AN ANALYSIS OF THE MANAGEMENT OF FUNDS FOR RISK AND UNCERTAINTY IN THE DEPARTMENT OF DEFENSE

Peter L. Woodward, Captain, USAF

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DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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Estimating and budgeting for risk and uncertainty in the Air Force and the Department of Defense is haphazard and inconsistent. Many cost overruns occur, especially in R&D where the risk and uncertainty is highest. The main objective of this thesis was to better identify the issues concerning the use of management reserves to budget for uncertainty. It was found that no one management technique or policy would cover all situations for all services within the Department of Defense. Only two methods stood out as candidates which would meet Carlucci's initiative requiring the services to budget funds for technological risk. They were the Air Force RISK Model and the Army's TRACE Model. The main difference in them is an issue of management style. TRACE requires a centralized money fund for risk while the Air Force RISK Model was designed to allow a decentralized money fund for risk under the direct control of the program manager. It was concluded that better risk management techniques are needed rather than development of more mathematical techniques to quantify risk. Finally, it was recommended that further research be conducted to evaluate managers' subjective decision making preferences. The information would then be used to aid the manager in making better subjective probability selections.

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A Thesis

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By

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INTRODUCTION

Problem Statement

Estimating and budgeting for risk and uncertainty in the Air Force and the Department of Defense (DOD) is haphazard and inconsistent. A DOD Acquisition Steering Group report, dated March 31, 1981, stated that "Early cost, schedule and performance estimates are consistently overly optimistic and highly unrealistic [23:8]." Because of this, project funds requested may not be adequate. For management purposes:

> The Military Departments should provide a reserve for unavoidable contingencies in RDT&E [Research, Development, Test & Evaluation] and initial production and support of weapons and material systems. The contingency reserve should be based on the program manager's assessment of program risks and fully supported in an approved acquisition strategy [23:12].

If we in DOD expect to respond to this call for management of risk and uncertainty costs, certain questions need to be answered. These are: How are risk and uncertainty treated throughout DOD? What effects do these various treatments have on our ability to estimate, budget, and manage? What are the advantages and disadvantages of each approach? Does any one approach appear to be superior?

Definition of Terms

In order to better understand what is meant by risk and uncertainty, the following example is presented. Suppose that the family car is beginning to show the result of age and high mileage, but we anticipate a year of service before any major repair. Let us assume we do not wish to pay the high interest in making payments for a car, so we wish to put enough money aside to cover the cost of purchasing a new replacement. The choice of how much money to put aside is complicated by: (1) What do we want? What kind of performance or capability is desired? (2) What kinds of price changes do we expect in the intervening period? (3) Will our car really last out the year?

How does this situation demonstrate risk, uncertainty, and the use of management reserves? We would face uncertainty in deciding that our car will make it one year since we have only a subjective feel for the probability of a breakdown occurring based on past experience. We also face uncertainty in that our requirements for performance might change in a year.

We would feel risk concerning the future of a new car. We do not know exactly what it will cost because costs change slightly from year to year, but we could develop an objective distribution of expected cost.

The only event that is certain is the present listed price on the new car that meets our current needs. This is certain because we have a copy of the written quote from our favorite dealer which includes all the options on the new car.

We must figure out how much to set aside for the new car to be purchased one year hence. The dealer-quoted price becomes the basis of our estimate. By adding on an amount for anticipated price increase we now have an approximate amount to put aside as savings. But this is not all. The old car could break down before the year is up. In addition, we could change our minds about the performance required. If so, we would have to choose a different new model at a different price. The extra money added to cover these contingencies is termed reserve since it is being set aside to cover unknown future events. It is a management reserve since, as the family financial manager, we have placed this extra in the family savings based upon future contingencies that are uncontrollable.

The following terms will be used throughout this report and are defined as follows:

1. Risk - an event or situation characterized by an uncontrollable random variable or event which comes from a known objective probability distribution (27:82).

2. Uncertainty - an event or situation characterized by an uncontrollable random variable or event which comes from an unknown subjective probability distribution (27:82).

3. Management reserve - money set aside by a manager to cover uncontrollable changes or events (6:112).

4. Certainty - an event or situation characterized by complete or total knowledge; a controllable situation.

5. Cost overrun - the difference between expected cost when a contract was signed and the current expected cost (17:I-1 to I-7).

6. Cost growth - the difference between the first estimate and the current estimate of costs (17:I-1 to I-7).

Although the terms "risk" and "uncertainty" are used interchangeably in much of the literature, it is necessary to understand that they are theoretically different concepts. Both contribute to cost overruns and cost growth.

Background

The problem of how to estimate costs and manage them for a given project is not new. Shortly before the beginning of the Christian era, the Romans decided to build an aqueduct for the Asian town of Troas. From the very beginning of construction, costs were exceeding the estimates. As construction proceeded, costs were more than double the estimate. Thanks to the generosity of Julius Atticus, a wealthy resident, all of the extra costs were paid so that the project could be completed (22:2).

Early U. S. Naval ship construction had similar problems. The construction of six large frigates was authorized by Congress in 1794. By the end of 1795, the number of ships to be purchased was cut to three due to delays and cost overruns (33:116). In this case, Congress limited the expansion of the U. S. Navy to the funds originally allocated.

Presently DOD is faced with the same problems of how to accurately estimate costs and control cost growth. Funds are limited and DOD has to compete with other increasing needs of the nation such as social welfare programs, energy, etc. Since the taxpayers are not like the wealthy Julius Atticus, cost overruns bring great public outcry. In fact,

> The rampant growth in the acquisition cost of most defense systems has been a great concern to the defense community for the past several years. From the pronouncements on Capitol Hill to the reports in the news media, criticism is focused on the Department of Defense for its rapid expansion of cost on major programs [25:93].

In one instance, Senator Sam Nunn indicated the U. S. is headed toward "unintentional, gradual, unilateral disarmament by cost overrun [12:4-B]." President Reagan, in an unpublished presidential memorandum to the Secretary of Defense (17 March 1981), "requested that the Secretary of Defense assess the situation and initiate actions to reduce cost growth [25:93]." Apparently this had already begun in DOD since the Under Secretary of Defense, William A. Long, discussed cost growth and other acquisition problems. In his memorandum, dated 23 December 1981, he stated:

Despite some initial steps [discussed in an earlier memorandum dated 30 April 1981], controlling cost growth (both real and perceived) remains a major problem. The solution must include more realistic estimates accurately reflecting future costs and difficult choices to reduce requirements when costs grow [24:4].

On 31 March 1981, a DOD steering group report presented the results of "a 30-day DOD effort to identify and assess options for major improvements in the acquisition process [23:11]." A copy of this report was sent to the Deputy Secretary of Defense, Frank C. Carlucci. Two recommendations of particular interest are Budget to Most Likely Cost and Incorporate the Use of Management Reserve (23:18-19). These indicate that a significant portion of cost growth could be attributed to our methods for estimating and managing funds for risk and uncertainty.

On 30 April 1981, Mr. Carlucci issued the thirty-one actions known as the Carlucci initiatives. Two of the initiatives addressed budgeting problems. They were Budget to Most Likely Cost (Number Six) and Budget Funds for Technological Risk (Number Eleven)(24:6-1,11-1). These two required the Services to "Budget to most likely cost or expected costs, including predictable cost increases due to risk, instead of the contractually agreed-upon cost [23:6-1]," and "budget funds for risk. In particular, each service should review the TRACE concept and either adopt it or propose an alternative for its use. . .[24:11-1]." Neither of these initiatives addressed uncertainty. In discussing Program Stability

(Number Four), cost and schedule uncertainty are mentioned (23:4-2). Overall though, the document containing the Carlucci initiatives did not relate risk and uncertainty in any specific way. It would appear that the term risk is used to also convey the idea of uncertainty.

The subject of setting aside money to cover risk and uncertainty is a very sensitive political issue. Any good manager realizes that the early phases of research and development (R&D) are characterized by high risk, since the concepts are still being defined and many times there has been no forerunner on which to base an accurate cost estimate. While all three services would admit to looking at risk analysis and uncertainty, they remain somewhat silent on the use of management reserves which would be necessary to properly implement these into a budget. Although there is a high level of interest in the analysis of risk and uncertainty and the creation of a visible management reserve to cope with factors that contribute to cost overrun, the perception that ". . . establishment of a management reserve is contrary to prescribed policy for budgeting and obligating funds [6:112]" remains.

Despite this perceived policy, the program manager is faced with unknown changes in his program brought about by either technological advances, changing systems requirements, changing mission requirements, unexpected cuts by Congress (i.e., decreases or deletions in appropriations for

DOD requirements), etc. In order to cope with these situations, the program manager has to build in extra money to cover these uncertainties. These monies are termed "management reserves" unofficially since they represent an informal way of funding for risks and uncertainty.

Research Objectives

The research objective is to better identify the issues concerning the use of management reserves to budget for uncertainty. The subobjectives are to:

- review management reserve practices in DOD
- identify and evaluate techniques used to estimate costs
- identify and evaluate techniques used to estimate resource requirements for risk and uncertainty
- evaluate the strengths and weaknesses of the best technique(s).

Scope

This effort was limited to Research and Development (R&D) practices since this is an area where risk and uncertainty are the highest and has been the primary concern of past DOD and service efforts. Historically, the conceptual phase and the full-scale development phase have been the most difficult areas in which to conduct a risk analysis. The production phase has been easier to model as the program is better defined.

It is well known by cost analysts that the management and control of risk and uncertainty involves the proper selection of technology, materials, performance characteristics, schedule determination, and proper production planning. Presently the services have been tasked to improve risk management via the use of management reserves. Therefore, this effort will be limited to the use of management reserve funds to cover the extra costs due to uncertainty.

Limitations

The accuracy of this research was limited by the extent to which people were willing to share information concerning this very sensitive issue. Past literature has been incomplete in its coverage of management reserves, although models to assess risk and uncertainty were covered in greater detail.

Research Questions

Three research questions in addition to those raised in the problem statement were posed?

1. Do management reserves need to be visible?

2. Should more approaches to estimate risk and uncertainty be developed and/or should a better management system be implemented?

3. Is this problem hiding another issue which has not been openly discussed?

CHAPTER 2

METHODOLOGY

Overview

Since the objective of the research effort was to better identify the issues concerning the use of management reserves to budget for the uncertainty inherent in any project, the Research Question Research Method approach was selected. This type of research is concept-building in order to expand the "frontiers of knowledge" (38) when any of the following exist:

a. A hypothesis cannot be qualitatively or quantitatively tested;

b. Sufficient information has not been generated to render a reasonable hypothesis;

c. Synthesis is appropriate and justified (39).

The first step was to conduct a preliminary literature review to evaluate whether DOD was experiencing problems in dealing with risk and uncertainty. Upon validating that there was a problem, another review similar to the first was conducted to identify sources of information concerning management of risk by the use of management reserve techniques. Little information was found and the results of the two literature reviews were used to formulate the problem statement, define terms, and define research objectives as well as give background information concerning the problem (39).

Once the literature objectives were defined, a more in-depth literature review was conducted in order to review any publications concerning DOD management of risk and uncertainty in R&D. This resulted in data which could then be analyzed in order to fulfill the research objectives and further identify the factors which bear on the problem. The data was analyzed to see if any trends in the management of risk and uncertainty could be identified. The various methods of handling risk and uncertainty were also reviewed to see if any were adequate to predict the amount of money needed to cover the risk and uncertainty in a project. If none were found, the next objective was to suggest ways to appropriately handle risk and uncertainty or suggest further areas of research based on the analysis (39).

In order to verify that the problem was current and to verify the findings of the literature review, interviews with practicing professionals in the fields of cost estimating, cost analysis, and project management at various levels of command were conducted. This was also used in the analysis of the data collected in the in-depth literature review. The two leading methods used by the U. S. Air Force (USAF) and the U. S. Army, identified during the above process, were analyzed and the examples given in the documents describing each method are presented in Chapter 4 and the Appendices. This method of illustration was selected since any data from an actual completed project would not show a complete breakdown of the risk and uncertainty. The interview results are presented in Chapter 3 following the discussion of the literature review. Chapter 5 contains a summary discussion of the research effort as well as conclusions and recommendations.

Literature Review

A search of recent periodicals was made. The main thrust of the search was conducted by submitting various key words to the Defense Technical Information Center (DTIC). The following terms were used to obtain Technical Report Summaries (bibliographies).

Technical Report Summary Number 1. Air Force Budgets, Army Budgets, Budgets, Federal Budgets, Military Budgets, and Naval Budgets were each compared with the more restrictive term Air Force Research with the emphasis on Cost, Cost Analysis, Cost Effectiveness, Cost Models, Cost Overruns, Costs, Design to Cost, High Costs, Indirect Costs, Life Cycle Costs, Low Costs, and Price Index.

Technical Report Summary Number 2. Cost Analysis, Cost Estimates, and Cost Overruns were cross referenced with the terms Management Planning and Control, Military Budgets, and Planning Programming Budgeting.

Technical Report Summary Number 3. Cost Models were cross referenced with the terms Management Planning and Control, Military Budgets, and Planning Programming Budgeting.

Technical Report Summary Number 4. Risk and Risk Analysis were cross referenced with the term Forecasting.

The results of searching through these bibliographies were forty-five possible candidates to be further studied to see if any information relative to the research objectives could be found. The results of this effort are found in Chapter 3 of this report.

Interviews

In order to get the latest information concerning the treatment of risk and uncertainty, personal interviews were conducted. A semi-structured approach was used. Before the interviews, a list of questions and objectives was prepared based on the data obtained in the literature reviews. The questions were prepared with the purpose of verifying that the data found in the literature review was still current and that there was nothing new that had been missed. The main objective was not only to verify the data but also to allow the individuals contacted to freely express their opinions without being unduly influenced by the objectives of the research.

The individuals were then to be contacted, and after a standardized brief introduction concerning the purpose of the interview, were to be allowed to comment as they saw fit until they had discussed all that they felt of worth. At that time, if the objectives and questions had not been covered, these would be brought up. It was felt that this approach would allow a free flow of information, unhampered by the resistance that structure can sometimes produce. Once the individual completed their presentation, the structured questions could be used to clarify any issues not covered or understood.

In conducting an interview in such a controversial area, it was felt that some individuals could feel like one was prying into areas that might cause political repercussions if revealed. Therefore, the introduction was important in establishing the purpose and ground rules of the interview. The interviewee was assured that any sensitive information would not be disclosed nor would be printed in this report. It must be remembered that in an area as controversial and politically sensitive as the use of management reserves and evaluating risk, one cannot give official statements on matters still in the process of resolution by the Congress, DOD, and other governmental departments and officials. The results of the interviews will be found in Chapter 3.

Analysis of Data Gathered

Analysis of the references found in the literature reviews leads to the identification of two leading techniques for possible DOD risk analysis, one used by the U. S. Army and the other by the USAF. The documents, containing a description of each of the techniques, contained an example which included both the input data and the output data. Both techniques are evaluated, with advantages and disadvantages for each. Examples of both are presented in the Appendices. The numbers presented are for clarification only and do not represent a real project.

Conclusions/Recommendations

Chapter 5 will present a summary of the findings and any conclusions reached as a result of the research efforts. Recommendations will also be presented as to the possible use of the research and suggestions for further study.

CHAPTER 3

LITERATURE REVIEW/INTERVIEWS

Overview

> Formal recognition and emphasis on risk and uncertainty analysis in DOD [Department of Defense] resulted from a 31 July 69 memorandum from David Packard, Deputy Secretary of Defense, to the Military Departments identifying problem areas in the weapon system acquisition process. In this memo, Secretary Packard cited inadequate identification and consideration of risks in major programs as a problem area requiring action and that risk analysis be applied by program managers in their daily activities. . . . The past decade has also witnessed an explosion of books and technical papers on risk and uncertainty analysis [34:12].

A 1969 Rand report suggested that their analysis of cost estimates for the 1960s showed a 25% less optimistic bias than those programs of the 1950s (28:vi). This bias refers to cost estimates that do not reflect the actual amount that is required for completion of a project. These cost estimates are called optimistic since they reflect a cost that one would like to occur rather than what will actually occur. This suggested that as each decade has passed, cost estimates have become more accurate and more "realistic". The Rand report concluded that

> The ability of the Government to make programmed and actual program outcomes [cost, performance, etc.] coincide has been of considerable concern to Congress, the military departments, and the public [28:41].

Although there was a demand for better cost estimating techniques, the Rand Corporation found it necessary

> to point out that the data suggest that estimating reforms are not likely to resolve the underlying problems. Not enough is known about the causes of cost escalation to support the contention that estimating errors are the major contributors [28:42],

or, looking at the other side of the coin, that improved tracking of actual costs with cost estimates could be attributed solely to improved cost estimating.

Leggitt, of Booz, Allen and Hamilton, stated that prior to 1961,

> the Defense Department developed its force structure by starting with a budget and then seeking out possible programs. There was no pragmatic way of relating costs to weapons systems, tasks and missions [7:1-2].

The period following the end of the 1960s saw the increased use of risk and uncertainty analysis with cost estimating techniques. Rich, of the Rand Corporation, found after comparing programs from the 1960s with programs of the 1970s, that the 1970s were "coming closer to their cost goals by some 10 to 20 percentage points [34:172]." He also made the observation that there was strong evidence that a substantial part of the cost growth in the government acquisition process was beyond the control and responsibility of the program managers, and at times outside the control of top level acquisition managers in OSD (Office of the Secretary of Defense) as well as the services (34:172). In fact, he said "that the search for better cost control should include consideration of changes in government policies and procedures outside the Department of Defense [34:172]."

In 1981, Colonel Martin, of the Air Force Business Research Management Center, pointed out that

> An assessment of uncertainty is critical; however, rigorous and formal treatment of this element has not been an integral part of management's information system. Only recently have serious efforts been attempted to structure the process of analyzing the uncertainty which confronts managers responsible for the development contract and the related program [34:178].

Today's manager has to contend with many factors which can cause the total program costs to exceed his initial estimate. These factors will be presented in the next section, categories of risk and uncertainty. It can be said at this time though, that these factors have caused large cost overruns. For example, Sherman and Gardiner found that

> unexpected high inflation, supply and demand factors, poor resource allocation and managerial inefficiency can cause total estimated program costs at completion to exceed early estimates by 10, 100, or even 300 percent [34:204].

There are many tools and techniques available to aid the program manager, but "Obviously, no set of tools or techniques is a substitute for [good] management . . . [34:58]."

In considering the factors to be presented in the following section, it should be remembered that some factors are project dependent and that there is not enough space in this report to include all of them. Only those which appeared to apply to all projects and were mentioned in numbers of articles were included in this report.

The next five sections cover: Categories of Risk and

Uncertainty; Uncertainty and Risk Management; Cost Estimating Techniques; Uncertainty and Risk Techniques; and Interview Results. The Cost Estimating Techniques have been placed before Uncertainty and Risk Techniques because a brief discussion of cost estimation will aid the reader in understanding the need for uncertainty and risk techniques. The section on Uncertainty and Risk Management will provide further information. The Interview Results are presented in the last section. No names have been attached to the results, for reasons given previously. In conducting these interviews, the researcher found that those people interviewed were willing to discuss the matter, but did not want to be identified, since government policy on this matter is still being determined. It was found that within the DOD structure the U. S. Army's Total Risk Assessing Cost Estimate (TRACE) and the U. S. Air Force Cost Uncertainty/Risk Analysis Model (described in detail in Chapter 4) were the leading methods proposed as fulfilling the requirements of the Carlucci initiatives.

Categories of Risk and Uncertainty

Before describing risk and uncertainty management, cost estimating techniques and risk and uncertainty techniques, a brief discussion of the categories of risk and uncertainty follows. This discussion will also include a brief description of some of the risk factors that are related to these categories. It should be emphasized at this point that not all of the risk factors can be presented. There are many different factors which can be identified in any system. This literature review presents those factors which seemed most prevalent. They have been presented here since these are some of the factors which a manager must consider when evaluating various management principles and techniques to be used in the management of a particular program. The factors which have been found to be a major cause of uncertainty should be given the most emphasis, but not all of the emphasis, when planning a new program. Carter studied and analyzed historical cost data and indicated that

> technological uncertainty is a major cause of production and development cost overruns. . . . Requirements and technological uncertainties are the primary causes of errors in the cost estimates of future weapon systems [4:27].

He made this statement in 1965 and described eleven factors which contribute to cost estimating errors. Tables 1 and 2 list the factors, authors, and the categories under which the factors have been placed.

Several categories of risk and uncertainty have been identified. Beverly et al. listed three types of uncertainty: "Design and Technology uncertainty; Uncertainty regarding the ability of the contractor to meet the terms of the contract (scheduling); and Cost uncertainty [34:265]."

Three categories of risk identified by Worm are: technical risk, cost risk, and schedule risk (34:97) which

TABLE 1

FACTORS BY AUTHOR

	AUTHOR		
	Carter	DARPA	Rowe & Somers
FACTORS	Technical Complexity	Quantity	Internal Control
	Technical Obsolescence	Engineering	Technological Uncertainty
	Schedule Slippage	Support	Customer Uncertainty
	Timing of Cost Estimate	Economic	Environmental Uncertainty
	Competitive Optimism	Estimating	
	Inaccurate Cost Estimates	Sundry	
	Price & Procurement Levels		
	Cost-Estimating Uncertainty		
	A. F. Requirements Uncertainty		
	Technological Uncertainty		

TABLE 2

CATEGORIES OF RISK AND THEIR ASSOCIATED FACTORS

	CATEGORIES		
	Cost Risk	Schedule Risk	Performance Risk
FACTORS	Competitive Optimism	Competitive Optimism	Competitive Optimism
	Inaccurate Cost Estimates	Schedule Slippage	Technical Complexity
	Cost-Estimating Uncertainty	Quantity	Technical Obsolescence
	Timing of Cost Estimate	Schedule	Price and Procurement Levels
	Estimating	Sundry	Air Force Requirements Uncertainty
	Economic	Internal Control	Technological Uncertainty
	Quantity	Customer Uncertainty	Support
	Internal Control		Engineering
	Customer Uncertainty		Internal Control
			Technological Uncertainty
			Environmental Uncertainty

are quite similar to those described by Beverly et al. These categories apparently were derived from cost, schedule, and performance which are described in life cycle costing and Cost/Schedule Control System Criteria (C/SCSC). Cost, schedule, and performance were identified at the beginning of the 1970s.

Worm's categories give the best description of risk. He stated that "The technical and schedule risks are important factors in the estimation of cost risk . . . [34:97]." Technical risks (related to performance risks)(27:97-115) are derived from a knowledge of the probability density function that describes the technical uncertainty in an R&D program which includes: technical feasibility, selection of the best technical approach, correct formulation of the problem, correct choice of the design parameters including a proper parametric analysis (includes performance factors such as kill radius, speed, range, payload, etc.), and correct trade-off analysis (i.e., the trade-off "between design speed and performance, between design payload and performance, and so on [27:113]"). Schedule risks are derived from a knowledge of the probability density function that describes schedule uncertainty (timing) in an R&D program which includes: delays in production, late delivery of parts or materials, and mistiming of the arrival/completion of sequential assembled parts (32:61). These relate to cost risk in that a probability density function can be derived which represents the combination of the technical and schedule risks. The cost uncertainty includes the cost variances that would result from the effect of technical and schedule uncertainty on labor and overhead costs, material costs, and unforeseen penalty costs (32:61).

It becomes necessary at this point to further describe some of the factors which cause cost growth since they are also those factors which contain an element of uncertainty. These factors can be used to obtain a risk estimate if enough historical data is gathered so that a probability density function can be derived. It is these factors which must be managed as well as other factors which arise such as top level directed program changes, budget cuts, and other unforeseen changes in the political climate. These factors must not only be included in estimating a cost of a program but are also necessary in the control of cost growth of a program and/or risk management.

In 1965, R. D. Carter (4) presented an analysis of the factors which influence cost estimate reliability and suggested that cost sensitivity analysis was the best method to examine the changes in the total system cost when these factors were varied over their relevant range (4:43). He stated that

> The incongruity between estimated and actual costs of today's weapon systems indicates a need for cost estimates which more accurately predict the cost of future weapon systems. Estimates made near the

beginning of a development program are particularly unreliable [4:iii].

He went on to explain that, without all the necessary elements of the total system included, the cost estimate would be inadequate (4:iii). The factors presented which cause cost estimate unreliability are as follows:

1. Technical Complexity
2. Technical Obsolescence
3. Schedule Slippage
4. Timing of Cost Estimate
5. Competitive Optimism
6. (This paragraph deleted from documents for open publication.)
7. Inaccurate Cost Estimates
8. Price and Procurement Levels
9. Cost-Estimating Uncertainty
10. Air Force Requirements Uncertainty
11. Technological Uncertainty [4:10-27]

The above factors are not easy to categorize under cost risk, schedule risk, and performance risk since some of them affect more than one category. This is not surprising since the categories are not independent of each other. For example, a change in performance requirements can lead to a change in schedule, which will cause a change in costs. If the performance risk has been underestimated, it could result in an underestimation of the schedule risk if the analyst used the performance characteristics to determine the schedule. Both affect the cost risk. Carter's eleven factors are described below.

Technical Complexity includes a large number of technical problems, the interrelation of the technical problems, and the large number of components when considered from the point of reliability (4:10). An example of technical interrelation could be the discovery that a newly designed cockpit display instrument will not fit into the instrument panel. In order to fit it into the panel, the other instruments must be moved which will necessitate the redesign of the instrument panel and possibly the rerouting of electrical, pneumatic, and hydraulic lines. As any system grows, reliability can change since there are more parts that can fail.

Technical Obsolescence occurs when the state-of-the-art advances beyond the present day level (4:10). An example could be the selection of vacuum tube operated components in the design of a new avionics system at the time transistorized components were just appearing on the market.

Schedule Slippages involve a change in the program milestones. These changes could result in stretching out the time required to complete the program. It could possibly include compressing (shortening) the schedule time if the customer wanted the project completed earlier than originally planned.

The Timing of the Cost Estimate can affect overruns, since more elements are better defined for later estimates.

Competitive Optimism results in estimates of schedule and costs which are less than what it would actually take to obtain a given set of performance characteristics. Competitive Optimism involves both the contractor and the

U. S. Air Force, since the contractor wants to obtain the contract while the Air Force wants to obtain a new weapon system. "The contractor usually reflects his desire to win the contract by outbidding the competition with optimistic cost estimates for initial development [4:14]." The Air Force may either discourage realistic cost estimates because of an inadequate budget or because they place a premium on maximum advancement of the state-of-the-art: the result, optimistic technical proposals and optimistic cost estimates (4:14).

Inaccurate Cost Estimates may be a result of an incomplete cost analysis. "Many times, the estimate of total system costs does not include all the necessary elements of system costs [4:17]." Price and Procurement Levels, while lumped together in Carter's article, were of unequal strength as sources of error.

> Changes in price levels during the development of a weapon system are relatively small sources of error, and the cost estimates are usually presented in [constant] dollar values [dollars adjusted for the effects of inflation][4:17].

Changes in procurement level (quantities bought) caused the largest cost overruns of the two.

Cost-Estimating Uncertainty is a result of the inaccuracies caused by the following: the cost functions not fitting the data exactly, extrapolations beyond the range of the sample data, and aggregation of data at a higher level.

> Cost-estimating relations used in cost analysis cannot be assumed to hold exactly. In estimating a certain cost component as a function of many variables, it cannot be assumed that the variables will predict the particular cost with certainty. . . . Cost-estimating relations from past experience are sometimes used. Extrapolations beyond the range of the sample or data base from which the estimating relation was derived are another source of uncertainty. Cost-estimating errors may arise because of the use of techniques which involve a considerable amount of aggregation. An important cost element may be overlooked. . . . Large aggregations also make cost comparisons of alternatives difficult [4:19].

Air Force Requirements Uncertainty addresses "sudden and unpredictable changes in technology, enemy plans, and U. S. defense policies which might require program redirection or even cancellation [4:19-20]." If the program is redirected, two kinds of configuration changes could evolve: hardware characteristics, or the system's operational concept (4:20). Either will cause an unknown increase in the cost over the original estimate.

Technological Uncertainty covers the many problems which can occur as technology develops or changes. Whether they will occur is uncertain. ". . . each of these unexpected difficulties has an effect on the contractor's ability to meet original time, quality, and cost predictions [4:21]."

In 1981, Defense Advanced Research Projects Agency (DARPA) researchers identified the following seven factors as contributors to cost increases:

1. Quantity--changes including scope.

2. Engineering--changes altering a system's established physical or functional characteristics.

3. Support--changes involving spare parts, ancillary equipment, warranty provisions, and government-furnished property or equipment.

4. Schedule--changes in delivery schedules, completion date or some intermediate milestone of development, production or construction.

5. Economic--changes that are influenced by one or more factors in the economy, such as inflation.

6. Estimating--corrections or other changes occurring since the initial or . . . baseline estimates for program or project costs.

7. Sundry--changes other than the above categories, such as environmental cost and relocation assistance for water and highway projects [9:I-5].

The above seven factors are identical to the Cost Variance Analysis Breakout found in the SAR (Selected Acquisition Report) except that the term "Other" is found in place of "Sundry" in the SAR (1; 18).

Not only have there been attempts to categorize the factors which affect risk, but there have also been attempts to categorize uncertainty. Rowe and Somers quoted Martin D. Martin's PhD dissertation which listed four basic categories of uncertainty: Environmental, Functional, Informational, and Technical. Environmental uncertainty includes such factors as social and political effects, factors external to the project, communication problems, and time. Functional uncertainty includes technological uncertainty, production inadequacies, and financial and business problems. Informational uncertainty can be attributed to the unknowns found in incomplete knowledge, whether anticipated or unforeseen (34:38).

A. J. Rowe and I. A. Somers also identified four uncertainty categories: Internal Program Uncertainty, Technical Uncertainty, Process Uncertainty, and Target Uncertainty. They described their four basic variables or categories as equivalent to those developed in a previous USAF Academy study. The Rowe and Somers' term is inserted in brackets next to the USAF Academy term of the same meaning and definition.

> 1. Internal Program Uncertainty [Internal Control]: Deals with the way in which the program is organized, planned and managed. Uncertainty of the initial estimate and its impact on program management. Uncertainty in the acquisition strategy and outcome. Uncertainty in resources needed, flexibility, or lack of contingency plans. Competing demands, including conflict between reliability, vulnerability and maintainability with performance and operating costs.
>
> 2. Technical Uncertainty [Technological Uncertainty]: Covers the feasibility of developing the system at all, including the degree of technical difficulty. Generally starts with an optimistic estimate of the state-of-the-art and often leads to a slippery technical baseline.
>
> 3. Process Uncertainty [Customer Uncertainty]: Deals with the sensitivity to changes in the external environment such as changes in priorities or policies, the president's budget, congressional political considerations, etc. Unavailability of funding/resources when needed. Uncertainty in criteria used for changes, control, surveillance, DSARC decisions, etc. Effects of inflation and government regulation.
>
> 4. Target Uncertainty [Environmental Uncertainty]: Covers the uncertainty in meeting performance, cost or schedule goals and determination of needs. Uncertainty in translating abstract needs into concrete specifications. Problems of early estimates which are seldom revised [34:26].

The next section will discuss the management of risk and uncertainty.

Uncertainty and Risk Management

Management policy must be developed which recognizes the fact that there are many tools involved in controlling a program. One tool for controlling a program is forecasting which is the most important function of program control. "It is looking downstream to see where a program is going and proposing alternatives to accommodate threats and hasten progress (AFSCP 800-3, p. 6.2)[5:22]." There are many areas which a program manager must consider such as selection of personnel, project organization, interfaces with other agencies, etc. He must also consider the risk and uncertainty involved in his project. Therefore, this section will discuss some of the techniques of management of forecasting or cost estimating with the attendant analysis of risk and uncertainty. Cost estimating techniques and uncertainty and risk techniques will be covered in the following two sections.

The factors described in the last section can be used to obtain a management reserve estimate if enough historical data can be derived. If a density function must be imputed, we are then dealing with uncertainty. If we can take the time and make the effort necessary we may be able to derive a probability distribution and thus be dealing with risk. It is these factors which must be managed as well as other noncontrollable events which arise, such as top level directed program changes, budget cuts, and other unforeseen changes in the political climate. These factors must not only be included in estimating a cost of a program but are also necessary in the control of cost growth of a program, which of course includes cost growth due to uncertainty and risk.

The government has initiated many programs and policies to improve their control of risk and uncertainty while at the same time reducing their effects. In looking through the indexes of the various Department of Defense Directives and Instructions, the term "management reserves" could not be found. Money used to cover risk and uncertainty was found in the engineering change order (ECO) line of a budget. The term "unencumbered funds" was another term sometimes used to delineate money set aside to cover those changes which are a result of unforeseen circumstances. Cost/Schedule Control Systems Criteria (C/SCSC, contained in DOD Instruction 7000.2, Performance Measurement for Selected Acquisition, and DOD 7000.10, Contract Cost Performance, Funds Status and Cost/Schedule System Reports) was the only policy found that allowed management reserve. The contractor is allowed to set aside a portion of the funds he receives as a management reserve and give his shops lower budgets in order to exercise proper management control of his work force. If an ECO change is made, the contractor receives more money which he can add to his management reserve.

In 1973, El-Sabban described C/SCSC and suggested that the information obtained from the contractor's monthly progress report could be used to forecast future cost and estimate changes. He stated that "The adoption of the Laird-Packard principle of closer ties with the contractor and more efficient supervision of the project operation throughout the life of the contract [14:11]" lead to the establishment of C/SCSC. The monthly cost performance report contained a work breakdown structure summary which allowed the program manager to assess the contractor's adherence to the planned cost and schedule. The program manager could figure the variance for each item in the work breakdown structure and monitor the progress of the project compared to what was originally planned.

Although C/SCSC was set forth as a government policy, it did not function perfectly. Feiler reported in 1978 on a study conducted by the Office of Naval Research to improve the effectiveness of the Navy's systems acquisition process. The conclusions showed that the Navy would have to add additional information to DODI 7000.2 in order to overcome problems found in applying the instruction to Navy shipbuilding project management (3:506-510). They found that

> The contractor's cost/schedule control system does not provide adequate data upon which to base a meaningful "forward look" . . . to:
>
> (a) Identify potential problems
>
> (b) Evaluate contractor's work load and work force planning
>
> (c) Evaluate cost/schedule impacts of change orders or other contract changes.

The contractor's use of a "deterministic" (as opposed to "probabilistic") scheduling approach results in schedules which are inherently optimistic [3:509].

It was also found that not only did the contractor fail to furnish the Navy with information concerning work order sequence so that logical predecessor-successor relationships could be established, but, also, actual start and finish dates for all work orders and rescheduled activities were not always reported (3:509-510). All this suggests that not only must each service tailor any DOD policies and directives to its own needs, but that it is each service's responsibility to insure that the proper management policies are in place to enable the program manager to obtain the necessary data required for an accurate cost estimate which can take into account risk and uncertainty.

In November 1969, the Rand Corporation published the results of their research which evaluated the accuracy of the predictions of "recent" military program cost and article-performance outcomes as well as a comparison of the ratios of actual-to-predicted outcomes for 1950s to 1960s programs. They found that the required information needed for their research was not easily obtained. In fact,

> Various data retrieval systems exist, but the underlying problems of defining, categorizing, and understanding program growth are accentuated by . . . ambiguities, and uncertainties in the data. Many of the problems stem from the basic difficulty of interpreting program goals . . . . Therefore, very fundamental changes in both acquisition procedures and management techniques may be needed if actual outcomes are to approach predicted (estimated) outcomes more closely [23:vii].

As Carter mentioned earlier, "Estimates made near the beginning of a development program are particularly unreliable [4:iii]." Yet,

> The major commitment to these expenditures [referring to life cycle expenditures for a new system] is made during the first five years of the program where approximately 90% of costs are locked in . . . . When the product is finally prototyped, design is solidified to a point where less than 25% of the anticipated FSD [Full Scale Development], production and O&S [Operating & Support] costs can be influenced. By the time production is initiated, tooling concepts, manufacturing and facilities plans will have been sufficiently established that major changes to these nonrecurring costs become costly and impractical [2:90].

Therefore, it is very important that correct estimates which take into account uncertainty and risk be made in the early phases of the program, preferably the conceptual phase since the decisions of the first five years have the most effect on the outcome of a program.

In a 1981 thesis, Second Lieutenant McClary described three areas which make R&D management difficult.

> First, upper level managers sometimes fail to accurately translate their understanding of corporate objectives and goals into the technical environment . . . . This creates the problem of an ill defined objective. . . . Second, because most of the scientists, engineers, and technologists in the R&D environment are moderately knowledgeable in their field of discipline, they often feel that they should decide which projects should be undertaken by the organization . . . . Finally, R&D activities are different when compared to other activities of business such as production and office administration. . . . Probably the most important difference is that it is difficult to measure outputs of R&D activities [20:1-2].

He proposed six common management techniques, which he chose after a literature review, to be presented in a survey of

R&D managers in order to determine which techniques were used and how useful they were in R&D management (20:5-11). The techniques selected were:

> Participative Objective Setting Techniques (POST), Project Scheduling Charts, Work Breakdown Structures (WBS), Activity Networks, Generalized Activity Networks, and Cost and Schedule Variance Analysis [20:5].

The value of the above techniques in risk and uncertainty management is in the detail the manager is required to use in their application. By looking at the detail involved in a new R&D effort, the likely areas of uncertainty and risk are more easily identified.

Lieutenant McClary found that "The managers were most familiar with the project scheduling charts and least familiar with the generalized activity networks [20:62]." Project scheduling charts include the Gantt chart and the milestone chart. The Gantt chart consists of a bar or line chart with a time line along the horizontal axis and people, machines, tasks, etc., shown as the variables on the vertical axis (see Figure 1). The horizontally drawn bars show the amount of time a particular variable should use (i.e., training, ground equipment, etc.). The milestone chart is similar to the Gantt chart but only identifies the timing of particular events (see Figure 2) which are necessary for project success (20:29). Generalized activity networks include such computerized solution techniques as Venture Evaluation and Review Technique (VERT), Graphical Evaluation

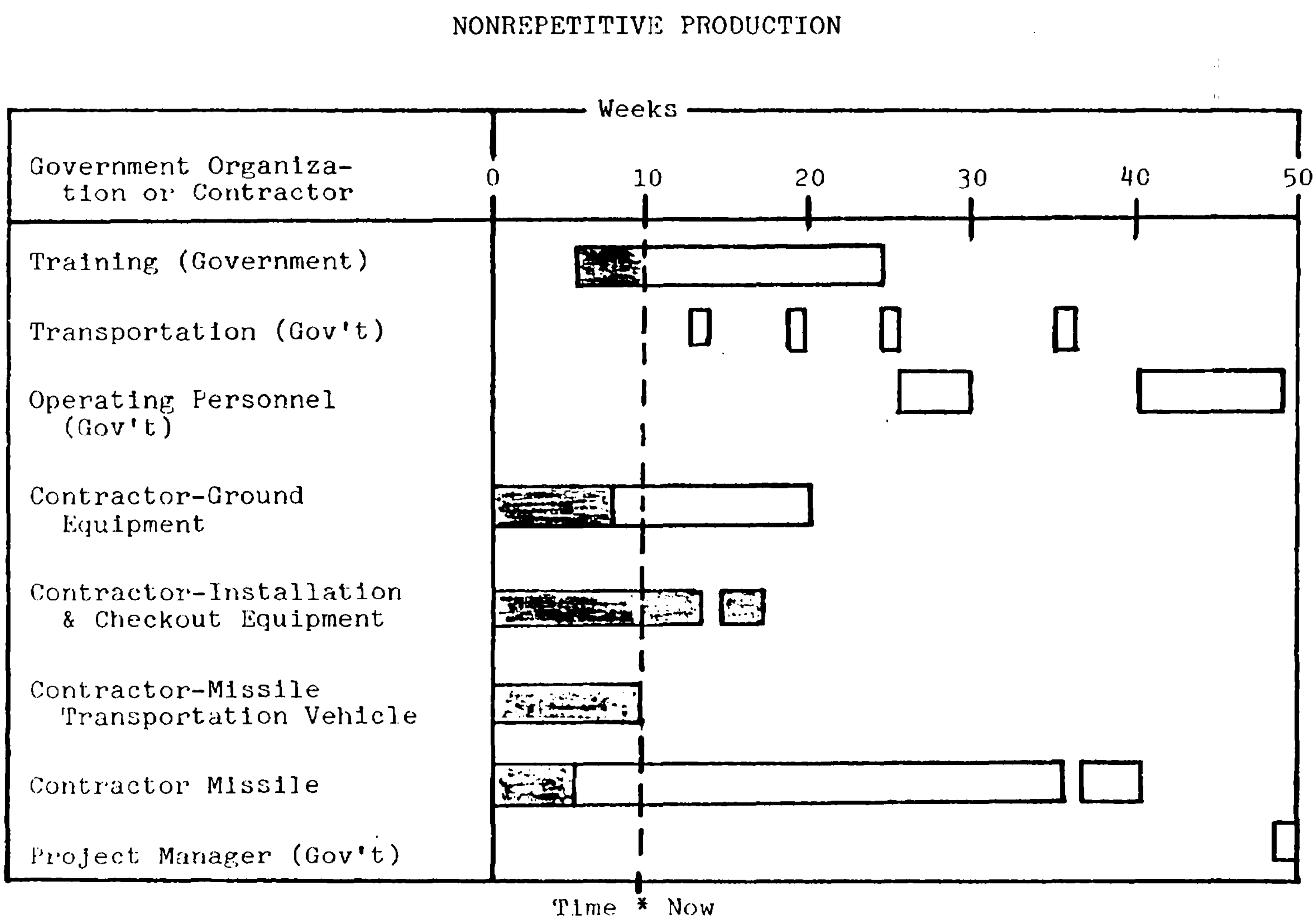

Figure 1. Gantt Chart. Source: AFSCP 800-3, 9 April 1976 [20:30].

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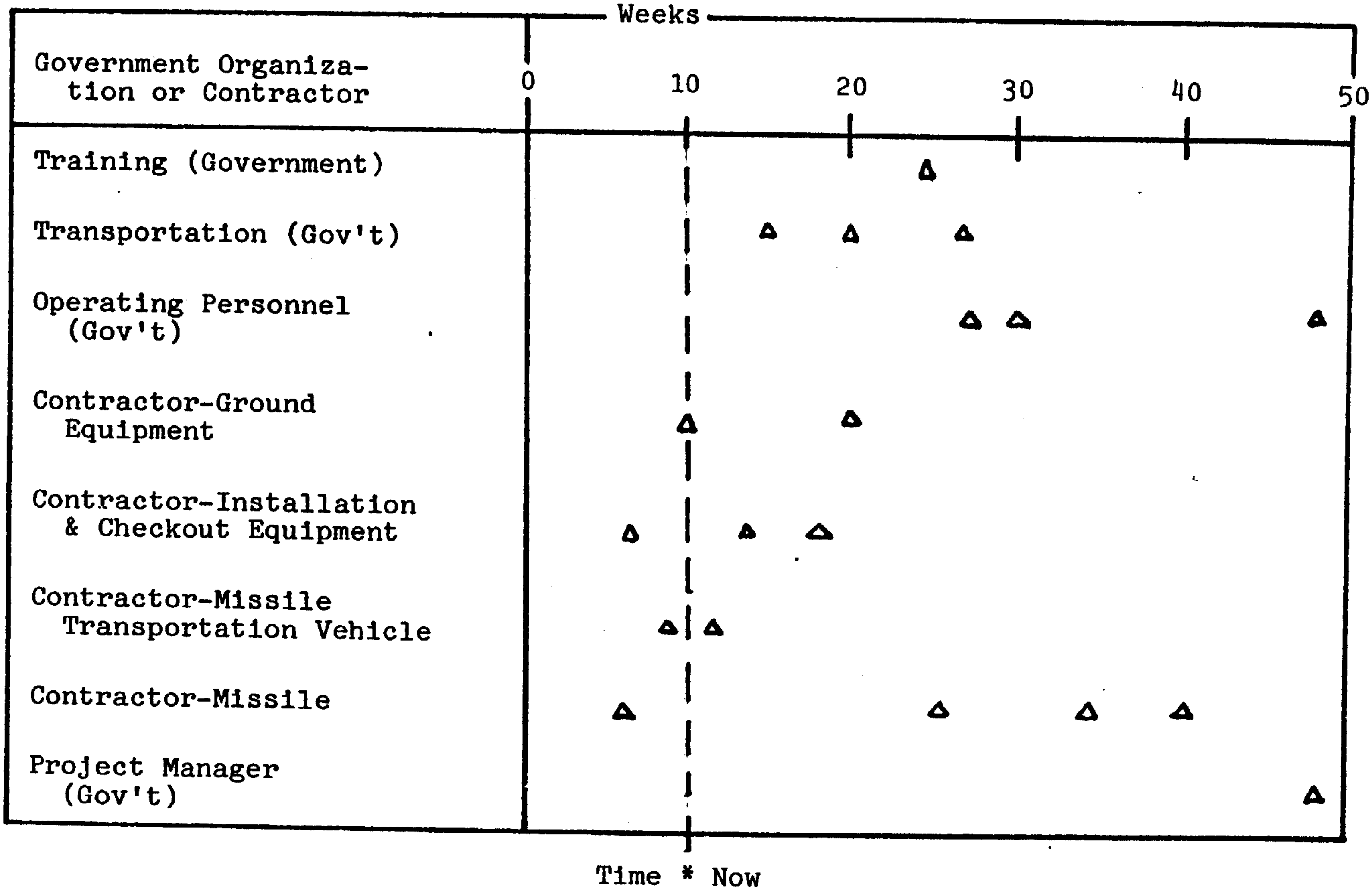

Figure 2. Milestone Chart. Source: AFSCP 800-3, 9 April 1976 [20:31].

and Review Technique (GERT), GERT Simulation (GERTS), and Q-GERT which is a queueing simulation model (20:40).

He also found that Project Scheduling Charts (PSC) (see Figure 3) were used more frequently than the other six techniques he selected to be included in his survey questionnaire. He conducted personal interviews with R&D managers in Aeronautical Systems Division and the Aeronautical Laboratories at Wright-Patterson Air Force Base (AFB)(20: 13-14,62). Using a statistical analysis, he found that

> . . . 53% of the managers were using project scheduling charts alone or with other techniques as a primary means of planning their project activities. . . . Of the managers, 45% used PSC or some combination including PSC as a primary control technique [20:59].

In a telephone conversation with Mr. Jack Gibson (15) of the Air Force Systems Command's Aeronautical Systems Division (ASD) at Wright-Patterson AFB, it was found that ASD cost analysts use various cost estimating techniques depending on the amount of time they have to complete a study and the complexity of the project being estimated. They have a library of estimates of completed projects from which the analyst can obtain data or methods of estimating a particular system. Different techniques were used within a given project, depending on when the cost estimate was needed. In other words, the amount of information available at the various stages of the project determined which technique could be applied. Mr. Gibson emphasized that there is no "cook book" approach to cost estimating.

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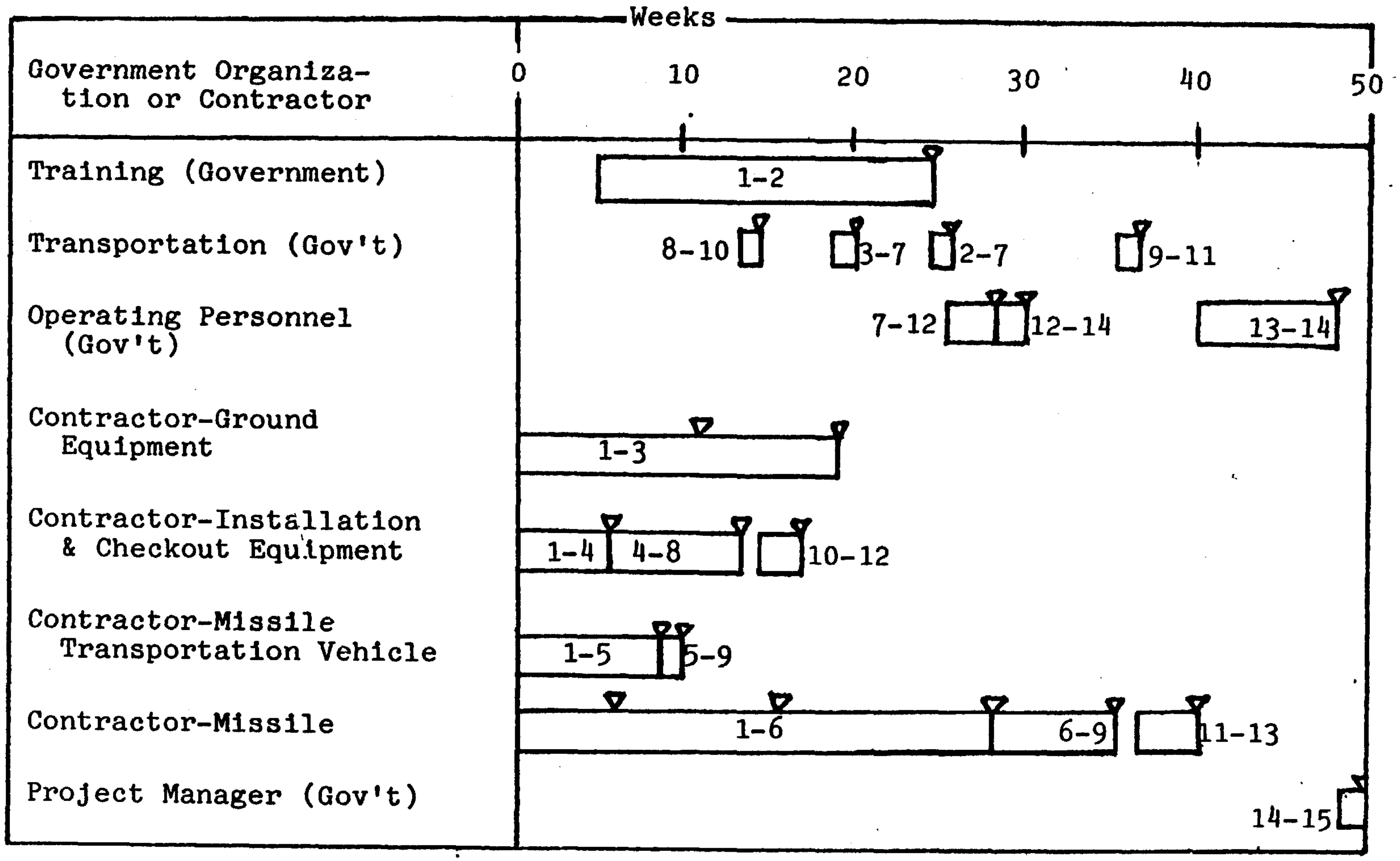


Figure 3. Project Scheduling Chart. Source: AFSCP 800-3, 9 April 1976 [20:32].

Captain Scheel found that "in Air Force laboratories . . . limited cost estimating guidance is available [31:92]." This means that no "cook book" was reported as existing by the forty-five project managers he personally interviewed in the seven R&D laboratories selected for analysis (31:11). In his introduction he described causes of risk and uncertainty such as inflation, requirement changes, schedule delays, policy changes, and the fact that only performance specifications were defined at the beginning of an R&D project (31:1).

> Because future funding requirements for R&D programs are largely determined by the initial or baseline cost estimates, it is critically important for project managers to minimize controllable error in cost estimating [31:2].

Two classes of commonly used estimating techniques usable when project cost is developed are as follows:

> (1) costing by analogy, in which costs of similar systems are used [as a basis] for the estimate; and (2) cost estimating relationships which are equations relating to system performance characteristics. . . . These techniques do not guarantee accuracy because of uncontrollable factors such as inflation or sudden price increase of foreign procurred raw materials [31:2].

Captain Scheel concluded the following based on an analysis of the thirty-five questions asked in his interviews:

> . . . in an Air Force laboratory . . . limited cost estimating guidance is available. Project managers rely almost exclusively on historical data from past work units or recent cost proposals and/or their own project management experience accumulated over the years [31:92].
>
> The project manager must rely on his own experience or, if a novice project manager, the guidance of seasoned project managers or experienced supervisors [31:10].

. . . Experienced project managers generally do not have a specific method to estimate costs, thus it would be difficult if not impossible to instruct the new project managers in a particular technique [31:94].

The project managers attributed the following as the major factors which contribute to inaccurate estimates:

1. Laboratory project managers inaccurately estimate manpower (both manhours and manhour rates).

2. Laboratory project managers inaccurately estimate overhead rates.

3. Laboratory project managers are required to use optimistic inflation factors [this was not supported by Captain Scheel's research][31:98].

4. Potential offerors misinterpret the Statement of Work (SOW)[31:97].

. . . Many project managers do not retain their original cost estimate [31:101]. [This means that the manager cannot compare the final cost to the original in order to determine how accurate he estimated the final cost.]

. . . The Job Order Cost Accounting System (JOCAS) is not a useful cost estimating tool [31:101].

. . . Managers felt constrained by the initial cost estimate made during the planning cycle, or were constrained by the laboratory or division budget. These constraints result in the following consequences:

1. The scope of the effort is reduced. As a result, the technical objectives of the work unit may suffer.

2. The project is stretched in duration. As a result, the total dollar value of the project may increase and new projects planned for the outyears may be deleted.

3. Planning estimates are always inflated to avoid an underestimation of costs [31:102].

Although the results of the above study are very interesting, one should keep in mind that this study was conducted at the Air Force Laboratories and did not apply to the product divisions such as Aeronautical Systems Division (ASD), Armament Division (AD), etc. The main difference is in the final product produced: the laboratories' main output is new technology (i.e., paper studies) while the product divisions' main output is hardware.

> In traditional management theory, managers are expected to collect and weigh facts and probabilities, make an optimal decision and see that it is carried out. In developmental projects, a clear sequence is not possible because of the extended duration, the many technical unknowns, the continual discovery of new "facts" and the changing constraints and pressures. The process must be designed that allows recommitment, reassessment and redirection without allowing never-ending improvement and excuses for missing budgets and schedules [34:15].

> Risk has two sides, the probability of failure and the consequences of failure. Uncertainty also has similar considerations. . . . In any analysis, as the risks and uncertainties are identified, alternated approaches must be developed and the cost, schedule and performance impacts considered. Contingencies must then be built into the acquisition strategy to cover the anticipated cost escalation, correct possible performance shortcomings, and provide adequate time in the schedule to recover [34:17].

General Thurman challenged the attendees at a conference on Management of Risk and Uncertainty to consider the following:

> 1. . . . Specific techniques are needed to address the front end of the acquisition where data is lacking and suspect. More needs to be done on managing uncertainty based on data developed for similar systems.

> 2. . . . [one should] not only look at models and their interaction with the data for "out of tolerance" conditions, but to look at trends in the data to anticipate "out of tolerance" conditions in the future. Well-publicized computerized schedule control techniques, such as PERT networks, are often well behind the action.

3. . . . [The] last challenge is to improve communications to both the professional and the analyst's program manager [34:21-24].

Before concluding this section, a summary of the Defense Advanced Research Projects Agency (DARPA) analysis of technical risk and uncertainty of selected DARPA programs "during the period of FY 1977 through FY 1980 [8:1]" should be considered. The objective of the effort was to establish a data base containing historical cost growth information of major R&D and production programs (8:1). The report included an analysis of the data collected and "a preliminary assessment of the implications of such analysis for management reserves for related high-risk DARPA programs [8:1]."

> Based on statistical analysis of these data subsets [included programs from such agencies as DOD, NASA, etc.], trends relating probabilistic measures of cost growth were developed. These trends displayed a remarkable consistency for all data sets. . . . The analysis shows that there is a predictable relationship between the size of an original estimate of program overrun (i.e., management reserve) and the confidence level that eventual cost growth will remain within that limit. . . . At the 95 percent confidence limit, DARPA cost growth factors (i.e., the ratio of actual program costs to original estimates) lie in the range of approximately 40 to 110 percent. The analysis also permits management to estimate, in the aggregate, what total program management reserves should be as a function of confidence limit [8:1-2].

DARPA did not define the term "management reserve" but it appeared that they were referring to the difference between the baseline or original estimate and the current estimate as found in the Selected Acquisition Reports (SAR). It should be kept in mind that there is a need for further study of the causal nature of cost growth and risk as well as the limitations imposed by the size and the nature of the data base before the above results can be fully used (8:2). The final DARPA report (9) proposed a model based on the earlier study (8) which will be described later in this chapter.

This section has covered a span of eighteen years and has presented some views on the problems involved in risk and uncertainty management. Some factors which contribute to uncertainty have also been presented. This review represents a cross-section of the many articles written about the problems concerning the management of risk and uncertainty. The next section presents a summary of cost estimating techniques since it is difficult to understand the uncertainty and risk assessment techniques without a knowledge of the errors that can occur when current cost estimating techniques are used to predict future costs in a new project or weapon system. It is followed by a section on uncertainty and risk assessment techniques.

Cost Estimating Techniques

This section will introduce several commonly used cost estimating techniques. The purpose of this section is not to provide an in-depth description of the various techniques, but to provide a brief introduction to these cost estimating techniques as a frame of reference. A basic understanding of cost estimating techniques is necessary in order to understand uncertainty and risk analysis techniques. While cost estimating techniques try to incorporate some of the unknowns in future costs, they do not normally take into account the probability distributions associated with all the different variables, both known and unknown. As the name implies, they are, at best, an estimate. The less risk and uncertainty involved in the project being estimated, the more likely we are to have an accurate cost estimate. For example, a cost estimate for a current model of an F-4 fighter would be much more accurate than a cost estimate for a B-1 bomber, which is currently in development.

> A cost estimate is a judgment or opinion regarding the cost of an object, commodity, or service. This judgment or opinion may be arrived at formally or informally by a variety of methods, all of which are based on the assumption that experience is a reliable guide to the future. . . . The techniques used for estimating hardware cost range from intuition at one extreme to a detailed application of labor and material cost standards at the other [36:1-2].

Although the advantage of cost estimating techniques lies in the fact that they do not require the use of probability density functions, a disadvantage can be found when statistical techniques must be applied via computer in order to analyze a large data base. Cost estimating methods or approaches can range from simple rules of thumb to the complexities of the parametric approach. These will be discussed in the following paragraphs.

Expert Opinion. Expert opinion or round-table estimates are the best guesses of an expert in the field which relates to the system being estimated. It is the simplest, cheapest method. It can also be used when there is no data available. The main disadvantage is that the estimate is difficult to verify.

Analogy. The analyst makes use of limited historical information. "The estimator collects resource information on a similar or analogous task and compares the task to be estimated with the similar or analogous one [32:47]." For example, if the estimator finds that the new task takes twice as much material, labor, time, etc. as the analogous task, he will multiply the known cost of the analogous task by a factor of two. This will be the estimated cost of the new task. While this method has the advantage of being simple and cheap, it is possible that the estimator could fail to identify subtle differences between the two tasks and thus use an incorrect adjustment factor.

Parametric Approach. The parametric approach is a method which involves the "collecting and organizing [of] historical information through mathematical techniques and relating this information to the work output that is being estimated [32:52]." "Many estimating relationships are simple statements that indicate the cost of a commodity is directly proportional to the weight, area, volume, or other physical characteristics of that commodity [29:33]." Statistical analysis can be used to derive these relationships. Simple linear regression and curvilinear analysis will be discussed in the following paragraphs.

Simple linear regression is used when two variables appear to be logically related in a linear form. It is a simple two variable equation of the form $y = a + bx$, where "a" is a constant and "b" is a coefficient of "x" which represents one of the variables. "x" could represent the weight of a missile while "y" could represent the cost. The values of "a" and "b" are determined by a method called least-squares. Basically the least-squares method measures the sum of the error squared of each data point from the line described by the above equation and through the simultaneous solution of two equations involving "a" and "b" and the data, the coefficients are derived which best fit the equation to the data, resulting in the least value of the sum of the squared errors.

Multiple linear regression is used when it is found that more than one variable can describe the cost relationship within the project. For a three-variable situation the equation has the form $y = a + bx + cz$. Again, "a" is a constant while "b" and "c" are coefficients. An example:

$$C = -3.752 + .104(W) + .018(F)$$

where

C = cost in thousands of dollars

W = weight in pounds

F = frequency in megahertz

[35:66].

The process of deriving the coefficients is more complicated but can be found in any good statistics book. Also, there are computer techniques which can calculate the coefficients for both this model and the simple linear regression model.

Curvilinear analysis is used when logic and/or analysis shows that the linear relationships do not accurately model the relationship. For example, the equation could have the forms: $y = a + bx^2$, $y = ax^b$, or $y = a + b/x$. There are many other types of non-linear functions which can also be used. Again, statistical packages available on a computer can calculate the coefficients.

As with any statistical technique, certain assumptions must be met or the models above will be in error. The conditions are as follows:

1. The x values are nonrandom (fixed) variables.

2. The residual deviations are independent random variables with normal distributions [about the true regression surface].

3. The expected value of the distribution of each of these random variables is zero, and the unknown variance is the same for all values of x [29:46].

The cost estimating relationships (CERs) are best used by a person who is familiar with the equipment for which the relation was developed. CERs are only useful within a limited range (29:81-87).

Industrial Engineering (Detailed) Approach. Another estimating technique is the industrial engineering approach. For this project, the project is broken down into segments at a low enough level of detail so that labor and material standards can be applied to come up with an estimate of the project cost (sometimes called grass roots estimating)(29: 2-7). Time and motion studies can be used to derive the necessary data to compute the standards needed for an estimate. The technique has the following disadvantages for government use:

> It is difficult to establish standards that will be applicable at some specified production quantity in advance of production experience.
>
> Industrial engineering estimating procedures require considerably more personnel and data than are likely to be available to government agencies under any foreseeable conditions [especially early in the system's development].
>
> They take too much time and are costly to both contractor and government during a period of limited funds. Moreover, for many purposes they have been found to be less accurate than estimates made statistically [29:5].

Essentially the industrial engineering approach collects all the estimated manhours and materials of each element and combines them with the subelements of work. The cost of the elements and subelements are summed to arrive at a total cost estimate (32:6).

In summary,

> The widespread use of estimating relationships in the form of simple cost factors, equations, curves, nomograms, and rules of thumb attests to their value and to the variety of situations in which they can be helpful. But an estimating relationship can only be derived from information on past occurrences, and the past is not always a reliable guide to the future. . . . estimating relationships . . . are an important tool in an estimator's kit and, in many cases, the only tool. . . . The limitations of estimating relationships stem from two sources: first, the uncertainty inherent in any application of statistics and second, the uncertainty that an estimating relationship is applicable to a particular article. The first pertains primarily to articles well within the bounds of the sample on which the relationship is based; even here, uncertainty may be found. The second source refers to those cases in which the article has characteristics somewhat different from those of the sample [29:79].

As mentioned at the beginning of this section, only a brief description was given of the more widely used cost estimating techniques. They ranged from analogy using adjustment factors, which can give a quick overall estimate without complex mathematical approaches, to parametric methods, which can involve complex mathematical manipulations of historical data. While these techniques can be used to obtain a point estimate of the future cost of a new system, they were not designed to be used alone to provide a total cost estimate that includes risk and uncertainty. Therefore, the next section will deal with techniques that can be used to incorporate risk and uncertainty into the total cost estimate.

Uncertainty and Risk Techniques

In applying the techniques described in this section, it must be kept in mind that ". . . it is extremely difficult to approach the field of risk analysis with the idea that a checklist or cook book type methodology provides the answer [18:38]." Cost, schedule, and performance have been found to be interrelated. "These interrelationships are not constant throughout the system life cycle [18:40]." For example, "Changing performance or schedule parameters late in the life cycle do not produce the same monetary results as an equal change which occurs earlier [18:40]." It is quite difficult to derive mathematical equations which adequately describe all the interdependencies involved in a real world situation as well as to recognize and choose the ones which have the most significant effect on the R&D project.

"The program manager is attempting to buy the best possible system for the least possible cost and assure its delivery within the required time [18:70]." In order to do this, the program manager must apply both objective and subjective techniques so that a balance is achieved between "cost, schedule, and performance in a manner which best enables him to fulfill the objectives of the program [18:70]." "Since risk is dependent both on the amount of uncertainty involved and on the management decisions made in the procurement process [18:9]," "any risk assessment program must be tailored not only to the situation being assessed but to the individuals who must perform the assessment [18:84]."

Objective techniques are based on measurements of directly observable phenomenon such as a statistical estimate based on earlier collected data. Objective techniques have "proved highly successful in many historical situations such as the management of gambling houses, industrial quality control and numerous scientific endeavors [18:48]." It must be remembered that many statistical techniques have been best applied to repetitive phenomenon (18:48).

Subjective techniques are best used where nonrepetitive phenomenon occur. The weapon systems process is a case in point. It is not a stable, repetitive

> process and the use of individual subjective opinions must be used to acquire the estimates of the future events either in the form of probability density functions or other types of estimates [18:49].

The subjective opinions are based on past experience. Because the analysis of risk and uncertainty must start at the early phase of a program, probability theory must be applied carefully since the "vast amount of historical data available concerning past system acquisition . . . [is] not [a] stable repetitive process as defined by probability theory [18:127]."

When a future program is evaluated similar programs or systems from the past are used to develop an estimate of the present program's cost, schedule, and performance parameters. This amounts to inferring one population's parameters from another population's data which is statistically incorrect. Therefore, "the analysis of the risk involved in advanced systems must involve the use of probabilities which cannot be based on direct experimentation [18:46]." Since "risk assessment of a weapon system acquisition program is time dependent and a function of the specific phases of the program life cycle [18:36]," different types of risk analysis must be performed at the different stages of the system's life cycle (18:42).

The Bayesian Approach. Further work was accomplished on El-Sabban's Bayesian model by Major Lenox in 1973. The proposed Bayesian approach incorporated present knowledge of a project's status with a knowledge of the past historical systems performance data to predict the future values of a chosen system parameter (i.e., cost, schedule, etc.). This model allowed the analyst to incorporate a weighting factor for his subjective feelings of confidence concerning the value of the present data compared to the value of the past available data. The model allows the analyst to evaluate the effect of various weighting factors in order to conduct a sensitivity analysis. This allows him to choose the best weighting factor based on his experience (18:55).

The analyst selects a distribution which represents the probability of an event based on the past/or present state of knowledge or judgement. This probability distribution is selected based on the knowledge of the mean, variance, and skewedness of the historical data chosen as a basis for estimating the costs of a new system. Two types of distributions commonly used are the normal distribution and the beta distribution (18:28-50).

Normal and Beta Probability Distributions. The normal probability distribution is the familiar bell-shaped curve in which the variable of interest can assume any value from minus infinity to plus infinity. The distribution represents the probability that the true value of the variable being measured is different than the mean which is centered at the highest point of the bell curve. ". . . The probability of the true value exceeding the mean is equal to the probability of the mean exceeding the true value. . . [18:29]." This distribution does not hold true in all situations since "the cost often has a greater probability of exceeding the mean than of being less [18:29]." This is especially true when considering R&D cost situations.

In R&D cost situations, the beta curve is the better choice many times and has found wide use in many risk techniques. The beta distribution looks like a bell curve but it does not have to be a symmetrical bell curve, depending on the parameter values specified. Three parameters must be specified in order to derive the curve: the variable being measured, the right endpoint, and the left endpoint. The right and left endpoints must both be greater than or equal to zero and less than or equal to one. Although the beta distribution endpoints are restricted to a range of zero to one, the variable of interest can have its values transformed so that they will fit into this interval (18: 28-31). Note that the normal distribution had plus or minus infinity for endpoints.

> By varying the "a" and "b" values, the individual can indicate his degree of confidence in the parameter he is estimating and can establish the shape of the curve [18:31-32][see Figure 4].

The beta distribution can be applied to a wide variety of shapes. By using the three parameters to represent the following: a pessimistic estimate, an optimistic estimate, and a most likely value, the analyst can indicate any degree of confidence he may choose (18:30-32). "The beta distribution is widely used in analysis due to its great flexibility [18:30]"[see Figure 5].

<u>Networking Techniques</u>. As mentioned earlier, cost, schedule, and performance parameters are interrelated and it is difficult to quantify these interrelationships mathematically. The use of network techniques provides a qualitative method which simultaneously evaluates these parameters by the use of a computer (18:71). The various networking techniques follow.

Program Evaluation and Review Technique (PERT), developed in 1958 for the Polaris Program, was developed to model a complex project involving several interrelated activities (18:74). The project to be modeled is broken up

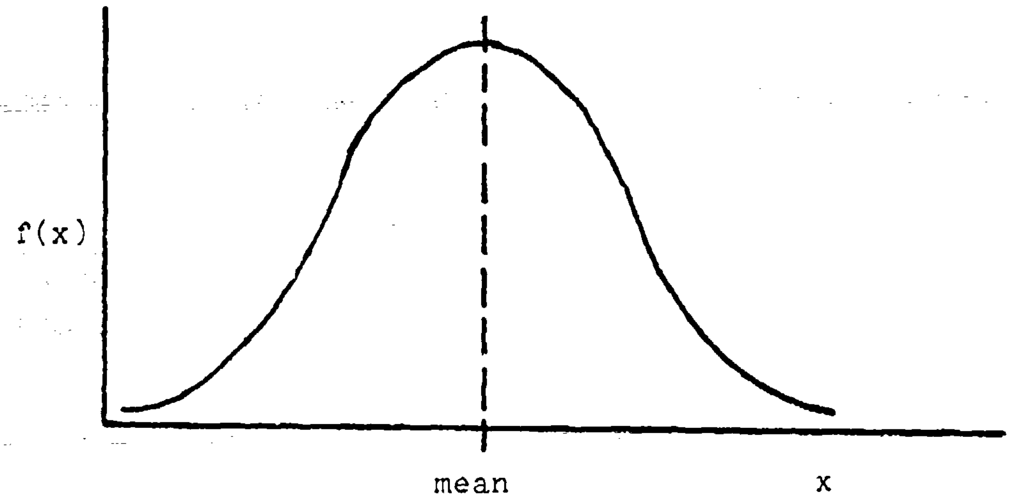


Figure 4. Normal Probability Density Function.

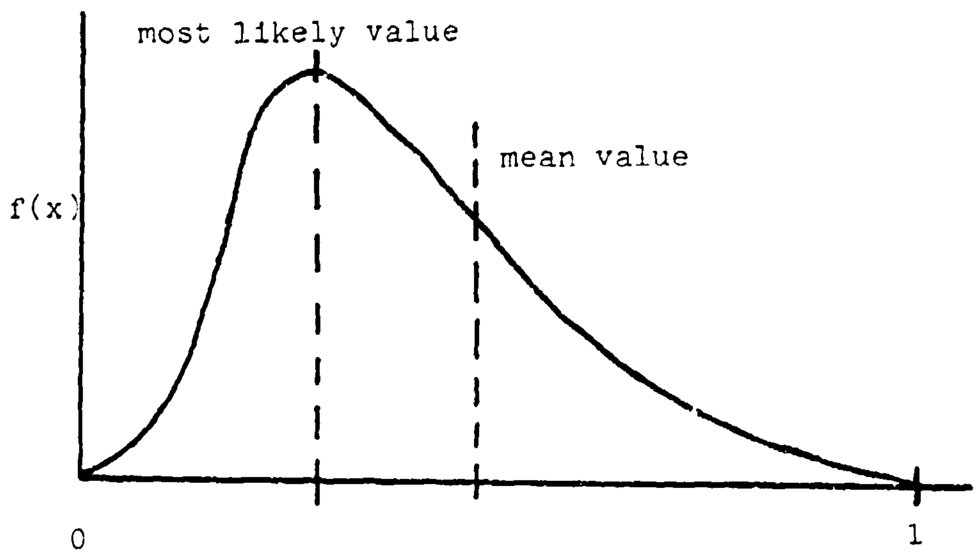


Figure 5. Beta Probability Density Function.

into several events which are then listed in sequential order for completion. The time for completion for each event is then entered into the model along with the correct order for each event. The PERT network is analyzed and the path for earliest project completion (critical path) is found. Any changes in the project schedule which would tend to extend this time would require management attention (18: 74-78).

The original PERT model made the following assumptions:

1. The project could be described by a network of activities with well-defined precedence relationships.

2. The distribution of the activity time for each activity could be described by a Beta distribution.

3. The parameters of the Beta distribution could be estimated from three subjective estimates:

   a. The optimistic (a)

   b. The pessimistic (b)

   c. The most likely (m)

4. The mean of the distribution was approximated by . . . 1/6 (a + 4m + b) and the standard deviation was approximated by . . . 1/6 (b - a).

5. The activity times were independent [18:76].

Some of the shortcomings of PERT are:

1. The requirements for the activity times to be independent. This shortcoming exists to some extent in all network techniques.

2. Every activity leading to an event must be completed before that event can be realized. Neither can any activity following that event be initiated until the event itself has been realized. This is a

significant shortcoming in many types of projects especially those involving complex systems and subsystems.

3. The events must be completed in a particular sequence in order to complete the project. This may not be a significant shortcoming in most projects as they involve a naturally ordered sequence of events [18:77].

PERT provides a limited capability for the use of probabilistic logic but would be "unrealistic for analyzing most system acquisition programs since the events are assumed to be deterministic. . . [18:78]." Graphical Evaluation and Review Technique (GERT) was developed to overcome this problem. "GERT allows an event to be realized without completing all activities leading up to that event [18:78]." One shortcoming, though, is GERT's "lack of realism in handling the interdependencies inherent in the acquisition process [18:78]."

So far no mention has been made of incorporating probability distributions since PERT and GERT do not have this capability. Risk Information System and Cost Analysis (RISCA) was one of the techniques developed to overcome this problem.

> It employs the use of simulation and Monte Carlo procedures [discussed in Chapter 4] to generate an output consisting of a frequency distribution for all possible terminal events and the corresponding time and/or cost distribution for each terminal event [18:79].

RISCA is much easier to use than the following described Venture Evaluation and Review Technique (VERT). "VERT, with its greater flexibility, is more difficult to use and requires substantially more memory [34:177]."

Although RISCA overcame some of the problems involved in the PERT and GERT techniques, it still has some shortcomings. It is not able to "realistically [deal] with the interdependencies [i.e., cost versus time] of the acquisition process [18:80]." While it can handle uncertainty fairly well, "RISCA does not provide for the risk assessment of the performance parameter [18:81];" it will analyze the performance parameter.

Venture Evaluation and Review Technique (VERT) performs better than RISCA since it does have a limited capability to handle a risk assessment of performance (18:83). VERT uses network simulation and Monte Carlo techniques which result in the computerized output as follows:

1. Pictorial histogram approximations to the probability density function and to the cumulative density function.

2. The mean observation, indicating the center of the distribution.

3. The standard deviation, indicating the dispersion of the distribution.

4. The coefficient of variation which enables the analyst to draw inferences concerning the spread of the distribution in relation to its mean [18:81].

VERT has the ability to perform a "formalized decision risk analysis [18:81]." It also has the capability of applying cash discount formulas (18:62).

VERT has 14 transformations of relationship to aid (in) the task of expressing the functional relationships among the parameters of time, cost, and performance. . . . VERT has sufficient flexibility to incorporate data as it becomes available for updating. . . .

VERT enables the identification of the following program areas or items for consideration:

1. Potential problems

2. Consequences of element failure

3. Both low and high risk program areas

4. Requirements versus state-of-the-art trade-offs

5. Adequacy of acquisition time

6. Sufficiency of appropriations

7. Insufficient performance

8. Optimum allocation of funds, time, and design effort

9. The existence of data gaps which might require further study or experimentation

10. Sensitive or critical parameters [18:82-83].

One disadvantage of VERT is the level of expertise required to model the complex interaction of all the variables in an R&D program (18:84).

Computer Models. Some other models which are available for handling the interdependencies of the acquisition process are: the Systems Engineering Model, the Generalized Risk Analysis Model (GRAM), and the Multiple Incentive Contract Evaluation Model (MICE). These models are used to analyze sub-areas of a network and "they may grant more accurate analysis of a specific problem area within the network than a general type network analysis [18:84]."

> The Systems Engineering Model is an integrated aircraft evaluation model with the capability for subsystem level trade-offs. . . . It gives an insight into a specific problem area in greater depth than a general overall analysis of the complete system would. In this respect, an analysis of this type is a valuable input to alleviating uncertainty and possibly reducing risk. Another valuable aspect of a model of this type is that it has been specifically designed to handle the performance parameter [18:85-86].

GRAM is essentially an analysis aid "which facilitates the adaptation of an evaluation model to a risk analysis by putting it into a Monte Carlo simulation framework [29:86]." MICE is a technique which allows a defense contractor to choose among several alternatives to select optimum contract parameters. It analyzes each alternative or strategy's effect on program cost, performance, and schedule (18:87).

Before concluding this section, a recent article by Dr. McNichols, of Management Consulting & Research, Inc. (MCR), described a procedure that had the possibilities of computerization. Although he did not describe the mathematics involved, he proposed a procedure for cost risk assessment of the various proposals that contractors submit to meet government specifications in a particular project. The procedure considers these risk factors: <u>risk assessment</u>, <u>risk management</u>, and <u>risk demonstration</u>, while taking into consideration the fact that "The military worth of a weapon system is often evaluated by several criteria: system performance, life cycle cost and developmental risk [34:249]."

The above risk factors are defined as follows:

- Risk Assessment: Identify the degree of technical risk with respect to realism, soundness, and credibility (i.e., the technical feasibility as well as the "contractor bias problem").

- Risk Management: Develop a plan for managing all types of risk (risk minimization plan) as a function of time (i.e., Acquisition Milestone I, II, and III).

- Risk Demonstration: A test and evaluation demonstration plan should allow early identification of risks and the steps required to reduce high risk program elements to demonstrated acceptable levels as well as the cost of doing so [34:249].

The steps involve (1) the identification of the key risks that are relevant to a particular component or system as well as the technological risk involved; (2) the development of measurement standards (i.e., cost) as a measure of effectiveness; and (3) develop an analytic methodology that combines the several types of risk identified as a means of deriving a cost-risk assessment (34:250). The advantages stated were:

- Consistency across technologies/manufacturers/program phases.

- Ease of application and explanation.

- Ability to quantify subjective knowledge of technical experts in each key area [34:250].

The disadvantage involved in the MCR procedure concerns the need to derive a probability density function of cost for each contractor's design and a composite probability density function for each of the parallel development alternatives

(34:251). The problem lies in the many alternative designs that each contractor may be considering, although he submits only one. This results in comparing contractors based on only one point of the cost-risk profile without knowing the cost-risk variation from the contractor's probability density function (34:253). It is likely that the program will not have enough data to derive the contractor's probability density function.

This subsection has described some of the computer models which have been developed. They basically described a static situation and were used to evaluate only a part of the whole program. The next subsection discusses simulation models which are able to look at the dynamic interactions of a total program.

Simulation Models. In 1978, E. B. Cochran described a model which could be used to measure and predict disruption which is a product of two factors: (1) the inherent uncertainty of development work and (2) such work is performed in an environment of urgency in order to obtain fast delivery to the military services (2:67). The model he developed is "an interactive computer program which allows the user to enter appropriate design, production and schedule characteristics [2:71]." Inputs to the program include: the parameters of the production facility (manpower, storage space, capacity, etc.), work center costs, the master schedule, data on direct effects of design uncertainty, and other factors such as cost penalty functions (2:71). The program uses a networking technique such as PERT for part of its data manipulations.

The output of the program is time-phased comparisons between projected manhours and budgeted (or actual) manhours. It would appear that this is the same as a variance analysis. The model allows the analyst to vary the model parameters in order to examine their effects. He may also try different types of cost functions. The model had good results in the earlier months of a test run but lost some accuracy due to weak (in the author's words) data on changes and delays (2:74).

A. J. Rowe and I. A. Somers defined disruption as the disorder and turmoil created by forces which were not part of the normal program plans and related production procedures. These plans and procedures are normally used to minimize program costs (34:28). Normally, a program is planned to make the best use of available resources. Production procedures developed over a period of time are used to keep costs to a minimum. Any unplanned changes in these procedures from outside sources (i.e., strikes, changes in technology, etc.) cause an increase of costs due to disruption. They defined "disruption cost" as the difference between the actual program cost and the amount that would be "reasonably required" without the penalties for late incorporation of changes needed to complete the project for delivery (34:28).

They proposed a Causal Integrative Model (CIM) to explain the disruption pattern found in any project. It is an extension of the Forrester type dynamic system model which is a dynamic computer model with the following features:

- Several levels or accumulations within the system; e.g., inventories, number of employees, work in process.

- Flow rates that transport the contents of one level to another.

- Decision functions that control the rates of flow between levels.

- Information channels that connect the decision function to the levels concerned [34:57].

The Forrester dynamic system model has the advantage of depicting a clear picture of the most likely areas of disruption problems. It also forces the program managers to understand their decision-making processes. This can lead to a greater insight into the program's problems including their cause and effect relationships. The disadvantages include:

- In simulation, all relevant variables and phenomena must be quantified. The reduction of all descriptive knowledge to quantitative measures is not always valid.

- Dynamic simulation is found to be most useful in price-quantity problems [note that this is a primary DOD concern], less useful in organization design and least useful in product-market strategy.

- Dynamic simulation is not easy to apply. It is a complex technique that needs considerable data and knowledgeable people.

- There are problems in acceptance of the approach because it is often considered a research tool [34:57].

CIM is an extension of the Forrester dynamic system model.

> [It] describes the processes, flows, variables, feedback loops, delays, exogenous variables and key decisions as they are related to the four basic variables in the acquisition process [Internal Control, Technological Uncertainty, Customer Uncertainty, and Environmental Uncertainty][34:57].

> [The CIM model includes]. . . many causal submodels, such as concurrency, learning curve, disruption, etc. It also covers the dynamic interdependencies that exist and the treatment of risk and uncertainty as integral parts of the model [34:58].

DARPA Model. In the section on uncertainty and risk management, the DARPA Model was referenced but not discussed. Historical data from DOD, Department of Energy (DOE), and NASA was used to build a data base to represent the government's acquisition history. Various statistical techniques were used to obtain trends from which to base an estimate of future overruns. "A 'cost-growth risk' relationship has been developed which provides a relative, but quantitative, measure of risk based on historical experience of major high technology programs . . . [9:II-2]."

> Overrun magnitude was represented in dimensionless "cost factor" form, that is the ratio of the year-end estimate, or actual cost, to the original program baseline cost prediction for the year [9:II-3].

They found that for a cost overrun that was predicted to lie at the mean value, "one could be 97.5% certain that the actual overrun would not exceed the mean value plus twice the standard deviation [9:II-4]." Experimental Evaluation of Major Innovative Technologies (EEMIT) data was plotted using a ratio of actual overruns to predicted overruns to derive a dimensionless cost factor. The results showed a bias towards developmental programs (9:II-4). In other words, since developmental programs have higher risk and uncertainty, the final costs (actual) will be higher than originally estimated. The bias mentioned above refers to the fact that the developmental programs have larger cost factors than the more mature programs. The plotted data is used to derive "zero risk cost growth" factors in order to derive a budget that represents a 100% confidence of zero cost growth (9:II-6).

The result of this DARPA effort is a proposal that by the use of this data base, upper management would provide top-down risk management. They would calculate what each program would receive as a management reserve for risk by the use of

> distribution factors based on program funding profiles. . . . [and] influence factors based on non-specific program characteristics . . . determined by consensus review of competing EEMIT programs by six DARPA "technology" offices [9:II-7].

"The proposed system will manage only risk and will not pre-empt the program managers' functions [9:III-2]."

It is the researcher's opinion that this is a move by DARPA to create a centrally controlled "risk fund" outside the control of the program managers. DARPA would apparently manage this fund and determine how much risk money would be assigned to each project. Essentially, this concept of centralized management would preempt some of the manager's control over his project by requiring him to obtain higher level management's permission to expend the risk money to cover what the manager perceives as cost due to risk. The manager could perceive that he would appear incompetent if he applied for some of the risk money. Therefore, he might build in a hidden reserve to avoid unnecessary exposure to the higher level management.

Subjective Methods. The major problem with any of the risk techniques has been how to determine the probability distributions with the given amount of data available. It is difficult for the analyst to specify the appropriate subjective probabilities. These subjective probabilities are especially needed when there is little relative data to be found concerning a new project. Major Lenox summarized eight methods to derive a subjective probability density function and provided references for the interested reader (18). They were identified as:

1. Choice-Between-Gambles Technique

2. Choice-Between-Gambles Technique Deriving Cumulative Distribution Functions

3. Standard Lottery

4. Modified-Churchman-Ackoff Technique

5. Modified Delphi Technique

6. Direct Approximation of Probabilities

7. Fit Values to Given Shapes of Probability Functions

8. Fit Curves from Point Estimates [18:131-132].

Colonel Martin also provides some further information concerning the use of these techniques in his article (34:182).

Quite often, analysts must develop subjective probabilities in order to derive an estimate of uncertainty which can be represented as a risk value. Yet, many analysts have not had formal training in this area. Moskowitz and Sarin conducted some experiments in order to determine whether "a high frequency of implicit violations of the probability calculus were observed [34:236]." They were endeavoring to evaluate the use of a Joint Probability Table (JPT) as an aid to selecting conditional probabilities in decisions. They noted that joint probabilities are an important input to decision models (34:236). They concluded that:

> conditional probabilities are, however, basic input to many forecasting and decision models. We have shown that a large number of consistency violations of the probability calculus occur in a direct assessment of conditional probabilities. These violations . . . result from systematic perceptual and cognitive biases in subjects' responses. . . . In the interim we propose that an analyst should make the decision maker aware of the consistency conditions and discuss with him qualitatively the impact of evidence on the event for which conditional probability is being assessed. The analyst should also use an assessment aid such as JPT in the elicitation process [34:242-243].

It has been seen so far that not only is the subjective probability difficult to measure, but that many analysts may have problems in correctly identifying the subjective conditional probabilities involved in a decision. Further research was reported by Yager concerning the application of fuzzy subsets as a means of determining how to model a person's approximate reasoning (34:185-187). "Fuzzy set theory provides a framework in which to construct models for multiple objective decision making [34:189]." What all this means is that a method is being researched that would advance "the idea of approximate reasoning as a means of simulating a large class of human reasoning operations [34:185]." This could lead to another method of modeling the subjectivity involved in the acquisition process. The mathematics involved in the set theory is used to analyze a new form of uncertainty called possibilistic uncertainty. Possibilistic uncertainty answers the question of "how easy it is for a particular outcome to occur in a given time [34:185-189]." Approximate reasoning is able to take imprecise values for some variables (i.e., x = about 45) and combine them with statements describing a relationship between variables (i.e, if x is near 50, then y is much greater than 100) to derive possibility distributions (34:187). This implies that imprecise statements could be given a quantifiable measure.

Summary. Before 1970, there was little done in the area of risk and uncertainty management and analysis. Since then there has been a growing interest with an ever increasing amount of published literature. Many techniques have been developed for both cost estimation and risk analysis. While the actual management of risk and uncertainty has been mentioned in most articles, very few have addressed in depth the needed management policies to assure the success of a risk management program. Most of the articles have addressed the need for risk management and described the factors which influence risk, uncertainty, and cost growth. A few of the more recent articles have addressed risk management in greater depth which would indicate an increasing interest in the actual management of risk and uncertainty.

The various cost estimating techniques mentioned earlier provide an estimate of the total future costs of a program based on an evaluation of past data on similar systems or subsystems. While these cost estimates do not identify risk and uncertainty, they do reflect some of the subjective opinions of the analyst concerning changes in the variables used to derive the cost estimate. For example, the analyst has to choose an adjustment factor for an analogous estimate. He must also make a subjective choice of the present and future inflation during the life of the program. The use of sensitivity analysis allows the cost analyst and manager to estimate the interval over which the estimate varies when the independent variables (used to derive the estimate) are varied over their possible ranges. While sensitivity analysis does not make use of probability theory, it does provide a means for the manager to select the most likely value of the future cost of the new weapon system from the interval derived.

Some of the cost estimating techniques use statistical manipulation of historical data to come up with an objective measure of the total cost of a system. Risk techniques have also been applied to derive an objective measure of total system cost. By analyzing historical data, a probability distribution function was derived which represented not only the possible ranges of cost, but also the most likely value. This objective measure was found to apply best for production situations where adequate historical data is available. In R&D situations though, there was not a good historical basis to determine an objective estimate of the probability density function. Yet, a probability density function is needed in order to apply the risk techniques described in this chapter. Sometimes the only estimate of risk is based on the manager's subjective feelings of risk. Techniques have been developed and are still being developed to quantify the manager's subjective probability distribution function. This not only gives the manager feedback concerning his preferences (or bias) for taking risks, but also allows him to better evaluate the risk involved for each of the alternatives he has to evaluate.

The initial cost estimate of a new system is based on an analysis of the historical data of a different but similar system which is already in existence. The data base must be adjusted for differences in: the categories used to classify costs, the physical and performance characteristics, price changes, the quantity bought, type of contract, manufacturing techniques, etc. (29:17-32). Without a sound data base and a knowledge of its reliability, the cost estimate including risk assessment can have built-in, unknown errors.

> There are three prerequisites for cost estimating research and analysis to have a meaningful impact on the decision making process in any public agency or private enterprise. They are:
>
> Policy
> Methodology and tools
> Credible data
>
> These prerequisites form a triad for effective decision making. . . . If either of the three are missing or weak, then we are bound to draw faulty conclusions and make less than optimal decisions [7:i].

Although there are many techniques to model risk and uncertainty, it is still difficult to derive a subjective probability distribution, especially in the early stages of an R&D project. There is still a built-in error in all techniques since the input distribution in the early stages cannot necessarily be modeled accurately.

Interview Results

As stated earlier in Chapter 2 under Interviews, the subject of setting aside money to cover risk and uncertainty is politically a very sensitive issue. The following paragraphs contain a summary of interviews conducted at various levels of DOD, including Army, Navy, and Air Force.

Any good program manager realizes that the early phases of research and development are characterized by high risk, since the concepts are still being defined, and many times there has been no forerunner on which to base an accurate cost estimate. While all three services admit to looking at risk analysis and uncertainty, they remain somewhat silent on the use of management reserves. This was consistent with the literature review.

The program manager is faced with unknown changes in his program brought about by technological advances, changing system requirements, changing mission requirements, unexpected cuts by Congress (i.e., budget cuts, program cancellations), etc. In order to cope with these situations the program manager has to build extra money into his program. These monies are termed "management reserves" unofficially and represent an informal way of funding for risks and uncertainty. Officially, there is no "management reserve"; rather, the Engineering Change Order (ECO) Line contains the extra money needed to cover unplanned expenditures. There also seems to be some confusion concerning the meaning of <u>management reserve</u> and <u>risk and uncertainty monies</u>. Some managers consider the terms one and the same. The Army is quite explicit that management reserves are not the same as risk and uncertainty monies. Essentially, risk money is allocated based upon a formal analysis of uncertainty, but some managers feel that management reserve is a "guess" or "fudge" factor without any quantitative basis.

Of all the services, the Army appears to be the only service that uses a codified and Congressionally approved method of taking into account the risk and known uncertainties of a project with the associated costs. One interviewee stated that the Navy had no single codified policy but that the program manager had undisclosed ways of providing the necessary slack to cover risk and uncertainties. It was stated that there is no codified system in the Air Force for management reserve. Risk is mentioned in AFR 173-1, but not management reserve.

It was asserted that the Air Force had looked at the Army's concept of TRACE and provided a response to Carlucci's initiative pertaining to Budget Funds for Technological Risk (Number Eleven). In essence, the Air Force evaluation indicated that it was already using methods which were essentially equivalent to the Army's TRACE concept to quantify and budget for risk, and that the Air Force distributes all funds to the program manager except in unique circumstances. It was said that the main difference between the Army's method of handling risk monies and the Air Force's is centralized management versus decentralized management. It also was stated that the concept of visible management versus hidden management reserves constituted the "horns of a dilemma." In other words, if the money is visible, then it could be taken away, thus crippling a program. On the other hand, a program that encourages hidden reserves has no means to evaluate the manager's performance in controlling risks. Chapter 4 will present a detailed description of the Air Force risk model and the Army's TRACE method.

One staff member stated, "Current Air Force practices make management reserve a smart technique." In some cases the Air Force does use sophisticated techniques for risk analysis. Management reserve is employed, but mostly by "rule of thumb" based on historical data. It is very difficult to quantify risk, and certain programs are more risky than others. According to a budgeting specialist, most of the risk money is contained in the ECO (Engineering Change Order) line of a budget. He also stated that, after a program is completed, the amount of ECO and management reserve used in a program is not readily apparent when reviewing the historical data. Another comment was that management reserve is only a problem because there are too many efforts trying to make it visible.

The main issue in dealing with risk money, uncertainty and/or management reserve centers on the Carlucci initiative (Budget Funds for Technological Risk, Number Eleven) which requires management reserves to be visible (up front). This is perceived as a problem by some, as there are expressed fears concerning the results of an up front management reserve system versus hidden management reserves. Past reprogramming efforts have resulted in the risk money/management reserves being removed from a program at times. It appears to be generally accepted that if all risk money/management reserves were openly identified for all programs, any Congressional budget cut would remove the risk money from all the programs, which could cripple their chances of success. Under the present hidden system, the Air Force is allowed to select those programs to cut which it considers to be of low priority.

Program managers are very success-oriented. Because of this, and because the management of success of present day systems is based upon program completion within the budgeted cost, many alternatives are not considered. According to one interviewee, there is no real interchange between the cost people and technical people, which results in single-point estimates being used.

In summary, Lieutenant Colonel John D. Edgar, USAF, Director of the Research Directorate in Defense Systems Management College's Department of Research and Information, wrote in an article

> Existing Department of Defense (DOD) and service policy directives clearly state that program managers should indicate bands of uncertainty in cost estimates and "include risk costs and costs of likely contingencies. . . ." In the past, however, program managers who explicitly requested funds to cover program uncertainties have usually found those funds deleted by the

services or DOD in the planning, programming, and budgeting system (PPBS), by the Office of Management and Budget (OMB), or by the Congress. Thus, when such adverse events actually occurred, the program manager was faced with some hard decisions. He could delay his program while trying to obtain additional funds through the PPBS or by reprogramming; or he could adjust funds internally by reducing the program scope, stretching schedules, deleting redundancy in tasks and hardware, and borrowing against the future by deleting test hardware, and reliability and maintainability tasks. Most program managers, whether they would publicly admit it or not, have responded to this problem by budgeting an undisclosed, internal management reserve. This reserve might be spread in small amounts across all the program tasks, or concentrated in the form of a single, "soft" work element that could be deleted without affecting the program [13:60].

CHAPTER 4

TRACE/AIR FORCE RISK MODEL--BRIEF DESCRIPTIONS

Overview

Interview data indicated that two models would satisfy the requirements of the Carlucci initiative "Budget Funds for Technological Risk"--the Army's TRACE (Total Risk Assessing Cost Estimate) Model and the Air Force RISK Model. Before discussing these models, the Monte Carlo Technique used in both will be briefly described. This technique is used to derive a probability distribution which represents the future total cost of a system, including an allowance for risk and uncertainties. Following the discussion of TRACE and the Air Force RISK Model, a comparison of both models will be presented.

Monte Carlo Technique

The Monte Carlo Technique is used to generate a sample distribution from limited sized input data which may have an unknown probability distribution (contains uncertainty). The input can be described by a probability function selected by the analyst to represent either a statistical or a subjective representation of the uncertainty contained in the input data (26:7). The beta distribution is most often used, as is mentioned in Chapter 3 of this report, to obtain a risk value within a given confidence level to represent the uncertainty contained in the input data. The technique is generally used as a computer simulation model when large amounts of input variables must be processed in order to obtain a potential distribution of the total future cost of a system. For small amounts of data, a hand calculator and random number tables can be used to calculate the total future cost of a system.

The method generally functions by taking a random single valued sample from each of the input factors and combining them according to the requirements of the system cost analysis model to produce an output that represents the system cost uncertainty. Each of the input factors can be represented by the beta distribution function by specifying the most likely value, the maximum value, and the minimum value. When all these variables are thus represented, the computer then derives a cumulative distribution function for each which can then be plotted. This function represents the actual or estimated uncertainty contained in the input data (26:8). The following paragraph describes how this sample is derived from the input data.

In order to keep the explanation simple, only one variable "x" will be used, with "y" representing the probability (see Figure 6).

> From the probability density, Y = f(x), describing the actual (or estimated) input uncertainty, a cumulative distribution is plotted. Next, a random decimal

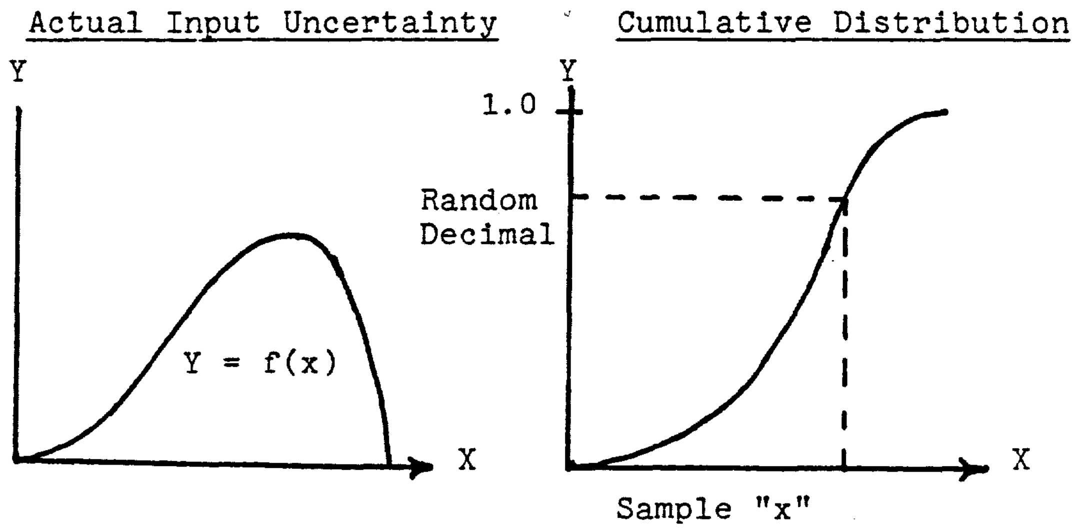


Figure 6. Monte Carlo Sampling [26:7].

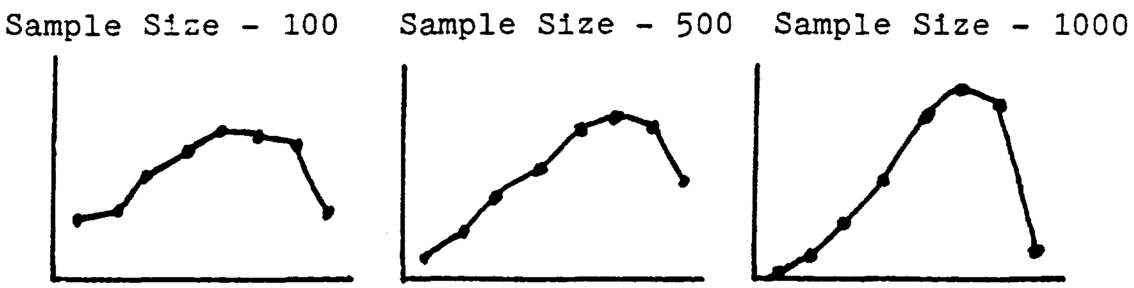


Figure 7. Simulated Input Distribution [26:8].

between zero and one is selected from a table of random digits. By projecting horizontally from the point on the Y-axis corresponding to the random decimal to the cumulative curve, we find the value of x corresponding to the point of intersection. This value is taken as a sample value of x.

The result, if this procedure is repeated numerous times, is a sample of input values that approximates the required input uncertainty. As seen in Fig. 5 [see Figure 7], the more repetitions, the better the simulated input distribution [26:8].

In order to fully understand how the output which represents the total cost including uncertainty is derived, a simple example is now presented. Suppose the total training cost is needed in order to fund a training program. The analyst found that the total training cost in dollars is equal to the number of personnel required times the unit training costs (dollars per man)(26:9). The analyst would represent the amount of uncertainty in each of the variables that produce the total cost with a beta distribution function which he would derive for each. These functions would represent the uncertainty involved in his estimate of each of the cost factors. The beta distributions could be different since the analyst might find that he was more certain of the training costs than of the manpower requirements. He would input these distributions into the computer along with his cost model. The computer would use these inputs to derive the cumulative distribution function for each input variable.

Using a random number generator, the computer would enter the cumulative distribution function for each variable and select the corresponding sample value for both the training cost and the manpower requirements. These two values are multiplied together to obtain a total training cost. The computer repeats this procedure, using a different random number each time, for the number of iterations selected by the analyst (i.e., 1000 times). The output can then be represented as a plot of the frequency distribution for the total training cost. By analyzing this distribution, the cost analyst can obtain the most likely cost (from the peak value) and the maximum and minimum cost from the endpoints. He can also derive the probability from the "y" axis of the output plot of the frequency distribution. If, for example, the analyst wants a total cost that includes enough money to cover a fifty percent risk, he would draw a line parallel to the "x" axis from the .5 division on the "y" axis. He would then select the point where this line crossed the distribution curve and read the value directly below the point on the "x" axis (26:9-11).

In summary, this technique is a method that can be used to theoretically simulate or derive the probability density functions for each input factor when only a limited number of data points are available. Many times the analyst only knows a most likely value and must somehow express his uncertainty concerning this value. He can either use statistics, if there is enough historical data available, or he can utilize subjective probabilities to express his uncertainty if no historical data is available. The beta function has been described as one method by which he may do this. The Monte Carlo Technique is able to use this input information to produce a sample population from which randomly selected values are obtained to estimate the total future system cost distribution, as described by the system cost analysis model (26:6).

Air Force RISK Model

The Air Force Risk Model is the name by which the Air Force Systems Command (AFSC) computer model "RISK" has been called by various Air Force personnel interviewed. The input work breakdown structure (WBS) elements are described by a beta distribution, simulated by a Monte Carlo Technique and an output produced by the RISK model that is: "1) a 'best measure of central tendency' for the total cost distribution, and 2) a probability of occurrence for each total cost interval comprising the total cost distribution [11:para 2.3]." The median is used to represent the "best measure of central tendency" since the mean "includes all the total cost distribution intervals, but could be greatly influenced by extreme low or high values if the distribution is skewed [11:para 2.3]." The analyst inputs variance for each element of risk (see Appendix A). The computer model produces an output that lists each interval evaluated and the probability of each occurring.

These probabilities are used to produce a plot of the cumulative probabilities versus dollars (see Appendix B).

For each WBS element or category, the beta distribution represents:

> 1) [that] some costs within the distribution of possible costs for a given category are more or less likely than other costs for the same category, and 2) the shape of the cost distribution is different for different categories [11:para 2.1].

The analyst fills out a sheet which contains the following information (see Appendix A):

> 1) the point estimate of the cost, 2) the lowest and highest costs possible for four categories of risk, and 3) the variation of possible costs around the point estimate within this range for each of the four risk categories [11:para 2.2].
>
> The variance represents the estimator's assessment of the certainty with which the point estimate can be known, irrespective of the category's cost extremes. A lower variance implies a more peaked cost distribution clustered tightly around the point estimate and high confidence in the point estimate. A higher variance implies a more rectangular (flatter) cost distribution and low confidence in the point estimate [11: para 2.2].

The analyst describes his estimate of the variance as low, medium low, medium high, and high by use of a numbering system ranging from integer 1, implying a high confidence, to integer 4, implying a low confidence in the point estimate. Figure 8 shows a pictorial representation of the above variances.

The RISK Model output is shown in Appendix B. The following is a description of the outputs of the RISK Model.

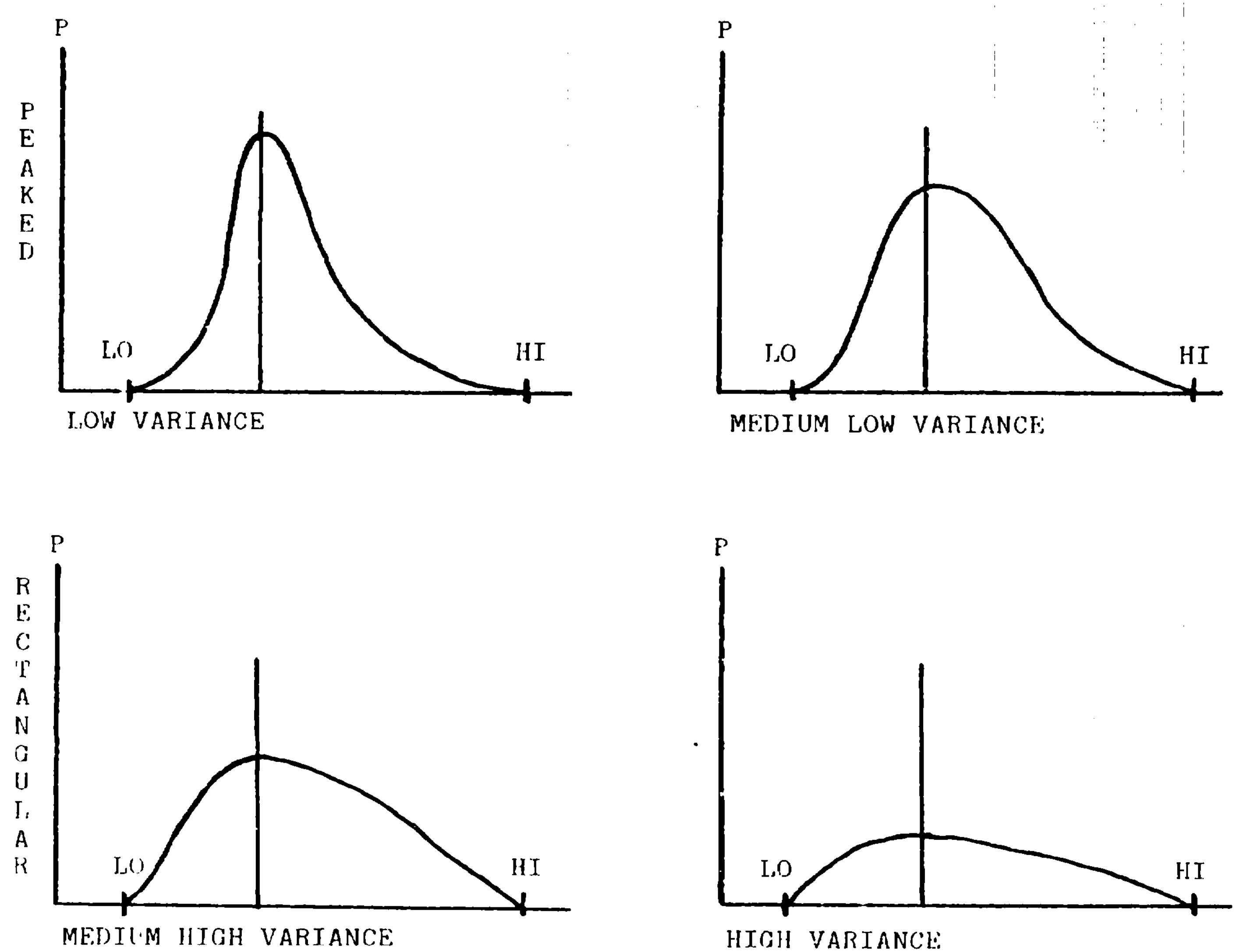


Figure 8. Risk Analysis Distributions [11:figure 3].

1) Echo Check of Input File, . . ., allows the user to review the file prior to running the model.

2) Summary of Item Estimates, Table 3, provides total cost estimates of category (WBS) element and their percent of total cost.

3) Total Cost Distribution, Tables 4A and 4B [Table 5], describe interval probabilities, cumulative interval probabilities, and shows the difference between the interval point and the total point estimate.

4) Total Cost Cumulative Probability Distribution, Table 5 [Table 6], graphically compares percent cumulative probability versus different levels of total cost [11:para 2.5].

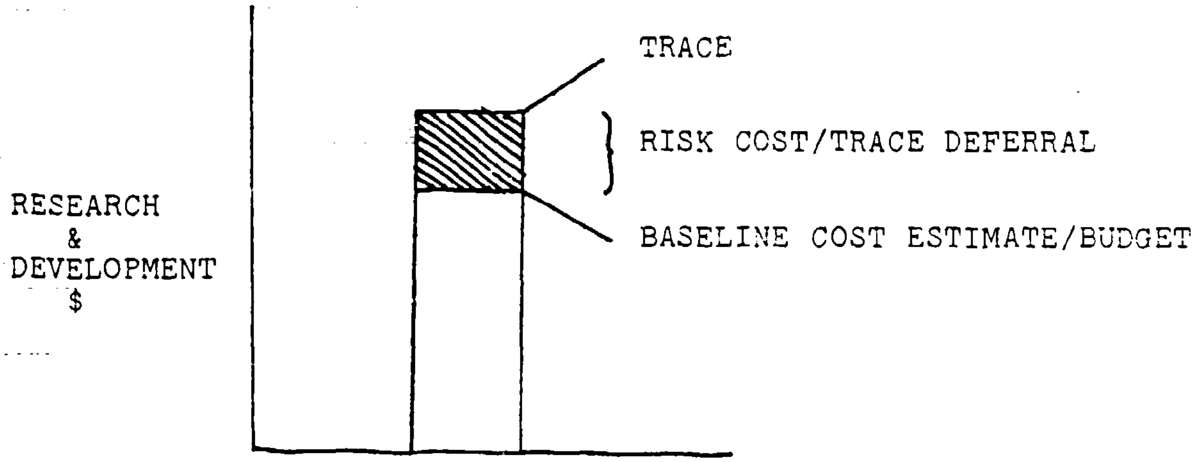
"The RISK Model uses the interdependent approach because it better represents the combination of technical and cost estimating dependencies [11:para 2.1]." Interdependency implies that a change in one category directly affects another category. This is simulated by using the same random number to generate an observation from each WBS category. If all the categories are assumed to be independent, a different random number is used to generate an observation from each category. For example, for a two category model, one random number would be generated and used to obtain an observation from the first category. The computer would then generate a new random number and use it to obtain the second observation from the second category. These two observations would then be combined according to the cost equation to obtain one sample cost value.

In summary, the Air Force RISK Model uses a Monte Carlo Technique to generate a total cost distribution based on WBS elements that are input into the model. These inputs are represented by a beta distribution for each element. The output is a Most Likely Cost, the aggregate Low and High Estimates (Table 5, Appendix B), and a Total Cost Cumulative Probability Distribution (Table 6, Appendix B) with the probabilities of the various total costs and the various total costs represented in graphical form. "Management reserve is the difference between the greater total cost and the median [11:para 2.3]" where the median represents the best estimate of total cost. This cost is "that total cost value whose cumulative probability of occurrence is 50% [11:para 2.3]." The RISK Model has the potential ability to allocate the management reserve (or risk money) for each fiscal year. The model is also capable of determining the quarterly status (or semiannual) of the "management reserve in relationship to the previous estimate [11:para 2.7]."

Army's TRACE Method

The Total Risk Assessing Cost Estimate (TRACE) is composed of two parts: 1) "Operational Flow" or the mechanics of managing the TRACE deferral funds and 2) the TRACE Methodology (10:2-3)(see Figure 9). Before discussing each part, however, the TRACE terminology will be discussed. After this discussion, the operational flow will be reviewed followed by a description of the TRACE Methodology.

The mechanics of managing the TRACE program was



TRACE (Total Risk Assessing Cost Estimate)--Refers to the Total RDT&E project cost which is the sum of the Baseline Cost Estimate and the Risk Cost.

BASELINE COST ESTIMATE (BCE)--The project cost, sometimes referred to as the engineering cost estimate, characterized by the general method of determining project cost against a fixed schedule for all planned activities.

RISK COST (RC)--The cost of project uncertainties and is mathematically the difference between the TRACE and the BCE.

RISK COST/FISCAL YEAR--The project risk cost for a given fiscal year.

TRACE DEFERRAL--The money allocated and retained by DA (Department of the Army) for project uncertainties.

BUDGET--That money given to projects to cover planned activities.

(Author's Note: The definition provided above implies that risk cost is driven by the sum of the derived probability distributions for cost element uncertainties. Obviously there will be some unknown uncertainties which have not been included.)

Figure 9. Total Risk Assessing Cost Estimate (TRACE) Guide [10:4].

referred to as the "Operational Flow" in the TRACE Guide (10). The process begins when the program manager determines the initial recommended TRACE values which includes a proposed allocation of the risk money by fiscal year over the life of the program. The TRACE estimate is then submitted through channels until it is submitted to DOD and the Congress for approval and funding of the program described in the TRACE estimate. When the appropriation is received by HQ DA, the program manager receives the baseline estimate and the TRACE deferral funds are kept at HQ DA. The program manager must submit a request for the TRACE deferral funds and must justify their release when he encounters a risk situation (32:17-19). This is essentially a centrally controlled risk management fund. Notice that the Army calls this fund risk money and <u>not</u> management reserve. Some of the typical uses of TRACE deferral funds that can justify the program manager's request are:

1. Rescheduling to work around technical problems.

2. Rescheduling to reduce program inputs from nominal budgetary limitations.

3. Design changes to correct deficiencies and hardware to support the modifications.

4. Additional testing to verify design corrections.

5. Schedule slippages caused by late delivery of components or materials.

6. Other actions for the reduction of cost uncertainties and cost impacts [10:20].

How did the program manager decide what he should submit as a TRACE estimate for his program? He applied one of three basic TRACE methodology categories: the Risk Factor Method, Probabilistic Event Analysis, and the Probabilistic Network Model (37:5). A brief description of each follows:

a. Risk factor Method (RFM). This is the most subjective of the approaches and is based largely on judgement. It consists of subjectively determining a risk factor and multiplying it by a given Work Breakdown Structure (WBS) element.

b. Probabilistic Event Analysis (PEA). This technique is also oriented to the WBS elements of a program and addresses the probability of a problem occurring for each element, what the problem will cost for that element, and the probability of the problem impacting other elements and the associated costs.

c. Probabilistic Network Model (PNM). The PNM is basically a combination of the Program Evaluation and Review Technique (PERT) and Monte Carlo simulation. The model is activity oriented, incorporating uncertainty associated with cost and schedule for a given level of technical performance. A computer is normally required so as to allow timely analysis of the program's activities and their interactions, and assessment of the technical, cost, and schedule risks. Once accomplished, the PNM can serve as a vehicle to develop the RDT&E portion of the BCE, the TRACE deferral, and the TRACE. It also allows for sensitivity analysis, cost tracking, and rapid reevaluation of the effect of program changes. Fiscal year costs can be determined in the form of cost distributions. Trace deferrals can be evaluated for a variety of risk levels. This is the preferred method of constructing the TRACE for complex programs [37:6].

The PNM will be discussed in more detail since it is the recommended method for complex projects. It is not exactly like the method presented in the Air Force RISK Model. Appendices C and D contain sample inputs and outputs of the PNM approach.

The TRACE methodology (PNM) uses a network modeling approach which is run on a computer using such computer models as VERT or RISNET (Risk Information System and Network Evaluation Technique). Any valid model can be used in the TRACE methodology. In selecting a model, "the major consideration is that the model should sufficiently demonstrate the management philosophy and interrelationships between activities [10:25]." Once this model has been chosen, the cost and schedule data associated with the network activities are input into the computer with a description of the analyst's choice of probability distributions to represent the uncertainty in each element of data (10:26).

> In most cases an analyst, using his experience, and the experience of this data source, can describe uncertainty in terms of a uniform distribution, a symmetrical triangular distribution, or a skewed triangular distribution. Other distributions are available and may be used when the conditions are appropriate [10:26].

Appendix C contains an example of inputs using the networking methodology.

RISNET is a computer program package that was not described in any great detail in any of the TRACE documents. RISNET was described as a computer program package that supported the TRACE network model technique (TRACENET). "TRACENET is a Monte Carlo network simulation program which uses the same network logic as RISCA III and incorporates [37:17]" an iterative technique which accomplishes "the yearly allocation of TRACE deferral while still making allowances for the PM's preferences or aversion to risk [37:14]."

Appendix D gives an example of the outputs of the computerized TRACE network methodology. The necessary statistical outputs which are needed to perform a TRACE analysis are:

1. Total cost distribution
2. Total cumulative cost distributions
3. Cost distributions for each fiscal year
4. Allocations of risk cost per fiscal year [10:26].

These computer produced outputs are used by the analyst to prepare the information and make a chart of the desired information as shown in Figure 10. The TRACE "is simply the point on the cost distribution corresponding to a desired level of risk taking. The recommended TRACE should not be less than the 50/50 point . . . [10:26]." The point can be chosen based on the manager's judgement and whatever trade-offs he feels are necessary. TRACE, Budget, and Risk Cost are defined earlier (see Figure 9). Expected Loss is defined as that expected cost which would result from any given fiscal year, should there be an overrun in that year (10:29).

In Figure 10, the expected loss is in reality an expected value calculation but it is not the same as the TRACE Level. A TRACE Level of 50% is defined as that point where there is "a 50/50 chance of producing either a cost overrun or an underrun [36:3]." A choice of 70% would suggest a 70% chance of success and a 30% chance of failure (a

TRACE Level	Fiscal Year	FY 80	FY 81	FY 82	FY 83	Total
50%	Trace (K$)					119,860
	Budget (K$)	51,600	18,800	10,080	10,200	90,680
	Risk Cost (K$)	8,302	9,322	2,100	9,457	29,179
	Expected Loss	8,396	9,427	2,123	9,564	29,509
60%	Trace (K$)					120,756
	Budget (K$)	51,600	18,800	10,080	10,200	90,680
	Risk Cost (K$)	8,557	9,608	2,164	9,748	30,076
	Expected Loss	8,396	9,427	2,123	9,564	29,509
70%	Trace (K$)					121,832
	Budget (K$)	51,600	18,800	10,080	10,200	90,680
	Risk Cost (K$)	8,863	9,952	2,242	10,096	31,152
	Expected Loss	8,396	9,427	2,123	9,564	29,509

Figure 10. Risk Cost Allocation for TRACE Risk Levels [11:43].

cost overrun). In other words, the actual costs are between the extreme of "funding for all possible risks and uncertainties, [and the other extreme of] funding for those activities which can be identified, costed, and scheduled with certainty [37:2]." The recommended TRACE Level is 50% but the analyst can choose a level which represents the risk that the actual cost will be greater than the estimate which is acceptable to him (37:2). Obviously, there is some subjective judgement required in selecting a TRACE level.

Comparison of TRACE and Air Force RISK Models

Both models use a Monte Carlo simulation technique. They both generate an output that represents the most likely cost of the program. They each are also able to present in graphical form the cumulative probability distribution of the total costs. They also are similar in that the analyst is required to input the data in some form which represents the uncertainty found in each data element or category.

Although they have similarities, there are some differences. The TRACE methodology not only produces a total cumulative cost distribution, but is able to produce probability distributions for each fiscal year over the life of the project. It is also able to predict an expected loss value which can be used to determine if the amount of risk money projected for any fiscal year is adequate.

The Air Force RISK Model places more emphasis on the use of WBS elements and the description of their variances and uncertainty distributions, while the Army's TRACE Model allows a choice of either a network model, probabilistic event analysis which addresses WBS elements specifically, or the use of a risk factor method which relies mostly on the analyst's subjective judgement. This does not appear to be a major problem, since the Air Force method allows the analyst to use either objective or subjective methods in describing the input data. The Air Force model takes into account the interdependencies that are represented in networking models by requiring the Monte Carlo technique to apply the same random number to each input element distribution when calculating the total cost in any iteration. The Air Force Model can also be run quarterly to determine the management reserve or risk money status, as well as to allocate this money for each fiscal year. Although their example did not show this (see Appendices A and B), Paragraph 2.7 of their document mentioned this ability (11). The Air Force mentioned that there are future enhancements possible for their model (11:para 2.6).

The major area of contention in comparing the two models is based on the management philosophy advocated by the TRACE method. The Air Force prefers a decentralized style of management, while the Army prefers a centrally controlled style. It is the author's opinion that the TRACE methodology would be more acceptable to the Air Force if this requirement for a centrally managed fund would not be required. The Air Force's RISK Model certainly does recognize the need for risk money, which they term management reserve. The Army avoids the term management reserve, since it represents to those Army officia. . nterviewed a source of money set aside to cover unplanned-for events without any attempt to analyze the risk associated with the uncertainty of the future. In other words, it can be considered a "slush fund" with no legitimate purpose.

Both models have the following advantages:

1. The cost uncertainty associated with the interactions of the input variables are considered.

2. Subjective as well as objective probabilities are considered. This includes an incorporation of the project manager's risk preference.

3. Both models provide an output which represents the cumulative probability of the total system cost.

4. Both methods use a Monte Carlo Sampling Technique which allows the theoretical derivation of a sample population's parameters when that data would not be available in the data base.

Both Models have the following disadvantages:

1. Both require a high level of analytical skill on the part of the analyst.

2. Both can become considerably expensive in the use of computer time.

CHAPTER 5

CONCLUSIONS

Overview

This chapter presents a summary of the results of the research effort. As stated earlier in Chapter 1, this effort was limited to the use of management funds to cover the extra costs due to uncertainty. This chapter includes a discussion of the conclusions that were based on the research.

Summary

It was found that three areas need to be considered in the management of risk and uncertainty: methodology and techniques, policy, and data base. In reviewing management techniques in Chapter 3, it was found that managers must be aware of the various factors that contribute to cost growth. They must also understand how these factors contribute to the uncertainty involved in a project. In order to understand the meaning of risk and uncertainty, they should have some understanding of probability theory and statistical methods. Risk is nothing more than the result of analyzing and quantifying the uncertainty involved in any endeavor. Various techniques have been proposed in order to better manage R&D programs within government. It is apparent from the literature review that there is no one universal technique to completely manage every program. Since each project and each organization developed to manage a project are somewhat unique, the risk and uncertainty management policies for that program must also have some program-specific features.

The techniques used to estimate costs were reviewed in order to understand their shortcomings in identifying risk. It was found that they fell short of quantifying uncertainty into a calculable risk. Therefore, further research was conducted concerning the various methods of risk analysis. It was found that objective techniques to statistically derive the probabilities of risk based on a prior similar system were not always possible, especially in R&D. The analyst's subjective observations and experience were, many times, the only evaluations that could be made concerning past historical data as applied to a new system. It was also found that various managers and analysts have different propensities for risk taking or, more commonly, have a point of risk aversion. Various techniques are now in development to aid the manager in understanding his risk aversion. These techniques are designed to reveal at what point any given manager or analyst will not take a risk, but will require either extra information or will include a certain amount of extra money (management reserve) to cover unexpected and unquantifiable risks.

It was found that there is no universal DOD policy at this time. The Carlucci initiatives, Budget to Most Likely Cost and Budget Funds for Technological Risk, are presently being evaluated by each service. Of the three services, the Air Force and the Army have proposed methods in response to the Carlucci initiatives. This does not imply, though, that the services have not been considering risk in their projects. As the literature review has shown, risk and uncertainty has been considered by all the services since the late 1960s.

The Army's TRACE and the Air Force's RISK Models were discussed in Chapter 4. It was found that they were both capable of projecting the future total cost of a s; based upon cost elements that were selected by the analyst. While TRACE provided more graphical outputs and information than the Air Force RISK Model, the RISK Model could be modified to do the same in the future. At the moment, the main issue separating the two is the requirement of a centrally controlled risk fund. The Air Force prefers a decentralized management style, while the Army uses a centrally managed system. Although the Air Force does not find TRACE acceptable, it might consider the incorporation of some of the TRACE features into its own RISK Model.

None of these models operate well without a good data base. The data base must be constantly updated to reflect new information as it becomes available. Any old and outdated information should be removed and stored. It should also be remembered that not every new system can be accurately estimated from the data base information, especially when state-of-the-art advances are incorporated into the new system.

The issue concerning the use of management reserves for risk and uncertainty is, at the moment, a political issue. Carlucci's initiatives are an attempt to formally recognize the need for a management reserve and/or risk money within DOD projects. As more and more Congressional leaders and upper level management gain confidence that this management reserve is necessary and will not be misused, the political fervor will recede and more managers will be willing to discuss the matter openly. The use of management reserve in any project is just good business sense.

No one approach appears to be clearly superior to any other. They each have their merits. As new methodologies come into practice and better management techniques and policies are developed, DOD's ability to budget, manage, and estimate will continue to improve, as it has since the 1960s.

The research objectives were met. Management reserve practices have been reviewed, cost estimating and risk management techniques have been identified and evaluated, the leading issues concerning the use of management reserves in risk and uncertainty management have been described, and the leading techniques have been identified and an illustration of their use has been provided in the Appendices. This summary has described the above research objectives. The conclusions which follow address the research questions that are found in Chapter 1 of this report.

Conclusions

The underlying problem found in this report is not whether management reserve should be applied in a government project, but rather what kind of confidence does Congress and other upper level management have in the DOD methodology of program management. The present DOD program management methodology manages the risk and uncertainty as well as the costs involved in a project for which the government has appropriated money in order to obtain a specific weapon system or completed research project.

The Army's TRACE concept has been accepted and recognized by Congress as an effective means to analyze and budget for risk in a program. Although this technique fits the Army's need, it should not be inferred that all services should use this technique. After all, each service is organized in a different manner, performs different missions, and has their own style of management. What should be required is that each service analyze and provide some kind of technique that higher level management and Congress will feel confident in accepting. This would allow each service to develop a program risk management technique based upon its individual management style, yet consistent with the need for good risk management in order to remain within the constraints of cost, schedule, and performance.

Thus, the hidden issue concerning management reserve is not the use of such a reserve itself, but the perception that Congress and higher level management have of a service's program to accurately manage risk and uncertainty without exceeding the budget constraints as defined in the program. In order to achieve this, more objective statistical techniques can be used to derive the baseline cost estimate. Therefore, the present system of submitting a point cost estimate (which includes fixed program milestones, fixed schedule, and fixed performance parameters) must be modified so that additional information gained as the program progresses can be used to get the necessary funds for its completion. At present, once a point estimate is submitted, it becomes the controlling guideline throughout the life of the program.

The present system of measuring a program manager's performance based on his avoidance of a cost overrun on his project forces the manager to maintain hidden reserves and high estimates in order to protect himself from the unknown causes (uncertainties) that cause cost growth within his program. The manager should be measured on the efficient use of the funds he controls, and whether he obtains the performance as specified when the weapon system was conceptualized. This has been the basis of industrial rewarding and control of their managers. While profit can be used in industrial settings to measure a manager's performance, the government, being a non-profit organization, cannot use the same measure. Therefore, the project manager's ability to manage the funds given him should be a criteria of his performance measurement and not just the fact that he did not have a cost overrun.

While it is important for all the services to have a risk management technique which the Congressional authorities have confidence in, unless the budget enactment process deficiencies are corrected, the DOD will not be able to make full use of risk management techniques. For example, it is impossible to take advantage of quantity buys and other cost-saving techniques when program managers are required to obligate all their funds within a year or two of their appropriation. It is also difficult to obtain these cost savings when a manager does not even know for certain whether his program funding will be cut from one year to the next. Until we better resolve the internal management problems which we have built into our government procurement system, it will be impossible for any risk assessment technique to accurately predict total program costs when the environment constantly changes, thereby causing a change in the assumptions used to estimate the cost of a program.

Admittedly, more and more techniques are being developed in order to quantify the subjective probabilities involved in risk analysis in a new acquisition program. While the development of better objective techniques should continue, more emphasis should be placed on the further development of subject probability estimating techniques. After all, at the beginning of a new program, where the highest risk and uncertainty occurs, little data is available to make an objective probability evaluation. The best available method is the use of subjective judgement. With improved subjective probability estimating techniques, the analyst will be able to better apply his subjective judgement at the start of a program which will result in a more accurate program baseline cost. The development of subjective techniques should involve development of better government management of the system acquisition process. Therefore, at the present time, there is no one best way to manage and control risk in any program. It is senseless to hold the manager totally responsible for overruns, when the majority of the time changes directed by higher level management, including Congress, cause cost overruns. These are clearly beyond the control of the manager.

In summary, there are no generalized risk management techniques that apply to every situation. While it is nice to be able to quantify everything in our environemnt, the reality is that subjective, qualitative-type judgements and estimates must still be made. Because of the myriad factors involved in real world situations, it is impossible as well as cumbersome at present to model the entire process accurately. In other words, the universal risk model which applies to every situation and all services, as well as every kind of system, does not exist. Therefore, risk minimization and control procedures must be developed that recognize that some cost overruns cannot be eliminated but only managed. Better risk management techniques are needed rather than just developing more mathematical techniques to quantify risk.

Recommendations

1. Further research should be done in the management control of risk and uncertainty, as well as cost schedule variances within government programs.

2. Further study should be performed concerning managers' subjective choices under risk and uncertainty. A method should be developed where an analysis could be made of the choices a manager would make, given various conditions of risk and uncertainty. From this data, a chart could be prepared which would aid a manager or even an analyst in making a selection of the probable risk in whatever system or sub-system he is evaluating.

APPENDICES

APPENDIX A

AIR FORCE RISK ANALYSIS INPUT (11)

Risk Analysis Input

WBS Element Name: ______________________________

Most Likely Estimate: ______________________

Element of Risk	Low	High	Variance
1. Estimating			
2. Schedule			
3. Technology			
4. Configuration			

Remarks/Rationale:

APPENDIX B

AIR FORCE RISK MODEL OUTPUT (11)

TABLE 3

ECHO CHECK OF INPUT FILE

System: Sample
(Data in Millions FY 1980 dollars)

		Low	High	Variance
WBS Element 1: Const				
Most Likely Cost Estimate:	267.00			
Estimating Tech/Appl Uncertainty		250.00	275.00	1 Low
Program Schedule Uncertainty		266.00	268.00	1 Low
Technology Advance Uncertainty		266.00	268.00	1 Low
System Configuration Uncertainty		200.00	270.00	1 Low
WBS Element 2: GFE				
Most Likely Cost Estimate:	68.90			
Estimating Tech/Appl Uncertainty		68.80	69.00	1 Low
Program Schedule Uncertainty		68.80	69.00	1 Low
Technology Advance Uncertainty		68.80	69.00	1 Low
System Configuration Uncertainty		68.80	69.00	1 Low
WBS Element 3: TIS				
Most Likely Cost Estimate:	38.90			
Estimating Tech/Appl Uncertainty		30.00	54.00	3 Med High
Program Schedule Uncertainty		33.20	54.00	3 Med High
Technology Advance Uncertainty		33.20	60.00	1 Low
System Configuration Uncertainty		35.00	58.00	1 Low

TABLE 3 - Continued

		Low	High	Variance
WBS Element 4: Chng Order				
Most Likely Cost Estimate:	40.70			
Estimating Tech/Appl Uncertainty		19.60	53.50	4 High
Program Schedule Uncertainty		19.60	53.50	4 High
Technology Advance Uncertainty		19.60	53.50	1 Low
System Configuration Uncertainty		19.60	53.50	2 Med Low
WBS Element 5: Claims				
Most Likely Cost Estimate:	13.90			
Estimating Tech/Appl Uncertainty		13.90	75.70	4 High
Program Schedule Uncertainty		13.80	78.00	4 High
Technology Advance Uncertainty		13.80	65.00	1 Low
System Configuration Uncertainty		13.80	60.00	2 Med Low
WBS Element 6: Sys Int				
Most Likely Cost Estimate:	15.70			
Estimating Tech/Appl Uncertainty		6.30	25.00	4 High
Program Schedule Uncertainty		6.30	25.00	4 High
Technology Advance Uncertainty		6.30	25.00	2 Med Low
System Configuration Uncertainty		6.30	25.00	2 Med Low

TABLE 4

SUMMARY OF ITEM ESTIMATES

WBS ELEMENT ANALYSIS

WBS EL	CEN VALUE	MIN VALUE	MIN VALUE UNCERTAINTY	MAX VALUE	MAX VALUE UNCERTAINTY	PERC SYS
Const	267.00	200.00	System Config.	275.00	Estimating Tech-Appl	22.
GFE	68.90	68.80	Estimating Tech-Appl	69.00	Estimating Tech-Appl	0.
TIS	38.90	30.00	Estimating Tech-Appl	60.00	Technology Advancement	16.
Chng Order	40.70	19.60	Estimating Tech-Appl	53.50	Technology Advancement	15.
Claims	13.90	13.80	Estimating Tech-Appl	78.00	Program Schedule	38.
Sys Int	15.70	6.30	Estimating Tech-Appl	25.00	Estimating Tech-Appl	9.

TABLE 5

TOTAL COST DISTRIBUTION

Sample
(Data in millions FY 1980 dollars)

(Cost Uncertainty-Risk Analysis with interdependent components; date of run: 4/16/81)

Interval	Range	Frequency	Probability	Cum Prob
1	338.5 - 342.2	0	0.000	0.000
2	342.2 - 345.5	0	0.000	0.000
3	345.9 - 349.6	0	0.000	0.000
4	349.6 - 353.3	0	0.000	0.000
5	353.3 - 357.0	0	0.000	0.000
6	357.0 - 360.7	0	0.000	0.000
7	360.7 - 364.4	0	0.000	0.000
8	364.4 - 368.1	0	0.000	0.000
9	368.1 - 371.8	0	0.000	0.000
10	371.8 - 375.5	0	0.000	0.000
11	375.5 - 379.2	2	.001	.001
12	379.2 - 382.9	0	0.000	.001
13	382.9 - 386.6	0	0.000	.001
14	386.6 - 390.3	6	.002	.003
15	390.3 - 394.0	3	.001	.004
16	394.0 - 397.7	3	.001	.006
17	397.7 - 401.4	33	.013	.019
18	401.4 - 405.1	31	.012	.031
19	405.1 - 408.8	23	.009	.040
20	408.8 - 412.5	46	.018	.059
21	412.5 - 416.2	75	.030	.089
22	416.2 - 419.9	94	.038	.126
23	418.9 - 423.6	61	.024	.151
24	423.6 - 427.3	107	.043	.194
25	427.3 - 431.0	97	.039	.232
26	431.0 - 434.7	161	.064	.297
27	434.7 - 438.4	123	.049	.346
28	438.4 - 442.1	141	.056	.402
29	442.1 - 445.8	146	.058	.461
30	445.8 - 449.5	148	.059	.520
31	449.5 - 453.2	118	.047	.567
32	453.2 - 456.9	137	.055	.622

TABLE 5 - Continued

Interval	Range	Frequency	Probability	Cum Prob
33	456.9 - 460.6	142	.057	.679
34	460.6 - 464.3	122	.049	.726
35	464.3 - 468.0	116	.046	.774
36	468.0 - 471.7	105	.042	.816
37	471.7 - 475.4	78	.081	.847
38	475.4 - 479.1	49	.020	.867
39	479.1 - 482.8	66	.026	.898
40	482.8 - 486.5	78	.031	.924
41	486.5 - 490.2	55	.022	.946
42	490.2 - 493.9	29	.012	.958
43	493.9 - 497.6	36	.014	.972
44	497.6 - 501.3	23	.009	.982
45	501.3 - 505.0	23	.009	.991
46	505.0 - 508.7	6	.002	.993
47	503.7 - 512.4	6	.002	.996
48	512.4 - 516.1	4	.002	.997
49	516.1 - 519.8	2	.001	.998
50	519.8 - 523.5	2	.001	.999
51	523.5 - 527.2	2	.001	1.000
52	527.2 - 530.9	1	.000	1.000
53	530.9 - 534.6	0	0.000	1.000
54	534.6 - 538.3	0	0.000	1.000
55	538.3 - 542.0	0	0.000	1.000
56	542.0 - 545.7	0	0.000	1.000
57	545.7 - 549.4	0	0.000	1.000
58	549.4 - 553.1	0	0.000	1.000
59	553.1 - 556.8	0	0.000	1.000
60	556.8 - 560.5	0	0.000	1.000

The aggregate most likely cost estimate is 445.1

The aggregate low is 338.5

The aggregate high is 560.5

The aggregate mean is 449.4

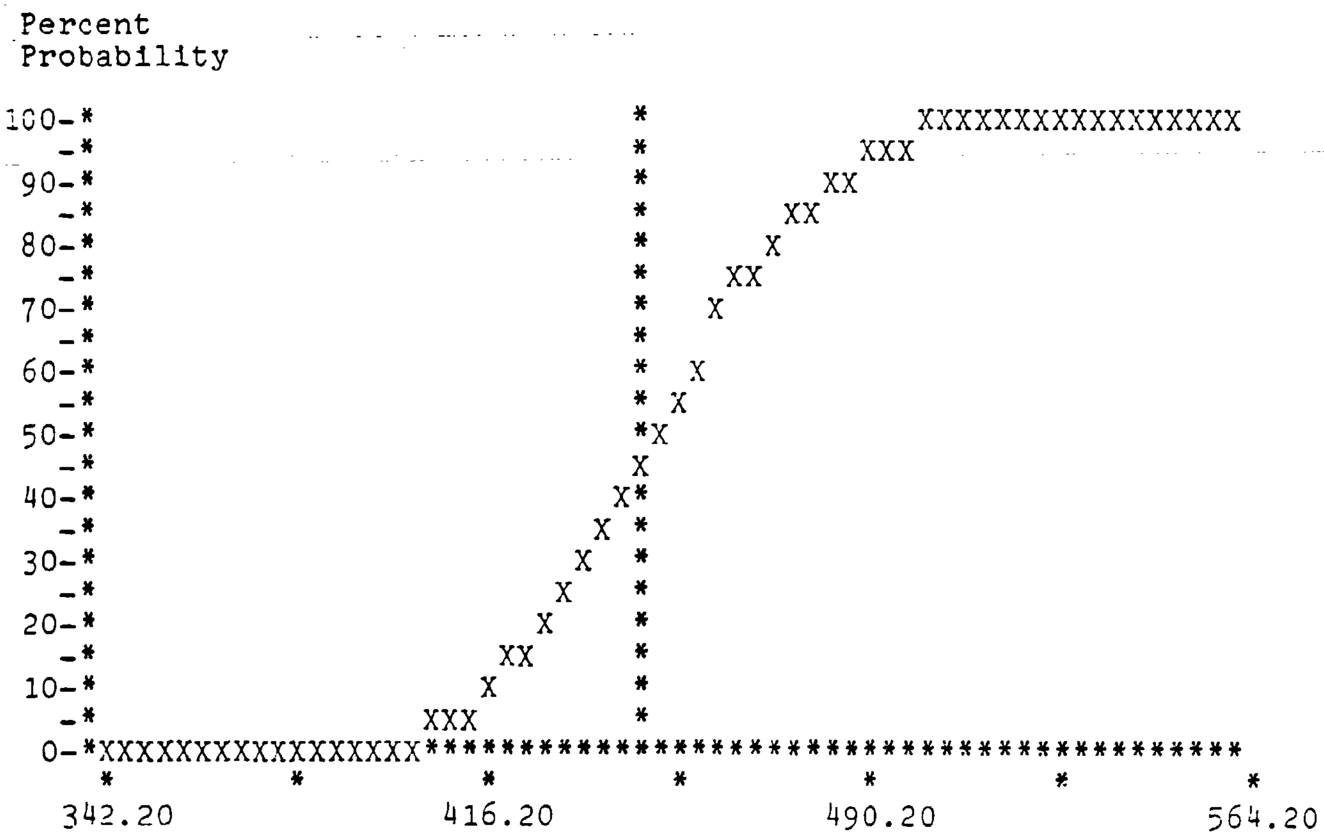
The 90 percent one-sided confidence interval is 483.6

The 50 percent one-sided confidence interval is 448.8

TABLE 6

TOTAL COST CUMULATIVE PROBABILITY DISTRIBUTION

Uncertainty Distribution - Cumulative Probability



APPENDIX C

TRACE COST/SCHEDULE INPUT DATA FOR PROJECT X NETWORK ANALYSIS (10)

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
1	Telemetry Dev & Support	a = 0 b = 31.3; 32.9; 36.2	t = 1., 2., 4.
2	Telemetry Effort	a = 242. b = 31.3; 32.9; 36.2	t = 10.; 11.; 14
3	European Kits	a = 0 b = 36.5	t = 1.5; 2.0; 3.0
4	European Kits Eng Support	a = 0 b = 0	t = Cont. to Joint Test
5	Admin Config Mgt Sys Support	a = 216. b = 56.3; 62.5; 68.7	t = Cont. to DSARC
6	Engineering Support	a = 64.8 b = 39.9; 44.9; 49.9	t = Cont. to DSARC
7	Fwd Sec SP Tools & Test Equip (Implementation)	a = 59.1 b = 81.0; 90.0; 99.0	t = 1.5; 2.0; 3.0
8	Impact Fuze	a = 115.9 b = 0	t = 4.0; 5.0; 7.0
9	Electronic S & A	a = 51.0 b = 218.0	t = 4.0; 5.0; 7.0
10	Assy Fwd Sec & Checkout	a = 40.0 b = 55.6; 61.6; 67.6	t = 3.0; 4.0; 6.0
11	Con't Elec S & A	a = 0 b = 21.6	t = 14.0; 16.0; 18.5

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
12	Signal		
13	Signal		
14	Manuf & Integ of MSL Rnd (4)	a = 550.0; 575.0; 600.0 b = 158.1; 166.4; 191.4	t = 9.0; 10.0; 13.5
214	Signal		
15	Fwd Sec Comp SP Tools & Equipment	a = 0 b = 81.0; 90.0; 99.0	t = 10.0; 9.0; 11.0
16	Signal		
	Manuf & Integ Msl Rnd (15)	a = 0 b = 158.1; 166.4; 191.4	t = 1.0; 2.0
18	Fwd Sec Qual	a = 1.4 b = 15.9; 16.75; 19.3	t = 3.0; 4.0; 6.0
19	Signal		
201	European Deliveries	a = 0 b = 0	t = 12.0; 15.0
202	Targets Procurement	a = 2000.0; 2000.0; 2300.0 b = 0	t = 12.0
203	Signal		
204	Signal		

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
20	Assy Qual Rnd & C.O.	a = 0 b = 0	t = 1.5; 2.5
21	Manuf & Integ Msl Rnd (40)	a = 0 b = 158.1; 166.4; 191.4	t = 1.5; 2.5
22	Signal		
23	Round Qual	a = 1.4 b = 15.9; 16.75; 19.3	t = 3.0; 4.0, 6.0
24	Manuf & Integ Msl Rnd (67)	a = 0 b = 158.1; 166.4; 191.4	t = 4.0; 5.0; 7.0
25	Signal		
26	Part "A" Testing Con't	a = 0 b = 5.0	t = 4.0; 5.0; 6.0
221	Joint Test	a = 3150.0; 3150.0; 3300.0 b = 0	t = 2.0
27	Signal		
28	Motor Producibility Tests	a = 0 b = 27.4	t = 5.0; 6.0; 7.0
31	Motor Qual (Phase I)	a = 0 b = 2.4	t = 6.0; 6.5; 7.5

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
32	Signal		
33	Motor Qual (Phase II)	a = 0 b = 14.8	t = 2.0; 4.0
34	Signal		
35	Propulsion Sys Production	a = 1000.0; 1100.0 b = 25.2	t = 15.0; 18.0; 24.0
36	Signal		
37	Msl Aft Sec Engr & Delivery (1st Unit)	a = 0 b = 219.0	t = 4.0; 6.0; 8.0
38	Launch Tube Del. (1st Unit)	a = 0 b = 49.2	t = 5.0; 7.0
39	Special Tools & Test Equip	a = 0 b = 74.0	t = 6.0; 6.0; 8.5
40	Warhead Eng Qual & Del (1st Unit)	a = 0 b = 52.8	t = 5.0; 7.0
41	Signal		
42	Aft Sec & Tube Fab Assy & Integ (4 Units for Joint Tests)	a = 0 b = 13.1	t = 4.0; 5.0; 8.0

ROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
43	Signal		
44	Con't Aft & Launch Tube (15)	a = 0 b = 148.7	t = 1.0; 1.0; 3.0
45	Warhead Fab Assy & Del (75)	a = 0 b = 86.8	t = 4.0; 6.0
46	Signal		
47	Safety Tests	a = 0 b = 0	t = 5.0; 7.0
247	Signal		
48	Con't Aft & Launch Tube (59)	a = 0 b = 292.0	t = 3.0; 3.0; 6.0
49	Con't Warhead (26)	a = 0 b = 49.6	t = 2.5; 3.0
50	Signal		
51	Con't Aft & Launch (52)	a = 0 b = 220.9	t = 2.0; 3.0; 5.0
52	Con't Warhead (12)	a = 0 b = 112.0	t = 0.5; 1.0
53	Signal		

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
54	Special Tools & Test Equip	a = 500.0; 600.0 b = 150.0; 200.0	t = Con't thru Integ & Test of F.U.
55	Launch & Guidance Control Fab Assy & C.O.	a = 620.9 b = 69.1	t = 8.0; 10.0
56	Aux Equip Fab Assy & C.O.	a = 500.0; 600.0 b = 62.0	t = 8.0; 10.0;
57	Cabin Fab Assy & C.O.	a = 600.0; 618.0; 700.0 b = 129.0	t = 10.0; 11.0; 14.0
58	Turret Fab Assy & C.O.	a = 1628.0; 1628.0; 1700.0 b = 130.0; 160.0	t = 11.0; 11.0; 14.0
59	Communication Equip (GPE)	a = 0 b = 47.0	t = 8.0
60	Fire Unit Integ Support	a = 177.8 b = 209.4; 210.4	t = 8.0; 10.0; 15.0
61	Con't Launch & Guid Control	a = 256.9 b = 62.0	t = 2.0; 4.0
62	1st Del Launch & Guid	a = 0 b = 0	t = 0
63	Con't Aux Equip	a = 155.0 b = 28.5	t = 3.0; 3.0; 5.0
64	1st Del Aux Equip	a = 0 b = 0	t = 0

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
65	Con't Cabin	a = 53.0 b = 72.1	t = 2.0; 4.0
66	1st Del Cabin	a = 0 b = 0	t = 0
67	Con't Turret	a = 89.4 b = 55.0	t = 2.0; 4.0
68	1st Del Turret	a = 0 b = 0	t = 0
69	F.U. Integ & Test Units 1 & 2	a = 64.5 b = 85.3; 90.5; 105.0	t = 2.0; 4.0
70	Complete F.U. Integ & Test (3 & 4)	a = 46.8 b = 78.5; 85.3; 92.6	t = 1.5; 2.0; 4.0
71	Deliver Units 1 & 2	a = 0 b = 0	t = 0
72	Integ Support	a = 0 b = 45.5; 46.9; 50.7	t = 8.0; 10.0
73	Training & Road Test	a = 0 b = 10.0	t = 2.0; 3.5
74	Con't Integ Support	a = 0 b = 10.2; 10.5; 11.3	t = Con't to Termination
76	PEP (BAC)	a = 0 b = 5.0; 6.7	t = Con't to OSD Review

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
77	Search Radar Eng Manuf & Test to 1st Delivery	a = 1000.0; 1100.0 b = 242.0; 269.0; 296.0	t = 10.0; 10.0; 13.0
78	Search Radar 1st Unit Delivery	a = 0 b = 0	t = 0
79	Search Radar Con't Eng Manuf & Test	a = 0 b = 242.0; 269.0; 296.0	t = 3.0; 3.0; 7.0
80	PEP (SEARCH)	a = 0 b = 39.6; 44.0; 48.4	t = 8.0; 10.0
81	IFF Procurement	a = 261.0 b = 4.0	t = 6.0; 7.0; 9.0
82	Track Radar Eng Manuf & Test	a = 1300.0; 1300.0; 1400.0 b = 612.0; 612.0; 676.0	t = 8.0; 10.0; 15.0
83	1st Unit (TRACK)	a = 0 b = 0	t =0
84	Con't Eng Manuf & Test (TRACK)	a = 50.0 b = 235.0; 235.0; 267.0	t = 3.0; 5.0; 7.0
85	PEP (TRACK)	a = 0 b = 11.0	t = 7.0; 9.0; 12.0
86	Electro Optical Eng Manuf & Test	a = 0 b = 150.0	t = 6.0; 7.0; 8.0
87	1st Unit (Electro Optical)	a = 0 b = 0	t = 0

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
88	Con't Eng Manuf & Test (Electro Optical)	a = 0 b = 110.0	t = 6.0; 7.5; 9.0
89	Support Integ (Electro Optical)	a = 0 b = 5.0; 7.0	t = Con't to completion of F.U. Integ
90	PEP (Electro-Optical)	a = 0 b = 55.0	t = 8.0; 10.0
91	OMTS Clear Weather Procurement Delivery & C.O. (No. 1 Set)	a = 1093.6; 1093.6; 1200.0 b = 61.1	t = 10.0; 12.0; 14.5
92	OMTS Proc Del & CO Clear Weather (No 2 Set)	a = 593.6; 625.0 b = 235.0	t = 18.0; 20.0; 22.0
93	OMTS Track Radar	a = 0 b = 10.0	t = 26.0; 32.6
94	OMTS Operator Proficiency Trainer No. 1	a = 1180.0; 1250.0 b = 250.0	t = 9.0; 11.0; 15.0
95	OMTS Operator Proficiency Trainer No. 2	a = 0.0 b = 90.9	t = 9.0; 11.0; 15.0
96	ILS Support FMTS	a = 0 b = 78.0; 80.0	t = Con't to End of Unit 1 shelter installation

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
97	System Design FMTS	a = 0 b = 62.1	t = 3.0; 4.0; 5.5
98	Fab & Assy (Phase I FMTS	a = 0 b = 20.3	t = 2.0; 3.5
99	Preliminary Design	a = 0 b = 127.0	t = 12.0; 13.0; 16.0
100	Hdw Design FMTS	a = 931.3; 931.3; 1100.0 b = 16.0	t = 2.5
101	Integ & C.O. 1st Unit FMTS	a = 0 b = 57.6	t = 10.5; 13.5
102	Shelter Installation 1st Unit FMTS	a = 0 b = 15.8	t = 4.0; 4.0; 6.0
103	Signal		
104	Con't Shelter Instal. FMTS	a = 0 b = 15.0	t = 1.0; 2.0; 4.0
105	Integ & C.O. Unit 2 FMTS	a = 0 b = 79.3	t = 1.0; 2.0
106	Environmental Tests (FMTS)	a = 45.5 b = 10.1	t = 2.0; 2.0; 4.0
107	Signal		

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
108	ILS (HAC) Includes LSAR Mag Tape and Training Opt	a = 0 b = 2.5; 3.5	t = Con't to OSD Review
109	Signal		
110	PROTO FAB ASSY & C.O. (2) + Queen (Vehicle)	a = 0 b = 115.7	t = 10.0; 10.0; 14.0
111	Prog Mgt Eng Pubs Tech Data & Test Support (Vehicle)	a = 0 b = 17.9	t = 11.0; 13.0; 15.0
112	Gov't Support (ARMCOM) (Vehicle)	a = 0 b = 39.2	t = 6.0; 7.0; 8.0
113	Deliver 2 Units (Vehicle)	a = 0 b = 0	t = 2.0; 3.0
114	Fab Assy & C.O. (Vehicle)	a = 0 b = 6.8	t = 6.0; 6.0; 7.0
115	Deliver 2 Units (Vehicle)	a = 0 b = 0	t = 0
116	Signal		
117	Manuals Provisioning Eng Vehicle	a = 0 b = 21.4; 23.8; 23.8	t = 8.5; 8.5; 11.5

PROJECT X TRACE NETWORK INPUT DATA

Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
118	Signal		
119	Prog Mgt (HAC/BAC)	a = 0 b = 413.3; 432.2; 505.5	t = Con't to OSD Review
120	Sys Eng & Test Support	a = 0 b = 555.6; 601.2; 698.0	t = Con't to OSD Review
121	DATA (BAC)	a = 0 b = 131.3; 136.8; 164.2	t = 1.5; 3.0; 4.5
122	Spares	a = 220.5; 245.0; 269.5 b = 53.2; 59.1; 65.0	t = 3.0
123	Spares Con't	a = 63.9; 71.0; 78.1 b = 19.7; 21.9; 24.1	t = Con't to OSD Review
124	PQT Part A BAC	a = 0 b = 5.0	t = 4.0; 5.0; 6.0
125	Problem Fix - 45% Probability of Occurrence	a = 0 b = 621.8; 623.8; 648.0	t = 1.0; 3.0; 8.0
126	Success (Part A Test) 55% Probability of Occurrence	a = 0 b = 0	t =0
127	Manuals	a = 3260.0; 3260.0; 3800.0 b = 991.25; 1049.75; 1096.3	t = 2.0
128	Contr/M.1 Training	a = 0 b = 115.0; 121.0; 137.0	t = Con't to OSD Review

PROJECT X TRACE NETWORK INPUT DATA

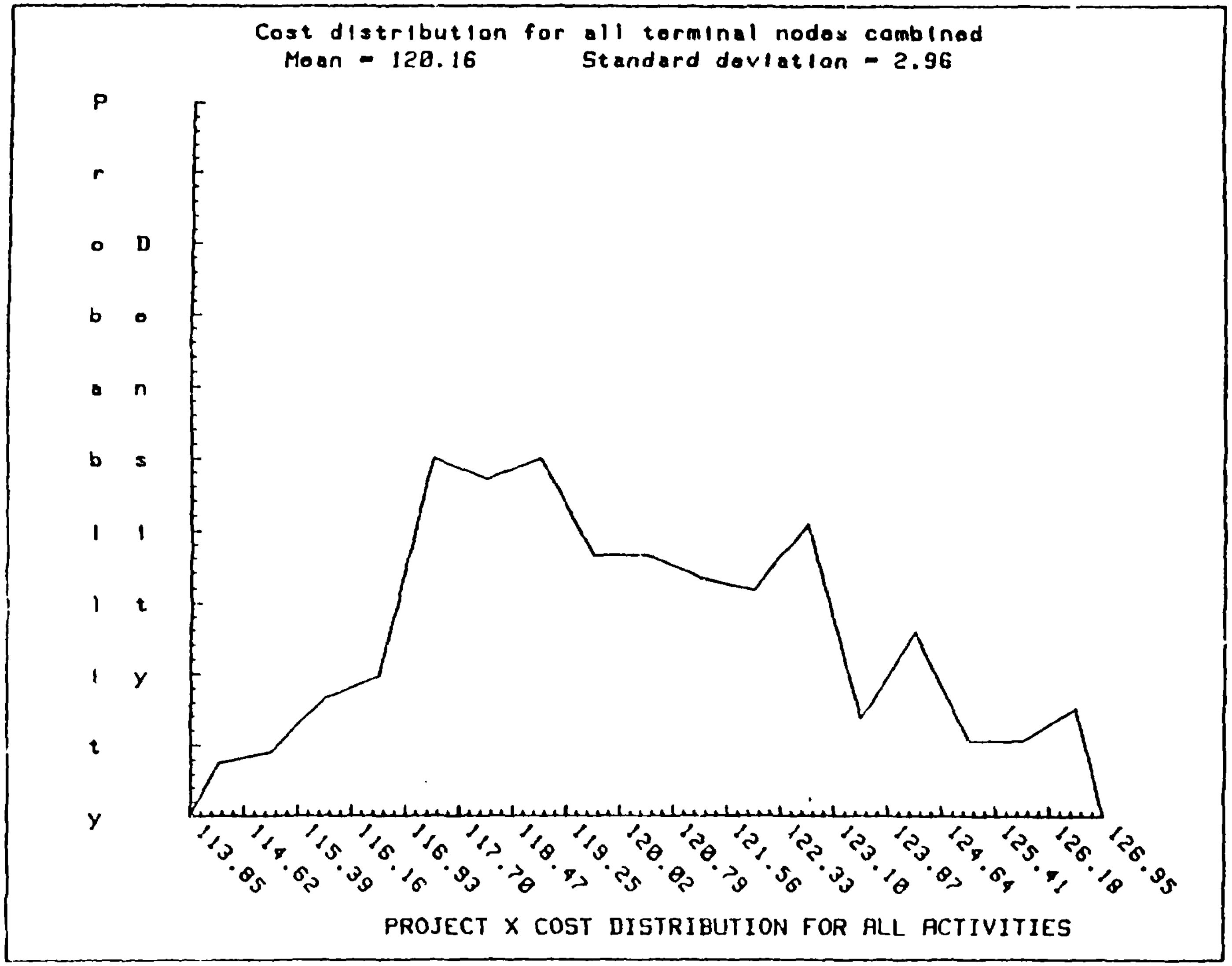
Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
129	Signal		
130	Signal		
131	Test Con't	a = 0 b = 44.8	T = Con't to Test Completion
132	BAC Test Support	a = 295.0; 315.0; 450.0 b = 205.0; 210.0	t = Con't to DSARC III
133	Complete Tests	a = 0 b = 110.3	t = 13.0; 13.0; 18.0
134	BAC TEST Support & System Engr	a = 12.2 b = 65.0; 68.9	t = Con't to Termination
135	DSARC III	a = 0 b = 435.6	t = 3.0; 3.0; 8.0
136	Production Planning	a = 0 b = 199.2; 210.0; 230.0	t = 5.0; 9.0
137	OSD Review	a = 0 b = 141.7	t = 10.0; 11.0; 13.0
138	LRP & IPF	a = 0 b = 250.0; 275.0	t = Con't to Production
139	Production	a = 0 b = 75.2	t = 3.0; 3.0; 5.0

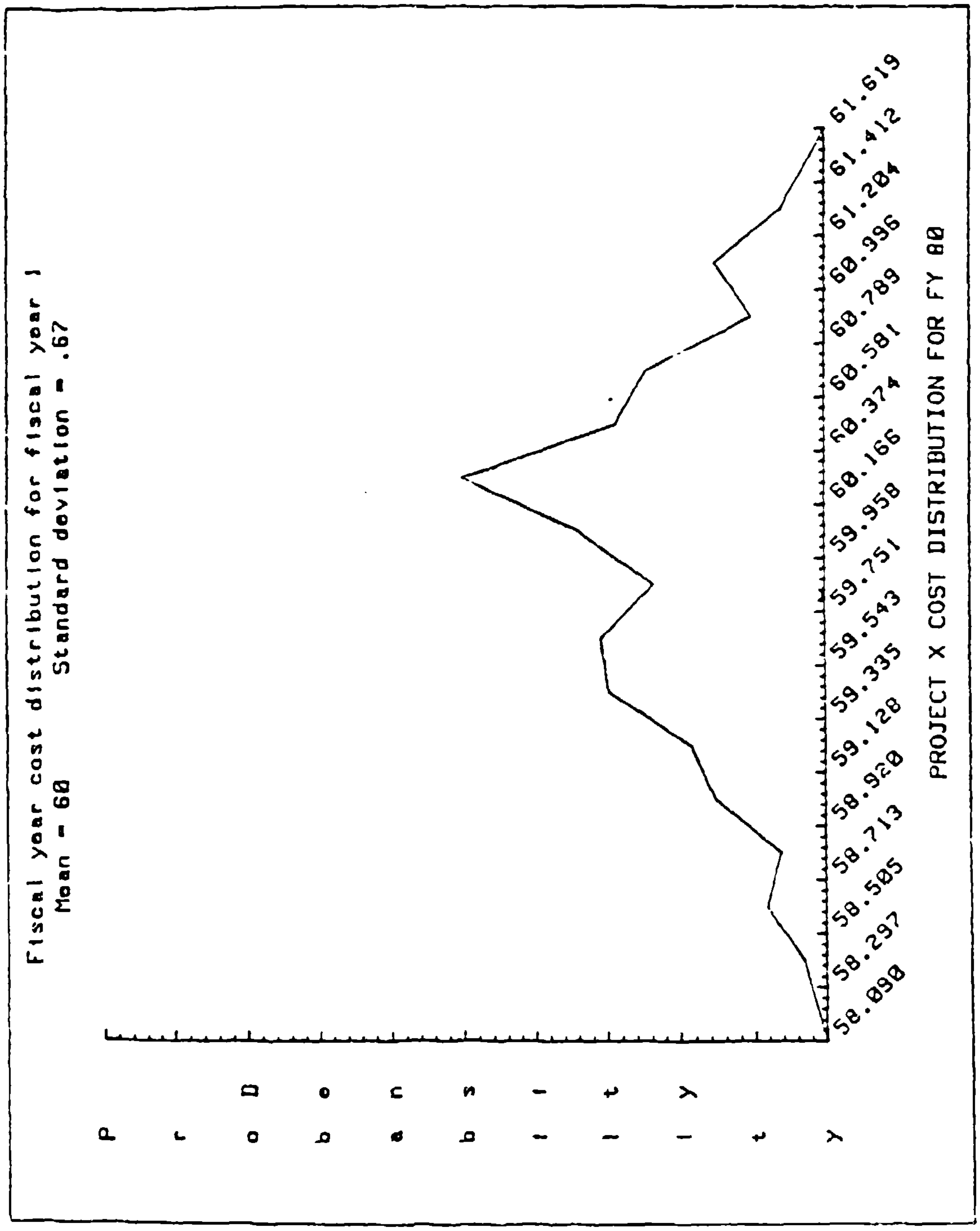
PROJECT X TRACE NETWORK INPUT DATA

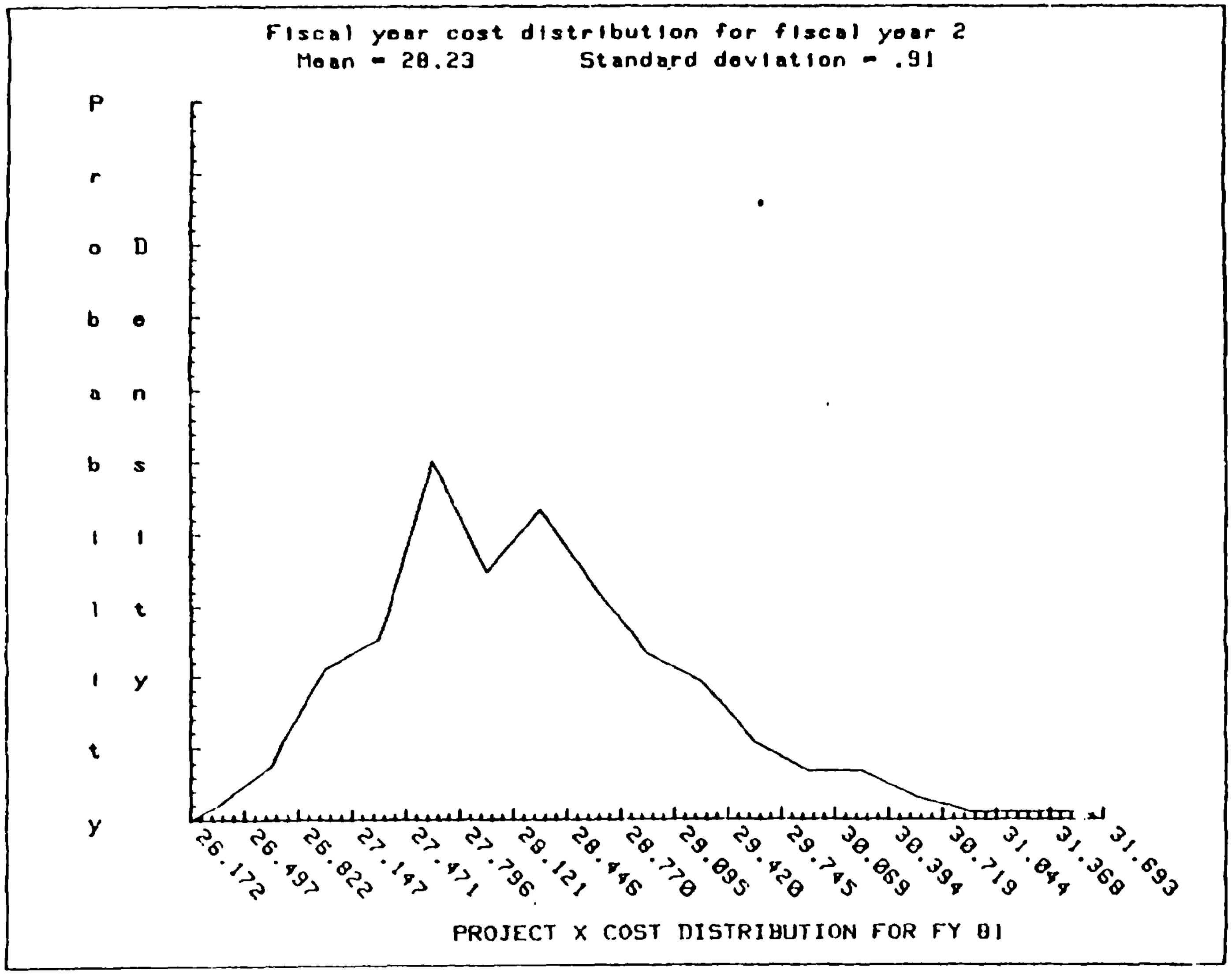
Act #	Activity Description	Cost ($K) a=fixed b=variable	Schedule (months)
140	Prog Mgt (BAC/HAC)	a = 0 b = 125.0; 131.0	t = 11.0; 13.0; 15.0
141	Sys Engr & Test Support (HAC)	a = 0 b = 125.0; 131.0	t = 8.0; 10.0
142	ILS	a = 0 b = 70.3; 10.9	t = 7.0; 9.0
143	M DEMO	a = 0 b = 15.0; 17.5	t = 3.0; 4.0; 6.0
144	Contr/Mil Training	a = 0 b = 20.0	t = 3.0; 6.0
145	Mil Training	a = 0 b = 2.0	t = 2.0; 3.0
146	Gov't Management & Administration	a = 0 b = 90.0; 115.5	t = Con't to OSD Review
147	Gov't Management & Administration	a = 0 b = 90.0; 115.5	t = Con't to Termination
148	PDEP's Full Up Final Copy (Preliminary Draft Engr Plan)	a = 0 b = 178.3	t = 7

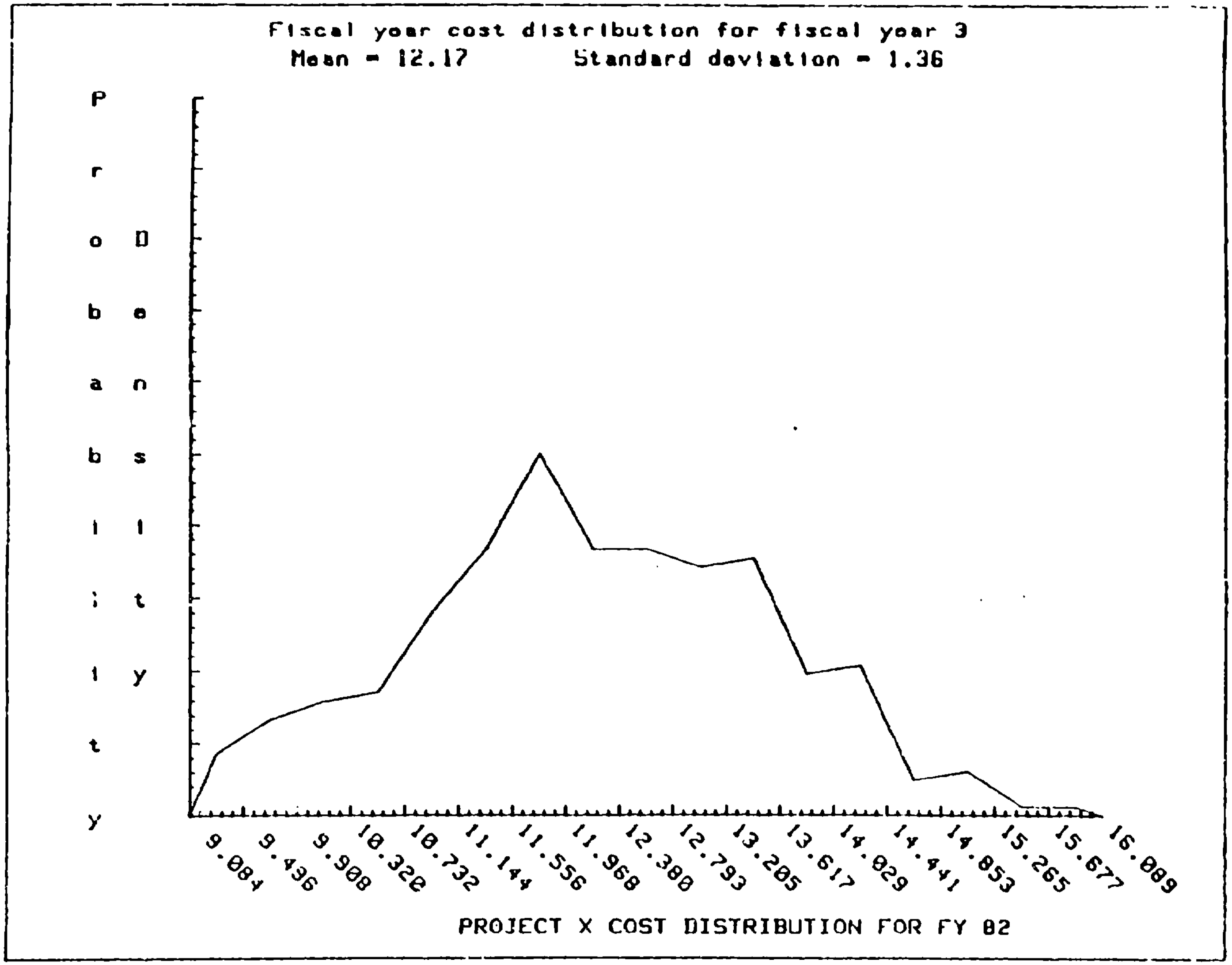
APPENDIX D

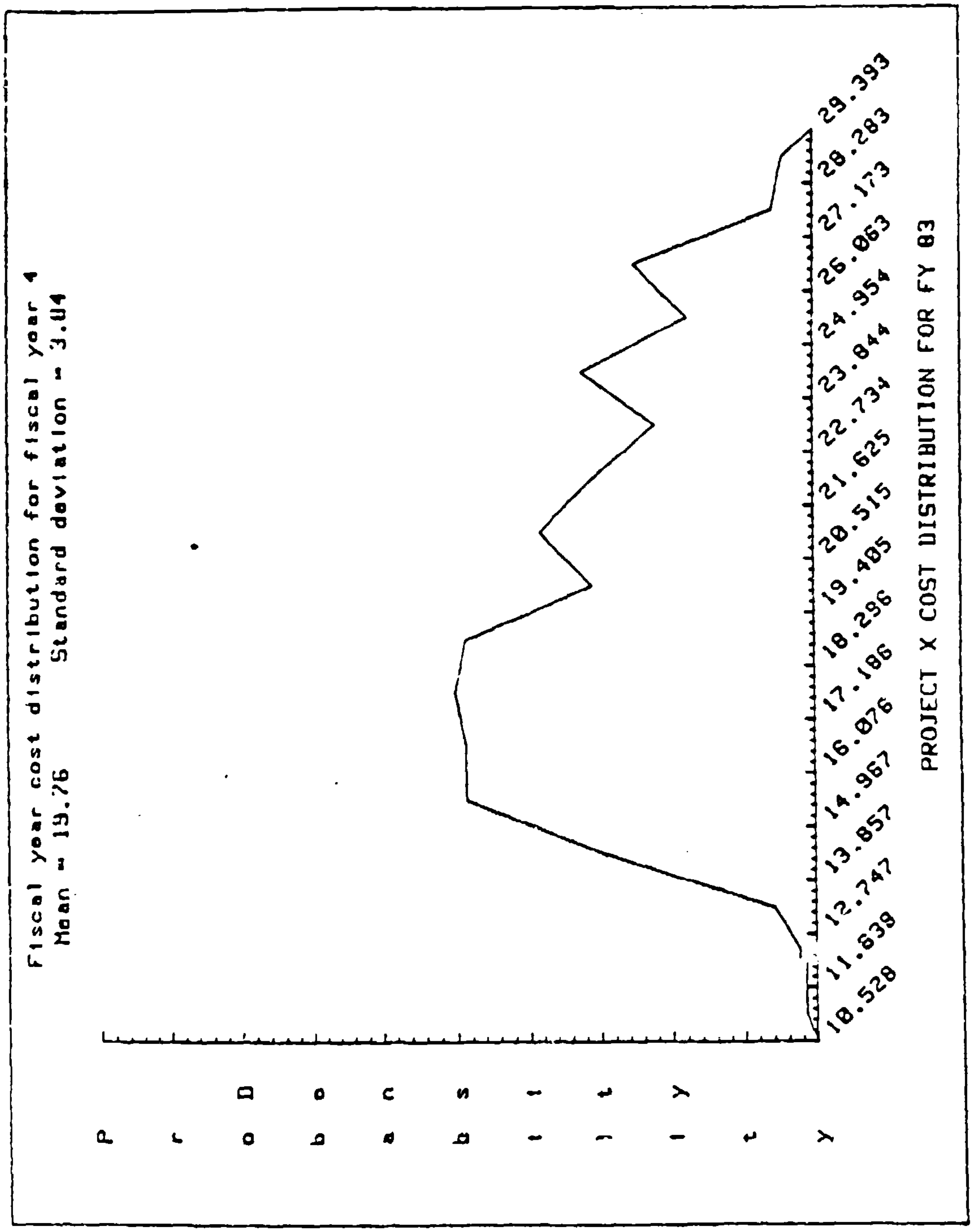
TRACE COST/SCHEDULE OUTPUT DATA FOR PROJECT X NETWORK ANALYSIS (10)

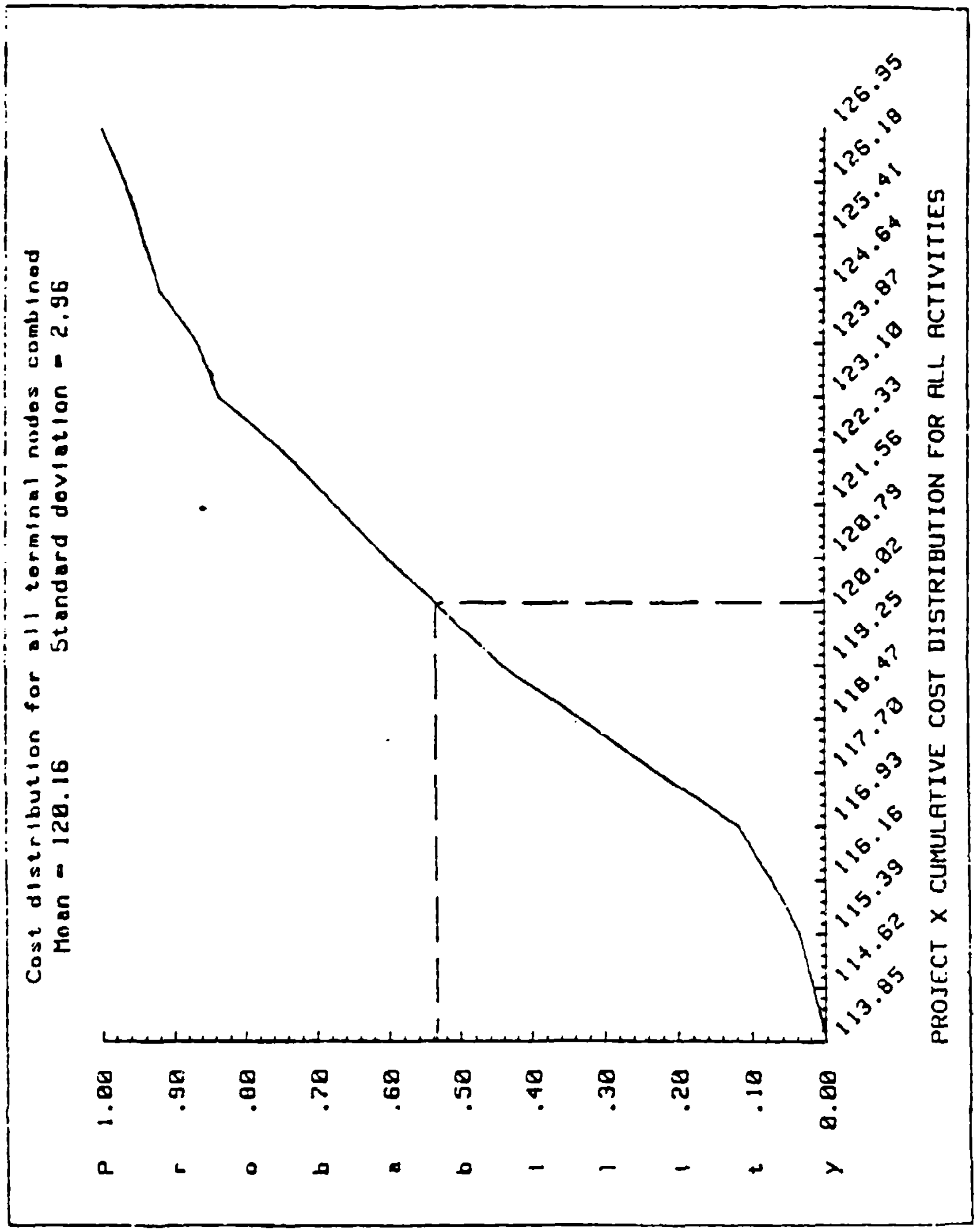

Cost distribution for all terminal nodes combined
Mean = 120.16
Standard deviation = 2.96
Probability Density
113.85
114.62
115.39
116.16
116.93
117.70
118.47
119.25
120.02
120.79
121.56
122.33
123.10
123.87
124.64
125.41
126.18
126.95
PROJECT X COST DISTRIBUTION FOR ALL ACTIVITIES


Fiscal year cost distribution for fiscal year 1
Mean = 60
Standard deviation = .67
Probability Density
58.090
58.297
58.505
58.713
58.920
59.128
59.335
59.543
59.751
59.958
60.166
60.374
60.581
60.789
60.996
61.204
61.412
61.619
PROJECT X COST DISTRIBUTION FOR FY 80

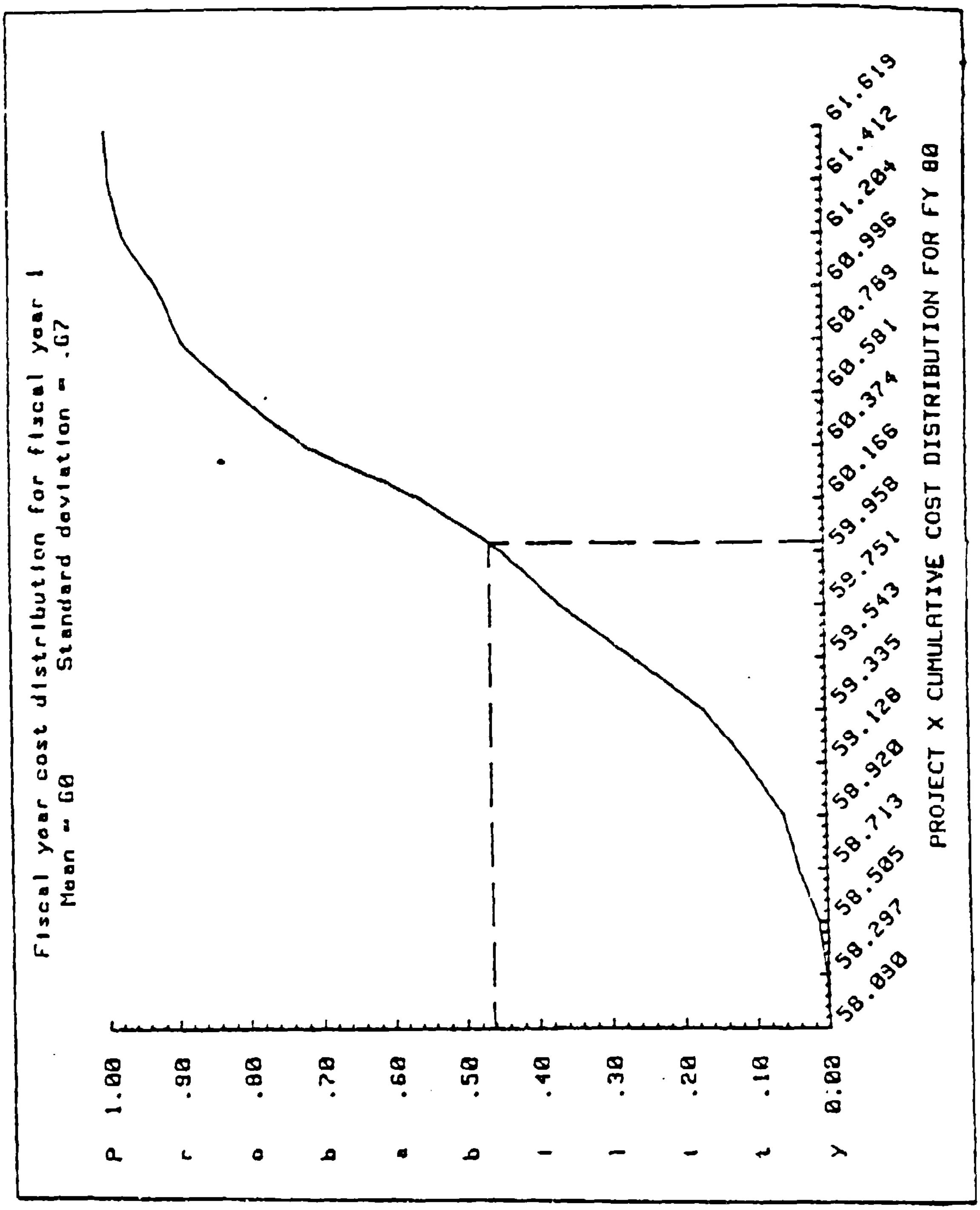

Fiscal year cost distribution for fiscal year 2
Mean = 28.23
Standard deviation = .91
Probability Density
26.172
26.497
26.822
27.147
27.471
27.796
28.121
28.446
28.770
29.095
29.420
29.745
30.069
30.394
30.719
31.044
31.368
31.693
PROJECT X COST DISTRIBUTION FOR FY 81

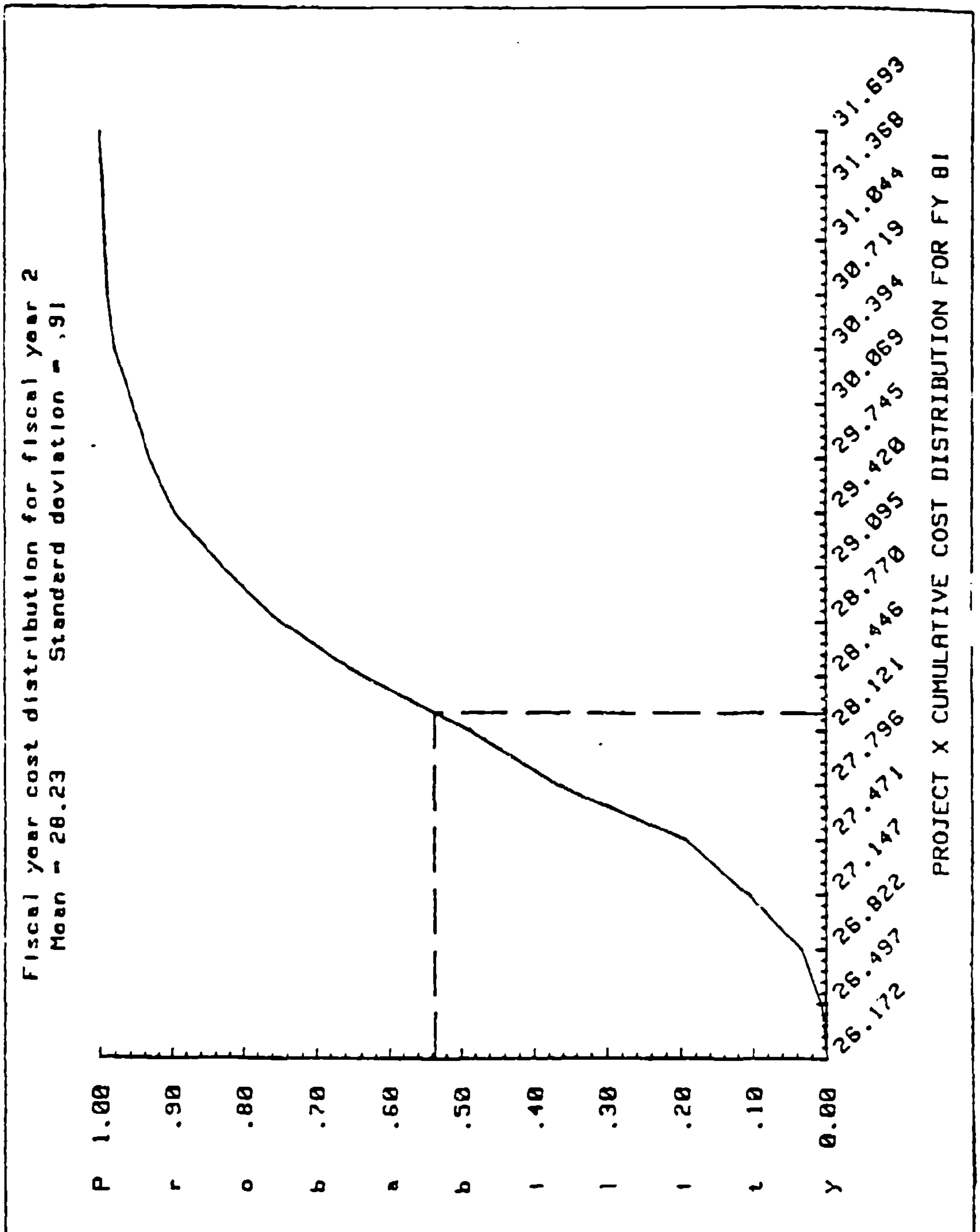

Fiscal year cost distribution for fiscal year 3
Mean = 12.17
Standard deviation = 1.36
Probability Density
9.084
9.496
9.908
10.320
10.732
11.144
11.556
11.968
12.380
12.793
13.205
13.617
14.029
14.441
14.853
15.265
15.677
16.089
PROJECT X COST DISTRIBUTION FOR FY 82

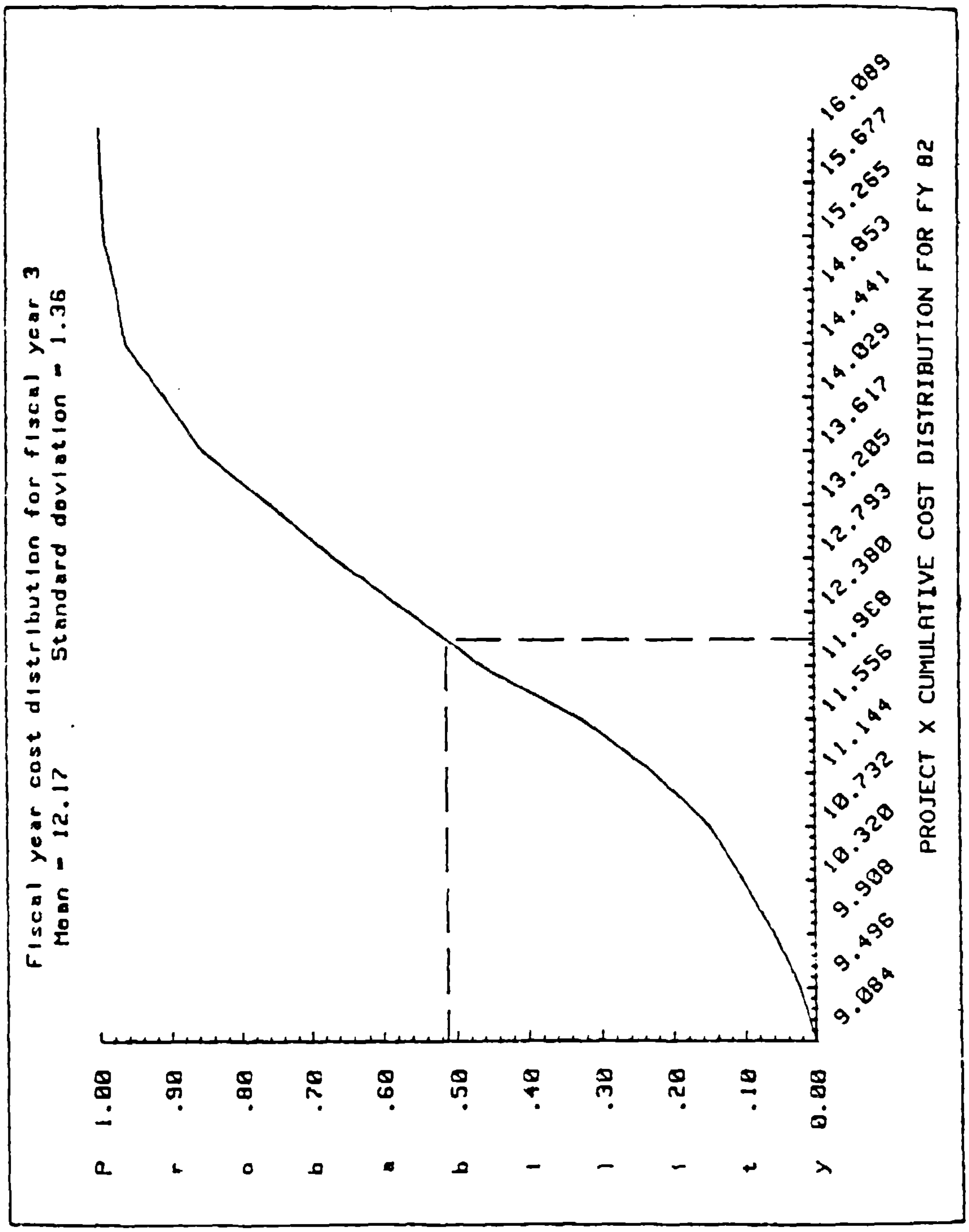

Fiscal year cost distribution for fiscal year 4
Mean = 19.76
Standard deviation = 3.04
Probability Density
10.528
11.638
12.747
13.857
14.967
16.076
17.186
18.296
19.405
20.515
21.625
22.734
23.844
24.954
26.063
27.173
28.283
29.393
PROJECT X COST DISTRIBUTION FOR FY 83



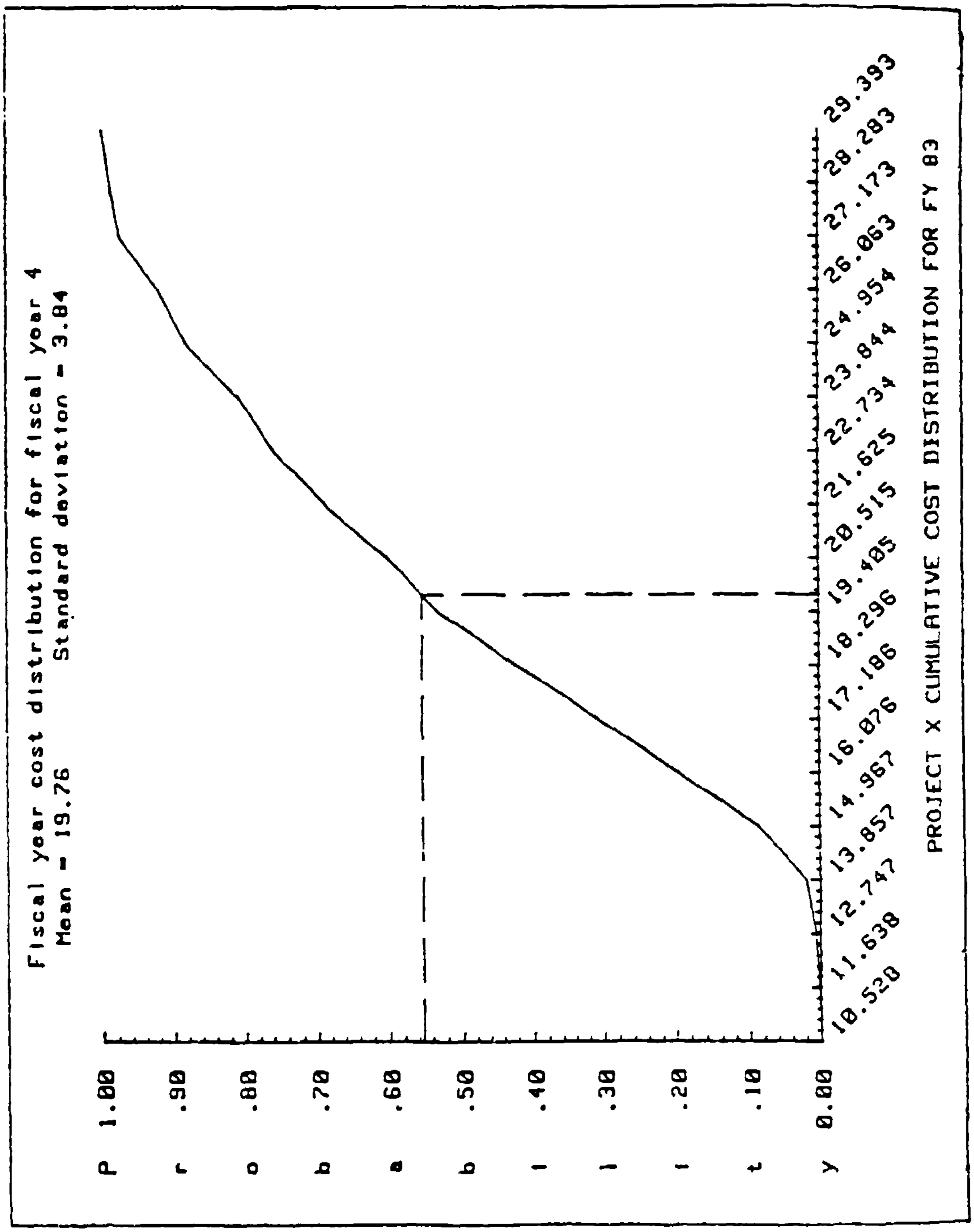
Cost distribution for all terminal nodes combined
Mean = 120.16
Standard deviation = 2.96
Probability
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.00
113.85
114.62
115.39
116.16
116.93
117.70
118.47
119.25
120.02
120.79
121.56
122.33
123.10
123.87
124.64
125.41
126.18
126.95
PROJECT X CUMULATIVE COST DISTRIBUTION FOR ALL ACTIVITIES


Fiscal year cost distribution for fiscal year 1
Mean = 60
Standard deviation = .67
Probability
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.00
58.090
58.297
58.505
58.713
58.920
59.128
59.335
59.543
59.751
59.958
60.166
60.374
60.581
60.789
60.996
61.204
61.412
61.619
PROJECT X CUMULATIVE COST DISTRIBUTION FOR FY 80

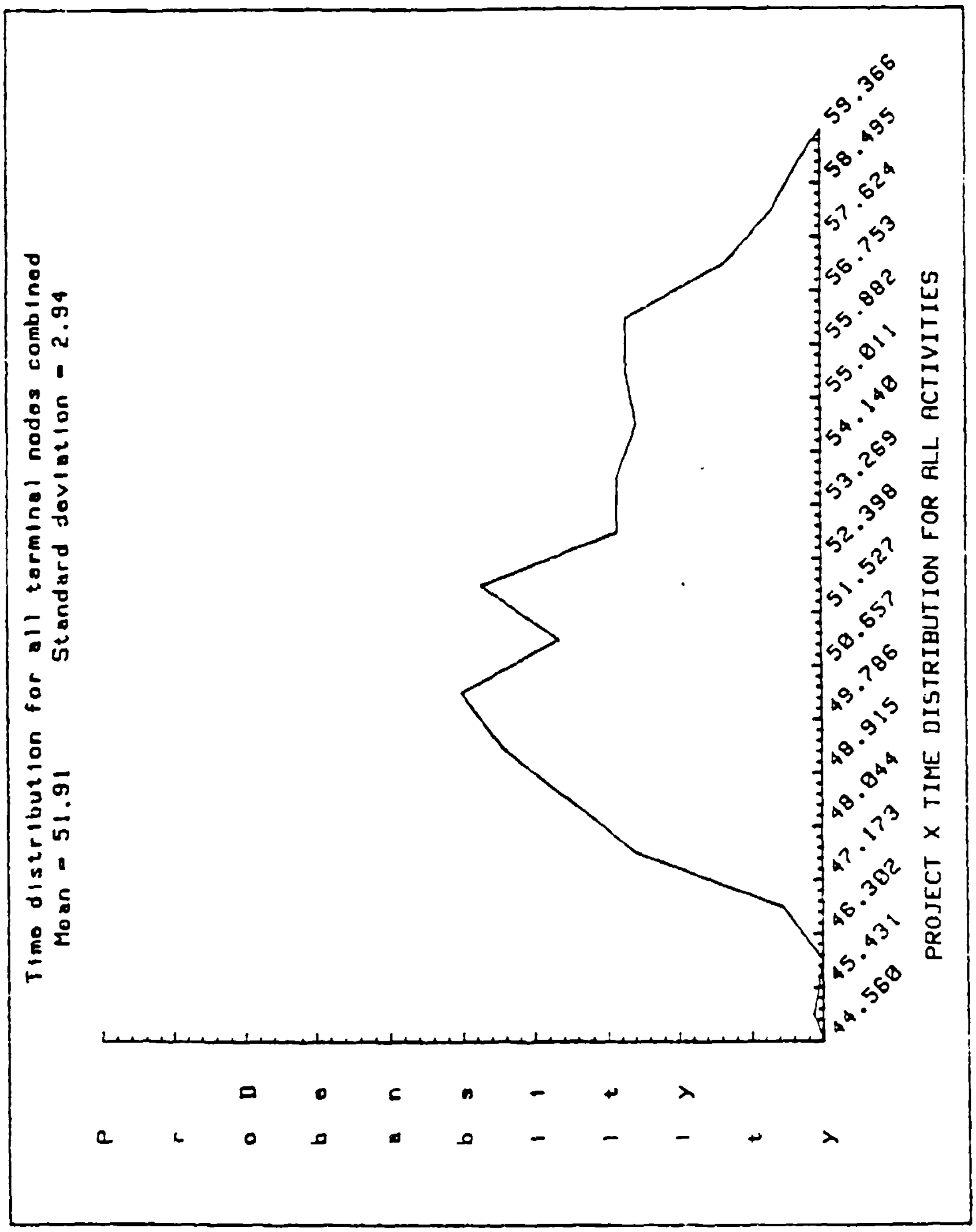

Fiscal year cost distribution for fiscal year 2
Mean = 28.23
Standard deviation = .91
Prob a b i l i t y
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.00
26.172
26.497
26.822
27.147
27.471
27.796
28.121
28.446
28.770
29.095
29.420
29.745
30.069
30.394
30.719
31.044
31.368
31.693
PROJECT X CUMULATIVE COST DISTRIBUTION FOR FY 81

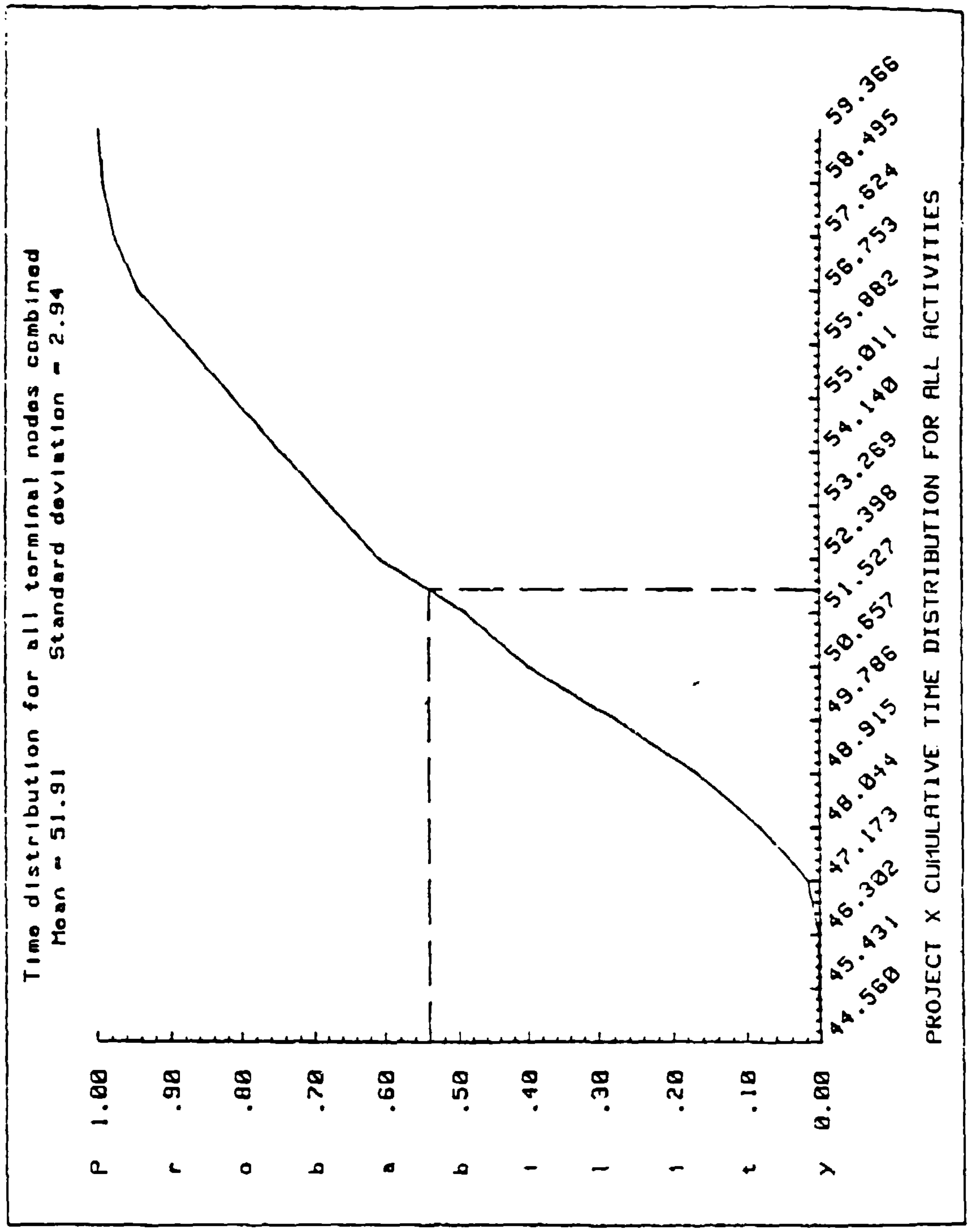


PROJECT X CUMULATIVE COST DISTRIBUTION FOR FY 82



Fiscal year cost distribution for fiscal year 4
Mean = 19.76
Standard deviation = 3.84
Probability
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.00
10.520
11.638
12.747
13.857
14.967
16.076
17.186
18.296
19.405
20.515
21.625
22.734
23.844
24.954
26.063
27.173
28.283
29.393
PROJECT X CUMULATIVE COST DISTRIBUTION FOR FY 83


Time distribution for all terminal nodes combined
Mean = 51.91
Standard deviation = 2.94
Probability
44.560
45.431
46.302
47.173
48.044
48.915
49.786
50.657
51.527
52.398
53.269
54.140
55.011
55.882
56.753
57.624
58.495
59.366
PROJECT X TIME DISTRIBUTION FOR ALL ACTIVITIES


Time distribution for all terminal nodes combined
Mean = 51.91
Standard deviation = 2.94
Probability
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.00
44.560
45.431
46.302
47.173
48.044
48.915
49.786
50.657
51.527
52.398
53.269
54.140
55.011
55.882
56.753
57.624
58.495
59.366
PROJECT X CUMULATIVE TIME DISTRIBUTION FOR ALL ACTIVITIES

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AUTHOR BIOGRAPHICAL SKETCH

Captain Woodward enlisted in the U. S. Navy in 1964 and flew as an aircrew member on SP-2H "Neptune" aircraft. He qualified as an Anti-Submarine Warfare Technician. After serving four years on active duty, he attended Brigham Young University in Provo, Utah and graduated in 1972 with a B. S. in Mechanical Engineering. He spent the next six years working in the field of plant engineering in various industries including nuclear waste reprocessing. He graduated from Officer Training School in October 1978 as a Second Lieutenant and was sent to HQ USAFE, Ramstein AB, Germany. There he functioned as a liaison to the various NATO countries. His duties included the evaluation and certification of bomb handling ground support equipment, USAFE representative at the Tornado (MRCA) POM, providing mechanical engineering support to NATO owned F-104 aircraft, and as a aircraft nuclear weapon compatibility engineer. Captain Woodward is married to the former Beverly J. Coil and has four children--David, Gregory, Jonathan, and Amy.