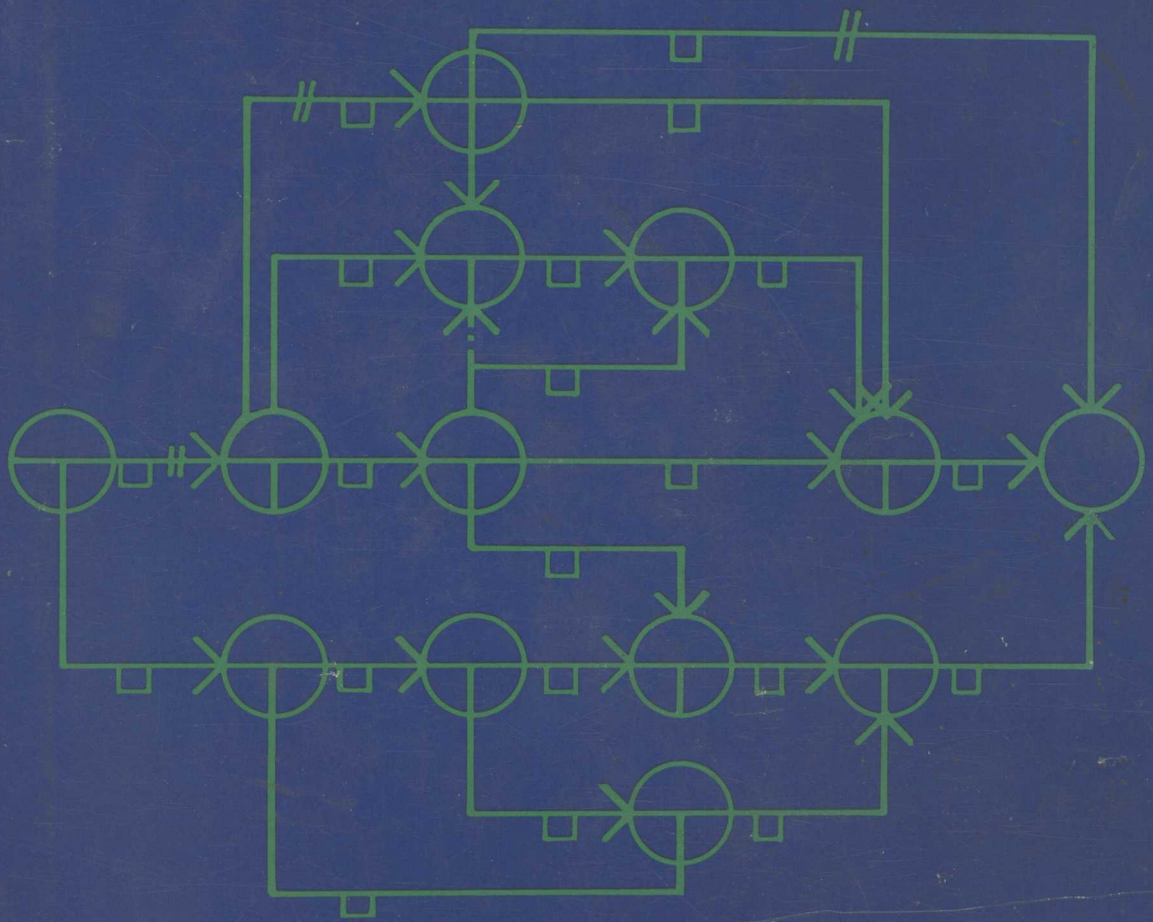
Project Management and Control: Volume I

Finding the Critical Path

R. L. MARTINO



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Project Management and Control

VOLUME I

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Preface to *Project Management and Control*

DURING THE PAST SIX YEARS I have discussed and used PERT and CPM with many people in many places. Whether with a company president or a foreman on a construction site, whether for a billion-dollar project or one costing a few hundred, whether in the United States, Canada, or Europe—two things have become clear. First, PERT and CPM are becoming indispensably necessary. Second, there is some confusion over their nature and use.

In the early days of PERT and CPM people told me that the techniques were not necessary because they embodied nothing new. "Who's using them?" they asked. Today, PERT and CPM are fashionable, and many experts and "fathers" exist. Furthermore, there are almost 50 variations, all with different acronyms. There are much opportunism, me-tooism, and bandwagonry. This faddism can obscure the truth, but, more important, it can lead to disenchantment when "PERT and CPM fail."

A long time ago, a very clever man said, "There is no royal road to learning." PERT and CPM are techniques; they are only as effective as the ability and experience of the user permit them to be. The rules are simple; their application, however, is *not* simple because it requires an analysis of what is to be done. We all tend to prefer to be "doing and planning by ear," rather than to plan before doing. Giving in to this tendency results in chaos. I think we are all familiar with the signs which indicate that planning is required.

There are currently literally thousands of applications of PERT and CPM. They vary from something as gigantic as our space program to something as common as replacing a valve in a steel plant. The projects vary in cost from a few hundred dollars to several billion. PERT and CPM are universal in the sense of their range of applications, both by type of project and by size.

I hope in this book to present to the reader, in non-technical language, the essence of PERT and CPM. I have a strong dislike of any book which presupposes that I know everything about its subject before I start reading it. I trust I have carried this bias as a reader into my efforts as a writer. I have found it necessary to be redundant in order to be clear. To those more quick-witted than I, my apologies for this redundancy.

When giving courses on the subject in conference room, classroom, and briefing room, it is easier to make a point by drawing a simple diagram and singling out the particular parts of the diagram referred to. This diagrammatic approach, with a heavy reliance on reference to specific parts of a diagram, has been incorporated into this book. My objective, as stated, is to explain what PERT and CPM are and how to use them profitably to solve problems. But it has seemed impossible to do this in just one volume. Consequently, the editors and I have decided to issue the material in two separate volumes. The first is entitled *Finding the Critical Path* and is devoted to the basics of both PERT and CPM; the second volume, entitled *Applied Operational Planning,* deals with the use of these basics in project management and control, covering the subjects of PERT/COST and resource allocation and scheduling.

Many people may require only the first volume in preparing an arrow diagram and in finding the critical path. Others with perhaps more knowledge of the basics will be mainly interested in the second. Both volumes, however, are required for an understanding of the PERT/CPM concept as a whole. In particular, I call the attention of the reader to Chapter Seven of *Finding the Critical Path,* which does, I believe, invalidate much of the literature published to date on the way to use PERT in project planning.

There is no doubt that PERT and CPM are revolutionizing the concept and method of project management and control. PERT and CPM are fashionable today (1964) because of the hard work and earnestness of the pioneers. Certain individuals stand out for their tremendous contributions to the state of the art. Some were developers or creators of the techniques, some spearheaded the initial applications to justify the worth of the techniques, and

some, in positions of authority, were convinced that these unknown techniques could help them. Their number is endless, and to attempt to select "the" list for the entire field of PERT and CPM would undoubtedly lead to omissions. There are, however, certain individuals with whom I have worked, or for whom I did work, who stand out for contributions which led to this particular book. These people are Dr. John W. Mauchly; James E. Kelley, Jr.; Morgan R. Walker; Ian D. Ritson; Air Vice Marshal C. F. Johns; Colonel E. Churchill; E. S. Steben; John R. Hopkins; and Borge Christensen.

Jim Kelley and Morgan Walker developed the original mathematics and the approach of what is now termed CPM. John Mauchly was the coordinating influence who brought Kelley, Walker, himself, and me together as Mauchly Associates in 1959. Ian Ritson, now with Olin Mathieson Chemical Corporation, believed in the capabilities of CPM in 1959 and, while with Perini Ltd., convinced top management to try it. He carried this conviction to Olin Mathieson, which is now one of the more advanced users of PERT and CPM in its project work.

Air Vice Marshal Johns (Assistant Deputy Minister of National Defence in Canada) and Colonel Churchill (Director of Special Projects for the Canadian Army) believed that these techniques could help them in certain aspects of their work. This led to extensive work with the Canadian Government during the spring and summer of 1960. Stan Steben, then Major Steben, was a dedicated and dynamic worker and "critical path enthusiast" all through that period (and has remained so since).

Some of the more "practical" aspects outlined in these volumes were developed, because of need, during this period. In particular, the concepts of resource allocation and scheduling were formulated and first applied in a rudimentary fashion at that time. I have since incorporated additional developments in these techniques and have called the overall approach MAP.*

Throughout the period, Jack Hopkins, now with UNIVAC, worked with me. I am indebted to him for much constructive criticism and suggestion.

I first met Borge Christensen, of General Electric, in September 1960 when he registered in a course I was conducting on CPM and MAP in Toronto. To him I am indebted for the manner in which he grasped the potential scope of PERT and CPM applications. His efforts led to the development of the CPM package for the G.E. 225. I shall always remember with nostalgia the time spent in Phoenix in May 1961 working with Borge to train G.E. Computer Department personnel and prepare the "225 Package."

Acknowledgment must also be made of the fine contributions of Admiral W. F. Rayborn and of the Special Projects Office of the U.S. Navy in spearheading the development and application of PERT on the Polaris program. The team of men from Booz, Allen and Hamilton, headed by Don Malcolm, deserve credit for developing PERT/Time.

*I first called it Manpower Allocation Procedure to avoid the acronym RAP for Resource Allocation Procedure. Now I call it Multiple Allocation Procedure. In any event, I like the acronym MAP, and we can always say it's "Martino's Allocation Procedure."

It goes without saying that I am indebted to the Olin Mathieson Chemical Corporation. When I was a "Mauchly Associate," that company was very receptive to the use of operational planning. Now, as a member of the corporate staff, I am even more pleased, looking on the inside, at the caliber of the work and the ability of the people doing it.

PERT and CPM are based on the premise that planning and scheduling are two separate and distinct functions. There is nothing new in any of the basic elements of these techniques. However, the manner in which all of the known concepts are rearranged is new—even revolutionary. This thought may be appreciated by considering radio and television. The components of the television set are not new. All of them were known when there was no television. Many of them were used in radio and often in exactly the same fashion as they are used in television. What is remarkably new in television is that by rearranging the known (or old) components, we suddenly get sight as well as sound—picture as well as voice.

PERT and CPM are, in that sense, the video of project management and control. By rearranging the basic and known elements, we proceed from "voice" alone to the clarity of a project plan and schedule.

No book can ever replace actual experience. This work is meant to provide the basic and fundamental information concerning the use of PERT and CPM. Applying the principles outlined in these two volumes to one project will be the first step in making you, the reader, an expert.

It is my hope that these books will be of value to the industrial student as well as the college student. In future I believe this material should be covered in undergraduate programs in business administration, engineering, science, medicine, and architecture. Arrow diagrams are as useful in the operating room as on the missile launching site.

A book of this nature incorporates recommendations, thoughts, and work of people other than the author. I am indebted to John J. McManus, Olin Mathieson Chemical Corporation, who constructively criticized the method of presentation; to Dr. Adrian McDonough, Professor of Industry, the Wharton School of Finance, University of Pennsylvania, for his guidance, encouragement, and moral support; to Dominic Fanelli, E. R. Squibb & Sons, and to Martin J. Gibson and E. S. Steben, Olin Mathieson Chemical Corporation, who commented on the manuscript; to Miss Catharine M. Haltigan, who typed it; and, most especially and appreciatively, to my wife Barbara, who suffered through the entire work with me. These two volumes are dedicated to her, the first woman in recorded history who had her wedding planned by PERT and CPM.

—R. L. M.
New York, 1964

Preface to Volume 1: *Finding the Critical Path*

THE BASIC ELEMENTS OF PERT AND CPM are a network diagram and a critical path. The network is a model of the project as a whole created by linking together arrows representing specific jobs which must be done. The time required to perform each job is used to find the critical path, which is the longest chain (or chains) from a project's beginning to its completion.

The true value of these techniques becomes apparent only *after* the critical path has been found. Before applying PERT and CPM, therefore, the rules must be determined for creating network diagrams and finding the critical path. This volume is concerned with developing, explaining, and applying just these rules.

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CHAPTER ONE

Introduction

MANAGEMENT IS A TOUGH BUSINESS. Not only is the margin for error shrinking between success and failure, between profit and loss, but the things we manage often appear unmanageable. Rapid technological change, decreased profit margins, increased competition, a shorter lifespan for new products, and a faster tempo combine to make management more difficult and demanding.

To make effective decisions, managers must have available pertinent and timely information. The decision makers of today are constantly deluged by a vast sea of data. Often this information is disorganized and irrelevant to the problem at hand. The needed facts, even when present, are impossible to extract.

Before a decision is reached, certain specific questions should be raised. For example:

What are the alternative courses of action, if any?

What is the cost of each alternative?

What are the risks?

When must the decision be made?

What will be the consequences if the decision is delayed?

In managing projects—both large and small—failure to have the answers to these and other basic questions can be costly or even disastrous. The high and increasing costs of idle equipment, idle manpower, and lost time must

be controlled. Ways must be found to develop better plans for projects, to allocate resources to project activities more economically, and to control all aspects of the projects more closely.

All this is true whether it concerns managing a business, supervising a research program, directing a voyage into space, or building one house. Many people recognize this problem of control, and many are working on its solution. PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) are project planning and control techniques that were developed to answer the basic needs of project management.

PERT/CPM

PERT and CPM were independently developed and first applied in the late 1950's. Initially, PERT was designed as a reporting technique to evaluate and monitor the phase-by-phase progress of the various projects (encompassing numerous contractors and subcontractors) in the Polaris missile program. CPM, on the other hand, was originally conceived as a computer-oriented planning technique designed to control construction, engineering, and plant maintenance projects.

Since PERT and CPM first appeared, their apparent differences have all but disappeared. In fact, features of one technique have been incorporated into the other, and vice versa. A difference that often used to be cited, for example, was that PERT was more suited to research and development projects in which more uncertainties were encountered. CPM was said to be especially effective in projects whose various jobs could be estimated in time and cost with a reasonable amount of accuracy—like the construction of a building. However, in recent years these differences, if they ever were valid ones, have disappeared.

The arrow diagram, or "network," is common to both methods. It is in the calculations that are made and in the emphasis that is placed on various aspects of the network that the differences appear. But, again, the variations between the way two users employ either PERT or CPM may be greater than the differences between the techniques themselves. The important point is that a working model of a project is developed by creating a master plan from which a realistic schedule can be prepared. This is true whichever method is used. The application of the basic approach, which can be termed operational planning, is more important than the specific rules by which the technique is applied (whether PERT or CPM).

Both techniques are equally applicable to planning, monitoring, and control, and both are equally applicable to *any* kind of project—R&D, construction, engineering, new product introduction, advertising campaigns, corporate planning, military tactical operations, and so on—provided the following concepts are continually borne in mind:

1. Planning must be geared to the operation to be performed; that is, the plan must be activity oriented. Attempting to plan with an event or "milestone" orientation can produce the *wrong* answer.
2. Reporting can be geared to the completion (whole or part) of

activities, or it can be geared to the arrival at, or expected date of arrival at, a milestone in the project. If an event orientation is selected for reporting purposes, then such a system can be properly established only from an activity-oriented plan.

This brief statement concerning the equal applicability of CPM and PERT is not perhaps convincing at this point. It will become obvious in later chapters.

Elements of a Project

There are three overall categories for the elements of a project:

1. Operations, or the things we *do*.
2. Resources, or the things we *use*.
3. The *conditions* or *restraints* under which we must work. These are the things outside our control.

Within these major elements there are certain characteristics or subclassifications that have to be considered. We are vitally concerned with the required sequence or order of operations. For example, it is fairly obvious that land must be leased or bought before building is started on it. However, if we are putting up two buildings side by side and we have only one excavating machine, it is not so obvious which hole should be dug first. The method of performing each operation must also be established. Associated with the method will be the time and cost of performance.

The resources are five in number: men, material, machines, money, and the one too often overlooked—time. These may be considered as *internal* restrictions. As to *externally* imposed conditions, a predetermined and necessary completion date is our greatest concern. Another external restraint may be capital restrictions of one kind or another. Quite obviously, any project plan must take into account the delivery by outside agencies of such things as design, materials, machines, and the like. Approvals, inspections, and just about anything else that can be thought of may likewise be called outside restrictions.

All these elements and subelements compose the project. The objective is to coordinate all of them—often conflicting—in a master plan which must be a working model of the project.

The first step in creating such a master plan is to determine what jobs are to be done and their sequence of performance. This is best carried out by producing an arrow, or network, diagram.

Management—What Is It?

Before outlining in greater detail how PERT/CPM can be applied to project management problems, let us take a look at management. Just exactly what is it? It obviously means many things to many people. For instance, making a profit in a corporation, passing an examination, winning a battle, or preparing a budget all require management. Here are four diverse activities, yet management can be generalized to cover each one of these and all others we can think of.

Essentially, management can be defined as—

1. Selecting the objectives of our enterprise (or project).
2. Determining what is required to meet these objectives.
3. *Judiciously* allocating the resources at our disposal to achieve these objectives according to a plan and schedule.
4. Controlling the entire process from point of decision or commitment to completion (achievement of objectives).

Its effectiveness is measured by the results it achieves and, more especially, by the response time of manager and method when things go wrong.

Quite obviously, planning is a vital function of management. However, there is the equally vital and more specific task of planning, scheduling, and supervising the various individual projects which are integral parts of an overall plan. Efficient planning of these constituent projects *always* means the difference between "on time" and "late," and it *can* mean the difference between success and failure.

Computers and Mathematics

Network analysis was developed as a computer-oriented project planning, scheduling, and control technique through the use of higher mathematics. The terms "mathematics" and "computer" do not, in any way, restrict CPM and PERT. The computer is a tool. While CPM and PERT calculations are often produced by computer, they can just as well be figured by hand. The only time a computer should be used is when speed is required for a large mass of calculations, or when it is cheaper.

Mathematics is not used in applying CPM and PERT, nor is any knowledge of mathematics required to apply these tools. Mathematics is used to develop, justify, and prove the rules, *which require only simple arithmetic to apply,* or which are programed into a computer.

In summary, mathematics justifies the rules, and computers can speed the result. We don't really need to know anything further about either.

Why These Techniques?

Just how and why are CPM and PERT applied to a project? The "why" is obvious. Decisions often commit a company to major outlays of capital. The projects such decisions set in motion lead to a need to coordinate the myriad interrelated functions that must be considered to produce a plan and schedule. Even more important is the need to be able to incorporate changes, as they occur, and immediately to know the effect of a change. What is required, therefore, is a dynamic planning and scheduling system which will not only produce the best possible initial plan and schedule but will be sufficiently dynamic to react instantaneously to changed conditions and still produce the best plan and schedule.

What a Project Is

Prior to outlining how network analysis is applied to project management, it is necessary to consider some additional basic concepts.