projects performed by the same organization. This does not seem to be a necessary condition even though it often exists.

The Wiest and Levy (1977, p. 3) characteristics essential for projects to be analyzed by PERT and CPM are incorporated with the exception of independent start and stop. Although this is a condition for applying PERT and CPM as conventionally conceived, it is not a necessary condition for a project.

Taylor and Watling (1973, p. 3) add "a need for central intelligence to direct it." This certainly is not unique to projects as compared to job, mass production, or continuous flow shops. This condition may not be necessary for craft mode work since, in the usual case, the craftsman is providing that "intelligence" directly. The intent of this phrase is met by the use of the phrase, "coordination of multiple, heterogeneous human and non-human resources" and "managerial emphasis" in the proposed definition.

The proposed definition is consistent with Archibald (1976, p. 18) except for his use of the word "complex." This is not a necessary condition although it is common in the projects he had in mind. Excluding "complex" makes the proposed definition more inclusive, while being more detailed, it is more able to discriminate projects from other modes of work efforts.

Finally, having been derived from Norden's (1960, p. 41) definition with justification for each modification the proposed definition is consistent with his.

Differentiation of Modes

The definition must differentiate project from other modes for organizing work efforts. The craft mode is different because it does not involve the coordination of multiple, heterogeneous resources.

At the other extreme, continuous flow process mode is distinctive in that it is a continuing operation, involves continuous (as opposed to finite) activities, and produces large quantities of product. Managerial emphasis in the continuous flow mode is on maintaining the steady state operations, including assuring continuous flow of inputs and outputs and constancy of operations of individual processing elements to achieve quality. Efficiency is incorporated into the design of the facility.

Mass production is also a continuing operation producing many units of product. The activities described at the micro level as work elements are highly repetitive. They are susceptible to study by conventional industrial engineering techniques. Managerial emphasis is on maintaining the steady state operations including assuring continuous flow of inputs and outputs, maintaining a stable work force, striving for conformity of operations to plan, maintaining quality by checking individual units and correcting deficient units at the end of a processing sequence. Efficiency is incorporated into the job designs as well as into the hardware but is achieved by close supervision of operatives to ensure they are performing to standard. The job shop is most difficult to

distinguish from the project; especially the unit job shop. The two major distinctions are the size of the job as compared to shop capacity and the managerial emphasis on the shop as a whole and its functional departments as compared to the single job. Also, it is not unusual for a product of a job shop to involve much more in-process waiting time than production time as compared to the project.

Applicability in Practice

It is important to test the applicability of the definition to a variety of examples from different industries and functions to demonstrate its generality. First, consider industries that are generally recognized as operating in the project mode. The construction industry varies from relatively small and uncomplicated projects such as installing a sidewalk to a very involved project such as a nuclear power plant. These are certainly consistent with the proposed definition. Use of mass production techniques for fabricating mobile housing units is precluded from being classed as a project because the activities are repeated on successive units, more than a few units are produced, and it is an ongoing operation rather than one designed to terminate. The installation of the units, such as in a multi-unit apartment building is a project even though the units installed in the basic structure may be identical. The variations in orientation and/or placement of the units minimizes the repetitive characteristics in addition to all the other work that must be accomplished to finish the structure.

Building a housing development also offers an opportunity to use a mixed mode of operation. A Wherry housing project near Sandia Base at Albuquerque, New Mexico involved some 720 units. It was organized in part as a job shop and in part as an assembly line. Most of the lumber was pre-cut in a yard shop. It was stored in bins in a sequence to permit loading of wagons in assembly line fashion. Major panels were prefabbed on jigs in the yard, also in a sequence to permit the assembly of a wagon load per house. Crews moved from house to house, each doing a relatively small amount of the total work on a unit, much as is done on an assembly line. The big difference here was that the product stood still and the crews moved. Nevertheless, the overall effort would be considered a project. Since there were some twenty different types of houses the work was less repetitive and the number of units of each was less than might have appeared. In addition to the houses, there were many other items in the total development that were a part of the project such as roads, sidewalks, sewers, and utility systems. The definition is useful in distinguishing this work effort as a project rather than some other mode of arranging work.

The aerospace industry is generally considered to work in the project mode, especially during product development and prototype fabrication. If appreciable volume of identical units can be achieved, they often perform final assembly in assembly line mode even though the product does not move as fast down the line as might be the case in many assembly lines. Operations preceding

final assembly are frequently done in job shop or assembly line mode. Another aspect of the aerospace and defense industry is the major developmental programs undertaken by government agencies such as DOD and NASA. A major SPO (System Program Office) in the Air Froce can become a very large bureaucracy. For example, the Minuteman Missile Weapons System SPO reportedly consisted of up to 2000 people. Can this legitimately be considered a project? Actually, in accordance with Air Force terminology, this was a program, i.e., a set of closely related projects, as discussed by Cleland and King (1975, p. 184 n). When all of the contractor, subcontractor, and supplies personnel involved were counted, the number of participants would surely have numbered in the 100,000's of people. By the proposed definition this Minuteman effort would still be considered a project, in part because it produced a relatively small number of units and was designed to be terminated.

The degree of bureaucratization involved in this SPO would seem to be more a function of the magnitude of the effort than any other characteristic. Bureaucratization of an operation of this magnitude is no doubt a necessity to accomplish such an undertaking in a reasonable time and cost and to provide a means of communicating with so many participants. Mere size of the bureaucracy does not detract from the characteristics that made this a project. If the work breakdown structure for the total program were analyzed, it is likely that the second level would be recognized as a set of projects related to the end products of the program. It is also likely that many of the major elements in the SPO were directly

identifiable with each of these second level elements in the work breakdown structure. Further analysis would probably reveal that many of the remaining parts of the bureaucracy were functional organizations there to serve the needs of all of these second level projects, i.e., service functions. Furthermore, many of those service functions undoubtedly operated in a job shop or mass production mode even though they were a part of the larger project.

CPPS was developed by duPont, a firm which uses the continuous flow process mode extensively in their operations. While clearly their primary operations are not project mode in nature, the major maintenance turnarounds and new facility construction are accomplished in the project mode. This work is certainly consistent with the proposed definition and demonstrates that work is performed in various modes within the same organization. Considering the work performed in various functions within an organization, there is nothing inconsistent with the proposed definition when applied to research and development; new product design, development, and launching; new facilities design, construction, and start-up; or systems design and computer programming. The advertising function can be considered as a program composed of a set of projects and is consistent with the definition.

The proposed definition must also be tested against some unusual and/or extreme situations to ensure that it does not fail under such circumstances. On the small end, could the process of an executive dictating a letter to a secretary be considered a

project? In general, this would be viewed as a job shop operation. Often there is considerable decoupling of the successive steps including dictation, typing, signing, and mailing. Occasionally, correspondence will be of such magnitude, involve enough people, and be of sufficient urgency that it is treated as a project. For example, a response to an order by the Occupational Safety and Health Agency (OSHA) threatening closure of a plant would likely be handled as a project. Going a bit beyond what would normally be considered correspondence, the filing of a new rate proposal with the Federal Power Commission would be handled as a project by the utility company and this is entirely consistent with the proposed definition. Interestingly, the firm that types, reproduces, and collates the copies of the filing probably handles their part of the effort in the job shop mode with some of it being done in assembly line fashion.

The operation of a restaurant would normally be in the job shop mode. However, the planning and serving of a large banquet may be much more like a project, even though the plates may be filled in an assembly line fashion. This is consistent with the definition. One could also consider the process of a student getting a college education to be a project. Relating course choices and time schedules certainly involves coordination of resources. Interestingly, from the point of view of the university, the process is more like a job shop, i.e., orientation and perspective play an important part in determining the applicability of the definition.

Computer Simulation

The final test of the definition is the ability to use it as the basis for computer simulation in the manner of Norden's (1960) study. This will demonstrate the precision of the definition and the potential for generalizing results of simulation studies based on this definition. Based on the description of the simulation study as conducted by Norden, it appears that nothing is lost. While he used an "Effort-Distribution Array" derived from the analysis of specific developmental projects, the greater generality of the present definition would seem to make it applicable to projects in general. The Effort-Distribution Array showed activities versus items on which the activities operated and the amount of effort expended. A Monte Carlo process could generate hypothetical work breakdown structures from which basic technological sequences could be determined. A Markov matrix could be used to determine which of the elements in the work sequence would have non-zero times and the times and resource requirements for them. A similar approach could be used to interrelate them into a network. Empirical or theoretical distributions could be used to determine the probabilities, whether continuous or discrete. Finally, if uncertainty in performance times for the activities is desired, a Monte Carlo technique could also be used to sample one or more distributions associated with the activities. Perhaps different distributions would be used depending on the type of activity.

This general outline of a simulation procedure could achieve comparable results to those described by Norden. For explicit

projects, the work breakdown structure and network diagram could be supplied rather than generated. Mean durations, uncertainties, and resources could be supplied or generated as desired. Thus, simulation capabilities would seem to exist over the full range from general to explicit.

Although this "testing" is not exhaustive or conclusive, it is representative of a variety of situations. In each case considered, there was no conflict or deficiency when comparing the definition to the example. Therefore, the definition as proposed will be considered adequate in terms of the necessary and sufficient criteria and in its applicability to real world situations.

Summary

Based on the above analyses, the following conclusions can be drawn.

1. While most writers on projects have given no definition of a project, those few who did provided definitions that were inadequate for general application. They did not uniquely identify a set of entities as projects nor exclude all other entities. The definitions were generally too restrictive having been based on examples drawn from specific industries.

2. Most authors of Operations/Production Management texts do not recognize the project mode as a major approach to organizing work efforts.

3. Woodward and Perrow, two authors who recognized that there is an interaction between the technology of an organization and the structure and behavior of the organization, did not specifically recognize the project mode as an approach to arranging work efforts.

4. The five modes of work arrangement developed herein provide a comprehensive taxonomy of work efforts and, more importantly, provide a rationale for the existence of the project mode in that taxonomy.

5. The five modes of work arrangement when viewed as a management technology, provide a rationale for the evolution of an organization from craft to project, job shop, mass production shop, and, depending on the production technology involved, perhaps to the continuous process mode.

6. There are adequate explanations of the underlying reasons for the tendency to evolve from the most primitive mode, i.e., craft, to the more rationalized modes, i.e., mass production and continuous flow process. In some cases it may be possible to reverse the process for the human resource by installing mechanized methods such as computers in accounting.

7. It is rare to find examples of the "pure" modes as the process of evolution progresses unevenly across functions in an organization. Nevertheless, it is of value in understanding the role of projects to consider analytically the pure modes.

8. The literature on project management generally recognizes four approaches to managing projects--expediter, coordinator,

confederation (matrix) manager, and general (ad hoc) manager. A comprehensive discussion of approaches must include the twelve loci of responsibility described herein.

9. The project as an identifiable mode of work arrangement is of very recent vintage as far as modern literature of general management is concerned. This raises questions as to the validity of the results of some of the research in general management when applied to managing work efforts arranged in this mode.

10. A definition of a project which establishes this mode of arranging work efforts as unique is feasible and in fact was derived as follows:

Project--a unique, technologically determined sequence of purposeful, usually non-repetitive activities; involving the coordination of multiple, heterogeneous human and non-human resources representing a significant proportion of the performing organization's capacity; operating on an interrelated set of items; accomplishment of which will result in the achievement of a specified set of objectives for one or a few units of output and termination of that work effort; with primary managerial emphasis placed on timely accomplishment of the work effort as a whole (as compared to the managerial emphasis for other modes of work).

In addition the definition of an activity, the basic entity of which projects are composed, was derived as follows:

Activity--a finite operation (physical or mental) performed on an item (concrete or abstract) to achieve specific technical

performance objectives requiring the lapse of time and, generally, the use of resources.

Based on the preceding discussion, certain research efforts are identified which seem warranted. They are listed below with no implication by their order.

A. Conduct a follow-on study of the relationship of mode of arranging work based on characteristics of that work in the manner of Woodward and Perrow, but recognizing a more complete typology including projects. The objective would be to develop a more complete knowledge of the ways of arranging work efforts.

B. Develop a useful measure of magnitude of work efforts and relate it, along with volume, to a meaningful concept of management technologies to show more clearly the role of project oriented work efforts.

C. Conduct a study of the actual scheduling and control practices used on projects and what priorities are involved in the application of these practices to projects as opposed to other modes of work efforts.

D. Conduct a study of the twelve different loci of responsibility for project management identified, including typical job descriptions, characteristics of occupants of these positions, pros and cons of each, and caveats appropriate in the use of each.

E. Conduct a study of the organization of a major SPO (Systems Program Office) to identify the functions served by each organizational entity and the major mode of arranging work efforts applicable to each.

CHAPTER III

THE ACTIVITY

Introduction

One of the major gaps in knowledge of the management of projects is of the activity and its characteristics. Various papers have been written to explicate mathematical solution techniques assuming certain characteristics of activities. Little has been presented on efforts to test any of these assumptions empirically.

It is the purpose of this chapter to present an analysis of the activity as an entity by examining each of its dimensions one at a time, in pairs, and all together. A conceptual model of an activity is proposed which seems to have utility in this analysis and is consistent with the three-dimensions of Malcolm et al. (1959). This model is used as the basis for analysis and the development of an explicit mathematical model. The results are "tested" by comparing some real world examples to the model to see if it has utility. Finally, the results of the above are summarized and research proposed to attempt to close some of the gaps.

Economics

An examination of representative texts on microeconomics reveals that the focus is primarily on the problems of mass production industries, i.e., quantity produced is the major independent

variable. Projects, being unique, producing only one or a few units of output, and consisting of finite, non-repetitive activities, do not relate to quantity as an independent variable. Quantity is not a relevant variable for economic analysis of a project activity. No examples were found in the economics literature examined which were consistent with the finite nature of a project as defined in the previous chapter. Some basic concepts of economics may be relevant to the understanding of project activities, if these concepts are suitably modified.

One basic concept from economics is the short- and long-run unit cost curve. The typical discussion of this usually states that each of the short-run unit cost curves represents a fixed plant size while the long-run unit cost curve "envelope" is over the range of feasible plant sizes (see Samuelson, 1964, p. 469, and Figure III-1 below).

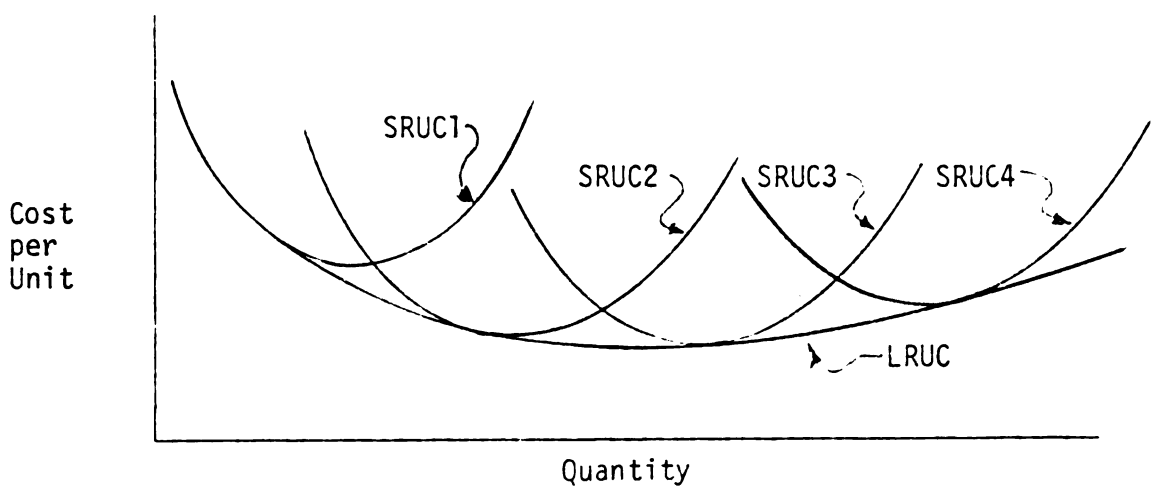


Figure III-1.--Short- and Long-run Unit Cost Curves.

Another basic relationship of economics is the capital-labor substitution relationship for determining optimal input proportions. The typical discussion includes a graph such as in Figure III-2 and illustrates the concept with an example such as acres of land per tract versus workers per tract of land (see Ferguson, 1969, pp. 146-181). Implicit in this example is a constant level of technology with the two dependent variables being units of capital and units of labor to achieve a given quantity of output, the independent variable. (Of course the relationship between dependent and independent variables can be reversed, depending on the analytical objective.)

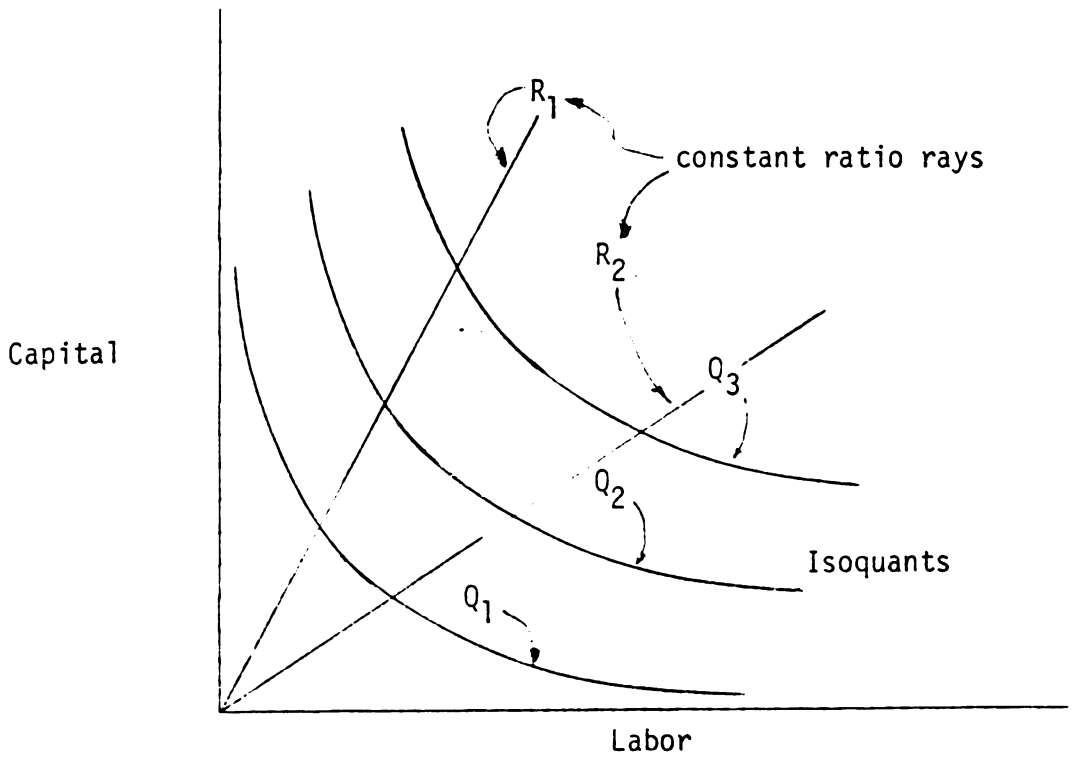


Figure III-2.--Capital-Labor Substitution.

While these relationships from microeconomics may be useful to the chief executive of the project oriented organization, they really do not provide much insight to the manager of a project. It should be noted that these models from micro economics focus on the overall operation, not on the specific work elements of which it is composed. To develop an adequate concept of the economics of a project it seems necessary to first have a clear understanding of the activity, the basic elements of which projects are composed. To develop such an understanding it is necessary to start with a conceptual model of an activity and examine its dimensions and their behavior in detail.

Conceptual Model of an Activity

A conceptual model of an activity must deal with the three principle deminsions of the activity--time, resources, and technical performance. These can be depicted graphically as a polyhedron as seen in Figure III-3.

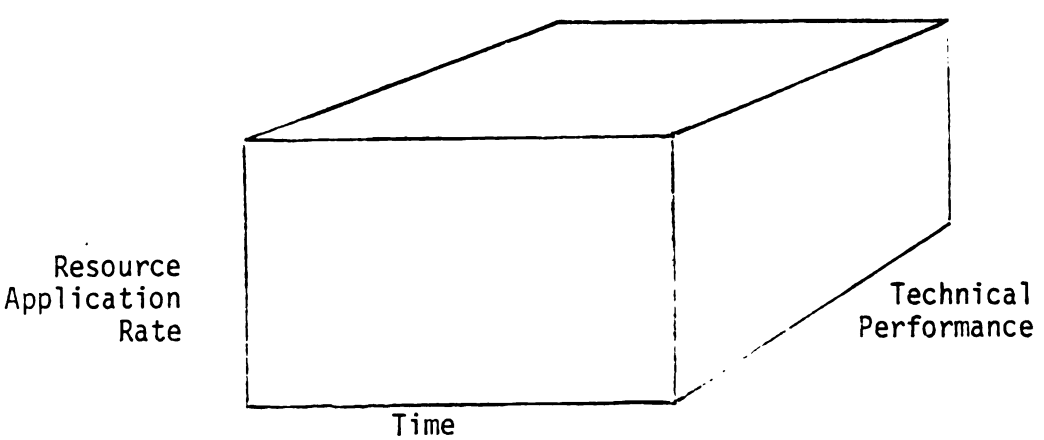
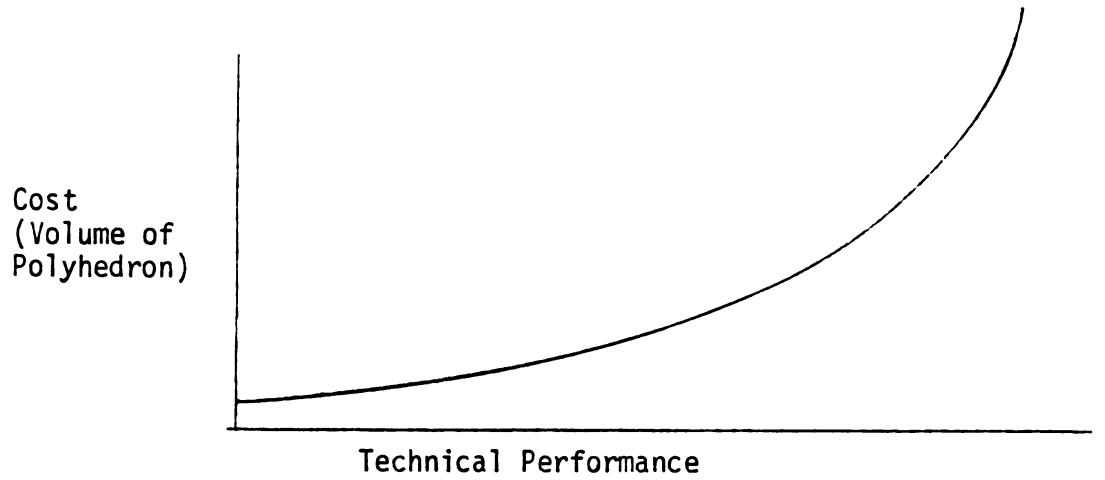


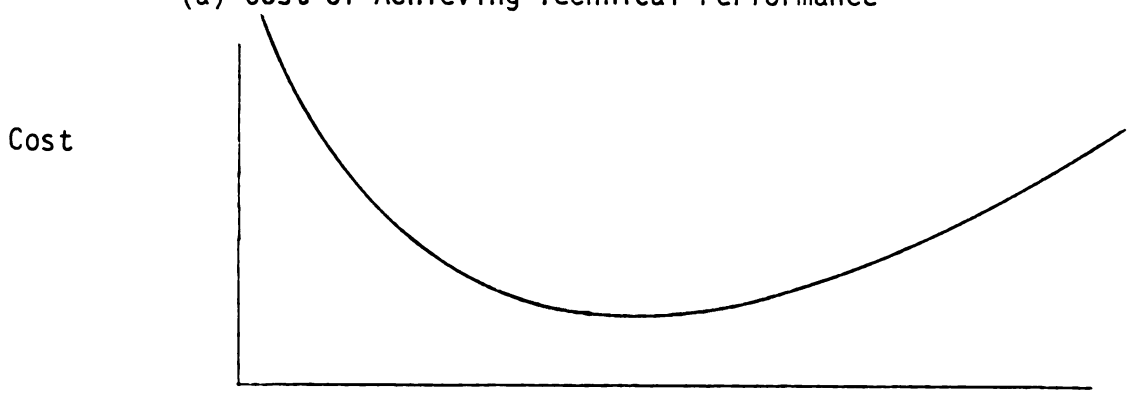
Figure III-3.--Activity as an Orthogonal Polyhedron.

Assuming the other dimensions to be held constant, in general, the greater the technical performance required, the larger the volume of this solid which corresponds with the increase in cost. The optimum in this dimension cannot be determined for the activity in isolation. It is generally recognized that there is an optimum time for a given task, technical performance and resources held constant. As time is reduced, or increased, from that optimum, total cost becomes greater. Likewise, for a given time and technical performance, there is an optimum resource application rate and the cost increases for less as well as more resources applied. These relationships between the three variables and the total cost, i.e., volume of the polyhedron are depicted in Figure III-4.

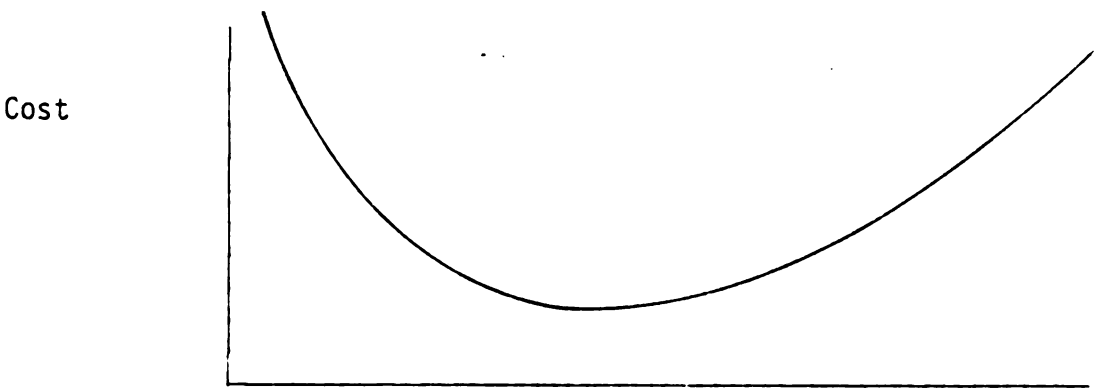
Of these relationships, it would seem that the relationship between time and cost is most understood. This was the relationship considered by Kelly (1959) in Critical Path Planning System (CPPS). However, closer examination makes clear that the CPPS model is really a limited model of the relationship between time and resources. Thinking only about the time-cost relationship leads to a limited set of considerations and factors. The time-resource relationship suggests a much broader set of considerations. Some of these have been receiving more attention in the literature of general management lately as research into behavioral factors in work are reported. Job enrichment and job enlargement concepts as promoted in general management literature by Hackman, Lawler, and others; leadership style as reported by researchers at the University of Michigan and



(a) Cost of Achieving Technical Performance



(b) Cost of Performing an Activity as a Function of Time



(c) Cost of Performing an Activity as a Function of Resources Used.

Figure III-4.--Functional Relationships between Cost and Activity Dimensions.

Ohio State; and organizational climate as reported by James and Jones, Schneider, and others, seem to have an effect on the time required to accomplish a given piece of work and therefore its cost. None of these really imply any additional resources applied to the activity. Rather they start to give insight into why essentially the same task may take a different amount of time for the same number of units of resource applied.

Ways to Improve Performance on Activities/Projects

It will be helpful to consider some ways in which performance on an activity, and therefore a project, can be improved. While the following are not exhaustive, they do suggest the variety of possible actions. Further, they are listed in a sequence that generally implies the relative cost or seriousness of the approaches.

1. Managerial Attention and Involvement
2. Expedite to Schedule
3. Improve Methods
4. Reassign Resources
5. Re-allocate Resources
6. Overlap Activities
7. Define the Activities in Greater Detail
8. Delete Certain Activities
9. Change the Technology Applied
10. Subcontract or Buy
11. Apply Additional Resources
12. Change Target Dates

13. Change the Scope of the Project
14. Change the Person Responsible, the Organization Structure, and/or the Management Information and Control System.

All of the above approaches are viable and necessary for effective management of activities as well as projects. Most of them are not really discussed in the literature on project management. Even this list includes no reference to behavioral approaches to improving performance on projects.

Conventional PERT/CPM really helps in only a few of these approaches to improving performance of an activity. The time-cost trade-off technique of conventional CPM addresses only the adding of resources, one of the least desirable (number 11 in the list above) ways of improving project performance. Other than adding resources, only a few of these are really applicable to just the time-cost relationship as considered in the context of the time-resource-technical performance model of this chapter. Those that are applicable to this time-cost relationship are (1) managerial attention and involvement, (2) expediting, (3) improved methods, (4) reassign resources, sometimes (7) defining the activity in greater detail, and sometimes (12) changing the target date. No explicit discussion of these approaches to improving performance of activities or projects was found. Thus, research would seem appropriate to achieve a better understanding of the relationship of each of these to activity time-resource-technical performance

and what we often consider the uncertainty associated with an activity.

In an effort to better understand the nature of an activity and the specific research that needs to be done at this level, each of the dimensions will be considered independently, in pairs, and all together. First, however, it will be helpful to consider the nature of uncertainty associated with an activity.

Analysis of Uncertainty

Sources of Uncertainty

The existence of uncertainty associated with an activity has been well accepted. Indeed, this one characteristic of activities has generated a considerable portion of the literature on managing projects. Interestingly, relatively little has been done to really understand the nature of the phenomenon. The research by Marquis and Straight (1965), Poust and Rubin (1966), and Baldwin, et al. (1971) provides some insight. The first showed the relative importance of criteria used in evaluation of project performance in R & D. Technical performance was overwhelmingly the most important criteria by all four types of respondents. This suggests that, on the types of projects considered in those studies, if any problems occur in meeting technical performance objectives, time and/or cost (i.e., resources) are going to be allowed to vary. In other types of projects, time or cost may have the highest priority, in which case,

the other two variables will be allowed to vary. Thus, when uncertainty is evaluated, it is important that the priorities with regards to the basic dimensions of an activity also be evaluated and controlled for statistically if not incorporated into the model.

In the Poust and Rubin (1966) article, the types of problems encountered corresponded very closely with the Marquis and Straight (1965) results. However, it is interesting to note that the laboratory manager, the one most closely measured by budget performance, ranked cost problems the highest. The data does not permit an evaluation of relative emphasis on cost as in the Marquis and Straight analysis. Both of these papers place uncertainties into perspective in terms of the three major dimensions of an activity.

The Baldwin (1971) paper provides some additional insight due to the additional detail on the factors. Table III-1 presents an analysis of those factors to suggest an even more penetrating analysis. Information on the nature of the factors in the article was limited to just the actual survey questions. Based on this information and some judgments based on personal experience, each of the factors was classified as to the dimension of an activity into which it might fit, plus two other classes, i.e., managerial performance and environmental variables. The factors are listed in sequence by the relative importance given them by all three types of respondents. The first category, time, is further specified as the "nature of the work," i.e., uncertainty as to the time required

TABLE III-1.--Classification of Causes of Delay on Construction.

	Time	Resources			Technical Performance		Other	
	Nature of Work	Human	Material	Equipment	Design	Execution	Managerial	Environmental
Weather					X		X	X
Subcontractors		X					X	
Labor Supply		X					X	X
Manufactured Items			X		X			
Material Shortages			X				X	
Foundation Conditions	X						X	X
Shop Drawings					X		X	
Design Changes	X				X		X	X
Finances							X	X
Permits							X	X
Jurisdictional Disputes		X					X	X
Construction Mistakes		X				X	X	
Sample Approvals							X	X
Equipment Failure				X				X
Contracts							X	X
Inspection						X	X	X
Building Codes					X		X	X

to perform the activity itself. This seems to be the characteristic most associated with the time only variable, three types of resources are shown--human, material, and equipment. Human problems may be a function of availability, skills, motivation or a number of other characteristics. Material problems may be a function of late delivery, non-conformance to specifications, or inadequate specifications. Equipment problems may be due to failure of the unit to operate or to its inadequacy for the job. Technical performance problems could be in the specification of the item on which the activity is performed in which case it is a design problem, or in the execution of the activity. Managerial causes could stem from bad decisions, lack of attention to the details of managing, poor information system design, inappropriate organization structure, or other considerations. Environmental variables are conditions external to the activity or the performing organization but within which the activity must be performed. In the construction industry weather would be expected to be a major variable in environmental causes of uncertainty. There are other variables which may contribute to uncertainties or delays including failure to recognize a necessary activity in the planning process, interruption of work on an activity (or a project), changes in objectives, and accidents whether preventable or due to natural causes.

While admitting that the process of relating the factors and the causes is purely subjective and arbitrary, the analysis does point out some interesting possibilities. First, only two of

the causes are related to the nature of the work itself. On the other hand, most of the causes could be related to managerial considerations. The weather, is normally thought of as an environmental variable. It need not be if construction is started at an appropriate time of year. Starting at the beginning of winter is sure to impose delays. Often the start time is a function of managerial decision, or indecision. Also, certain technical steps can be taken to minimize the effect of the weather. For example, a building which was started in late fall was protected from delays due to site accessability during the rains of spring by first installing black top over the entire construction site. Thus, uncertainty due to weather is not a function of the activity itself. Similarly, foundation conditions can be determined by adequate test borings. Nevertheless, unexpected conditions may be found. Therefore, it is shown to be a function of the nature of work, managerial considerations, or environmental variables. The findings reported by Eyring (1966) on the causes of uncertainties in a design project are consistent with these observations. It would seem that studies of other types of projects could also provide insights which, when combined, would lead to a more thorough understanding of the nature of uncertainties.

Based on this analysis, it can be seen that there are several sources of uncertainty including the nature of the work itself, the resources used, the technical performance specifications and their achievability, management considerations, and environmental variables.

The classical PERT model makes no distinction between these sources of uncertainty. Decision CPM and related approaches (discussed in Chapters IV and V) start to recognize some distinctions by providing for uncertainty as to the existence of the activity. The considerations incorporated to date do not seem to provide adequate treatment of uncertainties in light of the above analysis.

Non-repetitiveness

One characteristic which is credited with causing much of the uncertainty of project activities is their uniqueness, i.e., that they are non-repetitive. A project is generally composed of non-repetitive work, at least in comparison to assembly line work. Whenever possible, repetition of basic operations is sought to gain efficiency such as in a major housing project or the erection of successive floors of buildings like the World Trade Center Towers. This repetitiveness not only leads to lower unit costs but also to better ability to determine performance estimates. Even so, the degree of repetiveness is relatively low. The activity, rather than being very short in duration and repeated hundreds or thousands of times with little intervening time, as are the work elements in mass production, repeated activities in a project are longer in duration and have other activities interspersed between their repetitions.

The fact that a project is composed of non-repetitive work creates problems of estimating the time and resources required to accomplish an activity. A work element on an assembly line is

performed thousands of times. It is physically possible and economically feasible to expend industrial engineering time to establish a relatively objective time standard for the work element's performance. The time standard itself is often established as a result of observing at least several repetitions of the work. The non-repetitive nature of project work not only makes it uneconomical to apply industrial engineering techniques but makes it impossible if the work is to be performed only once.

Both repetitive and non-repetitive activities have uncertainties associated with them, both in estimating and in performance. For non-repetitive activities, that uncertainty is often the problem of a "sample of one" from the set of all possible occurrences. On the other hand, the sheer repetitiveness of assembly line work allows the law of large numbers to take effect and any observations of a work element are generally of multiple repetitions, and thus of the mean of many repetitions rather than the value of a single performance of the work element.

Project activities are generally many times longer than typical repetitive work elements. Assembly line work elements are measured in seconds while project activities are often several days or weeks in duration. This, coupled with the inability to average performance over a large number of repetitions, makes the variability of the project activity more serious.

The emphasis on pushing the state-to-the-art implies that project activities may never have been done before. Indeed, there

is no assurance that they can be done at all. There is much uncertainty inherent in these activities. To further complicate the matter, the number of persons available who can perform these activities may be quite small, if not singular.

The fact that a project is generally composed of non-repetitive activities necessitates a greater degree of coordination of resources. The scheduling of manpower of widely differing skills, the scheduling of special equipment, and the scheduling of the arrival of a variety of materials all create demands for careful coordination. The precision required in this coordination has increased in the last four decades as time and cost pressures have increased along with the magnitude of the projects. The trend of the past four decades to continually push the state-of-the-art in all sorts of project efforts, and the concommitant uncertainties, have made that coordination even more difficult.

In addition, the non-repetitiveness of project activities minimizes the opportunity for corrective action. If the requirements or instructions on a repetitive activity are not well defined, communicated adequately, or followed properly, corrections can be made on subsequent repetitions. At best, such a problem on many project activities can be corrected while the activity is in process, thus affecting its performance as compared to estimate. Sometimes it cannot be corrected until after the activity is completed in which case some or all of the work must be repeated. Worse, it may not be discovered until after several subsequent activities have

been completed necessitating, not only rework, but also the removal of the intervening work product. For example, an error by a surveyor in laying out a piping tunnel was not discovered until after several yards of concrete were in place. It had to be removed before the error could be corrected. Perhaps the worst case is the error not being discovered until the product is operational resulting in considerable damage and possible loss of life on some projects.

In spite of all of these sources of uncertainties due to the non-repetitive nature of project activities, the problem may be over emphasized. In any project, there will be some activities which are routine in nature. Although the values of the variables are different from before, their functional relationship may be relatively well understood. No research was found that attempted to determine the distribution of activities on the basis of their degree of uniqueness or non-repetitiveness.

Other Sources of Uncertainty

There are other causes of delays on projects. Generally we assume that the resources are going to be available on a regular schedule for the duration of the activity. Many things happen to negate that assumption. People get sick, are promoted (and replaced slowly, if at all), they quit, they have to serve on jury duty, and they go on vacations, just to name a few. Unique equipment, in addition to breaking down, may be scheduled for other uses and

may become available late. Although it is beyond the scope of the present study, further consideration of all the sources of uncertainties is needed.

In the graphs for the short-run cost curves, a single line has been used implying a certainty, or certainty equivalent, in the relationship. Each of the curves in Figure III-4 could be shown with a band about them similar to confidence interval bands about a regression line. Thus, the short- and long-run cost curves would also have a range of uncertainty associated with them, such as shown in Figure III-5.

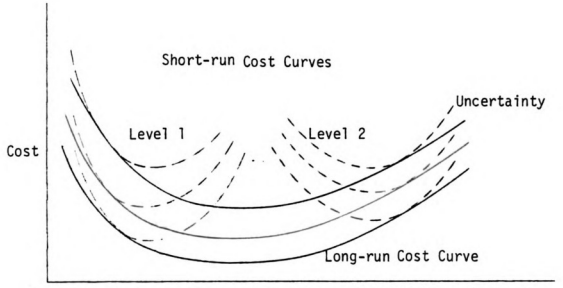


Figure III-5.--Uncertainties Associated with Short- and Long-run Cost Curves.

Such a representation does not clearly relate the dynamics of project activities. For example, it does not portray the trade-off relationship that results depending upon which dimension of the activity--time, resource, or technical performance--has the highest priority by the organization. It does not really indicate which dimension is most likely to be allowed to slip under pressure as one or more uncertainties are realized. Dodson (1972) implied that schedule slippage was the most critical. In other projects resources or technical performance may be more critical. It is conceivable that in some, total cost could be so restricted that a search for another combination of all three--time, resources, and technical performance--would be sought.

Treatment of Uncertainty

PERT was designed to deal specifically with the uncertainty in the time dimension. While numerous articles have addressed the mathematics of alternative means for dealing with this uncertainty, relatively little has been done to really understand the nature of the uncertainty itself. It seems that more is known about the robustness of the Beta distribution assumption than is known about the variables underlying the uncertainty. Indeed, most such research implicitly assumes "mechanical" relationships at the exclusion of human behavioral types of relationships.

DOD doctrine in the past has dealt with the broader concept of uncertainty but, it seems, in an ineffective manner. Within the PERT/COST concept, uncertainties of cost can be handled in two basic

manners. First, a factor can be applied to each activity to increase the budget for the activity to account for the uncertainties inherent in its performance. Alternatively, the activities could be estimated more "honestly" and a contingency account established to contain all of the budgeted amount for the uncertainties. The bidder has been fearful of the latter approach because it became a very visible target for downward negotiation. Whether this fear was well founded or not would be an appropriate subject for research. Nevertheless, it resulted in the "contingency" being spread over all activities. As a result, that increased amount may have become the target expenditure amount for that activity, whether it was needed in fact or not. If so, then the contingency amounts would be used up by activities not really requiring it and not be available on those requiring more than was allocated. It is general knowledge that in many (if not most) organizations, it is almost sinful to not fully expend a budget. Alternatively, the management of the contractor may have reduced each activity by a fixed amount to create an "internal" contingency fund. But this, in some cases at least, creates attitude problems within the contractor organization as well as problems in the attempts to conceal this action from the government representatives. How wide spread the practices discussed here are, in fact, is not known. It would be an appropriate subject for research to determine the facts in this regard and to attempt to determine the effect on total project performance as a result.

A similar problem in the time dimension was handled in a comparable manner in the application of networking in the Styling Studios of a major automotive manufacturer. The planner was sensitive to the uncertainties in the activities. Nevertheless, he made no allowance for this in the individual activities. Instead, he identified key points in the network before which he placed an activity which he called "water." There was no work associated with it. It was simply an aggregate contingency allowance to realistically reflect the probable course of events. These key points were often points of major convergence or divergence in the network.

Convergence often occurred before major styling reviews while divergencies occurred after such reviews or after controlling activities. An example of the latter was the transfer of character lines via templates from the clay model to an engineering metal draft (EMD). As soon as the EMD was completed to a certain point, a large number of design and detailing activities could start. Delay in accomplishing this work on the EMD could result in a number of people being idle while waiting for their inputs. Experienced schedulers, whether in a project, job shop, or mass production environment, seem to insert "water" in their schedules. This concept is not treated specifically in the writings on PERT even though it can easily be incorporated.

Uncertainty with the weather on a construction project is similar in concept. Snow, ice, and freezing temperatures can bring

construction to a halt. Should allowance be added into each activity for weather? It seems more reasonable to reduce the effective number of days per month or for the winter season. This can be accomplished by "water" with a standard calendar or by a reduced calendar. Doing either of these has implications on the information system design. It becomes more important to emphasize the time actually spent working on the activity rather than reporting the elapsed time as a result of recording the start and finish dates. This is not a common feature in the design of such systems.

Another source of uncertainty which becomes tedious to handle in conventional systems is the design, fabricate, test sequence in which the sequence has to be repeated in the event of test failure. An example of such a phenomenon is the testing of lamps on an automobile. The State of California has had more stringent standards than the rest of the U.S. Failure of the lamp assemblies to pass their test resulted in the affected car being prohibited from sale in California. For various reasons, failures occur. In this event, the sequence is repeated. However the activities that are repeated are done differently the second time around. In the rare event of a second failure, the next repetition is again different from the previous two. This is necessary due to the reduced time available. Different methods, manpower, and materials may be involved. Around the clock operations may be involved the third time. This can be handled in GERTS but with some tedium. Using expected values based on the probability of occurrence to determine how much time to allow

for the repetitions is not very helpful. If failure occurs, the full time required must be there while if no failure occurs no time is required.

Analysis of Dimensions

Time Only

The research of King and Wilson (1967) and others into the relationship of the estimated duration and actual duration of an activity has been discussed in terms of the measures of the difference between estimate and actual. The results seem to be inconclusive due to failure to consider or to control the other dimensions, as well as the difference in measures and their characteristics as used on the various studies. Some insight is gained from the Adams (1974) study of the possible effects of human variables. Other research has shown differences in activity characteristics as a function of the type of activity. These studies have been on such a limited variety of project work as to severely limit their general applicability at this time. All of these studies have, at least implicitly, assumed that the actual performance time was the accurate measure and the estimate was an unknown quantity which varied around the actual. This assumption is questioned here. The phenomenon cannot be more clearly stated than by Parkinson (1957) as his First Law . . . "Work expands so as to fill the time available for its completion" (p. 2). If this proposition is accepted, it seems reasonable to argue that the estimate becomes a target and the actual varies about it.

Closely related to this concept is a major concern about the practical application of PERT. The typical system implementation of PERT requires three time estimates to reflect the shape of the distribution of the performance times of an activity. Call this the a priori distribution. These are then converted into "t_e" which is printed on the report distributed to the performers. If this t_e becomes a target as discussed above, it seems reasonable that something we might call the a posteriori distribution, as if the activity were repeated a number of times, may be different. It could be different in shape as well as location. While the Parkinson phenomenon may truncate the left side of the distribution, other behaviors could result in the elongation of the right side of the distribution. For example, it seems to be a characteristic of human behavior to not want to report, or even admit to, failure. Thus, for those activities which do exceed "t_e," it seems reasonable that they may well exceed "b" because corrective action would not be taken as soon as possible. Thus, we would hypothesize that the a posteriori distribution would be to the right of and more skewed to the right than the a priori distribution as shown in Figure III-6.

One possible rationale for the Parkinson behavior is the frequent reaction of management to reduce a person's estimates if he consistently performs in less than the expected time. Rather than risk this reaction, the performer is likely to continue work on the activity well beyond completion to avoid reporting its completion early. Another rationale might be the tendency of at

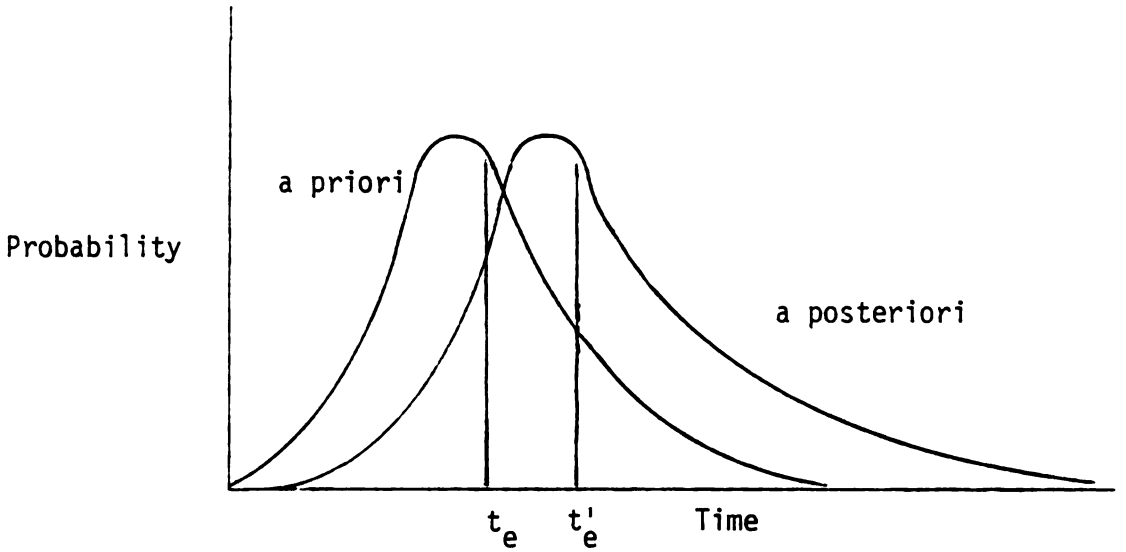


Figure III-6.--A Priori versus A Posteriori Distributions in PERT.

least some types of people to want to turn out the best possible product. Thus, they will use any time available to make improvements on whatever solution they may have even though it may have been satisfactory at an earlier time.

Estimate versus Actual

There has been considerable research into the relationship between estimates and actuals on the time dimension. Because of the orientation of the original researchers, i.e., King and Wilson (1967), much of this research was simply to determine if consistent patterns of bias in estimates could be found. Lock (1968) also showed some interest in this approach as he warned against "re-educating" the estimators as it "upsets the stability of the process and you don't know what the fudge factor is" (p. 40). The research

by Adams (1974) was really the first attempt to find reasons for the differences between estimates and actuals.

It is relevant to the discussion of the nature of an activity to consider the various measures of this difference which have been used to date along with some observations on the pros and cons of each measure.

Number of activities over- or under-estimated--This was used by Tyler and West (1975) as a measure of the degree of optimism or pessimism in estimating, "independent of the magnitude of the errors in individual activities" (p. 21). An activity was considered accurately estimated if the actual was within plus or minus one day of the estimate. As they said, it ignores the magnitude of the errors completely.

Total number days of error (the summation of the algebraic differences between estimated and actual over the sample of activities)--Used by Adams (1974), it focuses on net magnitude. Being an algebraic sum, the variance of this measure will be less than the variance of the individual activity differences (by the Central Limit Theorem).

Total Absolute Value of number of days in error--Also used by Adams (1974), it focuses on magnitude but overcomes the variance problem. Both of these measures are affected by the degree of detail in defining activities in the project.

Relative magnitude (estimate divided by actual)--This was the major comparative measure used by King et al. (1967)

and Kidd and Morgan (1969). The choice of the denominator may be interpreted as an implication that it is the "accurate" one. Another conceptualization could be based upon the accepted hypothesis (#5) by Adams (1974) that estimates tend to become targets. In this view, comparison would show how close the actual came to the estimate, arguing for the estimated to be the denominator. Differences between estimate and actual of substantially different absolute magnitudes are given the same weight. Thus, the comparison for two different activities may both give 110% when for a ten day activity this was a difference of one day while for a 100 day activity it was a difference of ten days, a much more serious error in project completion time. Of course, a series of ten 10 day activities could accumulate a total of 10 days difference. Also, it should be noted that the domain of this variable is from zero to infinity with perfect agreement being equal to one. The range of the variable is from zero to one for actual less than estimate versus one to infinity for actual greater than estimate; certainly not symmetrical.

Absolute Difference--This measure, focusing on the magnitude of the error regardless of direction, was used by Adams (1974). It implies that the cost, or problems to the organization, of an error is the same in either direction and increases with the magnitude of the error. It also gives

more emphasis to errors of smaller magnitude because the actual is limited by zero on the low side while unlimited on the positive side. It is also influenced by the degree of detail at which activities are defined.

Algebraic Difference--This was the basic measure used by Abernathy (1971). It permits recognizing that the costs of error in one direction may be different from the costs of a comparable error in the other direction. However, the distribution of errors by magnitude is greatly influenced by operating practices of the organization, i.e., in terms of the degree of detail by which the activities are defined.

Absolute Relative Difference (the absolute value of the difference between actual and estimate divided by the actual)--This measure was one of the four used by Adams (1974) and was selected for detailed analysis of the behavioral variables because "of its wide use in the literature as a measure of accuracy" (p. 107). While overcoming the weakness of the magnitude measure above, it still implies that the cost of error is the same in either direction. When viewed in the context used by Adams, i.e., the average of this variable over four activities selected at random, it can be seen that to use the algebraic differences would have led to smaller values of the variable because the negative values would have been subtracted from the positive values.

Relative Difference (the same as above without the absolute)--This was used by Tyler and West (1975) who were

> interested in optimism of estimating. It focuses on the magnitude of the error relative to the magnitude of the activity. It is particularly relevant for analyzing error as a function of the magnitude, i.e., correlation of relative difference with estimated. For other purposes, it might obscure the effective importance of the error in the same manner as relative magnitude above.

Another way to analyze these measures is as to their nature and what they measured. The nature of the measure can be subjective or objective, specific or general, and macro to micro. The object of measurement could be either a simulated/laboratory task or performance on actual projects. The unit of study could be an individual, a group, or an organization. Table III-2 presents a summary of studies reviewed classified with regards to these characteristics of the measures. The classification is purely judgemental based only on the information available in the referenced article. In no case did the original authors characterize their measurements on these scales.

From the above it can be seen that primary interest in comparing activity performance has been from the point of view of improving estimating accuracy. Other than the work by Boercherding, no reports of research were found which directed its attention to the point of view of improving the performance of activities. By implication, the estimating point of view assumes an "activity" is a fixed quantity which is theoretically capable of being estimated

TABLE III-2.--Measures of Activity/Project Performance.

	Organization		Group	Individual	Real	Simulated	Macro	Micro	Objective	Subjective	Specific	General
Marquis and Straight (1965)												
Technical Performance	x				x		x		x		x	
Meeting Schedule	x				x		x		x		x	
Meeting Target Cost	x				x		x		x		x	
Customer Satisfaction	x				x		x			x		x
Profit	x				x		x		x		x	
Follow-on Business	x				x		x		x			x
Company Prestige	x				x		x			x		x
Develop Technical Capability	x				x		x		x		x	
Commercial Applications	x				x		x			x		x
Aram and Morgan (1976)												
Technical Performance			x		x		x			x		x
Weinstein and Holzbach (1973)												
Questionaires Coded		x				x		x	x		x	
Schutz (1955)												
Problems Solved		x				x		x	x		x	
Andrews (1967)												
Technical Contribution (Self and Peer)			x		x		x			x		x
Usefulness of work (Self and Peer)			x		x		x			x		x
Output (papers published, patents, papers unpublished)			x		x		x		x		x	
Schneider (1973)												
Accounts Switched (Actual or Intended)			x		x			x	x		x	
Rubin and Seelig (1967)												
Project Performance	x				x		x			x		x
King et al. (1967)												
Estimated Time/Actual Time					x			x	x		x	
Kidd and Morgan (1969)												
Estimated Time/Actual Time					x			x	x		x	
Abernathy (1971)												
Actual Time--Estimated Time					x			x	x		x	
Adams (1974)												
Estimated Time/Actual Time			x		x			x	x		x	
Average of (Differences/Actual)			x		x			x	x		x	
Sum of Errors in Estimates			x		x			x	x		x	
Absolute value of Sum of Errors in Estimates			x		x			x	x		x	

precisely. The implied problem of estimating is one of specifying a quantitative value for an attribute of an entity about which knowledge is imperfect, by people who have differing motivations, skills, and perceptions.

An alternative point of view might be that an activity has finite dimensions and therefore a specific work content which theoretically is capable of being performed precisely if properly communicated. The implied problem of performance then is one of applying the appropriate resources to perform the given amount of work in a given amount of time by people with differing motivations, skills, and perceptions. This implies an "accurate" estimate of these variables.

Combining these views, another alternative point of view is that an activity is an ambiguously defined entity to which both the estimator and performer apply their selective perceptions depending on their respective skills, experiences, motivations, etc. Their perceptions may be affected by experience and conditions existing both inside and outside their respective organizations as well as within themselves and may be a function of a number of characteristics of the project, its activities, and other technical factors. This really focuses attention on the problem of communication of what was intended to be accomplished by performing the activity.

There are three basic approaches to analyzing, defining, and communicating the statement of work associated with an activity.

Cleland and King (1975) discuss the Linear Responsibility Chart (pp. 271-298) along with a model for the "management subsystem" for managing the work and responsibilities identified. Archibald (1976) discusses "Defining the Project and Identifying Specific Tasks and Responsibilities" (pp. 141-155). He advocates a Task/Responsibility Matrix (more commonly known as the Linear Responsibility Chart). The Linear Responsibility Chart generally says less about the activity than it does about who has what decision and/or action responsibilities with regard to activities in general.

Archibald (1976) discussed a Task Work Order document (pp. 180-190). It provides a checklist of supplemental documents which further specify details. However, it must be recognized that this document relates to his definition of a task as "a short-term effort (usually 3 to 6 months) performed by one organization which may combine with other tasks to form a project" (p. 18). He does not clarify whether or not, in practice, an activity is equivalent to a task as defined in the work order. If not, there is still a question as to the precise definition of the work content and product specifications for an activity. Based on his definition, the task is more comparable to a "work package" in PERT/COST which consists of several activities.

The more generally used method of defining an activity is by relying on industry standards, company technical instructions, past practice, and the like. This leaves a lot of room for ambiguity and misunderstandings. While the Task Work Order document involves

a lot of time and effort, too little documentation can be expensive also.

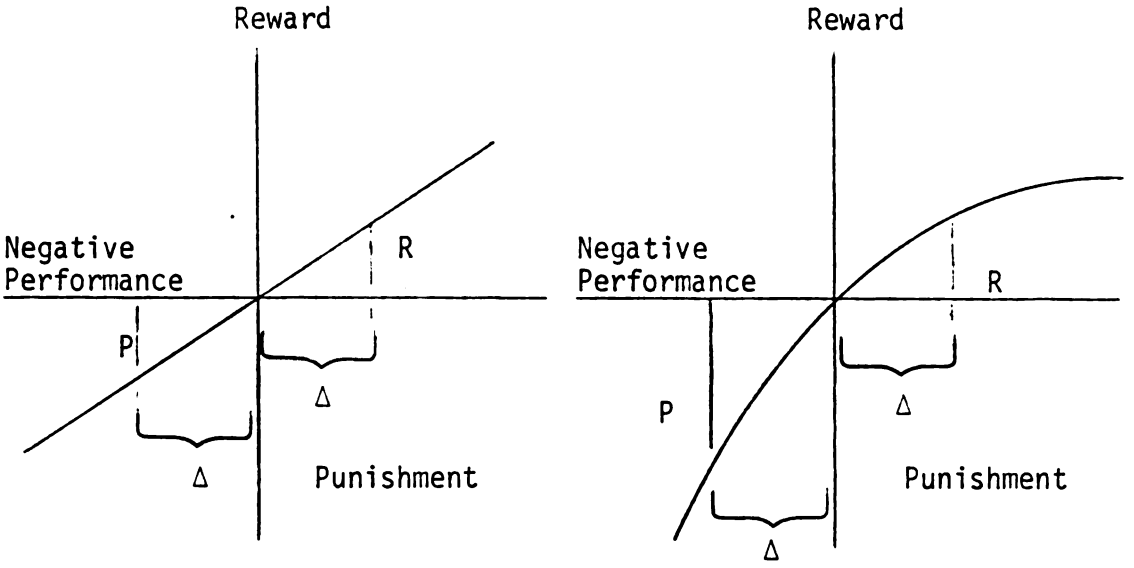
It should be noted that there are different approaches to developing estimates. Adams (1974) showed that the type of information sought by the estimator had an impact on the differences between estimate and actual. It is reasonable to speak of "estimating strategy." One approach is to list all activities, develop the network, and then estimate the activities. Another would be to estimate the activities at the same time as they are listed but without the aid of the network. Construction industry practice is to estimate the work content of a project from the bill-of-materials take-off. The activities are identified later and activity estimates sometimes compared to the bidding estimates. It seems reasonable that different approaches may give different estimates. For example, estimates made with the aide of a network may be biased either by the length of the arrow or by knowledge of the time available.

The problem of estimate versus actual is further complicated by the non-repetitive nature of project activities. Rather than objectively set time standards someone has to make an estimate of the duration. The difference between estimate and actual may be affected by whether the estimates are imposed by higher authority, made by an objective estimator, or made by the individual responsible for performing the activity.

Some organizations go to great lengths to separate the estimating from the performing. There are arguments pro and con

on this. One of the arguments in favor of separation is that the estimate is more objective. One of the major negative arguments is that the performer does not "own" the estimates, therefore he does not feel emotionally obliged to meet the estimate, or target. In much state-of-the-art work, the performer may be the only one who can make a well informed estimate.

When the performer makes the estimate he is likely to inflate it to increase the probability of success. A possible rationale for this behavior is based on the reaction of management to the relationship between actual and estimate. It is conjectured that management's reaction to this difference is dependent upon whether it is a positive or negative difference. Indeed, on a mapping of rewards versus punishment as a function of this difference, management's reaction may not be "symmetrical." For management's reaction to be symmetrical, the rewards for a positive increment i.e., favorable performance, would have to be equal but opposite to the punishment meted out for negative performance as perceived by the performer. This is shown in Figure III-7(a). Non-symmetrical reaction would be as shown in Figure III-7(b). Thus, the cost perceived by the individual of exceeding the estimated duration, i.e., negative performance, by a given increment, is greater than the reward for the same sized increment of positive performance. The significance of this in terms of an activity is the effect it has on the estimator/performer. If the assymmetrical relationship prevails, the estimator/performer will attempt to set



(a) Symmetrical Relationship (b) Non-symmetrical Relationship

Figure III-7.--Relationship Between Performance and Rewards/ Punishment.

the estimate higher to improve the probability of at least meeting the target. Thus, the estimates will be inflated. This is especially important in the management of project activities due to the lack of objective measures of what the estimate should be. It is also especially relevant in project work due to the fact that the symmetry of the relationship is basically within the control of management. The curve need not be asymmetrical. Some research laboratories have gone to great lengths to provide rewards in addition to monetary compensation. This would tend to raise the reward side of the curve. On the other hand, without ignoring negative performance, the nature of management's reaction can determine the slope of the punishment side of the curve. Such things as

rationally discussing the nature of the problem in private conversation accompanied by honest efforts to assist the person through educational programs, elimination of obstacles where possible, etc., could substantially reduce the perceived slope of the punishment side of the curve.

Experience in managing an Operation Research group led to a personal conviction that people motivated to achieve good performance, in an environment where they do not feel threatened by negative performance, will consistently estimate too conservatively. Performers were actually encouraged to increase their time estimates in most cases in this operation.

In the longer run, it is important to retain historical records of performance on all activities for which the person is responsible. If the a posteriori distribution of the normalized times is substantially skewed to either the right or the left, corrective action should be taken to improve the estimating or the performance, or both. No evidence was found of a system implementation which provides for such record keeping.

Still another phenomenon affects the relationship between estimate and actual. Often management, by direct or indirect action, causes estimates to be reduced. Sometimes there may be very legitimate reasons for this. If it is vital to win a bid, management may prefer reducing the estimates rather than submitting a bid too large to win. At least it may make a contribution to fixed costs and retain key workers. Nevertheless, for whatever reason the action

may be taken, if actual performance is compared to these reduced estimates, the results will be distorted. Performance should be measured on the original estimate, as well as the reduced, before taking corrective action.

It would also seem desirable to explain the rationale to the performer if their cooperation is desired. Of course, if it is solely to "squeeze" the performer into better performance, reactions by the performers may result in actual deterioration of performance. Although keeping some pressure on performers does seem to result in improved performance, there is reason to believe that excessive pressure may lead to frustration and very poor performance (Stedry, 1960). Perhaps such things as organizational climate and leadership style can be more effective ways of creating motivation.

One other consideration potentially affecting only the time dimension of an activity is divisibility. There seems to be two aspects of this. In the listing of ways to improve project performance, defining the project in more detail was included. This is available in any system implementation of the network approach to project management. The other aspect is normally called the "interruptible" activity, i.e., an activity, once started, can be interrupted and a portion performed at a later point in time so long as it is not inconsistent with other network logic. This is not a usual feature in existing systems.

While Jewell (1965 and 1970) and Bodin (1968) addressed the problem of an algorithm for handling the interruptible activity

optimally, they offered no empirical evidence for the assumption that the sums of the parts were equal to the whole. This seems reasonable in some cases. However, just as the job shop scheduler is concerned with set up costs, many activities may have set-up costs. In computer programming, and some other areas, this may be more of a re-learning time. As this process of dividing activities into smaller activities continues, there must be some optimum degree of dividing below which the sum of the parts becomes greater than the whole. Such a relationship has been shown to exist for assembly line balancing and some guides developed. The only guides that have been given for this in project planning are some general statements. "Do not sub-divide activities any more than necessary," or "Each activity costs xx¢ to process on a computer." The first is of little help at all and the other considers only a portion of the costs and none of the benefits.

Resources Only

There are five classes of resources to consider--labor, equipment, materials, space, and sometimes energy. Labor is the resource that is generally implied in most discussions. Several assumptions are made implicitly in dealing with resources on network activities depending on the technique used including:

1. Unlimited supply when needed
2. Homogeneity or interchangeability within broad classes
3. Availability of amounts of a resource is a continuous function

4. Uniform distribution of resources over the duration of the activity.

The assumption of unlimited supply has been well recognized for both PERT and CPM. This led to the development of resource leveling systems. Actually, this assumption is applicable to the individual activity only when requirements exceed supply, either for the activity or for the set of activities scheduled in the same time period, resulting in inadequate availability of resources to that activity.

The general availability of the resource is a major factor. If the resource is standard, there will be generally less problems of availability when needed than if it is a unique, scarce resource. In addition, even for a standard resource, the demand for the resource varies. If competition for the resource is high, its availability may be limited at the time required thus affecting performance on the activity.

A major difference in uncertainties associated with the resource is whether the resources are "in-house" with relatively close control or from outside the organization and subject to less control. The unsteady progress on house construction, depending on the availability of the subcontractor at the time needed, is an excellent example of this phenomena. It is important to realize that the subcontractor has a cost function to minimize which does not necessarily lead to decisions that optimize the cost function of the contractor.

The assumption of homogeneity of resources, i.e., that any unit of the resource can perform the activity with equal efficiency and effectiveness, is implicit in most CPM and resource leveling systems. The alternative assumption would be that every unit of resource has unique capabilities. Very little is found in the literature discussing this alternative's application to project management. For example, Cleland and King (1975, pp. 95-144) discuss the assignment problem, but only to show the extreme complexity involved in practical size problems. Most of the examples were generally broad strategic problems. Eyring (1966) refers to the problem of availability of the right resource to perform an activity. In seminars on network approaches to planning there is frequently an admonition to estimate based on the average worker, matching individual workers to activities based on criticality of the activity as time for performance is approached. This assumption of homogeneity/interchangeability is probably acceptable in most instances of CPM and resource leveling where the problem is the allocation of resources. It ignores the problems of first and second level supervision who must assign specific units of resource to specific activities in an "optimum" fashion. This assumption is frequently unacceptable on advanced technology projects where the resources are often highly specialized if not unique.

Experience in applying networking in an engineering and drafting room environment led to full realization of the problem of heterogeneity of resources. In this environment, the resources

are not homogeneous. One draftsman can lay out a bumper in maybe half the time of another. The other draftsman may be more efficient on quarter panels. Thus, there exists an assignment problem, but with another level of complexity. In addition to the man-activity dimensions, there is a time dimension. Activities do not become available to be performed at "convenient" times. When the activity becomes available to be worked on, the best person may be in the middle of another activity which will not be completed for some time. Thus, a decision must be made as to whether to wait for the best person or go ahead with the best available at the time. It turns out that this is a continuous process of decision making and, in a large engineering-drafting shop, over a large number of people and activities. This could be given the name of the "drafting room scheduling problem." Research has revealed no literature dealing specifically with this problem except for the very limited model by Pritsker et al. (1969) in allowing for resource substitution. Personal experience in dealing with the problem indicates that conventional PERT, CPM, and resource leveling systems are inadequate for this problem except to validate decisions made by supervision.

The assumption that amounts of a resource are available as a continuous function is certainly acceptable if the principle means of securing the additional resources is through overtime. Other alternative means include another shift, adding more people, opening a new plant, etc. In general these imply a discontinuous, normally stepwise, function. Only one system, RAMPS (Resource

several activities at the beginning of a shift and it can only service one at a time, all but one activity is going to be delayed. Such problems are left to first level supervision to resolve at the time. This may not be the best approach. It might be useful to provide some information to help them understand the conflict earlier so plans for its resolution can be made before it becomes a crisis. On the other hand, a cost-benefit analysis applied to the degree of detail practical in planning might lead to the conclusion that much of such detail should be left to first level supervision.

While not much has been said about it in the literature, space in which to perform the activity may be critical. Laying a pipe in the confined space of a too narrow ditch may take substantially longer than if the ditch had been dug properly. Mere lack of space may cause delays and/or interruptions. Sharing space may reduce the efficiency of the work crews. For example, installing floor tile while others are still installing overhead lighting in the same floor area is possible but may be very unproductive. Such relationships may not be stated in the technological relationships in the network. Therefore, coding space as a resource could permit checking for conflicts of this type. Clearly, all such problems cannot be accounted for in a formal planning system. Where practicable, it may be of value to provide supervision with information to aid them in anticipating the problems.

The resource that has seemed most ignored in project management systems is material. The conventional approach is to provide

Allocation and Multiple Project Scheduling) uses the discrete function, allowing three resource levels.

The assumption of uniform distribution of the resource over the duration of an activity may also be questioned. The research by Norden (1960) clearly indicated a pattern of resource buildup and reduction over the life of a project. At the other extreme, an activity can be defined at a level of detail for which the uniform distribution assumption is certainly applicable. Little is known about the distribution of resources over an activity defined at intermediate levels of detail. There are few guidelines that can be used to determine the appropriate level of detail when considering resource leveling. Perhaps there should be a capability to designate a resource requirement only over a portion of the duration of an activity. On the other hand such a capability might simply make the system more complex and cumbersome to use as well as costly to develop and run on a computer.

The handling of equipment has been done in the same manner as labor. Often, an item of equipment is required full time for the duration of the activity. Sometimes it is required only at specific points in the activity's duration. This often is the case with a crane, for example. The only way to recognize this is to estimate the resource requirement at some percentage (less than 100) which is implicitly assumed to be uniform over the duration. This could lead to conflicts between activities for the resource and therefore delays in performance. For example, if the resource is required by

an activity, often called "Material Received," preceding the activity requiring that material. No information was found in the current study indicating that material receipt, storage, and inventory systems have been integrated with or into a comprehensive project management system. One possible exception may have been in the construction of the twin tower World Trade Center on lower Mannhattan. News coverage of that project indicated that all material was received at a staging area in New Jersey. For example, each beam or column was uniquely identified. Trucks were loaded with material in reverse order of its need at the construction site so that it could be removed from the truck and installed directly. Thus, material inventory was at a minimum at the site. The equipment for the Ford Michigan Casting Plant was tagged on arrival with an eight part serially numbered tag. Storage location, inspection, move to installation site, and other steps were all controlled via the parts of that tag. Other approaches have surely been used. The literature is sparse in this regard. It would seem feasible to provide such capabilities as an integral part of a comprehensive project management system.

Explicit recognition of energy as a scarce resource has only begun to be accepted in many areas of our society. No mention of it was found in discussions of managing projects per se. Space projects have been concerned about energy requirements in the operation of the space vehicle but the energy requirements of the project itself appear to have been largely ignored except in the budget. It would seem

likely that energy considerations may have been recognized somewhat more directly in the Alaskan Pipeline project. As the cost of energy continues to increase, and as the cost becomes more a function of peak load usage, it seems reasonable that energy usage in project activities will become a matter of greater concern.

There is a question as to how many resources should be associated with a single activity. PERT considered time to be the only relevant variable. CPPS added the measure of cost of all direct resources on an activity but generally did not aggregate those for the project. PERT/COST, in an effort to recognize total budgeted costs, also incorporated indirect costs. Some versions also permitted evaluation of usage profiles of specific direct resources. The earliest systems to permit leveling of resources provided for only one resource. Later, the number was expanded. Various packages today provide for different numbers of resource types. Additionally, the method for dealing with these resources by the system varies. Clearly, the resource leveling problem is complex with only one resource considered. The more resource types that are considered simultaneously, the more nearly impossible the problem becomes. Intuition says that it is not necessary to consider all of several resources at the same time. On any one project there are relatively few resources that are really controlling. The system could concentrate on one or two such priority resources and simply audit the level and conflicts of the others. Another level of sophistication would allow the user to specify the priority

resources as a function of the phase of the project. A still higher level of sophistication would provide capabilities for the system to analyze and recommend priorities by phase. Nevertheless, for purposes of design of systems, a better understanding of how many resources should be allowed per activity and how they should be handled is important.

While it is customary to focus on time as the dependent variable associated with amount of resources applied to an activity, it is helpful in gaining an understanding of the economics of an activity to consider cost as the dependent variable, holding time and technical performance constant. Figure III-4(c) shows that the cost of performing an activity varies as a function of the amount of the resources applied, for a fixed duration. This is the familiar "U" shaped curve for which the optimal resource application rate is at the minimum. There is also the variable of method or technology used to perform the activity. Different technologies will require different amounts and/or types of resource at their optimums. Thus, the cost of performing an activity is a function of both the technology and the resource application rate, as shown in Figure III-8. Although the technologies, and their minimums, have been shown in a specific relationship, one to another, the relationship is only for convenience of portrayal and discussion. There does not appear to be much in the literature on this general relationship.

Finally, the cost of performing an activity can affect the relationship between estimate and actual. The higher the cost the

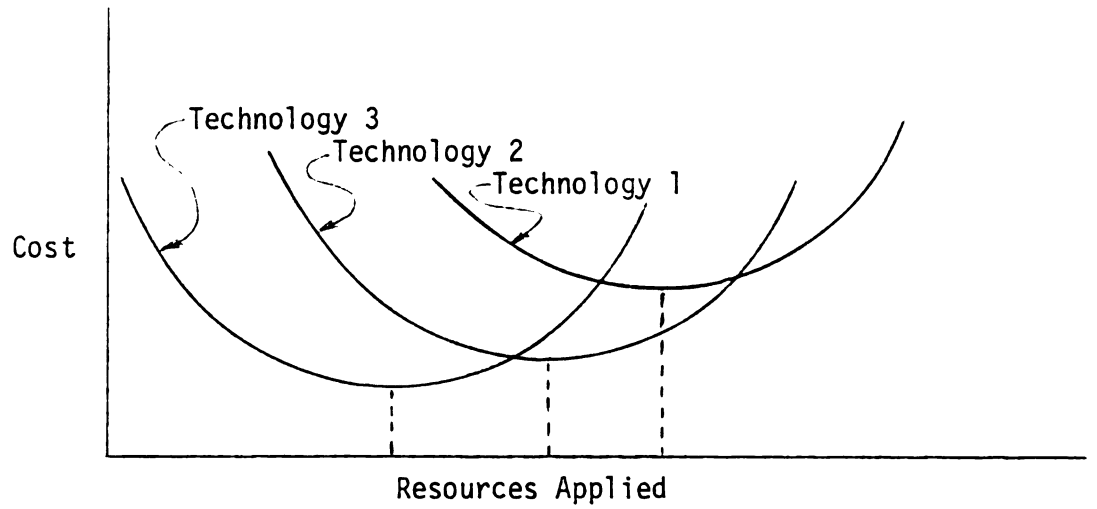


Figure III-8.--Total Cost as a Function of Quantity of Resources Applied for Different Levels of Technology (Duration Constant).

more likely it is to be performed to schedule. For example, the cost of a resource required on an activity can affect the attention that is given to the activity by management. A high cost resource is not dispatched until its need is highly certain and all activities requiring it are ready to use it. Thus, such activities are more likely to be performed in estimated time or less. Two measures might be employed for this variable. The percentage of the cost of the resource as compared to the total cost of the project would be the one typically used. It would tend to be relatively insensitive in most cases. A more sensitive measure would be the percentage of resource cost as compared to the planned profit or fee. These could be evaluated directly in percentage or subjectively as high, intermediate, or low.

Technical Performance Only

Consideration of technical performance of an activity parallels the discussion found in the typical text on purchasing. For example, England (1970) lists the following ways of describing the quality desired:

1. By brand
2. By specification
   a. Description of the physical and chemical characteristics
   b. Material and method of manufacture
   c. Performance
3. By miscellaneous methods, such as:
   a. Blue print
   b. Market grade
   c. Sample
4. By a combination of two or more of the above (p. 305).

The specification of technical performance on an activity can be considered in the same way. The performer of an activity can be considered a vendor to the project manager such as a subcontractor. Even when the performer is in the same organization an informal contract, e.g., a memo, is the basis for describing the expected product of the activity. Some communication must take place to establish a common understanding of what is desired. The above means of description are as applicable in this process as they are for general purchasing. The volume of communications can be reduced considerably by establishing standards, operating instructions, and technical instructions. If there is no ambiguity it may not be necessary to always cite the applicable instructions.

Unfortunately, for many activities, there may be considerable ambiguity. For example, while technical performance has been shown

as one dimension of an activity, there are many possible sub-dimensions. Some of the possible sub-dimensions of technical performance are:

Physical Criteria--Probably the criteria familiar to most people. They are well illustrated by the usual specifications of a house in terms of floor area, number of rooms, storage space, etc. Car design criteria are very detailed in terms of leg, head, shoulder, and seat dimensions as well as over-all length, height, and weight of the vehicle.

Performance--This is also a familiar concept to many people, especially pertaining to cars. Even it has a multitude of dimensions. Some of the performance dimensions of a car are speed, acceleration, and miles-per-gallon. Purchasing texts stress the importance of this type of criteria to achieve effective competitive bidding.

Reliability--This group includes such things as design life, mean-time-to-failure, and probability of system failure. The emphasis is on whether the item will in fact provide service when called upon.

Unit Cost of Production--This is critical in the design of a new product to compete for sales in the market place. Extensive efforts are involved in controlling this variable in new car design.

Facility/Capital Cost for Production--Can the product be produced in existing facilities on existing equipment or are large capital expenditures required?

Maintenance Cost in Usage--Does the product require constant attention and service, such as some computers, or is it essentially maintenance free such as the sealed motor-compressor units in modern refrigerators? Are those components requiring service easily accessible? Are special tools and/or skills required to perform the maintenance?

Unit Usage Cost--For example, although one car gets high miles-per-gallon, another may be more economical if the fuel it requires is considerably cheaper.

Aesthetic Features--Although immediately recognized as important in fashion goods, aesthetic features are involved in more and more products and therefore are important design criteria.

Esoteric Criteria--Sometimes "professional standards" or expectations go beyond form and function requirements resulting in extra work effort.

It is clear that there are a number of mutual inconsistencies in this group. High reliability and low unit cost is just one such example.

Much of the time of the participants in the early phases of a project is spent in the specification of the technical performance requirements. This process is replete with cost-benefit trade-offs and balancing the probabilities for achieving given levels of technical performance. This undoubtedly requires close interaction of relatively few people. As these specifications take shape,

larger numbers of people can work relatively independently. However, if the project is pushing the state-of-the-art in many respects, this same type of interaction may continue through other phases of the project. It seems that this could account for the types of human relationships described by Sayles and Chandler (1971) in their study of NASA project efforts. This is precisely the problem recognized by Eyring (1966) in his research on uncertainties in a design project. On the other hand, as more and more standard technology is employed, after the original tradeoffs, the less would appear the need for this "organic" type of interaction in the project. Thus, it would appear that the extent of pushing the state-of-the-art versus use of proven, standard technology would offer explanation, not only of the extent of uncertainties in all three dimensions of the activity, but also the extent of organic versus mechanistic organizational behavior one is likely to find. Preliminary research on this was reported by Adams & Barndt (1978).

Based on the literature reviewed, it would appear that there is little in depth understanding of this aspect of projects in general. An article by Dodson (1972) was the only exception. No doubt the different aspects of technical performance are dealt with extensively in the pertinent engineering and technical literature. What seems necessary are some generalizations drawn from that knowledge which would better guide the project manager and the designer of organizations and systems for managing projects. Research in this regard should be beneficial.

Examples of the application of this to systems design can be found in the automobile industry. The "design cost control" systems are extensive and have considerable impact on their organizations. A visit to the Tractor Division Offices in 1963 disclosed that Deere and Company had related product design cost control to a network application on the design of a new tractor. It considered not only piece part cost along with physical, performance, and other criteria, but also kept careful account of the implications on capital expenditures required to support production of this new design. Configuration management is the common term applied to this problem in the defense/space industry. It would appear that configuration management emphasizes unit cost somewhat less than careful documentation of the configuration of each unit produced. Control of changes is designed to insure good technical decisions and adequate communication of the changes to all affected as well as effect on schedule.

Implicit in most discussions of project management is the assumption that, although the time and cost of performing an activity may be uncertain, at its ultimate completion the product will be consistent with the technical performance requirements specified. Anyone who has managed the work of others, in projection type work especially, knows the frustration of measuring this dimension of performance and, even more so, taking action which results in compliance. Often, work of this type must be performed by persons lacking in essential skills, knowledge, experience,

desire, or time. Indeed, this sometimes seems to be characteristic of project work.

If all activities were performed in accordance with the technical performance specifications, the job of the project manager would be much simpler. The realistic situation is that it may be impossible for the project manager to monitor every activity for technical performance compliance. This monitoring is often done by subordinates or peers who are also responsible for meeting cost and schedule objectives with limited resources. Their perceptions of technical performance may therefore be baised. In other instances, they may leave this evaluation to the performer. These conditions create the need for some means of control of this dimension in large and complex systems design. It may also be valuable in smaller and less complex projects if the cost of achieving it were not too great.

Reliability Maturity Index (RMI) (Malcolm, 1963) types of information could rather easily be incorporated into a total system design to monitor the applicable characteristics of activities. It would appear that research may be appropriate to determine if this approach to control of technical performance has proven to be viable and what benefits are available from its application. Based on these results, the research could be extended to a thorough study of activities to develop guidelines for measurement of the appropriate characteristics and costs of incorporating this capability into a comprehensive system design.

The construction industry has had variable performance in this regard depending on the project management approach. Architects

frequently redesign a building after reviewing quotations from contractors which exceeded estimates by a considerable amount. On the other hand, it would appear that the range of error, i.e., the diligence in design cost control, is much better in the fixed price, design/build contracting mode.

In addition to the above sub-dimensions to be considered in making the technical performance trade-off decisions, all of which are in a sense relationships internal to the activity, there may be some externalities that come to bear. The argument in favor of CPM stresses the increasing "other" costs of a project, i.e., having a productive unit out of operation for the duration of the project. The technical performance decision on an activity also has "other" costs to consider. Sometimes higher performance on one activity will result in lower work content on another. For example, the more rigorously a part is designed, the less testing and re-work may be required on later activities. Therefore, we have a relationship between technical performance and cost as shown in Figure III-9. This was recognized implicitly by Eyring (1966).

Based on these observations, it would appear that there is a considerable need for research to better understand the nature of technical performance of activities as they interact in projects.

Time-Resources

The two variable relationship which would seem to be most understood is time versus cost as incorporated in CPPS. As was demonstrated in Figure III-4(b), time versus cost is really a

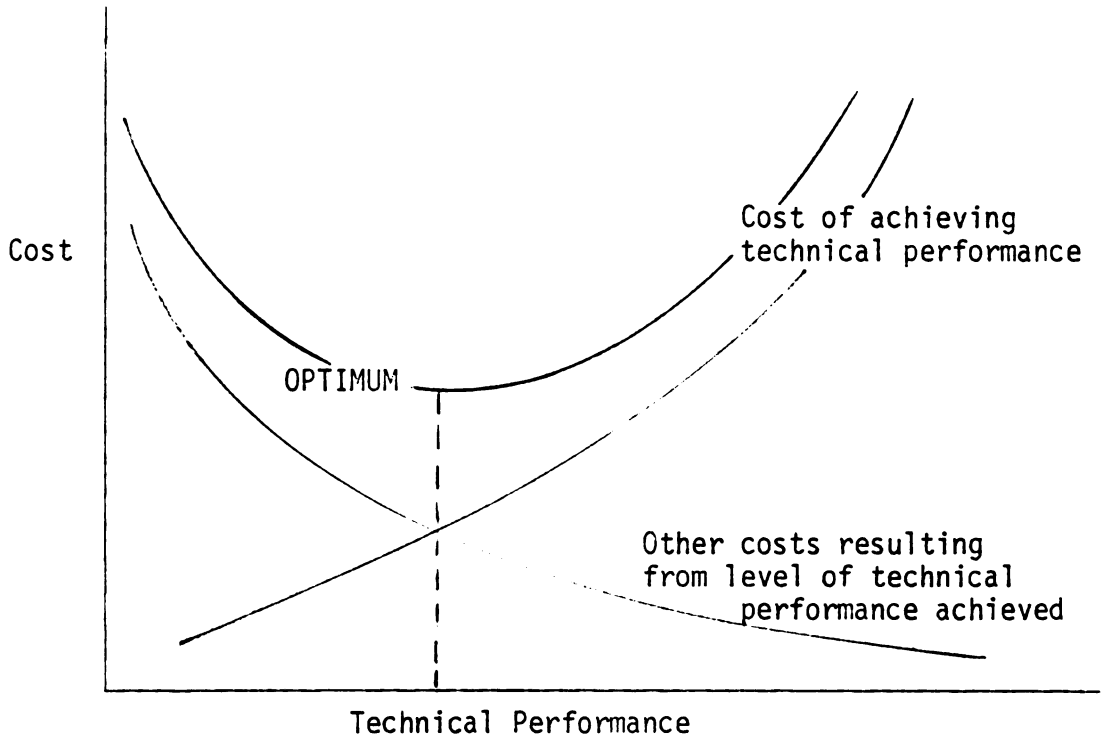


Figure III-9.--Total Costs Associated with Technical Performance.

relationship with resources and technical performance held constant. It also implies a constant level of technology. The relationship which is really implied by CPPS and related techniques is a relationship between time and resources, with cost being a surrogate for resources. In general, it is not necessary to assume a constant mix of resources over the domain of the time cost relationship although that seems to be implicit in discussions of CPPS.

Consider holding technical performance constant and assume control of the variables resulting in the time-cost variability, there is a range of times in which the activity can be performed. There is some duration below which it is technically impossible to

reduce the time any further, i.e., by adding resources. There may be a duration somewhat larger than this below which it would be economically infeasible to reduce the duration. This is generally called the "crash" duration and with it is associated the "crash" cost, i.e., a quantity of resources the cost of which is equal to the crash cost. There is another duration at which the cost, i.e., the quantity of resources required, is minimum. This is called the "normal" time and the cost of this minimum quantity of resources, the "normal" cost. Thus, holding technical performance constant and using cost as the third dimension, the cost as a function of time and resources is a convex function.

Ceteris parabus, all activities would be performed at their lowest cost and the project duration would be determined by summing normal times. However, when other costs are considered including costs external to the project, it is often worthwhile to reduce the project duration. In CPPS, this is done by shortening those activities that are critical which have the least slope time-cost curves. As time for the project is shortened, it becomes necessary to reduce the duration of activities in more than one path. Thus, sets of activities are identified consisting of an activity from each path such that the slope of the combined cost curves is minimum. Generally, only a few activities have to be reduced in duration which is in sharp contrast to a frequent practice of putting all activities on overtime.

The typical discussion of time compression assumes that it is achieved through the application of additional resources, i.e.,

overtime, larger crews, multiple shifts, etc. Other ways of accomplishing this were discussed above. Nevertheless, the problem of concern at this point is this trade-off of resources for time.

Subsumed in the resource dimension is the possibility of alternate technologies. For example, the laying of a brick wall by a masonry crew can be done using three levels of scaffolding technology--wooden, standard metal frames, and an elevator type. Assuming that the wooden ones will be discarded after use and that the others are rented, the short- and long-run cost curves would appear as shown in Figure III-10.

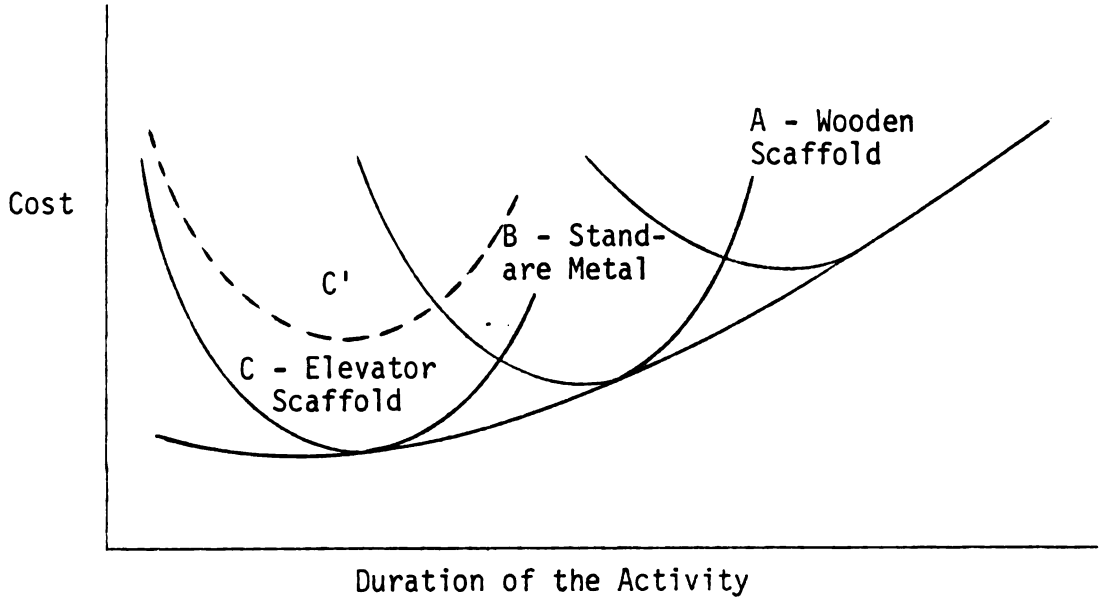


Figure III-10.--Short- and Long-run Cost Curves for Various Technologies.

Technology"A," the wooden scaffold, has the highest cost because the material will be discarded upon completion of this job,

it takes considerable labor effort to construct and remove them, and they are constructed in fixed increments of height. To complete the wall in a short period of time requires more materials whereas a longer time permits re-use of the scaffold for various sections of the wall. However, labor utilization of the bricklayers is lower as they have to wait for the scaffold to be moved. The curve is somewhat flatter to the right than the others because no rent is paid on these scaffolds. The standard metal scaffold units, technology B, require much less labor to erect and dismantle but they are also constructed in fixed increments of height. The cost varies depending on the number of units used as for the wooden scaffold but less time is required to move them so bricklayer labor utilization is better. Rental, or the comparable cost of capital if they are owned, is paid on these for their period of use. The elevator type scaffolding, technology C, requires less labor to erect and dismantle and also provides continuously variable heights. This is a distinct advantage for it is well documented that there is an optimum working height for a bricklayer. With the elevator type scaffold, the bricklayer can be at the optimum height relative to the wall for the entire job. Thus, not only does the cost for performing the activity decrease but the duration may also decrease. Since the rental on the elevator type is greater, the slope of its cost curve increases faster to the right. If the total volume of usage of the more advanced technology is not adequate, then the rental that must be charged to provide an adequate return on investment will be enough greater that the cost curve, C', will be higher

than the less advanced technology even though the duration is shorter. Occasionally, there may be other reasons for desiring the shorter duration that outweigh this high cost (C').

Each technology is represented by a "U" shaped curve implying that for the fixed amount of work to be performed, there is an optimum duration for the activity. If the longer duration is taken, perhaps due to other constraining factors, there will be additional labor costs due to decreased labor efficiency, additional rental of equipment, additional overhead, and additional interest on the money already invested. Furthermore, there is a possible opportunity cost if the project completion is delayed. If a shorter duration is required, it may require overtime premiums or the use of more people and/or equipment. Increasing the number of people and/or equipment often will not give a proportional decrease in the time required due to coordination and communication problems, overcrowding of space, and perhaps a set of problems which could best be described as behavioral. Excessive amounts of overtime not only incur the premium costs but also result in reduced efficiency, thus causing the cost to increase even faster.

Falk and Horowitz (1972) provided an algorithm for a concave cost function. They mentioned as an example the possibility of lower lease rates on equipment that was to be used for a longer period. Perhaps they had a specific situation that justified a need for this algorithm. The general problem of equipment lease price breaks would seem tractable by a somewhat more general algorithm

and a few simulation runs at the alternative rates. On the other hand, it might be feasible to incorporate logic in a computer program to determine the applicable rate to be applied in the time-compression process as well as the budget. There will be a difference in the treatment of this depending on whether the equipment is to be used on a single activity at a time or is to serve two or more activities, at least in part, concurrently. Research is needed on the nature of price structures that actually occur and the logic necessary to aid in decision making as well as budgeting for these costs.

The uncertainty relationship in the time-resource plane, i.e., the CPPS model by Kelley, varies over the range of the short run cost curve for a given technology. Bildson and Gillespie (1962) assumed constant ratios of "a" (optimistic) and "b" (pessimistic) to "m" (most likely) time estimates as the duration is crashed. Berman (1964) assumed constant absolute differences between "a" and "m" and "b" and "m." It seems reasonable to conjecture that as duration is decreased, neither of these applies. Considering the optimistic time estimate alone, the Bildson and Gillespie relationship may be the lower boundary. The more an activity is "crashed," the less likely it seems that it will actually be completed in less than its most likely duration. Thus, rather than being a constant ratio, it may be a decreasing ratio. Considering the pessimistic time estimate, it seems intuitively, that as the time is compressed and resources added, the chances for misunderstandings, the inclination to take greater risks, and the reaction of humans to excessive

pressure may tend to increase the probability of exceeding the "most likely" estimate. Thus, it would seem unreasonable that the absolute time difference between m and b would decrease. The absolute time difference would seem to be the lower bound for b. The ratio of "b" to "m" might increase such that the difference would actually increase. There seems to be no reports of research on this question. It should be the subject of research if uncertainty in time is to be considered jointly with time-cost compression.

While in general the performance of inanimate resources is not affected by the past or expectations of the future, humans are affected in many ways. The time required to perform an activity, for a given application rate of human resources, can be affected substantially by knowledge of past performance, by knowledge of management's expectations, by interpretation of management's actions, and by anticipation of future circumstances. For example, machining time required to perform a given activity on a numerically controlled machining center is not affected by the proximity of the completion of the project. Humans, facing all the uncertainties of the project coming to an end, are likely to slow down to prolong employment, spend work time thinking about employment options, be absent pursuing other employment opportunities, and even leave for other employment in the middle of an activity. All these affect performance time for a given resource application rate. Some general relationships between these variables are generally accepted but not at a level that could be usefully incorporated into a decision aid at this time.

One of the problems which leads to a low intensity of use of CPM is the cost of preparing the data. There is an implication that detailed historical data files are essential to estimate normal and crash durations and costs. Normal durations and costs are generally estimated with a minimum of historical data. Furthermore, even if extensive historical time and cost files exist there are serious questions as to their applicability to a new project. There are a host of variables in past projects which would have to be normalized, along with the associated durations and costs, for them to be truly meaningful. Thus, there is a question as to whether precise data are really necessary. An experienced estimator may be able to approximate costs at a level of accuracy consistent with the requirements of CPM, especially when considering Adams' (1974) conclusions with regard to understanding the nature of the individual who will perform the activity. Gross approximation of the time-cost function may be entirely adequate.

Time-Technical Performance

One of the prevalent arguments against scheduling certain types of activities is that they cannot be scheduled. The artist argues, "you can't schedule creativity." The inventor claims, "You can't schedule invention." They are difficult arguments to deal with, especially in the context that much project scheduling has been done. It is not unusual to assign the responsibility for constructing a network and getting time estimates to a relatively junior member of the management team. Often the artist or inventor

is a more senior individual, either in the organization or in his profession. The balance of "authority" is against the planner.

While the argument is accepted to a certain extent, there is another phenomenon which works counter to it. Personal experience suggests that the probability of serendipity is an inverse function of the time remaining. That is, as one approaches a deadline for accomplishing a "creative" task, somehow ideas are generated, insights achieved, and relationships conceptualized that had been elusive earlier. It is not a certain phenomenon nor does it give assurance of an optimum solution. Nevertheless, within the context of organizational commitments to achieve results, this proposition would argue for setting deadlines, i.e., scheduling creativity. There may be a body of literature which deals specifically with this phenomena. Regardless, research would seem worthwhile on the scheduling of creativity as it relates to project management.

Another relationship between time and technical performance has to do with management, or more particularly design, philosophy. It has been alleged that in the automobile industry there are three different design philosophies. One company allegedly starts with over-designed parts and reduces them to competitive levels over a period of time. This frequently results in an over-designed new car. Another company allegedly starts with under-designed components and increases them until they meet minimum performance criteria. The other allegedly starts two or more alternatives and selects the best. Whether or not these conform to actual practice in these

companies, it is helpful to understand that design philosophies differ and might have an impact on individual activities and their actual versus estimate differences.

This same phenomena has been observed by Adams (1974) in terms of different estimating practices based on different attitudes, experiences, etc., i.e., philosophies of the estimators. The impact of this on technical performance could have greater impact than is generally recognized in project management. If the management is risk aversive, the technical performance levels sought could be higher than necessary. If esprit and identity with the organization is low, the performer may set technical performance levels high to achieve status with professional peers. If it is too low, professional gratification may be sought in doing other things and technical performance on the activity may suffer as a result.

Another phenomenon which may affect technical performance on an activity in a project relates to quality control efforts. A close examination of the work content of an activity would reveal a mixture of more detail work elements. Some of these could be classified as "producing," some as "checking," some as "testing," and probably other classes. If the resources applied to an activity and the time allowed are consistent with some "ideal" total work content, all of these work elements will be performed with reasonable and appropriate care. As the product of resource application rate and time is reduced below the "ideal" total work content, the types of elements that are likely to be shorted are the checking and testing types. The performer is still obliged to turn out the

completed work product of that activity. The care in checking and testing will diminish and likely the technical performance, at least in some sub-dimensions, also. This relationship may not be directly proportional nor constant. It probably exists on the other side of the "ideal." If time is allowed in excess of the "ideal," the checking and testing may then exceed what is appropriate, thus increasing the cost of the activity without commensurate returns.

It would seem that research into the micro nature of different types of activities could provide helpful insights into the knowledge of projects and their management. All of these relationships are dealt with by both technical and general management. It is this writers opinion that none of them are well understood in terms of the body of literature on managing projects.

Resources-Technical Performance

At first glance it might be assumed that technical performance would improve as more resources are applied. However, the concept of decreasing returns to scale from economics should raise questions with such an assumption. Surely this applies to the work on an activity. Often, the work on an activity is such that only one person can perform at a time. Having two on hand may actually be a disturbing influence. Perhaps the work can be performed by two or more people in sequence, such as on three shifts in a twenty four operation. Depending on the communication requirements and comparability of skills of the three, technical performance may stay

constant or it could deteriorate. Too few resources would be the same as the situation discussed previously under "Time-Technical Performance" when time was less than the "ideal."

In addition, too few resources could result in an inadequate range of skills, knowledge, or even beneficial conflict that may be necessary to elicit the essential concepts for technical breakthroughs. Thus, it would appear that, for a fixed duration, there is an optimum resource application rate associated with a given level of required technical performance. For some types of activities this relationship may be very sensitive while for other types the curve may be flat over a broad range about the optimum. To some extent this may be a function of the specific individuals involved. It would seem that the more compatible, cohesive, similar in technical background, etc. the individuals, the better the technical performance. On the other hand, it has been popular in the last four decades at least to establish inter-disciplinary teams to solve especially difficult problems, e.g., operations research teams. The management of such teams under these circumstances has become a subject of considerable interest in management literature and is of special concern in the management of advanced technology projects.

Another variable is assigning the right resource to the activity. This was discussed in part earlier to point out that in some environments, allocation of resources is not the problem. Assignment of the best resource to the activity becomes critical to technical performance. "Best" implies skills, education, interest,

and motivation, at the least. This suggests a multiple criteria objective. In the section on "Resources Only," the trade-off between the duration of the activity and time delay before starting the activity, as a function of the earliest date the "best" resource could be applied to the activity, i.e., the drafting room scheduling problem, was discussed. Now it is necessary to add a measure of technical performance. To properly relate the latter, perhaps a measure such as the difference between desired and expected level of technical performance could be used. Then an objective function could be the minimization of that difference. If necessary, multiple subdimensions of technical performance could be used along with a weighting function.

It would appear that these relationships between resource application and technical performance are frequently overlooked.

Cost--Time, Resources, and Technical Performance

Each of the dimensions of an activity have been examined singly and in pairs. There are a few things that remain to be examined, some of which are applicable to the consideration of all three dimensions at the same time.

Perhaps the most important observation to begin with is to recognize how little is really understood about the nature of activities in a micro sense. Most empirical studies have dealt with one of the three dimensions. The job of the project manager is to balance all of these dimensions, not just on a single activity but, on all the activities within a project. It is clear that no dimension

of an activity can be measured in any absolute sense without considering the effects on the other dimensions. This casts some questions on the validity of attempts to compare performance (actual versus estimated) of an activity on any one dimension without adequate control for or incorporation of the other dimensions. It would be the exception rather than the rule to find sufficient a priori documentation on a real activity as required to completely specify its dimensions, let alone find the after-the-fact measurement of the actual values on all these dimensions. Longitudinal research is needed that is designed before the project start and is conducted concurrently with the project to clearly understand these relationships. Perhaps formulas such as the revised production function of Dodson (1972) would be found to be feasible. Such research is certainly necessary to advance the state-of-the-art to the point where all dimensions could be considered simultaneously.

In the meantime, better understanding of activities at this level could lead to better ways of estimating, documenting, and performing activities. This would also contribute to better overall project performance. Furthermore, recognition of how other factors, especially management behavior and reactions, affect performance also hold promise for improved performance. This will be considered further in the next chapter. It might also help to better understand the nature of the "game" or conflict aspects of estimating versus performance. Also, differences in goals of the performers of activities, of management at all levels, and of the organization

might be minimized and thereby minimize the effects of these differences on performance.

Other Considerations

Fourteen ways to improve performance on activities, and ultimately on projects, were discussed previously. All but four of these were dealt with at one or more places in the preceding discussion. The remaining ones are management attention; subcontract or buy; changing the scope of the project and changing the person responsible, the organization structure, or management information and control system (MICS). The MICS will be discussed in Chapter V. The second, basically the make-or-buy problem, is dealt with in purchasing and finance literature. It needs to be incorporated into the literature on the management of projects with whatever changes may be appropriate when applied to project type work. Management attention and involvement is discussed in the literature of general management but perhaps not in the context of differentiating between project type work as opposed to any other type. Changes in the scope of the project should be made only with agreement of the client. Changes in the organization structure or person responsible are not well documented and were pursued no further in this study.

Externalities to the activity have been discussed but basically confined to the trade-off relationship between activities in the same project. Externalities at the activity level can extend beyond that relationship both within the same project, across projects, and

between projects and other modes of work. Some of the reasons for considering externalities are loss of revenue, indirect costs, and use of idle resources.

The reason for the original development of CPPS was to permit the balancing of costs of maintenance or construction against the opportunity costs of not being able to use the equipment until the work is completed. For instance, a chemical plant shut down for maintenance results in lost production. Often this cannot be recouped because the plant operates at peak capacity 24 hours per day so this is a very real loss of revenues and profits. If down-time can be reduced, the savings are often appreciable. Thus, it is desirable to reduce the time for the maintenance to the point that marginal costs of reducing the maintenance duration are equal to the marginal loss of profits.

A second reason for desiring a reduction in duration of an activity is the possible reduction of indirect costs. For example, while it might not make sense to allocate building space costs to an activity, they must be recovered in total project costs. Therefore, that is an indirect cost to the project which can be minimized by reducing total project time. A third reason for performing an activity in a shorter duration than its optimum is to permit the use of resources that would otherwise be idle. For example, if as a result of scheduling a project considering resource requirements there exists a period in which some resources would otherwise be idle, it may pay to use them on an activity and thus reduce its duration.

Even though the activity has a steep time-cost slope the out-of-pocket cost could be zero. Such an action could also be beneficial if it created slack at a point in the project which is desirable or if it permitted a reduction in the peak resource requirement at another point in the project.

Finally, although the PERT/COST report has been available for over fifteen years, we apparently know little about the impact it has actually had on estimating, budgeting, and control of costs on projects, let alone on activities. The publishing of the Cost/Schedule Control Systems Criteria (C/SCSC) by DOD was certainly a retreat from their prior position on PERT/COST. Based on this, the conclusion can be drawn that contractors to DOD did not find it satisfactory, were not using it, and/or did not want the detail costs in it available to their customer. Nevertheless, there has apparently been little research in the 1970's on present practices in estimating, budgeting, and control of costs at the activity or work package level. It would seem worthwhile to conduct a study to document current practice in this regard. At minimum, it would provide material for presentation in cost accounting texts and courses.

From this brief review, it can be seen that there are a number of areas of potentially fruitful research in fully understanding the nature of the interactions of all three dimensions of an activity.

Other Characteristics of Activities

Magnitude

The research by Tyler and West (1975) suggests two important characteristics of activities--type and magnitude. For the types of projects used in their research, they found that activities of approximately eight weeks duration tended to have smaller differences between estimated and actual duration. This is somewhat less than the recommendation for work packages in the DOD and NASA Guide: PERT COST (1962) which stated that, "Normally, the lowest level work packages will represent a value of no more than $100,000 in cost and no more than three months in elapsed time" (p. 29). On the other hand, based on the illustration accompanying this comment, the typical work package might consist of two or more activities each of which could be consistent with the eight week duration guide.

The eight week duration would seem to be relatively long for resource management purposes, at least for certain types of projects. It seems unlikely that it would be appropriate for many projects which are in that range of duration or less. Also the ideal duration may vary as a function of the type of activity. It would seem important that other studies be made in the pattern of the Tyler and West study to determine if the eight week duration is applicable to all types of projects.

Beyond the above guidelines, there is little in the literature suggesting the best magnitude of activities. Perhaps the most surprising aspect of this was that in none of the research reviewed

was there any attempt to relate the difference between estimate and actual to the degree of criticality of the activity. This seems to ignore one of the greatest benefits of network approaches to managing projects, i.e., that its ability to focus attention on critical activities tends to improve performance on such activities. Research in this respect across industries, functions, phases of projects, types of activities, and especially by degree of criticality should provide assistance to practitioners in the application of the variety of tools available to aid in managing projects.

Types of Activities

Very little evidence of research on the nature of activities by type of activity was found. Tyler and West (1975) identified five types of activities--design, procurement, administration, installation, and evaluation. Their finding that administrative types of activities tended to have larger differences between estimated and actual durations raises the question as to whether it was a function of the duration of those activities, something inherent in the nature of those activities, or whether it is a reflection of management's attitude with regard to these activities. It seems possible to design research which could not only answer these questions with regard to administrative activities but also with regard to a more complete typology of activities.

Before research of that nature could be designed, it would be necessary to develop a suitable typology of activities. It should be based on a careful analysis of the characteristics of

different activities so that the results could be extended to other activities based on these characteristics. The types of activities identified for costing purposes in the DOD and NASA Guide: PERT/COST (1962) and by Archibald (1976) are not adequate for this purpose. The following is illustrative of such a typology and the differences in the activities considered.

Conceptualization--This type of activity frequently occurs in a pre-feasibility study stage in which a major question is "What is the problem?" or "What are the applicable solution approaches?" In both cases, there are potential "political" ramifications in which case there may be diverse interests as well as several parties involved.

Feasibility Study--At this stage, the problem has apparently been agreed upon. The task is to evaluate each of several solution approaches. Political interests are still frequently involved and attempts may be made to influence evaluations. There will be a tendency to prolong this sort of activity due, in part, to the fact that it immediately precedes a decision, often to commit appreciable resources. Delaying such a decision is also a common political strategy by those opposed to, either or both of, the conceptualization of the problem that is being used and/or the anticipated recommended solution approach.

Research--Relatively high degrees of uncertainty exist as to whether a solution will be found or not. Sometimes there are problems of communications and understanding involved in getting

congruency between the problem that it is desired be solved and that on which the researcher actually works.

Development--The uncertainty is much less as to whether a solution can be achieved than as to how many cycles of development will be required to achieve satisfactory results.

Design--This assumes that design parameters and solution techniques have been resolved and the effort is primarily a mechanical process plus making tradeoffs of various design characteristics. There may be a difference depending on the importance of aesthetic properties as compared to functional properties. There may be differences in the complexity of the product, level of technical performance, and state-of-the-art in technology that affect duration and resources required. Also as a result of test and evaluation, the design activity may have to be repeated in part or in total.

Fabrication--This may be accomplished by job shop or high volume techniques. If so, it may be amenable to classical industrial engineering techniques and, as a consequence, is often more predictible. The major variable may be quality control. On the other hand, if it is model or prototype work, it too is subject to some uncertainties.

Procurement--This is similar to fabrication with the exception that there is a loss of control to a second party. In both fabrication and procurement, there may also be a difference between standard and unique items.

Installation--This involves the integration of two or more components and thus involves a class of problems associated with

the interaction of components which may or may not be compatible. There may be a distinction here between unique and standard items, also. Even on standard items, there may be a difference depending on how many have been assembled. For example, during the launch period of a new model car the unit labor times are appreciably greater than later when they are in full scale production.

Evaluation--This involves various testing, measurement, and debugging activities. It is almost axiomatic that things will not work exactly as designed. Thus, this class of activity requires developing results from a trial, analysis of the results, diagnosis, and solving of problems. The process is repeated until satisfactory results are obtained or it is determined that it is necessary to recycle to one of the previous phases.

Documentation--Often considered a necessary "evil," it may be a contract requirement but is nearly always good procedure. Because many project people consider it to be onerous and not the heart of their work, it is often put off until the last possible moment, or perhaps later.

Administration--This may be the catch-all for activities that don't fit any of the above categories. It, too, is often considered a necessary "evil" by those involved in the technical aspects of the project and tends to be delayed. Also, efforts to keep overhead low tend to limit the resources allocated to these activities. This may account for the findings of Tyler and West (1975) that this type of activity tends to be underestimated. If

this is so, it would appear to be more of a problem of performance and management than of estimation.

Manageability

There is another characteristic of activities of which little or no mention was found. It is reasoned that there is a difference between activities in respect to the degree that they can be "managed." A simple example of this concept can be found in computer program development. Consider three activities that occur frequently in such a project--coding, computer run, and debugging. Of the three it would seem that coding is generally most manageable. While others' experience may vary from this, computer run time has been, from personal experience, the least manageable. From the time the run was submitted till the time output was available seemed almost unaffected by efforts to get it sooner. Debugging is intermediate on this scale, having tradeoffs with both coding and the number of computer runs necessary to complete debugging. Generally, the more thorough the coding the less debugging will be necessary. Likewise, the more thorough the debugging the fewer the computer runs required.

Operations research texts mention types of problems in which this sort of relationship exists. Problems dealing in strategies for accomplishing certain work such as the traveling salesman problem, a number of linear programming problems, and strategies for clearing snow or working an open pit mine are examples where performance time can be managed by planning. Generally, activities with

high labor content can be managed to a greater extent than those that are machine paced. It would seem that variability of performance time could be related to such a variable.

Analytical Model of an Activity

The basic dimensions of an activity were stated by Malcolm et al. (1959) to be time, resources, and technical performance. Beyond such statements, little has been said about these dimensions except as to the importance of estimating each, making tradeoffs between them, and reporting against them. Given the three dimensions, it is convenient to think of an activity as a three dimensional orthogonal polyhedron. The volume then is comparable to the cost of performing the activity. In general:

$$C = f(P, r, d) \qquad \text{(III-1)}$$

where: C = Cost

P = Technical performance

r = Resource application rate

d = Duration (time)

Cost is assumed to increase as the technical performance criteria are made more demanding, given a fixed level of technology. For example, requirements for closer tolerances for parts produced on a piece of equipment results in longer times to produce the part and/or a greater rate of rejection of unacceptable parts. Likewise, the advent of space missions introduced a need for higher levels of reliability of the system and therefore of the components. For a

fixed level of technology, such increased reliability resulted in substantially greater costs. (A by-product of this phenomena was the invention of new technologies with lowered overall cost curves.) It is plausible that the cost of an activity will go up exponentially as the technical performance criteria become more demanding, for a given technology and duration.

Start with Dodson's (1972) revised production function and apply it at the activity level. This is:

$$\log C = a_0 + a_1 \log S + a_2 \log T \qquad \text{(III-2)}$$

where: C = Development cost;

S = Measured state-of-the-art advance;

T = Development time;

a_i = parameters to be estimated (assuming $a_1 > 0$ and $a_2 < 0$).

Conceptually at least, it is plausible to estimate the value of the parameters of this equation for each activity in a project. Possibly by simultaneous equations, but more likely by search methods, the set of these that make up a project could be evaluated as a function of S or T. Thus, the externalities to the activity, in this case the other activities, would be the basis for selecting the optimum allocation of either S or T, or both. Without considering externalities to the project, optimum values of S and T could be obtained, holding the others constant. If the technology of the project were sufficiently well defined, presumably such an approach could seek

an equilibrium among activities which would give the required end item technical performance on the project.

Relating this equation to the three dimensions, for a given level of technical performance and duration, it is simply necessary to divide the "total cost" by the duration to obtain the resource application rate. Thus, conceptually it is possible to get the optimum duration, d_o, and resource application rate, r_o, as implied by dollars.

While this seems extremely complicated, especially when evaluating a major project type problem, certain simplifications could be made. First, out of a total project, not all activities have a direct influence on technical performance. Only those that do would need to be considered. The other activities could be viewed as support activities.

Secondly, of those activities involved, it may turn out that only one resource is vital to the determination of the relationship. Having solved for that resource, others are implied. For example, if six engineers are required to accomplish a given activity, it can be presumed that there are certain concommitant resources which simply add to the cost of the engineers. These might include support services such as technicians, clerical assistance, and the like.

Nevertheless, the real world application of such concepts are, it would seem, well into the future. Therefore, consider a somewhat less comprehensive model which would seem practical in the

near term. For this, assume that the optimum total resource application, R_o, to achieve a specific level of technical performance in a fixed amount of time is of the form:

$$R_o = a + bP^c \qquad \text{(III-3)}$$

where a, b, and c are constants for a given technology, $0 \leq P \leq \infty$, and P = 1 for a base level technical performance.

This is consistent with the curve of Figure III-4(a). Consistent with the theory of CPPS by Kelley (1961) and Fulkerson (1961) we know that there is an optimum time, d_o, in which an activity can be accomplished given a specific technology and the required technical performance. Associated with d_o is a rate of application of resources, r_o, such that $d_o r_o = R_o$, for any specific single activity. This also assumes the optimum mix of resources where that is applicable, but not necessarily the same mix over the domain of P. Then $C_o = d_o r_o k_o$ where k_o is the unit cost of the resource, or of the optimum resource mix.

Occasionally, an activity duration can be reduced by a linear increase in resources. In such case the increase in costs for a specific time reduction would be proportional to the decrease in time achieved as compared to the maximum reduction in time that is feasible. This proportion would be applied to the total increase in costs necessary to achieve the maximum time reduction. Thus, a reasonable description of such a cost function is:

$$C = C_o + (C_m - C_o)\ (1 - [d - d_m/d_o - d_m]) \qquad \text{(III-4)}$$

where: d_m = Minimum duration (crash duration)

C_m = Cost associated with d_m (crash cost)

Often the marginal cost of the first increment of time reduction is less than for subsequent increments. Thus, costs may increase exponentially as less time is consumed in performing the activity. This can be represented by the addition of an exponent on the proportion of time reduction, resulting in the following:

$$C = C_o + (C_m - C_o)\ (1 - [d - d_m/d_o - d_m]^a) \qquad \text{(III-5)}$$

where: $0 \leq a \leq 1$ for non-concave functions

$C_o \leq C_m$

$d_m \leq d \leq d_o$

Clearly, for a = 1, we have the linear relationship while for a = 0, there is no change in cost due to reducing the duration. This characteristic for a = 0 would permit the incorporation of a two level discrete cost situation by the way a program might be written. For intermediate values of a, the marginal costs increase at different rates (see Figure III-11).

This form of cost relationship requires one additional input as compared to CPPS. CPPS, providing only for the linear cost function, requires only two sets of time/cost estimates. This functional form would, in addition, require the specification of the exponent. While this seems to be a complicating factor, a realistic assessment of the

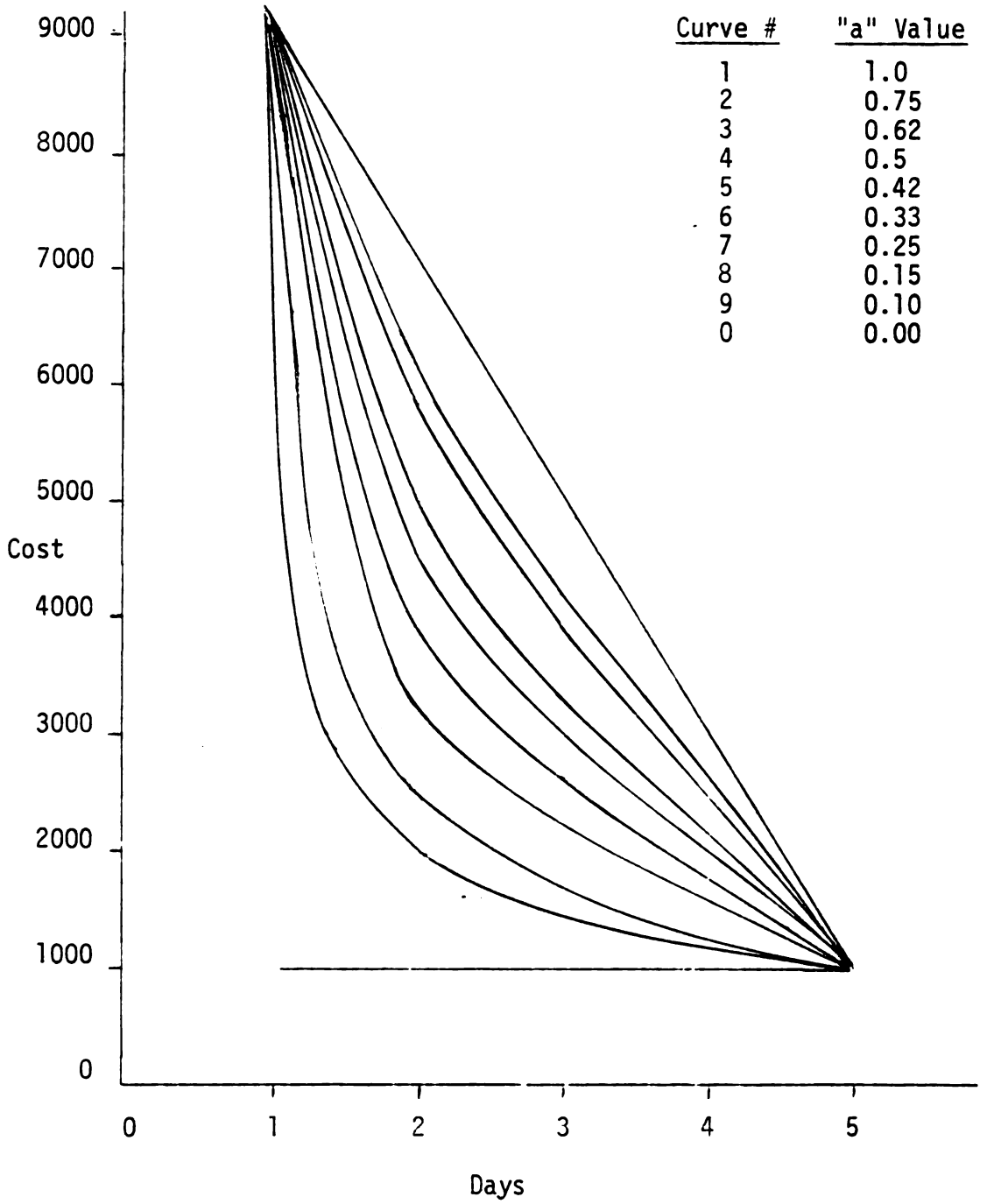


Figure III-11.--Time-Cost Curves for Various Values of "a."

accuracy of most cost accounting systems suggests that a reasonable approximation would be adequate for most purposes. In Figure III-11 nine curves are shown in addition to the linear relationship. Selection of one of these by an informed estimator should provide the required degree of accuracy. In implementation, it would be simple to assume a value of "one" for the exponent unless otherwise specified. The exponent could be implied by the selection of the curve by number, thus requiring only one character. The selection of the specific curve, and therefore the "a" value, would generally be a judgement by the project manager or estimator. It should be based on knowledge of the behavior of costs as a function of time. For example, it is generally accepted that productivity on overtime decreases as the amount of overtime increases. Factors could be developed to support such judgements in any given organization.

The evaluation of the slope is simple by using the differential of the cost function which is:

$$\frac{dC}{dd} = - (C_m - C_o) (x/d_o - d_m) (d - d_m/d_o - d_m)^{a-1} \qquad \text{(III-6)}$$

Summarizing, given a required technical performance using a specific technology, there is an optimum amount of total resources necessary. This implies an optimal duration and therefore, an application rate for the resources. The activity can be performed in less time for any of several reasons but, for the present purposes, only as a result of applying more resources. The amount of resources

required to achieve a unit reduction in time may be constant over the domain of possible durations, i.e., linear, or may increase as the severity of reduction is greater.

This formulation has some theoretical advantages. For example, it is possible to conceive of a model for resource leveling which permits augmentation of resources on activities in non-peak resource requirement periods. It is especially interesting to consider the ease of implementing a CPPS type algorithm using the slopes of the activity cost curves and a LaGrangian multiplier concept similar to that used in some aggregate inventory models to allocate aggregate inventory to part numbers. This would be similar to Berman's model (1964). Although the solution might not be as elegant as some of the linear programming solutions, it would seem to offer the possibility (without detailed specification of the approach) of being relatively more efficient on large networks or on micro-computers. This efficiency could be achieved in terms of human inputs as well as computer time by requiring estimation of cost details only on those activities for which they are relevant in terms of slack existing on the activities or resources.

The above logical derivation is to demonstrate that the behavior of the cost of an activity can be modeled mathematically in a manner that is consistent with the behavior of the three basic variables--time, resources, and technical performance. Given such a model, it makes sense to talk about optimizing with regard to one variable subject to constraints on the other variables. It is

recognized that in the short term it is not feasible to incorporate the full concept of technical performance. Nevertheless, it is desirable to show conceptually how it might work when the research has been accomplished to develop the understandings that are necessary to make it practical.

Comparing the above functional form to that used by Berman considerable similarity is noted. The major difference is the potential of using the cost components developed normally in estimating an activity for budgeting purposes and relating them to the type of cost information needed for time-cost trade-off analysis.

To fully capture that capability, it is necessary to further consider the cost factors. In general, the amount of material used on an activity is fixed. In some instances there may be more waste as the activity time is compressed. Also, it is possible to experience deterioration of materials if excessive time is taken. Therefore, while normally it is probably constant, in the general case that cost component should increase on either side of optimum time.

Equipment costs also vary as a function of time. If time is compressed by adding people, that usually implies more tools and equipment. For example, concrete can be poured more quickly by having more jitneys and drivers to distribute the concrete. Because all of them will be used for shorter durations, the lease cost per unit of time may be greater. A group of laboratory tests can be performed in a shorter duration by having more technicians and

equipment. On the other hand, extending the duration can result in excessive costs for labor and equipment that is retained on the job too long.

Interest on investment in place is not included as it is considered more applicable to the activities already finished and therefore to the project rather than to the activity.

A modification of the function by Berman might be of the following form:

$$C = L(1 + k_1[1 - Z^{a1}]) + M(1 + k_2[1 - Z^{a2}])$$

$$+ E(1 + k_3[1 - Z^{a3}]) \qquad \text{(III-7)}$$

where: L = Labor cost at normal duration

M = Material cost at normal duration

E = Equipment cost at normal duration

k_1 = Constant ratio for labor cost increase at minimum duration as compared to costs at optimum duration

k_2 = Constant ratio for material cost increase at minimum duration as compared to costs at optimum duration

k_3 = Constant ratio for equipment cost increase at minimum duration as compared to costs at optimum duration

a_i = Exponents to determine curvature of labor, material and equipment time-cost curves.

$$Z = \begin{cases} \dfrac{d - d_m}{d_o - d_m} & \text{for } d_m \leq d \leq d_o \\ \dfrac{(d - d_o)}{(d_o - d_m)} K_4 & \text{for } d_o < d \end{cases}$$

where k_4 = 1 if the cost curve is symmetrical on either side of d_o, less than 1 if the curve is flatter to the right, and greater than 1 if steeper to the right.

Lacking an empirically derived value, it is suggested that k_4 might be set at 0.5 i.e., half the slope of the left side of the curve, unless otherwise specified by the user.

In addition to the normal estimates for duration, labor, material, and equipment as are generally required for budget purposes, the estimator would have to provide the minimum duration for the activity, the ratios of increase in labor, materials, and equipment if applicable, and select the exponent for each if other than linear.

There are some typical situations that might occur for labor. If overtime could be added to halve the duration at no loss in efficiency, k_1 would equal the premium rate times the ratio of equivalent overtime days to total days. For $5000 and 10 days at straight time to $6250 and 5 days, giving an equivalent of 5 days of overtime, the ratio is 0.5 x 5/10 = 0.25. For the same example but assuming the maximum reduction of duration was by the equivalent of 2 days of overtime, the ratio is 0.5 x 2/10 = 0.1 for k_1. If the manpower were doubled at no decrease in efficiency, k_1 would equal the multiple minus one. For the situation above, 2 - 1 = 1. If there were a reduction in efficiency, then divide the increase by the efficiency, i.e., (2 - 1)/.9 = 1.111 for 90% efficiency. Thus, values for k_1 can be estimated rather quickly.

It is anticipated that there would normally be no increase in materials in which case k_2 = 0. It is also anticipated that

equipment costs would generally be negative. That is, as the duration of an activity is decreased, the amount that would be paid for rental (internal or external) would decrease. The ratio could be determined by any of the following:

$$\frac{E_m - E_o}{E_o} \text{ or for } E_o = 2000 \text{ and } E_m = 1400, \ (1400\text{-}2000)/2000 = -0.3$$

where E_m = Cost at minimum duration and

D_o = Cost at optimum duration

$$\frac{E_f - E_o}{E_o} \cdot \frac{d_o - d_m}{d_o} \text{ or for } E_f = 800, \ d_o = 10, \text{ and } d_m = 5,$$

$$(800\text{-}2000)/2000 \cdot (10\text{-}5)/10 = -0.3$$

where E_f = Fixed cost. It is easily seen that $k_3 = -0.5$ would assume no fixed cost of rental for this example.

$$\frac{E_v \cdot (d_m - d_o)}{E_o} \text{ or for } E_v = 120, \ 120(5\text{-}10)/2000 = -.30$$

where E_v = Variable cost

Also note that if $d_o < d$, the equipment would be used longer so the sign for k_3 would have to be positive. It might be desirable to provide for a k_3' if the equipment cost were likely to be different to the right of d_o. Of course if equipment costs increase due to compression, k_3 would have a positive value.

In summary then, an implementation of this model might set the following values unless otherwise specified in the input:

$k_2 = 0$ i.e., no increase in material costs

$k_3 = -\left\{\frac{d_o - d_m}{d_o}\right\}$ i.e., rental costs are strictly variable

$k_4 = 0.5$ i.e., slope for $d_o < d$ is one-half that for $d < d_o$

$a_1 = 1.0$

$a_2 = 1.0$ i.e., linear

$a_3 = 1.0$

Unless one or more of these are estimated to be different, the inputs for an activity are labor, materials, and equipment dollars at normal duration, the normal duration, the crash duration, and k_1, the constant for labor dollars.

The incorporation of uncertainty into this model could be in a manner comparable to Bildson and Gillespie (1962) and Berman (1964) as discussed previously. To establish the initial range of uncertainty, i.e., about d_o, estimates of percentage above and below d_o could be used, assuming it to be the mode of the distribution. To recognize that the Bildson and Gillespie model provides the lower bound for "a," the constant ratio, a/d_o, could be used to obtain the reduced "a," i.e., "a'". To recognize the Berman assumption as the lower bound for "b," the constant absolute difference between d_o and b could be used. These assumptions provide a substantial skew to the duration distribution as time is compressed. Additional skew could be provided by applying a ratio

of the amount of compression to each of these. This would not be introduced until research could establish that it was necessary.

In addition, it would seem desirable to at least provide the option of using the 5 and 95 percentiles and 10.2 instead of 36 as the divisor for calculating the variance as suggested by Moder and Rodgers (1968).

This approach to incorporating uncertainty puts all of the uncertainty on the time dimension. It is assumed that for many projects this would be appropriate due to the reactions of management to schedule slippages. Considering the three dimensions of an activity--time, resources, and technical performance--one is assumed to have a lower priority than the other two. It is reasoned that many (if not most) schedule slippages can be traced to failure to achieve satisfactory technical performance in the target duration. Thus, the technical performance uncertainty is transformed into the time-resource dimensions. The determination of whether it is going to result in time or resource slippage is a management decision. If it is to be in resource, the duration and uncertainty range may still be applicable. If it is to be in the time dimension, the activity duration and uncertainty range should be re-estimated immediately. It seems quite reasonable that alternative formulations could be developed based on the assumption that resources or technical performance carried the lowest priority in the organization. If technical performance carries the lowest priority, a system such as RMI could assist in measuring actual performance on that variable.

Thus, incorporating uncertainty only in the time dimension seems to be a reasonable compromise for the present. Also, associated with this would be a philosophy of providing for contingencies of both time and cost separate from the individual activity estimates, i.e., "water" appropriately placed in the network and one or more contingency accounts in the budget. The use of the mode instead of the mean duration introduces some bias into the estimated duration. Perhaps this would serve as a counter to the hypothesized difference between the a priori and a posteriori time distributions for an activity. Research is needed to determine the validity of this assumption.

The above model has characteristics consistent with CPPS and its several extensions with the exception of the concave cost function for an activity. It is anticipated that simulation can provide for that if such an activity is encountered.

Testing of the Model

The model as proposed in this chapter has several advantages. First, it corresponds to the elements of cost that are normally estimated in the process of preparing a proposal on a project, i.e., labor, materials, and equipment. Secondly, the normal and crash durations are consistent with the past usage of these terms. Third, the determination of crash cost is relatively straight forward depending on the method to be used, i.e., overtime or additional resources. Fourth, it has considerable flexibility in specification of the shape of the cost curve without requiring a degree of precision

that exceeds the capabilities of most cost accounting systems. Fifth, it is consistent with theory that has already been developed and tested (see Berman [1964] and Elmaghraby [1968]). Sixth, it is an easily differentiable function permitting the evaluation of the slope with a reasonable amount of computing time. Seventh, it provides for the incorporation of uncertainty by the methods of Bildson and Gillespie (1962) and Berman without requiring more than a minimum amount of data and only on those activities for which it is relevant. Eighth, the uncertainty computations incorporate, at least as an option, the findings of Moder and Rodgers (1968) to reduce the potential bias in the system.

It is important to demonstrate some of these features. The determination of crash cost factors was demonstrated along with the development of the model. The selection of the curvature of the time-cost curve was demonstrated by the use of Figure III-11. The differential of the cost function to evaluate the slope is:

$$\text{Slope} = \frac{Lk_1a_1(d-d_m)^{a_1-1}}{(d_o-d_m)^{a_1}} + \frac{Mk_2a_2(d-d_m)^{a_2-1}}{(d_o-d_m)^{a_2}} + \frac{Ek_3a_3(d-d_m)^{a_3-1}}{(d_o-d_m)^{a_3}} \qquad \text{(III-8)}$$

Using Berman's algorithm, it would be necessary to evaluate this equation for each activity on each iteration. This appears to be a formidable task and to require several locations of data in core

per activity. Careful examination of the function reveals that for any one activity the following are constants:

$$L,\ k_1,\ a_1,\ M,\ k_2,\ a_2,\ E,\ k_3,\ a_3,\ \text{and}\ d_o\text{-}d_m$$

The only variable is $d\text{-}d_m$, a simple difference which is the same for all three terms for a given iteration. Thus, defining the following constants:

$$C_1 = \frac{Lk_1a_1}{(d_o\text{-}d_m)^{a_1}}$$

$$C_2 = \frac{Mk_2a_2}{(d_o\text{-}d_m)^{a_2}}$$

$$C_3 = \frac{Ek_3a_3}{(d_o\text{-}d_m)^{a_3}}$$

and $d\text{-}d_m = \Delta$ we can rewrite (III-8) as:

$$\text{Slope} = C_1\Delta^{a_1-1} + C_2\Delta^{a_2-1} + C_3\Delta^{a_3-1} \quad \text{(III-9)}$$

The initial value of Δ would be $d_o\text{-}d_m$, so the slope could be evaluated at that to start the process. The process for compression would require decrementing Δ to recalculate the slope. Only those activities with a slope less than the "currently applicable" value need be recalculated. For those activities with $a_1 = a_2 = a_3 = 1$ or if

$(a_1 = 1 \text{ or } k_1 = 0)$ and $(a_2 = 1 \text{ or } k_2 = 0)$ and $(a_3 = 1 \text{ or } k_3 = 0)$

the function is linear and would not have to be recalculated.

Consider three activities with the following data:

	A	B	C
L	5000	2000	22000
M	10000	1000	1000
E	2000	1000	2000
k_1	2.0	1.0	0.2
k_2	0.1	0	0
k_3	-0.3	-0.5	-0.5
a_1	0.8	1.0	1.0
a_2	0.2	1.0	0.75
a_3	1.0	1.0	1.0
d_o	10 days	20 days	5 days
d_m	5 days	15 days	3 days
$d_o - d_m$	5 days	5 days	2 days
C_1 =	2207.6	400	2200
C_2 =	145.0	0	0
C_3 =	-120.0	-100	-500

$$\text{Slope A} = 2207.6\,\Delta^{-0.2} + 145.0\Delta^{-0.8} - 120\Delta^{0}$$

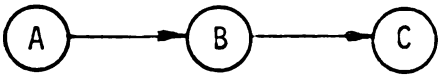
$$\text{Slope B} = 400\,\Delta^{0} + 0\,\Delta^{0} - 100\Delta^{0}$$

$$\text{Slope C} = 2200\,\Delta^{0} + 0\,\Delta^{-0.25} - 500\Delta^{0}$$

Evaluating these slopes for each possible value of d for each activity we get:

	A		B		C
10	1640	20	300	5	1700
9	1711	19	300	4	1700
8	1832	18	300	3	na
7	2005	17	300		
6	2353	16	300		
5	na	15	na		

Based on these results and assuming a network as follows:



the path length at normal times is 35 days. In reducing this, B would be taken to crash time first giving a path length of 30 days. Then one day would be taken from A, i.e., until the slope for the next day exceeds 1700. This would result in a critical path length of 29 days. Then C would be crashed giving 27 days. Finally, A would be taken on to crash of 5 days resulting in a path length of 23 days.

Evaluation of the time-cost function would give the following:

Path Length	Cost
35 days	$46000
34	46300
33	46600
32	46900
31	47200
30	47500
29	49140
28	50840
27	52540
26	54251
25	56083
24	58088
23	60441

Now suppose we add uncertainty as follows:

	A	B	C
$a_{5\%}$	8	15	4
$b_{95\%}$	15	30	6
a/d_0	0.8	0.75	0.8
b-d_0	5	10	1

Using $\sigma^2 = (b-a)^2/10.2$, we get for the normal times:

				Total
σ^2	$\frac{49}{10.2}$	$\frac{225}{10.2}$	$\frac{4}{10.2}$	$\frac{287}{10.2}$
σ	2.19	4.70	0.63	5.22 days

and for crash time:

a	4	11.25	2.4	
b	13	25	4	
σ^2	$\frac{81}{10.2}$	$\frac{189.06}{10.2}$	$\frac{2.56}{10.2}$	$\frac{273}{10.2}$
σ	2.82	4.31	0.56	5.17 days

and for various odds the project duration would be:

Odds	Normal Time	Crash Time
1 to 1	35 days	23 days
10 to 1	41.7	29.6
100 to 1	47.2	35.0
1000 to 1	50.7	39.1
10000 to 1	54.5	42.3

Comparable odds could be calculated at any intermediate project duration. Thus, the viability of the model has been demonstrated, at least for this limited range of examples.

Summary

In this chapter the activity has been analyzed in depth. It was shown that classical economics does not deal with work as found in a project activity. Some basic propositions were presented outlining the relationships that might be developed for an economics of the activity.

The magnitude of the dimensions of an activity are uncertain for several reasons. This stems in part from lack of precision in estimating the dimensions, lack of specificity in describing the work requirements to the performer, lack of precision in performing

the work, and to other characteristics of an activity as it is performed in the context of a project. It was demonstrated that while techniques for dealing with uncertainty have been analyzed in depth, there has been relatively little analysis of the sources of uncertainty.

The dimensions of an activity were examined to determine what has been and what could be said about each individually, in pairs, and all at the same time. It was found that a number of different measures of differences between estimated and actual duration have been used, raising questions about comparability of the results of studies of performance of activities. Also, it was shown that the measures were not comparable in other respects. Also, questions were raised as to the validity of studies of performance of activities on one dimension without incorporating, or at least controlling for, the other dimensions. A question was raised as to which is the best representation of the activity, the estimated or the actual dimensions.

Problems in resource utilization discussed included the drafting room problem, i.e., heterogeneous resources, patterns of resource usage on an activity, recognizing equipment usage patterns, space availability, and relating material to activities. Energy was recognized explicitly as a resource that should be accounted for on some activities.

The technical performance dimension was shown to have multiple subdimensions. It was suggested that the extent to which

organizational forms are found is at least in part the extent to which the activities involved are pushing the state-of-the-art. While approaches exist to assure adequate technical performance, they are not discussed to any extent in project management literature. Finally, it would seem relevant for some generalizations to be developed from technical literature about the nature and problems of technical performance as it relates to project management.

Looking at time and resources at the same time, the impact of alternate methods or technologies became apparent. It was argued that the distribution of the duration becomes more skewed to the right as the time of the activity is crashed.

When time and technical performance are considered at the same time, the argument about scheduling creativity emerges. It was suggested that design or creativity management philosophies may affect this phenomena. It does seem plausible that excessive time pressure will result in deterioration of quality control efforts on an activity.

Analysis of resources and technical performance at the same time suggests that there is an optimum resource level for any given level of desired technical performance. The optimum mix of skills is a technical problem specific to the technology involved. However, behavioral research is contributing to understanding some aspects of this in general.

When all three variables are combined, the need for longitudinal research is emphasized. This would be necessary to capture

sufficient information on the activities to compare performance on all three dimensions. Possible reasons for crashing an activity were explored.

Some other characteristics of activities were reviewed including magnitude, types of activities, and manageability. Finally a mathematical model of an activity based on the preceding was developed and demonstrated to behave consistent with the conceptual model.

From this analysis, gaps, inconsistencies, and/or deficiencies were identified and expressed in the following as questions to be researched or developments to be pursued.

The following gaps in knowledge of activities were identified for which research would seem beneficial:

A. Economics

1. Develop a subset of economics applicable to project activities.

B. Activities

1. Analyze activities in projects to assess the actual distribution of activities by degree of uniqueness and by degree of pushing the state-of-the-art.

2. Develop a typology of activities, along with some micro-description of them, relevant to understanding similarities and differences between them and relating these to other variables to aid in understanding the nature of activities.

C. Uncertainty

1. Analyze the causes of uncertainty and their effects on activity performance.

2. Conduct studies to determine the effect on uncertainty estimates, i.e., "a" and "b" as used in PERT, as a function of the duration of the activity as it is crashed.

3. Is there a tendency for the a posteriori distribution of activity uncertainty to be skewed to the right as compared to the a priori distribution? If so, how can it be countered?

D. Estimate versus Actual

1. To what extent is the difference between estimated and actual dimensions (time and resource) of an activity a function of the precision of the specification of the activity?

2. What is the effect on estimating accuracy resulting from the estimate being made by the performer, an independent estimator, or by management?

3. Does estimating strategy (i.e., with or without the aid of the network) affect accuracy of estimates?

4. What is the optimum magnitude of activities considering accuracy of estimating, cost of creating and reporting against the activity, type of activity, and management technique to be employed?

5. Determine the effect of cost of resources required for an activity on the difference between estimated and actual dimensions of the activity.

6. Is the difference between estimated and actual dimensions of an activity a function of its criticality? . . . of the degree of pushing the state-of-the-art? Does this vary across industries, functions, phases of projects or types of activities?

E. Management of an Activity

1. Is an estimate of the dimensions of an activity treated as an estimate, a target, or a commitment, and under what circumstances?

2. Develop the concept of manageability of activities to aid in understanding the potential impact of alternative ways of improving performance on activities.

F. Resources

1. Determine the patterns of resource application on activities as a function of duration and type of activity for manpower, equipment, material, space, and energy.

2. Determine actual patterns of resource augmentation, i.e., by overtime, additional units, extra shift, etc., by frequency of occurrence.

3. Determine the types and frequency of occurrence of alternative equipment leasing structures and how they should be handled in a computer program for scheduling.

4. Review purchasing and finance literature and conduct field research on purchasing and subcontracting as applicable in the project environment.

5. Determine if and how energy should be accounted for as a resource on activities.

G. Motivation

1. Evaluate the effect of alternate overtime strategies and amounts on the efficiency and effectiveness of the performance of different types of activities.

2. What is the relationship of the occurrence of creativity results to the time remaining on an activity? . . . to the time pressure on the completion of the activity?

3. To what extent are rewards and punishment perceived to be symmetrical as a function of positive or negative performance?

H. Technical Performance

1. What types of efforts are eliminated on an activity as a function of excessive time pressures?

2. Evaluate the effectiveness of Reliability Maturity Index and other similar concepts and recommend an approach which could be incorporated into a comprehensive systems design if appropriate.

I. Costing

1. Determine actual bidder reaction to uncertainty in terms of contingencies by activity or in total for the project in all three dimensions.

2. Conduct a study of present practices in estimating, budgeting and control of costs at the activity or work package level under the Cost/Schedule Control Systems Criteria of DOD.

3. Study the relationship between actual and applied indirect costs, burden, overhead and general and administrative

expenses on projects to evaluate the consistency with reality of current practices.

J. State-of-the-Art versus Organization

1. Analyze the correlation between the degree of organic organizational forms and the extent to which the activities involved are pushing the state-of-the-art technologically.

K. Techniques

1. Develop a solution for the drafting room scheduling problem, including a measure of technical performance.

2. Develop a resource management capability with self-modifying heuristics and alternative objective functions subject to constraints.

3. Develop a combined resource scheduling and allocation model which permits augmentation of resources to solve peak and valley leveling problems.

CHAPTER IV

PROJECTS

Introduction

An activity, having the dimensions of time, resources, and technical performance, exists in a larger space having the dimensions of time, resources, and technical performance. This concept has been implied in the literature primarily for one dimensional space (time) and for two dimensional space (time and resources or time and cost). In the time dimension an activity generally exists in bounded space. In the simplest concept, the lower bound is zero or "time now." The upper bound is some arbitrary target completion date or the earliest possible completion date. These bounds establish the time available. The difference between time available and time required is total float. Float is a measure of the flexibility in scheduling the activities. The activity also has an upper bound for cost as represented by the budget and a lower bound on technical performance. Seldom are any of these bounds absolute, except "time now." They are estimates and actual performance may vary from the estimate in either direction.

More generally, an activity exists in this space along with other activities which, if they are consistent with the definition derived in Chapter II, form a project. The project has bounds in

all three dimensions which may be relatively more inviolate than those for the activity. This permits trade-offs, not only within an activity, but also between activities. It is the process of making such trade-offs that is a major responsibility of the project manager. Associated with this process however is the problem of motivating members of the project organization to be responsive to the bounds of the activities and to the changes to them. The project manager must also monitor the performance on the activities to insure that they individually and collectively meet these bounds and that the resulting product is in accord with specifications. The purpose of this chapter is to discuss the relationships between activities in a project, the characteristics of projects and their performance, and the factors which affect performance of a project. First, it is important to recognize that there are different types of projects and different phases within a project.

Types of Projects

Little was found in the literature classifying projects by type. There has been some classification incidentally as a result of the background of the authors and/or the intended audience. For example, references were cited which dealt with projects such as defense/space, construction, system and data processing, education, and research and development. Even within some of these classes, the projects were different. For example, Sayles and Chandler (1971) focus on projects involving substantial "pushing" of the state-of-the-art. Other books, including Steiner and Ryan (1968)

and Cleland and King (1975) focus on the broader aspects of managing defense/space projects. Antill (1970) focused on heavy construction projects while Clough (1972) focused more on light to medium construction projects.

No references were found which attempted to classify projects by type and examine differences in their characteristics or the management techniques or systems that would be applicable to each type. This was not only true in the literature specifically on managing projects (much of which is differentiated as discussed above) but especially in texts on operations/production management. One consequence of this is generalized discussions of the subject which provide no preparation for the reader to make discriminating judgements as to the applicable management tool.

Another consequence is that the implementation of techniques on computers is often at such a generalized level as to make the resulting software only marginally beneficial on many projects. For example, a major type of project in the U.S. today is neighborhood renewal. The process of acquisition of a number of separate parcels of land almost defies accurate yet practical description in a networking language. Basically five options exist with respect to each parcel--purchase offer accepted, counter offer accepted, negotiated settlement, settlement upon filing condemnation proceedings, and full court hearing and verdict. The first generally has a maximum duration as limited by the terms of the offer. The second two alternatives are very difficult to predict for a specific parcel.

The fourth step may have a minimum duration as determined by arbitrary management action, i.e., a decision as to when condemnation proceedings will be filed. It is very difficult to predict an estimated duration for the fifth step as it depends on court schedules, legal motions, and the like. It should be noted that this problem could be defined in Decision CPM or GERTS but that these techniques prove deficient when considering practical numbers of parcels as well as in terms of the inputs and outputs involved. Nevertheless, the overall renewal project must be managed. The failure of standard PERT/CPM systems in dealing with these problems no doubt leads to decisions not to use the techniques on urban renewal projects.

The problems of managing new car introduction planning is similar where several hundreds of parts must be processed through several different manufacturing planning functions. While there is a sequence for each part, most of the parts are in parallel so the measurement of progress is substantially different than for most projects. Other examples of this type could be cited. Thus, a failure to classify projects by type leads to a failure to recognize their unique characteristics and failure to develop tools suitable to the project. It would seem important for a taxonomy of projects to be developed which would aid in differentiating the effectiveness of the tools of project management as well as understanding other aspects of each type of project.

Phases of Projects

Examination of the various classifications of phases of projects leads to two conclusions. First, there appears to be considerable similarity among them. Second, the starting and ending points vary and some of the phases in one type of project are not required in another. At the most general level, the four phases used by Adams and Barndt (1978) i.e., conceptual, planning, execution, and termination, provide a comprehensive classification scheme. While these phases were appropriate for their purposes, the simplicity of the categories does not provide the richness in understanding either of the differences between projects or the differing characteristics of the phases. An attempt was made to understand the phases in more detail to better understand the implications on the design of techniques and systems for managing projects. Table IV-1 Phases of a Project, presents the results of this attempt for five different types of projects. Since this analysis is purely conjectural no claim is made for its accuracy. Instead, it should be considered only to provide insight into the nature of the differences and the need for research which will provide a better understanding of projects.

Within the various types of projects there are many specific examples. For basic research a project such as the determination of effects of cryogenics on properties of metals was assumed. An applied research project might be the research necessary to develop a material having certain properties at cryogenic temperatures. The development

TABLE IV-1.--Phases of a Project.

Phases	Types of Projects				
	Basic Research	Applied Research	Development Project	Construction Project	System Project
Need Identification and Analysis	x	x	x	x	x
End Product Specification		x	x	x	x
-Concept		x	x	x	x
-Capabilities		x	x	x	x
Feasibility Analysis	x	x	x	x	x
End Product and Component Design	x	x	x		x
-Preliminary Layout					x
-Final/Detail					x
Directed Search	x	x	x		
Efficacy and Safety Testing	x	x	x		
Process Development		x	x		
-Laboratory		x	x		
-Pilot Plant			x		
Full Scale Plant Design				x	x
-Process				x	x
-Layout				x	x
-Detail				x	x
Execution Planning				x	x
Execution				x	x
Start-up and Debug				x	x
Disbursement/Training	x	x	x		x
Conversion to Steady State				x	x
Termination	x	x	x	x	x

(A) (B) (C) (D)

Note: (A) Conceptual; (B) Planning; (C) Execution; (D) Termination.

project might be to develop a process for producing the metal and the construction project could be the construction of a plant to produce the metal. The systems project could be the application of a real-time computer to control the process. (No specific or detailed knowledge of these example projects is implied.) In this analysis fourteen phases are identified with some of those subdivided. The actual phases required on each of the five projects varies substantially. Furthermore, the mapping of these onto the Adams and Barndt (1978) scale is not consistent across the projects with the exception of termination. The nature of that phase varies among the projects, however. The conceptual phase in basic research may include only the need identification and analysis while for the rest it probably goes through feasibility analysis and maybe into initial planning. For R & D projects, the planning may be relatively limited while for the construction and systems projects planning could extend through the design process and include execution planning. It should be noted that the types of projects analyzed by Adams and Barndt could probably be viewed as hybrids of development, construction, and system projects. Thus, the results they obtained might be even more vivid when analyzed against this more detailed categorization of phases. It should also be noted that other example projects might reveal different patterns of phases. This brief analysis is considered adequate to demonstrate the limited understanding of phases of projects and therefore the ambiguity of experimental as well as experimental conclusions on the understanding of projects and their management.

Stages in Managing Projects

General Management texts often speak of the functions of management in terms of planning, organizing, staffing, directing and controlling. While these are adequate for most discussions of management in general, they are not in sufficient detail to clearly understand what managers of projects actually do. The DOD and NASA Guide: PERT COST (1962) provides a more detail discussion but it is oriented specifically to explaining the use of the PERT/COST System. Basically it categorizes all the steps into two general cycles--planning cycle and control cycle--under which the detail is presented. The interrelatedness of planning cycle and the control cycle is portrayed in the diagram (Figure IV-1) by the control cycle looping back into the planning cycle.

For purposes of this analysis, the general stages of managing projects are pre-execution and execution. These and the detail stages are shown in Figure IV-2, Stages in the Management Process. Pre-execution can be defined as the establishment of the concept and parameters of the project, identification and scheduling of the work which must be performed, and the allocation of resources required. Execution is the performance of the work, hopefully according to plan, the evaluation of results, and taking of corrective action where deviation from plans occur. The detail stages were defined as follows:

Identify Purpose--Establish the justification for engaging in the project. Often times this includes identification of

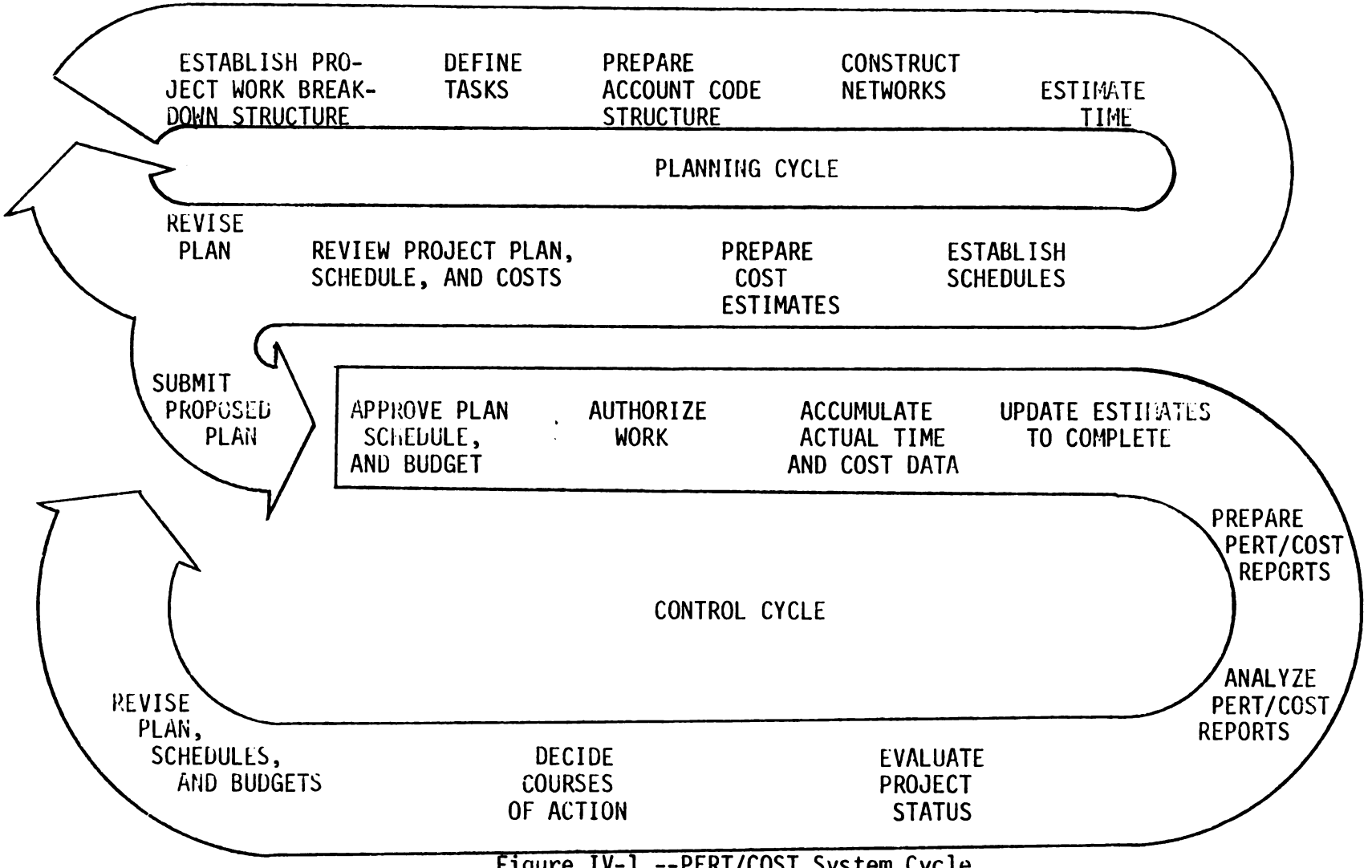


Figure IV-1.--PERT/COST System Cycle.

Source: DOD and NASA Guide: PERT COST, June 1962, p. 24.

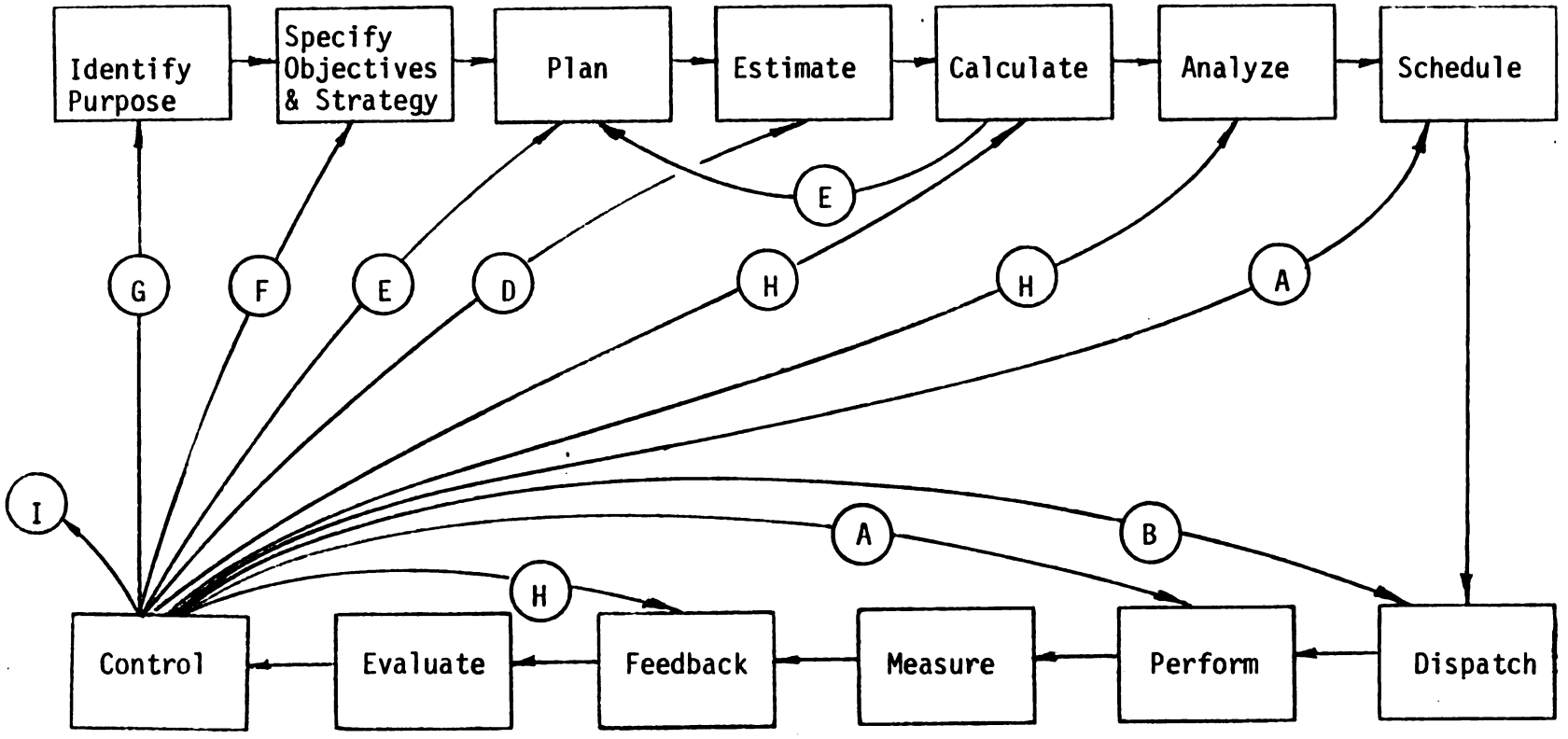


Figure IV-2.--Stages in the Management Process.

Note: A = Expedite; B = Re-dispatch; C = Re-Schedule; D = Re-estimate; E = Re-plan; F = Modify Objectives and/or Strategy; G = Modify Purpose; H = Modify Management Information and Control Systems; I = Terminate.

the problem as opposed to the symptoms which may have brought attention to the problem.

Specify Objectives and Strategy--Establish the specific objectives of the project, including specific technical objectives, and determine the general scheme, general methods, and anticipated general allocation of or limits on resources to be employed by which the purposes are to be fulfilled.

Plan--Explicitly identify the work required to accomplish the general and the specific technical objectives within the allocation of resources. One aspect of this is the identification of the activities that must be performed based on the methods to be employed and relating them as in a network diagram.

Estimate--Determine the specific methods, time, and resources required to perform the activities to achieve the objectives.

Calculate--Perform arithmetical computations such as early and late times and float determinations, time-cost trade-off, resource allocation and perhaps portions of the subsequent two stages.

Analyze--Review the results of the prior steps to assure consistency with project objectives and to identify opportunities to improve plans and methods.

Schedule--Identify the specific time period in which *it is intended* to perform an activity and the allocation of

resources necessary for its accomplishment. No resources are committed in this stage.

Dispatch--Issue instructions and authorizations to proceed on the performance of one or more activities and the actual commitment of the resources required to accomplish this work.

Perform--Conduct the work necessary for the completion of an activity. It includes direction and instruction by first line supervisors.

Measure--Determine the results from the effort expended in performing an activity.

Feedback--Transmit data and information to appropriate persons for use in performing their management responsibilities including appropriate transformations and summaries of the data and information into more useful forms.

Evaluation--The determination if the performance of the activity, as represented by the feedback, was adequate as compared to the general and specific objectives identified in the plan.

Control--The exercise of corrective action if and where necessary as determined in the evaluation stage.

Corrective actions can be any of the variety as suggested by the following:

Expedite--Motivate the designated people to perform in conformance with the plan. Emphasis is placed on people

because, even if the work is machine paced it is assumed that a human must take some action to modify the behavior of the machine.

Re-dispatch--Change or augment the resources originally dispatched to perform an activity. This may occur due to inadequacy of the original resources, to problems associated with the dynamics of human resources, or to a variety of other reasons.

Re-schedule--Revise the intended performance period or re-allocate resources to the activity.

Re-estimate--Revise the estimate of resources required to perform the activity.

Re-plan--Revise the plan by overlapping activities, defining activities in greater detail, changing methods, etc.

Modify Objectives and/or Strategy--Revise the objectives and/or strategy to make them consistent with a realistic assessment of attainable objectives and/or feasible strategy.

Modify Purpose--Re-assess and modify the stated purposes of the project to make them consistent with capabilities of the organization or in recognition of errors in their original identification.

It is asserted that the sequence in which the above corrective actions are listed is consistent with the priorities that management is likely to assign to their consideration. The last step in that sequence is premature termination or abortion of the project.

Not included in the corrective actions is the revision of the MICS. This is a real possibility as are revising the measure, feedback, and/or evaluate stages if they are not performed effectively.

The importance of identifying each of the above stages including the corrective actions will be made clear in Chapter V in considering how the techniques and systems should be evaluated in order to provide managers guidance in the selection of the proper tools for managing a project. For example, it is contended here that the requirements for a system design to be effective and efficient in the corrective action aspects listed above may be substantially different and/or more demanding than the requirements for the original planning efforts. Indeed, it may be that the ability to accept efficiently and deal effectively with changes is the crucial capability necessary for successful application of a project management technique. It is contended here that the requirements for a system to be effective in the execution stages are substantially different and more demanding than for the pre-execution stages and yet most of the literature and research has been directed at the pre-execution stages.

An important distinction between scheduling and dispatching is that the sunk costs generated by the act of scheduling are minimal and thus re-scheduling is generally a viable alternative. On the other hand, once resources are dispatched on an activity, the sunk costs associated with a revision are substantially greater. It is

important to recognize, however, that scheduling one activity may result in the dispatching of other activities preceding that activity, sometimes by a substantial lead time. For example, scheduling the installation of windows in a large building may trigger the start of manufacture, i.e., dispatching, of those windows several months prior. Control of this must be through the purchase requisition, purchase order and contract.

While measurement and feedback are not normally singled out for discussion in management literature, the dynamic nature of projects, and the management thereof, makes these essential aspects of the management of projects. Feedback includes the recording, transforming, summarizing, and transmitting of the data, and the presentation of the information. Control is based on the results of feedback but also is highly dependent upon the use made of the information. Furthermore, the use of that information has an effect on other stages of managing a project, especially estimating, measuring and feedback.

Variations in approaches to management of pre-execution and execution of projects imply, or stem from, variations in philosophy and practice of management in the application of the techniques. During the last two decades, various approaches to implementation of the techniques have been espoused. Some of these are inherently contradictory. However, closer examination seems to reveal differences in circumstances which help in understanding the philosophies and practices. Based on different philosophies and circumstances, the

design of systems for managing projects should vary. There is a need for more explicit research aimed at clarifying and justifying the differences and associated circumstances.

Interrelationships

General Relationships

Generally, activities in a project are related in some logical fashion as dictated by the technology of the work and for the item worked upon. For example, the often used illustration of a person dressing points out that the sock must be placed on the foot before the shoe. A more practical example would be that excavation must precede forming which must precede pouring of concrete in producing a foundation for a building. It is these relationships that are incorporated into a network portrayal of a project plan which forms the basis for CPTs. It is also the graphic capability that results in network based systems having substantial advantages over the Gantt Chart. The usual relationship which is provided for in most CPT systems is that activity "B" cannot start until activity "A" is finished. This is shown in both activity-on-arrow (AOA) and activity-on-node (AON) graphic notation in Figure IV-3.

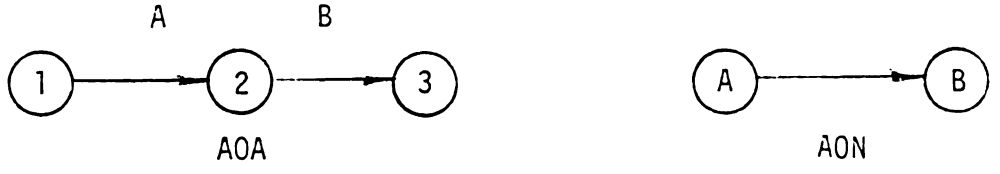


Figure IV-3.--Basic Logical Relationship of Activities in a Network.

Float

As a result of these relationships, it is possible to perform calculations on the network which determine the earliest and latest start and finish times for each activity. From these the float or slack can be calculated. These calculations are adequately described in a number of references including Wiest and Levy (1977).

The use of the word "slack" to designate difference between time available and time required for an activity originated with PERT while "float" was used with CPPS. These two words now seem to be used interchangeably with the exception that slack by itself implies total float. If the variations in float are to be uniquely identified it is necessary to use the appropriate adjective in all instances. Therefore, the term float with the proper adjective, will be used henceforth in this report.

There are a number of references including Elmaghraby (1977) which discuss the various measures of float. Interestingly, they are not in total agreement. All of those reviewed assumed an AOA graphic notation and are somewhat difficult to translate into AON notation. The possible variations can be more readily understood for both AOA and AON graphic notations by using the following symbols along with the interpretations provided:

ES = Early Start of an activity

EF = Early Finish of an activity

LS = Late Start of an activity

LF = Late Finish of an activity

D = Duration of an activity

LFp = Late Finish of the predecessors of an activity

LSs = Early Start of the successors of an activity

Then:

Total Float, TF = LF - ES - D,

implies that all successors start as late as possible and all predecessors finish as early as possible. This gives the broadest measure of the flexibility in scheduling.

Free Float, FF = ESs - ES - D

implies that all successors start as early as possible and all predecessors finish as early as possible. This indicates the extent an activity can be delayed from its early start without interfering with the early start of any successor activities.

Interferring Float, IIF = Total Float - Free Float,

indicates the amount of time the successors of an activity can be delayed beyond the amount of the free float.

Independent Float, IF = Max (0; ESs - LFp - D),

implies that all successors start as early as possible and all predecessors finish as late as possible. Thus, this is the amount of time the start of an activity can be delayed beyond the latest finish of all of its predecessors without affecting the early start of any of its successors.

Safety Float, SF = LF - LFp - D,

has essentially the same interpretation as Free Float except it focuses on the predecessor activities instead of the successors.

Event Float, EF = tj(L) - tj(E), or = ti(L) - ti(E)

Event Float is relevant only in AOA graphic notation as presently conceived.

Closer examination reveals that it is the same as total float on an activity having no duration. Thus, it is possible in AON graphic notation to identify an activity with zero duration to be the equivalent of an event in AOA notation

Other General Relationships

The basic relationship between activities that all predecessors must be completed before an activity can start is certainly adequate for a large proportion of activities. However, practical application soon revealed conditions which could not be handled, at least well, by this simple relationship.

Some relief is offered by systems employing AON notation by permitting overlap of activities. Such relationships are often found in engineering operations. It also, at least some people claim, got rid of the troublesome "dummy" activity of AOA notation. Still all of these imply that the follower can start when all of its predecessors are completed. No reference was found to a relationship in which the activity must start as soon as all its predecessors have been completed. By careful use of scheduled start and complete dates for two or more activities other relationships can be approximated. This can be tedious, inconvenient, and somewhat risky.

Failure to negate such a relationship after the conditions have changed results in errors. An alternative relationship is a required time separation between contiguous activities. This can be handled in AOA notation by a "dummy" activity with a non-zero duration. With AON notation the "delay" or interval feature can be used. No provision is made for an exact separation. Only an "at least" relationship can be specified. Likewise, not much is said on the concurrency relationship, i.e., that two or more activities must be performed simultaneously, other than by Gutsch (1969).

All of the above is relative to technological precedence. The admonition is frequently given to avoid putting any constraints in the network that are not essential to the technological relationship. Yet there are circumstances where other relationships would be useful. In some types of projects, some activities are essential while others are desirable for different reasons. Comparing this concept to similar problems in assembly line balancing gives some insight into the possibilities. In assembly line balancing, there are work units that must be done at a specific work station. These are called "must do" work units. Depending on the detail into which the work elements are broken, the getting of materials and getting and putting away of tools may be identified as work elements. These may be called "make ready and put away" work elements. Although they cannot be eliminated completely, they can be reduced in either magnitude or frequency, or both.

Similar concepts could be applied in project networks. A "must" relationship could be identified to indicate that an activity

must start immediately upon completion of its predecessors. Many activities in a network are essential to the technical achievement of project objectives. These activities are essential and often have very specific technological relationships. Others, such as administrative or logistical support activities, may have some consequences on the project if not done but, by and large, the consequences are not as serious as failure to achieve technical objectives. An excellent example is the set of quality control activities that should be done at a specific point but which may be done later or even omitted with the acceptance of the associated risk. These are often compromised under the pressure of severe time and/or cost constraints. These relationships could be identified as "should."

A similar phenomena exists in certain esoteric activities in a project. If time permits, they would be desirable, however, they may not be essential to project objectives. Landscaping around a building could be reduced or eliminated completely under severe time and/or cost pressures. The relationship for these activities, and the activities themselves, could be identified as "desired." Specific identification of activities such as these could lead to quicker recognition of potential opportunities to save time and/or money, or could result in getting that work accomplished if resources become available. To date there apparently has been no such relationship available in network planning systems.

"Scheduling precedence" would have been useful in scheduling die design, modeling, and fabrication. Due to limited capacities of

the operations, close coordination was required. The ability to add precedence relationships which were kept separate from the technological relations would have been very useful. One of the reasons for this was the recognition that the real problem which had to be dealt with in this instance was "re-scheduling." One objective in re-scheduling is to minimize the disturbance in the system by making the fewest possible changes to obtain satisfactory results. One type of change which can be avoided is in the sequence of activities as scheduled. This same problem occurs in many systems where several different resources are being scheduled so that problems of coordination are especially important and the technological relationships result in many parallel paths. This condition occurs frequently on major computer programming efforts.

Another type of logical relationship which is not provided for is what will be called the "punch list" problem. A set of tasks must be accomplished. There are alternative activities on which these may be attached. For example, a series of instrumentation tests have to be conducted on any of a number of flight tests of an aircraft. Which test is to be performed on which flight is really immaterial. However, all tests must have been completed by the final flight and not all tests can be conducted on any one flight. At present this situation must be handled by manual means. It would seem that provision for such a "punch list" could be incorporated into a system along with notation of the activities on which it is feasible to attach each item on the list and any

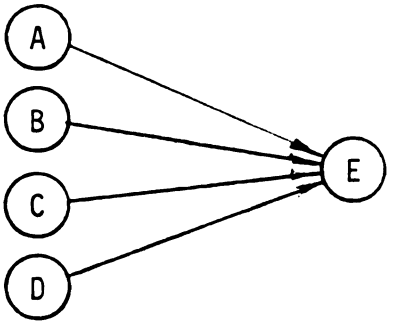
limitations on the number of items that can be attached to the same activity. Note that this is similar to the concurrent activity concept.

A similar problem exists in maintenance scheduling. Non-essential tasks could be held in file until emergency or other scheduled maintenance is required. At that time a list of the non-essential items could be provided to be done while the equipment was out of service or a crew was at a remote location. Often, when this type of capability does not exist, a crew is sent to the remote location without tools or materials to perform other work, they complete the emergency maintenance and accomplish little more for the shift. Provision of this punch list capability could lead to improved labor utilization by assigning other tasks that could be performed at the same time.

Another version of the punch list relates to the completion of a construction project. Two types of relationships may be involved. The simplest is the common resource relationship. When a crew with certain skills, say carpenters, is brought back to a construction site, they should be provided a list of all items on the punch list requiring their skill. Alternatively, where such work would place an area out of operation for a period, listing of all the tasks in that area by skills required could permit completion of these tasks during the same period of down time.

The use of "water" in scheduling has been discussed previously. Based on the results of Van Slyke (1963) this can now be approached

more deliberately. Consider a point of convergence in a network as illustrated below:



According to Van Slyke, as the number of predecessors increases the expected early start time of E increases while the variance decreases. He assumed that all predecessor paths have equal durations, an assumption which may occur infrequently in practice. However, it is not unusual in practice for all the predecessors to be performed in such a way that the slack on all of them approaches zero as the scheduled start time for E comes nearer. Thus, while the conditions may not be identical to the conditions assumed by Van Slyke, the results may be nearly the same. It is intuitively acceptable that the more predecessors an activity has, the greater the probability that at least one of them will be late. (This could be proven mathematically but is not necessary for our purposes.)

The problems of communication, interpretation, and coordination, often show up at this point. It seems wise to provide for this highly probable situation with a contingency. The contingency could be provided for by a separate activity, E', inserted in the network before E. It could be handled by an "end to start" relationship in AON with an interval or delay between each predecessor and E.

Regardless, it seems appropriate to provide some means for handling this. Clearly, the amount of time could be a function of the estimated uncertainties on the several paths converging at E. A routine in the computer program could provide the necessary information for the decision based on statistical analysis. Research should be conducted to better understand this problem both empirically and theoretically. It would have value because one alternative would be to schedule the predecessors of E at their earliest dates. This could result in deterioration of the resultant work product of the activity or changes in requirements necessitating extra effort.

A similar problem occurs at a point of divergence. For example, in R & D and engineering it is common to have review meetings at the end of each phase prior to authorizing the next phase to proceed. If the resources for the next phase are committed to these activities and the decision is delayed, the resources may remain idle for some time or alternatively, may be allowed to proceed on the work without authorization. In the first case labor productivity is lost while in the second case a risk is involved. Often it is desired to proceed as quickly as possible after the review meeting. Although there are several options available, there is little if anything in the literature providing guidance on dealing with this problem.

The problems and potential solutions offered raise a number of questions which should be researched. These include definition of specific conditions under which the "should" and "desired" logical relationships would be useful and how the re-scheduling should be

done using the "schedule precedence" relationships. They also include determination of the useful capabilities associated with the "punch list" and the use of contingencies to allow for uncertainties.

Resource Interrelationship

While most discussions of interrelationships deal with the technological relationships as portrayed in the network diagram, there are a number of interrelationships that are derived from the resources required by the project. These include availability, leveling, trade-offs between alternate ways of augmenting resources, and the dynamics of the resources.

Availability

In the original development of both PERT and CPPS it was assumed that whatever resources were needed would be available in both the quantity and the time period required. This was soon recognized to be an unrealistic assumption for most commercial projects. One extreme illustration of the problems that resulted was major construction projects exhausting the labor supply in a geographical area. Several bad effects resulted from this phenomenon. First, as the labor pool for a particular skill was tapped to greater and greater depths, the skill level of the next employee hired diminished and activities to which these resources were applied suffered in at least one dimension. Secondly, there developed an expectation of overtime by the employees which the employer had to recognize to maintain a full work force. The employee's alternative

was to switch to another employer who would guarantee the overtime. Furthermore, any question about the need for overtime on a particular job led to attempted slow downs to reinforce the need for the overtime if the job were to stay on schedule, probably affecting all activities requiring that resource and perhaps other activities associated with them. Third, in such a situation of high demand, the union had definite advantages when their contract came up for negotiation to demand and get substantial wage increases. Between negotiation periods the likelihood of work stoppage was greater because the workers were aware of the shortage of labor and were inclined to be more militant. Fourth, in many areas an employer is required to pay into an unemployment compensation fund to support workers whom they hired and released. The greater the variation in work force by an employer, the greater the costs for unemployment compensation.

Thus, for several practical reasons, an employer may be well advised to pay careful attention to the demands being placed on the labor market for various trades and to keep his peak demands as low as possible. This requires some form of resource leveling capability or other means of minimizing fluctuation and achieving high levels of utilization.

Leveling

The recognition of the importance of leveling resource requirements seems to have generated more research and articles than did PERT or CPPS themselves. Yet the evidence of the use of

computerized leveling procedures is certainly not overwhelming. The only analysis related to this was by Neel (1971) where he showed that, while management of resources was considered a major problem, relatively few companies were using that feature of project management systems. The emphasis on leveling resource requirements may have led to a failure to adequately research the needs of management for effectively managing resource utilization.

There are other problems associated with the effective utilization of resources. The nature of the problem of obtaining an optimum schedule for a project in terms of resource leveling was illustrated by Martino (1968). Using the simple project illustrated in Figure IV-4, Sample Project, he enumerated all of the 58 possible

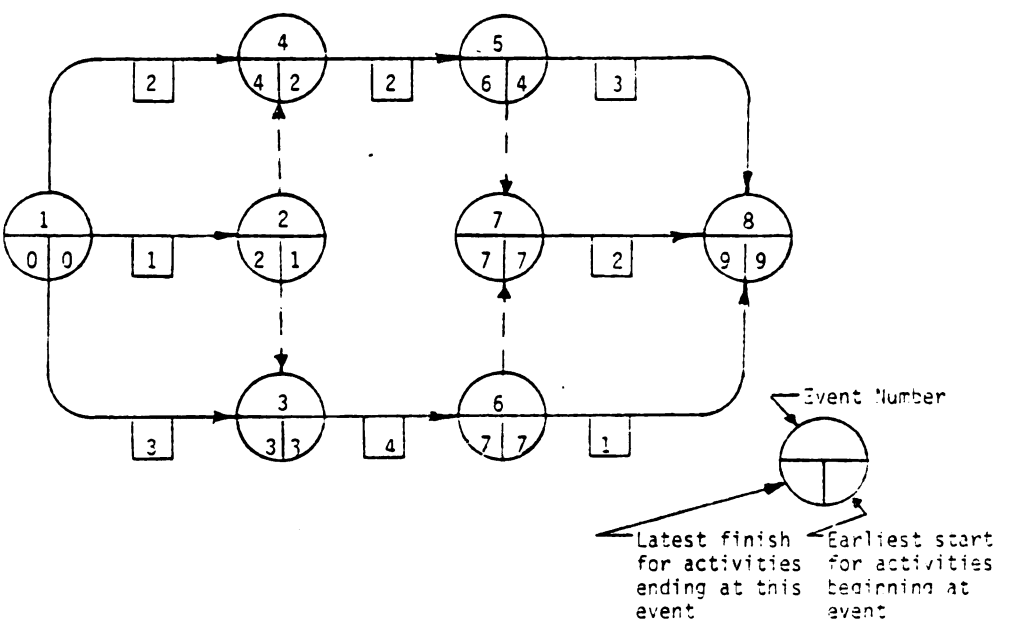


Figure IV-4.--Sample Project.

Source: Martino, R. L., Resources Management, MDI Publications, Wayne, Pa., 1968, p. 8.

schedules that can be derived and showed the resource profile for each. Of these 58 schedules, only three had optimum resource profiles. Thus, in this very simple case, the probability of finding an optimum solution at random is barely 5%. In more realistic problems that probability would be much lower especially when multiple types and quantities of resources are considered.

Coincidentally, this illustration by Martino can also be used to demonstrate the value of float in a network. Examination of the activity times discloses that activities 1-3, 3-6, and 7-8 form the critical path of nine days. Activities 1-2 and 1-4 each have 2 days of float. Thus, there are three possible schedule times for each of them. Activity 1-2 can be delayed 0, 1, or 2 days and the same for activity 1-4. Considering all of the possible alternatives, it can be seen how the unnecessary use of float reduces the alternatives and eventually requires additional resource costs.

Penalty costs are computed as follows. The optimum solutions require 18 man days of resource. To compute the non-optimum solutions, for minimum cost it is assumed that one person starts the project with the second being added when needed. For maximum cost, it is assumed that both persons are brought onto the job at time zero. All resources in excess of two are obtained through overtime at 150% of straight time rate. It is clear that indiscriminate use of float can result in incurrence of unnecessary costs.

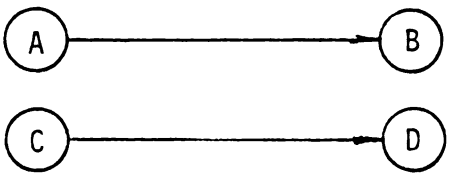
Because of this, time is frequently considered a resource and the use of float should be deliberate and carefully managed.

TABLE IV-2.--Value of Float in a Network.

Float on Activity		Delay on Activity		Number of Alternative Schedules	Number of Optimum Assignments Included in Alternatives	Penalty Cost (% Increase)	
1-2	1-4	1-2	1-4			Min.	Max.
2	2	0	0	58	3	0	0
1	2	1	0	38	1	0	0
2	1	0	1	27	2	0	0
1	1	1	1	19	0	.0278	.0833
0	1	2	1	8	0	.0278	.0833
1	0	1	2	2	0	.0278	.0833
0	2	2	0	16	1	0	0
2	0	0	2	6	0	.0278	.0833
0	0	2	2	2	0	.0556	.1667

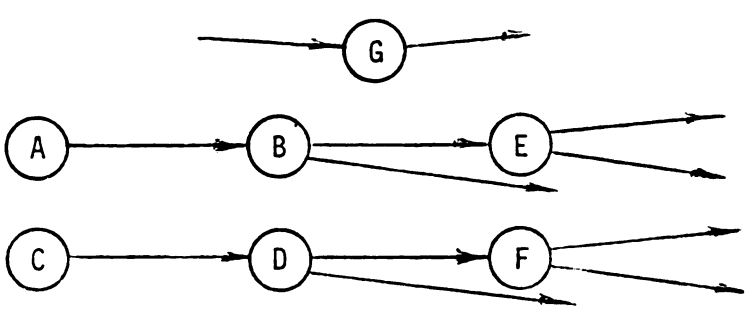
Once the leveling process has been completed, there is still a decision to be made as to how to augment the currently available resources. For example, an employer currently has ten carpenters on the role and fifteen are indicated as required for some period of time. Under certain circumstances it might be wise to hire five more carpenters. Under other circumstances it may be wise to work twelve hour days for the period. An appreciation of industrial engineering findings about overtime suggests that, even for very short periods, it is not likely that twelve hour work days would increase production by 50%. In fact, it might take thirteen or fourteen hours to achieve the required production. On the other hand, in extremely urgent situations people have been known to work much longer hours without stopping. This could be very hazardous in certain environments as the workers' reaction time increases and their alertness decreases. No evidence was found of any analytical capability to aid the project manager in this analysis.

There are other dependency relationships that occur as a function of resources. The assignment or drafting room problem was discussed previously. A similar problem exists between resources on non-contiguous activities. For example, consider the following activities.



B and D are to be performed by the same person, say Zed. Activity A is scheduled to be completed before C, permitting work to proceed

on B before D is available. For some reason, A is delayed. Some amount of delay will be tolerated, allowing Zed and whatever materials and equipment may be required to wait for A to be completed. Eventually, a decision will be made to proceed on D. Once this decision is made, a further delay is incurred until D is finished before B can start. The results from such a situation may be more consequential than is readily apparent. First, rental on the equipment required for B will probably be incurred while activity D is being performed. Thus, there will be a cost overrun. Secondly, the follower of D, say F, may be moved ahead now that it can be performed earlier. This may require expediting of materials and equipment for activity F and possible increased costs as a result. It may also affect the schedule for several other activities following either D or F. Finally, the later performance time for B may have similar effects on E, its immediate follower and other followers of B and E. Also, the delay in performance of B may cause a delay in the performance of G, another activity not in the same percedence chain but requiring the same resource as B and D. These activities are shown below.



Thus, there is truly an interrelationship between activities as a function of both common and different resources. This applies primarily to three categories of resources, i.e., labor, equipment, and space. Occasionally, material will be affected for an operation relying on a common inventory which is managed by EOQ procedures if material "mortgaging" procedures are not followed rigorously. A limited ability to relate items in a bill of materials to specific activities would provide a means for incorporating availability of materials, schedule dates, and cost from the bill of materials to the activity and vice versa. Such a capability could also be used for an equipment list, especially of the typical tool room inventory. These capabilities would be especially helpful in scheduling maintenance work.

Dispatching

Closely associated with this is the practical problem of dispatching to make work available which will permit keeping a work force occupied. At first glance this seems like the original scheduling/leveling problem. The difference is that the dispatching problem often is a re-scheduling problem. The dispatching problem results from four characteristics of the project--uncertainty as to the work force, uncertainty as to the environment, uncertainty as to the work content of the project, and uncertainty as to the performance of preceding activities. Uncertainties relative to the work force includes labor strife, jurisdictional disputes, and the

general vagaries of the human resource. This is discussed further in a subsequent section, Dynamics of the Human Resource.

Uncertainties in the environment on a construction job include such things as weather, unexpected sub-soil conditions for foundation, and conflicts between the contractor and client, architect, and/or subcontractors, to name a few. Inclement weather may prevent the work that was originally scheduled from being done but not prevent some other work from being moved ahead. For example, an ice storm may stop all structural steel work but not prohibit some work on lower floors that were protected.

Uncertainty as to the work content of the project is different, at least in degree, than uncertainty related to the activity. In the latter, it was recognized that the work had to be done but the ability to estimate its dimensions was limited. In the former, it was not recognized in the original plan that the work had to be done and therefore no activity was identified for it. Such an activity may have been an oversight in original planning, the failure of an intended approach to accomplish an objective, or a recognition that an alternative method has desired advantages.

Uncertainty with regards to performance of preceding activities is especially important on projects that are scheduled closely, i.e., with no time between activities. The phenomena occurs frequently in maintenance work. Nevertheless, the resulting perturbation of plans requires the project manager to revise schedules in the short run if a reasonable utilization of available resources is to

be achieved. The literature is very sparse in this area, generally limited to comments on the advantages of PERT and CPPS in revising plans. Having engaged in this extensively, it is easy to understand why the project manager tends to make these decisions by "seat-of-the-pants" methods. Until the recent introduction of time-sharing approaches to network planning and scheduling, the turn around time from making revisions in the data to getting the revised computer output made the system impractical for assistance in dispatching or short-run re-scheduling. Only when the problems got so serious as to justify a late-night session at the computer center was the system used to solve short-run problems. No evidence was found, even with time-shared, real-time computer capabilities, that significant changes in systems concepts have been adopted to apply those capabilities to these problems.

An example of the short-run rescheduling/dispatching problem from personal experience, even of limited complexity will illustrate the possibilities. While making additions and alterations to a house, using only family labor, a network permitted the answering of several types of questions. On a specific day the weather prohibited work on certain outside activities. Reference to the network revealed those activities which were not limited by the weather. On other occasions, given that a person of limited skills would be available on a near future day, referral to the network permitted determination of what work had to be accomplished to make available an activity consistent with those skills. On still other

occasions, the ability to foresee the need for additional help permitted determination of what work had to be accomplished before arranging for those resources. This permitted either the minimization of the length of time the resources were required or maximization of the work accomplished while they were available.

Thus, it is clear that there is a problem of short-run re-scheduling/dispatching which has different objectives than just leveling resource requirements. A major objective is the maximum utilization of resources. While measurement of direct labor efficiency is a standard practice in most manufacturing operations and in most construction firms, it does not seem to have been incorporated into network based project scheduling systems.

Another objective important in some projects is maintaining some flexibility in dispatching. In the same sense that slack is an indicator of flexibility in a network, the number of activities that are available to be worked on is a measure of the flexibility of dispatching. Clearly, maximizing flexibility is not a desirable objective. A more reasonable objective would be maintaining some minimal flexibility if possible. In most realistic projects of personal experience this has been a feasible objective. To accomplish this with the aid of a computer it is necessary to identify the dimensions upon which flexibility is desired, the data relevant to those dimensions, and the logic which is necessary to analyze that data and arrive at viable conclusions. No evidence was found of research in this direction.

Further, multiple objectives must be considered. Some other alternative objectives that are relevant are minimizing cash outflow (generally for short periods of time) or maximizing cash inflow (completing large dollar content activities in order to bill them or completing leasable space so that it can be rented). Since these are only representative objectives, it is presumed that others could be identified from suitable deliberate research. Further the research should identify changes in objectives, their nature, and the causes for the changes.

It can be argued that these objectives can be achieved with current capabilities. This is not denied. The relevant argument is that they cannot be achieved quickly and easily by project personnel who are typically under pressures of many kinds. Real-time computing offers the opportunity to be responsive to the needs of these people if their needs are adequately understood and appropriate capabilities incorporated in the system.

Re-Scheduling

A closely related problem is re-scheduling a project after a major delay. It would seem that a straight forward application of CPPS could solve this problem. Experience suggests that it may be more complicated. Structural steel erection may be limited by the availability of a crane. The cost of a second crane may be prohibitive or there may not be space for it. Labor contracts may limit hours for safety or other reasons. Thus, the options are very limited. If reports are given to the foreman showing that he

is so far behind he cannot possibly catch up, he may have no motivation to try to speed up the work. On the other hand, to relax the schedule dates too much will also lead to lack of motivation. If there were a capability to allocate the time that has to be made up between several activities in a sequence, the "task" or challenge provided on each activity could be attainable and the motivation to try to speed up might be stimulated. No such capability is known to exist, yet project efforts are often scheduled in that way when the scheduling is done manually. Another aspect of re-scheduling involves selectively releasing (from the previous schedule dates) activities which are least costly to re-schedule. Consider two activities on which the same labor crew is required. Activity "A" is pouring of concrete while activity "B" is the leveling of a ground area by manual means. Activity "A" also requires the scheduling of concrete delivery, of cement masons, and of special equipment used only for that one activity. Activity "B" requires no extra resources other than shovels and wheel barrows that are available. Clearly, re-scheduling activity "A" requires much more effort, inconvenience, and possible cost. It would be desirable to not disturb the schedule for activity "A" and others like it. On the other hand, activity "B" could be re-scheduled with ease. No evidence was found of such a selective re-scheduling capability.

Dynamics of the Human Resource

In mass production environments, it is well recognized that absenteeism is a reality and staffing exceeds minimum requirements

to protect for this. In job shop environments it is understood that equipment will breakdown so it is not loaded 100%. These considerations are discussed to some extent in literature dealing with these environments. No comparable discussion was found with regard to projects. Two aspects of this have been experienced that suggest a need for greater understanding of project type work. The first concerns organization slack and the second the coordination of diverse resources.

Organization Slack

Organization slack was defined by March and Simon (1959) as that "portion of the activities in the organization (which) is directed toward satisfying individual or sub-group goals" (p. 126). Organization slack can be measured by the difference between the work an organization is capable of producing by some reasonable standards and the amount it is actually producing. Casual observation of organizations indicates that there are a number of functions in which management personnel participate which, from time to time, they forego. Some of these are sanctioned if not encouraged by superiors while some are reluctantly accepted as necessary to retain competent staff. They may include attending professional meetings, representing the organization in various roles, or involvement in civic or social functions. The fact that they are foregone in the short run is evidence of organizational slack. Often it is as a result of this slack that an organization can take on a project and

complete it in short order. In other organizations where slack is minimal the esprit is such that greater than 100% effort is achieved for some period of time. Understanding this is essential for the chief executive of such an organization for it determines the amount of project effort that organization is capable of accomplishing in a given period of time.

To this point, it may appear that a typical problem of the behavioral sciences has been described. Rather, it is argued here, that the problem is one which is largely ignored by the behavioral sciences but is essential to project managers. As compared to the mass production and job shop environments the work content of projects, being uncertain, cannot be as accurately determined. Therefore, there is a greater probability of overloading the organization. Even where esprit is high, the effectiveness of individuals can be expected to deteriorate when pressure is maintained for too long. If pressure is excessive, other dysfunctional behaviors can be expected. It would seem that there is some length of time that individuals can endure substantial work pressures, foregoing participation in the "extra curricular" functions, beyond which they are unwilling to go. On the other hand, inadequate pressure results in the organization accomplishing less than it is capable of producing. It seems there is only experience at this point on which to base judgements of this type. The behavioral sciences seem to ignore the study of organizations operating under the degree of pressure which often occurs in projects.

This concept must be learned by technical personnel who move into management jobs and discover they have to make such judgements. It is important to every manager who must make commitments for his organizational unit. If he is too conservative, the organization will not achieve to its full potential. On the other hand, if he is too optimistic at least one of several phenomena may occur. Some organizations consistently start more projects than they can effectively perform. This may result in low technical performance on most, if not all, projects. Sometimes some of the projects are cancelled when partially completed resulting in wasted resources and again, lack of achievement of full potential. Sometimes most, if not all, projects are completed late with obvious reflections on the managerial capabilities of the responsible person. In every case, the organization is not achieving its full potential and the people involved will not gain the recognition they might have. A better understanding of these phenomena and better tools to deal with them should enhance the productivity of project oriented organizations substantially.

Coordination of Diverse Resources

The second problem, the coordination of diverse resources, is somewhat different yet it is one familiar to anyone who has managed projects involving more than a few people. One simple illustration is the problem of finding a suitable meeting time for several people. A critical aspect of projects is the bringing together of a sometimes diverse group of people. Each such person

has commitments outside the project which cannot be disregarded. Some of the commitments are regular and can be depended upon such as meetings of professional or civic organizations. Some of the commitments are irregular including other meetings, family emergencies, and personal problems. The latter create the more serious problems in the project. While the activities in the project can be scheduled in a mechanistic sense, even though with some uncertainty, these uncertain commitments of the individuals add another dimension to scheduling.

One of the outcomes of this phenomenon is delays. Sometimes there are critical meetings at which decisions must be made to permit work to proceed on a number of activities. Other times critical deadlines are not met because of the absence of supervision. A worst case example of recent experience was the unexpected absence of three levels of management and supervision at a critical time on a project. Generally, the absence of one level of supervision is not critical. The next higher level quickly recognizes the absence, inquires into the situation, and takes appropriate action. The absence of two successive levels increases the time required to recognize the absence and possibly is accompanied by a larger gap in understanding the commitments of the performing organization resulting in potentially misguided direction. The coincidental absence of three levels of supervision increases the seriousness of these problems even more.

Another aspect of the coordination of diverse human resources has to do with failure to perform. The larger the project organization,

the less likely the project manager knows each participant personally or has had direct experience working with each participant. Ability to select all project personnel on the basis of personal knowledge of capability to perform becomes severely limited. Inevitably, someone fails to perform a critical activity. Often, in such a situation, the project manager has no alternative but to become personally involved in the performance of that activity. This can range from such trivial tasks as personally getting on a fork lift and picking up a recalcitrant bundle of lunber to persuading a dissident group of employees to return to work. The breadth of capabilities of the project manager may be vital to the success of the project. The project manager must provide for some organizational slack which will permit recovery from such a situation.

A somewhat more subtle aspect of the coordination of diverse human resources has to do with the efficiency of communication of responsibilities and direction. It seems that the more a person considers himself a "professional" the more adamant he is about deviating from his own norms of roles or standards of performance. It is very difficult to get an "off-the-cuff" evaluation of a design by many professional architects or engineers. It is also very difficult to persuade some people to accept responsibilities which take them outside their area of professional competence or which may be contrary to their professional self image. Sometimes, to obtain the unique contributions of a specific individual, the project manager must compromise good organizational principles and judgements and modify previous commitments with other organizational

participants. Occasionally, these compromises and modifications weaken the organizational "fabric" either through creation of gaps in responsibility or strains in relationships between participants. Often the strains in relationships involve the project manager personally, thus weakening his future capabilities to resolve conflict by persuasion or negotiation. Sometimes the gaps go unnoticed until some critical incident occurs. Often the project manager must personally fill the gap.

These phenomena associated with the cordination of diverse resources are certainly characteristic of all human organizations. It is more critical in project organizations for one major reason i.e., the non-repetitive nature of projects. In craft mode work there is typically one person or only a few similar persons involved. Values are similar, personal knowledge of all other participants is high, and the variety of tasks to be performed is limited. In mass production modes, the repetitiveness of the tasks permits modification of the behavior of participants or their replacement. Job shops tend to de-couple operations and provide rather explicit instructions. Often, on projects, there is only one person or crew available to perform an activity and instructions may be only in terms of results expected. Redundancy may be too expensive or the uniqueness of the project may limit the number of persons capable of performing the task due to extant capabilities or learning of the peculiarities of the project. Furthermore, it is typical that projects are performed under at least some time pressure. Failure

to perform to at least an acceptable level on a critical activity does not leave time for the usual process of personnel requisition, recruitment and induction in the event of inadequate performance. Rather the work must proceed while longer term solutions are sought.

The wise project manager anticipates that these things will occur, i.e., that not all elements of the project organization will perform at 100% effort and in congruence with the responsibilities assigned. He must create slack in the project in one of several possible ways. Slack can be provided most obviously in the network sense of time slack or float. A less obvious but often practiced approach is resource slack. The resources required to perform an activity are often over-estimated for this purpose. A still less obvious approach is through technical performance specifications. It is not unusual for the specifications on some components to be more rigorous than would otherwise be necessary in anticipation that another component (or the organizational element responsible for that component) will not achieve the desired performance level. Another common method of providing slack is in the budget by incorporating a contingency account which is not related to any specific activity or activity dimension. Thus, the project manager has considerable flexibility in committing those funds as required. Finally, still another approach is by creating organizational slack, i.e., creating an organizational element with no real, pre-designated responsibilities. It can be assigned quickly to troublesome areas in the project. This may be an especially appropriate action on

very unique projects where familiarity with project development may be essential to the ability to take corrective action. The position of assistant (or assistant to the) project manager is frequently used for this purpose.

It seems that the problems discussed above were the real problems underlying the findings of Sayles and Chandler (1971) in their research of NASA projects. These problems do not seem to be discussed directly in the literature on managing projects. Of necessity then, successful project managers must learn by experience, not only to cope with, but also to recognize these problems. The speed with which these skills are learned may be a major determinant in the selection and development of project managers today.

Technical Performance Relationships

As has been shown in the previous chapters, very little is known about the technical performance dimension of an activity and especially its relationship to the other two dimensions. There appears to be even less discussion of the interrelationships of technical performance between activities. While nothing was found in the literature dealing with this dimension between activities, some rules of thumb seem plausible. It would seem that higher levels of technical performance in early phases of a project would reduce the probability of difficulties in later phases. Over emphasis on technical performance in early phases, however, may result in excessive use of time resulting in extreme time pressures in later phases. Both of these are familiar phenomena to those

generally involved in the later phases of project. For example, computer programmers are often the victims of this phenomenon as first management attempts to resolve differences in opinion as to what should be done and then systems analysts search for the best way to accomplish the agreed upon objectives. Decisions on the trade-off of time and resources versus technical performance taxes the political as well as technical and persuasive skills and judgement of the project manager during this period. While detail knowledge of trade-offs in the technical performance dimension is best left to the literature of the relevant technology, some generalizations should be developed to assist the aspiring project manager to understand these phenomena and how best to deal with them.

Other Characteristics of Projects

Magnitude

The most obvious characteristic of a project is its magnitude. Some of the measures of magnitude are total dollars, manpower involved, number of suppliers/subcontractors participating, and overall duration. The larger the project the more difficult it is to achieve coordination among all participants in the project. The larger the project the less visibility any one activity will have by the project manager and therefore the greater the potential for variability in performance as compared to estimate.

There has been considerable concern with the problems of managing extremely large (mega-buck) projects. The "State-of-the-Art" papers presented at the Ninth Annual International Seminar/

Symposium of the Project Management Institute (Proceedings, PMI, 1977, pp. 3-81) serve as an indication of the concern at this end of the magnitude spectrum. The large project was a major concern of Sayles and Chandler (1971) in their study of NASA. Boercherding (1974) has added insights into the attitudes of workers on very large construction projects. For example, he found that a major source of satisfaction for construction workers was in feeling a part of a successful project where there were few changes.

At the other end of the magnitude spectrum, Cook and Tso (1975) were concerned with relatively small projects in the range of $25,000 to $50,000 per year for from one to three years. Specifically, Tso's (1976) research focused on educational projects funded under Title III, of the Elementary and Secondary Education Act (ESEA) of 1976. Interestingly this was one of very few papers found specifically concerned with small projects. It is clear that there are substantial differences in the problems of managing projects at opposite ends of this magnitude spectrum.

It would seem reasonable that there would be found some guidance in the literature as to the techniques most appropriate to be applied over the range of this magnitude spectrum. On the contrary there was no specific mention of magnitude of the project in those references aimed at explaining how to use certain techniques to aid in managing projects--with one exception. That exception was the admonition in several operations/production management texts that networking techniques were not applicable for small to medium

size projects, an admonition which personal experience has demonstrated to be inappropriate. It would seem that research would be appropriate to identify the criteria that would lead to an optimum choice of techniques/systems to manage projects under different conditions.

There may be a tendency to conclude that projects of such differing magnitude would not occur in the same environment and therefore there would be no need for a common management technique/system. Some examples will serve to add perspective on this. In about 1963, an attempt was made to develop a general approach to managing all project work in a single manufacturing plant in an automotive company. These included major plant modifications which could reach into the millions of dollars to budget improvement programs which involved little or no out-of-pocket expense but rather the allocation of the time of one or more plant staff members to conduct a study of alternatives. The crucial problem, to which networking promised some assistance, was the allocation of limited resources to the many projects in the plant at the same time. Failure to recognize the competition among projects for these resources had resulted in substantial overloads on certain personnel at times, over-optimistic schedule dates, and often failure to meet schedule dates. While the approach showed considerable promise, it preceded the availability of time-shared or real-time computing which could have reduced the clerical costs of presenting the information in a timely and inexpensive manner. Another example

of projects of substantially different magnitude was the construction of some 25 million dollars of facilities by a school district at the same time that there were many small projects of the type studied by Tso (1976). Examination of the details of a major weapons system program in the Department of Defense would, it is presumed, disclose a substantial difference in magnitude among the projects identified within the program. Furthermore, it is anticipated that within most megabuck projects there could be found a number of relatively small sub-projects for which responsibility has been assigned to an individual and which, for all practical purposes, are comparable to the projects studied by Tso. Thus, the problems of managing projects are not uniquely those of the mega-buck project but also the concurrent management of a number of projects of substantially different magnitude.

The implications of magnitude on project performance go beyond mere selection of the appropriate technique/system. The philosophy of managing projects over the range of magnitudes may vary. The small project affords opportunities for a very personalized style of leadership and follow up. The level of detailed planning, documentation and communication, and follow-up by the project manager would be substantially different. It might be expected that as magnitude increases there would tend to be a less personalized approach to managing the project. Further, the larger the magnitude the more important it would seem that an estimate would be considered a commitment. Nothing of significance was found in the literature

which dealt specifically with these characteristics of managing projects with the exception of Sayles and Chandler (1971) on NASA projects and Borcherding (1974 and others) on large construction projects.

Criticality

The conventional definition of criticality relies on the definition of total float, i.e., the critical path is that set of activities with the least float. Based on that criteria, the critical path is a contiguous set of activities starting at the beginning of the project and ending with the completion of the project. The stipulation that it goes from beginning to completion of the project was dependent upon an early requirement that there be only one beginning event and one ending event. With the incorporation of improvements such as scheduled starts or completions on any activity it is no longer a characteristic of the critical path that it go from beginning to completion of the project. The Monte Carlo approach to computations (Van Slyke, 1963) introduced a "critical activity" concept. This was based on the recognition that each activity in a network has a distribution of occurrence times. It is possible that a path other than the conventional critical path may take a longer period due to the actual times approaching the pessimistic times on another path through the network. Based on such an analysis, probabilities can be assigned to each activity that represent the chances that the activity will be critical. The computational requirements of this concept have

proven too expensive for practical use on projects of more than a few hundred activities.

In addition to these concepts of criticality there are some others that may be meaningful. For example, a critical flexibility sequence could be defined as those activities which, when completed, afford the greatest opportunity to provide flexibility in scheduling, i.e. make the largest number of activities available for scheduling. The greater the number of activities available for scheduling, the greater the probability of achieving efficient resource utilization.

Critical predecessors could be valuable information on a scheduling report. Consider an activity which requires a number of resources and/or has a high cost. Delays in starting such an activity could be very costly. It may be very important that all its predecessors be completed to permit its start as scheduled.

Critical events might be identified by the number of activities which follow an activity. If an activity had a large number of followers, the potential cost of it being completed late may be high. Thus, like critical predecessors, the project manager should be made aware of such an activity so it can be given special attention and delays avoided.

It is reasonable to speak of critical resource in terms of the extent to which requirements come closest to or exceed availability. (The method of determining this is discussed in Chapter V under Resource Leveling.) The importance of this concept rests on the assumption that over the life of a project the critical resource

changes. An efficient resource leveling capability would have to recognize this and adjust the algorithm accordingly.

Within a project the potential for conflict, misunderstanding, and need for coordination would seem to be highest at points of transition of responsibility. This is easily seen on a construction project when a subcontractor may refuse to move in if all the work preceding his activities have not been completed. The same phenomena could probably be found in a matrix organization where the work moves from one functional area to the next. Analysis of a network by responsibility could reveal the critical transition points. The larger the diversity of responsibilities at any point, the more attention should be given. Also, the higher in the organization it is necessary to go to find a common superior, the more attention that should be given.

Within a "high-technology" project, there may be relatively few activities which are really pushing the state-of-the-art. To the extent that this is true and those activities can be identified, it would be possible to schedule those activities differently than the rest. For example, it may be desirable for such an activity to have nearly the same, the same, or even higher priority in scheduling than a conventionally critical activity. It is possible that such an activity would have a high probability of being critical by the Monte Carlo method of computation cited above.

Similarly, an activity could be identified as being environmentally critical. This could be one which was subject to a high

degree of uncertainty due to weather, sub-surface conditions, etc. or it could be one which requires special attention due to risk of damage to the environment. In either case, the project manager may want to give them special attention.

These concepts of criticality may not be relevant to every project. They do suggest a fallacy in the conventional definition of criticality. It has been claimed that one of the advantages of network based systems was that they identify those activities that are critical and therefore have the greatest probability of delaying completion of the project. Perhaps the simplicity of the concept has taken interest away from some of the other critical aspects of efficiently managing a project. It is not sufficient for a project manager to give attention to those "conventional" critical path activities. The other categories mentioned above have the potential of causing delays or using resources inefficiently, or both. Capabilities should exist to aid the project manager in recognizing the need for his attentions and serving as a "tickler file" to remind him to check on those activities in a timely manner. It is possible that an activity could be critical on two or more of the above measures. In that case, the project manager should receive special warning of the potential for problems.

Technology

The relationship of the technology required by the project to the general current state-of-the-art of that technology will likely affect the difference between estimates and actuals. In

general, the more familiar the technology, the smaller the difference. This comes from effects on both estimating and performing the individual activities and the project. This relationship would also seem to exist for the organization as a whole and, to a greater extent, for key members of the project team. The applicable technology may be well developed but still unfamiliar to the organization or to key members of the project team. The nature of the technology may manifest itself in terms of degree of uncertainty of the results, i.e., the probability that the work will have successful results or have to be redone, or in terms of the specialized knowledge, skill, or equipment required. It could be measured on a scale of standard procedure, frequently used, infrequently used, or never done before.

It would seem that the more the state-of-the-art is being "pushed" on a particular project the more the tendency for a personalized approach to managing the project. The lack of familiarity with the specific technology leads to uncertainty in estimating but it also leads to ambiguity in measuring performance. Therefore, success is highly dependent upon individual motivation which, it would seem, is enhanced by the personalized style of managing. For projects involving standard technology the estimates should be more "accurate" and the expectations of performance better understood. Also, there should be greater interchangeability of human resources so that failure to perform could be overcome, at least in part, by adding or replacing resources. Note that the types of judgements by the project manager as well as the range of reactions are quite different over this domain.

While Dodson (1972) looked at different levels of technology he did not consider the dynamics of technological change and possible effects on project performance. The nature of the problem is suggested by the following from Sayles and Chandler (1971):

> . . . creeping sophistication further delays the project, increases costs, and complicates enormously the whole development process. There will always be constant pressure for changed plans to convert older designs into what is currently pushing the state-of-the-art (p. 13).

This is further illustrated in a recent article (Time Magazine, May 8, 1978) reporting on cost overruns in Navy shipbuilding.

> Repeated changes in specifications for instance, have been made after a contract has been negotiated and even while the ship was being built. According to Electric Boat, this plan-as-you-build technique caused at least 40,000 alterations in the design of the Los Angeles-class attack submarine. Most of these changes created a ripple effect, because shifting the location of one piece of equipment usually meant modifying dozens of other parts of the ships (p. 20).

Thus the choice facing the project manager is between the more recent technology with a "better" solution versus the choice of a simpler technology and having the solution become obsolete earlier. Clearly, in a competitive environment this poses an interesting dilemma. It is very serious for military weapons systems.

Difficulty

Some projects are inherently more difficult than others. The more difficult, the greater the difference that can be expected between estimate and actual. There does not appear to be an objective measure of difficulty. A possible measurement scale would be substantially more, more, equally, less, or substantially less "difficult

than all other projects with which I am familiar." Since Marquis and Straight (1965) have shown that various participants perceive differently the importance of several criteria for evaluating a project, it might be interesting to determine what kinds of problems contribute to the difficulty of each project as perceived by the different participants.

Complexity

A contributor to difficulty of a project is complexity. Certainly there is a far higher degree of complexity inherent in the design and construction of a small space module than in the design and construction of a standard industrial building. One factor contributing to complexity is the degree of interdependency of components or participants in the project or activity. If all the complexities can be handled by one person, at least the problems of communication are minimized. With the progression from one individual to a small group to a large group comes more demands on communication and achieving agreement. Again, a completely objective measure of complexity seems unlikely although the degree of interdependency in the project network may provide some insight. Kaimann's (1975) "Coefficient of Network Complexity" might suffice. Otherwise, a scale similar to that for difficulty would seem appropriate.

While difficulty and complexity are frequently alluded to in the literature very little of an analytical nature was found. The usual reference to this is an "apology" for the perceived

complexity of project networks. It is pointed out that while networking is simple, the projects defined by networks may be quite complex. Sayles and Chandler (1971) allude to complexity repeatedly, showing how it is handled, but really make no comparison between projects at different points on the complexity dimension.

Closely related to the above is the scope of responsibility of the performers. If a few people see the project through from beginning to end the level of interest and concern for performance will likely be greater than could be expected where each performer has a narrowly defined, specialized scope of responsibility. A subjective scale comparable to "difficulty" and "complexity" again seems appropriate. About the only mention of this concept in the literature is in discussions of the relative merits of different organizational concepts for managing projects. Borcherding's (1977, p. 244) reference to cable installers on the very large power generating station project is relevant in this respect. Their job had such narrow scope that their attitudes were adversely affected. Indeed, Boercherding suggests that project strategy be such as to provide greater scope within smaller segments of the project.

Project scope is alluded to very indirectly by Adams and Barndt (1978) as they considered the different phases of a project. It could be argued that something which might be called "average scope" is much greater in the first phase of a project than in the middle phases. This is supported by the following logic. The

number of participants in the first phase tends to be small and they are all concerned with the overall characteristics of the project. As the project becomes more well defined the number of participants increases and each participant tends to focus on a rather limited scope within the project. Therefore, the "average scope" diminishes.

Project Progress

Project progress has been shown to have some relationship to estimating accuracy, although not statistically significant, by Lowry et al. (1975) and by Abernathy (1971). Lowry et al. also found that accuracy improves with the imminence of the start of an activity for some activities but not for others. Some of this might be explained by the types of activities. Kidd and Morgan (1969) also found some evidence of learning as the activity progresses but noted that this was on emergency repair type projects. They offered the explanation that the work definition was highly uncertain until they actually got into it. Progress has been measured in terms of the number of activities completed and in terms of the elapsed time since the start of the project.

Other Factors Affecting Performance

Performance

The growing pressures of time, cost, magnitude of projects, advancing technology, and nature of objectives in the twentieth century have brought increasing awareness of performance criteria

in the conduct of project work efforts. They have also increased the concurrency and complexity of projects. The nature of objectives has made demands for quality and reliability far greater than ever before. A manned space vehicle must meet the high expectations of the public that it will safely return its passengers to Earth. A nuclear weapons system must meet similar standards to assure effective mission performance, if called into use, plus comparable standards to prevent it's being triggered except on proper authority.

Thus, any evaluation of performance must be carefully controlled to assure consistency with recognized objectives of the organization. Malcolm et al. (1959) recognized three essential variables in project performance--time, resources, and technical performance. These are not always equally important, nor do they always have the same rank order of importance. Poust and Rubin (1966), found that the project manager and government technical monitor agreed that technical and schedule problems ranked first and second respectively, but that the project manager ranked cost third while the government technical monitor was seemingly unconcerned with cost. On the other hand, the laboratory manager preceived cost to be the number one problem followed by technical and schedule problems. Furthermore, these findings add another dimension to those of Davies and Francis (1975) in that both project managers and laboratory managers perceive different problems when they consider their jobs as a whole as opposed to the problems on a project. The implications of differences in perceptions become more clear when we understand their relationship to performance.

Differences in perceptions of performance may also be related to differences in perceptions of the causes of the problems such as reported by Baldwin et al. (1971). Not only has the concept of performance been dealt with ambiguously, the measures used in many of the studies have been varied in nature as indicated by Table III-2, Measures of Activity/Project Performance. If future research using performance as a variable is to be of maximum utility, more precision in concept and in measurement must be achieved. It is equally important to investigate the consistency between the measure of performance of concern and the objectives of the project or firm. If the major priority on the project were maximum technical innovation, then very likely actual activity durations would exceed estimate. It may be found that when less than ideal resources were applied, one resource was working on two or more activities simultaneously, or that extra time was allowed to achieve an elusive technical objective. There are a number of possible objectives that would be inconsistent with minimal differences between actual and estimated activities.

While the literature on efficiency of performance of project work is nowhere near as extensive as for mass production there is a growing interest as the importance of project work becomes recognized. King and Wilson (1967) and others who followed this line were primarily concerned with the effectiveness of estimating. They implied that performance on the activities was a given and, in a sense, was invariate. Sayles and Chandler (1971) and Steiner and Ryan (1968)

were concerned with documenting experience on projects and whether they were associated with good or poor performance. Borcherding also documented practices but with even more emphasis on their relationship to productivity.

Similarly, while there has been considerable research into the human elements associated with performance in projects, the interest seems to be intensifying.

Nevertheless, the research has lacked unifying coordination that would permit integration of the results and thereby lead to more comprehensive theory.

Individual Factors

Some of the relevant variables seem to be abilities, the relationship of those abilities versus the task requirements, education and training, experience, personality traits, motivational needs, attitudes, values, goals and aspirations, perception of rewards offered by the work and the organization, and job satisfaction. In addition, for some of the participants, leadership behavior is critical as well as the leader's approach to conflict resolution and authority. The characteristics of the managers of projects and their superiors seem particularly relevant. While there are others at intermediate levels in the management of projects, their behavior seems to be largely a function of the behavior of and guidance provided by their project manager.

Concern with productivity as a function of behavioral variables is evident in management literature ranging from the

work of Roethlisberger at Western Electric to the more recent concepts of organization development and teams. It has included results of research by the likes of Katz and Kahn, Likert, McGregor, Herzberg, Lawrence and Lorsch, and Burns and Stalker to name just a few. The emphasis in these studies has been on work in manufacturing operations as opposed to project oriented work efforts or has not specifically recognized the relationship of mode of organizing the work effort to their results. Relatively little of the widely recognized research has been focused specifically on the problems of managing project work. The one major exception in this regard is the management of research and development operations.

Participants In General

Murphy et al. (1976) placed "capabilities" first in the list of project team factors affecting project success. There seems to be general agreement that whatever the type of project, successful performance requires technical capabilities on the part of the participants. Since the relevant technical capabilities vary so much across projects there is little that can be said of a general nature. There are some other characteristics of project personnel which may be generalizable. It seems clear that the current status of knowledge is still primarily experiential and not well-differentiated by type or phase of project. The exceptions to this general statement are the works by Gemmill, Thamhain, and Wilemon; Adams and Barndt; Borcherding; and a few others.

In his study of accuracy of estimating, Adams (1974) used Ghiselli's "Self-Description Inventory" as a predictor of "managerial talent." It is composed of thirteen factors that are classified as motivational traits, personality traits, and abilities. While it is referenced in the following comments, it is understood that other instruments exist, and perhaps better ones. It is suggested that research is appropriate to develop an instrument which would receive general acceptance by those involved in research on projects and would be applied rather uniformly on most such project research to assist in leading to comparable findings.

Values

Although little was found on this in project management literature, values do have an impact on a worker's performance. Much is written today on the decline of the work ethic. This may or may not be a serious problem in project-oriented work. Nevertheless, spare time activities are increasingly competing for the individual's interests.

One value dimension that is particularly applicable to project management is the conflict between identifying with a profession as opposed to identifying with the organization, i.e., the cosmopolitan versus the local. It has been noted that scientists have a tendency to be more oriented toward their profession while engineers are more oriented toward their employer. This leads scientists to engage in activities which may detract from, or contribute to, their work, depending on their degree of involvement

and what they are trying to get out of the affiliation. In the skilled trades conflict between union member and employer may be of a similar nature to that of scientists. The same phenomena may also be found in human services agencies as discussed by Cook (1976). A better understanding of extant values, differences between employees in project work of different types, and differences between them and employees of other modes of organizing work efforts seems highly desirable. This could lead to better understanding of how to work with such people and to the development of management principles uniquely applicable to project-type work.

Attitudes

Measures of attitude are often with regards to the organization. Without getting into the argument on the causal relationship between satisfaction and performance, it seems to be generally accepted that a strong negative attitude at least results in excessive expenditure of time and energy on non-essential efforts. This is especially important in much project work where performance standards are uncertain at best and where many participants work with little supervision. Thus, it seems desirable for a person to be at least reasonably contented with the organization. A factor in this is the perception of the opportunities available in the organization. Another factor is confidence in management. This may be affected by the degree that management is effective in protecting the individual from annoying disturbances from other parts of the organization. This was evident in Borcherding's (1976b,

p. 91) report of the effect of excessive changes and, especially, tearing out and redoing work already done. He also found that workers took pride in their work if it was done well, thus leading to the conclusion that at least adequate technical performance is important.

Borcherding (1974) identified a number of factors affecting attitudes of construction workers. There has been considerable research to identify attitudinal characteristics of engineering and scientific personnel. No evidence was found of efforts to relate such findings across industries and functions in an attempt to differentiate between types of projects and relevant behavioral patterns. It is anticipated that, if comparisons were made between people who work on projects versus those who work in mass production, differences would be found.

Also, it would seem important to understand the focal points of attitudes in project work. In mass production, work standards, foremen, and work and non-work facilities are often focal points for attitudes. From Borcherding it might be concluded that the focal points for construction workers are the work itself, relations with coworkers, management's proficiency in organizing the work, and changes. R & D workers seem to focus on challenge of the work, involvement in setting goals, etc. Their attitude toward risk-taking also seems to be an important factor in creative and innovative efforts. Workers on other types of projects may have different focal points.

Research is needed on attitudes across the spectrum of project types in the same sense as for values.

Personality Traits

Ghiselli identifies five factors as personality variables. Adams (1974) used self-assurance, decisiveness, and working class affinity and found decisiveness to be significantly correlated to "decision methodology." The other two factors were masculine-femininity and maturity. A variety of other traits have been explored by various authors including anxiety, assertiveness, dominance, dependence versus counter-dependence, power versus personal orientation, risk preference, conscientiousness, optimism versus pessimism, persistence, response to stress, compulsivity, sociability, and self-esteem.

A review of literature would seem appropriate to identify traits which might be relevant and variables to which they might be related. Then a systematic study to narrow those down to a useful set via field research could result in identifying some which would be useful in selecting project personnel. For example, it would seem intuitively, as well as from the literature reviewed, that a project manager should be high on assertiveness, risk preference, and self-assurance but not high on anxiety. The stress involved in project management when combined with a high score on an anxiety scale might be correlated with physical ailments such as ulcers.

Abilities

The Ghiselli factors in this category are intelligence, initiative, and supervisory ability. Adams (1974) found initiative to be significantly correlated with "perceived importance of accuracy" and with "decision methology." Broadwell (1965) suggested that intelligence should be in balance with the job requirements. Nussbaum (1964) found a distinction between "systems engineers" and "non-systems engineers" based on measures of cognitive abilities. He concluded that systems engineers possessed "superior cognitive ability" as "characterized by flexibility in behavior, fluency in both verbal and ideational processes, and the ability to solve problems in the presence of distractions" (p. 83). Since project manager responsibilities are similar to those of a systems engineer, it would seem that the same would hold true for project managers. Conceptual ability to deal with abstract as well as concrete ideas would seem to be relevant.

The "fit" of the individual to the task seems important for scientists and engineers, possibly due to their attitudinal focus on challenge of the work itself. This phenomena may apply to other professionally-oriented people.

Beyond these efforts, little was found that was directly related to project-type work. Adams (1974) undoubtedly used only three factors to limit the time required of the participant in responding to the questionnaire. Other factors may have also been relevant.

Motivational Needs

Ghiselli identified five factors classified as motivational needs--achievement motivation, self-actualization, job security, need for power, and high financial reward. Adams (1974) used the first three of these, finding low negative correlations between self-actualization and security versus perceived importance of accuracy. Borcherding (1976b, p. 89) found that construction workers, and foremen in particular, desire recognition and growth. Recognition may be from customers, superiors, peers, subordinates, members of his family, or the community. Growth could be technically or managerially and in depth or breadth. Other individual variables which may be correlated with motivation of project managers are need for power, need for job security, and a measure of where the individual is on a Maslow-type scale.

Recognition of the findings of Farris (1969) that scientists were motivated by high involvement in their work, high influence on their work goals, contact with colleagues, and diversity of work activities, all of which are at least partially within the control of management, could lead to improved motivating schemes. Understanding which kinds of performance are related to which variables (a la Farris) would give even greater precision to management actions. A definitive statement of those controllable variables as they apply to different type of projects is needed.

A comprehensive literature search in this rather narrow area should precede further field research to better understand

motivation of project workers. There must be differences if we are to understand the reasons why project workers often spend far more time than is required, or for which they are compensated, endeavoring to achieve better results.

Perceived Reward Function

It is generally recognized that there may be a difference in perceptions as to what is the reward function. The management of the organization attempts to design and execute a system having certain properties. If they are successful in achieving their objectives, the employees should perceive the reward system in the same manner. Nevertheless, it is their perception of the reward system that in fact determines their behavior. Variables in this respect are equity, both with others in the organization and relevant to others outside the organization, balance of positive and negative rewards, and expectations of overtime, to name a few.

Weinstein and Holzbach (1973) found differences in behaviors as a function of rewards versus task-flow-interdependence. Many projects, it would seem, are characterized by high-task-flow-interdependency. Therefore, from their results, we might conclude that principles of rewarding project-type workers are different than for workers in other modes of work. Research should be undertaken to better understand, not only the actual reward structure, but how it is perceived and whether that perception is consistent with organizational or project goals.

Goals and Aspirations

The goals and aspirations of the individual may have an effect on their performance. If they are attainable within the organization, this could lead to higher levels of motivation. If they are unattainable within the organization, it may lead to behaviors that enhance his value in the broader job market. On the other hand, in an interview Wiese (1975) expressed a concern that some of his former project managers had been promoted too rapidly, thus developing expectations that could not be maintained.

Sayles and Chandler (1971) suggest that certain types of people are attracted to the large scale, high technology projects.

> Very large programs with highly ambitious social and technical objectives can . . . be a magnet for courageous, imaginative, energetic administrators and technical personnel. Such programs provide a focus and an incentive for the best efforts a society can produce (p. 16).

It also takes a specific type of person to comprehend a project of such magnitude and cope with its attendant problems. Fewer still can conceive of the possibilities of such efforts.

Challenge of work and future assignments certainly seem important to scientists and engineers and growth as an individual and with the firm seem relevant to construction foremen. It would seem that a better understanding of these would lead to better strategies for utilization of personnel and, concommitantly, to higher levels of motivation.

Education

Adams (1974) included in his data collection a measure of the highest level of formal education although his only use of it was to summarize the biographical data of the subjects in his sample. He found that all subjects had a high school education and 40% held at least a Masters Degree. The need for education would seem to be a function of the level of technology involved, especially for technical education. Nothing in Adams' data indicated whether the education was technical or managerial or both. There is no reason to exclude other types of education which may be directly or indirectly applicable. For example, on some projects, it is conceivable that an understanding of sociology and/or psychology might be helpful in getting a diverse group to work together effectively. In another type of project, a legal background might be useful. If PERT and CPPS are the major management systems in use, specific training in PERT/CPPS methodology would seem a relevant consideration. Other specific educational experiences may also be applicable to project performance.

The study by Barndt (1975) raises questions about the socialization effects of education. For example if the projects used in his experiment had been based on human services types of efforts, perhaps engineers would not have behaved so consistently. It should be replicated on different types of projects and people to gain an even better understanding of the effects of education beyond the transfer of knowledge.

Experience

It is evident from the research by Adams (1974) as well as others that prior experience as an estimator affects their behavior. It is also apparent that project managers are chosen for large projects based on their previous success on smaller projects. Thus, it would seem relevant on future research on projects to know the extent of experience of the estimator at estimating, with the specific type of project, with the specific type of activity, and with the specific organization.

Comparable measures would be appropriate for project managers. It could include number of projects, number of projects of this type, number of years as a project manager, size of largest previous project divided by the size of this project, percent of activities in the project that are substantially new as far as his experience is concerned, number of projects in this organization, number of years in this organization, and percent of key people in this project with whom he has had prior work experience. Some or all of these variables may be correlated with measures of project or activity performance.

Individual versus Task

There is some evidence (Broadwell, 1965) that there is an ideal balance between the abilities and knowledge required by the project or activity versus that existing in the individual. Apparently some challenge is important. Too much challenge leads to frustration and lack of confidence or motivation to try. Too little

challenge leads to boredom and lack of interest in trying. It may also lead to search for other interests in which to become involved to the detriment of the work and the project.

The diversity of knowledge and skills required on many projects precludes the project manager from being competent to provide technical supervision to all participants. In some cases, it may even exceed the ability of the functional manager. Thus, the individual will be required to perform the work, assess its adequacy, and recognize the need for alternative approaches, often without the assistance of supervision. End results may be the only common denominator. Thus, unlike machine paced or engineered standards types of work, failure to adequately match the individual to the task may result in very poor performance in one or more dimension of the task.

Other Considerations

While considerable work has been done on the relationship of productivity to varying amounts and patterns of overtime in factory types of environments, it does not seem to be as definitive on project-type work. It would be valuable to know how it affects creativity in R & D as well as output and safety in construction.

There are undoubtedly other considerations at the individual level which should be studied explicitly vis-a-vis projects. The foregoing should serve as a framework for both more thorough analysis of existing literature and subsequent research to gain a better understanding of the individuals who engage in project work of different types.

Project Managers

Since the project manager is the keystone of the project, it would seem that special efforts should be made to gain a clearer understanding of the characteristics necessary for him to be effective. In general, the literature is weak in this area. Most prescriptions for skills are based on experience and judgement of informed persons. Some dwell on limited skills to understand better how to use them such as research on conflict resolution and use of power and authority.

Steiner and Ryan (1968) list ten minimum desirable attributes of project managers.

Technical skills:

1. Does the man have sufficient technical skill in the major field of interest in the project?
2. Does the man have sufficiently broad technical abilities and background to be adequately conversant with all of the technical disciplines involved in the project?
3. If the project is to be done with the services of a contractor, does he have appropriate experience in negotiation and administration of contracts?

Human skills:

4. Can he establish a team effort through his abilities to work with people, command respect, and establish esprit de corps and enthusiasm?
5. Can he communicate his ideas and delegate responsibility for execution of these ideas?
6. Is he a good judge of people and can he properly utilize and weigh the opinions of experts?
7. Does he have sufficient aggressiveness and drive?

Conceptual skills:

8. Can he properly plan the work of both himself and others?
9. Can he properly assess and coordinate the various requirements of broad areas of activity?
10. Can he make timely decisions and establish the proper balance between thought and action? (p. 124).

In general it is hard to argue with the criteria specified by Steiner and Ryan other than its precision and completeness. It can be argued that more should be said about the types and characteristics of projects that affect the priorities that might be assigned to the various skills of the project manager for a specific project.

It would seem valuable to have more efforts along the lines of Richter (1977), aimed at developing specific techniques useful in resolving conflicts within each of the classes used by Thamhain and Wilemon (1975). The literature prescribes and colleges teach the general classes of relevant behaviors but neither offer much in the way of developing specific skills to implement those behaviors.

Leadership

The knowledge of leadership characteristics seems particularly uncertain. While there is considerable evidence favoring democratic, participative, or other such management styles, the language is ambiguous and the measurement tools seem less than adequate. There are "natural experiments" that document the favorable aspects of a democratic style over an autocratic style in R & D. Creativity seems to be enhanced by the more liberal leadership styles including near autonomy on basic research. On the other hand, for construction work Borcherding (1976b, p. 95) seems to suggest a much more directive type of leadership on the job accompanied by non-work types of activities to help people to relate and to enhance understanding of the total job.

There are at least four important measures--what the project manager believes to be his leadership behavior; what his superior perceives to be his leadership behavior; what his subordinates perceive to be his leadership behavior; and what his subordinates prefer to be his leadership behavior. Differences between the first and third are a measure of the effectiveness of leadership performance by the project manager. Differences between the third and last point out aspects of behavior the project manager might consider modifying. He may decide not to modify his behavior. This should be a conscious decision rather than one by default. Furthermore, the greater the diversity of subordinate preferred leadership behavior the more difficult it will be for the project manager to meet those desires and the greater the probability that dissatisfactions will be registered by some of the subordinates. Another difference which may be relevant is the difference in the project manager's leadership behavior (as he sees it) and the same perception by his superior. There is reason to suspect that wide disparities at this level can render a project manager ineffective.

An aspect of leadership behavior which seems to be missing completely is a strategic concept. It is made clear that the appropriate leadership style changes with the phase of a project and/or with, for example, good or poor climate. These studies are generally based on assessment of aggregate or predominant leadership style. Experience would suggest that effective managers use a mixed strategy depending on the matter of concern, some circumstances surrounding

it, and the specific people involved. For example, a manager may be very "directive" with subordinates on schedule or cost matters on immediate work. The same manager may be very participative in discussing long range plans or personnel evaluation. On technical matters outside of his field, he may allow almost complete autonomy. On matters of budget with his superiors, he may utilize the negotiation or consultative style. It seems that research into the dynamics of leadership would provide a better understanding of actual behavior and permit better prescription in a contingency sense.

The ambiguity of leadership language needs to be cleared up to permit the maximum utilization of results of a variety of studies. In literature reviewed dealing with leadership on projects, it appears that at least eight different instruments were used to describe leadership behavior. The ability to generalize from such varied studies is severely limited.

Nevertheless, contingency models of leadership seem to hold promise. Even the simple construct of leadership styles used by Thamhain and Wilemon (1977) indicates that a proper contingency model can provide useful insights.

A practical problem associated with leadership style, as well as other behavior variables, is the availability of time to behave in accordance with the prescriptions. Often in project work the time pressures are such that the project manager is scurrying from one problem to another and still working long hours. Engaging

in participative leadership style behaviors would be dysfunctional from the standpoint of either the progress on the project or the project manager's personal life style. There seems to be little evidence in the literature of a recognition of this fact. Similarly, casual observation of successful managers (judged by their organizational position) indicates that they are often very demanding to the point of verging on an autocratic style. The gap between theory and practice may exist in fact or may only be in the description. Nevertheless, much still seems to remain to be done to make leadership style a really meaningful concept in managing projects in terms of teaching the necessary actual behaviors.

Selection

Selection of project manager candidates should be based on measurable criteria. Apparently the only effective selection technique today is survival-of-the-fittest. Nussbaum's (1964) test for systems engineers would seem helpful. If it is accepted that one role of a project manager is that of integrator, then the findings of Lawrence and Lorsch (1967) would seem relevant. Thus, the characteristics of high need for achievement, aggressive, confident, persuasive, verbally fluent, ambitious, forceful and effective in communication should be good indicators. As Taylor and Watling (1973) point out, ". . . above all (he must be) someone who gets things done" (p. 26). The only indicator of this seems to be the things he has already done. Additional research is warranted

to identify the characteristics common to all types of projects as well as those unique to specific types. Also, the weighted matrix concept by Barndt and Adams (1977) would seem to make the selection process much more sensitive to the specifics of a particular project.

Education

The education offered in managing projects in regular management curriculums at this time appears inadequate. The emphasis on the arithmetic of projects has obscured the more critical skills of managing conflict, power, and change. Also, the separation of management sciences and behavioral sciences in academia discourages a coherent approach to training people in project management. This is unfortunate. There are two types of entry level assignments frequently given to management, engineering, and other college graduates--supervision of an ongoing operation or performing and/or managing a project. Thus, it would seem that at least minimal skills should be provided the student who goes the project route.

A comprehensive education in project management may best be achieved at the graduate level. One of the generally agreed desirable characteristics of a project manager is a multidisciplinary education. This normally implies "Management" in addition to a primary technology. Perhaps the University of Quebec model (Bernard, 1977) which combines academic and work experience is the most desirable.

Regardless, if the premise that project work is fast becoming, if it is not already, a major proportion of all work efforts in our

society today, then one must conclude that greater efforts must be expended to train people to operate efficiently and effectively in that mode. Furthermore, adequate information must be prepared to aid students in assessing the career opportunities associated with such education and selecting the appropriate course of study.

Managers of Project Managers

Of all areas, this seems to be the most lacking in the literature. Only by reading extensively can one find an occasional reference applicable to the manager of project managers. For example, Thamhain and Wilemon (1977) recommended that top management perform "effective long-range business planning and keep . . . people informed about the basic corporate objectives and business prospects" (p. 30). While they also indicated that work continuity and career growth are largely a function of economic conditions and beyond the control of the organization, it could be argued that the firm's ability to provide these are a function of corporate strategy. Overly ambitious growth goals can exacerbate the effects of economic cycles. The only reference specifically on this subject (Beck, 1977) would have to be considered primitive. The dearth of literature in this area is curious in view of the importance placed on organizational support by Decotiis et al. (1976). Looked at in perspective, this may not be so surprising. In many organizations, the managers above the project managers were probably project managers before moving up. Therefore, it can be presumed that they learned what they needed from experience. This may have

been a bad assumption. On the other hand, they may have gone back to school for graduate work in management. It is doubtful they were presented much there that was directly applicable. It was only in the late 1960's and early 1970's that the literature recognized that the principles of general management were not uniformily applicable in project management (Sayles and Chandler, 1971). Before that, with the exception of R & D, the literature was primarily the arithmetic and computer applications of planning and scheduling. Furthermore, much of the relevant literature reviewed was published in the 1970's. In an interview, Wiese (1975) expressed dismay that his recent attendance of graduate courses in management had given him little help in managing construction project managers.

Personal experience operating as a project manager under four different superiors makes clear the lack of understanding of the relationship of concern here. Only one evidenced an adequate understanding of their relationship. The project initiated under his brief period of supervising our operation was successful.

Personal experience also lends support to the importance of congruency of management styles. If it is true that creative endeavors are more productive under a participatory leadership style, then the manager over that work should strive to behave in that manner. If the next higher level manager uses an autocratic leadership style, the participatory style below him will likely be counterproductive. Many managers have been encountered who not only do not understand this but do not care about it. Their attitude is that, since they are the boss, they can behave as they wish

and their subordinates can adapt to their behavior. One such owner of a construction firm, when encountered by an assessment of his behavior, agreed with the assessment, but was fearful of changing his style because he was not sure he could do it successfully. Yet he implored the author to placate his director of construction.

The opportunities for managers of project managers to gain skills in, as opposed to knowledge of, styles of leadership in academia are extremely limited. Basically these skills can only be gained through commercial workshops. On-the-job-training may be adequate if there is an objective observer to provide feedback.

It would seem that a major gap in research and literature exists in this area which needs at least some work at an early date.

Organizational Factors

Rationalization

Adams and Barndt (1978) imply that "organistic" and "project" are essentially synonomous. It is argued here that this is not an appropriate distinction but rather that they represent two different dimensions. Thus, it is equally as feasible to have a mechanistic project organization as it is an organistic project organization. There may be some types of work which can be performed most effectively by an organistic project organization and other types which can be performed most effectively by mechanistic project organization.

Perrow (1970) used the term "rationalization" to describe the tendency of organizations to routinize production methods and

document organizational procedures. The distinction which was implied by Adams and Barndt (1978), can better be characterized by a low or high degree of rationalization. They describe the varying nature of certain behavioral characteristics as the project moves through the four phases--conceptual, planning, execution, and termination--of a project. They point out that the conceptual and termination phases are characteristically organic while the planning and execution phases are essentially mechanistic. While the author has no experience on Air Force Systems projects, he was involved in the planning of two Army projects, Missile "B" (Lance) and the MBT (Main Battle Tank, a proposed joint effort with the Federal Republic of Germany). The early stages were characterized by a very small team, communicating directly and informally, with a minimum of non-essential paperwork. As these efforts moved into more definitive planning, more people became involved; communications were somewhat more formal, especially in meetings; and more administrative paperwork became involved. These are characteristic of the process of rationalization of work procedures and with moving from an organic to mechanistic type of organization. Nevertheless, the efforts were organized as projects. The same phenomena have occurred on management information systems development, new product development, and any number of other projects.

Using this conceptualization of the process, it is easy to conceive of projects which very early move into a high degree of rationalization. A construction project on an already designed

building would proceed in this manner. The Duke et al. (1977) paper describing procedures of Fluor Utah, Inc., suggest a high degree of rationalization from the start. On the other hand, where creativity and innovation are central to the project effort, a more organic concept is appropriate with direct communication, very little formality, and a minimum of paperwork.

Assuming this conceptualization is accepted, it would seem appropriate to develop some measures of rationalization and conduct research on this variable as a function of project phase and type. Some possible criteria of rationalization are the goals, structure, and job descriptions. The more formally these are stated, the higher the degree of rationalization and the more mechanistic the organization.

Goals

Goals are a distinguishing characteristic of an organization as opposed to a group. Yet their effectiveness is dependent upon how they are understood and accepted as behavior guides by the people in the organization. Furthermore, as so clearly pointed out by Davies and Francis (1975), there not only are differences between the stated organizational goals and the operational goals but also differences in the perceived goals of different people, depending on their function and background. Even if the organizational goals are operational, there may be differences in the priorities assigned to the goals by different people and by the same people at different times. This may occur under different circumstances such as routine

versus emergency (Shaw, 1976) or as the individual considers his work from different points of view such as job versus project (Poust and Rubin, 1966). Clearly, sometimes this is functional and leads to appropriate behavior but often it is dysfunctional and leads to inappropriate behavior.

Projects are inherently goal oriented in terms of the end product. To consider project performance only to this goal is too simplistic.

Given a model, such as discussed in Chapter III, The Activity, it makes sense to talk about optimizing with regard to one variable subject to constraints on the other variables. This optimizing should be considered from two points of view--estimating the dimensions of the activity before contract award and performing the activity after contract award. It is argued here that the objectives of an organization performing project type work vary depending on whether they are trying to obtain authorization to perform the work or are performing the work pursuant to the approved authorization. It is a relevant concept regardless of whether the project is an in-house effort or contracted out. This is because the motivations of the performers are similar. The major difference is probably the dimension to optimize.

Looking first at potential objectives in the pre-contract phase, we have at least the following:

Maximize the probability of winning the contract--This is often done by the contractor in need of work to cover fixed costs

and make at least some contribution to overhead during periods of scarcity of work. On in-house projects, the same phenomena may occur to justify the existence of an organizational unit or to assure the acceptance of a "pet" project.

Maximize profit on a contract, if it is awarded--This occurs when the potential contractor is loaded with work and, although interested in the work, wants it only if it will contribute significantly to profit, if he gets it. This sometimes occurs on in-house projects to justify additional resources which, even though they are not necessary to accomplish the project, enhance the status of the organizational unit or improve the probability of achieving other objectives of that unit, such as "pet" projects that cannot obtain formal approval.

Minimize risk of losing money on a contract, if awarded--This occurs when the project involves significant uncertainties on which the contractor is unwilling to accept the risk. It may manifest itself in the form of compensation written into the contract, for example, cost plus, in the manner in which technical specifications are written, or by the lack of commitment to a specific time table.

Minimize risk of exceeding schedule targets--This may take the same forms as in minimizing risk of losing money above. One manifestation of this is in the way projects are proposed internally. Some engineering design projects are tied directly to a specific product introduction date. Others may be based on the first possible

model year. A plant operating improvement may be a part of this year's budget reduction commitment or a development effort with no direct commitment as to budget year.

Minimize risk of not achieving technical objectives--This is similar to the two preceding objectives. One manifestation of this is the provision of redundancy of development and/or design efforts with intent of using the first one that is acceptable or the one that turns out the best performance.

The first objective gives motivations to estimate low on resources and time whereas the second leads to high estimates. The last three lead to ambiguities as to the critical variables or avoidance of firm commitments. The objective of maximizing probability of contract award has been recognized as a factor in cost over-runs on government contracts. This may be aggravated by the size of many of these contracts relative to the total business done by the contractor. It could be that the probability of over-runs is a function of the dollar value of the contract relative to the dollar volume the contractor is capable of performing. If award of the contract is essential to the organization's survival, one might expect all sorts of aberrant behavior.

From the point of view of performance, assuming the contract has been awarded, four potential objectives are considered.

Minimize time for the project subject to technical and total cost constraints--This might occur on in-house projects where management has placed very high priority on time targets. The

greater the time pressure applied by the customer, the greater the tendency to relax either/or both technical and total cost constraints. This has been evident in major government contracts that are perceived to be essential to national defense or, on a smaller scale, in firms where the project is essential to continued operations. It is also manifest by the contractor who is trying to maximize cash inflow.

Maximize technical criteria subject to time and total cost constraints--This is a frequent occurrence in design efforts, conceptualization of a problem, and in feasibility studies. It seems to be a natural motivation of many who are imbued with "professional standards" or "esoteric interests." It accounts, at least in part, for the tendency to not report an activity complete until the last possible date.

Maximize utilization of resources subject to time, technical and total cost constraints--The frequent diverse nature of resource requirements on projects leads to low utilization of many resources. This can be minimized by having a larger number of projects on which to work, thus increasing the probability that a given resource will be needed continuously. This may lead to seeking and accepting work exceeding the capacity of the organization to perform the work.

Minimize total cost subject to technical and time constraints--This behavior has been experienced by many people who have had a house built. It is necessary to keep a close vigilance to be sure the contractor does not use inferior materials and/or construction

practices to reduce his costs. Although it is common in the construction industry, it is by no means limited to that industry. Often, this phenomena is taken to extremes of relaxing the technical and time constraints without customer approval, to wit, failure to adequately test welds in the Alaska pipeline. It accounts for the need for competent inspectors to assure meeting technical requirements and for close supervision to assure time commitments are met.

Maximize time, resource, and technical performance subject to "political" constraints--Although the word "political" is not precisely applicable, the prevalence of this phenomena in the political arena should suggest its applicability in other arena. It is a more detailed way of saying "maximize cost" which would be appropriate behavior on a cost plus percentage fee contract. It is often attributed to consultants as an explanation for their stretching out assignments and developing follow-on contracts. It is also consistent with recommended behavior in marketing products in the mature stage of the product life cycle. Therefore, in spite of first impressions, it is not necessarily unethical or even dysfunctional behavior.

In addition to these, the goals suggested in the review of literature can affect the priorities and performance on a project. Very little emphasis is given to these considerations in the general literature of project management. This is especially true of the potential conflicts at the interfaces between contractor and client and contractor and subcontractors and even between organizational

elements within the same firm. A better understanding of these potentially conflicting goals could lead to more explicit knowledge and skill in dealing with conflicts.

It is clear, then, that any research trying to understand the relationship between estimated durations of activities and the actual time taken must be cognizant of not only the other two dimensions, but also the stated and possible underlying objectives of the organization. Clearly, research into goals and their effect on performance is warranted.

Structure

Different organizations base the differentiation of their sub-elements on different criteria. A project organization is differentiated primarily on product. A functional structure will create different problems for project management than will a product oriented structure.

The matrix organization concept was developed to retain the best features of both the functional and product organization structures while overcoming some of their weaknesses. The literature is somewhat better developed on the matrix concept as compared to many other areas of project management literature. However, the degree to which it has permeated the basic texts still leaves something to be desired. Also, the problems of transition from a functional to matrix organization do not seem to be adequately treated. Such a change may be more difficult to achieve than a change of larger magnitude in a pure functional organization. In the latter,

the changes in responsibility are more vivid. Conflict is inherent in a well-developed matrix organization. The subtlities of these conflicts plus the newness of them to the chief executive of the organization suggests that they will be more frequent during the transition. Coupled with that, it is inevitable that some responsibilities will not be recognized or accepted and that some resistance to the change will develop. Thus, it may take more skill and patience to make the change than will be required after the transition is completed.

The interpersonal relationships that exist between key personnel will lead to different behavior patterns that may pervade the organization. In some organizations, estimating is done by the same person who is responsible for performing the activity while in others it is done by different people. If they are different, the number of levels they are below a common reporting relationship may be quite different for one organization as compared to another. The greater the vertical distance to the common reporting point, the more likely there will be major differences in the informal goals of the sub-units. The estimate may be affected by these informal goals. It is well-recognized in general management literature that more commitment to estimate is achieved if the performer has at least participated in the estimating process. On the other hand, the performer may have other motivations in estimating than simply stating reasonable expectations, as discussed previously in Chapter III.

In larger organizations, the meta-structure and all the motivations, attitudes, and behaviors associated with it may have an effect on both estimating and performance. The more mature (and especially the larger) the organization, the less will be the direct involvement of top management in the project and the more likely significant decisions at that level will be made based on judgements, impressions, and the like as opposed to specific knowledge and detailed analysis. Therefore, it is more likely, in the larger organization, as compared to the small one, that people will behave in a manner to elicit favorable judgements and impressions from superiors rather than in a manner always directly consistent with the objectives of the project or activity.

The problems of managing a "federal" organization are not dealt with adequately. Sayles and Chandler (1971) introduce the problems and discussed them at some length. Borcherding (1976b, p. 10) discusses it briefly with regards to the looseness of structure between a contractor and sub-contractors. Beyond that, most literature implicitly treats such relationships as little different than if they were permanent members of the same organization. For example, one strategy in dealing with sub-contractors is referred to as the "family of subs" concept. The idea is to choose one sub-contractor to perform a certain type of work, say heating, ventilation, and air conditioning (HVAC) and become a major portion of that sub-contractor's business. Having done so, the threat of dropping him is sufficient to elicit a reasonable degree of loyalty to the contractor. An alternative strategy is to "shop"

a subcontract for lowest bid price in which case the loyalty will likely be much lower.

Attempts to elicit comments from experienced construction superintendents on how they handle relations with subcontractors in such a "federal" organization have not been very fruitful. Some techniques have been discovered. The superintendent may delay on paperwork necessary for the subcontractor to get progress payments until an agreement is obtained. He may delay on preceding activities vital to the sub-contractor's ability to move onto the job. Essential equipment such as an elevator or crane may be "tied up" on other work. The techniques are subtle but do provide a means for maintaining discipline on a job. At present, the only means for learning such techniques appears to be through on-the-job-training.

Similar problems may exist in managing international projects. Again, Sayles and Chandler (1971) provide a helpful discussion pointing out how "national pride" can be useful in eliciting co-operation. Since this area of literature was not included in the review, it is not feasible to assess it accurately.

Job Descriptions

One aspect of rationalization of an organization is the preparation of job descriptions indicating responsibilities and authorities of various positions or people. Often in projects, the job description will be specific to the project to accommodate specific skills of the people assigned. As a result, an approach

to the process of creating these job descriptions should be designed to permit a quick and analytical approach. One device that would be helpful in this regard is a comprehensive checklist of responsibilities. Another device is the Linear Responsibility Chart. Ample references exist on the latter including Cleland and King (1975, p. 271) and Archibald (1976, p. 106).

Job descriptions for project managers were found in Steiner and Ryan (1968, p. 1618) and Taylor and Watling (1973, pp. 32-5). Cleland and King (1975, pp. 243-4) had no job description but provided a list of functions possibly reporting to the project manager. The lists were analyzed and compared and a comprehensive listing prepared (included as Appendix A). Twelve major categories of responsibilities were identified and the various items sorted to the most appropriate category. Many, if not most of the "verbs" could be changed to represent differing degrees of delegation of responsibility such as initiate, propose, guide, etc. While this list is certainly not exhaustive it does provide a checklist from which specific job descriptions could be developed. Indeed, it suggests the need and provides a framework for a more complete analysis of job descriptions as actually used in industry and government. Research into the effectiveness of each element of this checklist vis-a-vis the environment in which it was used would also be useful. This research should also relate those elements to the various organizational approaches to project management and loci of responsibility outlined in Chapter II. This could be especially

helpful where managers inexperienced in managing in the project mode attempt to install matrix management.

An organization was observed recently where an attempt to move to matrix management was being made with unsatisfactory results. It was discovered that the performance expectations from the "project managers" was inconsistent with the responsibilities and authority assigned. They were performing more consistent with the title "project coordinator." Furthermore, no modifications had been made in the job descriptions of the functional managers to reflect the assignment of some of their former responsibilities to the "project managers."

No reference was found which specifically addressed the problem of the revision of job descriptions for the functional managers changing from a functional to a matrix type organization or related to the various possible loci of responsibility.

Climate

Organization climate appears to be a useful construct for creating conditions for high levels of motivation. This seems essential in project work due to the lack of precision in estimating (i.e., setting standards) and the resulting dependency on the individual's own commitment and desire to perform.

Climate was found to relate to satisfaction directly and to performance indirectly, at least to some degree. Creativity was found to be enhanced where people were willing to share new ideas, felt they were able to do so, and felt there was enough flexibility

in the organization for accepting changes. Turnover was inversely related to satisfaction. It is suggested that causality is from climate to satisfaction to turnover.

As reported earlier, Adams and Barndt (1978) found climate to vary with the phase of the project. Although they did not indicate that climate was directly related to performance, it is suspected that, consistent with other research findings, it is both a necessary condition for, and linked by other variables to high levels of performance.

Organizational climate is not only visible to members of the organization. Schneider (1973) demonstrated that bank customers perceived differences in climate. Furthermore, their perceptions were consistent with their intentions to switch banks or their prior action of switching. If this is true for banks, then management of other organizations should be concerned with climate, not only in the interests of employee productivity, but also in the interest of customer satisfaction and continued loyalty. Many project oriented firms are dependent upon repeat business for success. Thus, customer satisfaction and loyalty are essential to their long term success. Surely, many people have experienced dealing with an organization whose product was very satisfactory but with whom it was distinctly <u>not</u> a pleasure to do business.

It is important in measuring this variable to determine if the perceived climate is consistent with management's desires. The fact that workers perceive a dimension of climate to be unfavorable

should not necessarily be taken as a mandate for change. Some authors have pointed out that high satisfaction with the climate may not be necessary or consistent with high levels of performance. Rather, negative perceptions of climate should be considered an opportunity for decision making by management as to whether change is desirable and, if so, in what direction, what degree, and whether in the short- or long-range. It is also important to determine whether the perceived climate is a result of management actions as opposed to having been created by the workers themselves.

Climate is still an imprecisely defined concept, especially in terms of its instrumentation. Schneider (1975) in a seminar suggested that the instrument has to be designed specific to the situation and the perceived problems. This would preclude generalization of results. On the other hand, Taylor and Bower (1972) have used a standardized instrument with apparent success on a number of studies. It would seem that use of such a standard instrument, adapted appropriately for project work environments, would be a useful step in gaining a more generalizable yet detail understanding of this construct in the management of projects. One step in creating such a standardized instrument is determining what are the essential dimensions of climate in various types and phases of projects to achieve objectives such as creativity, work involvement, etc.

External Factors

These factors establish the general environment within which the project is performed. In some cases their impacts are direct and readily apparent. In other cases they are indirect and subtle. Their impact varies substantially depending on the nature of the project. The impacts on projects of national concern such as the lunar landing or the B-1 bomber are readily imaginable but they also affect the construction of a building in the local neighborhood.

Social Conditions

The political environment is characterized especially by the legislative and executive branches of government, whether federal or local. The courts are playing an increasing role, especially in environmental and product safety matters. The existing or potential power of these bodies relevant to the project and the stability of them can have drastic effects on both estimating and performing. This has certainly affected many nuclear power generating projects in terms of delay, quality control, and extra paper work. Past experience with other projects (e.g., the Lockheed C-5 transport cost overruns) by the executive and legislative bodies has an effect on how new projects will be viewed.

Potential changes in the rules and regulations by administrators of legislation and the zealousness in enforcement can have as drastic consequences as the actual implementation of the changes. For example, discussions of possible wage and price controls

undoubtedly causes revisions in project estimates as do discussions of environmental protection and energy conservation measures.

Special interest groups can have a serious impact on projects by court actions which, even if not won, cause delays. Such actions delayed construction of the Alaska pipeline and a number of nuclear power plants and have generally resulted in escalated costs. Although not a pleasant subject, nevertheless corrupt government officials and others can have serious effects on projects.

In estimating, assumptions must be made as to labor availability in terms of numbers as well as specific skills. As the project is being executed, actual availability may vary substantially from the assumptions that were made. Variances in number are readily apparent but variances in skill are subtle and often do not become evident until later, frequently only when completion dates arrive and an activity is not completed. Expectation of overtime by the employees sometimes results in less than estimated performance in order to force overtime if the activity is to be kept on schedule. If labor is scarce and mobile (such as in the construction industry) it may be necessary to pay overtime just to attract a competent work force. Sometimes there are differences in performance depending on whether it is a "union job" or "non-union." Furthermore, if it is a "union job," unions vary substantially in their militancy and work standards. Some areas of the U.S., and of the World, are more noted for corruptness of labor officials. Costs and delays arising from these sources must be planned for.

Economic Conditions

The current and expected rates of inflation can have substantial impact on estimated costs of a project. They may also affect performance as a result of efforts to achieve progress in such a way as to minimize the impacts of inflation. Business activity levels, nondomestic as well as domestic, affect the cost of materials and also how competitively the project is estimated. It can affect the willingness and ability of suppliers to meet targets and to cooperate in solving the inevitable problems. Of even greater impact in the bidding, however, is the competitiveness in the line of business involved. The greater the degree of competition, the lower the estimates are likely to be and the greater the probability of unfavorable variances. General economic conditions also influence the terms and ease of financing projects. Extreme difficulties may result in delays by vendors who have not been paid and even postponement or cancellation of a project.

Finally, the degree of structure in the environment may constrain the imagination and innovation that can be brought to bear on the project to find less costly ways of achieving the project objectives. For example, union jurisdiction problems often cause labor costs to be larger than necessary. These often do not become apparent until the job is under way, at which time there may be little that can be done about them except to try to reach an affordable compromise.

Technology

The demands that a project or activity place on technology vis-a-vis the current state-of-the-art can have substantial effects on the time and resources required to meet technical objectives. The stability of technology can also cause problems. A project may be conceived, planned and approved under one level of technology and executed under the next in a rapidly advancing field. This can result in ineffective methods relative to the new technology or extensive learning to accommodate it. This happened on a major warranty claims system which was planned for one computer and implemented on its next generation successor. The maturity of the technology may affect the degree to which products and methods used in the project are standardized. Greater standardization may result in more economic ways of performing the project or activity. The nature of the project may permit the use of different levels of production technology. For example, housing projects of sufficient magnitude may employ assembly line technology to produce many of the components as opposed to the usual manual methods required for a single house.

Physical Environment

The very nature of the physical environment often places severe constraints on how an activity can be performed. For example, much of the welding on the Alaska pipeline had to be done inside portable sheds to achieve good welds in that extremely cold environment. Activities that must be performed in space, under water, and

under the surface of the Earth are similarly constrained. Even less rigorous environments pose serious problems and require innovative solutions such as completely paving a job site to permit work to continue without delay due to spring mud conditions. In addition, the uncertainty of these elements of the environment limits the accuracy that can be achieved in estimating the amount of work that will ultimately be done to accomplish an activity. For example, out door projects often incur reduction in actual work accomplished due to time spent starting cold vehicles or removing snow, ice, mud, and/or water from the work area.

In another sense, physical environment includes the physical space, facilities, and equipment available to perform the activity. Care must be exercised to prevent scheduling of two or more activities in the same space or using the same facilities or equipment. Failure to deal with this adequately sometimes leads to costly disputes between contractors if not between trades. Furthermore, the enactment of the occupational safety and health legislation at both federal and state levels establishes minimum conditions under which any space, facility, or equipment can be used. Sometimes meeting these conditions can result in extra costs and delays.

Customer

The nature and behavior of, and the relationship with, the customer may be a major detriment in both estimating and performing an activity. Decotiis (1976) found sponsor relations to be second or third ranked in importance in all four measures of performance.

Sometimes the plans and specifications are complete and accurate while at other times their development may be proceeding just ahead of the work itself. High inflation rates have given impetus to the "construction management concept" under which preliminary construction phases start well before the final specifications or drawings are completed. A recent very successful application of this concept resulted in completion of the Pontiac Silverdome on time and within budget despite a design switch "from a completely structural steel support system . . . to a reinforced concrete system . . ." after the start of the project (Harack, 1976).

The contractural arrangements may have significant impacts on the motivations of the participants on a project. The more fixed the time or cost constraints, the greater the probability of sacrificing the technical objectives in the performance of the work. Cost plus contracts, on the other hand, provide motivations to stretch the work out or to cause additional work as well as creating less concern about cost control. Penalties on late delivery are sometimes effective but must meet certain legal requirements, for example rewards for early delivery. Incentive fee contracts have been developed in attempts to motivate contractors in several dimensions of project performance. Success with these to date seems to be mixed.

Government contracts have frequently specified a required reporting system, often PERT or PERT/COST. The deficiencies of such a system have been alluded to in several articles. Abernathy (1971)

chose projects to include in his study only if "the network scheduling system was actively used by engineers and management as the sole planning tool" (p. B82). Underlying this was an assumption that the PERT system does not always reflect actual status and plans. This may well be a good assumption depending upon the contractor's expectation of the customer's reaction to "bad news" versus "good news." "Good news" might be that the project is ahead of schedule and/or under budget. In such case the customer may seek refinements and/or additions to the product. "Bad news" might be the opposite, i.e., behind schedule and/or over budget, in which case the customer may become excessively alarmed and attempt to "assist" in managing the project. If it is expected that the reaction of the customer will be "meddling" either way, then surely the customer should not expect honest reporting by the contractor. If the contract requires PERT/COST, or any of the other PERT related cost systems involving considerable detail, the contractor may be even more reticent to divulge accurate detail.

This concludes a brief review of the external factors affecting project performance. It certainly is not exhaustive but the framework should elicit a more complete discussion from future research. It would seem that training for project management should include an introduction to these external factors and especially the law pertaining to projects, both U.S. and international. No references were found to a text covering such material or even articles of any comprehensive nature. Considerable research seems appropriate in this area.

Summary

In this chapter the project, i.e., the set of activities as a whole, was examined. It was determined that there are many types of projects and yet there is neither specific differentiation or analysis of common characteristics of the different types of projects. Also, each project goes through several phases. Perhaps the simplest classification of the phases is conceptual, planning, execution, and termination. It was suggested that different projects varied in terms of the characteristics of these phases, and that a more detailed framework would be more enlightening.

In addition to the phases of a project, there are stages of the management process. Detail stages in this process were identified as an aid in understanding the process and also to form the basis for evaluating tools useful in managing projects.

The interrelationships of the activities were examined. In addition to the usual networking conventions, other relationships were discussed including "must," "should," "desired," and "scheduling" precedence. The need for a "punch list" capability was demonstrated. The effect of convergence and divergence of sets of activities and the possible use of "water" in the network were demonstrated.

The interrelationships that are a function of the resources used on a project were explored. They ranged from general availability and leveling to specific availability and the "drafting room problem." Leveling procedures as implemented in existing systems apparently do not offer positive cost-benefit relationship based on the evidence

that relatively few firms use the capability. One possible deficiency is the lack of a capability to analyze alternative approaches for augmenting the resources available to fulfill the indicated needs. Another possible deficiency is failure to provide an adequate dispatching capability. While most systems operate on certainty equivalents of the dimensions of the activities and the availability of the resources, all of the uncertainties manifest themselves in the day-to-day operations involving dispatching and expediting. In responding to these uncertainties, it seems that the objectives and priorities of various participants change from time-to-time. It would appear that the stages of the management process are not well understood.

It is easy to assume that projects, once scheduled, proceed in accordance with that schedule. On closer examination, it would appear that the schedule is constantly changing. Thus, a major problem in managing projects is the constant re-scheduling required.

One of the causes of the re-scheduling problem is the dynamics of human resources. Human resources do not always perform at 100% effort or in the desired direction. To protect against this, slack must be provided in terms of time, resources, or technical performance (on some activities) to permit recovery when a part of the system fails. Managing projects also calls for the coordination of diverse resources with different individual time commitments and different degrees of match of qualifications versus activity skill requirements. The project manager must assure himself of adequate

information flows to become aware of such breakdowns in the organization on a timely basis to permit corrective action before the loss is too great. Means need to be developed to train potential project managers to deal effectively with these problems.

While technical performance is a vital dimension of project work, very little of substance is available in the literature on project management.

Magnitude of the project is shown to be a factor in many aspects of project performance. While most attention has been given to large, technically complex projects, the large project probably includes a lot of small projects. Certainly many organizations are involved with a lot of small projects and occasionally a large one. A better understanding of this diversity seems desirable, as well as a system applicable to the complete range of project magnitudes.

It was pointed out that the singular definition of criticality based on float may be myopic, and that other measures should be considered and provided to the project manager. These include critical resource, critical flexibility sequence, and critical predecessors. In addition, there may be critical points of responsibility transfer to which the project manager should pay particular attention. There may also be only a few critical activities in terms of the degree to which they are pushing the state-of-the-art.

The dynamics of technological change is not well understood. The severe effects of this on certain defense projects emphasizes the need for improved knowledge in this respect.

In terms of the project itself, it would seem that some projects are more difficult and some more complex than others. Finally, there is some evidence of learning as the project progresses so that the plans and schedules should improve over time.

Having examined the nature of projects themselves, attention was turned to other factors affecting project performance. First, it was shown that performance is multi-dimensional, and often treated ambiguously. To be meaningful, performance measurements must be related to the priorities of the different objectives of the project and of the performing organization.

A number of characteristics of individuals involved in projects were examined, and some evidence provided that such persons are somewhat different from typical factory employees. It also appears that there are some differences between people as a function of the different types of projects.

Special attention was given to project managers and their selection, training, experience, and leadership style and skills. There is some evidence that the leadership style and skills vary by type and/or phase of project. It was pointed out that most leadership research deals with the dominant or average leadership style. The dynamics of using different styles is ignored. It was observed that academia provides relatively few opportunities to develop behavioral skills as opposed to exposing the student to "knowledge."

Knowledge about and guidance for the superiors of project managers seemed almost non-existant. Some general observations were

made about the effects of congruency of leadership styles. Also, the importance of good business planning was pointed out to permit the organization to fulfill the needs of individual participants.

The relationship of performance to organizational factors were explored. It was argued that projects can be performed by mechanistic beauracracies, but that certain types of projects may be more successful when performed in an organic organizational environment. Organizations were shown to adopt a variety of different goals, some of which pertain directly to the three dimensions of an activity/project. The specific goals adopted will have significant impact on the type of performance that results.

Two specific aspects of organization structure were explored. First, there seems to be little guidance with regard to the meta-structure in which the project organization exists. Secondly, it was asserted that very little is documented on the process and problems of changing from a functional to matrix organization. It would seem that one of the essential aspects of changing organization structures would be to re-write the job descriptions. While some sample descriptions of the project manager were found, there was little guidance for re-writing the others in the organization. The essential tool suggested was the Linear Responsibility Chart. Still, little was provided to aid the transition. Likewise, there seems to be a need for assistance for the project manager in delegating responsibilities and developing job descriptions quickly.

Some evidence was found that organization climate is a sensitive variable indirectly related to performance. Unfortunately,

the instruments used to measure climate were all different resulting in questionable generality. It would seem desirable to have a single instrument specifically designed for project environments of all types. If such an instrument were available and accepted by researchers, it would significantly improve the ability to generalize results.

Finally, some external factors were examined. These were classified as social and economic conditions, status of relevant technology, the physical environment, and the customer. While better understanding of these factors would seem important to a project manager in today's society, research on customer-project relations would seem especially beneficial.

Listed below are twenty-seven suggestions of gaps in knowledge of projects and their performance which seem to warrant research. Their relative importance will be examined in Chapter VI in the discussion of a strategy for research.

A. Nature of Projects

1. Develop a comprehensive taxonomy of projects and their nature and the types of tools applicable to their management.
2. Analyze the phases of projects over a number of projects and categorize their characteristics especially as to implications on tools for and approach to managing the projects.
3. Analyze the stages in managing projects and determine if the types of tools employed vary as a function of the stage. What are the essential system requirements of each stage?
4. Conduct a study of the role that magnitude of project has on the criteria relevant to selecting techniques or systems to aid in managing the project.
5. What are the different and common requirements for managing large and small magnitude projects, especially when performed by the same organization, and how can a single system span the managerial needs of the full range of magnitude?
6. How can difficulty and complexity be defined to permit legitimate comparisons between projects?

7. Is there a "learning" phenomenon associated with project progress and, if so, are there characteristic patterns of learning by the type of project?
8. What generalizations can be extracted from literature of various technologies that bear on understanding the trade-off relationships between activities in a project?

B. Interrelationships

1. Under what conditions and according to what rules would the "must," "should," "desired," and "schedule" precedence relationships be used?
2. What capabilities should be provided in and what rules should apply to the "punch list?"

C. Technique/System Development

1. What are the problems with which first-line supervision must deal on a day-to-day basis? What system capabilities would assist him in dealing with them?
2. What are the needs for and characteristics of flexibility in scheduling and dispatching that facilitate achieving high labor utilization?
3. What objectives and/or priorities are applicable on a project in the long, intermediate, and short range, and what are their dynamics from day-to-day and even within the day?

D. Individual Characteristics

1. What are the differences between employees who choose project-type occupations versus those who choose mass production occupations?
2. What are the critical characteristics of people who work in different types of projects which bear on their productivity, job satisfaction, and approaches to managing them?

E. Project Manager

1. What are the essential areas of knowledge and skills (not including technical background) of project managers? Does this vary by type or phase of project?
2. What are the strategic approaches to the use of various leadership styles and what are the consequences of the alternative strategies?
3. Determine the practices used by project managers to "discipline" recalcitrant participants, and assess their impact on the project and the organization.

F. Organization Behavior

1. Analyze the degree of rationalization in organizations characterized as organic or mechnistic and relate that to performance on different types/phases of projects.
2. Study the meta-structure of organizations engaged in project-type work.
3. Develop instruments to measure climate and leadership in project type organizations and encourage their use on all project research.
4. Analyze performance on projects as a function of the goals of the organization.
5. Analyze the problems encountered as an organization changes from a functional structure to a matrix structure.
6. Develop more complete guides for job descriptions in a matrix organization and a method by which the project manager can quickly accomplish this part of his organization responsibilities.
7. How can the project manager, or his managers, determine the true capacity of an organization to perform work, and how can they build slack into the organization to assure project performance in spite of failures, or less than required performance, by various elements in the organization?

G. Philosophies of Managing Projects

1. What implications do various philosophies of managing projects have on the pre-execution and execution stage of a project, and what do they imply about the associated management system design?

H. External Factors

1. Study the effects of external factors on project performance and alternative ways the project manager might deal with each. Special attention should be given to the relationship with the customer so the customer would better understand the effects his actions may have on project performance.

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CHAPTER V

TOOLS FOR MANAGING PROJECTS

Introduction

One of the major criticisms of project management literature which underlies this study is that too much emphasis is placed on network based techniques to the exclusion of a host of other tools that can be useful in managing projects. Attempts at finding references to many of the tools which are familiar from practical experience were fruitless in most instances except for Gantt Charts and network based techniques. Thus, it was necessary to rely heavily on personal experience to develop the taxonomy of tools for managing projects. There is no claim that it is exhaustive but, rather, that it provides a framework to which other tools can be related by those experienced in their use.

Another criticism underlying this study was the inability to find guidance as to which tool, and which variant, to use under what circumstances. Some comments are made on the evaluation approaches that have been taken to provide such guidance. A number of suggestions are made for research which should improve this guidance. These deal with the techniques, their implementation in terms of computer programs, if applicable, and their application on real problems.

Because of the dearth of literature on the other tools, critical analysis of the benefits and problems with the tools is directed primarily at network based techniques. A major premise of this study is that there is a need for a system to aid in managing projects offering a wide range of capabilities which would be applicable to many types and over all phases of projects; that would be applicable to large and small projects; and that would incorporate the best features of a variety of techniques and practices.

Some observations are made about potential for such an integration of some of these tools to provide a management information and control system having utility at least comparable to the best classical management systems in actual use in operating organizations.

Taxonomy of Tools

Basically the tools available to a project manager can be classified as formal and informal, and as techniques and practices. Table V-1 shows a variety of techniques, most of which are familiar to managers but few of which are actually discussed in the literature of either project management or operations/production management. The list is illustrative rather than exhaustive.

Techniques

Narrative Reports

This is one of the oldest and still one of the most used techniques. Various styles and formats exist. Often standard categories of information are prescribed to try to overcome one of

TABLE V-1.--Taxonomy of Techniques for Managing Projects.

Formal Techniques	Entity		Types of Information			
Schedule/Progress	Events	Activity	Time	Resources	Technical Performance	Cost
Narrative Reports						
Accomplishments	x	x	x	x	x	x
Status	x		x	x	x	x
Projection	x	x	x	x	x	x
Lists						
Bills of Materials(Bom)						
Engineering				x		
Assembly				x		
Construction						
Take-off				x		x
Task List						
Punch List		x				
Time Line	x					
Work Sheet						
Matrix (Combines Bom & Task List)		x		x		
Spread Sheet (Matrix with dates)		x	x	x		
Budget						
Administrative (by function)						x
Project (by Component)						x
Work Order System		x				x
Graphic						
Schematic Diagram				x		
Work Breakdown Structure				x		
Bar Chart						

TABLE V-1.--Continued.

Formal Techniques	Entity		Types of Information			
Schedule/Progress	Events	Activity	Time	Resources	Technical Performance	Cost
Gantt Chart		x	x			
Milestone Chart	x	x	x			
Manhour Charts	x	x	x	x		
Histogram (Manpower Loading Chart			x	x		
Process Chart		x				
Network Diagram	x	x	x			
Forward (early) Schedule (Including Harmonogram)						
Backward (late) Schedule (Including Lead Time Chart in LOB)						
Network Based						
Critical Path Technique	x	x	x			
PERT	x		x			
CPPS	x	x				x
Resource Management		x	x	x		
DART		x	x	x		
PERT/COST		x	x			x
LOB	x		x			
PERT/LOB	x		x			
Decision CPM	x	x	x			
GERTS	x	x	x			
RMI	x		x		x	
Other Formal Techniques						
Configuration Management		x	x		x	
Design Cost Control		x	x		x	x
INFORMAL TECHNIQUES						
Tickler File		x	x			

the biggest problems with this technique, i.e., the tendency for subordinates to report the good results and ignore bad results and problems. The categories indicated in Table V-1 under narrative reports suggest one approach to this, i.e., accomplishments, status, and projection of future plans. At times, headings such as "problems" and "assistance required" have been used to force subordinates to respond to these explicitly, even if to say "NONE" to each of them.

Often there is a tendency to emphasize events rather than the work itself. Cost data may be inaccurate if derived from a conventional accounting system because of inadequate relating of costs to the work. This may be overcome with an effective work order system. Even then, accounting constraints on the number of active work orders often results in too high a level of aggregation of costs, and therefore only a loose relationship to work progress.

Another problem with narrative reports is the tendency for them to be used for defensive purposes. Pleas for more resources, relief from too demanding technical requirements, etc., establish a basis for excuses at a later date in the event of failure to perform to specifications.

Lists

This is a general classification which includes listings of items. A basic list is a bill of materials (BOM). These exist in several forms including an engineering bill, assembly bill, and construction take-off. The construction take-off makes the significance of the BOM as a technique for project management more clear.

The items included in the BOM imply the work that must be accomplished to complete the project. For example, a door included in a construction take-off implies the framing of the opening, installation of the jamb, hanging of the door, and installation of the trim. While these occur in that sequence they may not be contiguous. Nevertheless, a construction estimator can estimate the total costs associated with that door from its listing in the BOM. The construction superintendent can identify the human and non-human resources required to accomplish the work and each trade foreman involved can identify his responsibility with regard to that door.

There are numerous forms of task lists. Perhaps the simplest is the notes on the back of an envelope of things that must be accomplished. Calendars are generally marked with things to do. Construction projects are concluded by a set of activities, possibly unrelated to one another, commonly called a "punch list." Sometimes costs and/or resources may be associated with each activity. If start and/or completion times are noted with each it may be called a "time line." While the activities may be unrelated as far as the list is concerned, the manager probably has some sense of relationship between them in his mind. Unfortunately, these are not conveyed to other participants. If the project is of overwhelming importance to the organization, the participants may be sufficiently dedicated to perform to schedule so this would not be serious.

Worksheets are also in various forms. Typically they combine a BOM with a task list in a matrix form. As each task is

finished on a BOM item it is "x'ed" or colored to note progress. On some projects, such as writing a report, this may be about the most useful techniques. Its strength is the emphasis placed on work to be done. Its weaknesses include no deadlines and no explicit estimate of work content.

A variation on the worksheet is often called a "spread sheet." It is similar except that completion dates are included in the matrix. Even so, there is no explicit estimate of work content and very limited ability to determine work load on the participants. An example of the "spread sheet" can be found in Morton (1977, p. 37). He recommends the use of such a form as an equipment list. The formating capabilities for spread sheets in a generalized computer application should be as flexible as possible to permit its adaptation to the specific needs of various users.

Budgets are a standard tool of most organizations whether they exist in written form or not. The typical administrative budget is by line expense item for a functional organizational entity. Seldom does it relate to the activities the organizational entity must perform. A project budget on the other hand is organized by the activities that must be performed or at least by the items that must be produced. A construction take-off with costing completed is a project budget. In a matrix organization, a single project budget may include only a portion of the budget for a functional organization entity. In a functional organization, project work is often controlled by a work order system. Often the work order

accounts are aggregated at too high a level to be helpful in controlling individual activities. Partially as a result of this level of aggregation, but often as a result of sloppy practices, the work order accounts are not closed on a timely basis. As a result, foremen, who maintain their own detailed accounting records, charge things to open work orders until they have used up 100% of the estimate for that work order. In one application of a network based system associated with a work order system, work orders were closed as soon as the activity was completed. The analyst/estimator marveled at finding he had been over-estimating the work orders, a fact which was only discovered as a result of requiring prompt closing of the work orders as soon as the related activities were reported completed.

Graphics

Another technique which is not discussed in the text books reviewed is the schematic diagram. It can take many forms. A simple one used on a housing development involving some 750 units was based on a plot plan of the entire project. As an employee of the contractor during the summer of 1951, the author's duties included updating the status chart described. Each house appeared on the plan in outline form. The outline was divided into several sections, each of which represented a major segment of work on the house such as "foundation poured," "floor poured," or "walls framed." As the specific element of work was completed, the section representing it was colored in its distinctive color. At a glance, the entire project

status could be seen, including the number of units of in-process work completed between each of the successive work crews. It is easy to visualize such an approach applied to the construction of the pyramids as well as the many floors of modern buildings such as the World Trade Center in New York or the Renaissance Center in Detroit.

Lockwood (1977) in an interview, described an approach similar to this which was used on the F-15 project in the Air Force. Top level management progress meetings were supported by a work breakdown structure (WBS) graph with pictorials of the components of the system shown by each element in the WBS. Project status on each element was shown by various colors in the WBS elements coded to represent the various phases of work completed on that element.

The "Bar Chart" first gained prominence as the result of its application by Henry L. Gantt to the production scheduling at the Frankford Arsenal in 1917. Many variations have been developed including its application to project work. It is probably the single most widely used technique for graphically portraying a project plan on a time scale. The U.S. Navy, dissatisfied by excessively long bars (too long in duration), added an inverted triangle to identify "milestones" and thus created the "Milestone Chart." Even so the bar chart has many deficiencies, the most significant one being that it is static. Considerable effort is required to revise a schedule shown in this form. This has largely been overcome by making this a standard output from a network based

system. The amount of information that can be portrayed, even on a 54" by 72" sheet of paper on a flat bed plotter is limited. Nevertheless, its popularity continues, particularly on relatively small projects.

An adaptation of the bar chart, the man hour chart, includes resource estimates by bar (or activity). These are summed down over all activities to obtain the resource requirements per time period. Based on the resource requirements obtained from the manhour chart, a useful graphic form is the histogram of resource requirements or resource profile. It makes more vivid the variations in research requirements and suggest revisions in schedule to avoid excessive changes in levels of resources.

The process chart is a standard technique for showing the relationship between the components of a BOM, with emphasis on the work required to assemble them. It is more generally used to portray job shop, mass production, and flow process operations. In such cases, operating times may be shown for each operation. Likewise, activity times may be shown on a process chart when it is used on a project.

It is only a short step from a process chart to a network diagram. If the chart is drawn from time now into the future it is sometimes called a "forward schedule." It is the same as an early schedule in CPT. The "Harmonogram" (March, 1976) was a version of such a chart. If the chart is drawn from project completion time backwards it is sometimes called a "project schedule."

It is the same as a late schedule in CPT. It is also the same as the Lead Time Chart in Line-of-Balance (LOB). The network diagram is useful in developing project strategy and also in long-range planning for a firm. In both cases, relating activities technologically is much more important than relating them in time.

Network Based Techniques

Clearly, PERT as conventionally implemented has not fulfilled its claimed benefits, at least according to the literature. CPPS has not found wide acceptance, except in specific application areas. Resource leveling has found only limited acceptance in spite of the extensive literature on technique development. Little if any of the literature really addresses the problem of why this lack of acceptance of these techniques on a rigorous basis. Rather, most of the problems described are really symptoms and give little guidance in redesign of techniques to remove the obstacles. An exception to this is the research by DeCoster (1965), Schoderbeck (1966), Hill (1966), and Neel (1971) all of whom trace much of the blame for limited use of PERT/COST techniques to incompatibilities with the accounting function.

Some discussion of the items listed under network based techniques is appropriate. Critical Path Technique was chosen as a unique name for versions similar to PERT and CPPS which use single time estimates and have no time-cost trade-off capabilities. It appears to be the version most commonly in use today.

Under resource management there are two types of applications--homogeneous resource and heterogeneous resource. The homogeneous resource classification includes most, if not all, of the literature in this area. Under heterogeneous resource there are two distinct types of problems. The first has been identified in this study as the "drafting room" problem, i.e., the assignment problem with a time dimension that considers technological precedence. The other is the dispatching problem applicable in an environment where the primary objective is efficient use of resources, giving adequate recognition to the dynamics of the human resource as well as some of the uncertainties associated with non-human resources. DART (Daily Automatic Rescheduling Technique), as reported by Marchbanks (1966), is closest to the latter problem. PERT/COST has clearly proven ineffective in its standardized form for several reasons. Unfortunately, the reasons provided are somewhat general and not substantiated by adequate research. Rather, they seem to be largely experiential judgements.

Relatively little has been said specifically about problems and deficiencies with Line of Balance (LOB) or PERT/LOB. LOB has apparently received little practical use other than by the U.S. Navy. They typically used it to diagnose problems on relatively small production contracts. Even though it has been computerized, no references were found to its application. The major problem with LOB seems to have been the effort required to collect all the data and to prepare the graphic display. Furthermore, in the manual

mode, keeping the graphics current also requires considerable effort. Siegel (1977), in an interview, mentioned a report which discussed the problems with PERT/LOB. Efforts to obtain a copy of that report have not been successful. In the absence of the report it can only be surmised that either the implementation on the computer was not cost effective, that it was too complex for practical use, that other tools accomplished the purpose better, or that there really was not the need for such a tool. There are other tools available which do not have all these deficiencies. One such tool is Material Requirements Planning System which has become available in the last decade.

While several references were found to the theory of Decision CPM and GERTS, relatively little has been documented about specific applications. A question is raised about the extent of application of this concept due to the conflict between lack of literature on applications versus the relatively frequent announcement of seminars on the use of the techniques. Because of the sparsity of the literature on applications or evaluation it is impossible to analyze deficiencies at this time.

As indicated earlier, Reliability Maturity Index (Malcolm, 1963) (RMI) has not been mentioned in the literature of project management for several years. Nor was any literature evaluating its efficacy found. Therefore, it is impossible to draw any conclusions on what should be done relative to RMI other than conduct research into its efficacy and its benefits and problems. It may have proved impractical in which case it should be forgotten.

Other Formal Techniques

Configuration management appears to be very necessary on military and space projects. It is also important on most other hardware projects and on other types of projects including computer program specification and development. Design cost control as used in the automotive industry is very similar to configuration management but with, it seems, a stronger emphasis on control of unit production and capital facility costs. Both emphasize cost-benefit analysis, but it is suspected that on many defense-space contracts the benefits in terms of improved performance of the product carries more weight than unit cost. This is possibly due to the fact that the product does not have to compete in the market place for unit sales, and perhaps due to the critical aspects of reliability and performance in operation of the product.

Informal Techniques

The literature is particularly sparse on what could be considered "informal techniques." The only item included in this category is the "Tickler File." This is often maintained by the project manager's secretary on 3" x 5" cards. They are filed by date of action such as receive a report, prepare a report, or accomplish an objective. When the date recorded for the action arrives, the cards, or notes from them, are given to the project manager for follow-up.

There are any number of techniques such as this which apparently are passed on via "on-the-job-training," or which are

re-invented as the need arises. It would seem that a deliberate search for such techniques would reveal many more which, if documented in a very brief and simple form, would aid potential project managers in gaining higher levels of skill.

Practices

Distinction between techniques and practices is arbitrary in many respects. Nevertheless, the listing of the practices in Table V-2 adds to the repertoire of tools the potential project manager may find useful in managing projects. A more complete discussion should include some of the pros and cons of each plus appropriate caveats on their use.

Practices can be divided into written and verbal for discussion purposes. Often verbal practices should be followed by written recording of them to assure proper documentation and to minimize misunderstanding. They also serve to record commitments made by project participants.

Written Practices

The organization chart is a basic written document in most organizations used to show the major delegations of responsibility. There are infinite variations on them, of which functional and matrix charts are only very general classes, and also a variety of different ways of presenting them graphically. While there are a number of references on this subject, most references on project management provide a few examples and little else. Practical

TABLE V-2.--Taxonomy of Practices Useful in Managing Projects.

Written Practices

- Organization Chart
- Linear Responsibility Chart
- Organization Manual
  - Organization Responsibilities and Authority
  - Policy
  - Procedures
  - Operating Instructions
  - Technical Instructions
- Planning Documents
  - Proposals
  - Technical Plans
  - Dissemination Plans
  - Termination Plans
- Memoranda

Verbal Practices

- Individual Meetings
  - Progress, Status, Plans
  - Problem Solving
  - Individual Performance Review
- Staff Meetings
  - Project Management Team
  - Total Project Team
  - Ad Hoc
- "Brainstorming"
- Plant Visits
  - Announced
  - Unannounced

Other Practices

- "Ag-Pos" (Agenda Position)

Integrated Management Information and Control Systems

experience suggests that there is a considerable gap between literature and practice. This is unfortunate because organizational relationships are one of the most sensitive variables available to the manager in creating an effective organization.

The Linear Responsibility Chart, analyzing the delegation of responsibilities, is mentioned in both Cleland and King (1975, p. 271) and Archibald (1976, p. 103) who refers to it as a "Responsibility Matrix." It is a matrix showing responsibilities, by activity or in general, on the left and positions or persons across the top. Various codes or symbols are used to indicate degree of responsibility at each intersection. Note that such a matrix could be manipulated to have degree of responsibility across the top with the cell entries representing the organizational entity. This would be a very useful tool for the project manager to confirm that he has adequately and appropriately assigned responsibilities.

Both of the above are very concise and therefore convey a minimum amount of information. This can be overcome by publishing organization manuals. One such manual could amplify on organizational responsibilities. Another could specify policy as adopted at various levels in the organization. The standardized procedures should also be documented. Furthermore, as the number of people involved becomes greater and the technology becomes more complex and/or demanding, it may also be worthwhile to develop operating instructions and technical instructions. Notice that this progression of more written documents also coincides with the concept of

rationalization, i.e. the movement from an organic to mechanistic organization.

Reading the typical chapter in an operations/production management text would suggest that the network based plan is an adequate statement of a plan. It may be adequate in some instances but, the nominal information per activity plus the need for communicating objectives, general guidelines, assumptions, parameters, and other information to a large number of participants, makes it desirable to develop planning documents. Major projects require a detailed planning document. These are sometimes called bid packages for external clients or project proposals internal to an organization. Often additional detail is developed if the project is approved for execution. Tso (1976) suggests a formal dissemination plan for education projects. Others suggest a formal termination plan.

On smaller projects, the purpose of the planning document is often served by memoranda. Regardless, memoranda are a basic means of communicating understandings, directions, instructions, and, occasionally, reprimands and the like. While this is not necessarily a subject that requires lengthy discussion in a text on project management, writing such memoranda is a necessary skill of an effective project manager.

Verbal Practices

The most direct form of communications is through one-to-one discussion. Meetings with individuals can serve a host of purposes, not the least of which is establishing mutual rapport and conveying

a sense of appreciation of the subordinate and his problems. The pressures on a project manager tend to make such meetings with many of the project participants low in priority. Because of the often lower intensity of supervision on project work as compared to job shop and mass production types of work, the project manager is more dependent than the functional manager upon the subordinate's motivation and consistency of thinking. The one-to-one meeting is valuable in achieving both of these. The meetings can often be informal, such as at lunch, on the golf course, or over coffee.

Staff meetings on projects are essential. They are the most immediate means of communication of a single message to the key members of the project team and sometimes to all members. The attendees at a meeting can vary depending on the need. Often a regularly scheduled staff meeting serves the general needs. Sometimes the needs are better met by an ad hoc meeting of only those affected in the solution of a specific problem. These may include lower level participants as required. Occasionally, it may be desirable to have a meeting of a larger group of project participants to permit them to obtain a broader view of and greater identity with the project. This would certainly be consistent with Borcherding's (1977, p. 244) recommendations for keeping project personnel informed of the overall concept and status of the project.

Staff meetings also serve as a problem solving forum, especially when the problems are not "owned" by a single participant. Discussions of potential trade-offs are essential to solve these

problems. Perhaps less obvious but still very important are some motivating aspects of the staff meeting if handled properly by the project manager. For example, a few judiciously chosen questions by the project manager will encourage all participants to be very well informed in their own areas of responsibility. This is especially true when the first time a participant fails to be informed is followed by a comment to all that "The staff meeting is a time to report on your homework, not to do it!" In one case this resulted in excellent performance in subsequent staff meetings. It could prove dysfunctional for some types of project participants.

The staff meetings also serve to motivate participants in terms of commitments. Few people who make commitments in front of their peers are likely to take it lightly, and as a result both timely and quality performance are likely to result. An approach that has proven effective in a project environment is to require participants to verbalize their plans for the next period. It is also important in that it conveys a reasonably accurate assessment to the project manager of what the participant understands he is expected to do. Without this the project manager has no assurance that the participant understood what the project manager said. Lack of understanding by the project manager of what the participant said is very likely to be followed by immediate questions and discussion. If the participant's understanding is at odds with the project manager's desires, corrective action can be taken before resources are expended. This is especially important in the project

environment due to the non-repetitive nature of projects as well as the tight time and cost constraints generally applicable.

One practice which is well documented that is effective in meetings for certain purposes is "brainstorming." It is particularly useful in developing original ideas for solving difficult problems. It may also be effective in discussions leading to the development of strategic plans.

Another practice that has proven helpful, if not essential, is plant visits. The announced visit will encourage clean-up of loose ends. The unannounced visit will disclose the loose ends. The effective project manager will cultivate personal relationships with plant personnel and, as a result, discover in undirected conversation problems of which he would not be informed through formal channels. While he must be cautious about giving orders outside the formal structure, often appropriate questions and involvement in problem solving will elicit cooperation that cannot be achieved otherwise. Sometimes he will discover the possible existence of a problem in another area. The reliability of information obtained in this manner should be considered suspect. Nevertheless, it can often be the basis for establishing hypotheses which the project manager can then pursue to either prove or disprove the problem's existence. Care should also be exercised to avoid disclosure of sources to prevent possible reprisals. This can be done easily if the hypothesis testing approach is pursued in a subtle manner.

Other Practices

There are other practices which might more appropriately be called strategies and tactics. One of these which has proven generally effective was given the name "ag-pos" for agenda position. It was suggested that items which may meet with controversy or objections be placed at the end of a long agenda of a meeting scheduled in such a way that meeting participants will be anxious to adjourn by the time that item comes up and will therefore be less inclined to object or even discuss at length. There are many such practices which should be researched and documented. While some of these may seem devious, they must be viewed in light of the project manager's primary responsibility of getting the project completed. Deliberate discussion of these would lead to a better differentiation between those which may be devious and those which are really unethical, immoral, or illegal.

Integrated Management Information and Control Systems

Finally, there have been references to "Integrated Management Information and Control Systems" (MICS) in texts on the management of projects. Generally, such references are very optimistic about the benefits to be derived. There are at least two sides to this issue. On the one hand, the general literature in which MICS are discussed indicates a strong note of pessimism. Much of this is warranted due to the tendency of many writers to suggest that MICS may be the new panacea. A more realistic assessment recognizes that

formal systems can only do a part of the job. Inherent time delays and biases limit their effectiveness. Inability to store all relevant information limits the potential considerations. They must be supplemented by informal techniques and practices which are more timely, more sensitive, and more qualitatively oriented such as meetings or plant visits.

On the other hand, there is no question that one of the serious problems associated with the management of projects is the disjointedness of the various information systems involved. Often, pieces of the systems are computerized. To relate data from one with data from another often requires extensive manual effort. Perhaps a totally integrated system, as is often envisaged in many articles, is unrealistic. Certainly some additional degree of integration does seem desirable. Comments in earlier sections of this report have suggested some areas as potential candidates for integration, such as inventory systems for parts. The findings of DeCoster (1965) and others make clear that major problems in this respect have existed in the accounting systems. The author's experience has been consistent with these findings. Thus, it seems that considerable work is warranted to gain an understanding of the possibilities, benefits, and potential problems associated with higher degrees of integration of project management information and control systems.

Evaluation of Network Based Tools

The evaluation of techniques occurs at several levels. As portrayed by the tables from AMETA course material included in Appendix B, Evaluations of Certain Tools of Project Management, most evaluations are at a very general level. They do not really assist in the selection of the proper technique(s) for a specific project. Furthermore, the evaluation is a gross consideration over all phases of the project life cycle and over all stages of the management cycle. It seems reasonable that the criteria for selection may also depend on the type of project and the type of activities involved.

For example, writing this dissertation had some characteristics in common with a project. The one significant difference was that the majority of the work was done by a single person which is characteristic of the craft mode for arranging work efforts. Otherwise, the characteristic which was unique to this effort, and to a number of similar efforts, is that the variance of the estimate of the work content is very large relative to the estimate itself. Put another way, the primary emphasis was on achieving some technical objectives for which the work content was indeterminant with time and resources expended being distant second and third priorities. The most useful technique for planning and control of the effort was not a network but the matrix work sheet which listed the tentative chapters and their outlines down the left margin and the tasks required across the top. Tasks included basic literature

search, notes made, first draft written, first typing, edit and revise, second typing, reproduce, review by committee, final revision, etc. Problems in estimating were as a result in part of the considerable literature available.

Nearly every facet of consideration led to a new set of literature. Drawing a boundary of relevance could only be done after at least some analysis and consideration. Therefore, the work content of these activities was essentially indeterminant. Secondly, the writing of a first draft was indeterminant to a large extent due to a process of progressive enlightenment. For some aspects at least, the explication of a concept raised other questions to which new insights were discovered. These required additional research and writing. Third, the typing time was a function of the number of pages written in the preceding step. Reproduction was probably the most estimatable activity in the project. The subsequent steps were unpredictable both in duration and nature. As it happened, at a late stage, revising the outline led to considerable re-work.

This somewhat detailed description of the present effort illustrates vividly the inadequacy of current evaluations of project management tools. Not only is the matrix worksheet not mentioned in any of the references reviewed, but the characteristics of different types of projects are not a significant part of the evaluations. In the present case, technical performance carries a significantly higher priority than either resource utilization or completion time. Other projects have different patterns of priorities as well as different characteristics. It is suggested

that research is required to more clearly identify the characteristics that are relevant for selecting the management tools to be used and evaluating the tools against those characteristics.

Some of the problems with network-based techniques stem from misapplication. Some of these are inherent in the nature of people. For example, resistance to change is encountered whether in projects or other efforts. When a technique clashes with traditional organizational patterns, it is likely to induce even more resistance to change. It is natural to fear the technique being used as a whip. If management behaves in a manner to reinforce these fears, then resistance will be strong indeed. Thus, some of the problems in application stem from errors by management. One of these results from project managers failing to learn the technique, delegating network preparation to staff, and not insisting that he and other line managers analyze the results personally. To some extent, this may be justified by the complexity of the project and by other duties of the project manager. However, if the project manager is unwilling to participate in the planning process, he is not likely to be committed to the resulting plan, if it in fact represents how he intends to execute the project. In the worst case, networking represents a duplication of effort if the project manager is running the project by more traditional techniques. This often happens when the technique is forced on the project manager.

Top management acceptance and support is often lacking. In early efforts under the DOD directives following June 1962, many

top managements tolerated the effort because it was contracturally required. Seldom would they allocate the time to understand the technique and to learn new patterns of behavior. Often lower level managers would be sent to seminars to learn how to apply the technique, only to return to an organization which asked questions that had to be answered based on the old technique, and to be asked no questions that required the use of the new technique.

On the other hand, top management's failure to accept, let alone endorse the technique may well have been the better part of wisdom. PERT/COST was not well developed before it was "pushed" by DOD and NASA. It is not clear that, had it become the only technique used in its area of applicability, success would have been forthcoming on the project. In this early stage of development, networking techniques did require more time of management to use effectively. In part this was due to problems inherent to its implementation in various forms and in part to the nature of the technique. Not being confident in the efficacy of the technique, managers were probably unwilling to depend entirely on it when their personal future, their company's future, and even national security and prestige hinged on success of the project.

Given the preceding discussion, it was relevant to critically consider the claimed benefits and problems of the network based techniques to attempt to determine possible improvements that would lead to greater acceptance. Some of the suggested improvements include incorporation of the less sophisticated techniques and

practices into a network-based system. The literature reviewed included comments on PERT, CPM, and PERT/COST. Analysis of the comments suggested that most were directed at PERT. Closer consideration revealed that many really applied to the more generic concept, which was defined as CPT (Critical Path Technique). Some were directed only at networking per se. Thus, it made sense to consider each of these separately, starting first with network graphics and proceeding through CPT, PERT, CPM (or CPPS), and PERT/COST. The analysis was directed more at the legitimacy of the claimed benefits and problems and what, if anything, can and should be done about it.

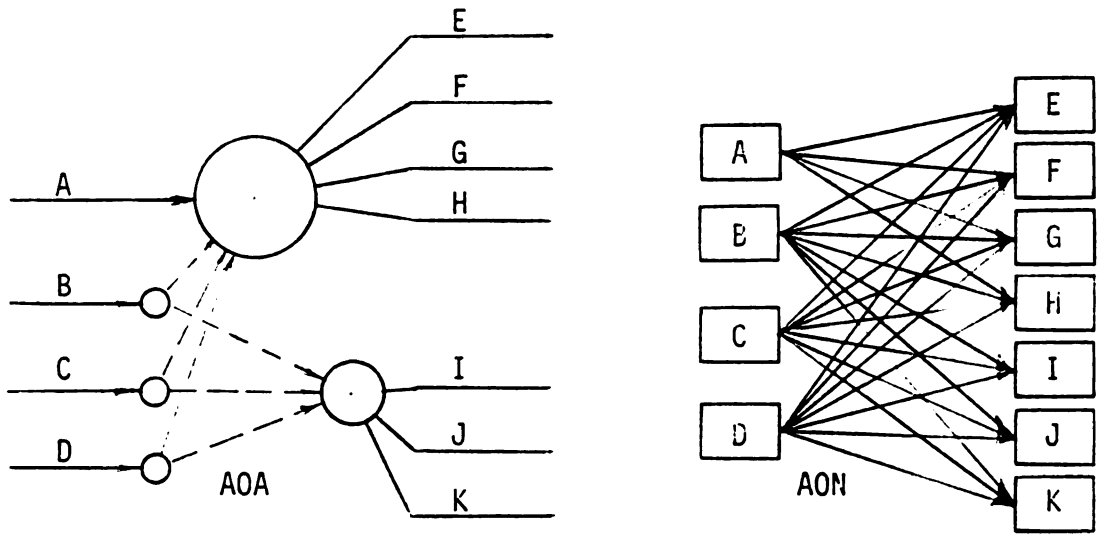
Graphics of Networking

The claimed benefits for networking included better planning, easier to improve on the plan, provides an acceptable compromise between complexity and simplicity, separates planning from scheduling, can be processed on a computer, stimulates a team spirit, improves overall business orientation, promotes better communications and therefore better customer relations, and gives top management assurance that planning is being done.

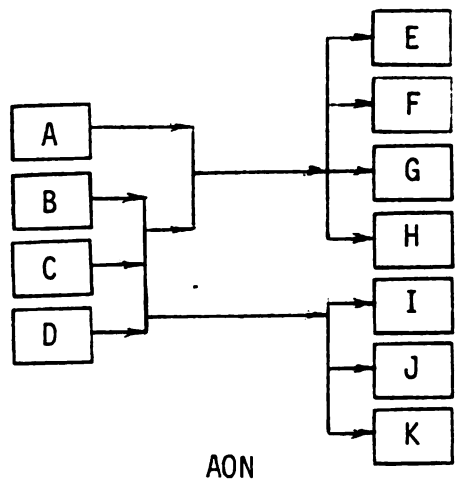
Against these were arrayed a number of problems. Some of these are inherent in projects. For example, complaints that the techniques are over-complicated is more a realization of the nature of some projects than the nature of the techniques. In the past, the use of Gantt charts, taking more time on projects, and performing less difficult projects permitted ignoring many of the complexities,

if they in fact existed to the same degree. Some of the complaints were about legitimate deficiencies in the techniques such as the network conventions being incapable of adequately handling certain realistic logical situations. The emphasis on AOA notation was a factor. For example, one comment was that no provision was made to easily portray parallel or overlap efforts. AON notation relieved this situation considerably. Still some additional conventions are required to describe some other realistic situations as suggested in Chapter IV. In some instances, the problems were likely as a result of applying the wrong tool to a project, including networking, when a simpler tool was more appropriate.

One important question which needs a definitive answer is which graphic notation is the better and by what criteria, activity-on-arrow (AOA) or activity-on-node (AON). As a result of AOA being used in both PERT and CPPS and the very rapid progress achieved in standardizing, publicizing, and gaining acceptance of PERT, AOA is the defacto standard notation today. The fact that most users of networking have been trained in AOA places a heavy burden on the proponents of AON to develop an overwhelming case in favor of AON if the current users of AOA are to be persuaded to convert to AON. The proponents of AOA notation have frequently given examples to support their case. For example Reynaud (1969) provides the following illustration (p. 337):



His illustration of AON implies a lack of familiarity with AON notation by failure to consider the following conventions for showing the same network.



This seems even more straight forward and simple than the "traditional AOA network."

It is also interesting to note that articles arguing the merits of AOA generally use examples that support the case for more computer storage when using AON notation. In reviewing this matter,

a network shown in Lock (1968, pp. 71-75), chosen for no particular reason, was analyzed in both AOA and AON modes. The results showed that in AOA, there were 79 activities, 37 dummies, and 88 events. The same network in AON mode showed 79 activities with 26 extra successors. That is, an activity with a single successor in AON is comparable to a single activity showing a predecessor event and a successor event in AOA. Thirteen activities had more than a single successor, all thirteen accounting for a total of 26 extra successors. Assuming a programming concept in which two words of storage are required for an activity in AOA as compared to one word for each activity in AON plus one extra word for each additional successor, the total storage space would be 232 words for AOA and 184 words for AON. Thus, not only would the storage space required be less in this case, but the processing time would also likely be less because only 79 activities need be calculated for AON while 116 (79 plus 37) activities must be calculated in AOA.

It is clear that the case is not closed on this matter as far as research is concerned. Telephone conversation with Dr. John Fondahl (1977), one of the most outspoken advocates for AON, did not reveal any formal research on either the graphic or computer advantages of AOA versus AON. When the other advantages of AON are incorporated in the analysis, it is anticipated that the case for AON will indeed be very strong.

The following additional advantages for AON are claimed in the literature:

1. AON lends itself to analysis of networks to determine optimum administrative arrangements (Klovstad, 1969).

2. Automatic plotting of an AON network is more straightforward than for AOA because the horizontal distance required per activity is constant, i.e., it is not a function of the duration of the activity (Klovstad, 1969, and Croissant, 1969).

Although it may be perceived as an advantage for AOA networks to be drawn to a time scale, experience has shown that once the network is defined and adjusted, participants in the project prefer Gantt charts to show the time phasing of the project activities. In the absence of research on the relative merits of AOA versus AON, experience in the use of both approaches suggests that the following also may be advantages for AON:

1. Quicker to learn because dummy activities are not involved.

2. Fewer logical errors.

3. Can use a meaningful alpha-numeric code structure to identify activities, possibly related to the Work Breakdown Structure (WBS).

4. Activities retain their original identity even after changes in the network diagram.

5. With reasonable pre-planning of the coding structure, the identity of activities can be maintained even with subdivision of activities as may be required in level-by-level planning.

6. As a result of maintenance of identity of activities, comparison of two plans for the same project is facilitated.

7. More activities can be planned per man hour with AON than with AOA because it is not necessary to draw the network manually before assigning event numbers.

8. Computer programs based on AON logic can easily be designed for partial calculation of a project after the introduction of changes.

9. Although not unique to AON, it does facilitate identification of activities by type based on the symbol used for the activity or, perhaps, the character used to outline the activity box if the plotting is done on a character printer (rather than a plotter).

10. The use of standard networks, and the integration of them and subnetworks, is facilitated by the AON notation.

Most of the claims above are subjective, i.e., they are not derived from hard research. Research could be conducted to determine if AOA is simpler to draw, results in fewer errors, and gives higher productivity. Ease of revising could also be tested objectively between the two methods. Indeed, a value engineering analysis of systems utilizing both approaches should lead to measures of total system costs rather than focusing only on the "computer costs." Some indication of the importance of the AOA time phased diagram can be measured by comparing the use of it versus the Gantt chart where plotting capabilities of both are available on the same system.

A claimed advantage of networking approaches is the ability to compare alternative plans. Few if any computer implementations have in fact exploited this "advantage." An objective analysis could be made to determine the relative ease of doing this via AOA versus AON. Subjectively, AON would seem to have an advantage due to the stability of activity identification. Changes in an AOA network necessitate changing event numbers on one or more activities thus modifying their identity. Furthermore, comparison could be made of the relative ease and straightforwardness of using standard networks and integrating sub-networks as a function of graphic mode.

Event notation is not without merit. The experience of the FBM application makes clear that there is a need for event identification. It appears that upper management is concerned primarily with key events. Indeed, it can be argued that, in a multi-project organization, if the chief executive allocates an excessive amount of time to any individual project, he may not be performing his primary functions properly. Nevertheless, he needs reassurance that the projects are progressing in an acceptable manner. For this purpose, monitoring the status of key events is probably most relevant.

The ability to distinguish between types of activities by symbol shape suggests interesting ways to classify activities. The most obvious classification might be as to type of work, type of equipment required (especially unique, scarce equipment), type of skilled trade required, or area of the work place. Another classification scheme might focus on the essentiality of the activity such as the must, should, and desirable relationships as discussed in the previous chapter. O'Brien (1971, p. 251) reports on a project by the Bureau of Labor Statistics in which the majority of negative slack was attributable to interdepartmental mail times. Identification of the mail activities would have aided in recognizing this problem.

Another question that warrants research is the consequences of alternative methods of plotting a network or Gantt chart. If an AOA network is to be plotted, activities can be shown at their

earliest, latest, scheduled, or other dates. Experience suggests that, if manpower planning is not going to be used, the network or Gantt chart should be plotted based on early dates if it is shown to workers on the project. This is based on the proposition that the less emphasis placed on latest allowable date to the participants, the less likely they are to start and complete the activities at their latest dates. In other words, this tends to keep some pressure on those responsible for performing an activity. On the other hand, showing that same chart to upper management might give too much cause for alarm and result in them spending too much of their time tending to falsely perceived problems. Providing top management with plots based on latest allowable dates may tend to minimize the extent of their "meddling" in the details to the chagrin of the project manager. However, neither of these represent exactly when the work will be done. Thus, some form of schedule dates would seem more appropriate, perhaps with the latest allowable for upper management.

Another aspect of plotting that warrants more deliberate consideration is the manner in which activities are shown vertically. There have been a number of alternatives proposed, typically in brochures on systems having specific capabilities. The plotting program available from one of the major plotting equipment vendors encourages centering horizontally the critical activities with those having progressively more slack being plotted further from the center. One suspects this is largely a matter of efficiency of the computer

program rather than one of human usefulness. Another alternative is to plot the most critical activities at the top or the bottom of the chart. This approach tends to focus attention more on the degree of criticality of the activities and the logical relationship of the most critical ones. It is similar to the slack sort listing of activities. Whether the critical activities are plotted at the top or the bottom depends largely on methods of display and analysis. For example, if a drafting table is to be used, it may be more convenient to put the critical activities at the bottom. There are other approaches. For example, in some of the DOD/NASA publications, a concept of "horizontal banding" is discussed. In this, activities are segregated into horizontal bands based on some common characteristic. This may be by organization, by major component, or by any other convenient and useful basis. These add to the ability to check the logic within each of these bands and the interfacing with other bands. There is apparently no research reported which clearly delineates the pros and cons of these or other methods of showing activities graphically.

In addition to the above comments, which apply primarily to conventional CPT, it should be mentioned that variations on CPT exist in which the node takes on more meaning than just identifying the beginning and completion of an activity. DCPM and GERTS both use the node to indicate a decision. This could be accommodated in AON plus, in an interactive system, that decision could be made external to the program by the project manager.

Staples (1971, p. 7) discusses a version used in a pharmaceutical company for extremely uncertain research which does not require time estimates such as in CPT but in which the network is the basis for describing what has been accomplished and what is to be done. This should be evaluated against other tools described above for the same basic circumstances.

Critical Path Techniques (CPT)

The benefits claimed for CPT included improved management decisions via simulation; ability to measure performance against plan; tendency for it to lead to initiation of replanning; better measure of relative importance of parts of plan; less time lag between performance and reporting performance; impartial, impersonal portrayal of progress; and minimized need for lengthy and frequent meetings.

These claimed benefits are not automatic. In the early days of usage of CPT, lack of management support, and therefore of computer availability, limited the amount of simulation that was permitted. Since then, computer costs have gone down and availability has improved, if only through time sharing. Without having research evidence for support, it is asserted that very little simulation or comparison of performance against plan is in fact done. Indeed, those computer programs with which this observer is familiar provide next to no capability of comparison at the activity level. Indeed, AOA notation, which is still the predominant notation used in the U.S., limits the ability to compare activities

if there have been appreciable changes in the network. Some comparison is performed at the project level but that is relatively primitive.

The claim that it leads to the initiation of replanning has to be considered on an if-come basis. Networks tend to become obsolete as changes take place in the way the work is accomplished. Often this leads to abandonment of the network and finishing the project by the seat-of-the-pants method. This decision is very dependent upon the ease of changing the network diagram, and what benefits are to be derived from the effort. In the past the balance between effort and benefit has not been favorable. Indeed, it was often claimed that the majority of the benefits from using CPT were in the original planning. While not arguing the benefits in planning, it is argued that the balance of benefits between planning and executing was largely a result of inadequacies of CPT in the execution stage of the project.

There is no question, based on practical experience, that CPT has led to better recognition of the relative importance of different parts of the project. Often the critical items as perceived by management were less critical than other areas recognized through CPT analysis.

While the report turnaround time was often unacceptable in the early days of CPT, improved capabilities of computers, and especially the advent of time sharing, have reduced turnaround times sufficiently to warrant daily updating and printing of reports.

The impersonal nature of the reports from a CPT system seems advantageous in at least three respects. First, they are presented

to the responsible individual as opposed to that individual writing a narrative report. Thus, there is less opportunity for bias and rationalizing. Second, in the event of poor performance, the computer report serves to criticize and chastize the individual rather than the project manager having to do it. This saves some credibility and personal relations between the project manager and the individual involved. This is true regardless of how the report is designed. If special attention is given to the design of the report, it can enhance this benefit from CPT. Third, proper design of the report can significantly reduce the length and frequency of project staff meetings. For example, on a major casting plant construction, project staff meetings were held weekly for approximately four hours. After redesign of the report formats, but still using the same CPT system, those meetings were reduced to bi-weekly and were often concluded in two hours. Of course, a strong, knowledgeable project manager contributed significantly by using the reports in the manner implied by their design.

The problems alleged with CPT can be grouped into seven classes. One, it was claimed that there was game-playing in estimating. There is no reason to believe that this was unique to CPT, but rather that CPT made this more evident. Being more evident, there is greater likelihood of taking some corrective action by astute management.

Two, in scheduling, it was claimed that CPT was not responsive to changes in priority and that low priority activities get pushed

back forever. It could be argued that both of these are strengths. The most "responsive" environments are where formal planning is weakest. There is no discipline in the systems, so the "hottest" problem today is the one worked on. Besides, responsiveness to changes in priority is not truly a function of CPT. Rather, it is a responsibility of management to assess priorities and take action. Possibly, after much more development, a higher degree of responsiveness consistent with management's desires may be achieved.

Three, it is often pointed out that CPT ignores the problem of availability of resources as required. This problem is trivial at this time as programs do exist that analyze resource requirements and some that develop schedules considering resource availability. The fact that they are not being used to a great extent suggests that there may still be deficiencies in those programs from a practical application point of view.

Four, in the feedback phase, delays are reported after the fact and without any indication of the cause of the delay. This seems to be a function of the design of the reports and management's approach and persistance in using them. If only completions are reported, their progress will be measured only after the fact. A successful implementation by this writer required reporting start dates and intermediate progress reports on activities as well as completion dates. Consideration has also been given to providing a coded set of causes for delay from which the performer could choose. In the absence of an appropriate code, consideration was given to

providing a short, written explanation which could be entered in the computer and printed on other reports containing that activity. Both of these are feasible and should be included in system design.

Two problems are largely management's responsibility directly. Lack of skill in using a dynamic system can be overcome. Training programs have been or could be developed to overcome this. CAPCONS (1969), a management game for instructional purposes has existed for a number of years. From a different point of view, this may have been, in part at least, a problem inherent in AOA notation. It is alleged that operating people tend to identify activities by abbreviated names and especially with their code names. With AOA, a change in the network often resulted in a new code name, i.e., either a different predecessor or successor event number, or both. Clearly, AON has a distinct advantage in this regard. Dynamics in terms of the identification of the work is not necessary and further inhibits effective application of the system.

Six, some managers seem to think that CPT is automatic. The extent of that problem should be much less now that more people have experienced using some sort of CPT and have become more realistic.

Seven, another claimed problem of CPT was the lack of integration with other management tools. This seems to be a diminishing problem as companies develop their own proprietary systems which are integrated with other systems in their organization. There is also some evidence of integration in commercially available systems. The lack of integration, no doubt led to claims that CPT was costly

in terms of dollars and also in terms of human effort to make it work. The problem still exists for smaller companies.

Program Evaluation and Review Technique (PERT)

The benefits unique to PERT are that it can include uncertainties; as a result, in estimating, a clearer statement of expectancies can be expressed; and also as a result, it is possible to predict probable performance. Clearly, from the analysis of the treatment of uncertainty as discussed in Chapter III, there are alternatives available for the expression and analysis of that uncertainty ranging from triangular distributions, the use of $\pm$ 1.96 standard deviations instead of the current $\pm$ 3.00, and the use of Monte Carlo approaches. Nevertheless, if such approaches have been implemented, they have received no publicity to date.

Problems identified with PERT stem mainly from the underlying assumptions for dealing with uncertainty. Those have been discussed rather thoroughly in Chapter III. On the other hand, it is argued that when consideration is given to the accuracy with which estimates of the dimensions of uncertain activities is known plus some behavioral problems in application, that the reduction in errors available by more sophisticated techniques of analysis are probably not worth the cost. Furthermore, other less costly ways of alerting the project manager to the same problems may be available.

There have been complaints about the cost of PERT specifically. The major cost it seems is in getting three time estimates for each

activity. In those few cases where uncertainty is a major factor, the increased information provided by PERT, as opposed to CPT, would seem to be worth the small additional cost.

Critical Path Method (CPM or CPPS)

The benefits uniquely claimed for CPM include minimizing the "crash everything" syndrome; ability to forecast cost and resource requirements; it reveals inadequacies in methods, skills, and supervision; thus, it tightens up performance; it places an explicit dollar value on change; and it results in improved management of resources.

The only argument with these claims is in the forecast of and improved management of resources. First, no CPM system reviewed explicitly considered any resources other than dollars. Second, none of them provided a resource profile, even in terms of total dollars. Indeed, the fact that it does not consider resource availability was considered a problem.

As compared to the previous techniques, only two problems were attributed to CPM that were related to its design. It was claimed that the report formats were not appropriately designed to meet the users' needs. This probably accounts for the claim that schedules are not monitored or updated. Those CPM systems familiar to this writer were not designed to make feedback or updating easy. The other problem is related to the cost of using CPM because of the four elements of data required. Sometimes historical records are not available. On the other hand, the inaccuracies inherent in

historical records as well as inaccuracies in defining the work content on a new project suggest that a good approximation is all that is required. This is the logic underlying the mathematical model developed in Chapter III. By linking the estimating of costs for bidding and budgeting purposes with data requirements for CPM, the costs of using CPM should be less and the likelihood of use greater.

The other problems with CPM are related to its use in practice. First, it is claimed that the planning is not done by the right people. The organizational arrangements in a construction firm, where CPM has found its greatest use, often result in people other than the project manager and construction superintendent being involved in the planning. As a result, the plan may not be consistent with the way they intend to do the job. Often the major sub-trades are not included for various reasons. As a result, as one writer stated, the network is likely to emphasize excavating and concrete work and exclude the work requiring the most coordination. Finally, it is claimed that there has been a lack of acceptance of decision responsibility by management as to the use of CPM. Again, it is argued here that this may have been a wise decision given the state-of-the-art in the design and implementation of such systems.

Program Evaluation and Review Technique-Cost (PERT/COST)

The claimed benefits of PERT/COST relate better to the stages of managing projects than did the previous techniques. In planning,

it aids conceptually by relating costs to tasks. This actually permeates the entire system. Examination of traditional approaches to project planning and monitoring revealed that there was seldom any relationship between the way that finance measured costs and project management measured progress. Thus, it was impossible to relate these two measures. If nothing else, PERT/COST has introduced the philosophy that these two measures can be related. For the first time, finance, project planning and engineering, and project field personnel can talk the same language.

In scheduling, it highlights the relationship between time and cost and permits assessment of cash flow requirements vis-a-vis financial planning. With cost and time included, it is easier to make comparisons between contractors bidding on the same work.

Control is improved because PERT/COST permits better overall appraisal of progress since cost and work are defined on the same entities. Evaluation of progress can be accomplished from multiple sources of information on a single set of reports. Potential cost overruns may be revealed as a result. Furthermore, if the system design is adequate, invoicing of progress payments is much more timely resulting in a reduction of cash outstanding. From the clients point of view, using "value earned" concepts provides greater assurance that the invoice is based on actual accomplishments.

The problems attributed to PERT/COST are much more numerous. They start with broad complaints that the cost is too high (estimates of 5% of project cost have been reported), and include accusations of

reports being as much as two months late. Both of these can be traced to the fact that, at least in early applications, PERT/COST was not integrated with other management systems but, in fact, supplemented them. Some firms felt they should be paid to use PERT/COST and on a few of the earliest applications they were. Those were test applications, however, and after that contractors felt there was no profit incentive to using it. It is likely that, had it been well integrated with the other systems, replacing reports that would no longer have been needed, the cost of using it would have been low enough to create a favorable cost-benefit ratio. This assertion seems to be supported by the evidence of 146 different management systems having been validated by DOD under the C/SCSC criteria. While C/SCSC does not require PERT/COST, it does require a system with essentially the features intended to be available with the implementation of PERT/COST.

Most of the problems with PERT/COST seem to originate in conflicts with the traditional accounting systems. These conflicts, as reported, exist with regard to project budgets versus annual budgets; treatment of overhead, joint costs, and organizational cost flows; financial stewardship; and other project and fiscal practices. The latter include the reconciling of PERT/COST accounting versus functional cost accounting, treatment of work-in-process, and too gross of assumptions about labor application rates. Hill (1966) and Schoderbeck (1966) provide some additional details, most of which are related to the above points. It is clear that the PERT/COST

concept or C/SCSC requires a more sophisticated accounting system, and will be even more useful when a good data base of historical costs are accumulated on which to base estimates.

There have been other alleged complaints with PERT/COST. Its reports are not capable of penetrating the technical problems of a project. It would appear that these problems can be assessed and corrected only by personal contact with the individuals involved. Indeed, contrary to what much of the literature would suggest, those most experienced with managing projects seem to rely on their informal contracts and sources of information to determine on a current basis what is actually happening technically. They consider the formal system as more of a back-up than as their primary source of information. This should say something about system design.

There is also a conflict inherent in a system which purports to operate on the management-by-exception principle that relies on the performers for the information by which they are to be judged. In mass production, this problem has been well recognized leading to automatic counting devices or production counts being reported by inspectors. Similar devices could be used on projects such as construction. It would be more difficult on projects with less tangible products such as R & D.

Lack of availability of personnel and computer capacity has often been a problem. On the other hand, the capability of computers to generate output fast has lead to excessive reports. Unfortunately,

many of those reports have been unimaginative in design and have, therefore, not been well suited to the needs of the user. For minor savings of computer or printer time, the systems have failed to be truly useful. The computer and systematic nature of PERT/COST tended to lead to an apparent sense of precision which probably was not justified.

Again, much of the blame for problems can be placed with management. They have prorated implementation costs in an illogical manner; underestimated jobs, relying on change orders and extensions to make the job profitable; "boilerhoused" PERT/COST to make it conform to the results from traditional internal systems; refused to decentralize planning and scheduling to the performing organization; and refused to divulge internal cost data. Of course, some of these problems can also be traced back to the customer, often the Federal Government. Often private businesses recognize the workings of competition, and are willing to permit a vendor to make a profit if he performs a valued service. Too often government agencies and employees, in the interests of protecting the public coffers, are over-zealous in seeking to eliminate all but the minimum profit by the contractor. This has undoubtedly led to some of the behaviors of the contractor management described above.

These same behaviors and constraints often lead employees to indifferent attitudes in allocating indirect costs and the manipulation of accounts to minimize the differences between estimated budget and actual expenditures. The results of these practices are than used in the bidding on the next projects.

Finally, the more explicit and detailed identification of estimate and costs in the use of PERT/COST has led to greater visibility of conflicting philosophies. Sometimes the estimates are treated as estimates, sometimes as targets, and sometimes as commitments. They could be treated as either so long as there is consistency. It seems quite reasonable that a person, not conditioned by past experience, would respond to a request for an estimate with a more optimistic appraisal than if asked for a commitment. In general, the word commitment carries a connotation of the exercise of sanctions in the event of failure to achieve the commitment. Requesting an estimate and using it as a commitment must surely lead to anxieties on the part of the performer. Future behavior will tend to reduce those anxieties by "padding" the estimate. This has been discussed earlier. It seems that there have been such conflicts of philosophy inherent in the literature of project management. There has not been a clear distinction between operating with an estimate philosophy versus operating with a strict commitment philosophy. Thus, practitioners having no clear guidelines for these two philosophies tend not to distinguish between them. It seems that a worthwhile contribution could be made by research which recognizes that there are circumstances which warrant different management philosophies and provides guides for operations as well as system design which would optimize performance under each philosophy. Perhaps these are two polar philosophies and there are intermediate positions, or other poles, which require similar treatment.

Resource Leveling

Resource leveling has not been the subject of serious consideration of benefits and problems as have the above techniques. The evidence that it is not used extensively by the very people who complain about the existence of the problems it is designed to solve, suggests that there are some serious shortcomings in the techniques or the systems in which they are implemented. While considerable research has been done on the resource leveling problem, it seems that the real potential is still on the horizon. The examination of the relationship between problem structure and heuristic performance by Patterson (1976) seems to be one key. Considerable experience with networks on both assembly line balancing and project resource leveling, has led this writer to the conviction that the information content of the problem has not been tapped to date.

An article published in the early 1960's* (author unknown) discussed a concept of upper and lower envelopes of resource requirements. The upper envelope is constructed by converting the duration of activities to the sum of the duration plus the (positive) slack on the activity. The upper envelope portrays the maximum of the resource that can possibly be used in each time period. The lower envelope is constructed by assuming the duration of the activity to be zero if the slack is equal to or greater than the actual duration or, if the slack is less than the duration, the time period

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*Considerable effort to locate the article was to no avail; therefore, at this time, the author is unknown.

between the latest start and the earliest finish. The lower envelope portrays the minimum amount of a resource that is absolutely necessary in each time period. Any resource leveling procedure must develop a solution between these two envelopes.

In using this concept, this writer has added the average resource requirement which can then be adjusted upward to account for periods in which the upper envelope goes below the average. The result is a realistic "trigger" level for the resource that varies by time period which can be used as a starting point to determine the minimum peak resource requirement for a heuristic routine to achieve a time constrained schedule.

There are other measures which give some indication of the character of a network. Kaimann's (1975) "Coefficient of Network Complexity" gives a measure of the complexity of the network. The ranking of a network as used in topological sorting of the activities can be used in this manner. The rank may be obtained by performing the early calculations assuming the duration of each activity to be one, and the start of the project to be zero. Thus, all activities having no predecessors will have a rank of one. The highest rank will be equal to the number of activities in the longest sequence of activities in the network. Performing the same process using the late calculation routine, gives a backward rank. The difference between these is a measure of the flexibility of the network. This flexibility can also be measured by plotting the frequency distribution of the forward ranks. One configuration which often occurs in R & D, a series of sets of activities connected by single decision

nodes, will be readily identified quantitatively as well as visually because the decisions nodes will be the only activity with that rank. This would be a signal that each set could be considered independently for leveling, much like the horizon problem of aggregate production scheduling.

A frequency distribution of the magnitudes of resource requirements by activity provides information about the relative ease of leveling. Clearly, a network in which all resource requirements are one per activity can be leveled to a maximum of ten units of resource with greater ease than a network where many of the activities have resource requirements in excess of five per activity. If this is done by rank at the same time, valuable information can be gained as to the possibility of getting an efficient schedule.

While the emphasis in this discussion has been on leveling in general, that is not the only approach for effectively utilizing resources. For example, there may be a piece of equipment or a crew which is required for a portion of a project. The costs associated with this resource may best be minimized by assuring that all activities requiring that resource are scheduled contiguously. Thus, an analysis of such requirements could lead to a resource "chain" which would then be considered as a whole unit in subsequent resource analysis. In addition, a comprehensive resource analysis capability should provide a means for considering other management objectives as discussed in the prior chapter. A capability to assign priorities on the basis of cost of the activity, on activities

that must be performed in the open (as opposed to protected from the weather), or to activities which involve high levels of risk or uncertainty should be provided. Objective criteria to judge the resulting schedules must be provided in addition to the relative levelness of the resource profile. Such capabilities are not discussed in the literature that was reviewed.

Another problem associated with resource management with which project management must deal is the decision as to what level of resources are actually to be hired as opposed to other alternatives for augmenting the resources. For example, peak resource requirements may be provided by working existing personnel overtime, by hiring temporary help, or by increasing the level of regular employees. Resources available in the valleys can be utilized on non-critical activities, if these have been properly planned for, or to augment activities which would tend to modify the resource requirements profile. For example, this writer has, on several oocasions, spent time removing nails from used lumber, cleaning up an area, or moving materials in preparation for a future activity as a way of productively using the resource available in the time of a valley in resource requirements. On other occasions, the same objective was achieved by joining another crew for the day, and thus reducing the duration of their activity. On still other occasions, the situation was converted into a learning opportunity for the extra person or the person they replaced on a crew.

Finally, the objective functions of existing systems are quite limited. Basically, they are to minimize the peak resource

requirements necessary to meet a specific target date or achieve the earliest completion date subject to maximum resource constraints. Another objective function which seems relevant to many project contractors, is to achieve the most economical balance between resource level and project completion time. Sometimes it is relatively inexpensive to augment regular resources for a short period of time through temporary employment agencies or the like. Overtime for short periods may relieve critical peaks in such a way as to enhance overall performance. Most importantly, the determination of how to use all available resources to their maximum in each time period is essential. Payment for resources which are not utilized effectively can increase the cost of a project dramatically. This can be approached at two levels. In planning and scheduling, careful attention can be given to recognizing activities which can be done in a broad range of time periods, i.e., are not tightly constrained by technological precedence. Secondly, a proper dispatching capability can assist the project manager in responding to the labor circumstances as they exist each day. Conversations with construction superintendents revealed that this is one of their major activities at the beginning of a shift. Frequently, the actual number of workers reporting is different than planned. Work crews on some activities must be augmented before they can proceed. Thus, other activities must be stopped for the day. Delays in making these decisions results in non-productive time by all workers involved. It is contended here that, not only are

provisions for the dispatching problem not extant in current project management information and control systems, with the possible exception of some features of this type in DART, but the dispatching problem is not even well understood.

Line-of-Balance (LOB)

There seem to be five major deficiencies in the basic LOB technique; other than those previously mentioned. First, although learning curve concepts can be incorporated in the contract schedule, there may be different learning curves applicable to the various operations. Thus, the actual lead times may diminish as a function of volume produced. Since the technique is applicable to low volume production as is common in development projects, the impact of the learning curve is often substantial over the full range of the contract. For example, for an 80% learning curve, the direct labor man-hours for the 100th unit is approximately 22.7% of that for the first unit and still decreasing by about 0.3% per unit (see Chase and Acquilano, 1977, p. 527). Also, the processing lead time should be much less than for the first unit. The article by Levitt (1968) mentions the planned incorporation of this feature, but there was no later mention in the literature of its actual application.

Second, there is no recognition of Economic Order Quantity (EOQ) concepts in the basic technique. Explanations of the evaluation process simply point out that a status bar above the line of balance is ahead of schedule. One reason for this is that set-up costs, etc., may be such as to dictate production in quantities greater than one

period's requirements. While EOQ should be incorporated, a risk analysis concept should be related to this evaluation process to avoid producing a full EOQ if there is an appreciable probability of design change, a common phenomena in development projects.

Third, there is no recognition of scrap allowances. An assembly with items having relatively long lead times and expected to incur some scrappage could create serious delivery problems for the end item. Some provision incorporating this would seem desirable.

Fourth, the only recognition of plant loading is the ratio of the lead time for a process step to the actual processing time. For example, machining a part might take one day. The lead time for that process step might be shown as two weeks in order to provide flexibility for scheduling the job on the machine. For the technique to be an effective aid in operations as opposed to analysis, some provision is required to relate the operation time to the machine loading, and the priority of the specific job to the priorities of all other jobs in that machine's queue.

Finally, LOB has a single focus on the specific contract or project. This would be adequate for a single contract organization. It could be very dysfunctional to the multi-contract organization if it caused attention to be directed on one contract to the exclusion of all others. It could cause the others to be late or could result in low efficiency in utilization of resources.

The above discussion of LOB detailed the problems with it. It would seem relatively easy to incorporate the additional features

into a computerized version of the concept. However, before this is done, it would seem wise to conduct a study to establish that a need for such a capability actually exists. Very little has appeared in the literature since the reports of plans to develop more sophisticated capabilities of this type.

Daily Automatic Rescheduling Technique (DART)

While this is a unique implementation as opposed to a classification of techniques, it is included at this point to emphasize the need to service the dispatching problems of a project. While only limited detail is available on DART, the daily calculations and preparation of reports indicates a sensitivity to the uncertainties inherent in the execution of a project plan. It would seem that research into the nature of the dispatching problem would be appropriate to assist in the design of such a capability.

From the above discussion of some of the claimed benefits and alleged problems with these techniques, some conclusions were drawn which required further consideration.

First, there is a need for better understanding of the various philosophies of managing projects, so appropriate guidelines can be provided practitioners and system designs can be made consistent with these guidelines.

Second, there is a need for better understanding of the objective functions available in existing techniques and required by product management so the gaps between these can be filled.

Third, evaluations of various techniques and systems are too general and not related to types of projects, phases of projects, or of the management. This seems essential if the correct techniques are to be chosen for a specific project.

Finally, there is a need for the integration of the best features from each of the techniques, including AON notation if it is indeed the better, along with other features which apparently have not been incorporated in a single system to date.

Other Considerations

Philosophies of Managing Projects

While this is not addressed specifically in the literature, there do seem to be significantly different philosophies. The most obvious aspect of this is leadership style. Next most obvious, perhaps, is the difference in treating the specification of activity dimensions as estimates, targets or commitments. There are surely other aspects to management philosophies in this regard. It does not seem logical that the same system design and guidance for use would be applicable over the range of possible philosophies, even if it is only on the two criteria above. Inconsistencies in philosophies of managing projects would seem to negate many of the benefits of some of the techniques even though they were best suited to the project in other respects.

It would seem that research would be appropriate to delineate the differences in philosophy and attempt to identify differences in system design and implementation appropriate for each philosophy.

As a part of such a study, attention should be given to the alternative ways of maintaining discipline in the system to assure accurate reporting of progress and status. Some of these alternatives are very close supervision, auditing using sampling procedures, elimination of negative incentives associated with reporting the facts honestly, and provision of positive incentives of either a direct nature or in the budgeting process for the coming period. There are surely others. Each of them has advantages and disadvantages. They all have certain costs in application. These all need to be better understood and documented.

Objective Functions of Techniques

It was demonstrated in Chapter IV that the objectives which may be important on a project are various and dynamic. Basically, the objective functions of the various techniques are few and static. Table V-3 Objective Functions of Techniques, presents most of the objective functions used in techniques at this time and some that might also be of value.

Minimizing project completion time is the basic objective function of CPT. It is based on analysis of the critical path and replanning of that work necessary to reduce the duration of the critical path. Assuring meeting a project completion date is similar although the target date may be before or after the early finish date thus requiring, or permitting, adjustments to schedules for activities on the critical path.

TABLE V-3.--Objective Functions of Techniques.

Extant
Minimize Project Completion Time
Assure Meeting a Project Completion Date
Minimize Project Cost by Time/Cost Trade-Off
Minimize Project Cost Including External Costs
Minimize Probability of Late Completion Subject to Dollar Limits
Minimize Resource Fluctuation Subject to Resource Limits
Minimize Resource Fluctuation Subject to a Time Constraint
Minimize Time and Budget Overrun
Possible
Maximize Utilization of Required Resources
Minimize Idle Resources
Balance Resource Application Rates for Various Crews
Maximize Dispatching Flexibility
Minimize Activity Interruption
Minimize Cost of Capital Tied Up
Maximize Cash Flow
Maximize The Present Value of the Project
Minimize Total Project Cost.

Miminizing project cost by time/cost trade-off is the objective function of CPM or CPPS. It only considers part of the resource costs, i.e., those directly associated with the activity. It ignores the costs of fluctuating resource requirements for the project. It ignores costs external to the project but internal to the organization such as overhead, interest costs, and the like. Some external costs may be combined with the CPM results to minimize total project costs. This was the intent of CPM.

Maximizing the probability of late completion subject to dollar limits is essentially the objective function of the Bildson and Gillespie (1962) combination of PERT and CPM. It could be stated

differently considering that the dollar limit may be based on a decision concerning the marginal cost of increased assurance.

Minimize resource fluctuation is the basic objective function of most resource leveling techniques. The alternative is "subject to a time constraint." Finally, PERT/COST's objective function could be stated as minimize time and budget overruns.

There are other possible objective functions listed. Maximizing utilization of required resources implies such things as collecting sub-sets of activities requiring the same resource so the resource can be used to its maximum while on the job. This is often done for high cost equipment or consultants. Minimizing idle resources implies adjusting crew size, etc., on activities to utilize resources available during valleys in the resource profile. The mathematical model developed in Chapter III would assist in this.

Balancing resource application rates for various crews would be particularly applicable on a multi-unit project such as an apartment or office building. Various crews are moving from one area or floor to the next. The time required for each crew to complete their work should be as nearly equal as possible.

Maximizing dispatching flexibility could be important where weather or not breakdowns were a factor. It would tend to promote maximizing utilization of resources. Minimizing activity interruption, particularly in a maintenance-type environment, might require some reserve resources to respond to emergencies.

Minimizing cost of capital tied up might lead to time/cost trade-off, but also might include installing expensive equipment or

performing high-cost labor-intensive activities as late as possible. Maximizing cash flow might lead to the opposite behavior if the holdback on a contract were such as to permit invoicing costs and fees in excess of cash expenditures to date.

Doersch and Patterson (1977) offered a program with another objective function, the maximization of the present value of a project. It considered the cash flows inherent in the project plan and allocated slack in accordance with the typical present value concepts. While it purportedly exists as a program it is not generally available.

Minimizing total project costs could be a very complex objective function to the extent that it included several of the above. If each of the others can be achieved, it seems reasonable that this one could eventually be achieved.

In addition to the objective functions of the techniques employed, there are some potential objectives of the planning process. There have been reports of projects being completed before the project plan was completed. Clearly the time objective of the planning stage was exceeded, if it ever existed. Thus, one objective is timely completion of the planning process. Another objective may be to minimize the costs of planning and scheduling. This may preclude considering certain approaches or techniques. Third, there is a quality dimension. Included in this should be congruency between the formal plan and the way the job is actually to be done. Completeness in terms of having all activities included and meaningful descriptions of the activities is also an important aspect of quality. Risk is a dimension. The contractor who asphalted the construction

site to avoid mud delays in the spring might have taken the risk that the spring would be dry. A plan may lack adequate quality assurance activities such as checking the welds in a pipeline. Another dimension is flexibility. A plan may so commit the organization to a single approach as to preclude alternatives in the event the original plan is not successful.

Clearly, these dimensions are not all mutually compatible. A short time target may not be the least costly. Higher quality and lower risk increase the cost of the project and the cost of the planning. Flexibility may be available only by starting on alternative approaches to a particular problem and abandoning all but one. This could be costly. A more thorough understanding of potential objectives, conflicts between them, and how they might be implemented in a technique would seem important.

Selection of a Technique

Jennett (1972) characterized the importance of determining the appropriate technique to meet the purposes and characteristics of the specific project. However, he only distinguished between PERT and CPM. As has been shown, there are a number of other techniques. Their unique values and deficiencies must also be understood. One way to distinguish between the techniques is as to their applicability to differentiate types of projects. The problems of managing basic research are significantly different than for building a standard house. The uncertainties involved, whether as to activity dimensions or occurrence or other types, would suggest different

capabilities in the techniques and systems. Likewise, the appropriate technique is likely dependent on the relative priorities of the three basic dimensions of a project.

In a similar manner, the type of technique varies as a function of the phase of the project. It may be that the nature of the conceptual phase of a project, i.e., the organic organizational characteristics, the close communication, etc., would make a matrix worksheet or a spread sheet more appropriate than networking per se. That is not to say that the work could not be described as activities, but it may be desirable to emphasize the lack of specific, yet pervasiveness of general, relationships between the various items being worked upon. For example, the weight of the armament and instrumentation on an airplane determines the size of engine for certain specified performance which in turn reflects on the airframe design and weight which gets back to engine size.

In the planning phase, a network based system using an "estimate" philosophy may be more appropriate. In the execution phase, a network based system using more of a commitment philosophy may be needed. Finally, in the termination phase, the inclusion of a punch list capability may be essential.

In a comparable manner, the stages of the management process have different characteristics upon which evaluation of a technique should be based. This can be illustrated using the phases as shown in Figure IV-2, stages in Managing Projects.

The first two stages are probably better managed with a technique other than the usual network based CPT. Possibly nothing

more than a statement of required decisions and a time line would suffice. To make the time line seem more realistic, it might be appropriate to have a very general network of the subsequent work to be accomplished after the purpose is identified and the objectives and strategy are specified.

The characteristics important in the planning stage include speed with which the plan can be formalized and the extent of commitment to the plan that is achieved. Using AOA, it appears that a team of about five people can generate about ten activities per hour or two activities per man hour. Using AON, the author has achieved about five activities per man hour on a 2000 activity network. This was achieved by recording the data in computer input form initially and using a plotter to draw the network. Thus, a minimum amount of time was required of key project team members. An essential step which was not accomplished in this process was a verification meeting of all members of the project team to reinforce the commitment to the plan. This could have easily been accomplished and would have encouraged team members to review their parts of the network more thoroughly.

Estimating is often done after the network is drawn. It should be done on a form which facilitates input to the computer. In the example cited above using AON, estimates were obtained at the same time the activities were defined.

Computer time is generally one of the smaller costs associated with network based techniques yet receives the most scrutiny. The

type of computer program depends on the characteristics of the project and organizational environment. If the project is very large, computational efficiency may be significant. If it is a multi-project environment, ability to interface separate networks may be important.

Analyzing the results of computation must consider at least three aspects. First, it should be relatively easy to check the logic of the network. Second, attention should be focused on problem areas with information presented in a manner conducive to analysis. Third, the changes resulting from that analysis should be easy for the planner to note and get into the computer.

Scheduling depends greatly on the objective functions appropriate to the project. Man-machine interaction at a computer terminal may be essential if the overall volume of input data is to be kept to a minimum.

Effective dispatching requires an adequate display of information plus knowledge of actual employee attendance early in the shift to permit quick decisions and adjustment of daily work plans.

Performance of the work is enhanced by an adequate report format that encourages both quality and timely execution of the work. That same report should provide a simple means of recording status of the activity, i.e., started, completed, or in-process. Measurement of performance, if the activity is in process, should focus on what has to be done to complete the activity rather than on what has been accomplished.

Feedback should include consideration of getting the status or progress information into the computer and incorporating it into

reports prepared to enhance the evaluation process. This was achieved outside the computer on the casting plant where staff meeting time was reduced by 75%.

The reports prepared for evaluation must focus attention on the problems that need to be resolved to achieve technical objectives in a timely manner. If this is accomplished, the control phase will quickly direct attention to the proper corrective action. These reports should also show the positive aspects of performance to promote participant motivation.

Since projects seldom proceed exactly as planned, it is also important that the technique be evaluated with regard to the needs of the various types of corrective action. Expediting requires a worksheet emphasizing only those items requiring expediting. Similarly, re-dispatching, since it must be done quickly and does not involve changing the schedule, would generally be done off of a daily work sheet or on-line at the terminal.

Re-scheduling should certainly provide for restricting activities in process from being moved as well as certain activities for which costs would be incurred if schedules were changed. Analysis of the results of the re-scheduling should be presented for comparison of the new schedule with the previous and/or original schedules and approval, if satisfactory. Re-scheduling should be permitted in a simple fashion, but controlled to insure the validity of the change. Re-planning should also be easy, but controlled to prevent unauthorized changes.

These features are not intended to be exhaustive but to suggest the level of evaluation that should be made with regard to the various techniques. In addition, there are technical computer considerations such as adequate file backup, audit trail for changes, and re-start capabilities. A more detailed study of the actual application of the techniques should identify the characteristics important in each phase and provide a much more effective evaluation procedure.

In addition, evaluation on this basis would be more likely to identify all the costs associated with planning and execution than is presently documented.

Features in a System

Two references are cited which classified the features available in the various techniques and some of the systems within which they are implemented. They are included as Appendices C and D. One of those (Jennett, 1972) provides an evaluation of the various features as a function of the graphical notation. Unfortunately, the evaluations are in error or misleading. Many of the features which are evaluated negatively for AON had either been implemented by the date of the article by the author or have been worked out in considerable detail for future implementation. Note that the column headed "Activity on Node (PERT)" would be "Event on Node (PERT)" for the current study. A few of the items evaluated which lead to erroneous conclusions with regard to the Precedence (AON) Method are shown in Table V-4, Analysis of Features in Project Management

TABLE V-4.--Analysis of Features in Project Management Systems.

Item	Evaluation
Emphasis on Events and Event Times	Doesn't Really Exist
-Can be achieved by identifying a node with an event name and assigning zero duration. Thus with AON, activities and events can be intermixed. With appropriate programming, these could be identified as milestone and a separate report printed for top level review.	
Subnetting Concept Permitted/Used	No
-Is easy by simply naming an activity in another sub-net as a follower. No interface events are required.	
Milestones	By Gimmicks
-But easy.	
Skeletonizing	Difficult to Impossible
-Can do on milestones with ease.	
Ability to Follow Float Paths	Difficult
-Same as for AOA if using float sort and program designed to print critical follower first.	
Ease of "banding" diagram by area, type or responsibility for work.	Low
-Same as AOA	
Ease of Manual Calculation	Low
-No different than AOA. May be easier.	
Multiple Time Estimates	No
-Can be without trouble	
Variable Data Dates Different Inputs	Not Accepted--Really
-Have done it	
Intermediate Schedule Dates	Not Generally
-Have done it	
Interfacing/Integration with Cost or Other Existing Systems	Possible, but can be Difficult
-Is easy due to integrity of activity coding.	
Multiple Starts and Ends	Some
-Easy	

Systems. The items from Appendix C are shown with only the comment by Jennett with regards to the AON notation. Below each of these is the author's comments to indicate the real potential for improving the features in an AON based system design.

There are a number of other items which are not properly evaluated. This points up the need for a more objective and complete evaluation of features of techniques relative to the graphic notation as well as evaluation of the implementation of the features. For example, some systems have extensive multi-project network interfacing capabilities. The actual utilization of them requires considerable skill and effort. Another type of evaluation would be the worth of each feature in terms of the frequency of occurrence of the problem for which it is relevant. Some features may look nice in the specifications but do nothing but add to the complexity of the system.

Some Considerations in the Design of Systems

There are some other features which should be considered in the design of an effective system. Caspe (1977, p. 46) suggested that no more than one hour per report period should be required for the supervisor to provide the information required by the management information system. While his admonition is appropriate, there are two things that should be considered in this respect. First, the statement could be considered to imply only the time required to use a CPT type system. If this is true, one hour might be appropriate. On the other hand, if a careful analysis were made of all the

administrative work done by the various supervisors, it may well exceed one hour per week per supervisor. What is needed is a careful analysis of the administrative requirements, as well as the planning and other such activities a supervisor performs on a regular basis. Then, a reasonable goal might be to reduce that time by design of the report form to make it a working tool for the supervisor, to integrate all possible reporting requirements into a single or a few closely-related documents, and to design the form to minimize the writing required to provide the essential information. Also, the supervisor may want to keep a copy to aid in answering questions in the future.

Some of the approaches for accomplishing this would include:

1. Print the form on 8 1/2" x 11" paper so it easily fits in a ring binder or on a clipboard. All supervisors could be provided with the same type of clipboard with any memory aids appropriate. The supervisors should approve of the clipboard.

2. Require only a "Y" (yes) or "N" (no) response normally, and explanations only if an out-of-line condition exists.

3. Print out a labor-time distribution sheet with names of workers assigned to that supervisor, and the codes for the activities on which they should be working preprinted. It is argued here that the only relevant entity to which the first-line supervisor should distribute costs is the activity. If accounting, with agreement of the project manager, chooses to accumulate costs to a higher level, that should be their responsibility and should be accomplished by

them providing a table to map activities to cost accounts. Adopting such a policy would reduce the quantity of account numbers, codes and the like with which the supervisor would have to be concerned. More importantly, it would reinforce the importance of the network and activities as the basic working tool of the project team.

4. Provide any other information about the activity which will aid in its execution such as the planned resource allocation, materials and equipment required, and drawing reference numbers as appropriate; and

5. Every computer listing should be designed specifically to be a working document for someone. Clearly, there is a difference in the utility to various report users between multiple sorts of the same data as opposed to providing multiple formats and careful selection of items to include on the report based on the specific needs of the individual.

These suggested items exceed the present capabilities of most systems, but are all feasible. A study of the supervisors present activities might show that these steps would reduce the time the supervisors have to spend on administrative chores, and therefore show them to be economically feasible if not desirable.

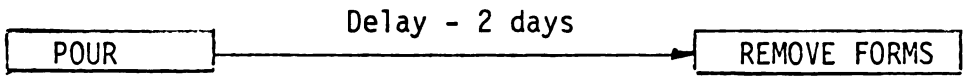
One functional area where a study of this kind would seem of value is purchasing. A careful analysis should be made of their needs to aid them in properly supporting a project effort. For example, most purchasing follow-up reports are of the "spread sheet" format. All of the activities or events associated with a single

item are shown on the same line. Careful integration of a materials management capability into a project management information system would facilitate providing purchasing with reports which are much more useful for placement and follow-up of purchase orders. It would also seem desirable to create a "partitioning," in effect, of purchasing from the rest of the CPT activities. Purchasing must obtain commitments from suppliers, often many months in advance of desired delivery. The conventional reports prepared by a CPT system are likely to show frequent changes to the dates the material is required as a result of perturbations to the network schedule. These changes could be very disconcerting to the purchasing function for they would not know whether they should seek revised commitment dates or not. It would seem much more functional to provide a purchasing/project interface report which analyzes the discrepancies and only allows those through the partition which the project manager desires purchasing to act upon. Similarly, purchasing tends to buy on a commodity basis. A number of activities may require similar materials. Instead of providing purchasing a listing of the materials required for each activity, the listing should be by material, and show those activities requiring that material. This would enhance the buying power of purchasing. It is conceivable that this could also be implemented on a multi-project basis for further advantages in negotiating purchasing terms.

There are some other detail decisions that must be made in the design of an effective project management system. Three of

these will be discussed here--the calendar, cost extrapolation, and overhead costs.

The difficulty in the calendar decision is best illustrated by the set of activities associated with pouring concrete. Using AON notation, it might be shown as:



The delay of two days is cure time. If the time-to-date conversion is based on calendar days, the two days may be two, one, or no working days, depending on where the weekend falls. If the time-to-date conversion is based on working days, the delay would always be two work days. This poses some potential problems with computation of early and late times, and with detail scheduling. Depending on the degree of "accuracy" required in scheduling, it could be necessary to perform the computations against the calendar, as opposed to the usual mapping to the calendar after the early and late calculations have been performed. A reasonable compromise in this regard would be to perform the scheduling computations and then map to a calendar and perform the dispatching calculations directly against the calendar for a very limited time into the future. If this were to be done, it suggests a whole new set of procedures and priorities for dispatching. For example, concrete pours of one day duration occurring no more than once a week should be dispatched for Friday, or perhaps Thursday, to utilize the weekend for curing and permit

removal of forms to start on Monday. Starts of major activities might be dispatched for Mondays. To some extent it might be desirable to dispatch activities so they will be completed by week's end. Scheduling starts on Mondays would permit changes in resource level to be coordinated by weeks. Scheduling completion at week's end permits resource reductions at the end of the week. It also provides an identifiable point in time to target activity completions. Personal experience suggests that it is easier to persuade people to work a little harder to achieve a specific accomplishment by Friday evening than it is by some less tangible target. Also, if the start of certain activities on Monday morning is dependent upon completion of certain predecessors on Friday, there are two intervening days during which overtime could be worked to maintain schedule. Care must be exercised with this, lest the motivation should work in reverse to assure overtime pay. The essential point is that some details on time-to-date conversions have implications on the scheduling dispatching procedures.

The second detail system design consideration is how to extrapolate cost and time deviations to project completion. There seems to be at least five different assumptions which would affect this calculation. First, it could be assumed that all future activities will be performed as estimated in which case the forecast at completion would be the same as the current deviations. Second, the deviations could be assumed to be proportional to the deviations to date based on percentage of time or cost expended relative to the

original plan. Third, the rate of deviation for extrapolation could be assumed to be the rate of deviation in the most recent report period. This would be the most volatile. Fourth, some sort of average rate of deviation, perhaps using exponentially weighted smoothing, could be assumed. A fifth approach could be based on a required reassessment of all activities for both duration and cost. Each of these has some pros and cons. It is not clear which one, or ones, should be used. Clearly, the fifth approach would be most valid, but also the most costly in terms of management time as well as dollars. The others would be less expensive, but give widely differing results. It would seem relevant to research the patterns of overrun behavior to determine the actual behavior of projects in this regard, the effectiveness of certain types of corrective actions, and the criteria by which the appropriate approach should be selected.

The handling of overhead costs has been difficult in conventional CPT systems. The nature of overhead costs is that they continue at some rate from the beginning of a project to the end of the project. Some may start and stop at certain intermediate points, but the concept is the same. The longer the project, the greater the costs. One solution to this is to define an overhead activity which is treated differently than the others. Its duration would be calculated based on the first activity which triggers its start, and the last activity which triggers its cessation. If such a capability were provided, it would not only solve the problem of

incorporating costs that behave in this manner, but would make those costs a function of other decisions. For example, it could be part of the time-cost trade-off procedure of CPM. It could also be used in evaluating alternative schedules resulting from a resource leveling application. Use of more than one could recognize the variety of costs associated with a project which are a function of the duration of other activities.

Another area of potentially fruitful research would be to determine the types of decision aids which would be of value to the project manager. The management sciences have generated some powerful tools, few of which have actually been incorporated in or related to CPT systems. Due to the often long time delays in adapting a management science solution technique and applying it, the answers would not be available in a timely fashion unless the capability were already provided.

Exception reporting was mentioned in the review of behavioral considerations. Exception reporting in a CPT context generally implies that the exceptions are negative, i.e., failure to meet a schedule date, low labor utilization, inadequate technical performance, or exceeding budget. Butler and Jaffee (1974) showed that negative feedback increased negative social-emotional behavior and decreased the efforts of the leader to use participative techniques. On the other hand, positive feedback made the leaders more task-oriented. The possible consequences of feedback from existing CPT systems seems obvious. This could be changed. Human relations precepts with regard to performance reviews advises starting with positive

comments on which superior and subordinate can both agree. This seems to be wise advice in the design of a project management system. It would be easy, for example, to provide the project manager with a summary, by person responsible, of activities completed early, on time, in less than the estimated duration, using less resources than estimated, and possibly, if provision were made for feedback on that dimension, of activities meeting or exceeding technical performance requirements. Properly prepared, a few personal notes could be added by the project manager and distribution made to all members of the project team. This would surely enhance relations with functional managers.

Closely associated with this, the approach taken in dealing with the negative performance of activities could have significant effect on motivation. An antecdote is recalled of a new plant manager's efforts at improving housekeeping in the plant. When a material container was found astraddle the new yellow line marking the aisle ways, he purportedly asked the foreman of that department, "Did we put the yellow line in the wrong place?" The subtlety of the comment apparently did not elicit bad feelings toward the plant manager, but rather left the foreman with a determination that he would do what he knew he was capable of doing. Leadership and climate theory indicate that supportiveness is a key element in eliciting high levels of performance. It seems that care in design of the project management system can assist the project manager in this regard.

In one system implementation which met with considerable success, the basic working document included a brief statement as to the status of the activity to assist the responsible individual in interpreting the data. A summary report was prepared for the project manager listing all activities categorized by the type of message sequenced from the most serious first to the least serious. Those messages were not designed with the precepts of leadership and climate in mind. There is no reason why they could not be. If they were, they could be positive motivators.

Closely related to this is the role the management system can play vis-a-vis the project manager. If the project manager does nothing but dwell on the negative, in addition to the negative social-emotional behavior, he is likely to build a negative balance of "favors." Consider the findings of Gemmill and Thamhain (1973) that future work assignment and friendship were two important factors in the minds of interface personnel. Personal experience suggests that these are intertwined. People like working for a reasonable person. Therefore, they are likely to perform well on his work and, in turn, receive further work assignments. A distinctly unfriendly, untrustworthy, or unfair project manager is not likely to elicit the same degree of cooperation. One way to avoid some of the ineviatable unpleasantness is by transferring it to another entity, in this case the management system. This was done on a casting plant project by coding the activities one through four. A "four" meant an activity had not started on its schedule start date while a "three" was an activity in process which had not been

completed on its scheduled completion date. All reports were issued to an individual, not an organizational unit. The project manager and the author were astonished at the intensity of effort of all participants to avoid having fours on their reports, and to only a slightly lesser extent to avoid having threes. The result of this was that the report was telling them, and everyone else, when they were not getting the job done. Any ill-feelings were directed at the report and ultimately to themselves, not at the project manager. This permitted the project manager to be supportive of them when appropriate. The level of motivation and effort on that project exceeded all reasonable expectations.

This same concept was used on a later system implementation. Unfortunately, there was no opportunity to observe it in operation in the same sense. Even so, advantage was not taken of the ability of the computer to summarize both positive and negative performances in score sheet fashion. Additional design effort could achieve even better results in this regard.

Another related aspect of system design, taking into consideration certain behavioral concepts, is the determination of what an individual can be expected to report upon in terms of measuring progress or status. Mention was made earlier that the measurement of performance upon which the performer may be judged for promotion, salary, and even continued employment is provided by that person. Hardly an unbiased measurement system. While eventually the facts on that performance will be known, delays in

determining the facts may be detrimental to the project's performance. It is suggested that the relevant question is, "Can the next activity start on time?" Assuming the responsibility for performance changes from one activity to the next, the question must be pursued, "What does the previous activity's performer have to lose by saying 'Yes,' when in fact the answer should be 'No?'" Sometimes a "no" response will be given. Repeated behavior of this type may be properly rewarded. Not drawing attention to an occasional problem, probably will elicit no action, and will perhaps save some explaining at a time when the performer is least desirous of explaining. Thus, the conclusion must be that it is probably worth the risk. Consider an alternative question, "Will progress on preceding activities permit you to start your activity on time?" At least the following actions and motivations are evoked. First, the performer must review what preceding work must be accomplished to permit him to start on his activity. Secondly, he must determine the status of that preceding work, and make his own judgement as to the likelihood it will be completed on time. Third, if he judges that it will not be completed on time, he has every reason to indicate he will not be able to start his activity on time. Thus, this question is more likely to elicit an "honest" response than the question as to whether his own activity is going to be completed on time. Furthermore, in the event he responds in the negative, there is a good chance that he has some idea what is required for him to proceed with only partial completion of the preceding work. This should permit earlier corrective action.

There is a problem. This writer has been timid about introducing this question into a very large organization due to concern over the behavioral consequences of a person being required to report on the failures of others upstream from him in the network. An opportunity has not been available to date to introduce it in a small organization where close observation and assessment of consequences could be continuous. It seems that a series of such test applications, without the participants being conscious of the test, should precede the general use of the question in a larger organization. Such tests should also determine desirable behaviors of the project manager when using this information.

The importance of pursuing this research is more vivid when consideration is given to implementing a system having several thousands of activities. The cost of using "PERT analysts" or PERT coordinators" to ensure accurate reporting would be excessive. Without them and using conventional report forms, the measurement and, therefore, the feedback is likely to be inaccurate. An approach must be found to elicit "honest" responses, and still be cost effective.

There is another consideration with regards to reporting status and/or progress. In the usual organization using traditional management systems concepts, reports pass to and are summarized by several levels before they are complete for the entire project. Using CPT, the lowest level participant's reporting contribution is entered into the system possibly without consideration by

successive higher levels in his reporting chain. The effect is rippled through the entire project whether it is realistic, optimistic, or pessimistic, and whether or not it is correctable at a relatively low level of management. As a result, every problem identified at the lowest level has the potential of indicating a delay in project completion. The constant changing of dates may be very disturbing to top management and other managers. It would seem desirable that each successive level should have the opportunity to pass judgement on the perceived problem, but not the ability to keep it from being reported. There should be a sub-networking capability consistent with the organizational structure which, without denying the existence of the problem, permits comment on it and prevents it from affecting a large number of other activities if the problem can be dealt with adequately.

One of the important considerations associated with this concept is how the management information and control system affects the sense of responsibility of the various levels of management. It is contended that progress/status reporting concepts incorporated in most network based systems actually weakens the responsibilities and concern of middle management. They are by-passed in the reporting system, often without opportunity to determine if adequate corrective action can be taken. It is also contended here that giving them the opportunity to correct their own problems will result in a more effective and efficient organization.

This concept of considering organizational responsibilities also enhances the project manager's ability to manage the organizational

interfaces of the project. The potential for conflict is highest when the work flows from one organizational element to another. This would also seem to increase with the number of levels up in the organization it is necessary to go to find a common reporting position for the conflicting organizational elements. It is possible to design a summary report to assist the project manager to know where those potential conflict locations are in the network, and when one is imminent. This would guide him in checking the status of the preceding activities to ensure the work will be transferred in a timely and quality manner.

Research should be undertaken into the design of reports and the reporting system to determine the behavioral consequences of the concepts introduced above.

Integrated Management Systems

Earlier, in the discussion of a taxonomy of tools for managing projects, some brief comments with regards to integrated management information and control systems were included. Having evaluated other aspects of techniques and features which might be considered in system selection or design, it is appropriate to comment further on integrated systems.

Clearly it seems relevant to incorporate the best features of PERT, CPM, resource leveling, and PERT/COST. Assuming AON notation is indeed as advantageous as suggested by previous analysis, it should be the graphical basis for the system. However, it should incorporate some of the best features of the other conventions. For

example, recognizing that different levels of management have different requirements for information and ways of thinking about a project, provision for event orientation should be included. This would facilitate the emphasis on major milestones for top level management, printing of milestone reports, and provide the basis for presenting summary networks. At an intermediate level, the activities could be defined primarily based on organizational elements for unity of responsibility. The most detail level in the plan could be based on the premise that each activity requires a unique set of resources at a constant level over its duration. Identification of activities at these different levels would permit provisions for different treatment of them in certain segments of the computer system.

Closely associated with this would be consideration of integrating certain capabilities of DCPM and/or GERTS, where they were found to be useful in operating applications of CPT. Identification of the nodes as decision nodes would permit them to be plotted with a different symbol. Identification could also permit them to be recognized by the system as requiring external inputs during processing in an interactive mode.

If some of the features discussed above are to be included, an effective interfacing with systems for controlling labor, material, and equipment at the organizational level would seem desirable. Major design decisions would be required. For example, it may be desirable to provide for differentiating between "permanent" and "temporary" employees. Materials could be ordered to the activity,

to the project, or to stock. If to stock, an overhead charge could be allocated to determine the cost of the material to the project. An allowance could be made for scrap, obsolescence, and general shrinkage. Material used could be charged to the activity or to a work package. A material usage and/or price variance could be determined by activity.

There also seems to be potential for integrating configuration management, reliability and quality (i.e., technical performance) control, and program planning and budgeting.

While much of the configuration management system would be separate, proper interfacing could permit recognition of activities which are dependent upon decisions pending in configuration management. That might tend to create more pressure for expeditious treatment of changes. Taylor and Watling (1973, pp. 95-102) provide a simplified discussion which could be the basis for considering this integration for the design phase. There is also a need for effective change control in the construction or fabrication phase. Field orders during construction require careful control to permit assessment of cost and time effects and proper charges.

Reliability and quality events or activities could be identified and used as a checklist for personnel assigned such duties as well as the basis for RMI types of measurement and summarization, if appropriate. This should appreciably reduce the cost of such a capability over the ways it was implemented originally.

Integration or interfacing with a program planning and budgeting (PBBS) capability would offer considerable benefits to

certain types of firms, notably real estate development and R & D oriented organizations. This would also be consistent with the life cycle costing concepts popular in DOD.

Indeed, specifications for such a system, i.e., combined CPT and PBBS, were developed for a real estate development division. Implementation responsibilities were the responsibility of that division's personnel. Current status of the effort is not known.

Some consideration should be given to the possible incorporation of management by objectives into the integrated system. CPTs are inherently oriented in that direction. The two concepts seem very compatible. Explicit consideration of the two should clarify the relationship between them.

Finally, although not necessarily in order of implementation, it would seem very desirable to integrate the accounting system and the project management system. Apparently, this is being done, to some extent at least, in those firms whose systems have been validated by DOD as being in compliance with C/SCSC. It is also apparently being done by the major design and construction firms as reported at the 1977 Symposium of the Project Management Institute (PMI, 1977, pp. 3-81).

One major conflict which would have to be resolved in this process is which aspect of accounting is to have the highest priority--operations management accounting or financial accounting. This conflict may well be the underlying cause of problems of cooperation of accounting alluded to by DeCoster (1965). It would

be the position of this writer that operations management would definitely have the priority.

Some problems exist with the pursuit of such integration efforts. First, the development costs are substantial. Often the uniqueness of the organization requires either original development or substantial customizing. Second, the dependency on such a significant software investment would lead to considerable inflexibility in system modification. Modularity would tend to minimize this risk. Third, it could exceed the capabilities of normal management personnel to comprehend and work with it.

Cost and Savings

The brief review of literature dealing with the costs associated with the various techniques reveals that it is inadequate for intelligent decision making. First, it is extremely limited in coverage, including only CPT, PERT, CPM, PERT/COST, and resource leveling, if the items are properly interpreted. While the costs are detailed further by O'Brien (1971) as to consultation and computer, they do not specify the actual work performed by the consultant nor the quality of the program or the computer used. The quality of the computer should include some measure of the cost per unit computation and cost of mass storage per unit. Second, the examples pertain to construction projects. Very little data was found for other types of projects. Third, there is no indication of the comprehensiveness of the projects, i.e., do they span conceptual, planning, execution, and termination or are they primarily execution as is typical of

the work of many construction firms. Fourth, there is no indication that they really include all the costs associated with the use of the technique. Finally, there is no comparison of the costs associated with more traditional techniques to permit comparison of alternatives.

The data on tangible benefits is even more sparse. Benefits are generally stated in terms of time saved or court judgements avoided. On a casting plant, management had confidence, based on the CPT application, that they could delay releasing the bid package by one month. They estimated that another five million dollars worth of work could be specified in that month. They also estimated that they would pay a 20% premium for all work which had to be authorized after the general contract was bid. Thus, they estimated savings to be about one million dollars. That alone paid the costs of the CPT application many times over.

Much more information is needed on both costs and benefits. Costs should be measured by stage of the management process. Benefits should be converted into dollars, if only by estimate. All such information should be related to type of project and any other criteria which would assist in analyzing it and providing guidance on future applications. Perhaps equally important, such information would be valuable in the design of a system to meet specific needs. Costs of using network based systems could be reduced by appropriate application of value engineering, industrial engineering, and human factors techniques to the design of such a system if adequate cost and benefit data were available.

Furthermore, the costs of using such systems could be substantially altered depending on the type of computer used. Most systems are programmed for medium to large scale computers. There are a few available on mini-computers. No evidence was found of a system available on a micro-computer. There was no information available on the minimum configuration or hardware cost for such systems. It is assumed that they exceed the level that would be reasonable to use on a dedicated basis for a single project except on the very large projects. To the extent this is true, the following analysis is valid.

The economics of computer usage on a project basically implies the greater the use and the more comprehensive the system in terms of features discussed above, the greater the costs to the project. Thus, there is a financial pressure to keep the usage at a minimum. It is argued here that, if an adequate system can be provided on a relatively inexpensive micro-computer, the variable cost of usage could be reduced to essentially the cost of electricity. The fixed costs would be prorated on the basis of calendar time the micro-computer is assigned to the project. With such low variable costs as compared to the fixed cost increment, it could be argued that the unit cost of usage is reduced by more usage. Assuming a relatively useful software, the users would be more motivated to use the capabilities. At least, without the increasing cost as a function of usage, the system capability would tend to be evaluated on its merits without the bias of cost of computer usage. Rather,

the comparison would be the benefits versus the time required of the user.

Summary

In this chapter, the tools applicable to managing projects were considered. It was shown that there are more tools available than are discussed in the literature on project management and operations/production management. A taxonomy of tools was developed under two major classifications--techniques and practices. The distinction between these was not intended to be precise nor was the list of tools intended to be complete. Rather, they were illustrative of the types of tools of which the aspiring project manager should be made aware.

Some evaluative comments were made of these tools in the process of discussing the taxonomy. A more intensive evaluation of the network based techniques followed. This evaluation was really an assessment of the benefits and problems claimed for the techniques in the literature, considering the merits of these claims. These techniques have received varying degrees of acceptance in practice. Some of the lack of acceptance can be traced to inadequacies in the techniques and/or their implementation. Some can be traced to incompatabilities with traditional methods of the accounting function. Some is due to management's failure to adapt to the requirements and capabilities of these new techniques. Still other reasons for lack of acceptance of these techniques can be traced to the spotty and inconsistent principles for the application

of the techniques. Failure to recognize the existence of, if not the need for, different philosophies of managing projects has led to a potpourri of advice with little or no discrimination as to the nature of, or the circumstances associated with, a specific project. As a result, the guidance that is provided for all projects in general is specifically applicable to none.

The detailed examination of the merits of AOA versus AON graphical notation revealed that little or no solid evidence exists to support the arguments either way. A review of the claimed merits of each, augmented by personal experience suggests the superiority of AON. Clearly, better answers are needed to clarify the argument.

The evaluations of the techniques in the literature has been too general to be truly useful in selecting the proper technique for a specific project for diagnosing the real deficiencies of the technique. This stems largely from the evaluations being based on an inadequate framework. The development of an adequate framework should be based on the results of some of the research proposed in this and the preceding chapters. One of the benefits of an improved framework for evaluation would be its usefulness in selecting the appropriate tools for managing a specific project. In part, a better understanding of the characteristics of different types of projects, of different phases of projects, and of the various stages in the management process will lead to an ability to differentiate the needs to be met by the technique or system. For example, the needs in the conceptual phase of a project are substantially

different from those in the execution phase. It was asserted that the needs of the execution stages of the management process are not adequately met in most systems. Specifically, the information, reports, and processing capabilities of most systems do not meet the needs for dispatching, performing and expediting, and providing feedback.

It was shown that the only detailed evaluation of techniques found in the literature, i.e., evaluation of the features, was either in error or was at least misleading. Further, it was suggested that the objective functions incorporated in existing techniques are not adequate to meet the range of needs of the project manager. Objectives vary from day to day and from the long run to the short run. Furthermore, very few techniques provide for more than two of these objective functions in the same implementation.

Some detailed considerations for the design of an effective system for managing projects were discussed. It was shown how such detailed design considerations may affect the utility of the system. Specific attention was given to the relationship between the design of a system, the reports generated by it, and the behaviors they might elicit from the participants in the project. It was suggested that explicit consideration of the behavioral consequences of system design could improve the effectiveness of the systems by ensuring that they support and compliment the organizational concepts, principles, and philosophies employed by management.

Some consideration was given to the possible benefits and problems of integrating techniques and systems into a more

comprehensive system for managing projects. At the minimum, the interfacing of systems could improve the efficiency with which information is collected and reports generated within the project environment. It could also reduce the inconsistencies between reports generated from separate systems. It would likely result in management being more efficient and effective.

Finally, the costs and savings associated with using network based techniques were discussed. Much attention has been given to the computer and personnel costs of adding network based techniques to the management process. There is hardly any mention of the costs incurred by the users of the system and the reports generated by it. Nothing was found on the cost reductions achieved by substituting network based systems for previously used tools or from the implementation of integrated systems. Discussions of project savings as a result of using network based techniques are very general, and those that exist concentrate on reporting reductions in the duration of individual projects.

Based on the analyses in this Chapter, the following suggestions are made for research which will expand the understanding of these tools and enhance their value in managing projects. The suggestions are grouped into related sets to suggest the general progression appropriate to the eventual design of more effective systems to aid in managing projects. There is no evaluation of the relative importance of each at this point.

A. Evaluation of Existing Techniques

1. Evaluate the current state of application of the techniques to determint the extent to which the benefits claimed to be available from various techniques are in fact being realized, and the extent to which the problems are still being encountered.

2. Conduct a study to determine the specific reasons why the many reported resource leveling techniques are not being widely used on actual projects.

3. Conduct a study of the methods used to reconcile the needs of a project management system vis-a-vis the needs of the financial accounting system in organizations validated under C/SCSC. Also identify the remaining areas of conflict.

4. Determine if there exists a need for a comprehensive computerized Line-of-Balance capability.

5. Determine if any of the theoretical alternatives for PERT estimation formulas have been implemented and used in practice and evaluate their results.

6. Conduct a comprehensive study of existing computer programs to identify the features available, including both application and technical computer programming features. Also, identify any other features which do not exist in any program, but which may be desirable in practical application.

7. Evaluate, by experimental or other objective means, the comparative merits of AOA versus AON graphical notation and evaluate these vis-a-vis the features identified in "6" above.

8. Identify the characteristics of projects that are relevant for selecting the management tools to be utilized on different types of projects, including the needs by phase of projects and by stage of the management process.

9. Evaluate the different tools against the characteristics identified in "8" above, including the relative ease of use; the computer, direct personnel, and user costs per activity; and, to the extent possible, the probability of the tool actually being used.

B. Evaluation of Management Methods

1. Conduct studies of the dispatching functions in project-oriented operations to determine what is done, how it is

done, any problems with existing methods, any cost reductions possible if provided the appropriate techniques or capabilities, and if there is a real need for such capabilities.

2. Conduct a study of the information and decision aid needs of purchasing functions supporting project type work efforts to determine how their needs can best be met by integrating their reporting requirements into a CPT type system.

3. Conduct a study of the administrative duties of first level supervisory personnel, and others who normally provide feedback input to a CPT system, to determine the nature of these duties, the time required to perform them, and the extent to which they might be incorporated into the reporting requirements of the CPT type system, and eliminated in their present form.

4. Conduct studies to determine the objective functions actually used in projects; their relative importance; how they change over time; the extent to which objectives are applied as constraints as opposed to being optimized; the types of trade-offs involved; and how the objective functions might be incorporated into a comprehensive project management system.

5. Conduct studies to identify more objective ways of evaluating the schedules for activities and resources, and determine how they might be incorporated into project management systems.

6. Conduct studies of decisions made by project managers to determine if there are any decision aids, such as management science models or simulation capabilities not currently provided, which might be incorporated into a comprehensive project management system, and evaluate the feasibility of incorporating them.

7. Investigate the success and problems encountered by a representative set of organizations, such as those validated under C/SCSC or some of the large engineering-construction firms, in the integrating of various management systems. Assess the need for further research in this regard.

C. Behavioral Considerations in Project Management System Design

1. Identify the different aspects of philosophies of managing projects with regard to activity dimensions such as estimate, target, or commitment, and investigate the implications on system design to support a consistent set of behaviors associated with each philosophy.

2. Evaluate the probable effectiveness of each possible combination of the identified aspects of the above philosophies, especially with regards to maintaining the discipline necessary to achieve accurate and timely reporting performance.

3. Evaluate the behavioral consequences of alternative report format designs with special emphasis on the execution portion of the management process.

4. Evaluate the behavioral consequences of requiring a project participant to report on his ability to start his own activity on time based on checking on the status of the preceding activities and, thus, report on the progress of his peers.

5. Conduct studies to evaluate the behavioral consequences of exception reporting on the various types of participants in a project with special emphasis on the effects of only negative feedback versus providing positive feedback along with the negative. Consider alternative strategies of incorporating the positive and the negative feedback.

6. Evaluate the behavioral consequences of the sense of responsibility and concern of middle management of present procedures for entering feedback data into the CPT system as compared to a hierarchical concept of reporting which permits evaluation and corrective action to be taken at each level before the final project report is prepared. Also, determine alternative strategies for implementing the hierarchical concept to permit incorporating decisions at each successive level in a timely fashion, and yet prevent the unwarranted biasing and filtering by middle management of the actual data as reported by first level management.

7. Conduct a study to determine if there are any characteristics of a scheduled start or completion date (e.g., end of work week as opposed to any other day for completion targets) which are most effective in motivating people. Also, assess any possible negative consequences associated with such characteristics, and how to deal with them.

8. Conduct a study to assess the pros and cons, and especially the behavioral effects, of alternative approaches to plotting activities, i.e., showing or not showing latest allowable dates, location of critical activities, and different horizontal banding criteria.

D. Needs of Managers of Project Managers

1. Conduct studies of the performance of projects as a function of the reporting requirements of the managers of project

managers, higher levels in the organization, and/or the client. From these results, assess the reporting needs appropriate for these other levels which are most likely to result in successful performance.

2. Assess the special educational needs of managers of project managers to enable them to take better advantage of the techniques and practices available, and thereby achieve better performance on projects under their direction.

E. Towards System Design

1. Conduct a study of the problems of scheduling scarce or costly resources to specify how appropriate capabilities can be incorporated into a resource management system, and specify the design of such capabilities.

2. Evaluate the potential usefulness of an "overhead activity" capability in both CPM and PERT/COST techniques, determine alternative ways of implementing the capability, and develop specifications for the recommended approach.

3. Design and specify the implementation of a "critical interface" report to aid the project manager in identifying significant activity-organization responsibility interfaces for follow-up purposes.

4. Develop, implement, and evaluate objective functions for resource management programs consistent with "B - 4 & 5" above.

5. Determine how the needs of the dispatching phase of the management process identified in "B-1" above could be combined with the needs for making a project management system more effective through design of working documents, preparation of analytical reports and providing man-machine interaction at a computer terminal.

6. Continue research into the structural characteristics of networks and their resource requirements to determine the criteria which will permit the development of better, more useful techniques for leveling and dispatching resources.

7. Evaluate alternative approaches for extrapolating or otherwise determining project duration and cost at completion while the project is underway, including not only accuracy, but also the costs of obtaining these values.

8. Conduct an intensive analysis of the problems of integrating the capabilities of the various network based techniques into

one comprehensive system, and integrating the various management systems, with emphasis on the practicalities of such steps.

9. Specify the methods for incorporating the following capabilities into a comprehensive project management system:

   a. To summarize performance versus estimate on individual activities for each responsible individual and organizational entity as an aid in providing guidance and counsel to the performer and, possibly, an assessment of the effect that management's actions are having on subordinate behavior.

   b. Provision for interruptible activities where resource leveling is an objective.

   c. Provision for identifying a "concurrent" activity relationship.

   d. Provision for a "must" relationship which permits stating that two consecutive activities must be performed with no time interval in between them.

   e. Provision for a "should" and "desired" logical relationship which permits identifying activities which "should" or it is "desired" be included as a part of a project plan with the ability to ignore the relationship under certain conditions. The conditions need to be defined.

   f. Provision for a "scheduling procedence" which would be kept separate from the technological precedence, and so identified on analytical reports. It should be incorporated in such a way as to facilitate exploration of re-scheduling possibilities with the objective of minimum impact on other scheduled activities.

   g. Provision of a capability to relate a "punch list," "bill of materials," and "equipment list" to activities in a network.

   h. To manage the receipt, inspection, storage, and other aspects of material flow to and into the project.

   i. To indicate if a resource is needed only for a portion of an activity's duration and, if so, when.

   j. To code the space within which an activity must be performed to aid in alerting management to potential conflicting needs for that space.

10. Develop a computer program which incorporates the best features of PERT, CPM, PERT/COST, resource management, DCPM and GERTS into a single system; provides interactive capabilities for selecting the technique applicable and making decisions, including the selection of alternatives in the DCPM/GERTS sense; and includes appropriate management working documents, analysis, and efficient capabilities for updating and changing the data.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

Introduction

The preceding reports the results of an extensive study to assess the state-of-the-art of literature on managing projects. Specific emphasis was placed on identifying gaps, conflicts, and deficiencies in the current literature and research on the management of projects. The expectation that the final result would be more questions than answers was certainly fulfilled. The questions ranged from theory to practice, from mathematical technique to leadership behavior, and from the simplest list of activities to accomplish to very sophisticated computer programs.

Some very general conclusions are appropriate at this point. First, there are more books and far more articles containing at least some material pertaining to various aspects of managing projects than was expected. The domain of subjects in this literature was somewhat greater than expected, but the characteristics of the literature over the domain was essentially consistent with expectations. That is, there are rather narrow areas within the domain which have received very intensive research and discussion. There are substantial areas which have received minimal attention.

There are some areas which have received no attention relative to projects specifically.

In another dimension, the literature is quite stratified as to type of industry or applications area. While no evidence was found of the deliberate identification of types of projects, the literature is largely oriented by industry as a result of authors' interests in a narrow area writing for a limited audience. No evidence was found of efforts to bridge the gap between these different areas.

A few of the areas which the literature covers most intensively are treatment of uncertainty in PERT, analytical techniques for solving various forms of the time-cost trade-off in CPM, analytical approaches for small project and heuristic approaches for large project resource leveling, estimating accuracy in the time dimension, and analyses of conflict management and use of authority. On the other hand, there was only superficial analysis of the sources of uncertainty in projects, with no evidence of an understanding of the effects of the different sources. No evidence was found of a body of economic knowledge of the activity, the basic entity of all projects and specifically relevant to the time-cost trade-offs of CPM. Only very recently was research reported on the structure of networks and their resource requirements which might be helpful in the leveling process. The measures used were point estimates representing the entire project, giving no knowledge of the way the structure changed from the beginning to the end of the project.

One article on such a concept appeared in the early 1960's, but has never appeared again in the literature. The recent literature on conflict management and authority represents the interests of only three collaborating researchers.

The treatment of project management in operations/production management texts is particularly weak. It emphasizes the basic arithmetic of CPT with only slight discussions of the simplest arithmetic of PERT, CPM, and occasionally resource leveling. Indeed, they generally conclude that such techniques are only applicable to the very large scale projects typified by defense-space efforts. Little if any attention is given to the problems of managing small to medium-size projects by which many college graduates are introduced to an organization.

While considerable effort has been invested in the development of mathematical routines for solving project scheduling problems, most of this has either been directed to specific applications or has been conducted in a vacuum of knowledge of the nature of actual project operations. The emphasis has been placed on the planning and scheduling of projects. Small wonder that the techniques gained a reputation for being of primary value in planning. Without comparable value in the execution portion of the process, they often fell into disuse as the project progressed.

Finally, while some attention has been paid to behavioral variables in the past, much of it was experiential in nature, or so-called "natural experiments." Only recently have any really

carefully-designed studies begun to appear having specific applicability to projects. Very little evidence was found as to why the behavioral variables may be more important on projects than on other modes of work efforts. Some of the reasons identified in this study were the non-repetitiveness of the work; the close coordination of multiple, heterogeneous resources often involving independent organizations; the advancing state-of-the-art technologically; and the magnitude of and time pressures involved in the projects.

An Assessment of the Products of This Study

The major objective was the identification of gaps, conflicts, and inconsistencies. These are identified in detail at the ends of Chapters II through V. They are the subject of further discussion in the subsequent section. There were some other products which were incidental to the process of assessing the state-of-the-art. In each case, they would have to be considered tentative products until such time as specific research can confirm or reject them and, no doubt, improve upon them. They are discussed in order of their presentation in the previous chapters.

A Framework for Analysis

This was the basis for organizing the literature review and subsequent analysis. It focuses attention on the activity as the basic building block of all projects. It enlarges the concept of an activity by explicitly recognizing that the cost of an activity

is the product of the technical performance required, the resource application rate, and the duration of the work on the activity. It draws attention to the fact that these dimensions must be measured--both before and after performance. There are a number of factors which affect these dimensions; before the fact in estimating them and after the fact as a result of performing the activity. A major factor in determining those dimensions is the management information and control systems employed on the project. For example, resource management calls for much more detailed planning than is characteristic of projects managed with the aid of only a Gantt Chart.

Finally, but very important, the framework demands an explicit definition of project and activity, a conceptual model of an activity, a clear understanding of interrelationships between activities in a project, and detailed analysis of the characteristics of each of the above.

Definition of Project and Activity

The review of literature disclosed only one reasonably acceptable definition of a project; that by Norden (1960). Even it was oriented toward the uniqueness of the development project. Analyses in the process of developing the definition provided the basis for making some changes to that definition which resulted in the proposed definition. It was "tested" against certain criteria of adequacy and found satisfactory. The definition of an activity

was also derived to be consistent with the definition of project. Two by-products of this analysis seem worthy of mention.

Taxonomy of Work Efforts

In order to develop a definition of project which would distinguish it from all other modes for organizing work efforts, it was necessary to determine a comprehensive classification of alternative modes. The resulting taxonomy--craft, project, job shop, mass production, and continuous flow process--was shown to be comprehensive and yet adequately detailed. It was shown that there is economic as well as organizational rationale for progressing from craft to flow process mode. A more detailed taxonomy fits within this scheme in a useful manner. Furthermore, it was shown to be all encompassing in that, with this scheme, it is unnecessary to distinguish between manufacturing and service industries.

Scheduling/Control Practices

Experience suggested that there were some differences between scheduling and controlling practices for the different modes of organizing work efforts. No references were found which compared these practices across the five modes identified. Therefore, based on experience with all five modes, a comparison was made. It clearly demonstrates differences in orientations, pressures, and objectives for each of the five modes. This lent support to the proposed taxonomy. In addition to providing a basis for further work in this study, this analysis also provides a useful framework for considering the broader context of operations management.

Conceptual Model of an Activity

The conceptual model of an activity based on the dimensions of technical performance, resource application rate, and duration proved useful in understanding the characteristics of an activity.

Economics of the Activity

Through analysis of the characteristics of each of the dimensions of an activity, elements of an economics of the activity was developed. It was found to be analogous in some aspects to the economics of mass production, but sufficiently different to warrant its separate development and presentation as a part of educating the aspiring project manager.

Uncertainty

Sources of uncertainty were explored. Classical industrial engineering techniques were shown to be inapplicable to project activities because of their non-repetitiveness. Estimates can be in error in any of the three dimensions, given perfect specifications. There could also be errors in communicating the specifications of the intended results of the work effort. Furthermore, the performance of the activity could be similarly affected. In addition, there may be other factors, which contribute to uncertainty, one of which is the objectives of the organization. It was shown that different objectives result in different behaviors and, hence, varying performance. Thus, the real sources of uncertainty are many and varied; some inherent in the nature of the activity itself, and some stemming

from the environment of the activity. It seems reasonable that such varied sources of uncertainty should be handled in more than two ways. Present techniques allow for only two types of uncertainty--duration and occurrence of activities. Whatever the source of the uncertainty, it must be accommodated in one or both of these types.

An Analytical Model

To demonstrate the applicability of the conceptual model, a mathematical model was derived. Its completeness was limited by the lack of specific knowledge about the technical performance dimension, i.e., not enough is known to predict the ideal work content as a function of required technical performance. Thus, leaving that step out, the model was structured consistent with normal estimating procedures which generally start with either material or direct labor, proceed to the other, and then to equipment. Time-cost trade-off curves are provided from which one can be selected which corresponds closely to the behavior of the costs as time is compressed. It is argued that such an approach will give answers generally as accurate as might be obtained from more detailed, and much more costly estimates derived from the typical cost accounting system. This reasonably simple method of using normally available estimating data requires only minimal additional inputs. Frequently, only the minimum duration and the ratio of labor cost increase (over the cost at the normal duration to achieve the time reduction) are required. However, in the most complex case where labor, material, and equipment costs increase with time

compression, three constants determine the cost increase of each; three constants select the shape of each cost curve; and one constant specifies the degree of symmetry of the total cost curve when the duration exceeds the normal duration. Since none of these are required, the capability would be transparent to the user not desiring these results. Furthermore, the computer program could be written to permit these to be inputs separate from other estimating data, and only on those activities for which they are applicable. Thus, it is anticipated that such an approach would make the CPM capability much more feasible on more types of projects.

Projects

Projects were shown to vary as to type, by phase, and by stage of the management process. Other important characteristics of projects were analyzed as summarized below.

Interrelationships in Projects

The provisions in current techniques to describe relationships between activities in projects was shown to be very limited. In techniques based on AOA graphical notation, only one relationship is provided, i.e., an activity can start any time after its predecessors' completion.

With AON graphical notation, three additional relationships are available, plus a "delay" feature which prohibits start until some time has elapsed from the origin of the relationship. This is still limiting. Other possibilities are suggested including the

must, should, desired, concurrent, scheduling precedence, and the punch list. While situations have been encountered in personal experience where such relationships would have been useful, no prescription is made as to exactly how they should be implemented.

The relationships that exist due to resources were explored, and the "drafting room scheduling problem" identified which is essentially a classical assignment problem with the addition of a time dimension. In general, resource leveling assumes homogeneity of resources in a given class of resources. The drafting room scheduling problem recognizes the heterogeneity of resources in certain types of operations. No evidence was found in the literature of attempts to solve this problem.

In addition, little is understood explicitly about the dynamics of the human resource. For example, leveling procedures implicitly assume that the number of units of resource required in any time period, after leveling, will be available. The proposed definition of project explicitly included the phrase "involving the coordination of multiple, heterogeneous human and non-human resources." It is generally accepted that non-human resources have certain characteristic aberrant behaviors such as equipment not operating or material arriving late or differing from specifications. Prescriptions are given for avoiding these such as proper maintenance of equipment and follow-up of materials ordered. Little was found about similar phenomena of human resources. The many and varied demands on key human resources plus the dependency of organizational

performance on their presence and effective execution of routine responsibilities makes this a major variable in project performance.

Also, relationships exist in the technical performance dimension. While techniques exist to consider the time-cost trade-off, none exist which incorporates technical performance. Yet it was suggested that there are some predictable technical responses to time and/or cost pressures, such as eliminating certain quality assurance types of micro-activities. The limited understanding of activities in this micro sense, as well as in the technical performance dimension, precludes incorporation of this dimension into practical models of projects at this time.

Criticality

Among the other characteristics of projects explored, the concept of the critical path appears to have encouraged a type of myopia or tunnel vision. The critical path is the set of activities having the least amount of float. One other concept of critical was found, i.e., the critical activity derived from Monte Carlo simulation on the network. There are other possible concepts of criticality which could be extracted from a network portrayal of a project. Included in these are critical flexibility sequences, critical predecessors, critical events, critical resources, critical organizational interfaces, and critical technology activities. One of the essential lessons a manager must learn is to identify key variables and points in a process which require close monitoring. The activities on the critical path are certainly a part of this.

These other concepts of criticality also deserve, if not require, close monitoring, and could be incorporated in the design of a project management information and control system.

Other Factors Affecting Performance

A major problem in studies of performance on projects is the lack of precision in defining performance and the failure to correlate actual performance with the objectives of the organization. The objectives of an utility line crew are certainly different after a severe storm than when performing normal maintenance. The conditions under which the work is performed are also different. Yet no studies were found which considered these factors.

The exploration of individual, organizational, and external factors affecting project performance established the limited degree of understanding of these factors with regards to projects. Most behavioral research is concerned with mass production or job shop environments. Much of the limited literature dealing with behavioral factors in projects is experiential. Most of that which is research based suffers from lack of consistency of concepts and instrumentation. Thus, the ability to generalize is extremely limited. Perhaps the greatest contribution in this respect is the recognition of the lack of consistency. It is important to develop a recognition of the need for consistency in terms of uniformity of instrumentation and collection of basic data to permit comparison of similarities and differences between studies. Otherwise, unless the attention given to research in the project mode increases substantially, it will be

many years before any appreciable increase will be achieved in understanding of these factors.

Tools for Managing Projects

Taxonomy of Tools

A taxonomy of tools was developed which portrays the range of tools actually available to the project manager. It was not intended to be precise or complete, but rather to provide a framework which could be refined and supplemented. It does suggest the varying characteristics of the tools identified and, through discussion of them, some of the pros and cons associated with each.

Evaluation of Network Based Tools

The evaluation of the network based tools vividly portrays the gaps, conflicts, and inconsistencies in the literature on managing projects. Conflicts over the merits of AOA versus AON have not resulted in research to evaluate the two. Evaluation of features as a function of the graphic convention were inconsistent with actual results obtained in practice, software already developed, and/or procedures already designed but not yet implemented. More serious, the frameworks which are the basis of existing evaluations are inadequate. No definitive framework was proposed because that should follow the results of some of the suggested research. Several facets of the framework were suggested based on both analysis of the tools and the preceding analysis of projects and activities. For example, it seems clear that the features needed would vary by type

of project, by phase within a project, and by stage of the management process. Other characteristics of projects such as magnitude, difficulty, complexity, and technology, would also be relevant. The key characteristic of activities would seem to be the nature and source of their uncertainty. Such a framework and the subsequent evaluations are needed along with a greater degree of objectivity in the evaluations.

Dispatching, Performing and Expediting, and Feedback

A perspective was developed which led to the conclusion that very little attention has been given to the needs of the execution stages of the management process. Scheduling is concerned with the broader concept of relating activities to time periods, and achieving effective utilization of resources. Dispatching is the actual commitment of resources to the performance of an activity and must deal with all the uncertainties of the activity, the project, the individuals involved, and other factors. It is at this point that actual resource utilization is determined. Only one computer program was discovered which addressed the needs of the execution stages of the management process, and it was very particularized. Similarly, many systems print different sorts and selection of the same report format to be used by the performers of the activities. Their needs are different than the project manager and "PERT analysts" and, it is contended here, are not being met. Likewise, the feedback required is not designed for quick yet meaningful posting.

Recognition of the lack of consideration of this area should elicit research to understand the problems and eventually offer better solutions.

Philosophies of Managing Projects

The literature on managing projects has many admonitions and caveats associated with the proper use of the tools; especially network based tools. Personal experience with the observation of project managers of varying degrees of competency suggest a variety of different philosophies for managing projects, most all of which were effective at one time or another. It seems reasonable that the admonitions and caveats in the literature come from such a varied group of managers. No evidence was found to relate the admonitions and caveats to the different philosophies. For example, activity dimensions may be treated as estimates, targets, or commitments. While there is recognition of this in the literature, there is no recognition that each may require different leadership styles, different organizational climates, or different information and control systems and reports. Thus, it is argued that the literature is a potpourri of advice derived from various types of projects that is specifically applicable to none.

Costs and Savings

Reports of costs of and savings available from using the tools discussed are incomplete. Often the emphasis is on computer costs. Sometimes direct personnel costs are considered. A few

references allude to the indirect costs incurred by the report users. Often the costs quoted were those of using the technique in addition to conventional management systems. Reports of savings are generally in terms of time saved. No references were found which converted that time saving into dollars saved or related it to the additional costs necessary to save the time.

There is a need to apply the methods analysis tools of the industrial engineer, the techniques of value engineering, and the knowledge from human factors analysis to the design of techniques and systems to aid in managing projects.

In addition, to change the cost function of using a computer, it seems important to develop systems for micro-computers which can be assigned to a project on a fixed cost basis. As a result, increased usage of the computer would not be detrimental to cost performance on the project.

Strategies for Research

There are several strategies for research and development by which the suggestions for further study could be pursued. It seems worthwhile to consider these and their implications.

The first strategy might be called "laissez faire." That is, not assign any priorities or provide any structure. It is advantageous in that it calls for little or no effort to stimulate and organize whatever research ensues. It is disadvantageous in that little additional research is likely to be stimulated, research that is undertaken is likely to be disjointed as in the past, it will

probably continue to be oriented by industry or academic discipline, and few generalizations will result.

Another strategy would be to encourage research through the academic disciplines. The chances of stimulating more research in this manner would probably be greater. The ability to draw generalizations would seem to be greater within each discipline. Industrial support would probably continue for specific academic departments where individuals with a keen interest in the subject relative to that industry have congregated. The chances of the generalizations reaching across disciplines or across industries would seem relatively low, and the rate of progress would likely continue to be quite varied.

A third strategy would be to encourage development of multi-disciplined projects within universities. This would assist in bridging the gaps between disciplines, adding more coherence to the research, and achieving greater depths of understanding of projects and their management. One obstacle to this approach is the institutionalized practices within academia which generally do not encourage graduate research spanning two or more disciplines. Also, this research would meet with some difficulty in obtaining financing from industries already committed to or interested in specific knowledge and techniques.

In terms of benefits, it would seem that the third strategy has the most merit. Unfortunately, it also has the more formidable obstacles. A combined strategy would seem appropriate, pursuing the second strategy in the short run, while developing support for the third strategy in the long run.

There are means by which the third strategy could be encouraged. First, a thorough analysis of the benefits from a coordinated effort would have to be developed. Generally, a strong emphasis on short run benefits accompanied by some medium to long range efforts should be stressed. Second, interest could be developed in a professional organization, the Project Management Institute being the most obvious. Third, certain governmental agencies might be interested in funding multi-disciplinary research. Fourth, one or more appropriate academic institutions would have to be found with an interest in providing support for such an effort. These do not seem to be insurmountable steps.

Given such a strategy, it is important to evaluate the proposed research in terms of the immediacy of its benefits to the possible user constituents who might provide financial support. Thus, they might be coded as to short run (S), intermediate (I), or long run (L) potential benefits. Another coding could be by potential beneficiary. Some of these are DOD, NASA, HUD and HEW at the Federal Government level. At the industry level, the codes might include defense-space (DS), heavy construction (HC), general construction (GC), research and development (RD), systems and data processing (DP), and miscellaneous (MI). Another important way of classifying the items would be by academic discipline including operations management (OM), accounting (AC), organization theory (OT), behavioral theory (BT), and engineering (EN).

Still another coding would be by use of information, for example, technique development (T), system design (S), determination

of functional needs (F), documentation of industry practices (P), and addition to general academic knowledge (A). Such coding should clarify the relative importance of each item, and bring some order to the efforts. Given these results, it should be possible to develop a network diagram showing the relationship of each element and, thereby, portray the efforts as a major project.

Applying such an approach in part, the recommended research and development items were sorted into two general sets. The first set was composed of those items with direct impact on the development of improved techniques and systems. The second set consisted of those items which primarily contributed to general knowledge concerning the nature and management of projects as a unique mode of organizing work efforts.

Two different approaches were used to relate the items in the two sets. Those in the second set were sorted by type of knowledge into the following subsets:

General Organization Theory

Project Specific Organization Theory

Project Organization Practices

Individual Behavior and Characteristics of Project Participants

Nature of Projects

Nature of Activities

Economics of Activities and Projects

Philosophies of Managing Projects

Factors Affecting Project Performance

Those items having an impact on technique and system development were related in a network diagram. The network portrays the precedence relationship and also a sense of priorities depending on which intermediate objectives are considered most desirable.

The results of this process of sorting the items gave results that are consistent with the two aspects of the suggested combination strategy. The set contributing to general knowledge is particularly suited to the second strategy for the short run. The set having direct impacts on technique and system development is consistent with the third strategy for the long term.

Proposed Strategy

Based on the above analysis, the combination strategy appears to be logical and feasible. While successful implementation will require continued efforts to involve interested people and organizations, the potential benefits from advancing the state of knowledge and practice of the management of projects makes the effort seem justified. The list of items contributing to the advancement of general knowledge of projects and their management are listed in Table VI-1. Those items having direct impact on technique and system development are listed in Table VI-2 and their relationships shown in Figure VI-1. The paranthetic notation at the end of each item is a reference to the chapter and item in the summary of that chapter.

TABLE VI-1.--Research Items Contributing to General Knowledge of Projects and Their Management.

1. General Organization Theory

   a. Conduct a follow-on study of the relationship of mode of arranging work based on characteristics of that work in the manner of Woodward and Perrow, but recognizing a more complete typology including projects. The objective would be to develop a more complete knowledge of the ways of arranging work efforts (II-A).

   b. Conduct a study of the actual scheduling and control practices used on projects and what priorities are involved in the application of these practices to projects as opposed to other modes of work efforts (II-C).

   c. Develop a useful measure of magnitude of work efforts, and relate it, along with volume, to a meaningful concept of management technologies to show more clearly the role of project oriented work efforts (II-B).

2. Project Specific Organization Theory

   a. Study the meta-structure of organizations engaged in project type work (IV-F.2).

   b. Develop instruments to measure climate and leadership in project type organizations and encourage their use on all project research (IV-F.3).

   c. Analyze the degree of rationalization in organizations characterized as organic or mechanistic and relate that to performance on different types/phases of projects (IV-F.1).

   d. Analyze the correlation between the degree of organic organizational forms and the extent to which the activities involved are pushing the state-of-the-art technologically (III-J.1).

   e. Analyze performance on projects as a function of the goals of the organization (IV-F.4).

   f. To what extent are rewards and punishment perceived to be symmetrical as a function of positive or negative performance? (III-G.3).

TABLE VI-1.--Continued.

3. Project Organization Practices

   a. Analyze the problems encountered as an organization changes from a functional structure to a matrix structure (IV-F.5).

   b. Develop more complete guides for job descriptions in a matrix organization and a method by which the project manager can quickly accomplish this part of his organization responsibilities (IV-F.6).

   c. Conduct a study of the twelve different loci of responsibility for project management identified, including typical job descriptions, characteristics of occupants of these positions, pros and cons of each, and caveats appropriate in the use of each (II-d).

   d. Conduct a study of the organization of a major SPO (Systems Program Office) to identify the functions served by each organizational entity and the major mode of arranging work efforts applicable to each (II-E).

   e. How can the project manager, or his managers, determine the true capacity of an organization to perform work, and how can they build slack into the organization to assure project performance in spite of failures, or less than required performance, by various elements in the organization? (IV-F.7).

4. Individual Behavior and Characteristics of Project Participants

   a. What are the differences between employees who choose project-type occupations versus those who choose mass productions occupations? (IV-D.1).

   b. What are the critical characteristics of people who work in different types of projects which bear on their productivity, job satisfaction, and approaches to managing them? (IV-D.2).

   c. What are the strategic approaches to the use of various leadership styles and what are the consequences of the alternative strategies? (IV-E.2).

   d. What are the essential areas of knowledge and skills (not including technical background) of project managers? Does this vary by type or phase of project? (IV-E.1).

5. Nature of Projects

   a. Develop a comprehensive taxonomy of projects and their nature, and the types of tools applicable to their management (IV-A.1).

TABLE VI-1.--Continued.

b. Analyze the phases of projects over a number of projects and categorize their characteristics especially as to implications on tools for and approach to managing the projects (IV-A.2).

c. Analyze activities in projects to assess the actual distribution of activities by degree of uniqueness and by degree of pushing the state-of-the-art (III-B.1).

d. How can difficulty and complexity be defined to permit legitimate comparisons between projects? (IV-A.6).

6. Nature of Activities

a. Develop a typology of activities, along with some micro-description of them, relevant to understanding similarities and differences between them and relating these to other variables to aid in understanding the nature of activities (III-B.2).

b. Analyze the causes of uncertainty and their effects on activity performance (III-C.1).

c. Develop the concept of manageability of activities to aid in understanding the potential impact of alternative ways of improving performance on activities (III-E.2).

d. What types of efforts are eliminated on an activity as a function of excessive time pressures? (III-H.1).

e. What is the relationship of the occurrence of creativity results to the time remaining on an activity? . . . to the time pressure on the completion of the activity? (III-G.2).

f. Evaluate the effect of alternate overtime strategies and amounts on the efficiency and effectiveness of the performance of different types of activities (III-G.1).

g. Is there a tendency for the a posteriori distribution of activity uncertainty to be skewed to the right as compared to the a priori distribution? If so, how can it be countered? (III-C.3).

h. What generalizations can be extracted from literature of various technologies that bear on understanding the trade-off relationships between activities in a project? (IV-A.8).

i. Determine if and how energy should be accounted for as a resource on activities (III-F.5).

TABLE VI-1.--Continued.

7. Economics of Activities and Projects

   a. Develop a subset of economics applicable to project activities (III-A.1).

8. Philosophies of Managing Projects

   a. Identify the different aspects of philosophies of managing projects with regard to activity dimensions, such as estimate, target, or commitment, and investigate the implications on system design to support a consistent set of behaviors associated with each philosophy (V-C.1). Is an estimate of the dimensions of an activity treated as an estimate, a target, or a commitment, and under what circumstances? (III-E.1).

   b. Evaluate the probable effectiveness of each possible combination of the identified aspects of philosophies of managing projects, especially with regards to maintaining the discipline necessary to achieve accurate and timely reporting performance (V-C.2). What implications do various philosophies of managing projects have on the pre-execution and execution stages of a project, and what do they imply about the associated management system design? (IV-G.1).

9. Factors Affecting Project Performance

   a. What is the effect on estimating accuracy resulting from the estimate being made by the performer, an independent estimator, or by management? (III-D.2).

   b. Is there a "learning" phenomenon associated with project progress and, if so, are there characteristic patterns of learning by the type of project? (IV-A.7).

   c. Does estimating strategy (i.e., with or without the aid of the network) affect accuracy of estimates? (III-D.3).

   d. To what extent is the difference between estimated and actual dimensions (time and resource) of an activity a function of:
      the precision of the specification of the activity? (III-D.1)
      the cost of resources required for that activity? (III-D.5)
      of its criticality? (III-D.6)
      of the degree of pushing the state-of-the-art? (III-D.6)
      Does this vary across industries, functions, phases of projects or types of activities? (III-D.6).

TABLE VI-1.--Continued.

e. What is the optimum magnitude of activities considering accuracy of estimating, cost of creating and reporting against the activity, type of activity, and management technique to be employed? (III-D.4).
f. Study the effects of external factors on project performance and alternative ways the project manager might deal with each. Special attention should be given to the relationship with the customer so the customer would better understand the effects his actions may have on project performance (IV-H.1).

TABLE VI-2.--Research and Development Items Having a Direct Impact on Improved Techniques and Systems.

A. Integrated Systems

Develop an integrated system concept incorporating management information and control systems not currently a part of conventional project management systems, and incorporating the best features of existing and new techniques.

1.1 Investigate the success and problems encountered by a representative set of organizations, such as those validated under C/SCSC or some of the large engineering-construction firms, in the integrating of various management systems. Assess the need for further research in this regard (V-B.7).

1.2 Conduct an intensive analysis of the problems of integrating the capabilities of the various network based techniques into one comprehensive system, and integrating the various management systems with emphasis on the practicalities of such steps (V-E.8).

B. Technical Performance Monitoring

Evaluate the effectiveness of Reliability Maturity Index and other similar concepts and recommend an approach which could be incorporated into a comprehensive systems design if appropriate (III-H.2).

C. Line-of-Balance Technique

Determine if there exists a need for a comprehensive computerized Line-of-Balance capability, and if it should be a part of an integrated system (V-A.4).

D. Advanced Systems Design Features

Develop additional features which would be incorporated into an integrated system.

1 Design and specify the implementation of a "critical interface" report to aid the project manager in identifying significant activity-organization responsibility interfaces for follow-up purposes (V-E.3).

2 Provide an ability to code the space within which an activity must be performed to aid in alerting management to potential conflicting needs for that space (V-E.9.j).

3.1 Provide an ability to summarize performance versus estimate on individual activities for each responsible individual

TABLE VI-2.--Continued.

and organizational entity as an aid in providing guidance and counsel to the performer and, possibly, an assessment of the effect that management's actions are having on subordinate behavior (V-E.9.a).

3.2 Conduct studies to evaluate the behavioral consequences of exception reporting on the various types of participants in a project with special emphasis on the effects of only negative feedback versus providing positive feedback along with the negative. Consider alternative strategies of incorporating the positive and the negative feedback (V-C.5).

4 Evaluate the behavioral consequences of requiring a project participant to report on his ability to start his own activity on time based on checking on the status of the preceding activities and, thus, report on the progress of his peers (V-C.4).

5 Evaluate the behavioral consequences of alternative report format designs with special emphasis on the execution portion of the management process (V-C.3).

E. Integrated Techniques

Develop a computer program which incorporates the best features of PERT, CPM, PERT/COST, resource management, DCPM and GERTS into a single system; provides interactive capabilities for selecting the technique applicable and making decisions, including the selection of alternatives in the DCPM/GERTS sense; and includes appropriate management working documents, analyses, and efficient capabilities for updating and changing the data (V-E.10).

1 Conduct a study to assess the pros and cons, and especially the behavioral effects, of alternative approaches to plotting activities, i.e., showing or not showing latest allowable dates, location of critical activities, and different horizontal banding criteria (V-C.8).

2 Evaluate alternative approaches for extrapolating or otherwise determining project duration and cost at completion while the project is underway, including not only accuracy, but also the costs of obtaining these values (V-E.7).

F. Resource Management Capabilities

Develop a comprehensive resource management capability.

TABLE VI-2.--Continued.

G. Drafting Room Problem

Develop a solution for the drafting room scheduling problem, including a measure of technical performance (III-K.1).

H. Self-Modifying Heuristics for Resource Leveling

Develop a resource management capability with self-modifying heuristics and alternative objective functions subject to constraints (III-K.2).

1 Continue research into the structural characteristics of networks and their resource requirements to determine the criteria which will permit the development of better, more useful techniques for leveling and dispatching resources (V-E.6).

I. Scheduling and Allocation of Resources

Develop a combined resource scheduling and allocation model which permits augmentation of resources to solve peak and valley leveling problems (III-K.3).

1 Provide a practical capability for interruptible activities where resource leveling is an objective (V-E.9.b).

2 Provide a capability to indicate if a resource is needed only for a portion of an activity's duration and, if so, when (V-E.9.i).

J. Dispatching

Develop a capability to assist in the dispatching function.

1.1 Conduct studies of the dispatching functions in project-oriented operations to determine what is done, how it is done, any problems with existing methods, any cost reductions possible if provided the appropriate techniques or capabilities, and if there is a real need for such capabilities (V-B.1).

1.2 Determine how the needs of the dispatching phase of the management process identified in "J.1.1" above could be combined with the needs for making a project management system more effective through design of working documents, preparation of analytical reports and providing man-machine interaction at a computer terminal (V-E.5).

2 Conduct a study to determine if there are any characteristics of a scheduled start or completion date (e.g., end of work

TABLE VI-2.--Continued.

week as opposed to any other day for completion targets) which are most effective in motivating people. Also, assess any possible negative consequences associated with such characteristics, and how to deal with them (V-C.7).

3 What are the needs for and characteristics of flexibility in scheduling and dispatching that facilitate achieving high labor utilization? (IV-C.2).

K. Uncertainty

Evaluate how uncertainty can be incorporated into a comprehensive technique.

1 Conduct studies to determine the effect on uncertainty estimates, i.e., "a" and "b" as used in PERT, as a function of the duration of the activity as it is crashed (III-C.2).

2 Determine if any of the theoretical alternatives for PERT estimation formulas have been implemented and used in practice and evaluate their results (V-A.5).

L. Logical Relationships

Investigate and specify how to develop certain logical capabilities which will improve the usefulness of networking techniques.

1 Provision for a "scheduling precedence" which would be kept separate from the technological precedence, and so identified on analytical reports. It should be incorporated in such a way as to facilitate exploration of re-scheduling possibilities with the objective of minimum impact on other scheduled activities (V-E.9.f).

2 Provide for a "should" and "desired" logical relationship which permits identifying activities which "should" or it is "desired" be included as a part of a project plan with the ability to ignore the relationship under certain conditions. The conditions need to be defined (V-E.9.e).

3 Provision for a "must relationship" which permits stating that two consecutive activities must be performed with no time interval in between them (V-E.9.d).

4 Provide a capability for identifying a "concurrent" activity relationship (V-E.9.c).

5 Evaluate the behavioral consequences on the sense of responsibility and concern of middle management of present procedures

TABLE VI-2.--Continued.

for entering feedback data into the CPT system as compared to a hierarchical concept of reporting which permits evaluation and corrective action to be taken at each level before the final project report is prepared. Also, determine alternative strategies for implementing the hierarchical concept to permit incorporating decisions at each successive level in a timely fashion, and yet prevent the unwarranted biasing and filtering by middle management of the actual data as reported by first level management (V-C.6).

6 Under what conditions and according to what rules would the "must," "should," "desired," and "schedule" precedence relationships be used? (IV-B.1).

M. Objective Functions and Evaluation of Schedules

1.1 Develop, implement, and evaluate objective functions for resource management programs consistent with "M.1.2" and "M.1.3" below (V-E.4).

1.2 Conduct studies to identify more objective ways of evaluating the schedules for activities and resources, and determine how they might be incorporated into project management systems (V-B.5).

1.3 Conduct studies to determine the objective functions actually used in projects; their relative importance; how they change over time; the extent to which objectives are applied as constraints as opposed to being optimized; the types of trade-offs involved; and how the objective functions might be incorporated into a comprehensive project management system (V-B.4). What objectives and/or priorities are applicable on a project in the long, intermediate, and short range, and what are their dynamics from day-to-day and even within the day? (IV-C.3).

N. Technique Development--Resource Management

Conduct studies to learn more about the specific needs in a resource leveling capability.

1 Conduct a study to determine the specific reasons why the many reported resource leveling techniques are not being widely used on actual projects (V-A.2).

2 Conduct a study of the problems of scheduling scarce or costly resources to specify how appropriate capabilities

TABLE VI-2.--Continued.

	can be incorporated into a resource management system, and specify the design of such capabilities (V-E.1).
3	Determine the patterns of resource application on activities as a function of duration and type of activity for manpower, equipment, material, space, and energy (III-F.1).
4	Determine actual patterns of resource augmentation, i.e., by overtime, additional units, extra shift, etc., by frequency of occurrence (III-F.2).
O.	Evaluation of Graphical Notations
	Evaluate, by experimental or other objective means, the comparative merits of AOA versus AON graphical notation and evaluate these vis-a-vis the features identified in "U-3" below (V-A.7).
P.	Purchasing/Materials Management Features
	Gain an understanding of the relationship to the project, and the information and control needs, of the purchasing function.
1.1	Conduct a study of the information and decision aid needs of purchasing functions supporting project type work efforts to determine how their needs can best be met by integrating their reporting requirements into a CPT type system (V-B.2).
1.2	Determine the types and frequency of occurrence of alternative equipment leasing structures, and how they should be handled in a computer program for scheduling (III-F.3).
1.3	Review purchasing and finance literature and conduct field research on purchasing and subcontracting as applicable in the project environment (III-F.4).
2.1	Develop capabilities to relate a "punch list," "bill of materials," and "equipment list" to activities in a network (V-E.9.g).
2.2	What capabilities should be provided in and what rules should apply to the "punch list?" (IV-B.2).
2.3	Conduct studies to determine what system features are required to assist in the management of the receipt, inspection, storage, and other aspects of material flow to and into the project (V-E.9.g).

TABLE VI-2.--Continued.

Q. Finance and Accounting

Gain an understanding of present practices in the financial and accounting functions in order to better meet their needs in a project.

1 Evaluate the potential usefulness of an "overhead activity" capability in both CPM and PERT/COST techniques, determine alternative ways of implementing the capability, and develop specifications for the recommended approach (V-E.2).

2 Conduct a study of present practices in estimating, budgeting and control of costs at the activity or work package level under the Cost/Schedule Control Systems Criteria of DOD (III-I.2).

3 Conduct a study of the methods used to reconcile the needs of a project management system vis-a-vis the needs of the financial accounting system in organizations validated under C/SCSC. Also, identify the remaining areas of conflict (V-A.3).

4 Determine actual bidder reaction to uncertainty in terms of contingencies by activity or in total for the project in all three dimensions (III-I.1).

5 Study the relationship between actual and applied indirect costs, burden, overhead and general and administrative expenses on projects to evaluate the consistency with reality of current practices (III-I.3).

R. Needs of Managers of Project Managers

Gain a better understanding of the information and control needs of the managers of project managers.

1 Conduct studies of the performance on projects as a function of the reporting requirements of the managers of project managers, higher levels in the organization, and/or the client. From these results, assess the reporting needs appropriate for these other levels which are most likely to result in successful performance (V-D.1).

2 Assess the special educational needs of managers of project managers to enable them to take better advantage of the techniques and practices available, and thereby achieve better performance on projects under their direction (V-D.2).

TABLE VI-2.--Continued.

S. Needs of Project Managers

Gain a better understanding of the informational and decision-making needs of project managers.

1 Determine the practices used by project managers to "discipline" recalcitrant participants, and assess their impact on the project and the organization (IV-E.3).

2 Conduct studies of decisions made by project managers to determine if there are any decision aids, such as management science models or simulation capabilities not currently provided, which might be incorporated into a comprehensive project management system, and evaluate the feasibility of incorporating them (V-B.6).

T. Needs of Other Project Participants

Gain a better understanding of the needs of operations personnel in their use of network based techniques, as well as their total administrative responsibilities. Conduct a study of the administrative duties of first level supervisory personnel, and others who normally provide feedback input to a CPT system, to determine the nature of these duties, the time required to perform them, and the extent to which they might be incorporated into the reporting requirements of the CPT type system, and eliminated in their present form (V-B.3). What are the problems with which first-line supervision must deal on a day-to-day basis? What system capabilities would assist him in dealing with them? (IV-C.1).

U. Evaluation of Existing Techniques and Needs

Conduct studies to better understand the current availability and use of tools applicable to managing projects.

1 Evaluate the current state of application of the techniques to determine the extent to which the benefits claimed to be available from various techniques are in fact being realized, and the extent to which the problems are still being encountered (V-A.1).

2 Evaluate the different tools against the characteristics identified in "U-4" below, including the relative ease of use; the computer, direct personnel, and user costs per activity; and, to the extent possible, the probability of the tool actually being used (V-A.9).

TABLE VI-2.--Continued.

3	Conduct a comprehensive study of existing computer programs to identify the features available, including both application and technical computer programming features. Also, identify any other features which do not exist in any program, but which may be desirable in practical application (V-A.6).
4	Identify the characteristics of projects that are relevant for selecting the management tools to be utilized on different types of projects, including the needs by phase of projects, and by stage of the management process (V-A.8).
5	Conduct a study of the role that magnitude of project has on the criteria relevant to selecting techniques or systems to aid in managing the project (IV-A.4).
6	What are the different and common requirements for managing large and small magnitude projects, especially when performed by the same organization, and how can a single system span the managerial needs of the full range of magnitudes? (IV-A.5).
7	Analyze the stages in managing projects and determine if the types of tools employed vary as a function of the stage. What are the essential system requirements of each stage (IV-A.3).

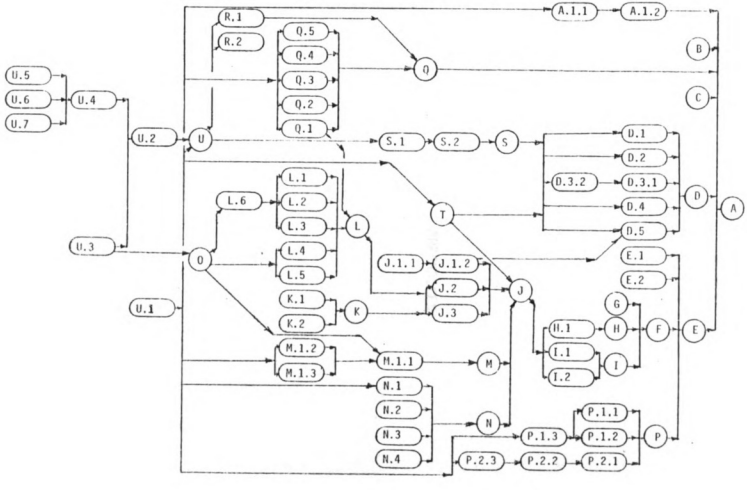


Figure VI-1.--Research and Development Network Plan for Integrated Systems for Project Management.

APPENDICES

APPENDIX A

CHECKLIST OF RESPONSIBILITIES FOR PROJECT MANAGERS

APPENDIX A

CHECKLIST OF RESPONSIBILITIES FOR PROJECT MANAGERS

The following is a composite job description derived from job descriptions from three sources. The sources and specific item are identified by A, B, or C followed by the item number in the respective source. The sources are:

A. Steiner and Ryan (1968, pp. 16-18)

B. Taylor and Watling (1973, p. 32)

C. Cleland and King (1975, pp. 243-4)

A. Precontract

1. Liaise closely with the sales executive so as to ensure that sales management is aware of situations that may affect sales strategy, both short and long term (B-12).

2. Initiate, review, approve and timely submission of project proposals (A-1). Providing appropriate financial details indicating profitability of the project and stating clearly all foreseeable problem areas (risks) with recommendations on how these risks may be avoided or minimized, and the implications (B-14).

B. Contract Negotiation

1. Exercises surveillance over contract negotiations with the customer to insure that program objectives can be met within the terms of resulting contracts (A-2).

2. Ensure, in conjunction with sales management and comptroller, that the contract is one that is acceptable to the company and, prior to the draft contract, ensure that any variance to any standard contract terms are acceptable and checked with sales, commercial and technical management and legal advisers (B-13).

C. Sales

1. Coordinates the Company position and serves as the primary representative in dealing with the customers and related sub-contractors on project matters (A-10).

2. Develop a cooperative spirit with the customer so that user action can be sought where necessary to meet agreed objectives (B-19).

3. Hold regular meetings with the customer to ensure that he is aware of progress on the project (B-20-a).

4. Ensure that all objectives and policies are continuously reviewed and updated to meet customer satisfaction requirements (B-26).

5. Provide guidance to the customer in preparing himself for using efficiently the system from the "ready for service" date, including operating instructions, training of staff, preparation of building and site, and maintenance necessary to meet serviceability requirements (B-20-b).

6. To establish acceptance criteria, the use of which will show between the company and the customer that the company has carried out its technical obligations; (B-3) and to obtain, from the customer, agreement that the contractor has carried out his obligations under the contract and in accordance with the acceptance criteria (B-24).

7. Maintain awareness of customer attitudes, desires and any other factors that could affect the program.

D. Planning

1. Develop the general requirements of the project, i.e., establishing the overall project strategic plan (C-1).

2. Preparing the general and technical specifications of the product or project including the reliability, maintainability, and supportability requirements for the overall system and for individual equipments, (C-4) and ensure that company departments committed to assisting the project are fully aware of what is required of them (B-21-b). (In this context, the general specifications express the customer needs and desires, while the technical specifications designate product parameters.) (C-2)

3. Responsible for the development and maintenance of program plans covering the technical, financial, and schedule aspects

of the project, for make or buy recommendations, for task assignments, and for instructions required to fulfill contractural requirements. Assures the development and maintenance of compatible implementation plans and programs by all contributing organizations (A-3). This requires the identification of all activities and their time scales, the risks, any necessary back-up plans, and the resources necessary to successfully implement the project in accordance with the functional requirements (B-4-a) (B-6).

4. To prepare, with the customer, a basic planning network for all significant activities and their time scales, after obtaining agreement on company activities with the appropriate management in the company and with any sub-contractors (B-4-b).

5. To ensure that all "special requirements" are "raised" at the earliest opportunity, where necessary, with supporting functional specifications when approved. These special requirements must be reflected into the basic planning network (B-8).

6. Assures the establishment, coordination, and execution of support programs to the extent required or permitted by the contract. In this context, support programs include value engineering, quality control, reliability, maintainability, environmental engineering, configuration management, data control, design review, and components, materials, and progresses engineering.

E. Personnel

1. Ensure that suitable staff are obtained for the project. Prepare job descriptions and terms of reference for the project team covering the following stages: (B-16).

   a. Pre-sales (if applicable)
   b. Implementation
   c. Post-implementation (e.g., during maintenance and operations)

2. To make sure that any project staff reporting to him are adequately trained, that their future career development needs are satisfied, and to assist them to make a satisfying move from this project to another task when the appropriate time arrives (B-18).

F. Finance

1. Prepare a project budget from conception to completion and regularly update to show anticipated actual cost (C-11-a &

B-7). All budgets and accounts must be signed off by sales, program management or other departments, as necessary (B-7).

2. Responsible for the allocation of funds necessary for performance of approved work and such reallocations as necessary due to changing conditions. Recommends pre-contractural coverage as required (A-8).

G. Control

1. Responsible for the establishment and maintenance of the necessary system of management control and visibility on all aspects of project performance, such as conformance to contract terms and conditions, technical performance requirements and specifications, schedules, allocated funds, cost and profitability, and post-delivery coordination (A-4 & C-11-b).

2. Develop, coordinate and maintain the master and supporting schedules required to produce the product within the time restraints (C-7).

3. Coordinate the use of company resources in order to achieve customer objectives in a timely and business-like manner (B-2).

4. Ensure that appropriate design, buying, manufacturing, or other instructions are issued, that any special requirements are correctly interpreted, and that they are updated if changes occur (B-9 & 10).

5. Review the project plans regularly, including monitoring the progress of all company departments and others committed to assisting on the project, (B-21), and initiate corrective action when actual performance deviates, or is predicted to deviate, from established project plans to recover slippages or to minimize their effects upon the total project (A-9 & B-5).

6. Identify problems requiring support on or off site, and to solve these problems by action resulting from discussing with appropriate line and support management, whether legal, engineering, system, or of any other appropriate discipline (A-13).

7. To identify the stage at which handover of the project can be effected to the standard sales support function and to see that this transition is efficiently carried out (B-23).

8. Regularly informs the General Manager, Sales Management, and other interested management of project progress, status, and trends for future progress and recommend action as may be necessary for the expeditious conduct of the program.

H. Administration

1. Assures that properly coordinated and timely replies are provided to all correspondence received by the company in connection with the project (A-12).

2. To ensure that appropriate procedures, policies and standards are established and can be maintained to guarantee continued customer satisfaction (B-25).

3. To manage the team directly answerable to him in order to achieve all the requirements of the project.

I. Design

1. To develop the best possible understanding of the customer's functional requirements so as to ensure that they have been correctly interpreted and that the system is designed to be cost effective in terms of standards for performance, quality, reliability, and maintainability which must be agreed with the customer, own company operating divisions and subcontractors. Such requirements must then be configured into standard products and/or into special products that have been endorsed by management in line with company overall policy, both technical and commercial (B-1).

2. Providing technical leadership for the product line and maintaining the maximum state of the art in the project within the cost and schedule restraints. This is accomplished on the existing product generation, and is not to be confused with the overall R & D function to be carried out for the company as a whole (C-13).

3. Responsible for systems analysis and systems engineering, including

   a. preparation of system specifications and functional requirements
   b. system integration (A-5).

4. Establish the product configuration and performance characteristics and track these characteristics throughout the project's life (C-12) by establishing and administering the necessary configuration management (A-7) and change procedures to ensure that any changes and requirements that affect the

project are dealt with quickly through the proper channels by agreement with the customer, the company and any sub-contractor. Ensure that such agreed changes are properly costed and, if appropriate, paid for by the customer (B-15).

5. Plan, schedule, direct, and control a balanced test program; assuring the timely availability of funds, manpower, facilities, equipment, and other resources needed for testing; and monitoring to assure the program is completed as planned (A-6).

J. Production

1. Fabrication, testing, and evaluating the prototype and production models (C-3).

2. Identifying and selecting sources for the items of the project which are to be procured (C-5).

3. Negotiating and administering all contracts consummated with suppliers and participants in the project effort (C-6).

K. Documentation

1. Determine requirements for; assign responsibility for creating, publishing, and distributing; allocates funds for; and monitors for quality and schedule all technical manuals, reports, and data required for the product in its intended operational environment as required by the contract (A-11 & C-8).

L. Operations/Logistics

1. Plan for, and subsequently install, operate and maintain the completed product (C-9).

2. Identify and develop the personnel skills necessary to use the product (C-14).

3. Provide operational logistic concepts required to assure the supportability including supplies, spare parts and specialized support equipment of the product after it is produced (C-10).

APPENDIX B

EVALUATIONS OF CERTAIN TOOLS OF PROJECT MANAGEMENT

APPENDIX B

EVALUATIONS OF CERTAIN TOOLS OF PROJECT MANAGEMENT

The following tables were included in course material prepared by the Army Management Engineering Training Agency for their course in project management. They demonstrate the level of detail at which such techniques are frequently evaluated for purposes of guiding managers in the selection of the tools to be used on a particular project.

Gantt Technique--Strengths and Weaknesses

Criteria	Strengths	Weaknesses
1. Accuracy	Good in repetitive work--time estimates likely to be good and production is easy to count.	In non-repetitive work accuracy of estimate of task completion percentages subject to error.
2. Reliability	Simplicity of technique helps project manager to set up consistent progressing system.	In repetitive work production count can be "doctored." Large non-repetitive projects involve many different progress estimators, which tends to hurt consistency.
3. Simplicity	Easy to understand, to accept, and to implement.	Requires good time estimates or standards, which are not simple to develop.
4. Universality of Project Coverage	Effective at work center levels. Can cover well a given phase of a life cycle.	Not effective for large, complex projects.
5. Decision Analysis		No capability to simulate alternatives.
6. Forecasting	Shows clearly ability to meet schedules in repetitive work.	Does not readily show ability to meet schedule if many interrelated tasks are involved.
7. Updating	Easy to update if program is static.	
8. Flexibility		Much chart reconstruction needed to show program changes.
9. Cost	Data gathering and display are relatively inexpensive.	Frequent program changes cause costly redrafting of charts.

Networking--Strengths and Weaknesses

Criteria	Strengths	Weaknesses
1. Accuracy		The technique is as accurate as the activity time estimates. The margin of error is generally less in construction than in development.
2. Reliability		Compounded unreliable estimates in a large project may lead to unreliable status info.
3. Simplicity	Brings simple order out of mass confusion.	Concepts of slack and network families sometimes difficult to grasp. Computerized networking vastly complicates the process.
4. University of Project Coverage	Very good for one-time programs like construction and development projects.	Weak in production phase of life cycle. Not well-suited for quantity production.
5. Decision Analysis	Excellent for simulating alternatives, especially when coupled with time-cost data.	
6. Forecasting	Excellent for forecasting ability to meet schedules.	
7. Updating	Easy to update estimates as progress info is received.	
8. Flexibility	Portions of network can be easily changed to reflect program changes.	
9. Cost		Since considerable data is required, it is usually costly-especially if computerized.

LOB Technique--Strengths and Weaknesses
(In Repetitive Production)

Criteria	Strengths	Weaknesses
1. Accuracy	Completion time estimates are good, since work is repetitive.	
2. Reliability	Compares favorably with Gantt technique.	
3. Simplicity		How the line of balance is constructed is not always understood.
4. University of Project Coverage		Well suited only for production phase of life cycle. Does not emphasize resource allocation directly.
5. Decision Analysis		No capability to simulate alternatives.
6. Forecasting	Very good for indicating whether or not schedules can be met.	
7. Updating		Considerable clerical effort needed to update graphs. Computer processing can reduct this effort.
8. Flexibility		Inflexible. When major program changes occur, all LOB phases must be redesigned.
9. Cost	Data gathering and computations can be handled routinely and at moderate expense.	

APPENDIX C

FEATURES OF NETWORKING METHODS

Features of Networking Methods

Features of Networking Methods	Activity on Arrow (CPM)	Activity on Node (PERT)	Precedence Method (PDM)
Emphasis on events and event times	Difficult-can be gimmicked.	Heavy-basis of diagram.	Doesn't really exist.
Emphasis on activities and activity times	Moderate	Practically none	Highest
Subnetting concept permitted/used	No	Yes	No
Completion oriented or emphasis	Not strong	Strong	Not strong to no
Milestones	By gimmicks	Yes	By gimmicks
Skeletonizing	Not usually	Designed to permit	Difficult to impossible
Ease of logic change	Difficult	Most difficult	Easiest
Overlapped activities/sequencing requirements	Requires gimmicks & extra activities	Difficult if not impossible	Easily handled
Ability to follow float paths	Best	Moderate	Difficult
Ease of presentation as diagram	Acceptable to poor	Poor	Considered best
Inability to misinterpret output	Least	Some	Most
Ease of updating/correcting logic	Moderate	Low	High
Ease of preparation of network	Moderate	Low	High
Ease of "banding" diagram by area, type or responsibility for work	High	Moderate	Low
Ease of timescaling diagram	Moderate	Moderate	High
Need for special, elaborate symbology	Some	Yes	Virtually none
Usefulness of diagram as working document at performer level	Moderate	Low	High
Usefulness of diagram as working document at scheduler level	High	Moderate	Low
Ease of manual calculation	Highest	Moderate	Low
Standardizing influences exist in terminology and presentation	Some few	Most	Practically none
Features of Computer Programs			
Either stand alone or interfaced processing allowed	Concept doesn't exist	Designed for it	Concept doesn't exist
Both start and completion dates, actual or calculated, used	Depends on program	Almost never	Generally used

	Activity on Arrow (CPM)	Activity on Node (PERT)	Precedence Method (PDM)
Levels of reporting	User can build in	Available	User can build in
Multiple time estimates	No	Permitted	No
Single time estimates	Yes	Yes	Yes
Use of accounting code as node number	Difficult to impossible	Not practical	Designed to accept
Costs can be activity and event independent	Can fake some	Yes	Difficult but can fake
Overlap or sequencing function of work durations	If networked, increase activity	Difficult to impossible	Built in
Variable data dates different inputs	Not accepted really	Can be accepted	Not accepted really
Intermediate schedule dates	Can get some programs	Standard	Not generally
Interfacing/integration with cost or other existing systems	Difficult to impossible	Designed to permit	Possible but can be difficult
Multiple starts/ends	Some	Yes	Some
Variable work day and work week	Possible in a few	Possible in some	Possible in a few
Tied activities possible	Yes-some	Yes-some	Yes-some
Designed activities continue non-work days	Yes-some	Yes-some	Yes-some
Ease of handling multiple projects	Varies-usually difficult	Designed for it	Can be done
Project Characteristics			
Completion of work important	Can be used	Best choice	Can be used
Work content not well defined	Not suitable	Preferred	2nd choice
Uncertainty in durations of work content	Not suitable	Preferred	Not suitable
Project first-of-a-kind or state-of-art	May be difficult	Preferred	2nd choice
Multiple project control desired	Difficult but possible	Preferred	Difficult but possible
Assured correct logic sequence display	Preferred	Difficult but possible	Can be confusing
Logic expected to change relatively frequently or in major way	Can be done but difficult	Poor choice	Preferred
Interfacing with other company systems desired	Possible	Preferred	Possible
Measure accomplishment/progress to intermediate dates	Not easy	Preferred	Quite difficult
Multilevel reporting or skeletonizing needed	Possible but not easy	Preferred	Possible but not easy
Multiorganization effort	Difficult	Preferred	Possible
Work dispersed geographically (diverse reporting dates)	Difficult to impossible	Preferred	Difficult to impossible

	Activity on Arrow (CPM)	Activity on Node (PERT)	Precedence Method (PDM)
Possible need/desire to isolate area of network	Not too practical	Preferred	Not practical
Possible need/desire to expand detail in selected areas of project	Possible	Much preferred	Can be done
Work heavily overlapped or laddered	Gets confusing	Very difficult	Preferred
Work largely sequential with parallel, independent chains	Preferred	Can be used	No advantage
Minimum restrictions desired event names	Can be problem	Preferred	No problem
Accommodating "computer needs" objectionable/difficult	2nd choice	Poor choice	Preferred
Calculation results to be displayed on network	Preferred	Not too easy	2nd choice
Network diagram to be banded by work type, area, etc. desired/needed	Preferred	Difficult	Can be done
Network diagram to be presented timescaled	Can be done	Difficult	Preferred
Network diagram to be used in input/ progress recording	Preferred	Can be done	Difficult
Network diagram to be regularly distributed or used in presentation	2nd choice	Poor choice	Preferred
Network to be used by workers/managers	Can be done	Not desirable	Preferred
Inexperienced (networking) individual to draw	2nd choice	Poor choice	Preferred
Output to be used as "working-to" schedule	Preferred	Poor choice	2nd choice
Updated output to record accurate project history	Preferred	Very poor choice	2nd choice
Degree of sophistication required by output users	Intermediate	High	Lowest
Degree of sophistication required by network viewers/users	Intermediate	High	Lowest

Source: Jennett, Eric. "Choosing Your Networking Technique," Project Management Quarterly, Vol. III, No. 4 (Dec., 1972), pp. 16-18.

APPENDIX D

CLASSIFICATION FEATURES

CLASSIFICATION FEATURES

Input Characters

1. Multiple activity time estimates (vs. single time estimates)
2. Scheduled activity completion times.
3. Probability an activity will occur given that its predecessor occurs.
4. Type of node combination to be used (e.g., AND/DETERMINISTIC, EXCLUSIVE or/PROBABILISTIC).
5. Single cost estimate for activities and/or project.
6. Multiple cost estimates for activities and/or project (alternative to preceding two characters is no cost estimate provided).
7. Estimated activity resource requirements (e.g., manpower, materials, equipment).
8. Resources available for project by type and quantity.
9. Estimated costs of extra resource units.
10. Identification of key time periods (e.g., milestones).
11. Identification of organizational element responsible for activity(ies).
12. Identification of activities and their performance times to be fixed in the resulting schedule.
13. Weights assigned to scheduling objectives (e.g., minimize idle resources, meet project completion dates, minimize activity interruptions, maximize number of activities scheduled concurrently).
14. Identify all project activities that generate a direct cost to the project--even those not to be scheduled.
15. Identify work breakdown schedule for project.
16. Identify cost work packages for project.
17. Identify new proposals and their probability of being accepted.

Process Characters

18. Network based (vs. charting technique).
19. Stochastic activity times.
20. Stochastic entry of activities--activity occurrence treated as uncertain.
21. Consider repetitive or recurring activities.
22. Produces more than one project schedule.
23. Considers both direct and indirect costs.
24. Deterministic cost estimates for activities.
25. Deterministic resource estimates for activities.
26. Considers resource requirements and availability in estimating project schedule(s).
27. Allocates slack/float to activities in deriving final project schedule.
28. Predetermined (canned) schedules are available for use.
29. Provides for more than one terminal event for the project.

Output Characters

30. Activity precedence relationships.
31. Critical project activities (e.g., critical path).
32. Variance of activity times.
33. Activity earliest start and finish times.
34. Activity latest start and finish times.
35. Probability of successfully meeting scheduled completion date--single terminal event.
36. Probability of successfully meeting scheduled completion date--multiple terminal events (alternative to preceding two characters is no probability estimate provided).
37. Status on activity completion.
38. Status on funds expenditure.
39. Status on resource expenditure.
40. Activity/event slack or float.
41. Total cost in project delay or total cost of alternative project schedules.
42. Resource schedule for activity over time.
43. Forecast of project completion date after project is initiated.
44. Forecast of funds required for project completion after project is initiated.
45. Project problem area(s) are highlighted or flagged.

Source: Klaver, Robert P. "Selecting a Project Management Technique," Defense Management Journal, April, 1976, pp. 53-60.

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