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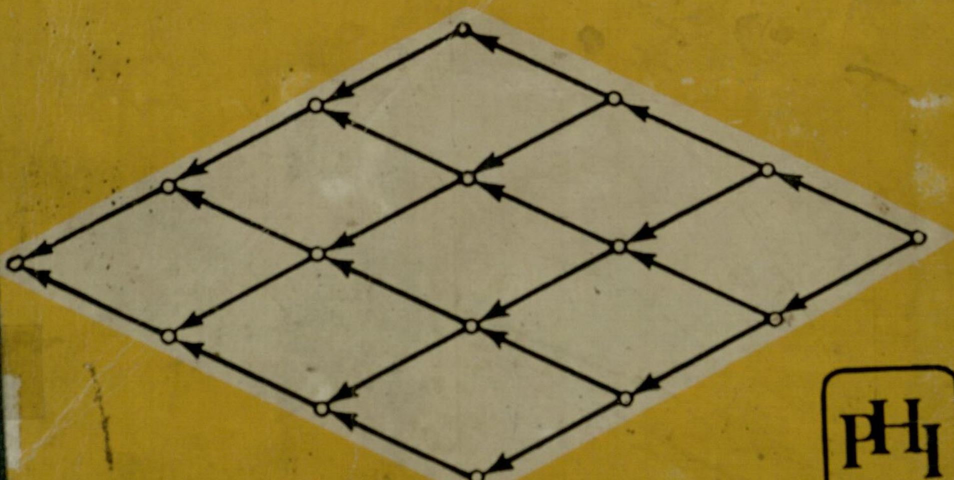
JEROME D. WIEST
FERDINAND K. LEVY

A MANAGEMENT GUIDE TO PERT/CPM

WITH GERT/PDM/DCPM and other Networks

Second Edition



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by Jerome D. Wiest and Ferdinand K. Levy

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To Yvonne and Mimi

Contents

Preface

The first edition of this book had two purposes. First it was intended to acquaint the student in management-oriented courses with all the fundamental concepts necessary to understand and use PERT/CPM scheduling techniques. Second and equally as important, the book was designed to be a basic guide and reference to those techniques for both potential and actual users in industry. The second edition follows closely the pattern of the first. In addition, applications of these two powerful techniques have been expanded and clarified in exposition. Moreover, the newer network scheduling techniques which PERT/CPM have spawned in the past five or six years, for example, GERT, PDM, etc., have been added to make this edition a more complete reference and study guide.

The emphasis throughout this edition remains on the basic ideas of network scheduling techniques and the variety of management problems to which they are applicable. As in the first edition, more advanced methods using mathematical and computer techniques are fully discussed in appropriate appendices to the chapters. New and expanded exercises, complete with solutions, are included at the end of the book and are designed to make sure that the reader fully understands the fundamentals explained in the body of the book. These exercises are keyed by chapters so that a concept introduced in a specific chapter has a problem that uses it in the exercises.

The literature on network scheduling techniques was voluminous five years ago and has continued to expand at a geometric rate. We have expanded the bibliography at the end of the book which, although not complete, is comprehensive in its coverage of concepts of network scheduling techniques and their myriad of applications. An understanding of the ideas presented in this book should be sufficient background for anyone wanting to pursue reading further in this ever-growing area.

We should like to acknowledge the environment that the Graduate School of Industrial Administration at Carnegie Institute of Technology provided us in the early 1960's so that we were able to collaborate on a series of research papers introducing and developing network scheduling techniques. The first edition of this book was a product of the papers developed at Carnegie and was written at Rice University. The University of Utah and Georgia Institute of Technology have provided partial support for the present edition.

We also want to thank the journals whose work we reproduce here for granting us permission to include material originally presented in them. Finally, we express our deepest appreciation to Ms. Alice Erdman at Prentice-Hall for a competent and thorough editing of the final manuscript and to Mr. Bruce Toth, currently of the Graduate School of Business at Stanford, for his help on the bibliography.

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1

PERT and CPM Come of Age

Developed in the late 1950s to aid in the planning and scheduling of large projects, PERT and CPM are today widely used in industry and services throughout the United States and in many other countries around the globe. Their life history to date, although short, has been interesting and rather hectic. In their early years, the tools were heavily promoted, especially by U.S. government agencies, which insisted on their use by contractors on major government projects. There followed a period of critical examination of network techniques, a more rational assessment of their strengths and weaknesses, and a shifting of their use from less appropriate to more suitable applications. Today their use is firmly established among organizations concerned in one way or another with the managing of projects, and surveys indicate that they are among the most commonly used of all quantitative tools of management.

Basic concepts of PERT and CPM, such as activities, events, and predecessors, have become a regular part of the language of project managers and have facilitated communication at every level of management and across organizational lines—between foremen and engineers, managers and technicians. Extensions and modifications of the tools have greatly increased their usefulness and the range of their applications. Although such developments are continuing, PERT and CPM have reached a degree of maturity that justifies the assertion that they have, indeed, come of age.

The historical development of PERT and CPM gives us some idea of their purpose and nature and helps to explain both their similarities and

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Planning and Scheduling Networks

In this chapter we develop the terminology necessary for a thorough understanding of CPM and PERT planning and scheduling. As pointed out previously, the prerequisites for using either of these techniques include separating the project to be scheduled into independent jobs, or activities, and determining an order of precedence for these jobs. That is, we must see which jobs have to be completed before others can be started. The next step is drawing a picture, or graph, which portrays each of these jobs and the predecessor and successor relations among them. The concepts associated with constructing and understanding this graph will be our major concern in this chapter.

Let us begin our discussion with a simplified example of the budgeting process in a large manufacturing firm that we shall call the W-L Company. Suppose that the president of W-L wants his next year's operating budget prepared as soon as possible. To accomplish this *project*, the company's salesmen must provide unit sales estimates for the period to both the sales manager and the production manager. The former must estimate market prices on the forecast and give these to the financial officer. The production manager must make machine schedules of the units to be produced and assign machines for their manufacture. Next, he must give these schedules and machine assignments to the accounting manager, who must then provide costs of production to the financial officer. Then the financial officer, using the information provided by the sales and accounting departments and

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Finding the Critical Path

Once we reduce a project to a network of activities and events and we estimate activity durations, we are in a position to determine the minimum time required for completion of the whole project. To do so, we must find the *longest path,* or sequence of connected activities, through the network. This is called the *critical path* of the network, and its *length* determines the duration of the project. In this chapter we are primarily concerned with finding and measuring the critical path in a project network. First, however, we must clearly define what we mean by a *path* in a network and by the *length* of a path. We hope to accomplish this with the aid of the following simple example.

Suppose that the W-L Company has two salesmen who meet for dinner one night in San Francisco. They discover that they are both going to Los Angeles the next day and agree to continue their conversation at dinner that night. The first salesman, whom we shall call Mr. Allen, lives in Santa Barbara and plans to go through that city, have lunch with his wife, and then travel on to Los Angeles. Mr. Baker, the other salesman, has an appointment with a customer for lunch in Bakersfield and must go there on the way to Los Angeles. As both have to work in Los Angeles the day after they arrive, they want to meet for dinner as early as possible. Their problem then is to decide the earliest possible time to meet for dinner if they both leave at 8:00 A.M. the next morning.

The driving time from San Francisco is about 8 hours if one goes through Bakersfield on U.S. 99 and about 11 hours if one goes through Santa

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The PERT Model

Both CPM and PERT, as we have noted, use the project network. It is the basis of both techniques, and the notions of critical paths and activity slack are common to each. How, then, do they differ? Why two models? For historical reasons mainly. The models were developed independently and in somewhat distinct problem settings. As it has turned out in actual applications of the two models, some of their differences have disappeared or at least have become less important. But, traditionally, each has had a special emphasis of its own—each has been concerned with somewhat different aspects of the scheduling problem. Perhaps this is because they were originally applied in different kinds of industries and to somewhat different kinds of problems.

The Problem of Uncertainty

PERT was developed for and has been used most frequently in the aerospace industries—notably in research and development types of programs. These industries are relatively new; their technology is rapidly changing, and their products are nonstandard. CPM, on the other hand, has most frequently been applied to construction projects. For the most part, houses, bridges, and skyscrapers use standard materials whose properties are well known. They employ long-developed and well-seasoned components, and they are based on a more or less stable technology. Changes occur mainly in design—sizes, shapes, and arrangements—rather than in design concepts.

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The CPM Model

The critical path method was originally developed to solve scheduling problems in an industrial setting. For this reason, probably, it was less concerned with the uncertainty problems that PERT attempted to cope with and more concerned with costs of project scheduling and how to minimize them. Thus, unlike PERT, CPM does not make use of probabilistic job times; it is a "deterministic" rather than a "probabilistic" model. It does, however, allow for variations in job times, not as a result of random factors (bad luck or good luck) but as the planned and expected outcome of resource assignments.

Most jobs, CPM argues, can be reduced in duration if extra resources (men, machines, money, and so on) are assigned to them. The cost for getting the job done may increase, but if other advantages outweigh this added cost, the job should be expedited, or *crashed.* On the other hand, if there is no reason to shorten a particular job—if it has a generous amount of slack—the job should be done at its *normal* or most efficient pace, with a lesser assignment of resources. Thus there is no need to crash all jobs to get a project done faster; only the critical jobs need be expedited. Which jobs to expedite and by how much are the problems CPM attempts to solve.

Schedule-Related Project Costs

The cost of a project is not due solely to the direct costs associated with individual activities, or jobs, in the project. Normally, there are indirect expenses as well—overhead items such as managerial services, indirect sup-

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PERT/Cost: A Network Cost Accounting System

In their original developments, both PERT and CPM were essentially time-oriented. As planning tools they enabled managers to estimate the *time* required to complete a proposed project. As scheduling techniques they provided a means of establishing *time* schedules for project activities. And as control devices they allowed managers to check scheduled *times* against actual *times* for activity durations or event occurrences. While it is true that CPM included a cost–time trade-off feature, costs were to be considered only as a means of finding activity times. No provision was described in early CPM literature for compiling activity costs which resulted from the optimizing process in order to obtain total project costs, either for predictive or control purposes. Thus the output of the original CPM model was a list of optimal activity *times* (durations), generally with associated early and late start schedules, rather than a list of activity costs or a project cost summary.

Users (and critics) of CPM and PERT early commented on the need for an extension of these network techniques into the area of cost control. They argued that managers are concerned with activity costs as well as with elapsed activity times. Cost control is usually as important as time or schedule control—and frequently even more so. The incorporation of cost features in PERT and CPM seemed like a logical and desirable extension of these models, but several years elapsed after their introduction before network cost control systems were developed and made generally available.

A few individual users devised procedures of their own during the early years of network analysis, but the major impetus to cost-control systems came with the publication in 1962 of a U.S. government manual, *DOD and*

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Network Scheduling with Limited Resources

Until now we have assumed that the only constraints in scheduling an activity—that is, in assigning to it start and finish dates—have been technological in nature. An activity can be started, we have implied, as soon as all of its technological predecessors have been completed. If all activities were scheduled as soon as technologically possible, we would have an early start schedule, either of the PERT or CPM variety. Similarly, by considering successor activities, we could create a late start schedule, and if this differs from the early start schedule, there are any number of other schedules that we could create by shifting slack jobs back and forth within the limits of their respective slacks. All these schedules may be generated from only two sets of data: (1) activity precedence relations, as exhibited by a network diagram, and (2) activity durations (either expected values based on PERT calculations or optimal durations resulting from CPM procedures).

Implicit in such scheduling procedures is the assumption that the resources required to perform activities are available in unlimited supply, or at least that sufficient resources are available for each activity to be scheduled sometime between its earliest and latest start dates. It is true that, in some instances, estimates for individual activity times are influenced by a consideration of available resources. But such estimates are usually made independently of other activity estimates, and the possible competing claims for the same resources are not explicitly considered. While the assumption of unlimited resources may be justified in some cases, most project managers are faced with the problem of relatively fixed manpower availabilities, a certain number

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Modifications and Extensions of Network Models

It is probably inevitable that the development of new management techniques such as PERT and CPM will be followed by efforts to modify or elaborate on the techniques. No matter how general the model or broad its applications, there will be situations in which it does not quite apply or is not completely satisfactory in its present form. Efforts will then be made to extend its usefulness by incorporating additional features and capabilities. Sometimes the model stimulates researchers or practitioners to think of how a like approach might be used to solve similar (or even dissimilar) problems; and major modifications in the original model result from attempts to adapt it to new applications.

Such a course of development has certainly been true in the case of PERT and CPM. We have already described the extension of PERT into a cost accounting system (Chapter 6) and the incorporation of resource constraints in network scheduling models (Chapter 7). In both these cases, the concept of a project network remained unchanged: it still consisted of a collection of partially ordered jobs, all of which had to be performed in accordance with certain fixed precedence constraints (and, in Chapter 7, resource constraints) before the project was completed.

This chapter deals with extensions of the model in which the concept of the network itself is modified. Some of the assumptions on which the network model is based have been criticized as inappropriate or insufficient in certain project planning and scheduling situations. For example, the single precedence relationship used in the network ("a job must be finished before

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Problems and Prospects in Applications of PERT/CPM

More than two decades have passed since critical path scheduling was first introduced—enough time so that we can look back with a measure of objectivity and appraise what happened during its early and rather hectic introductory period. We do so with the intent of considering the lessons that can be learned for the benefit of today's managers who make use of PERT and CPM.

As is true of many new techniques (or new commercial products of any kind), there was a lot of initial ballyhooing for PERT and CPM. Interest was greatly accelerated when the federal government, particularly the Department of Defense, jumped on the PERT bandwagon and began requiring PERT capability of major defense contractors. Converts—willing or unwilling—were numerous. Since the model was basically simple, it could be learned readily; and instant experts offered themselves in great numbers as consultants. Published literature abounded, with articles appearing everywhere—from trade magazines to learned projessional journals. Many students won master's and doctoral degrees with theses based on project scheduling models. PERT entered the English language not only in its original form but also as a verb ("the project was *perted*"), an adjective (*pertable* and *pertorial*), an adverb (*pertwise*), and in various noun derivatives (*pertor, pertee, pertocracy,* etc.).[1]

[1]See M. Krakowski, "PERT and Parkinson's Law," *Interfaces*, 5, No. 1 (Nov. 1974).

Bibliography

The literature on network planning and scheduling techniques has continued to expand rapidly. Not surprisingly, the following bibliography has also grown from that in the original edition. But we have been guided by the same purpose: to compile a representative rather than comprehensive list of references. As before, we have categorized the entries according to general content or purpose, in order to make the list somewhat more useful to the reader.

First listed are general sources, mostly of an expository nature, whose major purpose is to acquaint the reader with the basic network techniques. Most of these are articles which have appeared in a wide variety of journals and magazines. We have attempted to select explanatory rather than descriptive articles, omitting, for the most part, short news articles of from one to four pages from newspapers and trade journals. Following the articles is a list of books primarily devoted to project management and network analysis. Some of these are "how-to-do-it" books (for example, those by Miller, The Federal Electric Corporation, and Martino), while others contain material of theoretical interest (those by Battersby, Kelley, and Moder and Phillips).

The next major heading is "Theory: Analyses and Extensions of Network Scheduling Techniques," followed by a number of subtopics. Entries in this section are drawn mainly from technical journals and were typically authored by persons more interested in theoretical rather than practical aspects of the techniques. Their purpose has been to analyze critically rather than to describe the models and to suggest modifications or extensions of conceptual interest. The subheadings reflect what we feel have been some of the major areas of analysis and research. Not all articles fit neatly into our categories, however, and some of our placement decisions may seem a little arbitrary. Fulkerson's article, "A Network Flow Computation for Project Cost Curves," for example, obviously straddles our categories, "Cost-Time-Performance Relationships" and "The Network: Theory, Interpretations, *Complexity, Decomposition, Divisible Activities,*" though we placed it in the former.

The final section, "Managerial and Operational Aspects," lists articles with a more practical slant—those describing particular applications of PERT and CPM or evaluating such applications from a managerial viewpoint. Operational rather than theoretical strengths and weaknesses of the models are stressed. The section closes with a list of bibliographical sources which will guide the interested reader to more articles—and perhaps more bibliographies!

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