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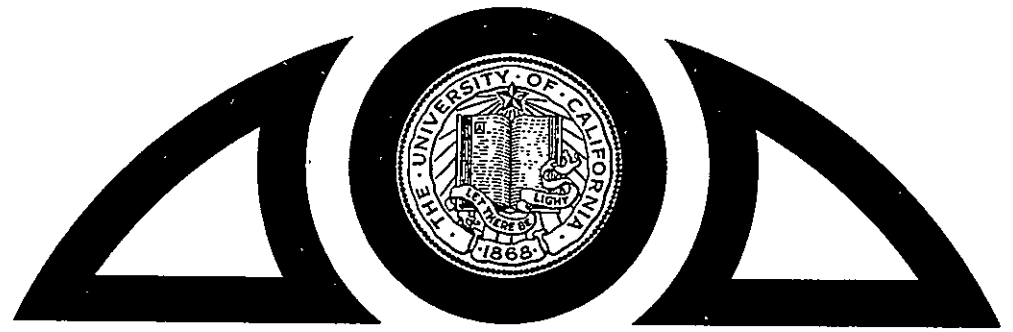

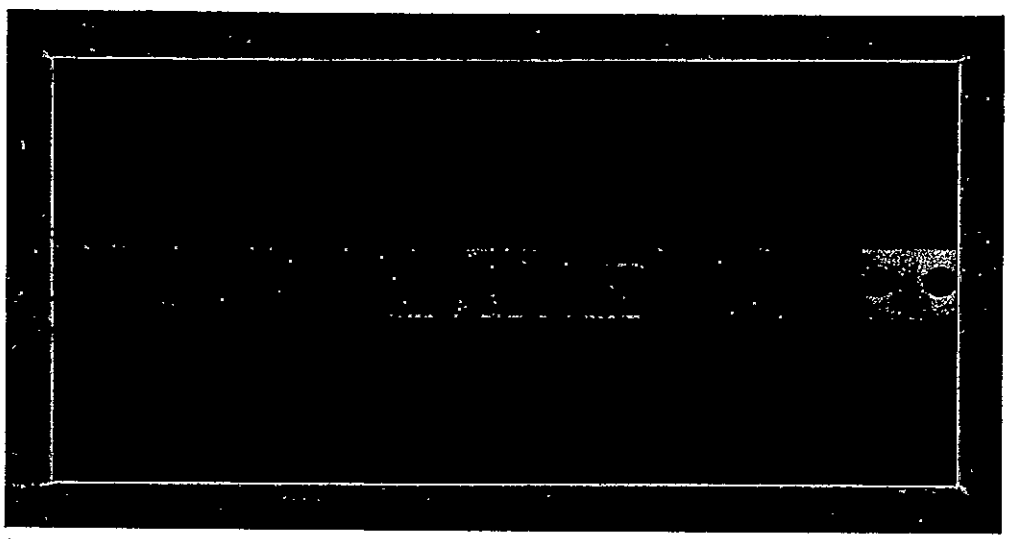

NASA RESEARCH PROJECT

Graduate School of Business Administration / Division of Research

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PERT AND PROCUREMENT POLICY

By

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FOREWORD

The Program Evaluation and Review Technique (PERT) has come to play an increasingly important role in the planning and control of the defense and aerospace effort. However, no tool can be used indiscriminately. It is important to know when, how, and under what circumstances PERT can be employed effectively in the procurement process.

In PERT and Procurement Policy, Jack Hayya presents a set of optimal rules that enable government procurement officers and the aerospace industry's contracting personnel to make decisions about the appropriate use of PERT. Though the audience of the study is to be found primarily among those engaged in defense and aerospace procurement, all managers who are currently using or planning to use PERT will find the research findings useful.

The reader who is interested only in an overview of the study will find a succinct resume in chapters I and VI.

PERT and Procurement Policy is a part of a continuing series of studies on the management of research and development programs conducted in the Division of Research, Graduate School of Business Administration, University of California, Los Angeles. The study was largely supported by National Aeronautics and Space Administration (NASA) funds.

George A. Steiner
Director, Division of Research

PREFACE

This study is designed to establish a basis for a rational solution of the major problems associated with the use of Program Evaluation and Review Technique (PERT) in the procurement of aerospace and defense weapon systems. The need for such a study became apparent when discussions with aerospace industry personnel indicated a growing dissatisfaction with the emphasis the government was putting on PERT as the major planning and control technique in the procurement process.

The research investigation involved a thorough review of the literature, interviews with industry and government representatives, and a comprehensive questionnaire survey. This paper summarizes the findings of these investigations with emphasis on the results of the questionnaire survey. A more detailed discussion of the literature, the interviews, and the survey methodology and results is found in the author's doctoral dissertation.[1]

The quantitative analysis presented in this report is based on twenty-seven projects reported for PERT/Time and thirty-four for PERT/Cost. Because much of these data were in the category of privileged information, it was necessary to provide anonymity for most of the projects reported and many of the people who participated. The topic itself made necessary the use of specialized aerospace terms. For the convenience of the reader, a glossary of these terms is provided in Appendix I.

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[1] Jack C. Hayya, A Study on the Appropriate Use of PERT in Procurement Contracts (Ph.D. dissertation, the University of California, Los Angeles, 1966).

It is difficult to express sufficient appreciation to Professor George A. Steiner[2] who gave unstintingly of his time in the guidance of this research. Special thanks are due also to the Division of Research, Graduate School of Business Administration, University of California, Los Angeles, for making available National Aeronautics and Space Administration funds, which financed the greater portion of the research.

It would be impossible to thank personally all of the aerospace industry representatives and systems project officers who assisted or participated in this study. The author must, however, give special mention to Colonel Alvin Dill of the United States Air Force, Mr. Burt DeVisser of the Lockheed-California Company, and Mr. Hyman Silver of Aerospace Corporation.

The author, finally, wishes to express his appreciation to Marilyn McElroy, who typed this manuscript, and to Patricia Hay, who edited it. Thanks are also due to Mary McMurray, who handled the important administrative details connected with its publication.

Jack C. Hayya

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CHAPTER I

INTRODUCTION

This paper is an extension of previous and complementary studies on planning and control network models in general and on Program Evaluation and Review Technique (PERT) in particular. Earlier studies include one by Henry B. Eyring on network planning models[1] and another by Peter P. Schoderbek on PERT.[2] Eyring and Schoderbek both treat the network model largely as a requirement endogenous to the firm. They do not analyze its impact on the firm when the use of the model itself is dictated by exogenous circumstances--that is, when the government requires the use of a network planning and control model such as PERT.[3]

Since this NASA Research Paper deals with the latter, it in this respect differs from other studies on network planning models or PERT. Furthermore, it is oriented to the functions of government procurement or systems project officers in that it presents optimal decision rules for the use of PERT in procurement contracts.

The government's need of PERT for planning and controlling complex weapons' systems may be traced to the failure of less sophisticated techniques (such as Gantt charts) in harnessing cost-overruns

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[1]Henry B. Eyring, Evaluation of Planning Models for Research and Development Projects (doctoral dissertation, Harvard University, 1963).

[2]Peter P. Schoderbek, PERT - An Evaluation and Investigation of its Applications and Extensions (Ph. D. dissertation, The University of Michigan, 1964).

[3]Schoderbek, however, considers a requirement by the government that a firm use PERT to plan and control a project only one of the reasons for the firm's resistance to PERT.

and schedule slippages. The reliance on PERT instead of previous methods, however, infringes in some cases upon the proprietary and managerial rights of aerospace firms as, for example, when government procurement and systems project officers monitor defense and aerospace contracts in too great detail.

It is clear that there are situations when the government is justified in requiring an aerospace firm to use PERT, or any other technique, in a particular contract. There are other times, however, when an aerospace firm, as a unit in a competitive and free society, is best fitted to exercise judgment and discretion regarding policies of management. Department of Defense (DOD) Directive 3200.9,[4] other government memoranda, and even the current PERT literature do not clearly draw the line between the reasonable domain of government intervention in the management of aerospace firms and the justified proprietary domain of the firms themselves. To be sure, the boundary line between the domain of public interest and the domain of private concern is sometimes non-existent in the defense and aerospace effort. Into this no-man's land, characteristic of the government - aerospace industry relationship, fall many of the problems associated with the use of PERT in procurement contracts. Much of the friction between the government and the aerospace industry attributed to PERT is really due to the older, more subtle and extremely more complex "marriage" between the defense establishment and the aerospace industry

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[4]DOD Directive 3200.9 from Secretary of Defense Robert S. McNamara, February 26, 1964, and July 1, 1965.

Objectives of the Study

It is possible to look at the use of PERT in the procurement process by itself, apart from the more general question of what constitutes a reasonable relationship between the government and the aerospace industry. Thus some basic decision rules, or principles, may be derived to aid government procurement officers in determining when, where, and under what circumstances to require an aerospace contractor to use PERT. The objective of this study is to develop a set of such principles, although they are subject, of course, to the needs of the government, the rights of the contractor, and the logic of the situation.

When this study was launched in the fall of 1963, it was apparent that four areas of controversy relating to the use of PERT in procurement contracts existed between the government and the aerospace industry. The first of these concerned the type of contract. For example, should a procurement officer require a contractor to use PERT in cost-plus-fixed-fee contracts as well as in firm fixed-price contracts? Contractor and government responsibility differs sharply in these two contracts according to the Armed Services Procurement Regulation.[5] Obviously, the type of contract should influence the government's requirements for managing a project in a specified manner.

The second area of controversy was related to the type of project where PERT should be used. At the beginning of the study, some procurement officers were not aware that PERT was designed primarily

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[5]Armed Services Procurement Regulation, Department of Defense (Washington, D. C.: July 1964), pp. 327-340.

for research and development projects. In the rush of enthusiasm for PERT, many people advocated it as an overall tool of planning and control in any type of procurement, whether basic research, research and development (R&D), or production. It was necessary, therefore, to seek a definitive answer to this question even though it seemed to the author from the start that PERT should be used in R&D projects only.

The third controversial point involved the threshold contract prices that make mandatory the application of PERT in procurement contracts. When this study (which antedated DOD Directive 3200.9, dated February 26, 1964) was initiated, this was a problem of grave concern for both the aerospace industry and for procurement officers. Even after DOD Directive 3200.9 was issued with threshold contract prices, making the use of PERT/Cost mandatory on projects in engineering development or operational systems developments that exceeded $25 million in RDT&E or $100 million in production investment, there was a question as to the arbitrary nature of the choices made by DOD. It was interesting to note that the quantitative analysis made in the course of this study showed that the DOD threshold price criteria were not unreasonable.

The fourth, or final, subject of controversy was the level of PERT/Cost detail that should be required by a procurement officer if and when PERT/Cost was a contractual requirement. This was an extremely complex issue because only by looking at detailed data could the government effectively prevent cost-overruns and schedule slippages. Yet, it was at this point that the aerospace industry was

most vulnerable, and it was sensitive to what it considered an abrogation of its managerial rights and abuse by procurement officers of the government's enormous market powers.

Methods of Research

An attempt to formulate criteria or principles to resolve the above problems required three steps. First, a thorough review was made of the relevant literature. It was clear from this that a controversy about the value of PERT as a planning and control technique for the firm raged some time before the government took an active interest in PERT. Furthermore, the literature indicated that the government made a number of arbitrary decisions concerning criteria for the use of PERT when it became interested in its use as a planning and control tool in procurement contracts. There was also evidence that some form of dialogue about the subject was taking place between the government and the aerospace industry but the position of the aerospace industry was not being represented accurately.

The second step in the research investigation consisted of a series of interviews with representatives of the aerospace industry and the government. The aerospace industry group consisted of top managers, directors of PERT, and members of PERT staffs. The government group consisted of procurement and systems project officers. The purpose of the interviews was to clarify the industry-government situation relating to PERT, gather other information useful to the study, and aid in developing a questionnaire to deal directly with the major areas of controversy.

The interviews revealed that the industry-government environment in relationship to PERT was clouded with suspicion, but they also made clear that the suspicion antedated PERT and, indeed, was characteristic of the relationship between the government and the aerospace industry. In addition, the interviews showed that problems arose even if the firm utilized PERT on its own volition and the situation was not complicated by the government's requiring its use in a specific contract.

One of these problems was that accounting departments in firms organized functionally were not geared for the cost estimating requirements of the PERT/Cost system. Another was the resistance of the operating personnel and top managers to change symbolized by the furor created in the introduction of PERT into a firm. This resistance, however, was directed more at PERT/Cost than at PERT/Time, because PERT/Time generally proved its worth in solving scheduling problems while creating a minimum of operating difficulties for the firm. PERT/Cost, on the other hand, required extreme changes in organizational procedures (for example, in accounting) and was therefore resisted by those who were accustomed to the former practices.

The third stage of the research consisted of a comprehensive questionnaire survey of aerospace firms and systems project officers. (The questionnaire is reproduced in Appendix II.) The survey concentrated on those firms and project offices that the interviews had indicated were using PERT, and it had three purposes. The first was to poll the opinions of those working, or contemplating work with PERT, on the applicability of PERT when it is a government contractual

requirement as a function of contract type, project type, and threshold contract prices. Opinions were also sought as to what constituted a reasonable level of detail when PERT/Cost was used.

The second purpose of the questionnaire was to collect quantitative data so that expressions for the cost of PERT (PERT/Time and PERT/Cost) and for the size of the PERT/Cost work package might be developed. Evidently, criteria for the use of PERT as a function of contract price might depend on the cost of PERT itself. The size of the work package, on the other hand, might be constrained by some quantitative considerations that could be measured in the study.

The third purpose of the questionnaire survey was to validate the attitudes of the aerospace industry toward PERT. These attitudes, as expressed in the interviews, were marked by a good deal of skepticism about the value of PERT to the aerospace firm.

As a whole, the firms to which questionnaires were sent received 90 percent of all contract dollars in 1963. They included, according to the information collected during the interviews, all firms using PERT at the time. They also included the top twenty-one defense and space contractors of 1963, of which nineteen replied to the questionnaire. In all, respondent firms accounted for 80 percent of the defense and aerospace business in 1963.

Government systems project officers participated in the questionnaire survey as indicated earlier. Their responses and those of the aerospace industry personnel were represented in ninety-seven questionnaires returned by the participants.

Organization of the Research Paper

This chapter has introduced some of the problems associated with the use of PERT in defense and aerospace procurement contracts. The objectives of this paper and the methods of research used have also been discussed.

Chapters II, III and IV compose the body of this paper and deal exclusively with the major findings of the research. Chapter II considers the appropriate type of procurement contract for the use of PERT, while Chapter III deals with the type of project or activity suitable to its effective employment. Chapter IV concerns the threshold contract prices that make the use of PERT/Time or PERT/Cost mandatory, and Chapter V deals with the difficult question of what constitutes an appropriate level of detail when PERT/Cost is used in a particular program.

Thus Chapters II through V enumerate the findings of the research as they relate to the four major objectives of the study; they rely heavily on the questionnaire survey discussed under Methods of Research.

Chapter VI concludes this Research Paper and presents a set of recommendations. These recommendations are conceptualized in a simple decision model for the use of PERT in procurement contracts.

CHAPTER II

PERT AND TYPE OF CONTRACT

There are two major types of procurement contracts--cost-reimbursement and fixed-price--according to the Armed Services Procurement Regulation (ASPR).[1] Each type is comprised of several contract categories, which are described in detail in the ASPR.

There is one essential difference between cost-reimbursement and fixed-price contracts. The ASPR states that cost-reimbursement contracts are to be used only when the uncertainties of the program are too great to estimate costs accurately. In cost-reimbursement contracts, the government is responsible for cost overruns, which is generally not true in fixed-price contracts. The problems of low estimates and poor visibility encountered by systems project officers do not usually arise with fixed-price contracts, but if they do, they are the responsibility of the contractor, not of the government.

It is surprising, therefore, that DOD Directive 3200.9[2] does not clearly differentiate contract type as far as the use of PERT is concerned. There has, however, been confusion in government circles on this subject. The USAF PERT Implementation Manual, published August 1, 1963, maintains that the government need for PERT exists for all contracts.[3] Figure II-1 graphically portrays how this need

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[1] The Armed Services Procurement Regulation, Department of Defense (Washington, D. C.: July 1964), pp. 327-340.

[2] DOD Directive 3200.9 from Secretary of Defense Robert S. McNamara, February 26, 1964, and July 1, 1965.

[3] Air Force Systems Command, USAF PERT Implementation Manual, August 1, 1963, p. 75.

diminishes as the contract changes from cost-reimbursement to fixed-price. The kind of risk associated with the different types of contracts no doubt underlies the pyramid of figure II-1. This is as far as the government literature goes in recognizing that a distinction between contract types must be made.

However, even this recognition is completely lacking in some of the literature. For example, in a PERT/Cost conference between the aerospace industry and the government, Mr. George E. Fouch, Deputy Assistant Secretary of Defense, Installations and Logistics, stated in answer to a specific question posed by Mr. Art Simonian of Pratt & Whitney Aircraft:

> "If I were a contractor and bid on a fixed-price contract, I wouldn't want to go to work in the morning unless I had done a real good PERT/Cost job in the beginning and throughout this particular contract. Now there are people who, under fixed-price contracts, have volunteered to give this information. I do not know whether legally or ethically the cost provisions of PERT/Cost would be a requirement on a fixed-price contract. On the other hand, I say I wouldn't get caught as a contractor in a fixed-price contract if I did not have a real good PERT/Cost operation. How did I arrive at the bid in the first place"?[4]

Statements such as this caused a good deal of alarm within the aerospace industry. The apprehension concerning the prospect of having to use PERT in fixed-price contracts was evident during the interviews conducted by this author. Responses to the questionnaire also revealed that the concern was genuine and that the aerospace industry objected

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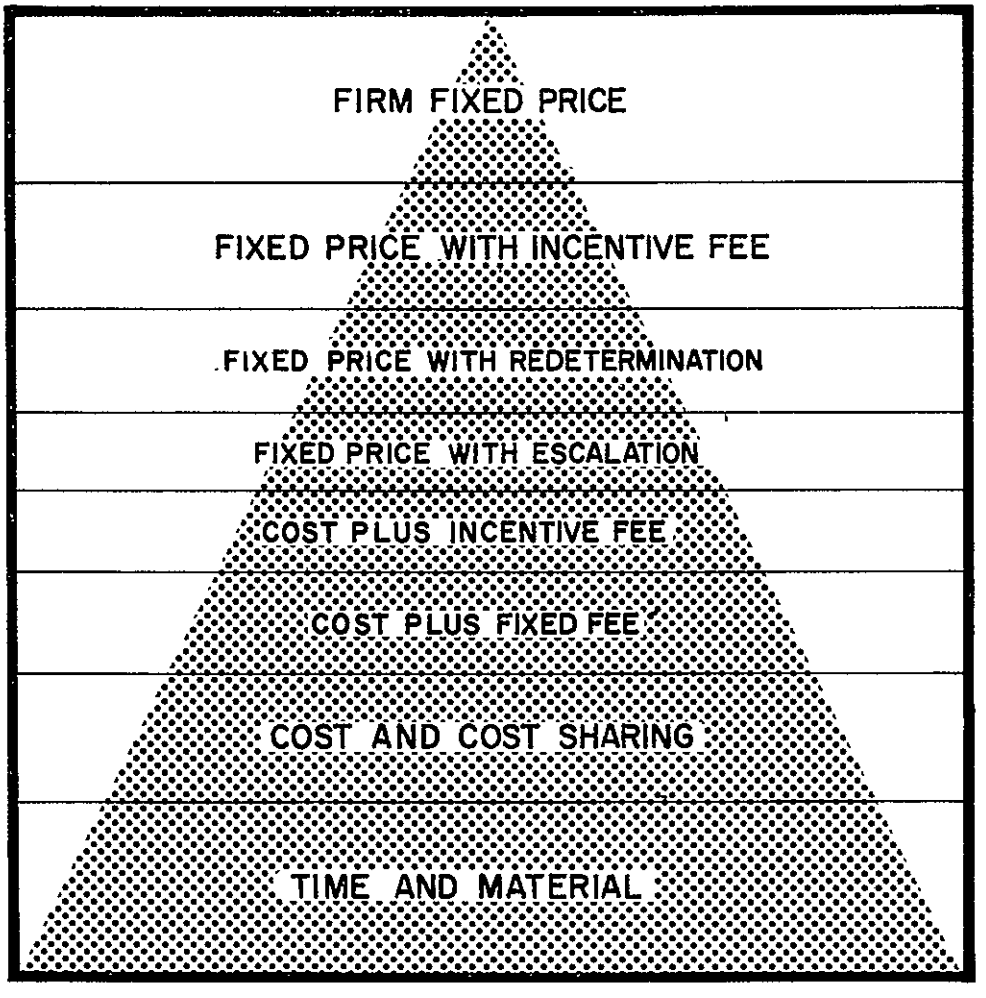
[4]DOD PERT Coordinating Group, Government-Industry PERT/Cost Conference Proceedings, Rock Island, Illinois, October 1 and 2, 1963 (unpaginated).

FIGURE II-1

SPO* NEED FOR PERT MANAGEMENT CONTROL
IN RELATION TO CONTRACT RISK



* *SYSTEMS PROGRAM OFFICE*

SOURCE: AIR FORCE SYSTEMS COMMAND, USAF PERT IMPLEMENTATION MANUAL AUGUST 1, 1963, P. 75

strongly to a governmental PERT requirement in fixed-price contracts.

Analysis of the Questionnaire Responses

The responses of the groups surveyed indicated that distinctions must be made between types of contracts when deciding whether to use PERT. That is, the greater the uncertainty and complexity of a particular contract, the more advisable the use of PERT.

Table II-1 summarizes, by group and category, the responses to question 7, part A of the questionnaire: "In your judgment, what should the criteria be for using PERT on one type of contract versus another?" The table shows that schedule uncertainty is the main criterion for both the government group and the directors of PERT programs. This means that the main concern of both groups is the completion of programs on time. Top managers and members of the PERT staff also place schedule uncertainty high on their lists. But top managers are more concerned about the complexity of the job (how difficult it is), and cost uncertainty (impact on profits) may be highly important also to the top managers in deciding to apply PERT on one type of contract rather than another.[5] These two criteria are also high on the list of the PERT staff (with the order reversed).

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[5]The history of aerospace contracts shows that the higher the uncertainty or risk in a given project, the greater the tendency toward the cost-reimbursement type of contract. An examination of Table II-3 shows that it is in these types of contracts that top managers are willing to accept the mandatory imposition of PERT.

Table II-1

RELATIVE WEIGHTS GIVEN TO CRITERIA FOR USING PERT ON ONE TYPE OF CONTRACT VERSUS ANOTHER

Criterion[a]	Group Sampled			
		Industry Group		
	Government Group	Top Managers	Directors of PERT Programs	PERT Staff
Cost uncertainty	0.87	0.97	0.69	1.00
Technical uncertainty	0.59	0.85	0.76	0.80
Number of interfaces	0.71	0.84	0.84	0.76
Complexity of the job	0.99	1.00	0.96	0.92
Schedule uncertainty	1.00	0.89	1.00	0.98
Reliability requirements	0.50	0.28	0.30	0.28
Type of incentives	0.46	0.62	0.63	0.61
Past performance of contractor	0.61	0.52	0.53	0.58
Project priority from customer viewpoint	0.73	0.70	0.66	0.66
Contract price	0.69	0.54	0.44	0.74
Life of contract	0.59	0.54	0.47	0.68

[a]Criteria are listed in the order given in the questionnaire.

Source: The questionnaire data.

The above findings confirm those of another study on PERT by Peter P. Schoderbek at the University of Michigan.[6] Schoderbek's

[6]Peter P. Schoderbek, PERT - An Evaluation and Investigation of its Applications and Extensions (Ph.D. dissertation, The University of Michigan, 1964).

study was directed at all types of industry; it did not focus on the aerospace industry, nor did it include a government group.[7] Nevertheless, the findings were that the main criteria for the use of PERT, in general, were complexity and size, cost, and time in that order.[8]

Returning to the specific issue of table II-1, it seems that in deciding whether to apply PERT on one type of contract or another (for example, fixed versus cost-reimbursement contracts), uncertainty (in time, cost, or job complexity) is the major criterion. High uncertainties, in the opinion of the respondents, require the use of PERT in a particular kind of contract; conversely, the type of contract should determine whether the government can require the use of PERT. This conclusion is based on the responses to question 8: "In your opinion, should the type of contract (e.g., CPIF) have anything to do with the customer requiring PERT?" The responses to the latter question are summarized in table II-2.

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[7]The study is descriptive and exploratory and does not delve into questions of public policy.

[8]Schoderbek, op. cit., p. 72.

Table II-2

SHOULD THE TYPE OF CONTRACT HAVE ANYTHING TO DO WITH THE CUSTOMER REQUIRING PERT?
(answers in percent of those sampled)

Group	Response	
	Yes	No
Government	68%	32%
Industry		
Top managers	71	29
Directors of PERT programs	63	27
PERT staff	67	33

Source: The questionnaire data.

Most of those who answered "yes," as indicated in Table II-2, believed that the customer had the right to require the use of PERT only in cost-reimbursement contracts (the government group, excepted). This is shown in table II-3, which summarizes question 9: "If 'yes' on question 8, in which of the following contract types should the customer require PERT? Please check the appropriate boxes in the table below and give the reason for your choice, if any."

Table II-3 shows that there is almost complete agreement between the government and industry groups that the customer should require PERT in cost-reimbursement contracts. This agreement extends to time and material contracts, but does not cover all types of fixed-price contracts. Table II-3 is significant in that it focuses attention

on the use of PERT in fixed-price contracts as a source of controversy.

The reasoning given by the respondents for the choices shown in table II-3 is described, by the types of contracts, in the sections below. Major attention is given to those areas where the opinions of the respondents differ substantially.

Cost-Reimbursement Contracts

An overwhelming majority of the groups sampled advocated the use of PERT in cost-reimbursement contracts. The reason given was that this type of contract was suitable for use only when the uncertainties involved in contract performance were of such magnitude that the cost of performance could not be estimated with sufficient reasonableness. Hence, the use of PERT in such contracts would be essential for planning and control by the customer.

The respondents associated the use of PERT with contracts where the customer carried most of the risk. One, a supervisor of analytical programming, expressed this idea by stating: "PERT should be used only when the customer has a substantial risk. Where this risk is vested in the contractor, financial control from the outside should be minimized."

Fixed-Price Contracts

There was marked disagreement between the government and the aerospace industry group about the government's use of PERT in fixed-price contracts. This disagreement is illustrated below, by group.

The Government Group. The majority of the government group advocated the use of PERT in all fixed-price contracts, with the exception of the firm fixed-price contract (see table II-3). In the case of fixed-price with escalation, fixed-price with redetermination, and

Table II-3

IN WHICH OF THE CONTRACT TYPES LISTED SHOULD THE CUSTOMER REQUIRE PERT?

Contract type	Group	Response		
		Yes	No	No opinion
Cost-reimbursement contracts				
Cost and cost sharing	Government	64	14	22
	Top managers	76	6	18
	Directors	55	10	35
	PERT staff	86	7	7
Cost plus fixed fee	Government	93	7	0
	Top managers	100	0	0
	Directors	85	5	10
	PERT staff	100	0	0
Cost plus incentive fee	Government	93	7	0
	Top managers	100	0	0
	Directors	85	5	10
	PERT staff	86	7	7
Fixed-price contracts				
Fixed-price with escalation	Government	50	36	14
	Top managers	24	70	6
	Directors	25	45	30
	PERT staff	29	50	21
Fixed-price with redetermination	Government	57	29	14
	Top managers	12	76	12
	Directors	35	40	25
	PERT staff	29	57	14
Fixed-price with incentive fee	Government	57	29	14
	Top managers	35	59	6
	Directors	30	45	25
	PERT staff	29	57	14
Firm fixed-price	Government	21	72	7
	Top managers	0	100	0
	Directors	20	60	20
	PERT staff	7	86	7
Other contracts				
Time and material	Government	29	43	28
	Top managers	29	59	12
	Directors	40	35	25
	PERT staff	43	29	28

Source: The questionnaire data.

fixed-price with incentive fee, the government group felt that the use of PERT facilitated contract negotiations and revisions, which were the major features of those contracts. In the words of one procurement officer, "PERT is necessary in these types of contracts because it offers a detailed history of the costs incurred."

The firm fixed-price contract provided for a price that was not subject to any adjustment. Hence, the government group felt that the customer had no valid argument for requiring the use of PERT in these contracts.

The Industry Group. The industry group generally felt that PERT, when imposed as a contract requirement, encroached upon the contractor's freedom of management, which was contrary to the purpose of fixed-price contracting. Furthermore, the underlying philosophy of fixed-price contracting obviated the government's need for PERT, according to the majority of the industry respondents. One assistant vice president for finance answered simply, "If costs are fixed, the procuring agency does not need PERT."

Table II-3 shows that the directors of PERT programs are not as strong in this feeling as the other two subgroups. This is because a substantial number felt that, with the exception of firm fixed-price contracts, the use of PERT in fixed-price contracts facilitated contract negotiations with the customer.

Time and Material Contracts

The Government Group. In the government group, a plurality (43 percent) felt that the use of PERT in time and material contracts was not necessary. The reason generally given for that attitude was

that time and material (T&M) contracts were usually small, in terms of dollars, and straightforward, in terms of planning and control. A minority (29 percent), on the other hand, advocated the use of PERT in T&M contracts because these contracts did not offer the contractor any positive profit incentive to control the cost of materials or to manage his labor force effectively.

The Industry Group. The opinions of the top managers coincided with those of the government group. Fifty-nine percent stated that time and material contracts were rare, usually small, granted either because objectives were obscure or effort was of small consequence. Hence there was no need for PERT. Twenty-nine percent stated that PERT would be useful in time and materials contracts, giving the same reason put forth by the government group minority.

The plurality of managers of the PERT programs and the members of the PERT staff (40 percent and 43 percent, respectively) advocated the use of PERT in time and material contracts for reasons given above. Again these facts appear in Table II-3.

Research Findings

Cost-Reimbursement Contracts

The findings of this study indicate that the government has a valid argument for requiring PERT in cost-reimbursement contracts. The uncertainties involved in the performance of most cost-reimbursement contracts are generally of such magnitude that the cost of performance cannot be estimated with a reasonable degree of accuracy. As long as the government is paying all allowable costs, it should

have the duty and the privilege to monitor the programs as closely as it desires. PERT is, then, a proper technique, if the government chooses to use it.

The responses to the questionnaire survey support the above conclusion. Table II-3 shows that both the government and the industry groups indicated overwhelmingly that the customer should be able to require the use of PERT in cost-reimbursement contracts if he chooses to do so.

The study demonstrates, therefore, that there is agreement on this issue by the government and industry groups surveyed. Such agreement is based upon a logical interpretation of the ASPR relating to type of contract. The author, therefore, recommends that the government apply PERT to all cost-reimbursement contracts, subject to the constraints of type of project and threshold contract prices which are defined later in this chapter.

Fixed-Price Contracts

In fixed-price contracts, the contractor is generally responsible for the cost of a satisfactory completion of the agreement; the risk is the contractor's. The government, therefore, should disengage itself from planning and controlling such contracts, or from suggesting the planning and control tools to be used. PERT should not be required in fixed-price contracts.

This conclusion is supported, at least in part, by responses to the questionnaire survey. The industry group states that it objects to the PERT requirement on all fixed-price contracts for the reason given above. The government agrees, but only as applied to firm

fixed-price contracts (see table II-3). On the other hand, the majority in the government group are of the opinion that the government should require PERT in the three other categories of fixed-price contracts: fixed-price with escalation, fixed-price with redetermination, and fixed-price with incentive fee.

The author will now present his arguments against the requirement of PERT in any type of fixed-price contract. The four types of contracts will be discussed in order. These are: the firm fixed-price, the fixed-price with escalation, the fixed-price with redetermination, and the fixed-price with incentive contract.

Firm Fixed-Price Contracts. There are two reasons why the government personnel sampled are willing to exclude firm fixed-price contracts from a PERT requirement. First, the firm fixed-price contract places a maximum risk upon the contractor. According to the ASPR:

> The firm fixed-price contract provides for a price which is not subject to any adjustment by reason of the cost experience of the contractor in the performance of the contract. This type of contract, when appropriately applied as set forth below, places maximum risk upon the contractor. Because the contractor assumes full responsibility, in the form of profits and losses, for all costs under or over the firm fixed-price, he has a maximum profit incentive for effective cost control and contract performance.[9]

Second, the aerospace industry has become greatly alarmed by statements emanating from the Department of Defense (DOD) to the effect that it would be wise for aerospace firms to be able to PERT fixed-price contracts. The aerospace industry is jealous of its right to

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[9] ASPR, op. cit.

manage fixed-price contracts without interference from the government. The issue is particularly clear in the case of firm fixed-price contracts, because as Frederic M. Scherer puts it:

> The firm fixed-price contract corresponds most directly to the contractual relationship prevailing in a market environment. With it the contractor promises to supply certain specified goods or services at a price which, after agreed upon by buyer and seller, is not subject to adjustments reflecting the seller's actual cost experience.[10]

How a contractor arrives at a bid in a firm fixed-price contract should not be revealed to the government in a PERT network cost analysis, according to a majority of the industry questionnaire respondents. Furthermore, how a contractor manages a firm fixed-price contract is for him to decide, as this management is directly correlated with his profit. The contractor usually has sufficient incentive for managing firm fixed-price contracts efficiently because for every dollar of cost reduction his profits are increased a dollar.[11]

The PERT requirement in any contract creates a hardship for a contractor as a result of the cost associated with acquiring PERT capability. It is demonstrated in Chapter IV that for the cases investigated this cost is in excess of $200,000. The outcry of the industry against the thinly-veiled coercion implied in the statements from DOD is justified. The industry makes it clear that it does not

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[10]Frederic M. Scherer, The Weapons Acquisition Process: Economic Incentives (Cambridge, Massachusetts: Division of Research, Graduate School of Business Administration, Harvard University, 1964), p. 132.

[11]Ibid.

wish to have its firm fixed-price contracts monitored.[12] Apparently this is the reason why the government group represented in this survey shows little desire to force PERT on firm fixed-price contracts.

Thus, there is an agreement between the groups surveyed upon the disengagement of the government from the administration (or PERTing) of firm fixed-price contracts. There is no agreement, however, in the case of the other types of fixed-price contracts. The government group believes that in fixed-price with escalation contracts, fixed-price with redetermination, and fixed-price with incentive fee contracts, it should require PERT because a part of the risk is being shared with the contractor.

Fixed-Price Contracts with Escalation. The fixed-price contract with escalation provides for the revision of the agreed price upon the occurrence of certain contingencies which are specifically defined in the contract. The risks, to either party, are reduced by the inclusion of escalation provisions.

The fixed-price contract with escalation is only appropriate where serious doubt exists as to the stability of market and labor conditions. It is normally not employed when the economy is stable. The questionnaire survey, for example, failed to uncover one fixed-price contract with escalation among the cases reported. Even if

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[12]This is stated categorically in the National Security Industrial Association's Report of PERT, PERT Cost and Line of Balance for Submission to Government PERT and Line of Balance Coordinating Groups (Washington, D. C.: April 1964), p. 16.

there were such contracts, the cost of applying PERT to them would be prohibitive because of continuous revisions. It would, therefore, be unwise to apply PERT to this type of contract.

Fixed-Price Contracts with Redetermination. The fixed-price contract with redetermination provides for a ceiling price and for a retroactive price redetermination after completion of the contract. The ASPR states that the redetermined price should be negotiated so as to give weight to the management effectiveness and ingenuity exhibited by the contractor during performance. It also specifies that the basis of such negotiation should be fully discussed with the contractor where this type of agreement is made.

The fixed-price contract with redetermination is appropriate in procurements where it is established at the time of negotiation that a fair and reasonable firm fixed-price cannot be established, and where the amount involved is so small, or the time of performance so short, that any other type of contract is impracticable.

It will be shown in chapter IV that as the contract price becomes smaller, the cost of applying PERT (in percent) becomes higher. Soon the cost is too high to warrant the expense. As the fixed-price contract with redetermination is not to be used unless the procurement is for research and development at an estimated cost of $100,000 or less, the use of PERT in this type of contract is not recommended. Significantly, the questionnaire survey uncovered no samples of such a contract in the cases reported.

Fixed-Price Incentive Contracts. The fixed-price incentive contract provides for adjustment of profit, for the establishment of the

final contract price by a formula based on the relationship which final negotiated total cost bears to total target costs. The formula may be expressed by

$$\pi = \pi_t + a(C_t - C_a), \qquad \text{(II-1)}$$

where

π = profit earned by the contractor,

π_t = target profit,

C_t = target costs,

C_a = actual costs, and

a = a sharing proportion, ranging from zero to one.[13]

The magnitude of a in equation (II-1) determines the relative risk carried by the government. In the typical fixed-price incentive contract, a is about 0.20.[14]

According to the ASPR, the fixed-price incentive contract is appropriate when use of the firm fixed-price contract is inappropriate, and when the supplies and services being procured are of such a nature that assumption of a degree of cost responsibility by the contractor is likely to provide him with a positive profit incentive for effective cost control and contract performance. The ASPR states that contract performance requirements must be such that there is reasonable opportunity for the incentive provisions to have a meaningful impact on the manner in which the contractor manages the work. The fixed-price

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[13]With a = 0, the contract becomes a cost-plus-fixed-fee contract; with a = 1, the contract becomes a firm fixed-price contract.

[14]Michael D. Intriligator, "Optimal Incentive Contracts" (unpublished paper, July 16, 1964), p. 2.

incentive contract is not to be used, according to ASPR, unless the contractor's accounting system is adequate for price revision purposes and permits satisfactory application of the profit and price adjustment formulas.

Therefore, the author questions the utility of the government's use of PERT in fixed-price incentive contracts. It would appear that the two should be mutually exclusive.[15] That this is not the case is demonstrated by responses to the questionnaire survey. Thirteen of the sixty-one cases reported use of PERT in FPIF contracts; in ten of these, PERT is a contractual requirement.

Although the government shoulders part of the risk contracts based on fixed-price with escalation, fixed-price with redetermination, and fixed-price with incentive fee, the fact remains that the contractor carries the heavier risk.[16] Since the major risk is carried by the contractor, it is he who should determine the planning and control tools appropriate for his job. Furthermore, it is more economical from a cost-effectiveness point of view for the government to divert resources (in terms of costs incurred in PERTing fixed-price contracts) to more productive endeavors.

Other Contracts

Other types of contracts, such as time and material, are significant

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[15]According to the ASPR, the government awards an FPIF contract only after it has determined that the contractor possesses satisfactory controls. If the contractor is prepared to furnish such controls, why should PERT be required?

[16]This is true in theory at least. The author has been told by many procurement officers that they have traditionally allowed the contractors to minimize their risks in these types of contracts--that in a sense there are really no actual fixed-price contracts.

in terms of systems development or procurement of hardware. In addition, these contracts have traditionally dealt with simple, straightforward projects that do not require sophisticated planning and control methods. The government has no need, therefore, to require the use of PERT in these other contracts.

To summarize the above arguments, it appears necessary for the government to require the use of PERT in cost-reimbursement contracts because it carries a preponderant share of the cost uncertainties. The converse, however, is true for fixed-price contracts. The author recommends, therefore, that the government apply PERT to cost-reimbursement contracts but refrain from such a requirement in fixed-price contracts.

The above recommendation is consistent with the philosophy of relaxation of controls under study at present by the United States Air Force. According to the Air Force Procurement Newsletter, it is the long-held opinion of the aerospace industry that the Air Force over-controls weapon producers--indeed, that new controls are added faster than old ones are removed.[17] As a result, Assistant Secretary of the Air Force Joseph S. Imirie has indicated a willingness to take reasonable risks when justified by potential gains; he directed a study to reduce controls.[18] On the basis of that study, the PERT requirement was removed from a Federal Electric cost-plus-incentive-fee contract at

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[17]"Contract Management," Air Force Procurement Newsletter, No. 1 (September 1964), p. 15.

[18]Ibid. This directive was issued to Lt. General T. P. Garrity, DCS/S&L, on April 9, 1963.

the request of Federal Electric, but this was done only after the company demonstrated that it possessed a comparable system to do the job.[19]

Lieutenant General T. P. Garrity, Deputy Chief of Staff for Systems and Logistics, Headquarters, United Stated Air Force, expressed this philosophy of relaxation of controls as follows:

> "...as we move further into fixed-price and incentive contracting we are not only willing but anxious to reduce, in a sensible manner, the controls and close surveillance we found necessary in the past in cost-plus-fixed-fee contracting."[20]

Generally, the government is becoming aware of the need to be selective in the application of controls. For one thing, it is believed that the growth of total procurement costs has been insignificant except in the case of cost-reimbursement contracts.[21] For another, there is the increasing pressure of the philosophy that the government should interfere less in the affairs of contractors.

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[19]Information obtained in correspondence between the Air Force and the author.

[20]Speech by Lt. General T. P. Garrity, DCS/Systems and Logistics, HQ USAF to the Industrial Association Convention, Sheraton Park Hotel (Washington, D. C.: September 13, 1963).

[21]This statement is based on privileged correspondence with Headquarters, United States Air Force, made available to this author.

CHAPTER III

PERT AND PROJECT TYPE

There are three general types of projects that are involved in the weapons and aerospace acquisition processes. These are in the areas of basic research, research and development (R&D), and repetitive production. The proper role of PERT in each of these areas is dependent upon the nature of the activities.

PERT has been used to date only in the R&D phase of procurement contracts. A memorandum dated January 18, 1963, from the Director of Defense Research and Engineering at that time, pointed out that "the Secretary of Defense has previously encouraged the use of PERT/Cost as a management tool in research and engineering efforts," and he recommended that each Service "use its judgment in determining the types of projects to which it should be applied."[1] This position was later amended so that PERT would apply to two R&D categories only: engineering development and operational system development. The rationale underlying this decision was that these two categories are later stages of development where high cost estimates have a serious impact on expenditures.

Some government officials concerned with procurement problems have suggested that PERT should be made applicable to other stages of R&D and even to basic research and production projects. Thus PERT would become the principal management technique used in procurement. Although this problem is a very important one, no discussion or

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[1]Memorandum to the three Services, from Harold Brown, Director of Defense Research and Engineering, January 18, 1963.

examination of the possibility of extending the use of PERT to other project types has appeared in any government publication. The USAF PERT Implementation Manual merely mentions the fact that PERT has never been used in a production phase.[2] For repetitive production, the line of balance (LOB) technique is an excellent management tool. But because the line of balance does not have the forecasting qualities of PERT, efforts were at one time made to extend PERT into the production field.[3]

PERT, on the other hand, has been used successfully in construction programs. According to a February, 1963, article in the Sunday edition of the Los Angeles Times, construction companies using the Critical Path Method (CPM) were achieving reductions of from 5 percent to 30 percent in time, and 2 percent to 25 percent in costs.[4] The same article cited the Stonegate Estates' development in California's Simi Valley as an example of the use of CPM.

A pertinent feature of construction programs, however, is that they combine R&D and production. Where PERT has applicability, construction programs are often "one-time-through" projects. In this sense, construction may be thought of as one of the categories of R&D.

The entire problem of the types of projects where PERT can be applied is extremely complicated. Even though extending PERT to some of the categories or stages of R&D other than engineering developments

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[2]Air Force Systems Command, USAF PERT Implementation Manual, August 1, 1963, p. 9.

[3]This statement is based on an interview with A. W. Buschman, Head of the PERT Coordinating Group, Department of Defense, Washington, D. C., April 1, 1964.

[4]Tom Cameron, "Missile Program Gives Builders Key to Efficient Production," Los Angeles Times, February 16, 1964, Section J, p. 1.

and operational system development may achieve more effective management and cost control, it will be seen that the use of PERT in certain areas, such as repetitive production, is not desirable.

Analysis of the Questionnaire

Table III-1 shows the relative importance assigned by the questionnaire respondents to the type of project where PERT should be applied.

Table III-1

RELATIVE IMPORTANCE ASSIGNED TO TYPE OF PROJECT WHERE PERT SHOULD BE APPLIED

Type of project where PERT should be applied	Groups Sampled			
		Industry Group		
	Government group	Top managers	Directors of PERT programs	PERT staff
Basic research	0.16	0.35	0.49	0.37
R&D	1.00	1.00	1.00	1.00
Production	0.80	0.43	0.32	0.26
Other: military construction	x	x	x	x

Source: The questionnaire data.

It can be seen that there is unanimous agreement that PERT should be applied to R&D projects, but there is only minor support for the application of PERT to basic research or to production.[5] All the

[5]The exception is the government group, which supports the application of PERT to production projects.

groups sampled advocate the application of PERT to military construction projects.

Research Findings

Basic Research

PERT cannot be used in basic research projects because it is difficult, if not impossible, in such situations to define network events, or to estimate the duration and cost of activities with reasonable accuracy. PERT is based on a definable network; there must be an element of certainty attached to that definition. In basic research, however, this element is lacking. For example, only one questionnaire response referred to a basic research project and the respondent stated that PERT was not applicable. This illustrates the general attitude of the questionnaire respondents with respect to the use of PERT in basic research (see table III-1).

The PERT literature generally supports the findings of table III-1. In particular, the literature shares the skepticism of many questionnaire respondents as to whether PERT's range of applicability includes basic research. For instance, the editor of the IRE Transactions on Engineering Management has stated:

> We have taken the time to study a great many trees of research -- and even when these relate to the "development" of new drugs, we have found that you could not with knowledge available at the time have predicted the sequencing of events, a priori. We have checked this in other labs. --- At any given stage, you have the probability of new knowledge - which is why you do the research - but you do not know how many steps or what specific events are going to take place before the new knowledge appears.[6]

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[6] IRE Transactions on Engineering Management, Vol. EM-7, No. 3 (September, 1960), p. 81.

The conclusion of this study is, therefore, that the government should not attempt to use PERT in basic research projects, since these projects are not amenable to the reasonable cost and time estimates that PERT requires. Moreover, basic research projects do not involve the vast sums of money that would normally make the use of PERT profitable.

Research and Development

A thorough study of the literature, as well as interviews in the aerospace industry and in government, indicate that PERT is applicable to one-time-through R&D projects. The questionnaire survey verifies this. As shown in table III-1, the respondents are in agreement that PERT is applicable to R&D projects. There are six categories of research and development: research, exploratory development, advanced developments, engineering developments, management and support, and operational system development.

The reader may recall that DOD Directive 3200.9 directs the application of PERT/Cost to major engineering developments and operational system development projects (those exceeding $25 million in RDT&E, or $100 million in production investment). The rationale for the selection of these two groups is that major development projects in the later stages of development have the most serious impact on total expenditure and on defense capability. The indicated categories represent projects in the later stages of development, projects that are better-defined than those in the earlier stages. As mentioned earlier, definition of events and activities is the backbone of PERT.

It is possible to apply PERT to categories of R&D other than engineering developments and operational system development. As may

be seen in table III-2, only one-half of the "PERTed" projects reported in the questionnaire survey belong to these two R&D categories. Table III-2 shows that the balance are exploratory development or advanced development projects as well as projects that are a combination of a number of R&D categories. In one case, for example, the project included the entire range from research through operational system development.

It is also interesting to note in table III-2 that there is only one case where PERT/Time is being used in management and support. Management and support include military construction, and PERT/Time has been of unquestionable merit in that area.

This author recommends the use of PERT in all six categories of R&D for the reason that a particular R&D program generally includes all or most of these categories. The aerospace industry has already demonstrated its capability to apply PERT in this way, as illustrated in table III-2.

Repetitive Production

Responses to the questionnaire survey indicate that, of the firms responding, twelve are working on repetitive production contracts but only three of these are using PERT to plan and control such contracts. The latter state that PERT is useful in production contracts where the time from beginning to completion of the project is long, say twenty-four months, and where the number of items produced is small. These are the types of production projects where PERT is being used.

The interviewees state that generally there have been no problems, of schedule slippages or cost-overruns, related to the inadequacy of

existing controls in production contracts. These controls, such as the line of balance, have been, and are, still adequate.

Table III-2

FREQUENCY OF THE USE OF PERT IN R&D AND OTHER CATEGORIES FOR THE CASES REPORTED

R&D and other categories	PERT/Time frequency	PERT/Cost frequency
Research (a)	0	1
Exploratory development (b)	0	2
Advanced developments (c)	3	5
Engineering developments (d)	5	11
Management and support (e)	1	0
Operational system development (f)	8	7
a + b	0	2
a thru f	1	0
b thru f	1	0
c + d	1	0
c + f	2	0
d + f	1	1
PDP*	1	3
Early production*	2	2
Construction	1	0
Total	27	34

*Other categories.

Source: The questionnaire data.

Thus this study has not uncovered a need for the use of PERT in repetitive production.

On the other hand, PERT is useful in the area of military construction, which falls in the realm of management and support--an R&D category. A few questionnaire respondents, however, are of the opinion that military construction belongs in the area of production. Whether military construction programs are considered R&D or production projects, the literature, the interviews, and the questionnaire survey (see table III-1) suggest that PERT may be successfully used in these programs.

On the basis of the analysis concerning the use of PERT in basic research, research and development (R&D), and production projects, the author recommends that PERT should be applied to research and development and military construction projects only.

This recommendation is subject to constraints relating to the type of contract and to threshold contract prices. The former was discussed in chapter II and the latter is considered in chapter IV.

CHAPTER IV

PERT AND THRESHOLD CONTRACT PRICE

DOD Directive 3200.9, originally issued on February 26, 1964, makes mandatory the application of PERT for each program passing through engineering development and operational system developments that exceed $25 million in research, test, development, and evaluation (RTD&E), or $100 million in production investment.[1] The directive, however, was primarily concerned with the project definition phase, or what was later called contract definition. As for PERT, the directive only reiterated the substance of a memorandum from Dr. Harold Brown, now Secretary of the Air Force, who at that time was Director of Defense Research and Engineering. In reference to PERT, the memorandum stated:

> Projects requiring cumulative RTD&E funding in the engineering development or in the operational system development categories in excess of twenty-five million dollars will undergo this process unless this requirement is specifically waived by me....[2]

Apparently some confusion remained in the Department of Defense, however, about PERT and threshold project costs in the interval between Brown's memorandum and McNamara's directive. Eight months after Brown's memorandum, Mr. Barry Schuler (of the Control Data Corporation, Minneapolis, Minnesota) asked Mr. A. W. Buschman (head of the PERT

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[1] DOD Directive 3200.9 from Secretary of Defense Robert S. McNamara, February 26, 1964, pp. 2 and 5. This directive was cancelled and superseded by another DOD Directive 3200.9 from Secretary of Defense McNamara, dated July 1, 1965. For the purposes of this study, these two directives are identical.

[2] Memorandum to the three Services, from Harold Brown, Director of Defense Research and Engineering, January 18, 1963.

Coordinating Group, DOD) if the Department of Defense had established a minimum dollar value for the imposition of PERT/Cost, and the answer was "no."[3]

For all intents and purposes, DOD Directive 3200.9 formally establishes minimum dollar values for the imposition of PERT/Cost. There is no clue in the current literature, however, to the rationale underlying these minimum values. In response to an inquiry to the Department of Defense by this author, the following explanation was given by Mr. James W. Roach:

> Existing directions to the Military Departments regarding application of PERT/Cost are contained in Director of Defense Research and Engineering memorandum dated January 18, 1963 and DOD Directive 3200.9 dated February 26, 1964. The memorandum directs application of PERT/Cost to major Engineering Development and Operational Systems Development projects and permits Departmental judgment in determining the magnitude and types of projects to which it should be applied. The DOD Directive concerns Project Definition Phase, of which P/C is only one aspect. Thus at the present time the Departments are required to use P/C for all projects undergoing a Project Definition Phase and are encouraged to use P/C for other major Engineering Development and Operational Systems Development projects. The Departments are applying P/C to many more projects than they are required to. We are considering direction to the Departments which will require use of P/C for Engineering Development and Operational Systems Development projects at lower dollar levels than those of DOD Directive 3200.9. The depth of P/C effort would depend upon the dollar level of the project.
>
> With regard to the criteria of DOD Directive 3200.9, it is important to recognize that there

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[3]DOD PERT Coordinating Group, Government-Industry PERT/Cost Conference Proceedings, Rock Island, Illinois, October 1 and 2, 1963 (document unpaginated).

> are two criteria: that the project be in Engineering Development or Operational Systems Development (both of these categories represent items being developed for operational use and thus are in the later stages of development) and that the estimated RDT&E funding be $25 million or more or estimated production investment be $100 million or more. The rationale is that major development projects in the later stages of development with high dollar estimates have the most serious impact on our total expenditures and on our defense capability. The application of the complete Project Definition Phase discipline is reserved for a relatively small number of the most important projects. The discipline of P/C is intended to be applied on a broader basis.
>
> No formal quantitative analysis was conducted to arrive at the criteria for PDP. The criteria were selected against the background of the existing budget and projections for several years, but without formal quantitative analysis. The intent was to set criteria which would limit the application of PDP initially to a small number of major development projects. It is possible that after more experience with PDP the criteria will be lowered to expand PDP application.[4]

Mr. Roach also stresses that the dollar criterion for the application of PERT/Cost is on a project rather than a contract basis; it would be possible, therefore, for a total project to be in excess of the $25 million RDT&E level but the individual contracts below this level. For example, it is conceivable that the estimated cost of an RDT&E project consisting of several contracts might be approximately $30 million yet one of the contracts amount to less than $100,000. Thus, one difficulty with the directive is that PERT could be applied to very small contracts. There are, consequently, two problems that arise from this aspect of the directive: first, whether

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[4]Letter written to the author by James W. Roach, Assistant Director (Engineering Management), Office of the Director of Defense Research and Engineering, Department of Defense, November 24, 1964.

PERT should be applied on a contract or a project basis; second, whether the PERT threshold prices are justified.[5]

Analysis of the Questionnaire

One of the purposes of the questionnaire was to obtain opinions on the soundness of the threshold contract prices of DOD Directive 3200.9. The results of the poll are shown in table IV-1, which is a summary of answers to question 15, Part A, of the questionnaire: "In your judgment, is the $25 million for research, test, development, and evaluation (RDT&E) or $100 million for production investment (minimum program prices that make the application of PERT mandatory) required by DOD Directive 3200.9 a good rule"?

Table IV-1

OPINIONS OF THE DOD MINIMUM PROJECT CRITERION
(in percent of those sampled)

Groups sampled	Response		
	Approve	Disapprove	No opinion
Government	58%	26%	16%
Industry			
Top managers	42	42	16
Directors of PERT programs	47	35	18
PERT staff	52	29	19

Source: The questionnaire data.

[5]The example is, of course, for illustrative purposes only. It would be rare indeed if a mechanized PERT/Cost system were applied to a $100,000 contract.

Table IV-1 shows a division of opinion with a majority (or plurality) of the respondents approving of the DOD minimum price criterion. It may be interesting to note that a few of those respondents who disapprove Directive 3200.9 do so because they consider the minimum prices of the directive too high. Generally, however, most of the respondents consider these minimum prices necessary for controlling R&D expenditures, although the majority of respondents also recognize that there are more important criteria for the use of PERT than minimum contract price. According to one industry respondent:

> "There are values, other than money, that should determine the use of PERT. Contracts requiring less money may be very important as far as technical accomplishment is concerned; and these contracts should be PERTed."

Before proceeding to analyze the quantitative portion of the questionnaire (Part B) so that cost functions for both PERT/Time and PERT/Cost are developed, it should be pointed out that one of the main assertions about PERT during the interviews was that its cost was excessive. Some aerospace industry representatives maintained that the cost of using PERT was as high as 8 percent of contract price. Systems project officers interviewed stated that the cost of PERT was instrumental in deciding whether to require its use in a contract.

It was necessary, therefore, to shed light on the cost of PERT before recommending principles for its application. Inquiries were made by this author about costs during the interviews; the results of such inquiries were in the form of unofficial or hearsay estimates, such as those shown in table IV-2. The opinions of the cost of PERT differed, as seen in the table, however, the size of the contract was

not taken into account. Interviewees were of the opinion, for example, that the larger the contract, the smaller was the percentage cost of PERT. As a result, table IV-2 might reflect differences caused by a variability in contract size.

Table IV-2

UNOFFICIAL ESTIMATES OF THE COST OF PERT AS A PERCENT OF CONTRACT PRICE

Company	PERT/Cost	PERT/Time
Hughes	6 - 8 percent	2 - 5 percent
U. S. Navy	Unknown	1 percent
U. S. Air Force	Unknown	5 percent
DOD	1.5 -.2.0 percent	Unknown
Convair	3 - 5 percent	.5 - 1.5 percent

Source: An interdepartmental memorandum of an aerospace firm made available to the author.

It appears, then, that a more accurate expression of the cost of PERT could be obtained if it were related to contract price. Opinions as to the cost of PERT expressed by participants in a PERT/Cost workshop conducted by IBM for aerospace industry representatives (December 2-3, 1963) are shown in Table IV-3, as a percent of contract price.

Table IV-3

OPINIONS OF THE COST OF PERT AS A PERCENT OF CONTRACT PRICE

Contract price	Under $100,000	$100,000-$2 million	$2 million-$50 million	$50 million-$100 million	Over $100 million
PERT/Time	3.3%	2.3%	2.0%	1.4%	1.0%
PERT/Cost	6.1	4.6	3.8	3.0	2.3

Source: An interdepartmental memorandum of an aerospace firm made available to this author.

Data for tables IV-2 and IV-3 were composed of mere opinions or unofficial estimates; they did not constitute the sound evidence needed for the development of principles for the use of PERT as a function of contract price. A number of systems project officers pointed out, for example, that the aerospace industry was overpricing PERT. If this were true, overpricing might be reflected in the cost data given in tables IV-2 and IV-3.

In the endeavor to obtain a more accurate idea of the cost of PERT, questions dealing with the possible determinants of such cost were included in Part B of the questionnaire (see Appendix II).[6] Part B was designed so as to deal with one defense or aerospace project PERTed by the responding firm. On the basis of the answers to these questions, it was possible to make rough estimates of the cost of PERT.

The respondent first was asked to identify the project reported. This was done in question 1: "What is the name of the project or

[6]Specifically questions 1 to 19 (with the exception of question 9).

application"? Questions 2 to 19 (with the exception of 9) concerned identification of a range for contract price, a range for contract life, the direct labor and computer hours used in PERTing the project, and other variables of interest.

On the basis of the amounts of computer hours reported in answering question 15, and the direct labor man-months given in replies to question 16, the direct cost of PERT was estimated. The estimating method used by this author assumed standard computer, direct labor, and overhead rates. These were applied equally to all the cases reported in order to maintain comparability.

At this point, the reader is reminded that there are no standard costs in the aerospace industry; the estimates given in this chapter are extremely rough and based on suppositions that may not hold true for every firm. The assumptions used in computing the cost of PERT are designed merely to develop a first approximation of the cost of PERT, based solely on contract price.[7]

This chapter must be viewed, then, as a ground-breaking effort. The charts and equations exhibited in it are simply descriptions of the data gathered from the questionnaire survey and are applicable only to the cases reported.

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[7]For a second approximation of the cost of PERT, the reader may refer to Jack C. Hayya, A Study on the Appropriate Use of PERT in Procurement Contracts (Ph.D. dissertation, University of California, Los Angeles, 1966), pp. 227-239. In addition to contract price, the second approximation accounts for other variables such as type of R&D, type of organization, and the level of detail of the work breakdown structure.

Cost Estimating Method Used

It is assumed in estimating the cost of PERT that its direct operating cost consists of:

1. Computer rental costs, and

2. Pay (or salaries) of those employed in the PERT operation.[8]

It is easy to compute data on the monthly direct cost of PERT from responses to Part B of the questionnaire--questions 12, 13, 15 and 16 are designed to provide such information. In order to compute the total operating cost of PERT from the direct operating costs, overhead rates must be included. These rates differ from firm to firm, and from contract to contract.

The analysis of the direct cost of PERT only (which does not include overhead) is not meaningful, because both industry and government refer to the total cost of PERT. Therefore, it is necessary to include overhead rates. Once different overhead rates are applied to accommodate individual firms, however, the comparability of the total costs is destroyed. One standard overhead rate is assumed, then, for all firms. This rate is taken as 150 percent of direct labor hours, and applied, as common practice dictates, to direct labor only.

The inclusion of overhead rates in the calculations is reasonable when one notes that the government is usually paying for PERT as a direct charge. Thus it is paying for: (1) the direct labor hours, and (2) an indirect, or overhead, charge computed by applying an overhead rate to the direct labor hours. The findings of the questionnaire

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[8] See ibid., pp. 389-394, for the computer rental rates and personnel salaries used in the computations.

survey generally substantiate the above. Responses to question 19 ("Is the cost of the PERT operation a direct or an indirect charge in this contract?) indicate that 72 percent of the firms replying to Part B of the questionnaire are compensated for PERT as a direct charge.

A First Approximation of the Total Operating Cost of PERT

The total operating cost of PERT is calculated by multiplying the total monthly cost by the estimated life of the contract. The estimated life of the contract, in months, is based on answers to question 3, Part B of the questionnaire: "What is the duration range for the life of the contract in months"? The middle point of that range is assumed to be the estimated life of the contract for the project under consideration.[9]

Figures IV-1 and IV-2 present scatter diagrams and linear regressions for the total operating costs of PERT/Time and PERT/Cost as a function of contract price. The linear regression equation for PERT/Time is:

$$Y = 0.206 + 0.00156\ X \qquad \text{(IV-1)}$$

where

Y = total operating cost of PERT/Time, in millions of dollars, and

X = contract price, in millions of dollars.

The correlation coefficient of the variables in equation IV-1 is 0.70. The standard error of the estimate is 0.198.

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[9]This applies also to establishing point estimates for contract prices. It would have been easier, of course, to work with the actual figures for contract duration and price. In testing the questionnaire, however, it was evident that respondents had grave reservations about divulging the specific data because of proprietary or national security considerations. Ranges were then agreed upon as a satisfactory compromise.

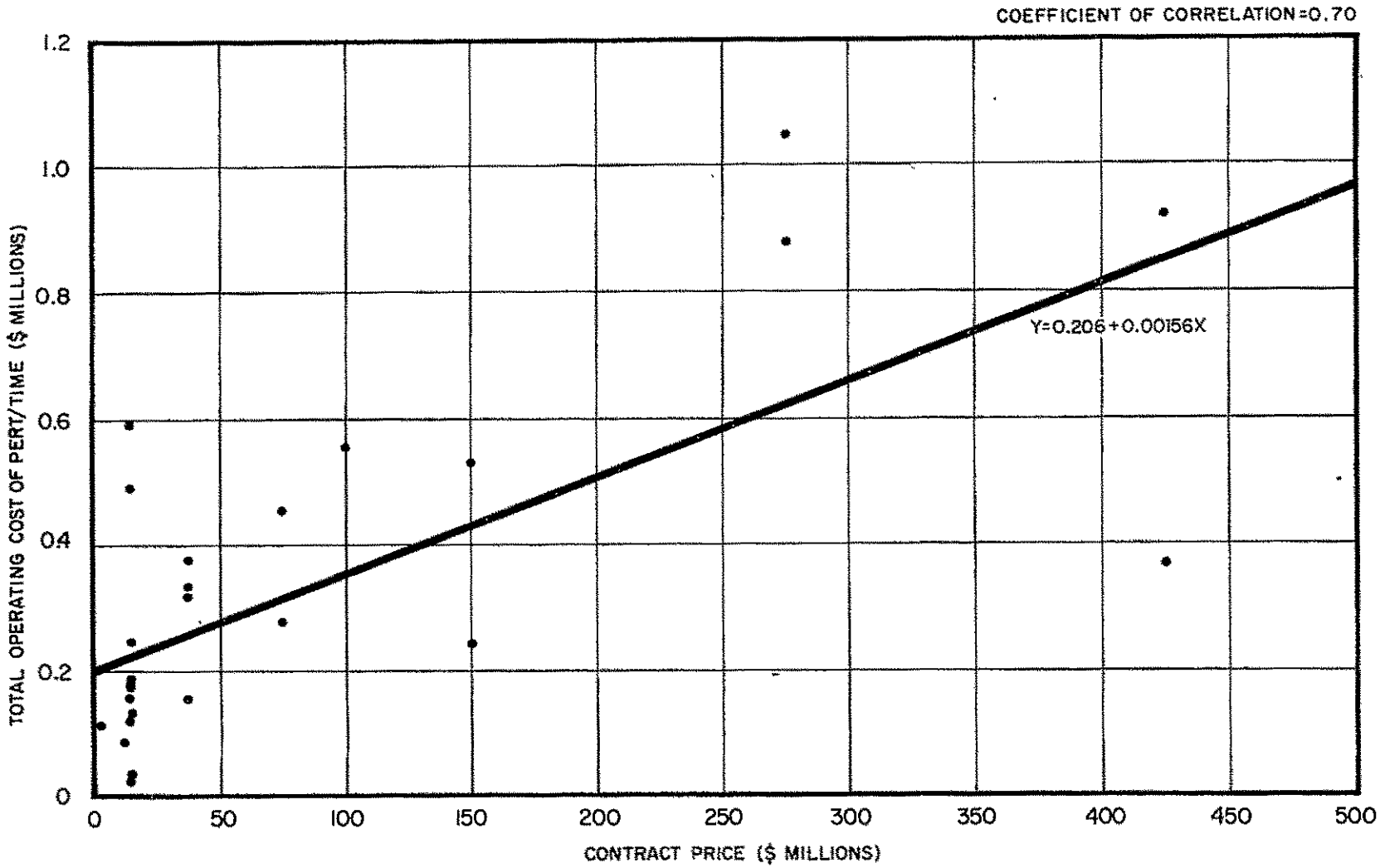

FIGURE IV-1

PERT/TIME - TOTAL OPERATING COST VERSUS CONTRACT PRICE

SOURCE: THE QUESTIONNAIRE DATA

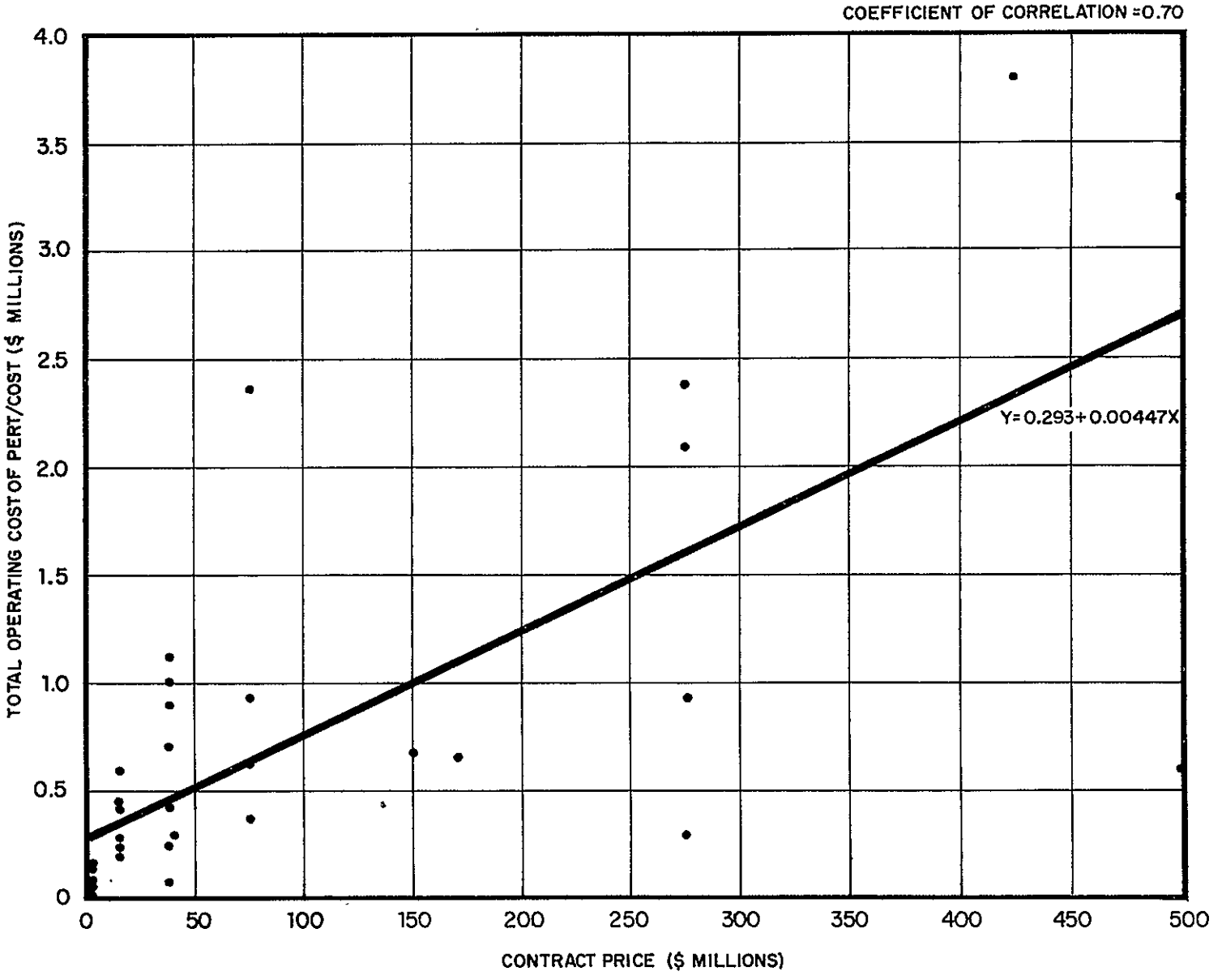

FIGURE IV-2

PERT/COST -TOTAL OPERATING COST VERSUS CONTRACT PRICE

SOURCE: THE QUESTIONNAIRE DATA

The linear regression equation for PERT/Cost is:

$$Y = 0.293 + 0.00447\ X \qquad \text{(IV-2)}$$

where

Y = total operating cost of PERT/Cost in millions of dollars, and

X = contract price, in millions of dollars.

The correlation coefficient of the variables in equation IV-2 is 0.70. The standard error of the estimate is 0.671.

It is important to note the fixed costs associated with equations IV-1 and IV-2 above: $0.206 million for PERT/Time and $0.293 million for PERT/Cost. These high fixed costs lend credence to the hypothesis that it is easier for larger firms than for smaller ones to use PERT, because larger firms are more apt to possess the necessary funds. Koontz and O'Donnell point this out as follows:

> A large firm can almost certainly engage in more thorough planning than a small one, because the ratio of planning expense to operating expense or to capital resources will be small. Since many planning problems which face the small firm are almost as complex and varied as those which face the larger firm, in the area of planning thoroughness and the resources to accomplish it, the larger firm has an important advantage.[10]

The analysis of the questionnaire data reflected in equations IV-1 and IV-2 supports the above statement. Small firms evidently have more difficulty than larger firms in implementing PERT because of their more limited resources.

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[10]Harold Koontz and Cyril O'Donnell, Principles of Management (New York: McGraw-Hill Book Company, 1964), pp. 196-197.

A First Approximation of the Cost of PERT as a Percentage of Contract Price

The cost of PERT as a percentage of contract price is the most meaningful index of the cost of PERT because it shows the fraction contributed by PERT to the total cost of the contract. The percentage cost of PERT is calculated by dividing the total cost of PERT (equations IV-1 and IV-2) by the contract price. This yields the hyperbolic functions of figures IV-3 and IV-4. These functions are similar to the classical average fixed cost functions. As pointed out earlier, there is a fixed cost associated with acquiring a PERT capability. This fixed cost is responsible for the shape of the curves of figures IV-3 and IV-4.

Figures IV-3 and IV-4 present scatter diagrams of the percentage costs of PERT/Time and PERT/Cost as a function of contract price, in addition to being the hyperbolic fits discussed in the preceding paragraph. The equation of the fit for PERT/Time is:

$$X\ (y - 0.156) = 20.6 \qquad \text{(IV-3)}$$

where

X = contract price in millions of dollars, and

y = the cost of PERT/Time as a percentage of contract price.

For PERT/Cost, the equation of the fit is:

$$X\ (y - 0.447) = 29.3 \qquad \text{(IV-4)}$$

where

X = contract price in millions of dollars, and

y = the cost of PERT/Cost as a percentage of contract price.

Research Findings

A comparison of figures IV-3 and IV-4 reveals that it is less costly in terms of percentage costs to use PERT/Time than to use PERT/Cost. Conversely, given a percentage cost constraint, PERT/Time can be applied in smaller contracts than can PERT/Cost. For example, if the government is willing to pay no more than one percent of contract price for planning and control, it has the choice, according to data shown in figures IV-3 and IV-4, to apply PERT/Time to contracts that exceed $25 million or to apply PERT/Cost to contracts in excess of $62.5 million.

A study of figure IV-4 is of interest from the standpoint of Department of Defense Directive 3200.9 (dated July 1, 1965). As stated previously, this directive requires the use of PERT/Cost in all engineering developments and operational systems developments estimated to require cumulative RDT&E financing in excess of $25 million or estimated to require a total production investment in excess of $100 million. The percentage costs associated with these threshold contract prices, according to figure IV-4, are 1.6 percent and 0.8 percent, respectively. On the basis of figure IV-4, the threshold contract prices of DOD Directive 3200.9 seem reasonable, particularly in view of the fact that these threshold contract prices were chosen without the benefit of a quantitative analysis.

Is the Cost of PERT Excessive?

Equations IV-3 and IV-4 are first approximations of the percentage costs of PERT/Time and PERT/Cost with contract price as the independent variable. A comparison of these first approximation estimates with the

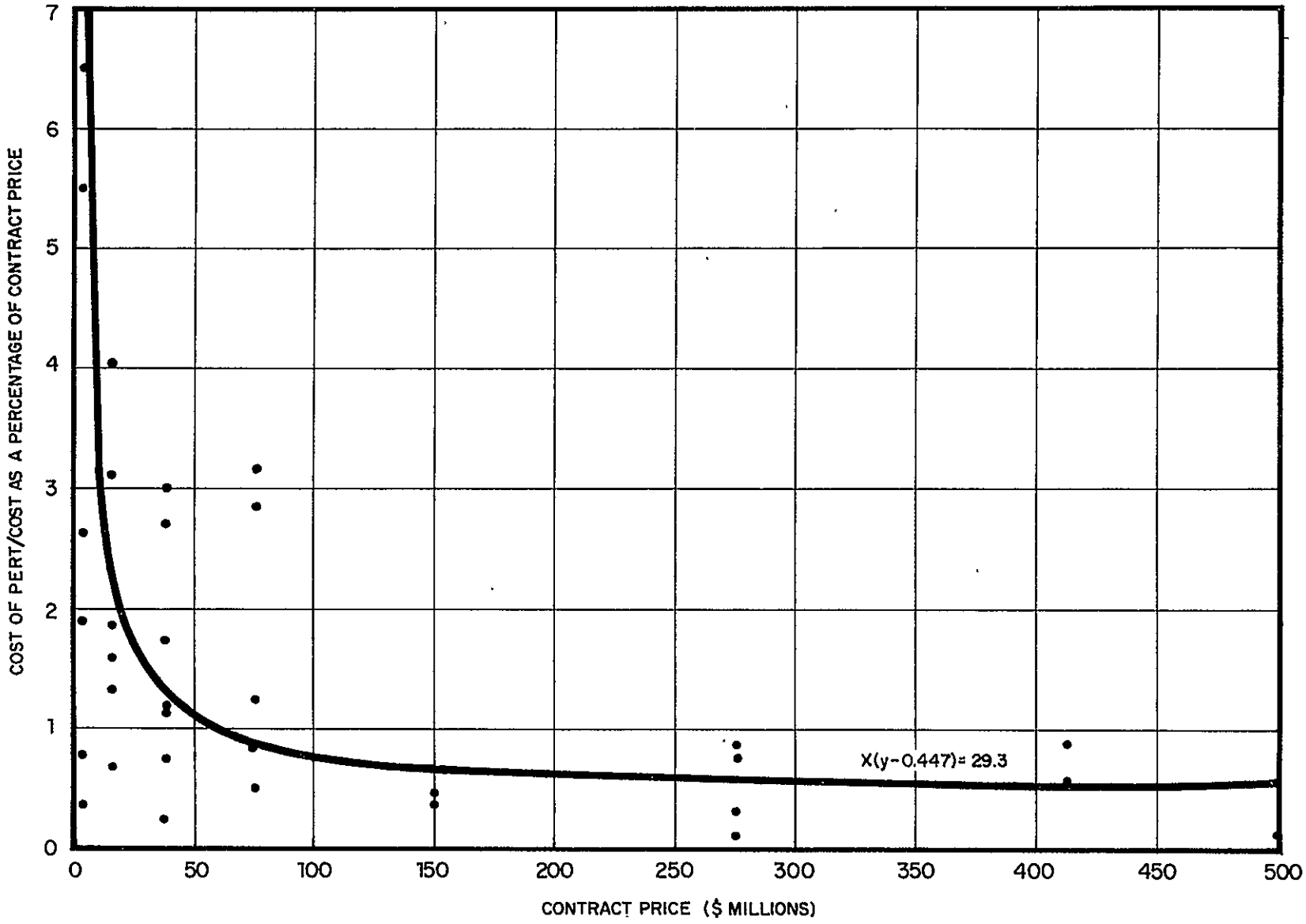

FIGURE IV-3
PERT/COST-PERCENTAGE COST VERSUS CONTRACT PRICE

SOURCE: THE QUESTIONNAIRE DATA

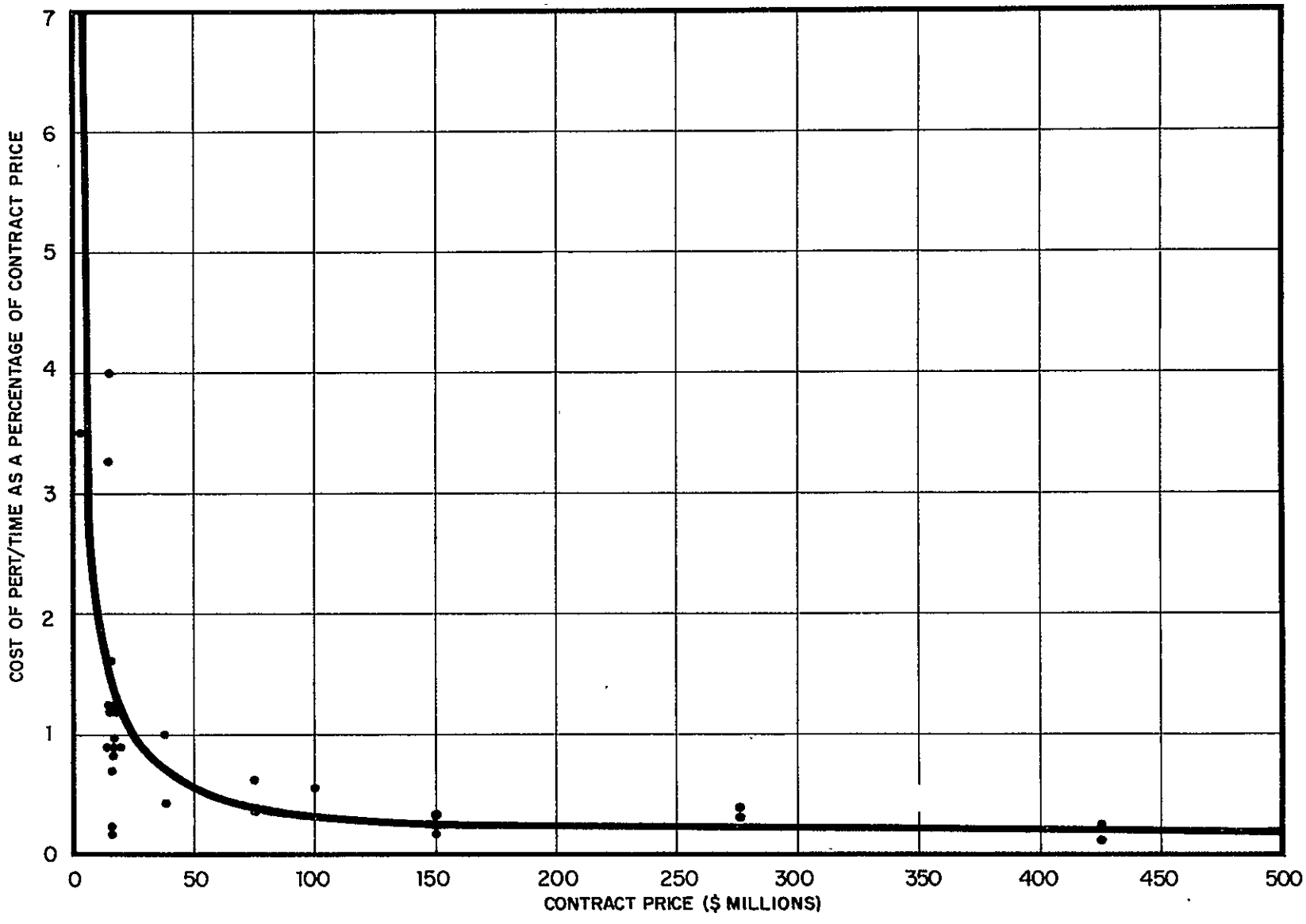

FIGURE IV-4
PERT/TIME -PERCENTAGE COST VERSUS CONTRACT PRICE

SOURCE: THE QUESTIONNAIRE DATA

opinions of the cost of PERT given in table IV-3 illustrates that PERT is perhaps not as costly as it is thought to be. Such a comparison is shown in table IV-4.

Table IV-4

PERCENTAGE COST OF PERT--INDUSTRY OPINIONS VERSUS FINDINGS OF THIS STUDY

	PERT/Time		PERT/Cost	
Contract price	Industry opinions[a]	Findings[b]	Industry opinions[a]	Findings[c]
<$100,000	3.3%	N.A.	6.1%	N.A.
$100,000-$2 million	2.3	N.A.	4.6	N.A.
$2-$50 million	2.0	1.0	3.8	1.6
$50-$100 million	1.4	0.4	3.0	0.9
>$100 million	1.0	<0.3	2.3	<0.75

[a]Data from table IV-3.

[b]Data from fig. IV-3.

[c]Data from fig. IV-4.

This study has not been designed to give accurate estimates for contract prices below $5 million, hence estimates of the cost of PERT for such contracts should not be read from figures IV-3 and IV-4. On the other hand, it is evident by glancing at table IV-4 that the aerospace industry has overestimated the cost of PERT.[11]

The cost of PERT should decline with time. It may be reasonable

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[11]The possible reasons underlying such overestimates are discussed in detail in Hayya, op. cit., pp. 83-112.

to assume that most firms were in the higher regions of the learning curve vis-à-vis PERT when this survey was undertaken in the fall of 1964. For example, the cost computed in this study of using PERT/Cost for the Comsat program at Philco was 1.86 percent. This cost has been verified for the fall of 1964.[12] According to H. Silver, of the Aerospace Corporation (which monitors Comsat): "This cost has now been reduced to 0.5 percent as a result of experience gained to date; this 0.5 percent connotes a net saving in the cost of planning and control of the Comsat program at Philco."[13]

The experience of all firms in the Aerospace industry with PERT may not be as fortunate as Philco's. Nevertheless, PERT (particularly PERT/Cost) is a new method whose cost should decline with time and use.

Cost-Effectiveness of PERT

This study has not attempted to establish that the use of PERT in the projects reported by the questionnaire is justified through cost or time savings. These savings, if any, cannot be calculated because the schedule and cost experiences of each research and development program are unique. On the other hand, the government, as the customer, may be in a good position to judge whether PERT is effective in terms of the costs incurred in its use.

An inquiry as to the worth of PERT related to its cost was

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[12] From conversations with Mr. H. Silver, Aerospace Corporation, February 1965.

[13] Ibid.

directed by this author to the Department of Defense. Mr. James W. Roach replied:

> Your question about the cost-effectiveness of PERT is a difficult one to answer and inevitably involves a judgment factor. We believe, as is evidenced by inclusion of a requirement for PERT/Cost in Directive 3200.9, that PERT is worth its cost when used for large projects in the Engineering and Operational Systems Development categories. There is some statistical evidence that PERT/Cost has reduced cost overruns and contract growth.[14]

The statistical evidence Mr. Roach refers to is based on a Department of the Navy, Bureau of Ships, study, in which contracts using PERT/Cost are compared, in terms of cost overruns and contract growth,[15] to contracts employing other techniques. The Bureau of Ships' study is concerned with cost overruns only; it does not deal with schedule slippages. Results of the study are given in table IV-5.

Table IV-5

BUREAU OF SHIPS' STUDY: COST OVERRUNS AND CONTRACT GROWTH

	Cost overruns %	Approved increase %	Contract growth %
19 Contracts using PERT/Cost	7.1	4.2	11.3
48 Contracts not using PERT/Cost	23.4	49.1	72.5

Source: Department of the Navy. Bureau of Ships. Memorandum Ser. 606A-315, October 22, 1964.

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[14] Letter to this author from Mr. James W. Roach, Assistant Director (Engineering Management), Office of the Director of Defense Research and Engineering, Department of Defense, April 30, 1965.

[15] Contract growth is defined as the approved increase in a contract plus cost overruns.

Commenting on the above table, Mr. Roach stated that although it is difficult to isolate the influence of PERT/Cost, some evidence is provided of its value. Table IV-5 shows cost overruns of 7.1 percent for contracts using PERT/Cost as compared to cost overruns of 23.4 percent for contracts not using PERT/Cost. Furthermore, the detailed planning and control PERT affords inhibits the expansion of contracts beyond their initial objectives. Table IV-5, for example, shows approved increases of 4.2 percent for contracts using PERT/Cost as compared to similar increases of 49.1 percent for contracts not using PERT/Cost. Contract growth, the sum of the cost overruns plus approved increases, is, according to table IV-5, 11.3 percent for the contracts using PERT/Cost as against 72.5 percent for those contracts not using PERT/Cost.

The Bureau of Ships' study shows, also, that reductions in overruns in ten out of the nineteen contracts using PERT/Cost (see table IV-5) represent a potential saving of approximately $37 million.[16] This $37 million, in turn, represents a saving of approximately 19 percent of contract prices. If such savings are inherent in every contract using PERT, it is easy to see by reference to figures IV-3 and IV-4 that PERT is worth the cost.

What are Reasonable Threshold Contract Prices?

It is evident that if the main criterion for the use of PERT is its cost, then PERT should be applied on a contract basis (one firm) rather than a project basis (several firms). This avoids the absurd

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[16]The Department of the Navy, Bureau of Ships, Memorandum Ser. 606A-243, August 21, 1964.

situation where PERT is required in each of a large number of small contracts that comprise one big project.

For the time being, it appears that PERT should not be utilized in small contracts regardless of the size of the parent project. The contracts where PERT is used should be of such magnitude that the cost of the PERT operation has minimum impact upon total expenditures. The index of such an impact on total expenditures is the percentage cost. The threshold contract prices must be chosen so that the percentage cost is at, or near, the minimum (or below a datum chosen by a decision-maker such as DOD). These threshold contract prices differ for PERT/Time and PERT/Cost, because the latter utilizes more resources than the former.

The research findings show that the threshold contract prices of DOD Directive 3200.9 are reasonable;[17] they show also that lower threshold contract prices may be used.

PERT/Time and Contract Price. Figure IV-3 shows that the percentage cost curve of PERT/Time is almost vertical (and asymptotic to the y-axis) at small contract prices, and that it begins to bend at approximately a cost of 2 percent and at a contract price of $10 million. The curve finally becomes almost horizontal (and asymptotic to the X-axis) at a cost of 0.25 percent and at a contract price of $150 million. Thus, it may be advisable for a procurement officer to apply PERT/Time to all R&D contracts over $10 million if he decides to use

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[17] DOD Directive 3200.9 mentions PERT/Cost only. This study deals with both PERT/Time and PERT/Cost.

PERT/Time for planning and control.

PERT/Cost and Contract Price. Figure IV-4 reveals that the percentage cost curve of PERT/Cost is almost vertical (and asymptotic to the y-axis) at small contract prices and that it begins to bend at approximately a cost of 2 percent and a contract price of $15 million. The curve finally becomes almost horizontal (and asymptotic to the X-axis) at a cost of 0.6 percent and a contract price of $200 million. A procurement officer wishing to use PERT/Cost for planning and control could easily do so in contracts that exceed $15 million.

CHAPTER V

PERT/COST AND THE LEVEL OF DETAIL

The selection of an appropriate level of detail has been a source of considerable friction between the government and the aerospace industry. The DOD and NASA Guide[1] refers to the development of a work-breakdown structure where the end-item subdivisions are manageable units for planning and control purposes. The end-item subdivisions appearing at the last level in the work-breakdown structure are divided into major work packages, such as engineering or manufacturing. The level of desirable detail, according to the Guide, depends on several considerations: the size and complexity of the project, the structure of the organization, and the judgment of the manager.

The Guide states that "normally, the lowest level work package will represent a value of no more than $100,000 in cost and no more than three months in elapsed time."[2] It does not indicate, however, why a $100,000 - three month guideline is appropriate or applicable to every situation. Such a basis is no doubt chosen to facilitate cost control by the government. Nevertheless, the choice of an appropriate level of detail may depend more on internal considerations--for example, the calibre of management, the economic characteristics of the firm, or the relative criticalness of a given work package--than on external considerations--such as the government's desire to apply a standard level of cost control in contracts where PERT is being used.

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[1] DOD and NASA Guide: PERT/Cost Systems Design, Office of the Secretary of Defense-National Aeronautics and Space Administration (Washington, D. C., June 1962).

[2] Ibid., p. 29.

Some procurement officers insist on the $100,000-three month work package, even though the aerospace industry does not consider this as an appropriate level of detail. One major difficulty has been isolated, however, by the DOD PERT Coordinating Group. This group believes that industry in general has not had enough experience with PERT/Cost as an internal management tool to enable project managers to select an appropriate level of detail.[3]

Analysis of the Questionnaire

To develop a reasonable measure for the size of the work package, the groups sampled were asked to evaluate a list of probable criteria. Table V-1 shows the relative weight assigned to these criteria by the respondents to the questionnaire.

The table summarizes the answers to question 12, Part A: "In your judgment, what should the criteria be for the size of the PERT work package?"

The major criterion chosen for the size of the work package was that it should have a definable work content. In other words, the logical sequence of events is the criterion to consider first when deciding upon the size of the PERT work package. Although, as was mentioned earlier, the government advocates a $100,000-three month guideline for the size of the work package, table V-1 shows that neither dollar size nor time span is the primary consideration in the

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[3] Common Problems Associated with Implementation and Operation of the PERT/Cost System, PERT Coordinating Group (Washington, D. C.: Special Projects Office, Bureau of Ships, Department of the Navy, 1964), pp. 23-25.

opinion of the respondents. Time span, however, received more consideration than the dollar size of the package. A work package with too long a time span may delay the completion, or the evaluation, of an entire program; on the other hand, the establishment of an appropriate dollar size of the package is only necessary for cost control purposes. In essence, responses to the questionnaire indicate that given a choice, schedule control is a more important criterion for the size of the work package than is cost control. This is consistent with interview findings.

A tally of the opinions of the respondents regarding the $100,000-three month guideline as the sole criterion for the size of the PERT work package is presented in table V-2. It is a summary of replies to question 13, Part A, of the questionnaire: "Is the $100,000-three month work-package guideline meaningful?" Table V-2 shows that the government group is divided on this issue. On the other hand, most of the industry group does not consider the $100,000-three month guideline meaningful.

Those in the government group supporting the $100,000-three month guideline stated that it helped in controlling costs and schedules. According to one systems project officer: "The guideline, when followed, keeps money and time at levels which most people can comprehend. Management can also do something about the problem areas before it is too late and too much money has been spent."

Government people who did not approve the guideline cited the weakness that it disregarded logical work-package units in a program. One government respondent said, for example: "We want identifiable

Table V-1

RELATIVE WEIGHT GIVEN TO CRITERIA FOR THE SIZE OF THE WORK PACKAGE

Criterion[a]	Groups Sampled			
		Industry Group		
	Government group	Top managers	Directors of PERT programs	PERT staff
Phase of the program	0.70	0.69	0.72	0.70
Number of events	0.54	0.54	0.44	0.50
Criticalness of events	0.88	0.98	0.69	0.95
Cost uncertainty involved	0.80	0.85	0.86	0.90
Technical uncertainty involved	0.66	0.88	0.75	0.73
Schedule uncertainty involved	0.76	0.87	0.80	0.80
Dollar size of package	0.66	0.63	0.75	0.68
Time span	0.84	0.65	0.89	0.97
Cost control	0.88	0.87	0.87	1.00
Definable work content (logical structure of events)	1.00	1.00	1.00	1.00
Other:[b]				
One individual responsible for the work package	x	x	x	x
Management skill	x	x	x	x

[a]Criteria are listed in the order shown in the questionnaire.

[b]These criteria were volunteered by only some respondents. In order to avoid improper comparisons, they have not been weighted.

entities that are meaningful." That is, a work-package must have logical beginning and ending events.

A majority of the industry group advanced similar arguments in opposing the guideline. Many such respondents stressed that the work package must be manageable, and one top manager wrote that "manageability of an activity is a more important criterion than an arbitrary

Table V-2

SUMMARY OF OPINIONS ABOUT THE $100,000-THREE MONTH PERT WORK-PACKAGE DOD GUIDELINE
(answers in percent of those sampled)

Type of Group	Response		
	Meaningful	Not meaningful	No opinion
Government	42%	42%	16%
Industry			
Top managers	21	63	16
Directors of PERT programs	29	68	3
PERT staff	33	53	14

choice of cost and schedule levels of control." A middle manager shed more light on the problem of "manageability" by saying: "Other factors such as type of contract, previous history, customer attitude, customer reactions, and changes in the program may override the guideline. Manipulation of funds, tradeoffs, and other such factors can void the guideline. The $100,000 or the three-month limit is valid in the classroom--in actual practice it is not used." One may conclude

from the above that most of the questionnaire respondents viewed the $100,000-three month work-package guideline as an artificial device, one that does not deal with the real situation.

Research Findings

In addition to the size of the work package, the government and the aerospace industry tend to use the number of end-item levels on the work-breakdown structure as another index of the PERT level of detail. The number of end-item levels on the work-breakdown structure, however, generally reflects the vertical stratification of an organization. That is, an organization with a large number of organizational layers is able to take the work-breakdown structure to a correspondingly large number of end-item levels. Normally, organizations possess a relatively fixed number of authority layers, which may explain why a majority of the questionnaire respondents state that the number of end-item levels of the work-breakdown structure is between four to six for the projects reported.

The questionnaire data and the interviews showed that the number of end-item levels in a work-breakdown structure did not change radically as the organization, the size of the contract, or the type of project was altered. The questionnaire data suggested, however, that the size of the work package (in dollars) was primarily affected by contract price. The interviews validated this finding. During one interview, for example, a manager at an aerospace firm told the author that the use of PERT by his firm in a prospective $1 billion contract might result in work packages in the magnitude of $250,000 to $500,000. The reason

given was that the organizational controls of the firm were tied to its basic departmentation, and each department controlled work packages in its own area of responsibility according to certain procedures. The nature of these controls, and the depth of detail to which the controls were extended, did not differ from one work package to another in spite of the fact that work packages might differ in magnitude.

Large contracts, while involving large work packages, entail higher absolute costs of planning and control than do small contracts. This explains the phenomenon that the larger the work package, the greater the expense of using PERT/Cost. This is illustrated in figure V-1 which shows a best fit of

$$Y = 0.36361 - 0.00172\ X + 0.00003\ X^2 \qquad \text{(V-1)}$$

where

Y = total operating cost of PERT/Cost, in millions of dollars, and

X = mean size of the work package, in thousands of dollars.

A relationship that describes the dependence of the size of the work package upon contract price is given by

$$Y = 83.57 + 0.60\ X \qquad \text{(V-2)}$$

where

Y = the size of the work package, in thousands of dollars, and

X = the contract price, in millions of dollars.

The linear correlation coefficient of the variables in equation V-2 is 0.63. The standard error of the estimate is 109.11.

According to the analysis, then, the PERT/Cost detail in terms of the number of end-item levels for the work-breakdown structure

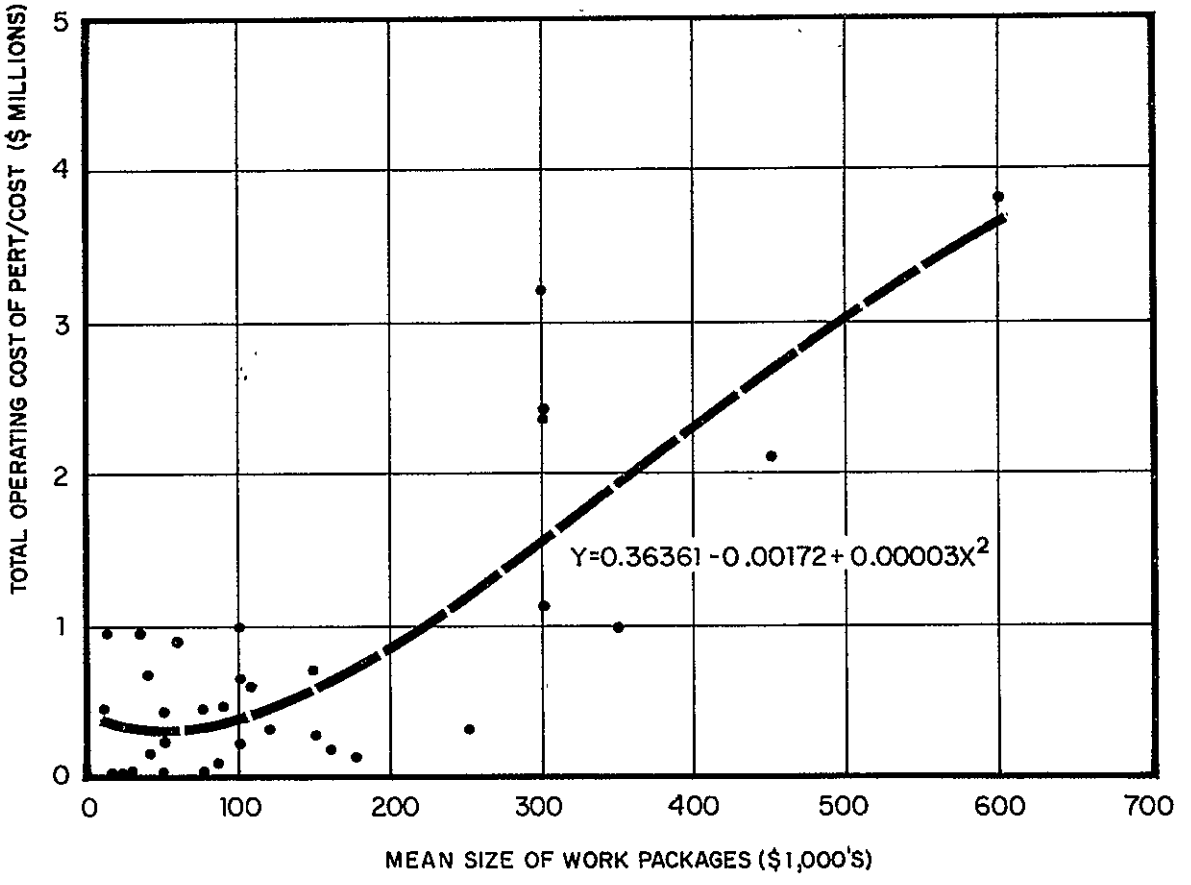

FIGURE V-1

)TAL OPERATING COST OF PERT/COST VERSUS THE MEAN SIZE OF THE WORK PACKAGE

SOURCE: THE QUESTIONNAIRE DATA

does not vary a great deal. Also the size of the work package, in dollars, is dependent mainly on the size of the contract. This latter fact is illustrated in equation V-2 above. It is also demonstrated in table V-3 which is a summary of a stepwise regression[4] of a number of relevant variables, such as contract price, number of end-item levels, duration of the work package, type of organization, and class of R&D.

Table V-3

COST OF THE WORK PACKAGE: STEPWISE REGRESSION SUMMARY

Step No.	Variable entered	Multiple correlation coefficient R	R^2	ΔR^2	F value to enter[a]
1	Contract price	0.6292	0.3959	0.3459	20.97
2	Number of end-item levels	0.7342	0.5390	0.1432	9.63
3	Duration of the work package	0.7650	0.5852	0.0461	3.33
4	Functional organization	0.7846	0.6156	0.0305	2.30
5	R&D class II	0.8037	0.6460	0.0303	2.40
6	Contract life	0.8101	0.6563	0.0103	0.81
7	PERT/Cost as the only control system	0.8131	0.6612	0.0049	0.38
8	Contractual requirement	0.8149	0.6640	0.0028	0.21
9	Cost-reimbursement contracts	0.8151	0.6644	0.0004	0.03

[a]The "F value to enter" is the square of the ratio of the variable's regression coefficient to its standard error.

Source: A stepwise regression computer program of the PERT/Cost data.

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[4]See W. J. Dixon, ed., BMD: Biomedical Computer Programs (Los Angeles: University of California, Los Angeles, 1964), pp. 233-257, for an explanation of the stepwise regression.

A multiple linear regression for the cost of the work package as a function of contract price, number of end-item levels, duration of the work package, type of organization, and R&D class yields

$$Y = -234.48 + \underset{(0.12)}{0.65}\ X_1 + \underset{(2.83)}{4.61}\ X_2 + \underset{(35.64)}{55.19}\ X_3 + \underset{(43.88)}{77.08}\ X_4 + \underset{(12.86)}{43.92}\ X_5 \qquad \text{(V-3)}$$

where the values within the parentheses are the standard errors of the regression coefficients, and where

Y = the cost of the work package, in thousands of dollars,

X_1 = contract price, in millions of dollars,

X_2 = duration of the work package, in months,

X_3 = R&D class (class I made of PDP, research, exploratory development, or advanced developments = 0; class II made of engineering developments, management and support, or operational system development = 1)

X_4 = type of organization (functional = 1; product or project = 0), and

X_5 = number of end-item levels in the work-breakdown structure.

Some of the variables, such as the size of the contract and the type of organization, which affect the PERT/Cost level of detail are considered in the DOD and NASA Guide. As stated previously, the Guide recommends that the level of detail should depend on three qualitative considerations and one quantitative factor. The qualitative considerations are: the size and the complexity of the project, the

structure of the organization, and the judgment of the manager.[5] The quantitative consideration is that the lowest level work-package be no more than $100,000 in cost and no more than three months in elapsed time.[6]

The interviews conducted by the author revealed the latter guideline as sometimes the sole basis for determining the level of detail where PERT was used. This represented a rigid adherence to the Guide, and a lack of concern for the realities of the particular project and the needs of the individual firm.

Because the $100,000-three month guideline, taken alone, disregards individual considerations of aerospace firms, it has not met with support. The questionnaire survey, for example, shows that of ninety-seven respondents, only twenty-one considered this guideline meaningful, and even then there were reservations related to motives more vital to the firm (see table V-2).

The motivation for the $100,000-three month guideline lies, undoubtedly, in the unhappy history of the cost overruns and schedule slippages characteristic of defense and aerospace weapon systems. The author has been unable to discover in the literature a theoretical basis for this guideline, but the literature and the questionnaire data do suggest refutations for the guideline.

Time and cost are interchangeable resources, with trade-offs between the two dependent on the economic characteristics of the

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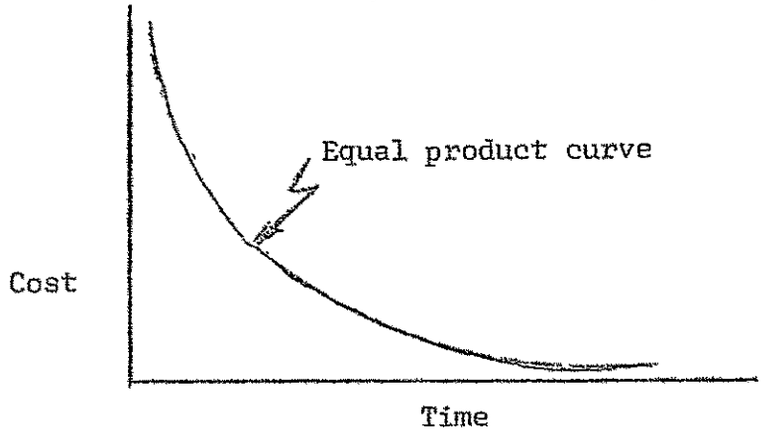
[5] DOD and NASA Guide - PERT Cost, p. 29.

[6] Ibid.

individual firm. The time-cost relationship for the production of a particular work package in a given firm may be described by the equal product curve shown in figure V-2. The points on the curve represent the different combinations of time and cost that can be used to produce the same work package.

In a study of the time-cost relationship, Charles E. Clark has postulated a hyperbolic time-cost function (like that in figure V-2) to show the possible time and cost relations for an event in a network of activities.[7] Clark has shown that, given a hyperbolic cost function, there is a unique slackless schedule.[8] This schedule determines a specific time duration for each activity in the network. Therefore, the time geometry of the total project fixes the time span of a work package.[9] The time required for the completion of each work package also determines the cost, as shown in figure V-2. This pair



[7]Charles E. Clark, "The Optimum Allocation of Resources among the Activities of a Network," Journal of Industrial Engineering (February, 1961), pp. 11-17.

[8]The term "slack," or "float," is the difference between the latest allowable date and the expected date for the completion of an activity.

[9]A work package is assumed to consist of one or more logically connected activities.

(time, cost) determines an optimum situation in terms of time and cost, because the choice of each is based on a slackless schedule. The slackless schedule means that no activity has been planned in shorter time, and therefore at higher cost, than was necessary to meet the completion date of the project. That schedule is, therefore, the lowest cost plan for a project.[10]

In theory, then, the slackless schedule of a project determines the time span of each activity. The time, in turn, determines the cost of that activity. One, or a number, of connected activities (or subpackages) that may be managed by one man should become a work package without any arbitrary constraints of time and cost, because these are determined by the slackless schedule. The slackless schedule is naturally a function of the project itself, the resources of the firm, and the calibre of management.

The main weakness of the $100,000-three month guideline is that it assumes a unique set of conditions for all firms. This connotes a standard project, a standard work package, and the economic constraints whereby all firms have an identical equal product curve. Observations in the aerospace industry do not support these assumptions.

The data on the cost and time of mean work packages, gathered in replies to questions 21 to 23, Part B of the questionnaire, do not suggest one equal product curve for the firms reporting. A scatter diagram of these data are shown in figure V-3, with the cross-hatched area indicating the set conforming to the $100,000-three month guideline.

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[10]Henry B. Eyring, Evaluation of Planning Models for Research and Development Projects. (DBA dissertation, Graduate School of Business, Harvard University, 1963), p. 31.

Figure V-3 shows that the scatter of the points does not lend itself to one equal cost-time product curve for the data reported. Furthermore, figure V-3 shows that only four out of thirty-four firms reportedly using PERT/Cost adhered to the $100,000-three month guideline; these four firms fall in the cross-hatched portion of figure V-3.

As mentioned earlier, a $100,000-three month work-package guideline is justified only if all aerospace firms possess an identical equal product cost-time function. (Such an improbable situation is presented in the isoquant of figure V-4.) In addition, the guideline must assume that all aerospace firms possess a unique budget - schedule constraint (see figure V-4) that is always tangent to the equal product curve at $100,000-three months.

The author argues that aerospace firms possess unique equal product cost-time functions. Moreover, each project has a unique slackless schedule. The interaction of the project with the firm, therefore, determines the optimum mode of operation, including the size of the work package. To specify an arbitrary guideline for all firms obviously is illogical.

Although a mathematical model for the size of the work package has been derived from the questionnaire data (see equations V-2 and V-3), the author is not suggesting that qualitative criteria for the size of the work package are not of paramount importance. For any particular firm, these qualitative criteria can be the result of experience and good judgment. Of these qualitative criteria, the most important is how a work package fits into the overall schedule of the project; that schedule should determine the time duration and,

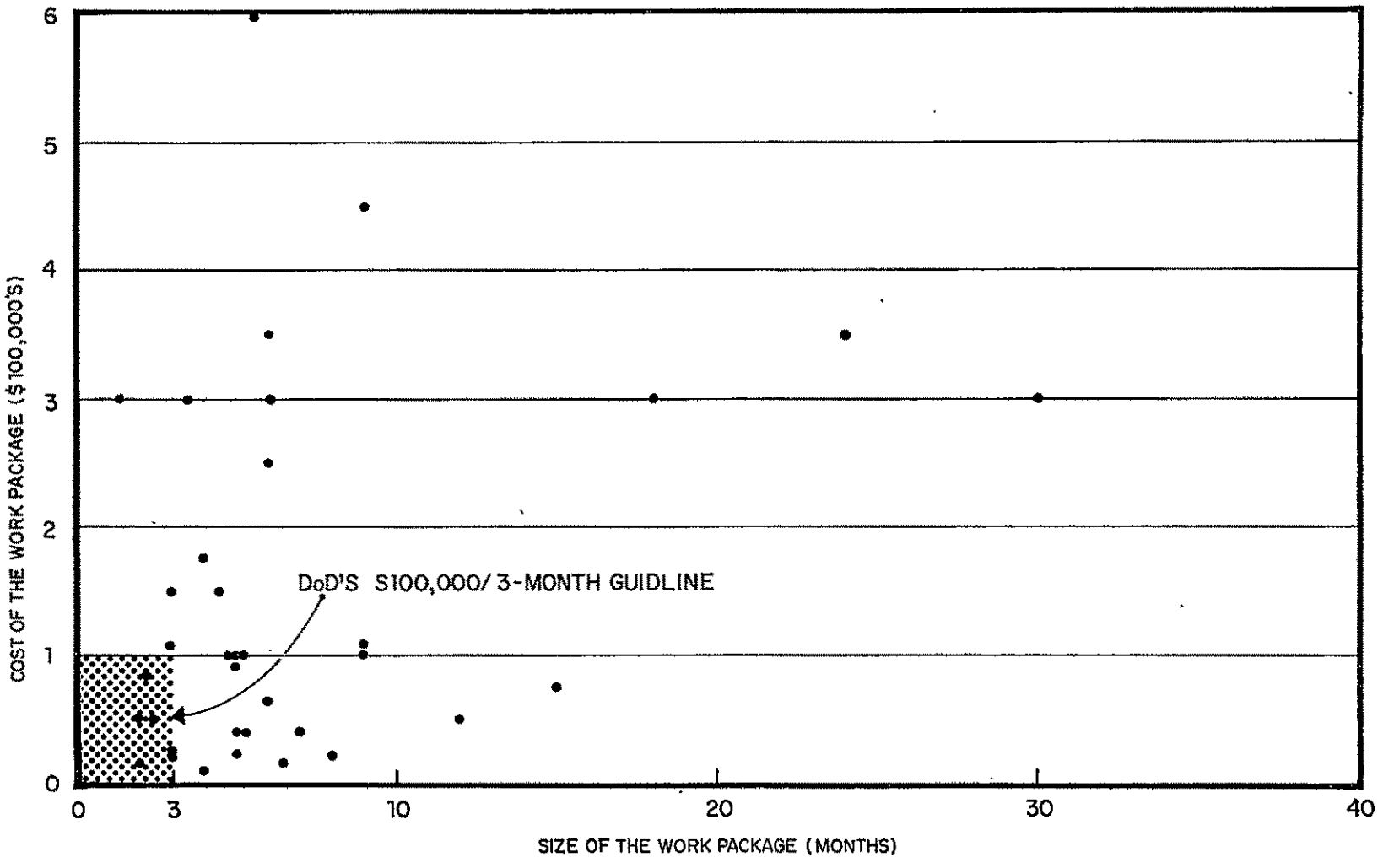

FIGURE V-3
SCATTER DIAGRAM -TIME VERSUS COSTS, WORK PACKAGE

SOURCE: THE QUESTIONNAIRE DATA

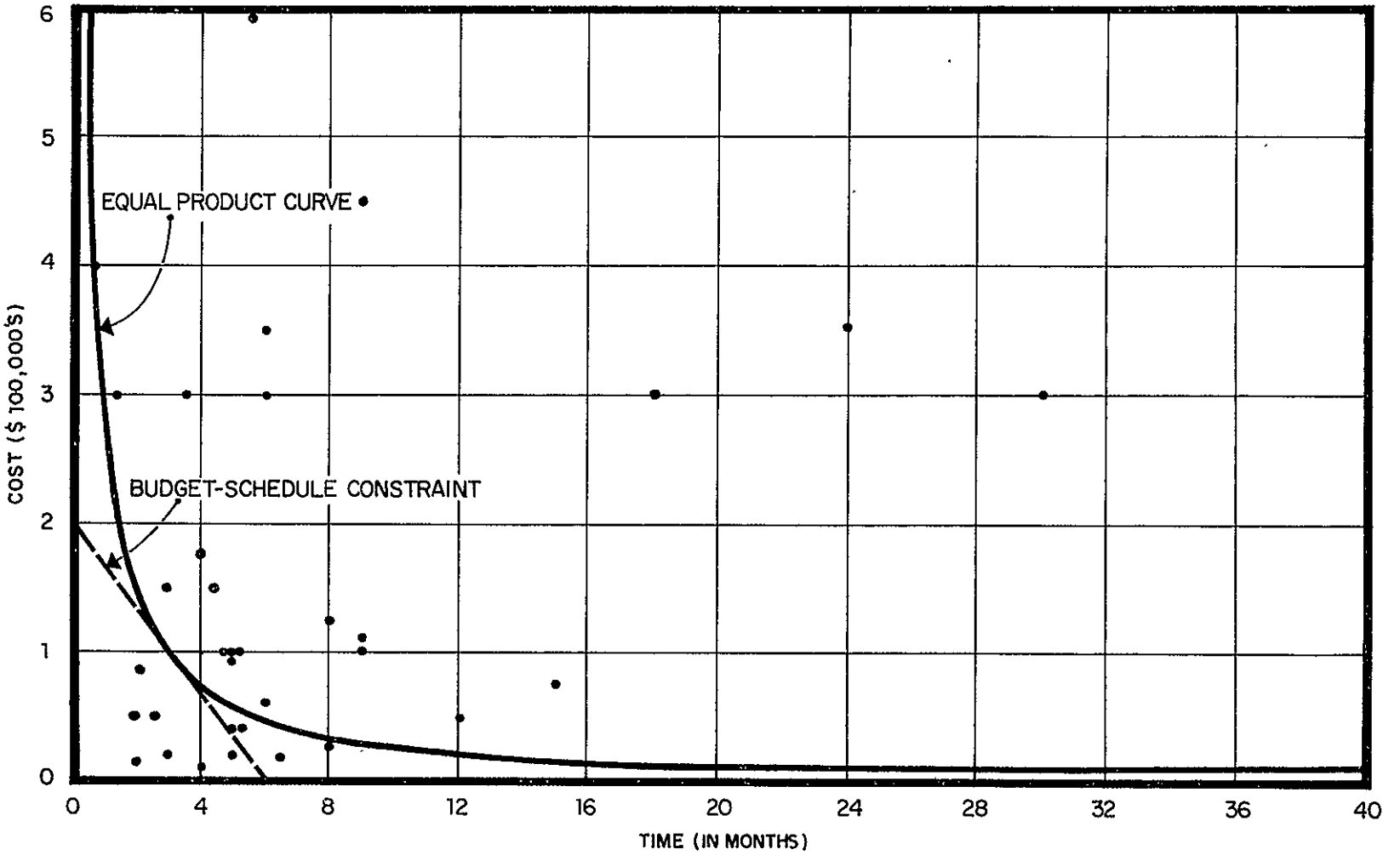

FIGURE V-4
POSTULATED EQUAL PRODUCT CURVE

SOURCE: THE SCATTER OF THE POINTS IS BASED ON THE QUESTIONNAIRE DATA.
THE EQUAL PRODUCT CURVE AND THE BUDGET-SCHEDULE RESTRAINT ARE POSTULATED BY THE AUTHOR.

hence, the cost of network activities. Several of these activities may be combined together under the direction of one man, but the work package must be of reasonable magnitude--it must not be managed by more than one man. A logical structure of events and a definable work content should be the underlying features of any work package.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

In analyzing the government's position on the use of PERT in procurement, it appears that it made some arbitrary decisions. Furthermore, in many instances, DOD Directive 3200.9,[1] The DOD and NASA Guide,[2] and various government memoranda were imprecise about when, where, and under what circumstances PERT should be used.

The vague and arbitrary nature of the government criteria provoked great controversy within the aerospace industry and between the aerospace industry and the government. The industry feared that PERT would be applied to all types of contracts, fixed-price as well as cost-reimbursement, and that it would be applied indiscriminately to production as well as to R&D projects. Many individuals in the aerospace industry were alarmed also that the level of detail suggested by The DOD and NASA Guide would contribute more to a proliferation of reports than to effective management and control of weapons' and aerospace systems. In addition, the seemingly arbitrary nature of the threshold contract prices of DOD Directive 3200.9 provoked questions about the value of such criteria.

The situation, however, was not an altogether surprising one. The government was trying to correct the excesses of the past and to solve the problems of schedule slippages and cost overruns. It turned to PERT as the most sophisticated tool available for the purpose at

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[1] DOD Directive 3200.9 from Secretary of Defense Robert S. McNamara, February 26, 1964, and July 1, 1965.

[2] DOD and NASA Guide: PERT/Cost Systems Design (Washington, D. C.: Office of the Secretary of Defense-National Aeronautics and Space Administration, June 1962).

hand; it could only hope to find its way by trial and error. PERT had never been used for the management of a large system involving many contracts. The nature of the criteria, and the ensuing complication of interpretation, reflected the difficulties involved in such an undertaking. The greater portion of these difficulties was shouldered by procurement and systems project officers, who were generally divorced from the DOD policy makers.

This study is designed to assist procurement and systems project officers in overcoming some of these difficulties and in seeking solutions to the problems associated with the use of PERT as a method of planning and controlling defense and aerospace weapons' systems. The principles suggested for the use of PERT in procurement contracts were developed on the basis of the insights and findings of an extensive research effort.

The research was designed in three steps, generally sequential. First, a review was made of the literature. This included material that described the general environment of PERT in the aerospace industry. It also included government directives, memoranda, and various articles that presented the government case for applying new controls (in the form of PERT) to the procurement process.

The literature, however, did not provide a complete nor accurate description of the positions of the aerospace industry and of systems project officers on the use of PERT to plan and control procurement contracts. Thus, the second step of the research was comprised of a series of depth interviews with aerospace industry and government personnel. Industry interviews were conducted with selected top managers,

directors of PERT, and members of PERT staffs. The government group consisted of procurement and systems project officers. Apart from determining the problems associated with the use of PERT, the interviews furnished the basic framework for the third step of the research.

In this latter step a comprehensive questionnaire survey was conducted among aerospace firms and systems project offices using PERT. The survey was, in effect, a non-probability sample with three purposes: (1) to solicit opinions on the use of PERT as it related to contract type, project type, threshold contract prices, and level of detail; (2) to secure numerical data for the development of models for the cost of PERT and for the size of the PERT/Cost work package; and (3) to verify the validity of attitudes of skepticism toward PERT expressed during the interviews--if prevalent, such attitudes could easily impede efforts to implement PERT.

The analysis of the questionnaire results suggests that the attitude of the aerospace industry toward PERT is not as negative or as skeptical as it was thought to be during much of the interviews. Apparently the aerospace industry approves PERT as a planning and control tool. The analysis also suggests that the aerospace industry does not object to the government requiring PERT in procurement contracts so long as the government is selective about where and when this is done.

According to the questionnaire respondents, PERT should be confined to research and development and military construction projects. The use of PERT in basic research or repetitive production activities appears to be unnecessary because basic research cannot be controlled closely, at least meaningfully, and because production activities are being

mastered by simpler methods, such as the line of balance (LOB) and Gantt charts. The need for PERT, therefore, exists only in R&D projects and in military construction programs.

Analysis of the questionnaire replies and the force of logic indicate that the government should require a contractor to use PERT in cost-reimbursement contracts only, provided that the project is in R&D and that it is of sufficient magnitude to warrant the cost of using PERT. There is a sharp division, however, between the industry and government groups surveyed on the issue of requiring the use of PERT in fixed-price contracts. The government group argues that the government PERT contractual requirement should include all fixed-price contracts, with the possible exception of firm fixed-price contracts. The industry group, on the other hand, objects to the intrusion of government control in all fixed-price contracts, because the major burden of the profit and loss risk is carried by the contractor himself. The evidence supports the view of the aerospace industry.

The numerical data provided by the questionnaires made possible the development of approximations for the cost of PERT. A first approximation for the cost of PERT/Time was found to be

$$X(y - 0.156) = 20.6 \qquad \text{(VI-1)}$$

where

X = contract price in millions of dollars, and

y = the cost of PERT/Time as a percentage of contract price.

A first approximation of the cost of PERT/Cost was found to be

$$X(y - 0.447) = 29.3 \qquad \text{(VI-2)}$$

where

X = contract price in millions of dollars, and

y = the cost of PERT/Cost as a percentage of contract price.

Equations VI-1 and VI-2 are hyperbolic functions similar to those of the average fixed-cost functions in classical economics. These hyperbolic functions show a high percentage cost for using PERT in small contracts and a low, and almost constant, percentage cost for using PERT in large contracts. These functions suggest that if PERT is to be used, it should be in instances where the percentage cost is at or below 2 percent. This indicates threshold contract prices of $10 million for PERT/Time and $15 million for PERT/Cost.

The analysis of the questionnaire also suggests that the number of end-item levels in the work-breakdown structure does not vary a great deal. Usually a firm using PERT/Cost takes the work-breakdown structure to about 4 to 6 levels. The size of the work package, however, varies a good deal, depending on the magnitude of the project--the bigger the project, the bigger the work package. A relationship of the size of the work package and contract price derived from the questionnaire data is given by

$$Y = 83.57 + 0.60\ X \qquad \text{(VI-3)}$$

where

Y = the size of the work package in thousands of dollars, and

X = the contract price, in millions of dollars.

The questionnaire data failed to yield a meaningful model for the duration of the work package. It depends, however, on the qualitative criterion of how the package fits in the overall program schedule. The analysis suggests that the work package, in terms of cost and time, must be of manageable size, that it must be structured

logically, and that it must be managed by one man.

On the basis of the above conclusions, the author recommends four principles to be used by procurement and systems project officers in making decisions about requiring PERT in procurement contracts. These principles relate to the use of PERT in certain types of contracts and projects. They also relate to constraints of minimum contract price and to the level of detail desirable for planning and control. These principles are:

1. Type of contract. Systems project officers should require PERT in cost-reimbursement contracts only.
2. Type of project. Systems project officers should require PERT in research and development (R&D) and in military construction programs only.
3. Threshold contract prices. The threshold contract price that makes the use of PERT/Time mandatory should be $10 million; that for PERT/Cost should be $15 million. These threshold prices are subject to constraints relating to type of contract and project.
4. PERT/Cost level of detail. The work content of the lowest level work package in the PERT/Cost work-breakdown structure must be well defined and the package itself must be of such size that it can be managed by one man or one department. Furthermore, the duration of the work package must be subordinated to the overall plan or schedule.

From principles 1, 2, and 3 suggested above, it is possible to devise a simple decision model for the use of PERT by procurement and

systems project officers. This model is illustrated schematically in figure VI-1.

By use of the model a procurement officer may easily determine when, and under what circumstances, he may apply PERT/Time or PERT/Cost. The model of figure VI-1, however, does not take into account the criticalness of a particular project in the defense and aerospace effort. Procurement officers may wish to control such projects closely. They should, therefore, use PERT/Time or PERT/Cost regardless of the constraints shown in Figure VI-1.

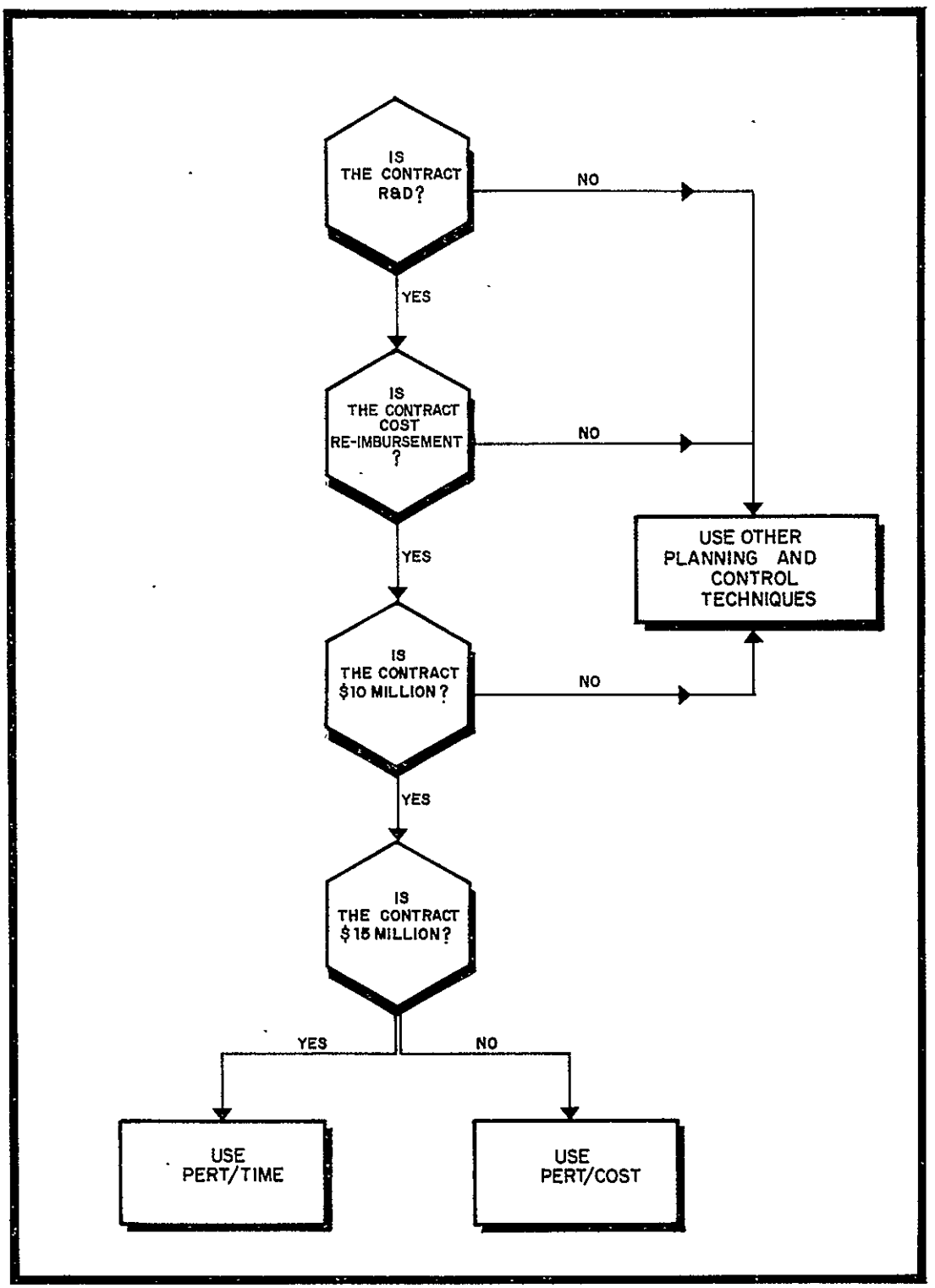

FIGURE VI-1

A DECISION MODEL FOR THE USE OF PERT IN PROCUREMENT CONTRACTS

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Horniman, Alec, Management Controls, Rocketdyne, Canoga Park, California, May 20, 1964.

Holtz, Professor J. H., Graduate School of Business Administration, University of California, Los Angeles, on several occasions.

Howerton, Lorne, Director of TFX PERT Program, General Dynamics/Fort Worth, in Santa Monica, California, November 18, 1964.

Hurd, Glenn, Financial Planning, Advanced Program Staff, Lockheed-California Company, on several occasions.

Ivy, Kelly, Systems Administrator, Vickers, Inc., Torrance, California, August 18 and 25, 1964.

Jakes, Major J. E., Secretary of the Air Force Special Projects Office, El Segundo, California, September 25, 1964.

Kaplan, Morton, Hydraulic Research Inc., Burbank, California, on several occasions.

Kelgard, Major P. E., Ballistics Systems Division, AFSC, Norton AFB, San Bernardino, California, October 8, 1964, and November 10, 1964.

Kunsmiller, John, USAF, SSD, El Segundo, California, on several occasions.

Lyman, W., Manager, Operations Research, Autonetics, Anaheim, California, January 29, 1964.

Margolis, Milton A., Cost Analysis Department, RAND Corporation, on several occasions.

Mason, Reuben D., U. S. Army Audit Agency, Los Angeles District, April 30, 1965.

Miller, E., Head, Economics Planning, Autonetics, Anaheim, California, January 29, 1964.

Minckler, Lt. Colonel H. R., Space Systems Division, AFSC, El Segundo, California, September 22, 1964.

Morrissey, Thomas F., BSD, AFSC, Norton AFB, San Bernardino, California, September 21, 1964, and October 8, 1964.

Murphy, Lt. Colonel J. T., Ballistics Systems Division, AFSC, Norton AFB, San Bernardino, California, September 21, 1964, October 8, 1964, and November 10, 1964.

Murray, William J., Lockheed-California Company, Burbank, California, April 27, 1964.

O'Leary, Colonel John A., Chief of Procurement and Production Office, Ballistics Systems Division, Norton AFB, San Bernardino, California, March 19, 1964.

Pardee, F. S., RAND Corporation, on several occasions.

Pearson, E. S., PERT Supervisor, Space Technology Laboratories, Inc., Redondo Beach, California, December 3, 1964.

Perry, Robert L., RAND Corporation, on several occasions.

Profant, John E., Supervisor, Technical Planning, Northrop Norair, Los Angeles, California, June 16, 1964.

Roberts, Edward, of MIT and RAND Corporation, on several occasions.

Rubinstein, Albert H., Northwestern University, August 28, 1964, at Santa Monica, California.

Schwartz, Lee, General Dynamics, Pomona, California, June 3, 1964.

Scott, Lt. Colonel Winton A., USAF, SSD, El Segundo, California, February 19 and September 4, 1964.

Shely, Captain William, USAF, Wright Patterson AFB, Ohio, August 4, 1964, El Segundo, California.

Silver, H., Management Controls Systems, Aerospace Corporation, on several occasions.

Simpkins, R., General Dynamics, Pomona, California, June 3, 1964.

Sliney, Admiral J. G., Director of Programming, Hughes Aircraft Corporation, Culver City, California, on several occasions.

Staszak, Lt. Colonel Leonard, USAF and RAND Corporation, on several occasions.

Tarika, Elio, Executive Vice-President, Union Carbide Corporation, (telephone interview) May 21, 1965.

Warga, Levente, North American Aviation, Downey, California, on several occasions.

Wenzel, Walter, PERT Coordinator, Vickers, Inc., Torrance, California, August 26, 1964.

Wert, Major William H., USAF, SSD, El Segundo, California, September 4, 1964.

Williams, Major Harold J., USAF, SSD, El Segundo, California, September 2, 1964.

Williams, James, Financial Planning, Advanced Program Staff, Lockheed-California Company, on several occasions.

Wienecke, Lt. Colonel E. R., Contracting Officer, USAF, SSD, Los Angeles, October 16 and October 23, 1964.

Wolfson, Robert, RAND Corporation, April 17, 1964.

Young, Major Stewart, USAF, SSD, El Segundo, California, September 8, 1964.

Appendix I

GLOSSARY OF TERMS

Advanced developments. Advanced developments include all projects that have moved into the production of hardware for experimental or operational test. They are characterized by line item projects, and program control is exercised on a project basis. A further characteristic lies in the design of items being directed toward hardware for test or experimentation as opposed to items designed and engineered for eventual service use. Examples are VTOL aircraft, ARTE-MIS, experimental hydrofoil, X-15 and aerospace plane components.

Aerospace industry. The aerospace industry is the segment of trade that is primarily engaged in the production of aircraft, guided missiles, and all other air and space vehicles.

Control. Control is a process that involves the measurement and correction of performance in order to insure that objectives and plans are accomplished.

Critical path. The critical path is the longest path through a network.

Delivery schedule. A statement, often tabular, of delivery of quantities of procured items, by dates that were, or are, to be delivered.

End item. An end item is the lowest level component in a work breakdown structure.

Engineering developments. Engineering developments include those development programs being engineered for service use that have not yet been approved for procurement or operation. For example: MAULER,

TYPHON, B-70. This area is characterized by major line item projects and program control will be exercised by review of individual projects.

Exploratory development. Exploratory development includes all effort directed toward the solution of specific military problems, short of major development projects. This type of effort may vary from fairly fundamental applied research to quite sophisticated bread-board hardware, study, programming and planning efforts. It would thus include studies, investigations and minor development effort. The dominant characteristic of this category of effort is that it is pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters. Program control of the exploratory development element will normally be exercised by general level of effort.

Government. For this study, the term government includes:

1. The Office of the Secretary of Defense
2. Department of the Army
3. Department of the Navy
4. Department of the Air Force
5. Atomic Energy Commission
6. Bureau of the Budget
7. Federal Aviation Agency
8. National Aeronautics and Space Administration.

Interface. An interface is an event that signals the necessary transfer of responsibility, end items, or information from one detailed network to another. Examples of interface events are the receipt

of an item, such as hardware, or the release of engineering drawings to manufacturing.

Line of balance. Line of balance (LOB) is a technique for assembling, selecting, interpreting and presenting in graphic form the essential factors involved in a production process, from raw materials to completion of the end product, against a background of time. It is a management tool that utilizes the exception principle to show only the most important facts.

Management and support. Management and support include effort directed toward support of installations or operations required for general research and development use. Included would be test ranges, military construction, maintenance support of laboratories, operations and maintenance of test aircraft and ships. Costs of laboratory personnel, either in-house or contract-operated, will be assigned to appropriate projects or as a line item in the research, exploratory development, or advanced development program areas, as appropriate. Military construction costs directly related to a major development program will be included in the appropriate element.

Milestone. A milestone is a significant event within a project.

Network. A network is a diagram showing the interrelations and interfaces of activities and events required to accomplish a specified objective.

Operational system development. Operational system development includes effort directed toward development, engineering and test of systems, support programs, vehicles and weapons that have been approved for production and service employment. This area is included for

convenience in considering all RTD&E projects. All items in this area are major line item projects which appear as RTD&E costs of weapons systems elements in other programs. Program control thus will be exercised by review of the individual research and development effort in each weapon system element.

Overhead. Overhead is expense which is not directly identified with a productive cost center or operating activity.

Overrun. An overrun is the difference between the estimated cost of a work performed and the actual cost.

PERT. PERT (or PERT/Cost) is a method of providing systematic cost analysis information (via regular reports) correlated to time. The objectives of PERT are:

1. Definition of the work to be performed.

2. Development of realistic schedule and cost estimates based on the resources planned to perform the work.

3. Determination of resource allocation to optimize time, cost, and technical performance objectives.

4. Identification of potential delays and cost overruns for corrective action.

Phases in Weapons Acquisition. There are five consecutive phases in weapons acquisition. These are:

1. The pre-request for proposal phase.

2. The program definition phase.

3. The weapon system development phase.

4. The weapon system production phase.

5. The operational phase.

Planning. Planning is a process which involves the selection, from among alternatives, of objectives, policies, procedures, and programs.

Polaris. Submarine-launched, 2-stage, solid propellant missile.

Principle. A principle is a general proposition sufficiently applicable to a series of phenomena under consideration to provide a guide to action.

Project definition phase. The project definition (or contract definition) phase consists of: (1) predefinition, (2) actual project definition, and (3) weapon system development contract definition. The main feature of this phase is that definitive program planning is accomplished prior to granting full-scale development contracts. It has the following objectives: the preparation of detailed plans, realistic cost and schedule estimates; identification of high risk areas; evaluation of time-cost performance trade-offs; determination of achievable system performance or design requirements specifications and end item detail specifications; and the development of a basis for firm fixed-price or incentive contracts for the acquisition phase. The fundamental purpose of the definition phase, then, is to define the cost, schedule, and technical requirements of a program as early as possible in its life cycle.

Research. Research includes all effort directed toward increased knowledge of natural phenomena and environment and toward the solution of problems in the physical, behavioral and social sciences that have no clear direct military application. It would by definition thus include all basic research and, in addition, that applied research

directed toward the expansion of knowledge in various scientific areas. It does not include efforts directed toward proving the feasibility of solutions to problems of immediate military importance or time-oriented investigations and developments. The research elements are further characterized by using level of effort as the principal program control.

Slippage. Slippage is a delay, or nonaccomplishment, of an event or task.

Uncertainty. Uncertainty is the relative unpredictability of the outcome of a contemplated action.

Weapon system. An entity consisting of a weapon, weapons, or equipment, together with all related and integrated material and supporting facilities, required to bring the weapon on target or cause the equipment to perform the function for which it was built.

Work-breakdown structure. The work-breakdown structure is a family-tree subdivision of a program, beginning with the end objectives and then subdividing these objectives into successively smaller end-item subdivisions.

Work package. The work package is the unit of work required to complete a specific job or process. Examples are reports, designs, documents, or pieces of hardware.

Appendix II

THE QUESTIONNAIRE WITH LETTER OF TRANSMITTAL

INSTRUCTIONS

The purpose of this questionnaire is to support research which will help establish basic principles to permit NASA and DOD procurement officers determine the appropriate application of PERT/Cost. It attempts to evoke responses from industry as well as government, and to integrate those responses in an objective manner. The questionnaire pertains only to defense and aerospace work, and the term PERT will be used synonymously with PERT/Cost.

The questionnaire consists of two parts: A and B. Part A is to elicit your opinions in the areas of contract type, minimum contract price, level of detail, and project type. Part B pertains to general information on one project only.

Your own estimate or your own opinion is all that is required in answering both parts of this questionnaire. If you find that a particular item is not applicable to your organization, write "Not Applicable" in the space reserved for the answer to that question. If you wish to expand further on any question, please attach additional sheets.

Be assured that no information from this questionnaire will be revealed. This information will be aggregated with that of other respondents before conclusions are drawn.

In the appendix are standard definitions that are well known to the practitioners in the field. These definitions may be referred to in case of doubt.

Please fill in the questionnaire and return it at your earliest convenience to:

Jack Hayya
Division of Research
Graduate School of Business Administration
University of California, Los Angeles
Los Angeles 24, California

PART A

THE FOLLOWING QUESTIONS ARE DESIGNED FIRST TO IDENTIFY YOUR POSITION WITHIN YOUR ORGANIZATION, AND SECOND TO ELICIT YOUR OPINIONS IN THE AREAS OF CONTRACT TYPE, MINIMUM CONTRACT PRICE, LEVEL OF DETAIL, AND PROJECT TYPE.

1. Do you hold a position in a firm or a systems project office?

   a. Firm_____

   b. Systems Project Office_____

2. If the answer to question 1 is "a", what are the name and location of your firm?

   _____

   _____

3. If the answer to question 1 is "a", how is your firm organized? Please check one or more.

   a. Functional basis_____

   b. Project basis_____

   c. Product basis_____

   d. Other (Specify)

   _____

   _____

4. If the answer to question 1 is "a", what is your position in your firm? Please check one or more.

   a. Top manager_____

   b. Supervisor_____

   c. Director of PERT Program_____

   d. Single Project Manager_____

   e. Multiple Project Manager_____

   f. PERT Coordinator_____

   g. Other (Specify)

   _____

5. If the answer to question 1 is "b", what are the name and location of your systems project office?

   _____

   _____

6. If the answer to question 1 is "b", what is your position?

   a. Systems Project Officer_____

   b. Procurement Officer_____

   c. Contracting Officer_____

   d. General Accounting Officer_____

   e. Other (Specify)

   _____

7. In your judgment, what should be the criteria for using PERT on one type of contract versus another? Please check what you feel are the critical elements.

Criteria	Very Important	Important	Less Important	Not Important
Cost Uncertainty				
Technical Uncertainty				
Number of Interfaces				
Complexity of the Job				
Schedule Uncertainty				
Reliability Requirements				
Type of Incentives				
Past Performance of Contractor				
Project Priority from Customer Viewpoint				
Contract Price				
Life of Contract				
Other (Specify)				
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

8. In your opinion, should the type of contract (e.g., CPIF) have anything to do with the customer requiring PERT?

Yes _____ No _____

9. If "Yes" on question 8, in which of the following contract types should the customer require PERT? Please check the appropriate boxes in the table below and give the reasons for your choice.

Contract Type	Yes	No	No Opinion	Reasons
Time and Material				
Cost and Cost Sharing				
Cost Plus Fixed Fee				
Cost Plus Incentive Fee				
Fixed Price with Escalation				
Fixed Price with Redetermination				
Fixed Price with Incentive Fee				
Firm Fixed Price				

10. What should the criteria used by the customer be before deciding to impose PERT? Please check the critical elements.

Criteria		Very Important	Important	Less Important	Not Important
Type of Project Where PERT Should be Applied	Basic Research				
	R&D				
	Production				
	Other (Specify) _____				
	_____				
	_____				
No. of Interfaces					
No. of Subsystems					
Technical Uncertainty					
Schedule Uncertainty					
Cost Uncertainty					
Dollar Size of Contract					
Past Performance of Contractor					
Project Priority from Customer Viewpoint					
Other (Specify) _____					
_____					
_____					

11. In your judgment, what should the criteria be for the level of detail of a PERT work breakdown structure? Please check the critical elements.

Criteria	Very Important	Important	Less Important	Not Important
Management Skill				
Size of the Firm				
Manageable Size of the Work Package (in dollars and time)				
Number of Interfaces				
Contract Price				
Technical Complexity				
Schedule Uncertainty				
Cost Uncertainty				
Technical Uncertainty				
Cost Control				
Schedule Control				
Other (Specify) _____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

12. In your judgment, what should be the criteria for the size of the PERT work package? Please check the critical elements.

Criteria	Very Important	Important	Less Important	Not Important
Phase of the Program				
Number of Events				
Criticalness of Events				
Cost Uncertainty Involved				
Technical Uncertainty Involved				
Schedule Uncertainty Involved				
Dollar Size of Package				
Time Span				
Cost Control				
Definable Work Content (Logical Structure of Events)				
Other (Specify) _____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

13. Is the $100,000/3-month work package guideline meaningful?

Yes_____ No_____

14. Why?

_____

_____

_____

_____

_____

15. In your judgment, is the $25 million for research, test, development, and evaluation (RTD&E) or $100 million for production investment (minimum program prices that make the application of PERT/Cost mandatory) required by DOD Directive 3200.9 a good rule?

Yes_____ No_____

16. Why?

_____

_____

_____

_____

_____

PART B

PLEASE ANSWER THE FOLLOWING QUESTIONS AS THEY PERTAIN TO ONE DEFENSE OR AEROSPACE CONTRACT BEING HANDLED BY YOUR ORGANIZATION.

1. What is the name of the project or application?

_____

2. What is the general range of the size of the contract in million dollars? Please check the appropriate box.

a. $ 0M - $ 4.99M ☐
b. $ 5M - $ 24.99M ☐
c. $ 25M - $ 49.99M ☐
d. $ 50M - $ 99.99M ☐
e. $100M - $199.99M ☐
f. $200M - $349.99M ☐
g. $350M - $499.99M ☐
h. Above $499.99M ☐

3. What is the duration range for the life of the contract in months? Please check the appropriate box.

a. 0 mo. - 5.99 mo. ☐
b. 6 mo. - 11.99 mo. ☐
c. 12 mo. - 23.99 mo. ☐
d. 24 mo. - 39.99 mo. ☐
e. 40 mo. - 59.99 mo. ☐
f. Above 59.99 mo. ☐

4. What is the type of the project? Please check one.

a. Basic Research _____
b. Research and Development _____
c. Repetitive Production _____
d. Other (Specify) _____

5. If an R&D contract, what is the stage of the project at this time? Please check the most relevant stage(s).

   a. Research_____
   b. Exploratory Development_____
   c. Advanced Developments_____
   d. Engineering Developments_____
   e. Management and Support_____
   f. Operational System Development_____

6. What is the stage of the contract, using a more general terminology shown below? Please check the most relevant stage(s).

   a. Research_____
   b. Early Development Phase_____
   c. Fabrication_____
   d. Testing_____
   e. Redesign_____
   f. Prototype Production_____
   g. Other (Specify)_____

7. Is PERT contractually required at this stage?

   Yes_____ No_____

8. If "No" on question 7 above, are you PERTing this stage of the contract anyway?

   Yes_____ No_____

9. If "No" on question 8 above, what control systems do you use on this contract? Please check one or more.

   a. Line of Balance_____
   b. Bar or Gantt Charts_____
   c. Budgetary Controls_____
   d. Milestone Reports_____
   e. Input/Output Reports_____
   f. Others (Specify)_____
      _____
      _____

10. What is the contract type? Please check one.

    a. Time and Material_____
    b. Cost and Cost Sharing_____
    c. Cost plus fixed fee_____
    d. Cost plus incentive fee_____
    e. Fixed price with escalation_____
    f. Fixed price with redetermination_____
    g. Fixed price with incentive fee_____
    h. Firm Fixed Price_____
    i. Other (Specify)_____

PLEASE ANSWER THE FOLLOWING QUESTIONS ONLY IF YOU ARE PERTING THE CONTRACT AT THIS STAGE.

11. Are you using PERT/Time or PERT/Cost? Please check one.

    a. PERT/Time_____
    b. PERT/Cost_____

12. Do you use a computer at this stage?

    Yes_____ No_____

13. If "Yes" on question 12 above, what is the make and model of the computer you use?

    Make_____ Model_____

14. If "Yes" on question 12 above, please identify PERT computer program being used.

    _____

    _____

15. If "Yes" on question 12 above, what is your estimate of the number of computer hrs used last month to PERT this contract?

    _____hrs

16. Please fill boxes in table below as they apply to this contract. You own estimates are acceptable.

PERSONNEL EMPLOYED LAST MONTH IN PERTING THIS CONTRACT (Please convert part time personnel to equivalent full time personnel)	
Type of Personnel	Number Full Time
PERT Analysts	
Supervisors	
Engineers	
Secretaries (inc. clerical help)	
Others (Specify) _____ _____ _____	 _____ _____ _____

17. Does your PERT system substitute for your conventional pre-PERT control system (e.g. Gantt charts) at this stage of the contract?

Yes _____ No _____

18. If "No" on question 17, is PERT a major control system at this stage of the contract?

Yes _____ No _____

19. Is the cost of the PERT operation a direct or an indirect charge in this contract? Please check one or both.

Direct Charge _____ Indirect Charge _____

20. How many end item levels are there at this stage? Please check one.

Level 1 _____ Level 6 _____ More than 10 Levels _____
Level 2 _____ Level 7 _____
Level 3 _____ Level 8 _____
Level 4 _____ Level 9 _____
Level 5 _____ Level 10 _____

21. What, in your opinion, is the size of the mean work package (in dollars) at this time?

$_____

22. What, in your opinion, is the duration of the mean work package (in months) at this time?

_____months

23. What, in your opinion, is the range in size of work packages at this stage in dollars and time?

Dollars: $_____ to $_____

Time: _____ months _____ months

24. What problems relating to PERT, if any, have you encountered in the last six months?

25. What is your opinion of PERT as a management system?

Appendix

DEFINITIONS

Research (DOD Category 1): includes all effort directed toward increased knowledge of natural phenomena and environment and efforts directed toward the solution of problems in the physical, behavioral and social sciences that have no clear direct military application. It would, thus, by definition, include all basic research and, in addition, that applied research directed toward the expansion of knowledge in various scientific areas. It does not include efforts directed to prove the feasibility of solutions of problems of immediate military importance or time-oriented investigations and developments. The Research elements are further characterized by using level of effort as the principal program control.

Exploratory Development (DOD Category 2): includes all effort directed toward the solution of specific military problems, short of major development projects. This type of effort may vary from fairly fundamental applied research to quite sophisticated breadboard hardware, study, programming and planning efforts. It would thus include studies, investigations and minor development effort. The dominant characteristic of this category of effort is that it be pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters. Program control of the Exploratory Development element will normally be exercised by general level of effort.

Advanced Developments (DOD Category 3): include all projects which have moved into the development of hardware for experimental or operational test. It is characterized by line item projects and program control is exercised on a project basis. A further description characteristic lies in the design of such items being directed toward hardware for test or experimentation as opposed to items designed and engineered for eventual Service use. Examples are VTOL Aircraft, ARTEMIS, Experimental Hydrofoil, X-15 and Aerospace Plane Components.

Engineering Developments (DOD Category 4): include those development programs being engineered for Service use but which have not yet been approved for procurement or operation. For example: MAULER, TYPHON, B-70. This area is characterized by major line item projects and program control will be exercised by review of individual projects.

Management and Support (DOD Category 5): includes research and development effort directed toward support of installations or operations required for general research and development use. Included would be test ranges, military construction, maintenance support of laboratories, operations and maintenance of test aircraft and ships. Costs of laboratory personnel, either in-house or contract-operated, would be assigned to appropriate projects or as a line item in the Research, Exploratory Development, or Advanced Development Programs areas, as appropriate. Military Construction costs directly related to a major development program will be included in the appropriate element.

Operational System Development (DOD Category 6): includes research and development effort directed toward development, engineering and test of - systems, support programs, vehicles and weapons that have been approved for production and Service employment. This area is included for convenience in considering all RDT&E projects. All items in this area are major line item projects which appear as RDT&E Costs of Weapons Systems Elements in other Programs. Program control will thus be exercised by review of the individual research and development effort in each Weapon System Element.

Organization: the term "organization" pertains to one firm, or to one systems project office.