MANAGEMENT OF RISK AND UNCERTAINTY IN SYSTEMS ACQUISITION

Proceedings of the 1983 Defense Risk and Uncertainty Workshop

COMPONENT PART NOTICE

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P002 315	Experiences and Lessons Learned in Project Risk Management.
P002 316	A Linguistic Approach to the Construction of Expert Systems.
P002 317	Risk Management in a Multiobjective Decision-Making Framework.
P002 318	Implementation of Risk Information into the DoD Decision Making Structure.
P002 319	Issues Involving Uncertainties in Defense Acquisition and a Method for Dealing with Them.
P002 320	Risk Analysis Training within the Army: Current Status, Future Trends.

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P002 323	Quantitative Techniques for DARPA Program Risk Management.
P002 324	Two Modes of Decisionmaking.

1983 Defense Risk and Uncertainty Workshop

Developed and Conducted by
the U.S. Army Materiel Systems Analysis Activity
and
the U.S. Army Logistics Management Center

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Fort Belvoir, Virginia

July 13 - 15, 1983

Edited by
Robert F. Williams
Richard D. Abeyta

THEME: MANAGEMENT OF RISK AND UNCERTAINTY IN SYSTEMS ACQUISITION

OBJECTIVE: REPORT ON STATE-OF-THE-ART TECHNIQUES AND EXCHANGE INFORMATION ON RISK AND UNCERTAINTY IN DOD

PREFACE

I was privileged to kick off the Defense Risk and Uncertainty Workshop with a panel that speculated on how well DOD analysts and decision makers are handling risk and uncertainty. The problem is of course quite complex. It will take a lot of good people and a lot of good ideas to improve our analysis and decision making processes.

A forum such as this one serves to surface ideas in a very efficient manner. You will note in these proceedings a number of different approaches in handling risk and uncertainty. All of these papers were subject to the critique of peers in the various panels of the workshop, and I feel this peer group interaction ultimately provides the greatest benefit to the attendees.

To those of you not at the workshop I commend these proceedings to your attention. To the participants--continue the dialogue.

Walter W. Hollis
Deputy Under Secretary of the Army
(Operations Research)

WORKSHOP SUMMARY

The Department of Defense has embarked on a modernization program unprecedented since World War II. The sophistication and complexity of emerging weapon systems have rendered managerial as well as technical decisions exceedingly difficult. As technological boundaries have expanded, the attendant risk and uncertainty of defense acquisition programs have also expanded. Morever, in this fast-paced environment, the state-of-the-art in managing risk and uncertainty has not kept pace with the state-of-the-art in technology. Often the result has been cost overruns and schedule slippages.

The first step in managing risk and uncertainty is to admit that they exist. This has been partially accomplished and is evidenced by numerous references to risk and uncertainty in DOD literature. In 1969, Deputy Secretary of Defense, David Packard, wrote a memorandum to the military services in which he listed inadequate risk assessment as one of five major problem areas in system acquisition. Since that time, slow but steady progress has been made. DOD Directive 5000.1 and DOD Instruction 5000.2, the top acquisition policy documents, have gradually become more specific in their requirement that risk analysis must be included as an integral part of the acquisition process. More recently, the DOD Acquisition Improvement Program that evolved from the 1981 Carlucci Initiatives directed the military services to estimate most-likely costs and budget for risk. A result of all this high level recognition has been the development and implementation of such concepts as Decision Risk Analysis (DRA) and Total Risk Assessing Cost Estimates (TRACE). A basic legitimacy has been established and a framework is now in place to permit development and application of new methodologies.

This workshop is the third gathering of the risk analysis community to specifically address acquisition. The first was hosted in February 1979 by the University of Southern California and was not limited to the Defense environment. The second was co-sponsored in February 1981 by USC and the Air Force Business Research Management Center and became more defense-oriented. Based on the success of the two previous conferences, this third workshop was commissioned by the Defense Acquisition Research Council and hosted by the Army. The workshop in effect has evolved into a biannual Defense activity.

The theme of this year's Workshop was "Management of Risk and Uncertainty in Systems Acquisition" and the general objectives were to report on state-of-the-art techniques and exchange information on risk and uncertainty in DOD. It was called a workshop rather than symposium to emphasize an interactive environment in which maximum participation and discussion were encouraged.

The format of the workshop was based on two concurrent tracks, one focusing on Quantitative Risk Analysis, and the other on Managerial Use of Risk Analysis. Each track consisted of five panels, each with a panel chairman and two to four presenters. Additionally, there were three plenary sessions with presentations of general interest to the entire body. At any given time, there were at most two concurrent speakers. This enabled the participants to attend and contribute to a variety of different discussions. Computer demonstrations on risk software were also given by various experts by appointment.

The participants in the workshop included representatives from each of three military services and DOD staff, private industry and academia. Panel chairmen, speakers, and general attendees were all carefully selected from among experts in the field. This broad spectrum of viewpoints and experience assured a healthy exchange of information.

The program started, continued, and finished strong with outstanding plenary speakers. After introductions by the Workshop Chairman and the Acting Commandant, COL Forburger, the opening address was conducted by Dr. Alan J. Rowe, USC, who had chaired and co-chaired panels in the two previous Workshops. This was followed by a plenary panel consisting of senior level decision makers, Mr. Hollis of the Army, Dr. Shoup of the Navy, and Mr. Thomas of the Air Force, who made presentations and answered questions from the audience. To start off the second day, Mr. Bowers, the Chief Executive, Sanders Associates and former Assistant Secretary of the Navy (Installations and Logistics), delivered an informative and provocative presentation on the sharing of risk between Government and Industry. The final two speakers, Dr. Cetron, from Forecasting International, and Dr. Hurta, of the Naval War College, rounded out the program. Dr. Cetron talked about the uncertainties of the future. Dr. Hurta chaired a practical clinic on the analyst's difficulties in working with decision makers.

The ten workshop panels were where most of the work took place. Outstanding experts presented papers on a variety of germane topics, of a practical as well as theoretical nature. These sessions were informative, spirited and displayed a great deal of interaction between the participants. The two objectives of the workshop, to "report" and to "exchange information" were unquestionably achieved.

This workshop not only achieved its objectives but produced two important side benefits. It got representatives from the three military services and the private sector talking to each other in a frank and open manner. And, it surfaced controversial issues that require additional research, perhaps for the next workshop. The primary issues are the need to better translate theory into application and to break down the barrier that exists between analysts and decision makers. Theory is wasted unless it is translated into practical application and effectively communicated to senior level decision makers.

Finally, the need for periodic workshops of this nature is critical if we are serious about coming to grips with risk and uncertainty in systems acquisition. It is only by talking to each other, sharing information, and surfacing issues that we can hope to advance the state-of-the-art.

Robert F. Williams

ROBERT F. WILLIAMS, Ph.D.
Chairman, Defense Risk
and Uncertainty Workshop

Richard D. Abeyta

RICHARD D. ABEYTA
Administrative Chairman,
Defense Risk and
Uncertainty Workshop

The general objectives of this workshop were to report on state of the art techniques and exchange information on risk and uncertainty within the Department of Defense. Panel sessions covered these topics:

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0900 Greetings and Administration (Abilene Room)

Robert F. Williams, Workshop Chairman
US Army Logistics Management Center

COL Thomas V. Forburger
Acting Commandant, Defense Systems Management College

0915 Opening Address: History of Risk and Uncertainty Research in DOD

Alan J. Rowe, University of Southern California
(Co-author - Ivan A. Somers, Hughes Aircraft)

1000 Plenary Panel: The Theoretical vs. the Real World

Chairman, Walter W. Hollis, Deputy Under Secretary of the Army (Operations Research)
Panelist, Clayton J. Thomas, Scientific and Technical Advisor, Assistant Chief of Staff Studies & Analyses (Air Force)
Panelist, Frank E. Shoup, Deputy Director for Studies and Analyses, Program Planning Office (Navy)

1045 Coffee

1100 Plenary continued

1200 Lunch

1300 Commence Split Sessions

Methods and Models I (CR A)

Chairmen, Erwin M. Atzinger
Army Materiel Systems Analysis Activity and Robert M. Stark, University of Delaware

Robert M. Love
Lockheed Aircraft Corp.
Decision Analysis Project at Lockheed

John K. C. Woo
Naval Sea Systems Command
Quantitative Risk Analysis of Impact of Major Changes on Navy Programs

Budgeting and Contracting Risk (CR B)

Chairman, Michael Fiorillo
Naval Air Systems Command

E. G. Ingalls
Defense Systems Management College
Risk Assessment Techniques for Budgeting in Defense Systems Acquisition Management

Paul E. Grover
US Army Logistics Management Center
Total Risk Assessing Cost Estimate for Production (TRACE-P): Will History Repeat Itself?

Vincent Alfieri
US Army Communications-Electronics Research & Development Command,
Procedures for Modeling TRACE-P Estimates

William Waymire
US Army Aviation Research and Development Command
The RPV Project Manager Manages His Program Risks

1445 Coffee

1500 Computer Aids in Decision Making (CR A)

Chairman, Gerald Moeller
US Army Armament Materiel Readiness Command

George H. Worm, Consultant
Concept for Interactive Risk Analysis

Curtis Farrell
Martin Marietta
A Manager Oriented Micro Processor Hosted Program

Ann Martin
Decisions and Designs, Inc.
Decision Aids for Resolving Uncertainty

Ivan A. Somers
Hughes Aircraft
Causal Integrative Model (CIM)

Management View of Acquisition Risk I (CR B)

Chairman, John D.S. Gibson
Air Force Systems Command

Guy E. Jette
Air Force Systems Command
Addressing Risk & Uncertainty in Cost Estimating

Jules J. Bellaschi
Deputy Director, Plans, Analysis & Evaluation (Army)
Weapon System Cost Risk Reviews

Richard J. Baker
US Army Materiel Development and Readiness Command
Budgeting for Technological Risk in Procurement

1700 Close

Thursday, 14 July

0830 Plenary Paper: The Equitable Sharing of Risk Between Defense and Industry (Abilene Room)

Jack L. Bowers, CEO, Sanders Associates, Inc.

0930	<u>Methods and Models II (CR A)</u>	<u>Behavior Under Risk and Uncertainty (CR B)</u>
	Chairman, Kneale T. Marshall Naval Postgraduate School	Chairman, Robert F. Williams US Army Logistics Management Center
	Robert Black Grumman Aerospace Corporation <u>Approximately Bounded Cost Risk Regions</u>	T. O. Jacobs Army Research Institute for the Behavioral and Social Sciences <u>Cognitive Correlates of Behavior Under Conditions of Uncertainty</u>
	Alan D. Kazanowski The Aerospace Corporation <u>A Quantitative Methodology for Estimating Total System Cost Risk</u>	Ralph Swalm Syracuse University <u>The Contribution of Cardinal Utility to Real Life Decisions</u>
		Roy M. Gulick Decisions and Designs, Inc. <u>A Framework for Risk Assessment: Uncertainty, Consequence, and Decision</u>
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1100	Split Sessions continued	
1200	Lunch	
1300	<u>Risk Analysis: Implications For Acquisition (CR A)</u>	<u>Management View of Acquisition Risk II (CR B)</u>
	Chairman, William D. Rowe Institute for Risk Analysis, American University	Chairman, David D. Acker Defense Systems Management College
	William D. Rowe Institute for Risk Analysis, American University <u>Risk Analysis: A Top Down View</u>	Lewis R. Ireland SWL, Inc. <u>AN/SAR-8 Risk Management Model</u>
	John S. Gardinier US Coast Guard <u>Successful Risk Management: A Concept</u>	MAJ Waldon R. Kerns Air Force Business Research Management Center (Co-author CAPT Michael C. Tankersley) <u>Application of Risk Analysis: Response from a Systems Division</u>
		A.M. Feiler Log/An, Inc. <u>Experiences and Lessons Learned in Project Risk Management</u>

1430 Coffee

1445 Advanced Theory (CR A)

Chairman, Jerome H. N. Selman
Engineering Research Associates, Inc.

Ronald R. Yager
Machine Intelligence Institute
Iona College
A Linguistic Approach to the Representation of Risk & Uncertainty in Expert Systems

Yacov Y. Haimes
Case-Western University
Risk Management in a Multi-Objective Decision-Making Framework

Alvin W. Drake
Massachusetts Institute of Technology
The Uncertainty Importance of Components in Fault Trees

Issues in Risk and Uncertainty (CR B)

Chairman, Richard D. Abeyta
Army Materiel Systems Analysis Activity

John M. Cockerham
John M. Cockerham and Associates, Inc.
Implementation of Risk Information into the DOD Decision-Making Structure

Bernard H. Rudwick
Planning Research Corporation
Properly Including Risk when Evaluating System Alternatives

Joseph G. King
US Army Logistics Management Center
Risk Analysis Training Within the Army: Current Status, Future Trends

1645 Close

Friday, 15 July

0830 Plenary Paper: Uncertainties of the Future (Abilene Room)

Marvin J. Cetron, Forecasting International

0930 Plenary Paper: Problems in Applications

Donald W. Hurta, Naval War College

1015 Coffee

1045 Plenary continued

1130 Closing Summary

Robert F. Williams
U.S. Army Logistics Management Center

1200 Close

OPENING ADDRESS

HISTORY OF RISK AND UNCERTAINTY RESEARCH IN DOD

HISTORY OF RISK AND UNCERTAINTY RESEARCH IN DOD

Alan J. Rowe, Ph.D.
Univ. of So. Cal.
Los Angeles, CA.

Ivan A. Somers, Ph.D.
Hughes Aircraft Co.
El Segundo, CA.

INTRODUCTION

The Department of Defense has had a continuing concern regarding the management ot risk and uncertainty and has supported considerable ettort in an attempt to tind appropriate approaches to dealing with the problem. In part, the ditticulties that arise are a result ot the military's desire for maximum performance which involves high technology, often at an advanced state-ot-the-art. The uncertainty ot congressional tunding and contractual constraints and the lack of definition in the introduction of new weapon systems also contribute to program risk and uncertainty. Since risk and uncertainty will not disappear, it is requisite that the management ot the weapons acquisition process address take these factors.

The Government, as is evident by O.M.B. circular A-109, identified the need to deal with risk end to have alternative system designs submitted for evaluation. Department of Detense Directive 5000.3 states that test and evaluation should be conducted throughout the acquisition process to assess and reduce acquisition risk.

The objective ot this paper is to trace the significant approaches that have been taken in dealing with the risk and uncertainty associated with military acquisitions. From this perspective, direction for future effort will be identified.

RESEARCH TRAIL

Early work in the tield ot risk and uncertainty was done primarily at the RAND Corporation. In addition, each ot the services conducted studies on how best to deal with the problem. The major efforts that were undertaken will be reviewed along with an evaluation of their contributions.

Cochran (1) was one ot the tirst to recognize the combined effect ot concurrency, technological uncertainty, and contractural urgency on risk and uncertainty. He proposed an approach called Disruption Theory which attempted to predict the degree of uncertainty in a given program. As a result of his efforts, the first symposium on the management of risk and uncertainty in the acquisition process was held in 1979 at the University ot Southern Calitornia.

Major General Dewey Lowe, at the 1979 symposium, reviewed an Air Force Study of seven major aircraft systems including the B1, F15, F16, A10, E3A, E4 and EF111A. This study revealed a consistent improvement in the ability to control program cost growth. Starting in the 1950's, major system cost growth exceeded 200%, while systems suttered trom high risk, poor definition, and low visibility. In the 60's, risk was moderate, definition was better, total package procurement and concurrency was used, and cost growth was between 100% and 200%. The 70's witnessed growth of less than 100% with the application ot prototypes, change controls and Detense System Acquisition Review Council. When adjusted for intlation, the approximately 90% growth rate ot the 70's was really a 30% rate in base-year dollars. General Lowe estimates that as much as 70-80% ot cost overrun was caused by intlation.

A second symposium was held in 1981 at the Air Force Academy which dealt with defining the state-of-the-art in the management ot risk end uncertainty. The current workshop on Defense Risk and Uncertainty at Defense Systems Management College is a recognition ot the continuing importance ot the subject to the acquisition community.

Finally, the current success with a Causal- Integrative Computer Model will be used to help identify tuture directions that can profitably be taken to "manage risk and uncertainty"

BACKGROUND

Because of the complexity of the acquisition process, the definition of risk has tended to be associated almost exclusively with the technology involved and to ignore the management aspects ot the problem. Admiral Freeman (2) stated that we tend to blame acquisition problems on technical uncertainty or technical change; whereas, what is needed is a manager who is emotionally capable ot managing uncertainty and who has the ability of taking the risk of making decisions based on judgement with access to limited or suspect data.

General Thurman (3) supported this position in his statement regarding the planning for uncertainty and risk assessment. "Managers are expected to collect, weigh tacts and probabilities, make optimal decisions and see that they are carried out. However, in development projecta, a clear sequence is not possible because ot the extended duretion, the many technical unknowns, the continual discovery of new tacts, and the changing constraints and pressures." Protessor Winkler (4) extended this further by hia concern for the problem of reaching agreement with respect to competitive and group decision processes and the role ot information and the impact ot organization structures in situations with multiple decision makers. Dr. Kerns (5) identifies two distinct aspects ot risk and uncertainty as involving both correct technical analysis and acceptance and implementation of the results. Given this perspective, the complexity of the risk end uncertainty problem becomes apparent.

A TAXONOMY OF RISK APPROACHES

In order to review profitably the developments in the field, the following four fectors are suggested:

1. Estimation - The ability to forecast, predict or identify the risk involved.
2. Perception - The manager's skill in recognizing risk and applying judgement to finding enswers.
3. Impact - The consequences eppliceble to situations Involving risk and to determination of the level of vulnerebility.
4. Management - The knowledge end ettitude required to implement risk taking decisions.

Keeney (6), in his article on decision enalysis, identifies a number of factors which contribute to the complexity of decision problems. These include: multiple objectives, difficulty of identifying good elternatives, intangibles, long-time horizons, many impacted groups, risk and uncerteinty, risks to life and limb, interdisciplinary aspects, severel decision makers, value tredeoffs, risk attitude, and the sequentiel neture of decisions. He summarizes these fectors into four categories which he states are characteristic of complex decision problems:

1. They involve high stekes
2. They heve compliceted structure
3. There ere no overall experts
4. There is need to justify the decisions

He concludes that at one extreme intuition end informality may be used while at the other extreme, models are needed to capture the full complexity of the problem.

If the problem of risk end uncertainty is looked at in terms of the ability to manage and the impact of the decision, the following two tebles can be constructed:

TABLE 1. IMPACT OF RISK ON PAYOFF

LEVEL OF RISK	MANAGEMENT COMPLEXITY: LOW	MANAGEMENT COMPLEXITY: HIGH
HIGH	USE OF FORECASTS, PERT	PREDICTIVE MODELS, SIMULATION
LOW	ESTIMATES OR PRIOR EXPERIENCE	DECISION SUPPORT SYSTEMS

SP-1S88

TABLE 2. MANAGEMENT APPROACHES TO RISK

LEVEL OF RISK	IMPACT: LOW	IMPACT: HIGH
HIGH	HIGH RISK, BUT CAN BE CONTROLLED	VULNERABLE, DIFFICULT TO CONTROL
LOW	LOW RISK, MODERATE PAYOFF	LOW RISK, HIGH PAYOFF

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An examination of the texonomy of epproeches to risk and uncerteinty and the two tables shown ebove, indicates clearly that additional research is needed to integrate these factors with the other aspects of the acquisition process such as contracting, pricing, etc. For example, Carlucci (7) in a memo to secreteries of military departments ceutions, "It makes little sense to place unreasonable risk upon industry by meens of firm commitments negotieted at high prices, but unenforceable in practice or in fact."

DESCRIPTION OF THE ACQUISITION PROCESS

Any description of the acquisition process is, at best, only a static representation of an extremely complex set of interdependent activities. The matrix shown in Figure 1 (8) is suggested as e basis for understending ceusality. For example, internal control assumes all things are known and controllable with estimates besed on past date, prccedures, designs, etc. The other three categories, however, represent the reelity in mejor acquisition end are otten overlooked.

Although Figure 1 does not reflect tne dynamics and interactions that occur in an on-going organization, it does illustrates a number of key concepts that will be developed in the report. The linkeges between the four basic uncertainty variables end acquisition management help to define the processes, or activities thet contribute to the uncertainty of acquisition management. The four basic uncertainty variables considered are:

1. Internel Control: A measure of the organization's ability to perform the task requirements.
2. Customer Uncertainty: The time compression, concurrency, or degree of overlap betwen phese of development, and changes in scope.
3. Technological Uncertainty: A measure of the state-of-the-art end the degree of interdependency among system components.
4. Environmental Uncertainty The factors that cause disruption, delays, shorteges, failures, etc. that are not under the control of management in the acquisition process.

The variebles define e network of interdependencies which ultimately contribute to the uncertainty and the consequent problems in the acquisition process.

The categories shown in Figure 1 correspond to ones developed by the USAF Academy Risk Analysis Study Teem (9). The description of the USAF categories is as follows:

Internal Program Uncertainty: Deals with the way in which the program is organized, plannad and maneged.

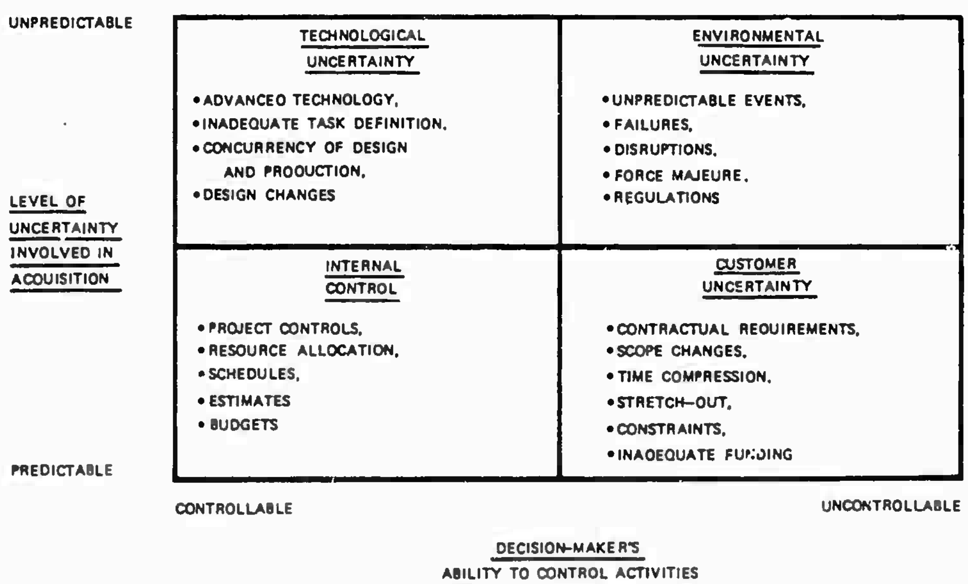

FIGURE 1. ACQUISITION UNCERTAINTY

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.

Technical 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.

Process Uncertainty: Deals with the sensitivity to changes in the extenal 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.

Target Uncertainty: Covers the uncertainty in meeting performance, cost or schedule goals and determination of needs. Uncertainty in translating abstract needs into concrete specifications. Problem of early estimates which are seldom revised.

Martin (10), in a paper on the relationship between cost and cost estimation, indicates that a cost estimate is at best a reasoned guess about a future outcome. The estimate requires judgment and therefore is subjective in nature. Furthermore, because cost estimates are probabilistic in nature and are valid only as long as the assumptions on which they were based remain the same, there is need to revise estimates in consideration of the uncertainty which exists. He points out that the level of uncertainty is very high in the early phases of an acquisition, in part due to the vagueness of system specifications. The uncertainty is reduced as information is obtained from testing and evaluation. The conclusion drawn is that mistakes are made using the wrong approach for the given phase of the acquisition cycle.

The conclusions drawn by Martin, are supported by studies which show that initial estimates seldom reflect the final cost. Davis (11) supports this finding in his analysis of uncertainty associated with cost estimating. He contends that lack of information contributes to the uncertainty of cost estimates. He also maintains that diffusion of authority and responsibility for cost estimating throughout the acquisition cycle complicates the process. Furthermore, short-fuse requirements impose severe time constraints and also contribute to estimating errors. He concludes that there is a need for greater flexibility in the acquisition of major systems in order to cope with program uncertainties. Single point estimates do not recognize the basic uncertainty involved in cost and a cost range would provide greater flexibility. Basically, he argues that cost overrruns will be a way of life unless consideration is given to the impact of program uncertainty on estimating.

In a study conducted at USC (12), six major programs were analyzed to determine the primary causes for cost growth, schedule shippage and performance degradation. Twenty-six factors were identified as specifically contributing to cost overruns.

Examination of the data from the many studies conducted reveals that there are no simple answers to reducing cost growth when dealing with the uncertainty inherent in the acquisition of programs. It would be unreasonable to prevent advances in state-of-the-art and changes in design to meet requirements that are determined during system test and evaluation. Furthermore, there will inevitably be some degree of concurrency during development, as well as overlap of authority because of multiple organizations involved in the process. There is little doubt that over-optimism in new designs leads to design changes and ultimately to cost overruns. Inflation, changing political and customer influences and environmental catastrophies will continue to plague the acquisition process. Low bidding, poor or inappropriate estimates, improper budgeting and cost control--all contribute to the problem.

The importance of uncertainty as a cause of overruns has been documented by the RAND studies (13), which after over twenty years of studying complex development programs in the U.S. and abroad concluded that:

> "High system cost growth appears to arise primarily from efforts to subdue difficult technology on highly compressed schedules... (and the) acceptance of optimistic assumptions about the long-term predictability of technology and the cost of coping with it."

For example, in describing system acquisition experience, Perry (14), points out that initial estimates tend to be overly optimistic and do not consider, or understate, technological difficulties actually encountered in program development. As a consequence, these difficulties which lead to increases in total program costs are seldom accounted for early in a program. He found that, in nearly all cases, renegotiated contracts were much closer to actual performance requirements and that this was reflected in adjusted costs. Thus, the earlier a prediction of cost is made, the greater the expected uncertainty of actual cost. In general, in the early conceptualization stage, the required technological advances and eventual system configuration are poorly known. Their conclusions concerning cost growth and performance faults were that they were principally due to changes in program scope and they were outside of the contractor's control. These generally accounted for the difference between predicted cost of the original program and the final cost of the program as actually delivered.

In its attempt to control cost, the DOD instituted the Design to Cost Concept (DTC) for major weapon system acquisition. Although this approach was an attempt to keep cost within limits that could be achieved by a specified design, it is now recognized that frequent changes can undermine confidence in the process. Thus, flexibility is needed because of the difficulty in estimating major system requirements with precision. This implies that performance parameters must be variable if cost remains relatively fixed.

DEFINING UNCERTAINTY

Although uncertainty is defined as lack of knowledge about specific effects, it also can be examined in terms of the factors that contribute to disruption. Typical factors leading to disruption are shown in Table 3.

TABLE 3. FACTORS IN DISRUPTION

1. Delay: gap in carrying out a program
2. Interruption: short term delay
3. Stretch-out: slow down of program
4. Interference: delay by other projects/stoppage
5. Redesign: change scope, redo previous work
6. Work stoppage: partial interruption
7. Interdependencies: indirect delays
8. Shortages or errors: delays due to rework
9. Overlap: interferences & delay due to concurrency
10. Redirection of effort: disruptive effect of reorganization

Risk and uncertainty are defined using classical probability theory as well as how they apply to the acquisition process. Lev (15), defines risk as the condition where each outcome of the decision maker leads to one of a set of possible specific outcomes, each occurring with a known probability. Uncertainty is defined by Lev as the situation where the probabilities of the various outcomes are completely unknown. Although risk and uncertainty are often used interchangeably, they are not the same state of knowledge in a given situation.

Peck and Scherer's (16) comprehensive analysis of the weapon systems acquisition process defined risk as the level of consequences of a wrong prediction. They operationally defined uncertainty as the relative unpredictability of an outcome of a contemplated action. They categorize uncertainty as either internal or external where internal uncertainty related to the possible incidence of unforeseen technical difficulties in the development of a specific weapons system. Examples of internal uncertainty include development time of interrelated technologies, substitutable technologies, and performance to specification. External uncertainty covers factors external to a given project, but affect the course and outcome that can be expected. Examples include rate of technological change in weaponry, changes in strategic requirements and shifts in government policy.

The USAF Risk Analysis report (9) defines risk as the probability of an occurrence and uncertainty as incomplete knowledge. A risk assessment is where estimates are made of the risk associated with given alternatives and risk management as the actions taken to reduce risk. Risk analysis is considered the combination of risk assessment and risk management. It is the latter definitions which are most directly applicable to the acquisition process. As was shown previously, they use uncertainty to describe target, technical, internal program and process effects. They also use a network simulation to develop individual and joint risk profiles as the system progresses over time.

Harrison (17) defines risk, certainty, and uncertainty as follows:

> **risk** - a common state or condition in decision-making characterized by the possession of incomplete information related to a probabilistic outcome.
>
> **certainty** - an uncommon state of nature characterized by the possession of perfect information related to a known outcome.
>
> **uncertainty** - an uncommon state of nature characterized by the absence of any information related to a desired outcome.

Harrison further contends that "genuine uncertainty is as common as complete certainty". The more common state of nature is incomplete or imperfect information, which means that the expected outcome contains an element of risk for the decision maker. There is no situation that deals with the future that can be completely known when the acquisition process lasts anywhere from 2 to 12 years. How can a program manager possibly forecast events that far in the future with any meaningful degree of accuracy?

Beverly (18), describes uncertainty in systems acquisition as the lack of knowledge in development requiring state-of-the art technology. Risk, on the other hand, is based on historical phenomena for which probabilities can be established, and certainty or uncertainty deals with the existence of knowledge. Uncertainty is greatest when knowledge is at its lowest level. Uncertainty would describe the situation where a new system is being developed which involved advanced state of the art technology. The lack of knowlege, in turn, inevitably leads to errors in estimating, in design and ultimately in cost control. This leads to three kinds of uncertainty in weapons acquisition: design and technology uncertainty, scheduling uncertainty and cost uncertainty. They point out that there is conflict among goals because reduced design/technology uncertainty enhances performance while cost minimization tends to adversely affect both performance and schedule goals.

Martin (19) deals with uncertainty in terms of our inability to predict the future in the face of unknown variables. His taxonomy of uncertainty conditions represents a comprehensive treatment of the subject. He includes four basic categories of uncertainty as follows:

1. **Environmental:**
   a) natural factors
   b) social & political effects
   c) communication disparities
   d) time which results in distortions
   e) external to the project or exogenous
   f) internal approaches or endogenous
2. **Functional:**
   a) income/business risk
   b) financial/earnings risk

c) technological uncertainty
d) production inadequacies

3. Informational:
   a) unknowns of which contractor is aware
   b) unknowns that cannot ba foreseen
   c) lack of knowledge
   d) unknowns that cannot be anticipated
4. Technical:
   a) uncertainty - no known probability distribution of events
   d) risk - outcomes can be described by a probability distribution
   c) cartainty - predictable outcome determined
   d) subjective - probabilitias derived independent of tha problem at hand

Martin describes a twenty year period in which measures to reduce cost growth were not effective. He recommends the use of antropy to measure tha laval of information in a system which is directly ralated to the uncertainty undar which decisions hava to be mada. As entropy incraasas, so does uncertainty and what is needed is a means to incraase information efficacy rather than increase choices or randomness.

McNichols (20) presents a means for estimating tha distribution of cost uncartainty where actual costs diffar significantly from original cost astimatas. He contends that cost overrun is a meaningless concapt becausa all cost astimates raly heavily on subjective judgments and ara subject to considerable uncertainty. Ha considars four basic steps in the treatment of uncertainty. Thase includa: ganeration of probability distributions for individual cost alements; generation of a total cost by additive distributions; combination of the probability density functions to form a compound distribution; finally, the correlation or dependance batwaen cost elements is takan into account. Tha problam of uncertainty then is to determine a measura of the dagrae of difficulty or likelihood of achieving cost goals.

Tha dascriptions of risk and uncertainty prosantad above illustrate the variety of approachas that can be takan. The ralevent question, however, is how best can management daal with the problem of uncertainty in the acquisition process. Although it is assumed commonly that any major overrun signifies poor managemant, this pramise fails to recognize that uncertainty is inherant in acquisition and that managers operate under severe time and resource constraints.

TECHNOLOGICAL UNCERTAINTY

Technological uncertainty refers to either the highly abstruse demands at the very forefront of scientific knowledge or the major gap between an organization's area of expertise and what is required to perform effectively.

In order to examine technological advance, factors are needed to determine the state-of- the-art. The ones shown in Table 4 provide a starting point (8):

TABLE 4. FACTORS THAT CAN BE USED TO DETERMINE STATE-OF-THE-ART

1. Size - number of interrelated components, physical voluma
2. Complexity - difficulty in meeting performance raquirement
3. Experimental nature of technology - has it been proven
4. Degree of newness - percent of components of proven technology
5. Company's experience in the field - work on similar programs
6. Interdapandancy of subsystems - number of linkages
7. Dagree of precision - quality requirements
8. Unique resources - testing, or tooling requirements
9. Dafinitiva specifications - clarity in meeting requiremants
10. Dasign flexibility - tolerance level, substitutes available
11. Required theoretical analysis - need to support proposed dasign
12. Degree difference from existing technology - lifa cycle of technology
13. Infra-structure support required - dagree of dependency on vendors

The factors shown in Table 4 include the newness as well as the dasign requiramants for datermining the state-of-the-art. Thus, stata-of-tha-art for a given organization can be construad as the "ability" to produce a given dasign, in addition to the nawnass of the technoiogy involved.

Technological uncertainty also arises from the overlap or "concurrance" of davalopment and production. The perceived necassity to initiata tha pondarous and involved processes of production befora thare is certainty as to tha stability of tha product design, placas programs at the mercy of changes which occur in the dasign. Such dalays or changes are more likely to occur as the degree of concurrancy increasas.

In ragard to technological uncertainty, Duvivier (21) recommends tha usa of technological forecasting to assess tha risk in meeting tha demand for increasingly advancad technology. Ha postulates that advances are extrapolations of current knowledge and that breakthroughs ara rare. Even whan breakthroughs do occur, such as the laser, it takes 8 to 12 years to incorporate them in new systems. He shows examplas of engine weight, lift and fual consumption all following smooth curves. Thus, the cost and benefit of new technologies can ba basad on an extrapolation of technology growth curves.

Because technological uncertainty impacts projects with advanced state-of-the-art, reduction in development time is possible through the maintainance of a strong research and development posture. New technologies can be tested and evaluated prior to incorporation in major systems and thus "avoid" some of the uncertainty. Considering that new tecnnology is limited to a small percent of components, advanced or anticipatory development can contribute significantly to the reduction of technological uncertainty, reduced need for concurrency and, ultimately, reduced disruption. Thus, "demonstreted" technical capability could supplement "fly before buy" as an approach to the management of risk and uncertainty in major acquisitions.

If the degree of state-of-the-art is a driver of technological uncertainty, then interrelatendness is a major multiplier on cost of development- and production. Interrelatedness of design relates a change in one component or subsystem to many others. Interrelatedness can also affect production and vendor activities, since a chenge in production methods or delivery cycle in one erea or component may affect production of other components or work in other areas. A product in an advanced area of technology will be subject to higher levels of interrelatedness.

INTERNAL CONTROL

Internal control defines the level or degree of unknowns that are internal to the system rather than the external exigencies. Factors related to internal uncertainty could be measured using dimensions such as:

1. The organization's ability to respond to new or unforeseen requirements.
2. The sleck or flexibility that has been built into the orgenizetion.
3. Prior experience with the given technology.
4. Number of linkages of subsystem dependencies or interaction with other projects.
5. Percent of the project's subsystems being developed that are at the state-of-the-art of the technology.
6. The amount of time compression or tightness of schedules (concurrency).
7. Availability of, or access to, resourcea.
8. Maturity in the planning and control of operations, including computer systems and organization structure.
9. Amount of overlap of development, design, and implementation.
10. Number of contractors or organizations involved in the project.

These factors contribute to manegement's ability to cope with uncertainty. In turn, the delay, disruption, or slippage that can be anticipated would be measured by the relationship of this capacity to customer demand as shown in Figure 2 (8).

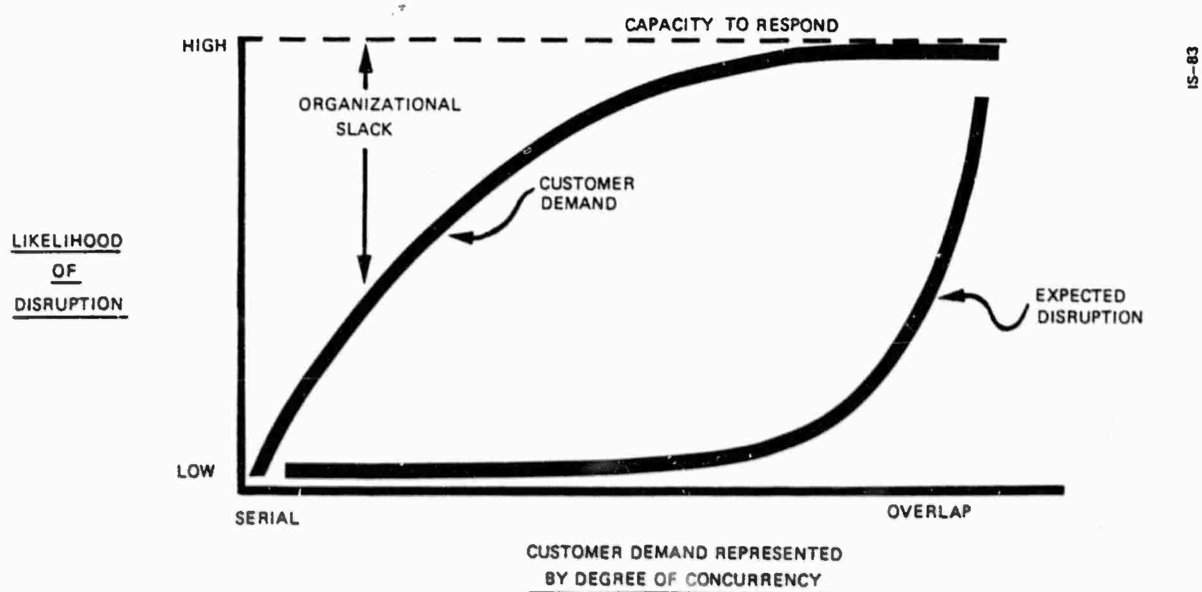

FIGURE 2 IMPACT OF CONCURRENCY ON DISRUPTION AND RESPONSE CAPACITY

Expected disruption is an exponentially increasing function which is dependent on the organizational response capacity, which in turn depends on the level of concurrency. Thus, when the level of concurrency approaches response capacity, the delay increases. This formulation does not deal with uncertainty per-se, but whether the organization is able to cope with problems as they arise, or is able to anticipate problems. In turn, the amount of slack or flexibility in the organization determines the ability to respond to uncertain requirements. If management is operating with minimum slack, then any disruption can cause a large delay.

Another perspective on management practices is based on four agencies studied by RAND (22) covering R&D management. An examination of the findings reveals the considerable latitude given program managers in dealing with creative individuals needed in R&D programs. Given this kind of organizational environment, the accuracy of estimates is highly questionable. At best, the estimate is a target that permits a level of effort to be applied in attempting to achieve what are often elusive objectives or requirements.

Perry (13), in a study of acquisition strategies, recommended that acquisition management use an incremental approach. This support was based on an analysis of 36 major DOD programs which revealed that high cost growth was caused by:

1. Willingness to pay the price for having high technology with compressed schedules.
2. Over-optimism regarding the cost of coping with long term technology.
3. Little evidence that the programs had extreme urgency.
4. Little improvement in cost based on:
   a) contractual approaches
   b) complex management reforms
   c) improved estimating
   d) early identification and correction of cost growth.

Despite these four factors, a number of programs had surprisingly good outcomes and were able to predict cost performance and schedule. Using their findings, the authors suggested that an incremental strategy and control in the early phases of development would have the most effect on avoiding cost growth.

The incremental strategy recommended the following steps:

1. Resolve uncertainty early in the program.
2. Avoid concurrency of development and production.
3. Separate performance from reliability and maintainability.
4. Require periodic reassessment, redefinition, and readjustment regarding proposed changes.
5. Conduct tradeoff studies to resolve restructuring.

The benefits from an incremental approach to management would lie in greater predictability based on prototype demonstration and in uncovering difficulties early in program life. It would also encourage competition and transfer of technology as the need required.

DETERMINING A PATTERN OF DISRUPTION AND UNCERTAINTY

The ability to define causal relations among variables in disruption and uncertainty is a first step in predicting cost overruns and in determining which actions a program manager should take to avoid cost growth. For example, Augustine (23) proposed using additional planning funds based on an assessment of risk. He contends that even the most capable program manager is not able to forecast all the problems that will be encountered in a development program spanning anywhere up to ten years. However, it is quite possible to forecast the "probability" that additional funds will be required. He recommended the use of TRACE (Total Risk Assessing Cost Estimate) as the basis for justifying the additional funding.

One of the early attempts to deal with uncertainty was proposed by Marshak, Glennon and Summers (24). They indicated that where "component" interrelatedness is defined, one can predict the effects that are likely to occur. Under conditions of uncertainty, low slack heightens interrelatedness and substantially increases the risk of redesign. Furthermore, the risk of redesign is sensitive to the degree that design reaches beyond past state-of-the-art and where there are requirements to use existing components which can strain the designer and lead to suboptimization. Based on three conditions describing component interrelatedness, one is in a position to predict potential disruption. When there is a high degree of close coupling or interrelatedness, the likelihood of design change is substantial. Where there is loose coupling and engineering slack, when components are redesigned the deviation does not influence the other components, and there is less propensity to redesign. It is argued that the tightness of component interrelatedness can be traded off against uncertainty, and thus achieve more effective control.

Another measure of uncertainty is system complexity. Table 5 illustrates the impact of complexity on maintainability and availability. Complexity is indicative of the uncertainty related to potential disorder and resultant cost overruns.

TABLE 5 COMPLEXITY, MISSION CAPABILITY, AND MAINTAINABILITY OF VARIOUS WEAPON SYSTEMS.

(Source: Armed Forces Journal International, May 1980)

	Degree of Complexity	Not mission capable	Mean Flight Hours between failure	Maintenance man-hours per sortie
Air Force				
A-10	low	32.6	1.2	18.4
A-7D	medium	38.6	0.9	23.8
F-4E	medium	34.1	0.4	38.0
F-15	high	44.3	0.5	33.6
F-111F	high	36.9	0.3	74.7
F-111D	high	65.6	0.2	98.4
Navy/Marine Corps				
A-4M	low	27.7	0.7	28.5
AV-8A	low	39.7	0.4	43.5
A-7E	medium	36.7	0.4	53.0
F-4J	medium	34.2	0.3	82.7
A-6E	high	39.3	0.3	71.3
F-14A	high	47.1	0.3	97.8

RISK MODELS

Many approaches utilize risk, rather than uncertainty to predict possible outcomes. Figure 3, on the other hand, shows the relationship between risk and uncertainty as related to causality. Models of known phenomena provide a more certain basis for prediction than random events which are used for estimating probabilities. Uncertainty, covers those areas that are ill-defined or where there is a lack of knowledge of effects.

Figure 4 relates state-of-the-art to interdependency and level of concurrency. The likelihood of disruption is shown as a function of varying levels of concurrency. The more complex the program, and the higher the interdependencies, the greater the likelihood of disruption. Thus, the likelihood of disruption increases with increasing concurrency (25).

CURRENT APPROACHES TO ACQUISITION MODELING

A number of representative models applied to the acquisition of major systems are examined here. The types of models will be grouped into two major categories - probabilistic/stochastic models and general models. Within this framework several aspects of each of the models will be explored.

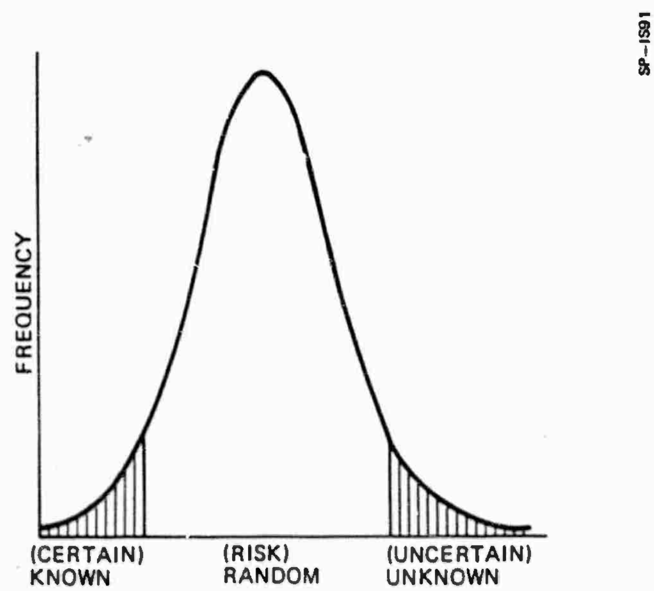

FIGURE 3. TAXONOMY OF CAUSALITY AND UNCERTAINTY

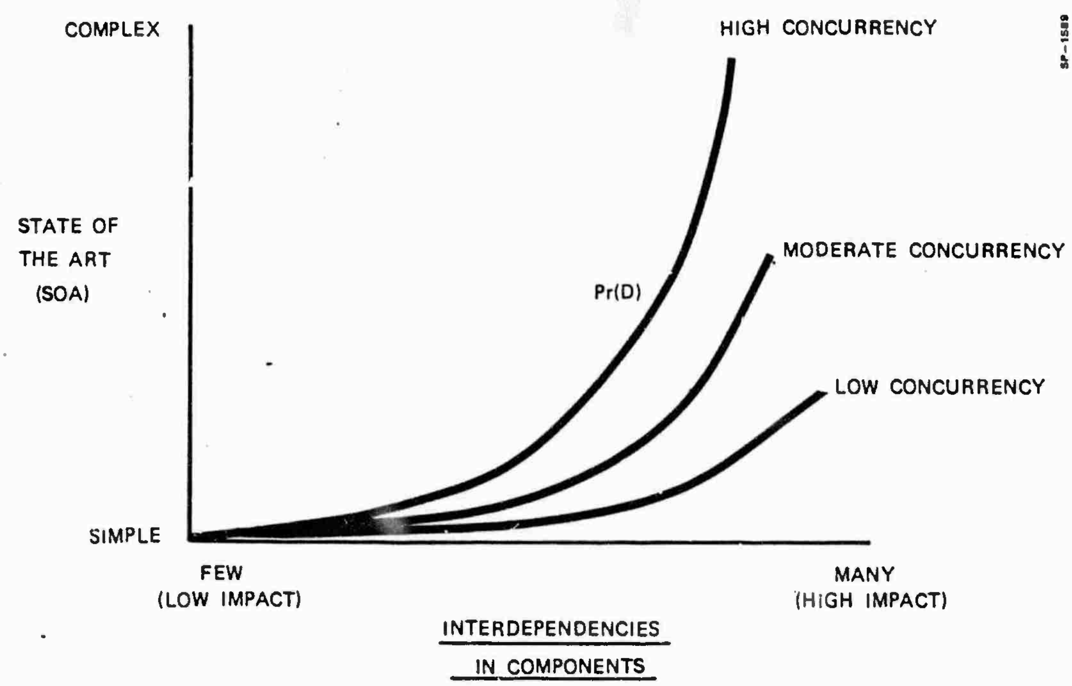

FIGURE 4. RELATIONSHIP BETWEEN STATE-OF-THE-ART AND CONCURRENCY

The extension of the two groups of models leeds to a proposed approach - the Ceusel- Integretive Model (CIM) - which is suggested as e meens to deel with factors those used by many of the current models.

Stochestic/Probebilistic Models

Within this cetegory, three models will be discussed. These are - VERT; the Risk Analysis Model presented by Admiral Freeman et the 1979 Symposium on Risk end Uncerteinty; end TRACE.

VERT - Venture Evaluetion end Review Technique

VERT was developed in 1973 and has been used almost exclusively by U.S. Army program managers to determine the "best" balance emong the three program parameters: cost, schedule, and performance. The model evolved from eerlier methodological approaches such as GERT (Graphical Evaluation and Review technique), CPM (Criticel Path Method), PERT (Program Evaluation and Review Technique), MATHNET (Mathematical Network Analyzer), and RISCA (Risk Information System and Cost Analysis). The short comings of these earlier models when compared with VERT was their failure to include the performence variables along with the cost and schedule variables in the total risk-analysis methodology. The VERT model corrects this problem.

A Monte Carlo simulation process is iterated as many times as the need warrants in order to create a large sample of possible outcomes concerning: sleck time, completion time, cost, end performence. Frequency distributions, scetter diegrems, end probabilities of exceeding given velues are elso genereted. Finelly, pictoriel histograms are generated for desired events, giving the program maneger an integrated risk enelysis for e perticuler point of interest in the program. Menn (26) reported in *The Defense Menagement Journal* thet "some minor problems heve arisen with VERT, but none ere considered mejor obstecles to its effective use." The reported problems center about the probability distributions. Most deta sets in VERT are triangular indicating pessimistic, optimistic, end most likely values. This factor reduces the flexibility of the model and the accuracy of the simulations. Another problem, according to Mann, is the inability to obtain expert estimates of the time and cost requirements. The experience is that most of the values obtained have been overly optimistic.

Risk Analysis Model

RADM Freeman's risk analysis model (2) allows various alternatives or systems to be objectively compared through aggregate risk analysis. The process begins with a segmentation of the various program functions into categories reflecting the schedule, cost, and performance variables. Risk distributions, represented by utility functions, are used to determine utility values versus a change in one of the variables. For example, the question of "how much additional risk is presented by a change in performance variable A ?" is answered. The next atep consists of developing a Risk Matrix where the options (or alternative systems) are presented versus the criteria for choice. The summary risk or probability for aach system/alternative can then be compared on a quantitative basis. The term risk lactor is presented in the form of an equation:

$$R_f = 1 - P_s (1 - C_f)$$

Where: R_f = Risk Factor

P_s = Probability of Success

C_f = Consequencea of Failure

With: $0 < P_s < 1$

$0 < C_f < 1$

If C , the consequence of failure, is interpreted to represent a utility function, then the risk factor curve will be defined as a utility function. The shape of this function will be in the form of a negative Pareto curve. If the system criteria and associated risks developed from the Risk Matrix earlier in the sequence were plotted in rank-ordered fashion, it too would be representative of a negative Pareto function.

TRACE - Total Riak Asseaaing Coat Eatimates

TRACE, an approach designed to provide program managers with a method of costing for risk, was developed by the Army (27) in 1974. The methodology incorporates several levels of estimates which are available to the user. These estimates represent different levels of detail and complexity. The simplast approach for a TRACE eatimate requires only a baseline estimate by the program manager and some estimate derived subjectively of the total program risk.

Starting with the simplified approach, the model accepts inputs including WBS elements, subelements, interaction among WBSs, and unit probabilitles to derive more detailed risk estimates. Three additional levels of risk estimates capable of being generated the are riak factor method, probabalistic event analysis and probabalistic event modeling. The third and fourth methods require highly skilled analysts to develop the data inputs.

General Models

This category covers three types of models - regression models, parametric cost estimation and dynamic modeling.

Regression models have contributed significantly to the understanding of causality in the acquisition process. For example, Leech and Earthrowe (28) have shown that the ratio of actual costs to estimated expenditures can be predicted based on a regresaion with actual size of the job. Using a sample of 64 jobs, they developed a regression curve, where $r = .955 + .009X$, and X = actual job size in man hours. As they point out, in every case a commitment was made to the customer based on an initial design. However, where the job is large, requires considerable technical innovation and the quantity ordered is small (no opportunity for learning) the design and development costs contribute significantly to the final cost. They recommend an investment portfolio approach to minimize tha risk associated with design uncertainty.

Parametric Coat Eatimation

Parametric Cost Estimation is the primary costing methodology for DOD weapon system acquisition. This approach evolved from research by the RAND Corporation in the late 1950's. The basic idea was to make accurate estimates of weapon system costs at the early stages of system design. This approach uses performance variables such as speed, weight, range, power, etc. to predict costs because estimates of these parameters are usually known early in the design phase.

The estimates are based on historical data of previous or similar systems and utilize statistical relationships between cost and the performance parameters of these past or similar systems. These statistical relationships, called cost estimating relationships (CER), take the form of an equation which uses cost as a function of the performance variables and constant coefficients. McNichols (20) describes the relations in simplified format by:

$$C = f(X) = f(X_1, X_2, \ldots \ldots . X_n)$$

where X_i denotes, a performance parameter. The total cost would then depend on each of the values of X_i using data from similar systems. McNichols criteria for selection of the variables is given by:

- The logical or theoretical relation of a variable to cost (thus implying that a real dependence between cost and the value of the particular variable or set of variables exists, subject to some random disturbance or uncertainty.)
- The statistical significance of the variable's contribution to the explanation of cost (thus implying that relevant cost experience exists to test and calibrate the postulated cost dependence - subject to measurement uncertainty.)
- The dependence pattern of the contribution made by a variable to the explanation of cost (thus the analyst must have sufficient confidence in the relationship that he is willing to extend it to estimate a new item - and different analysts will have different degrees of confidence).

There are several adavantages to the parametric cost estimation approach. First, aince the method conaiats of a series of CER's and requires aggregation, it is easily adapted to a computer. Output and turnaround for new estimates can be obtained quickly when compared with the detailed engineering approach. Second, sensitivity analysis is eaaily performed using this method. For any change in a given parameter, the corresponding change in cost is eaaily determined. Third, coat/benefit analyses or trade-offa are also easy to perform. Fourth, each time a new generation syatem is estimated, the historical data base already developed can be updated and used.

Dynamic Modeling

Computer-based dynamic modeling was proposed by J.W. Forrester in the 1950's as an approach to help solve problems of complex, continous systems. A dynamic model is based on four factors that have improved understanding of complex systems:

- The theory of information-feedback systems.
- A knowledge of decision-making processes.
- The experimental approach to analysis of complex systems.
- The digital computer as a means to simulate realistic mathematical models.

Expansion of the concepts presented by Forrester into an acquisition model could contribute to a better understanding of the likelihood of cost overrun and disruptions. The main advantage of dynamic simulation is that it forces managers to clearly define their decision making. This approach leads to greater insights into the acquisition process.

However, dynamic modeling is not without disadvantages. Among these are:

- In simulation, all relevant variablea 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, less useful in organizational design, and least-useful in ill defined external problems.
- 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.

Causal-Integrative Model (CIM)

An extension of the dynamic modeling approach is described as a Causal Integrative Model. The model shown in Figure 5 (25) 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 shown in Figure 1. As noted earlier, acquisition models currently being used do not address all of these variables; thus, each of there models lacks some degree of completeness.

Referring to Figure 5, the Causal-Integrative Model can be used, for example, to determined how a change in economic uncertainty affects the level of environmental uncertainty which, in turn, affects mission, scope, and funding. These changes pertrub the system to effect changes in organizational slack, technological uncertainty, and customer urgency. Thus, a change in one variable can be shown to cause changes in the others through the pervasive network of interdependencies. These changes in a key variable impact the acquisition cycle in ways that are not intuitively obvious without the aid of a dynamic model to deal with the causal relationships.

The direction in acquisition management prompted by this approach requires the following:

- development of a comprehensive computer-based acquisition model,
- testing of the model with actual programs,
- validation of the model using current programs,
- implementing the model for policy level decisions in acquisition management.

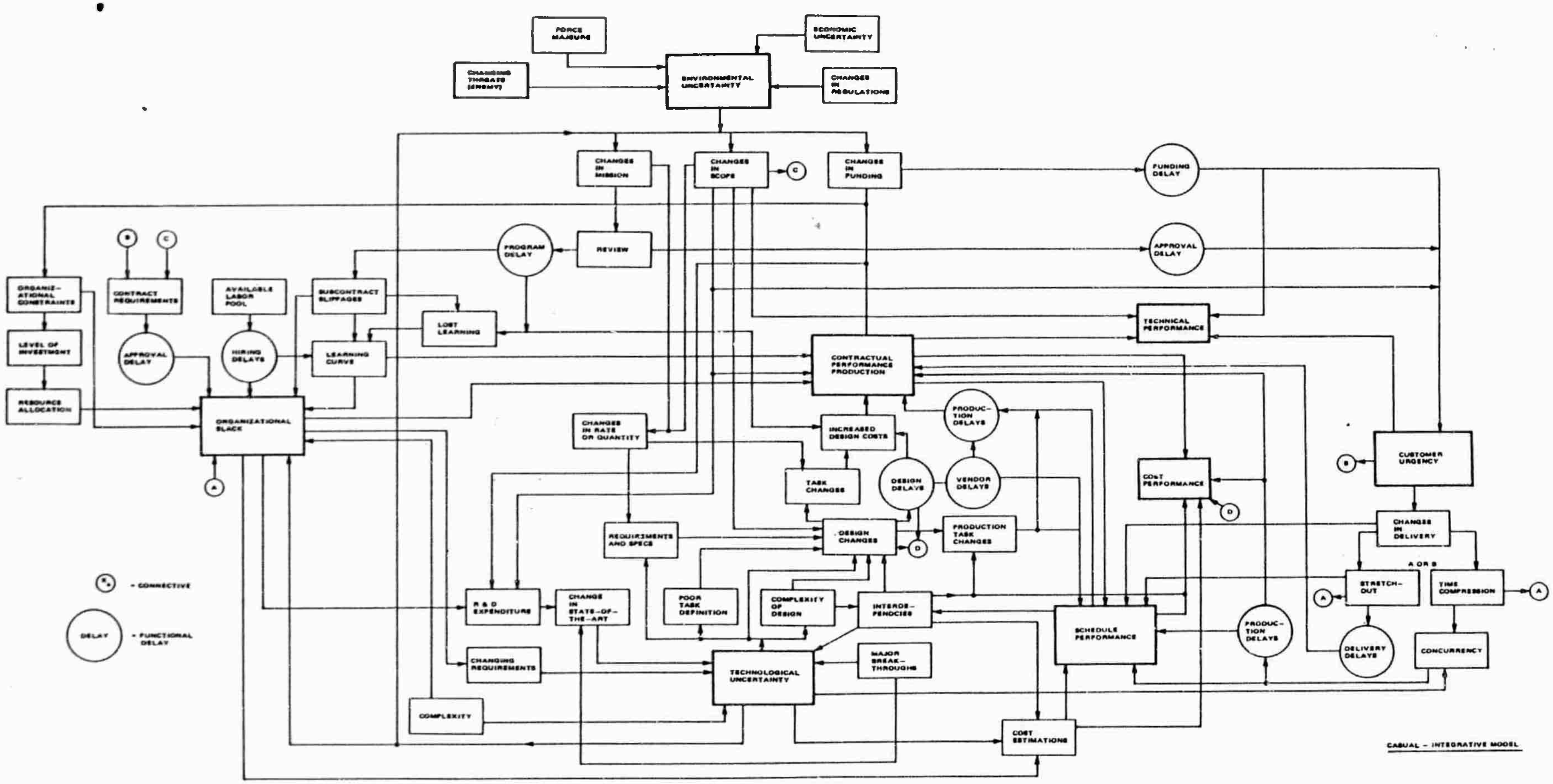

FIGURE 5. CAUSAL-INTEGRATIVE MODEL

CONCLUSION

The material presented hera has attempted to highlight research related to tha DOD acquisition process. Because of the pervasiveness of the subject, of necassity, not all relavent research or applications could be included. Rather, what has baen prasentad hera can be considered as indicative of the current state-of-tha-art in acquisition managament and a baseline approach for future developments.

For example, it was pointed out that uncertainty and disruption cannot be eliminated, but rather can be controlled if thera ara causal models that relate cost to advances in state-of-the-art.

The acquisition community has daveloped many programs that incorporate approaches to manage risk and uncertainty. These programs included procurement methods such as Design-to-Cost, Total Package Procurement, VERT, and Life Cycle Costs. Post-acquisition attempts to control risk and uncartainty included PERT and its derivatives, CPM, C/SCSC, and CSSR. In a study of 47 major programs reported in Selected Acquisition Reports (SARs) dated 30 Juna 1981, Brabson (29) indicates that current estimates for these programs are 218% of the original estimatas. These levels of cost growth indicate that the problem of risk and uncertainty is still impacting the acquisition community ragardless of the efforts employad.

REFERENCES

1. Cochran, E.B., and Rowe, A.J., "The Sources of Disruption to Project Cost and Delivery Performance," *Proceedings 8th DoD Symposium on Acquisition Reserch,* West Point, New York, 1978

2. Freeman, R.G., RADM "New Initiatives in Managing Uncertainty", *Menegement of Risk & Uncerteinty Proceedings, u.S.C., 1979*

3. *Thurmen, W., BG "Meneging Risks end Uncerteinty: Looking to the Future", Menegement of Risk & Uncerteinty Proceedings, u.S. Air Force Acedemy CO, February 1981.*

4. *Winkler, R.L., "Research Directions in Decision Meking Under Uncerteinty", Decision Sciences,* Vol. 13, 1982

5. Kerns, W.R., "Risk and Uncertainty: State-of-The-Art in Application", *FAI Proceedings,* May 1982

6. Keeney, R.L., "Decision Analysis: An Overview," research, Vol, 30 Sept 1982

7. Carlucci, F.C., Memorandum for Secretaries of the Military Departments, D.O.D. June 18, 1982

8. Rowe, A.J. and Somers, I.A. "Methods to Measure, Predict, and Evaluate Cost Overruns." *Menegement of Risk end Uncerteinty Proceedings,* U.S. Air Force Academy, CO February, 1981.

9. Lochry, Robert R. et al, "Final Report of the USAF Academy Risk Analysis Study Team," U.S. Air Force Academy, CO., Aug, 1971.

10. Martin, Martin D., Lenz, Joseph O. and Glover, William L., "Uncertainty Analysis for Program Management," *Project Menegement Querterly,* Vol. VI, No. 3 (1975), pp. 15-18.

11. Davis, Guy W. "The Dilemma of Uncertainties Associated with Cost Estimating in the Project Management Office," Defense Systems Management College, Ft. Belvoir, VA. May, 1976. LD-36420A.

12. Rowe, A.J., (principal investigator) Disruption Research Project. Unpublished Paper, University of Southern California, April, 1977.

13. Perry, Robert et al, *Systems Acquisition Strategies,* R-733-PR/ARPA, RAND Corp., Santa Monica, CA., June, 1971. AD/730-921.

14. Perry, Robert L. et al, *System Acquisition Experience,* RM-6072-PR, RAND Corp., Santa Monica, CA. Nov., 1969.

15. Lev, Baruch, *Finence Stetement Anelysis: A New Approech,* Prentiss-Hall, Englewood Cliffs, N.J. 1974.

16. Peck, Merton J., and Frederic M. Scherer. *The Weepons Acquisition Process: An Economic Anelysis.* Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1962.

17. Harrison, E.F., *The Menageriel Decision - Meking Process.* Houghton Miffin Co., Boston, MA, 1975.

18. Beverly, J.G., Bonello, F.J., and Davison, W.I. "Economic and Financial Perspectives on Uncertainty in Aerospace Contracting." *Menegement of Risk end Uncerteinty Proceedings, u.S. Air Force Acedemy, CO., Februery, 1981.*

19. *Martin, M.D., "A Conceptuel Cost Model for Uncerteinty Peremeters Affecting Negotieted Sole Source Development Contrects." Unpublished Ph.D. dissertetion, University of Oklehome, 1971.*

20. *McNicols, G.R., "On the Treetment of Uncerteinty in Peremetric Costing." Unpublished Ph.D. dissertetion, George Weshington University, Weshington, D.C., 1976.*

21. *Duvivier, G.F., "Technologicel Advences end Progrem Risks." Technological Forecesting end Sociel Chenge,* Vol 2, No. 3-4, 1971. p-277-287.

22. Press, S. James, et. al., *Methodology for Subjective Assessment of Technologicel Assessment.* R-1375 RAND Corporation, Santa Monica, CA., Apr., 1975.

23. Augustine, Norman R. "Augustine's Laws and Major System Development". *Defense Systems Menegement Review,* Spring, 1979, p.50-78.

24. Marschak, Thomas, et. al., *Stretegy for R &D: Studies in the Microeconomics of Development.* RAND Corporation, Santa Monica, CA, 1967.

25. Rowe, A.J. and Somers, I.A., "Methods to Predice Cost Overruns in the Acquisition Process." *Proceedings, Federel Acquisition Institute Research Symposium,* May, 1982.

26. Mann, Greg A. "VERT: A Risk Analysis Tool for Program Management" *Defense Menegement Journel.* May-June 1979. p. 32-38.

27. Edgar, J.D., "Controlling Murphy: How to Budget for Program Risk." *Concepts,* Summer 1982.

28. Leech, D.J., and Earthrowe, D.L., "Predicting Design Costs," *Aeroneuticel Journel.* Sept. 1972.

29. Brabson, G.D., "The DOD Acquisition Improvement Program." *Concepts,* Autumn. 1981.

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ASSISTANT CHIEF OF STAFF STUDIES AND ANALYSES (AIR FORCE)

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DEPUTY DIRECTOR FOR STUDIES AND ANALYSES
PROGRAM PLANNING OFFICE (NAVY)

Each panelist discussed (1) the uncertaintes his individual service faced and the risk he felt the service is taking ("the real world") and (2) how well he felt analysts perceived and measured the uncertainties and risks ("the theoretical world").

PANEL SESSION

ON

METHODS AND MODELS I

CHAIRMEN

ERWIN M. ATZINGER
ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY

AND

ROBERT M. STARK
UNIVERSITY OF DELAWARE

RISK AND DECISION ANALYSIS PROJECT AT LOCKHEED-GEORGIA

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R. M. Love

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ABSTRACT

This paper describes the evolution of the Risk and Decision Analysis Project at Lockheed-Georgia which develops new methods, automates existing methods, and performs analyses in support of program definition and conceptual design of new air vehicles. The analytical methods that we have found most useful are identified. Application such as technology assessment and program risk analysis are discussed. Observations are given on the practice of decision analysis in an engineering environment.

INTRODUCTION

Interest in decision analysis at Lockheed-Georgia began as a result of a U. S. Air Force (USAF) competition. On 15 October 1980 Lockheed-Georgia, along with Boeing and McDonnell-Douglas, received a Request for Proposal (RFP) from the Air Force (Reference 1) to develop and build a transport aircraft known as the C-X (Cargo Experimental). The C-X was specified to be a dual-purpose airlifter, having both intercontinental range and short field landing and takeoff capabilities. Responses were due on 15 January 1981.

One of the proposal volumes specified by the RFP was entitled simply "Risk." Lockheed-Georgia's Engineering Systems Analysis Division (Figure 1) was assigned to select a study approach, collect information, conduct a risk analysis, and write a 40 page volume. Unlike most proposal volumes which describe what the contractor will do _if_ he is selected, the Risk volume was specified to be a report of the results of a thorough, systematic analysis. One of the authors of this paper was assigned as senior author of the Risk volume.

Near the end of the competition, it was recommended to management that when the proposal team disbanded and Systems Analysis reverted to requirements analysis and methods development, an R&D project be established to continue the development of methods for risk and decision analysis. Our recommendation was followed and the Risk and Decision Analysis Methodology project was established with funding for one-half man-year of methods work. The rest of our funding was to come from the projects we supported. This division of effort between methods and applications continues today in an environment which we now briefly describe.

Engineering Systems Analysis Division is one of two divisions controlled by the Chief Advanced Design Engineer, the other being Advanced Design Division. Systems Analysis is responsible for requirements definition and for performance of cost and effectiveness evaluations of proposed designs. Advanced Design is responsible for conceptual and preliminary design studies, for both new and derivative aircraft. These two divisions are managed by a matrix arrangement: Each working level engineer is assigned to an R&D activity (e.g., cost methods) and participates in one or more interdisciplinary projects as needs arise.

PROJECT OBJECTIVES

The long-range objectives of the Risk and Decision Analysis Methodology project are to develop a comprehensive framework of decision science methods, and implement these methods at Lockheed-Georgia to assist planners and decisionmakers. Annual objectives are set to enable these two objectives to be attained. These short-range objectives specify products (software or study reports) to be produced by year's end. Careful assessment is made to assure adequate manpower is held in reserve for applications assignments, both planned and unplanned.

The term "decision science" is used here to mean both a problem-solving philosophy and a collection of methods. The philosophy is to use the objectives and goals of the manager in structuring the decision situation, to allow as input to the model the judgment of the manager and his staff, and to give explicit consideration to the problem environment (timing, organizational factors, uncertainty, and constraints). By decision science methods, we mean a collection of techniques which include, but are not limited to:

1. decision analysis
   a. decision trees
   b. multiattribute utility theory
   c. probability encoding
   d. multiple criteria decision models
   e. decision making under competition
   f. policy testing via System Dynamics

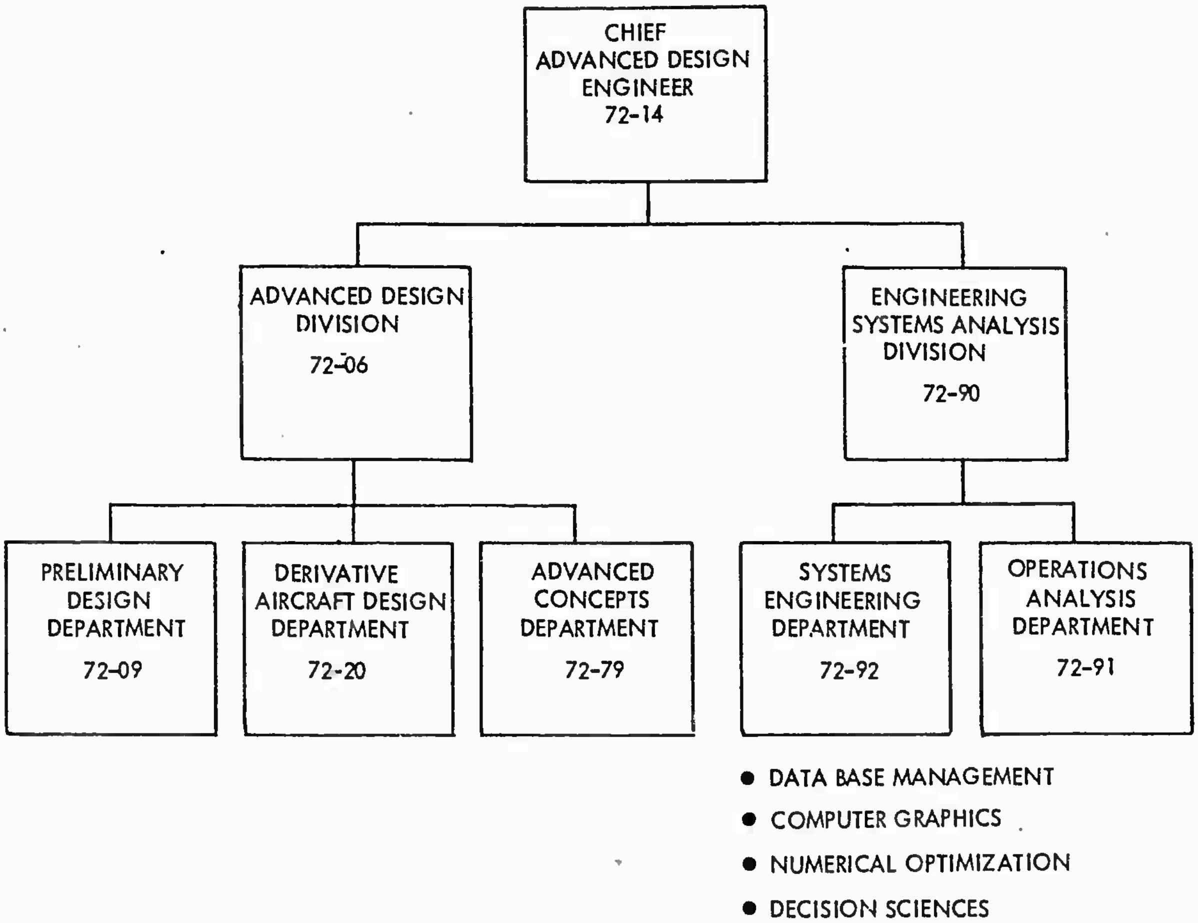

Figure 1. Immediate Project Environment

2. risk analysis

   a. Monte Carlo simulation
   b. iso-risk contours
   c. diagram methods for potential problem identification

3. statistical analysis

4. network analysis

   a. PERT/CPM
   b. CPM Crashing
   c. VERT
   d. GERT

The first three of these are the methodology focus of the 1983 project, as shown in Figure 2. Next year, a new R&D project devoted to network methods is planned. Figure 2 also illustrates how methodology development and applications feed each other. To develop our methods, the project analysts utilize the open literature and interact with theoreticians at universities and government-sponsored laboratories. The process represented is the well-known "applied research circuit" whereby theoretical developments eventually find their way into applications.

BASIC TOOLS AND EXAMPLE APPLICATIONS

There are certain decision analytic methods which we have used repeatedly over the last 3 years. Not surprisingly, they are not the more advanced methods available. However, these methods, and modifications/ combinations of them, provide a well-rounded decision analysis capability for an engineering environment. The methods are:

1. Probability Encoding

2. Monte Carlo Simulation

3. Multiattribute Utility Analysis

4. Critical Path Method

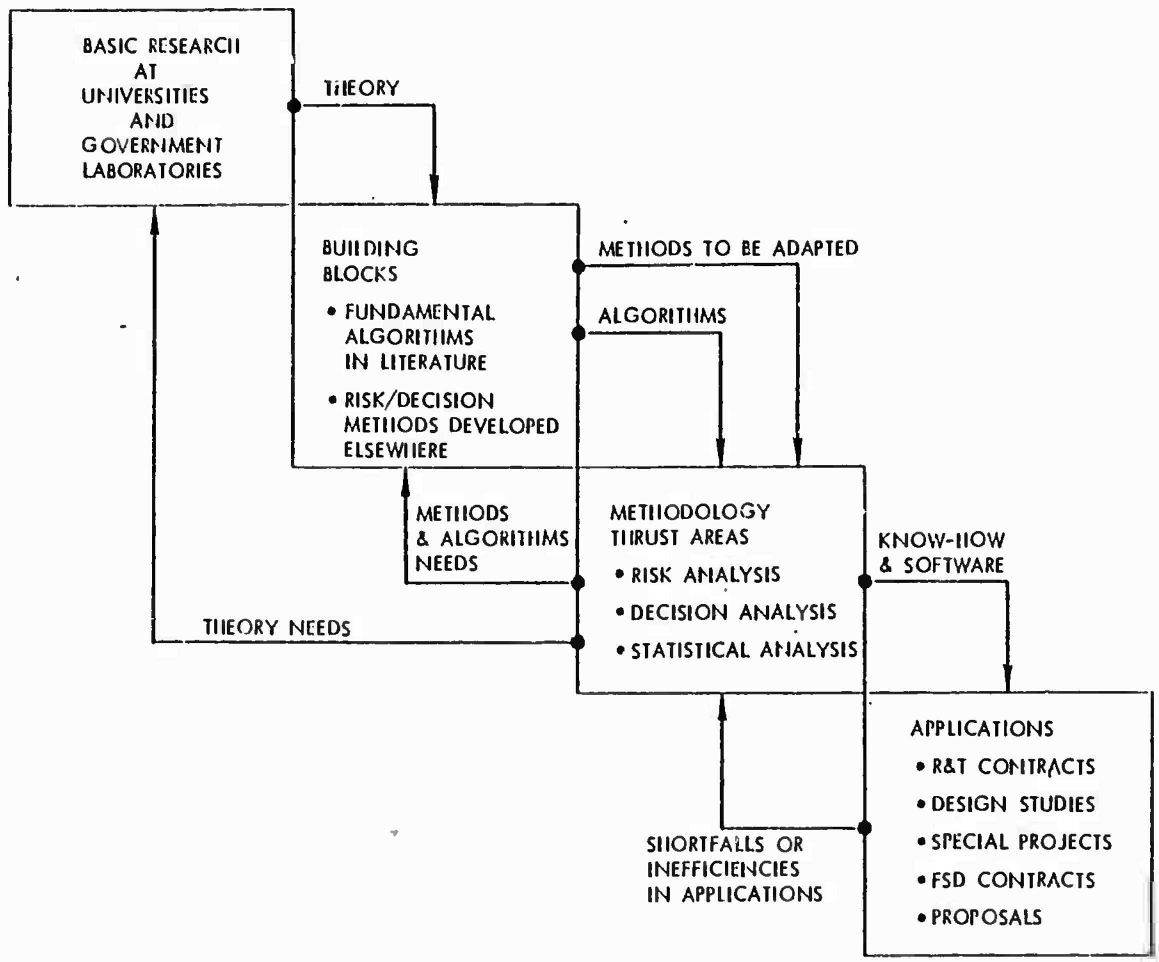

Figure 2. Applied Research Approach Employed by Project

Probability Encoding

Because most variables in engineering studies are continuous rather than discrete, the decision analyst must have a method for encoding subjective probability distributions for such variables. By subjective probability, we mean the "Bayesian approach" which interprets a distribution as one's degree of belief about the outcome of future events.

We use a four-part questionnaire (Figure 3) to convert responses from a specialist (technical or management) into a beta distribution. In the example shown, we have asked a reliability engineer to estimate "Effective Mission Capable (EMC) Rate" for an aircraft conceptual design. In giving us his estimate, he takes into account all reliability analyses conducted on the design, together with his experience on previous aircraft development programs. In effect, the engineer serves as the data base upon which the estimate of probability is based—he interprets the uncertainty much in the same way as the sample mean and variance calculated in frequency-based statistics. Caution must be applied in extracting a subjective probability distribution: assumptions upon which the distribution is conditioned must be specified; the bias in using a single engineer to provide the estimate must be addressed (perhaps through the use of a Delphi approach).

In Figure 4, four beta distributions are displayed. Each distribution was obtained from the project engineer responsible for the variable shown. The specific values for end-points and mode were removed for proprietary reasons. The information displayed is valuable in itself, but the real payoff is in using these data to calculate uncertainty in aircraft range with a given mission payload. The next subsection explains how this is accomplished.

Monte Carlo Simulation

We use Monte Carlo simulation to generate a sample distribution on an output variable whose distribution is not known by using a functional relationship between this output variable and

FOR THE VARIABLE EMC RATE, PLEASE ANSWER THE FOLLOWING:

A. LOWEST VALUE = 0.55 (LESSER VALUES HAVE A NEGLIGIBLY SMALL PROBABILITY OF OCCURRING)

B. MOST LIKELY VALUE = 0.66

C. HIGHEST VALUE = 0.76 (GREATER VALUES HAVE A NEGLIGIBLY SMALL PROBABILITY OF OCCURRING)

D. CONFIDENCE IN THE MOST LIKELY VALUE (CIRCLE ONE)

EXTREMELY CONFIDENT	(VERY CONFIDENT)	CONFIDENT	SLIGHTLY CONFIDENT	NOT CONFIDENT

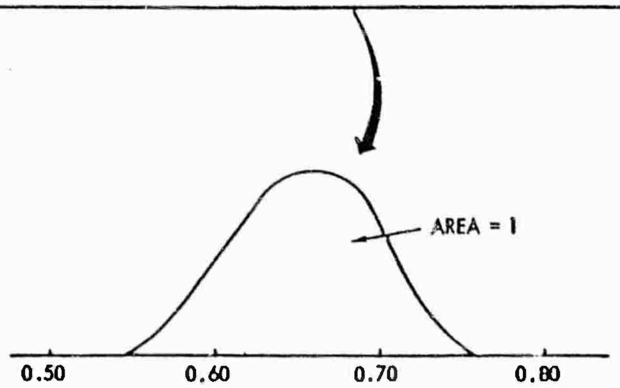

Figure 3. Conversion of Questionnaire Responses to Beta Distribution

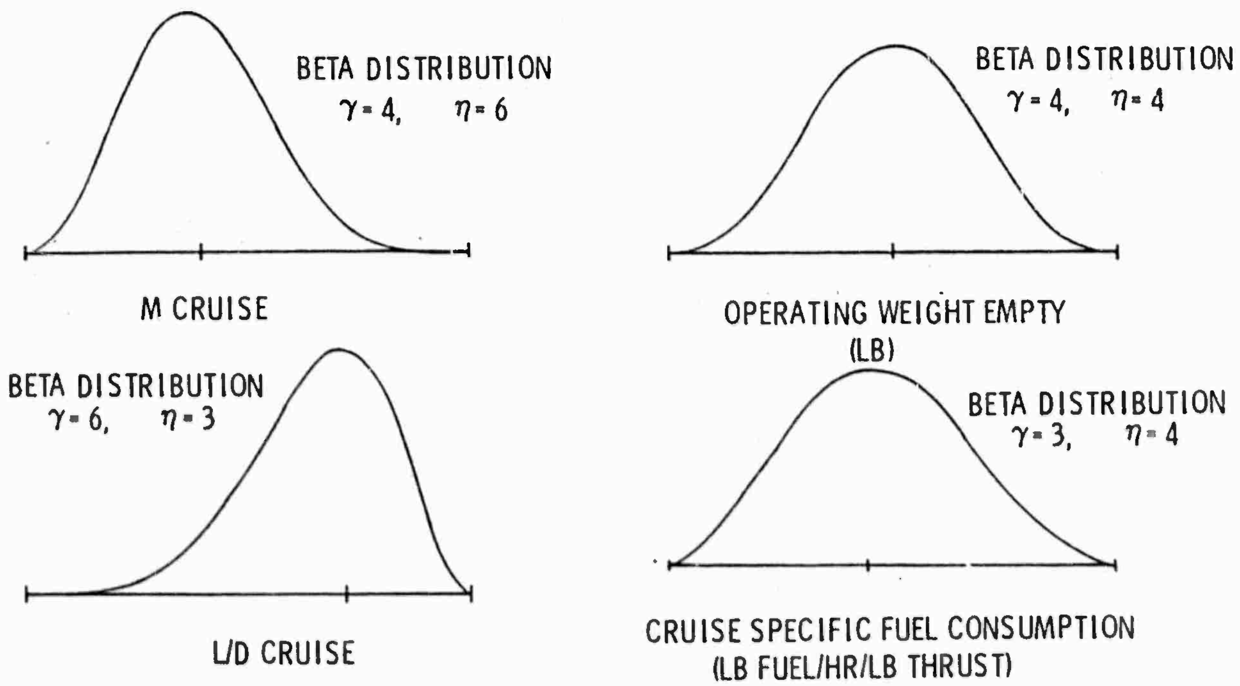

Figure 4. Probability Distributions for Variables Upon which Range is Dependent

input variables with subjectively estimated distributions. The process, also known as "quantitative uncertainty analysis," is shown in Figure 5. In some cases, we calibrate the function with the results of prior, deterministic analyses by means of either an additive or a multiplicative constant. For instance, with the aircraft range example, we substituted the nominal values of the input variables into the Breguet range equation and solved for a multiplicative calibration constant that would yield the nominal value for range. Once the function is calibrated, Monte Carlo simulation quickly develops a sample distribution for the output variable. A sample mean and variance may be calculated, and a theoretical distribution may be fitted. Figure 6 shows the results from the aircraft range example. The probabilities shown are the kind of information management needs. Note that no one individual on the project could have answered the question, "What's the uncertainty in this aircraft's range?" The value of the distribution on range is highlighted when comparisons among aircraft have to be made.

Quantitative uncertainty analysis need not be restricted to a single equation, such as in the range example. Often, an entire model (systems of equations) has been linked as a subprogram to the main Monte Carlo simulation program. An example would be linking with the USAF Cost Oriented Resources Estimating (CORE) model to quantify uncertainty in airlifter fleet O & S cost. Furthermore, at Lockheed-Georgia uncertainty analysis processes are being performed sequentially to conduct what may be termed "large-scale uncertainty analysis." To illustrate, consider Figure 7 which depicts the data flow for the Airlift Fleet Cost-Effectiveness Uncertainty Estimator (AFCUE) model (Reference 2).

In AFCUE, uncertainty analysis is repeatedly used to convert distributions on independent variables into distributions on dependent variables. The objective is to convert uncertainty in key technical aircraft variables into uncertainty in fleet life cycle cost. By performing this process on aircraft with different technology mixes, the effects of technological uncertainty on typical "point-value" estimates in conceptual design may be judged. Advanced technologies, while offering significant performance benefits, also introduce risk into all estimates of performance, effectiveness, and cost. AFCUE quantifies this risk, in

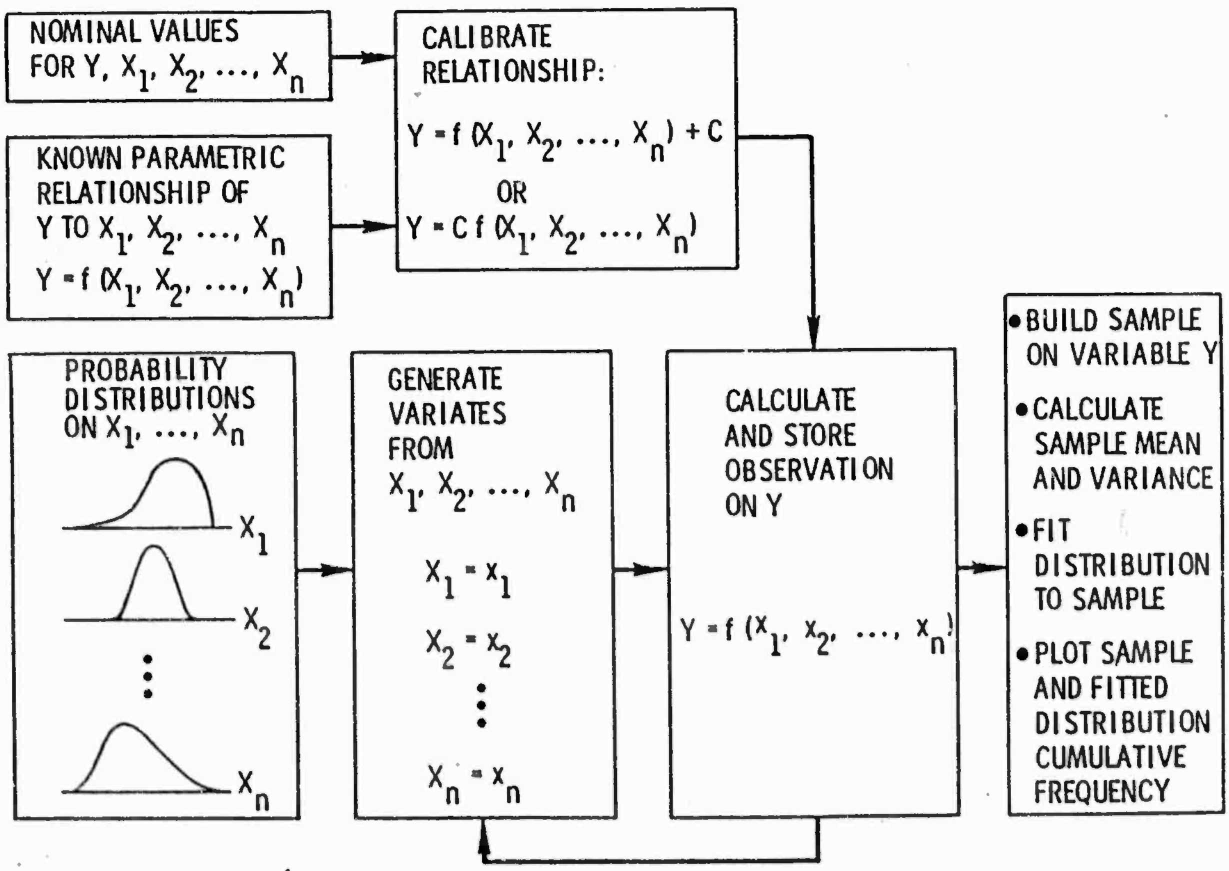

Figure 5. Flow Diagram for Quantitative Uncertainty Analysis

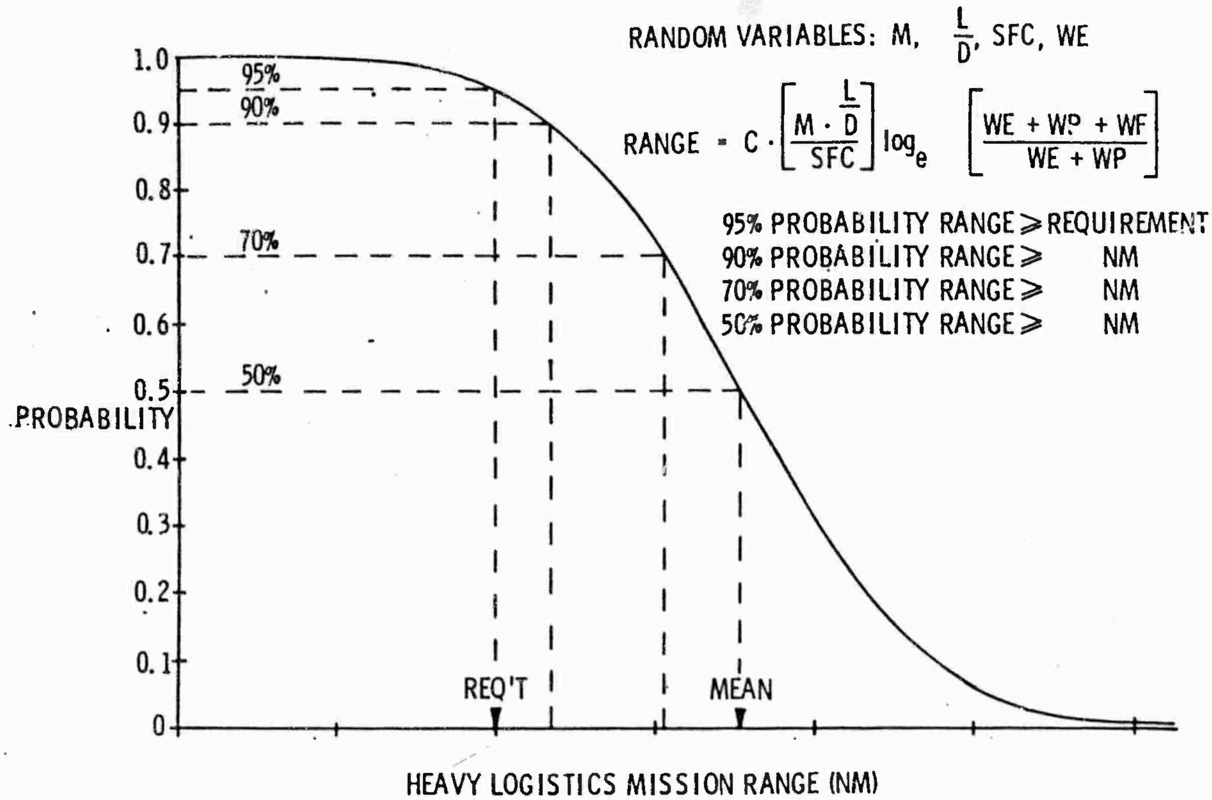

Figure 6. Uncertainty in Aircraft Range

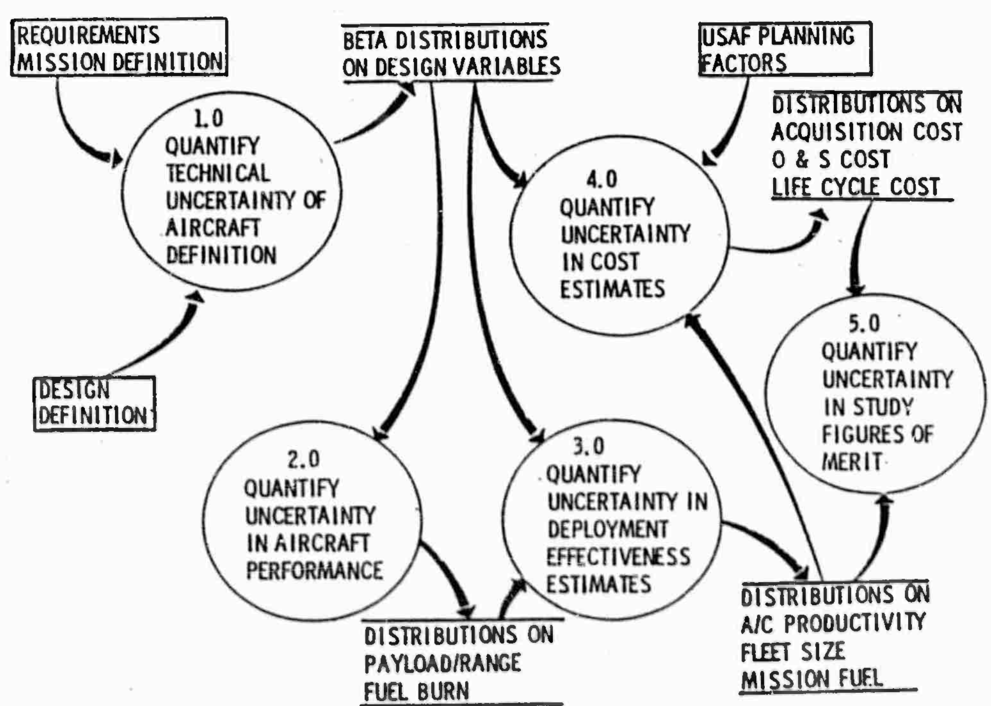

Figure 7. Data Flow Diagram for AFCUE

effect layering an uncertainty study over the standard conceptual design process. This seems reasonable, since the configuration/technology combinations for which cost-effectiveness estimates are typically generated are 10-15 years from production.

Multiattribute Utility Analysis

Multiattribute value and utility methods are receiving increasing recognition and application in industry. At Lockheed-Georgia, multiattribute methods have been used to assist in both program-level and design decisions. As part of the program risk analysis activity for the C-X proposal, we built an additive multiattribute utility model (Figure 8) to represent our customer's value system. This model was used to demonstrate how Lockheed's approach to C-X risk areas minimized program risk (maximized expected utility).

Two design decision studies have used multiattribute value models. The first was a model of the C-X Source Selection Criteria, used to screen potential cargo-box dimension combinations. The second model constructed lends structure to the numerous effectiveness criteria for a tactical airlifter. This is particularly significant since tactical airlift, with its multiplicity of missions, has historically resisted quantification of effectiveness and worth.

To use multiattribute methods to solve a management problem, the decision analyst needs five things:

1. A hierarchy of objectives and attributes.
2. Characteristics of each alternative in each of the attributes.
3. Utility or value functions, one for each attribute.
4. A weighting scheme for the hierarchy
5. A math model which accepts the information in 1, 2, 3, and 4 and outputs utility scores for each alternative.

The analyst must devote significant time to the first four activities which by their nature require repeated iteration and significant personal interaction. For this reason, the availability of an automated model (item 5) becomes significant. The analyst needs to be able to (1) input the multiattribute model and the characteristics of the alternatives in the attributes, and (2) have value, utility, or

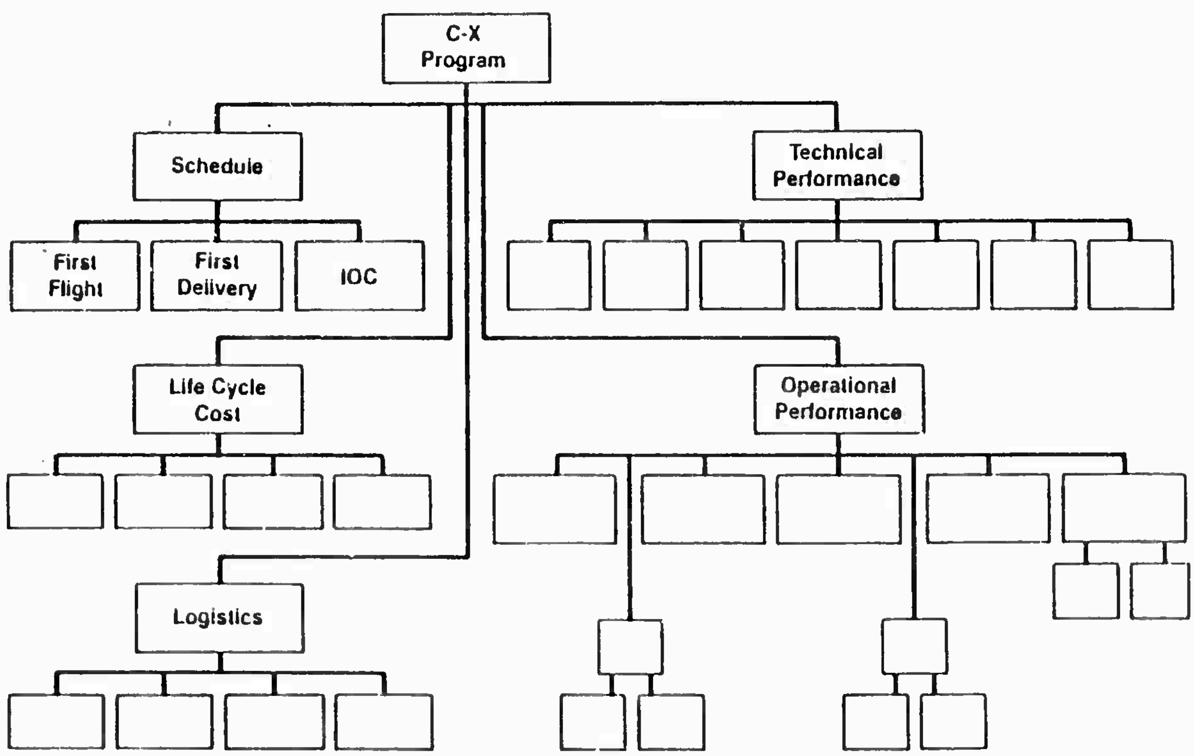

Figure 8. Typical Program Multiattribute Model

expected utility scores calculated and summed rapidly. A FORTRAN program developed under R&D by the project during 1981 (Reference 3) fulfills these two needs as well as permitting rapid plotting of utility and probability curves. A flow diagram is shown in Figure 9.

The preliminary work of defining criteria and alternatives, as described in Reference 4, is critical to the success of a multiattribute decision analysis. These activities should receive the majority of the study time, with numerical manipulation on the computer being the final step leading to recommendation.

Critical Path Method

The use of CPM networks in conjunction with project planning is well-known. Our experience in Advanced Design indicates that the difficulty in pinpointing start and end dates for technology development projects means that the most useful data a decision scientist can provide are: (1) how much can a development schedule be accelerated (feasibility), (2) which activities should be accelerated (and in what order), and (3) what will each increment cost. In the literature this is known as "time/cost crashing" and the computer code we use to estimate the acceleration is aptly named CPM/CRASH. A flow diagram for CPM/CRASH is shown in Figure 10.

Besides its basic usefulness, this program is interesting for two reasons. First, the program uses the algorithm described in Reference 5, "A Flow-Preserving Algorithm for the Time/Cost Trade-off Problem" and hence represents a direct transfer from academic research to industrial applications. Second, consider how CPM/CRASH works. Inputs to the model are (1) a network description of enabling activities, and (2) a linear time/ cost trade-off curve for each activity. CPM/CRASH systematically accelerates the development project, "crashing" the activity on the current critical path which gives the maximum time reduction per dollar until no further acceleration is possible. Zeleny (Reference 6, pp 55-58) points out that the project time/cost trade-off curve is an "efficient boundary" in the terminology of multiple criteria decisionmaking.

After obtaining a time/cost curve for the development project, the decision analyst must quantify the uncertainty in the predicted acceleration. A confidence band about the trade-off curve is needed. We obtain such a band by developing a probability distribution on project completion time at each of several costs ranging from normal to maximum acceleration. We use network simulation rather than the PERT formulas because of their well-known underestimation of both mean and variance in

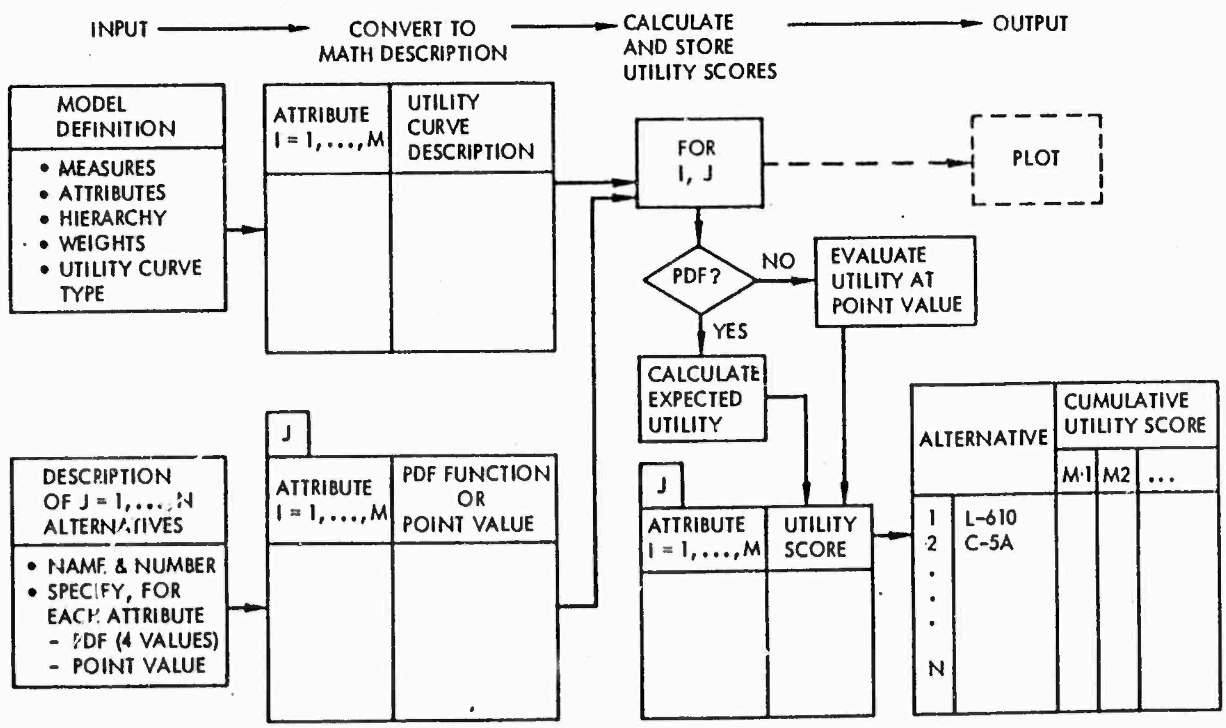

Figure 9. Flow Diagram for Multiattribute Decision Analysis

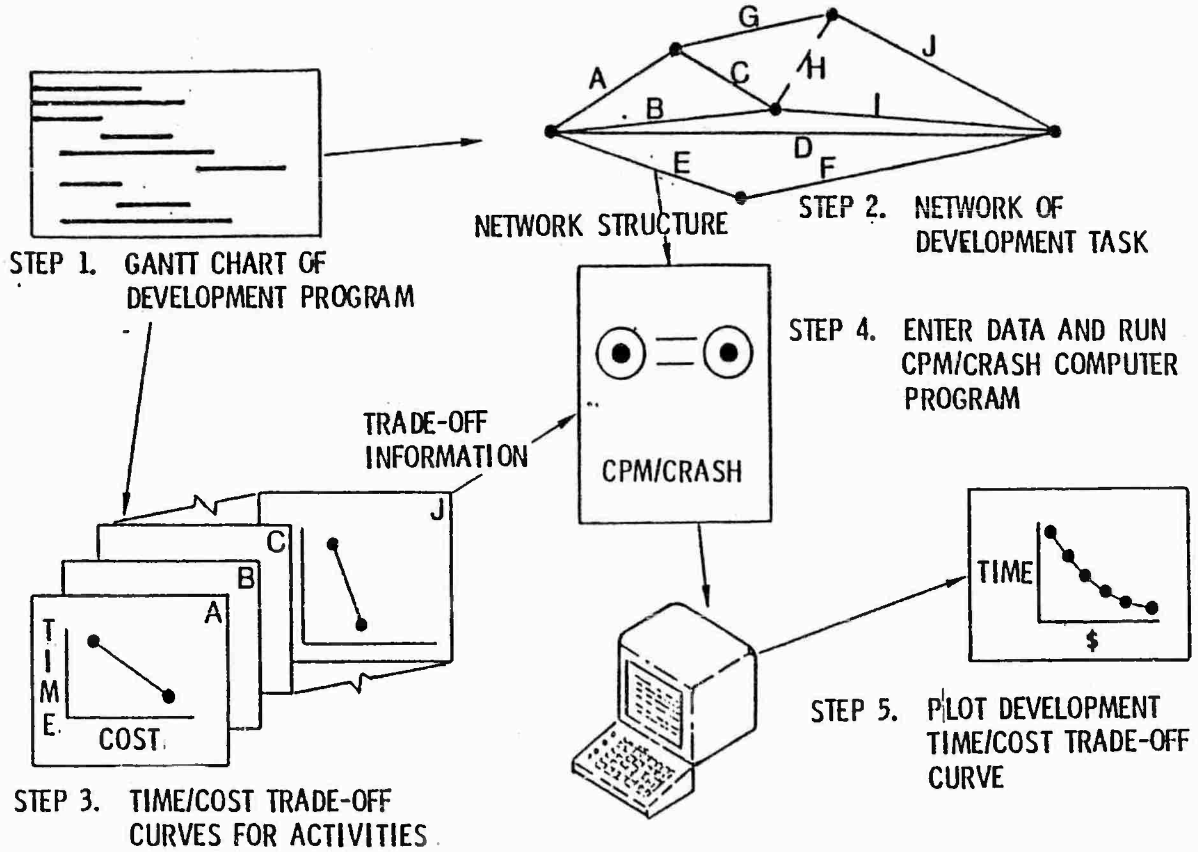

Figure 10. Process to Determine Project Time/Cost Tradeoff Curve

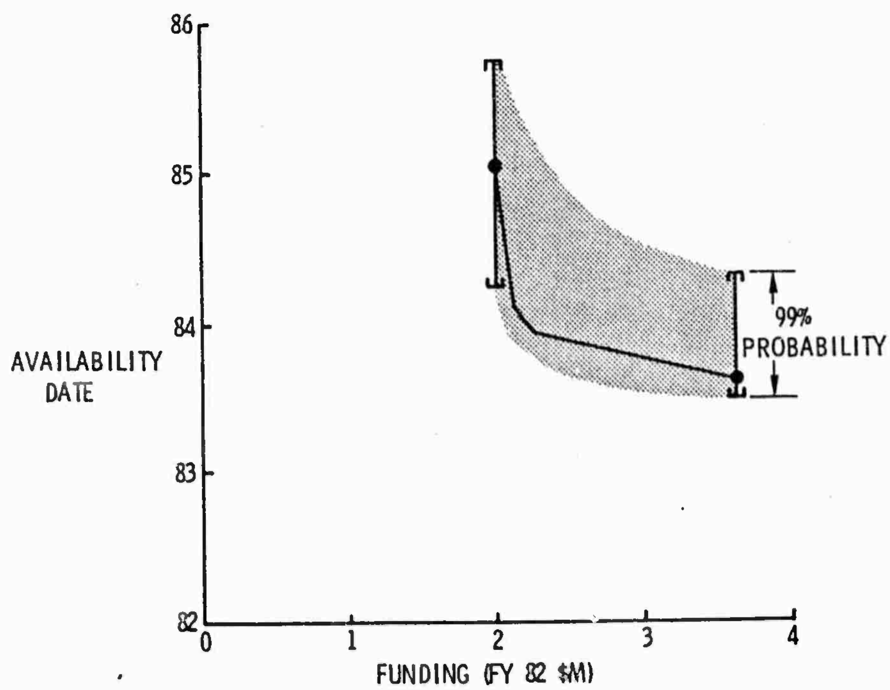

Figure 11. Confidence Band on CPM/CRASH Results

PROJECT STATUS AND DIRECTIONS

In this section, we summarize where we stand in three areas: (1) development of a unified framework for risk analysis studies of DoD procurement programs; (2) methods development beyond the basic tools in the preceding section; and (3) applications to problems in areas outside our current environment.

Program Risk Analysis Approach

Based on two years of methods development, our current approach to the types of risk studies required on new DoD business is shown in Figure 12. Our philosophy is that risk emanates from the technical definition of the system, manifesting itself in the probability that technology, mission, cost, or schedule goals will not be met. The first two models shown, QUALM and CPM/CRASH, are being used to conduct the technology assessment task of the study contract "Technology Alternatives for Airlift Deployment," sponsored by USAF Flight Dynamics Laboratory. QUALM is the Lockheed-Georgia software for implementing the quantitative uncertainty analysis process depicted earlier in Figure 5. The third model, called CPM/RISK, is an R&D task for the project in 1983. This model will take information on potential technical problems, provided by the specialties, and simulate the impact of these problems on a program activity network with both cost and schedule estimates on each arc. Model output will be probability distributions on project time and cost, as well as statistics for each activity (e.g., probability that an activity will be on the project critical path). CPM/RISK is a Lockheed-Georgia modification of a methodology conceived of by Kraemer at Boeing-Vertol (Reference 7).

Advanced Tools

We are developing more advanced tools than those discussed earlier. The reader can find adequate references in the open literature for the methods listed below. Each of these we consider necessary to make the step from adequate to outstanding methodology readiness.

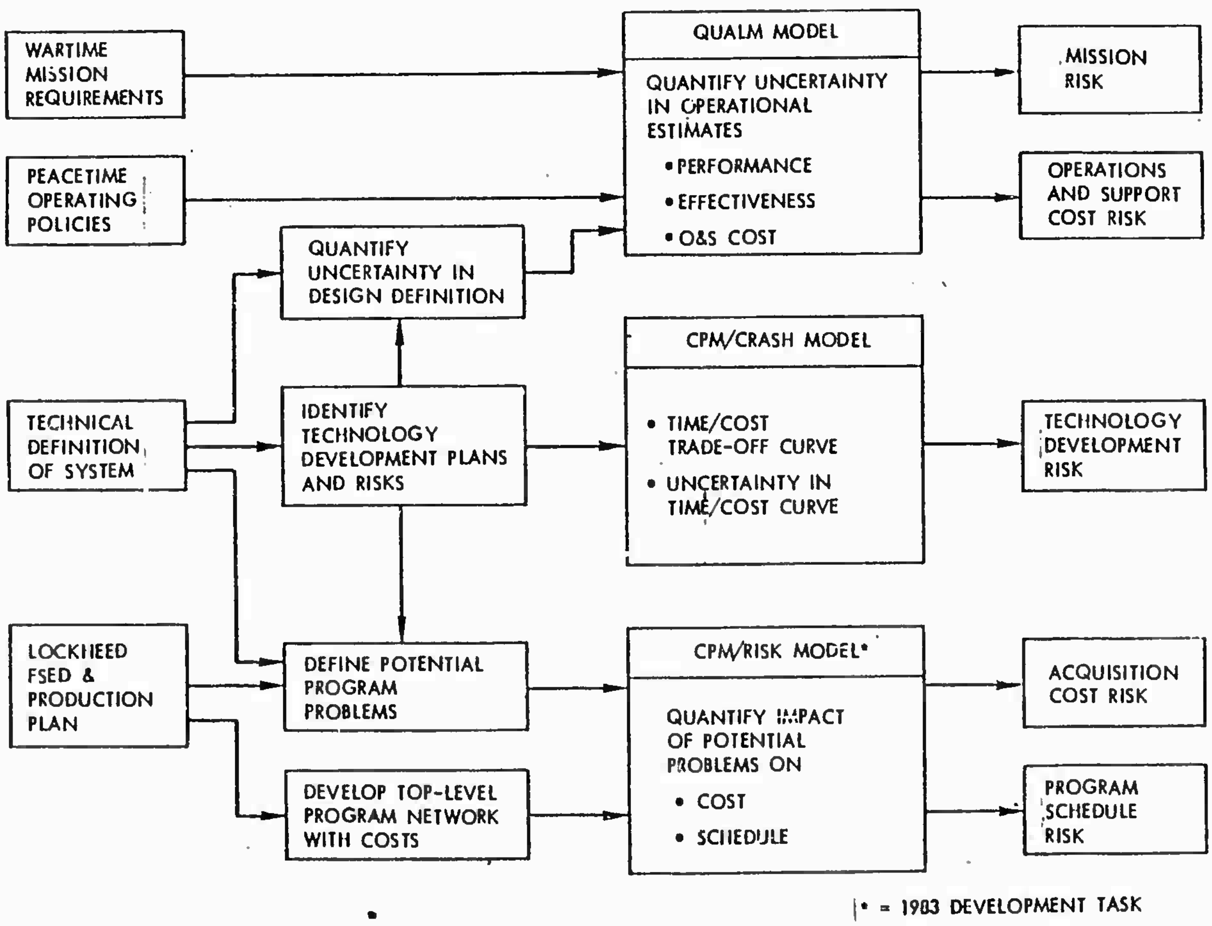

Figure 12. Unified Approach to Risk Analysis

Methods Currently Ready

- Goal Programming
- Decision Trees
- Statistical Package
- Venture Evaluation and Review Technique (VERT)
- Impact Diagram Method
- Iso-Risk Contour Method

Methods In Development or Ordered

- CPM/RISK Simulation Model
- Graphical Evaluation and Review Technique (GERT)
- Linear Multiobjective Programming
- DYNAMO

Extended Project Environment

As described earlier, through 1982 the project applications had been exclusively to activities within Lockheed-Georgia's Engineering Branch. Through a series of briefings in early 1983, we have reached out to other branches of the company, to other divisions of the corporation, and to potential DoD customers. The project environment has therefore been extended as shown in Figure 13, resulting in a respectable demand for our services. For example, we are currently engaged in studies for two directorates which report directly to the president -- Strategic Planning and Advanced Programs. We also are negotiating a government-funded study contract for 1983-84. These requests for our services simply reflect the fact that managers in technologically-oriented work have problems for which the decision analyst can offer structuring and quantitative insight.

While methods development will continue in 1984, we see our division of effort shifting from half-time methods development and half-time applications to 65-70% applications. In our view, we have tremendous advantages over an outside consultant when working on Lockheed-Georgia problems, even outside of our immediate environment — we are trusted with proprietary data, we are aware of problem subtleties and personalities, and we know the organization chain, both formal and informal. In summary, we are becoming the "in-house decision analysis staff" at Lockheed-Georgia, a development which Ulvila and Brown forecast for all large corporations in their recent paper "Decision Analysis Comes of Age," Reference 8.

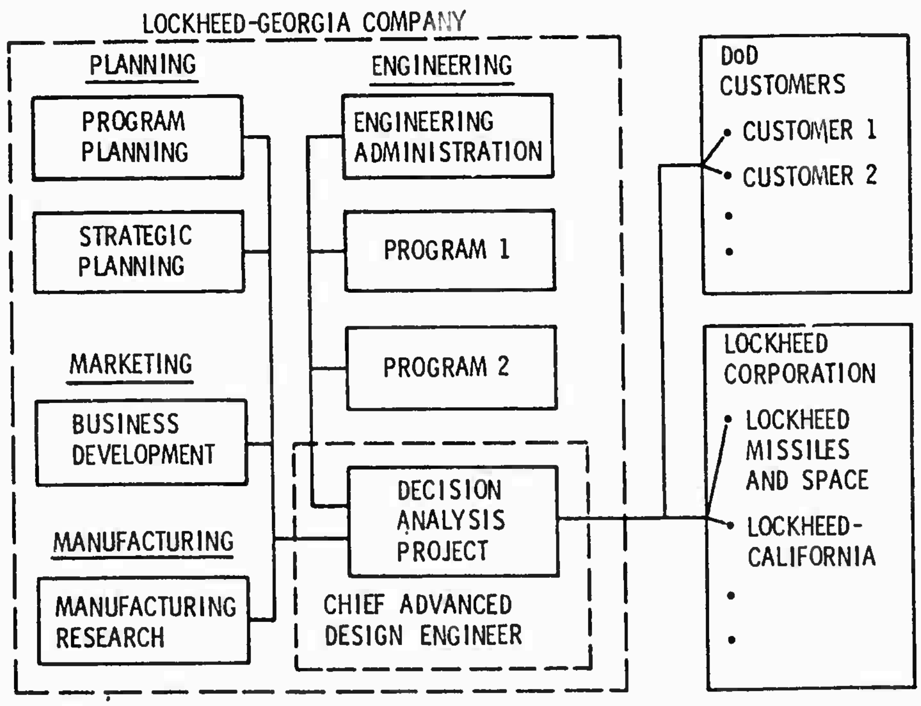

Figure 13. Extended Project Environment

CONCLUSIONS

The need for quantitative risk assessment on DoD technology studies and procurement programs has been recognized since the late 60s. Methodology evolved during the 70s to meet this need, and is now readily available. Methods exist to assess uncertainty in developing technologies — uncertainties in time and cost to reach maturity, and uncertainties in operational benefit at maturity. Once technologies advance to a point were they may be proposed on a new aircraft programs, methods exist to help identify and quantify program risk.

An analyst equipped with methods as described in this paper can contribute to the system/program definition and analysis. This contribution, of course, is dependent on management acceptance and engineering specialty support. Management wants risk studies performed because they are acutely aware of uncertainties, and because their counterparts in the government require risk be identified and measured. Engineers will cooperate with the risk analyst once they have seen that their specialty/judgment will not be misrepresented. The risk analyst has become an accepted member of conceptual design teams at Lockheed-Georgia, much as the cost analyst did 10-15 years earlier.

Risk analysis methods are treated as a technology at Lockheed-Georgia. IR&D funding permits analysts to improve existing methods, to perform research, and to create new methods and the accompanying computer codes. This funding has permitted us to build an adequate framework for risk analysis of defense systems and programs in less than three years. We have expanded into related decision sciences of network, analysis, statistical analysis, and decision analysis. While continuing to provide risk studies in engineering as our primary duty, we are now working on a broader variety of problems throughout the company.

REFERENCES

1. Air Force Systems Command, Aeronautical Systems Division, Request for Proposal No. F33657-80-R-0227, "Full Scale Engineering Development/Production: Interim Contractor Support and Spares for the C-X Aircraft System," October 1980.

2. Batson, R. G., "Description of the Model AFCUE: Airlift Fleet Cost-Effectiveness Uncertainty Estimator for Parametric Design Studies," Lockheed-Georgia Company, PM92D364-6, August 1982.

3. Bailey, T. M., and R. G. Batson, "Multi-attribute Decision Analysis Model (MADAM): Program Description and User's Guide," Lockheed-Georgia Company, LG81WP7292-002, August 1981.

4. Keeney, R. L., and H. Raiffa, Decisions with Multiple Objectives: Preferences and Value Tradeoffs, John Wiley & Sons, New York, 1976.

5. Tufekci, S., "A Flow-Preserving Algorithm for the Time/Cost Trade-off Problem," IIE Transactions, Vol. 14, No. 2, June 1982, pp. 109-113.

6. Zeleny, M., Multiple Criteria Decision Making, McGraw-Hill, New York, 1982.

7. Kraemer, G. T., "A Successful Quantitative Risk Assessment Technique," Journal of Parametrics, Vol. 1, No. 3, Winter 1982, pp. 13-21.

8. Ulvila, J. W., and R. V. Brown, "Decision Analysis Comes of Age," Harvard Business Review, Sep-Oct 1982, pp. 130-141.

AD P002301

QUANTITATIVE RISK ANALYSIS OF THE IMPACT OF MAJOR CHANGES ON NAVY PROGRAMS

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ABSTRACT

This paper presents an overview of Naval Sea Systems Command's (NAVSEA) experiences and current use of quantitative schedule risk analysis for major acquisition, ship overhaul and modernization programs. On February 7, 1983, Mr. Sawyer, then ASN(S&L) requested that a quantitative analysis be provided of the risk to ship delivery dates caused by the first introduction of a selected new system. NAVSEA, working with NAVMAT, surveyed the available schemes and current quantitative schedule risk analysis used by NAVSEA program managers to determine if a standard quantitative risk analysis schene should be used for all Navy programs. As a result, a number of risk analysis predictive systems were looked at, among them PROMAP, TRACE, and SMS. PROMAP experiences and lessons learned in project risk management will be presented in a separate paper by Mr. A. Feiler during this workshop. TRACE will be addressed by Mr. Grover, Mr. Alfieri and Mr. Cockerham during this workshop. This paper will describe very briefly the computer-based Schedule Management System (SMS) currently used by several program managers within NAVSEA for risk assessment as a management tool.

PURPOSE

The purpose of this paper is to provide to other services and to other departments within the Navy a report on current and planned use of quantitative risk assessment by NAVSEA as a management decision and reporting tool for major acquisition programs. Specifically, quantitative risk assessment/management as it relates to the acquisition schedule is addressed.

BACKGROUND

The Carlucci initiative (Reference 1) stated that review of 47 major acquisition programs indicated that there was a total overrun of 129% in final cost as compared to the milestone II estimates. Additionally, this report identified 15% of these overruns as being attributable to schedule change. It further reported that of the 45 programs with schedule change, 41 had increased costs. This is a significant problem considering the magnitude of these programs. The important question addressed here is what could have been done to forewarn the manager of these developing problems. In countering the possibility of cost overruns in major ship acquisition programs CHNAVMAT recognized that managers must take into consideration risk and uncertainty in their decision making processes. As a result, on December 13, 1982 the NMC revised the requirements for implementation of the NMC Selected Acquisitions Tracking System (NSATS) to reinforce the requirements for program managers to take risk factors into account within the SYSCOMS (Reference 2). In response NAVSEA published instructions updating NAVSEA Policy and Procedures of the revised NSATS (Reference 3). Under this instruction it is the policy of the Commander, Naval Sea Systems Command, that acquisition programs will be appraised, the results of which will provide consistent, timely assessments to ensure the programs are technically, financially, administratively, and logistically sound. These assessments are to provide a high degree of confidence that the programs are, in fact, sound and executable and reflect the position of COMNAVSEA and the Chief of Naval Material

(CNNAVMAT). This policy has been implemented at four levels within NAVSEA. The four levels are:

1. COMNAVSEA Appraisal. COMNAVSEA will appraise those acquisition programs recommended by the Acquisition Review Board (ARB), as well as others of his choosing.

2. NAVSEA ARB Appraisal. The ARB shall serve as the principal forum for review of acquisition category (ACAT) programs which are being presented to the Office of the Secretary of Defense (ACAT I), Secretary of the Navy (ACAT IIS), Chief of Naval Operations (ACAT IIC), the OPNAV Sponsor (ACAT III) and those being presented for NAVSEA approval (ACAT IV). The ARB shall also serve as the principal forum for program status appraisal of designated programs.

3. Directorate Appraisal. Acquisition programs which are listed in the NAVSEA Acquisition Program Index but are not appraised by the ARB will be appraised annually within the Directorate at a level senior to the Program Manager.

4. Program Manager Appraisal. Each NAVSEA acquisition program listed in the NAVSEA Acquisition Program Index will undergo Program Manager appraisal quarterly. The appraisal will be reflected in the quarterly Naval Material Command NSATS submission.

NSATS REPORTING REQUIREMENTS

Figure 1 depicts the NSAT program manager reporting format. Although selected programs within NAVSEA utilize quantitative risk

GREEN - Essentially On Plan (G)

YELLOW - Potential Significant Deviation From Plan (Y)

RED - Significant Deviation From Plan (R)

NET ASSESSMENT

ELEMENT	STATUS
PROGRAM PLANNING	○
SCHEDULE	○
DOCUMENTATION	○
FINANCIAL	○
RESOURCES	○
CONTRACTOR PERFORMANCE	○
GOVERNMENT PERFORMANCE	○
PRODUCT TECHNICAL INTEGRITY	○
LOGISTIC SUPPORT	○
FLEET INTRODUCTION	○
COMPUTER HARDWARE/SOFTWARE DEVELOPMENT & SYSTEM INTEGRATION	○
PROGRAM RISK	○

DOCUMENTATION STATUS

DOCUMENT	SYSCOM	CNM	CNO	SECNAV	SECDEF	STATUS
JMSNS/MENS/OR						○
PROJECT CHARTER						○
SMD						○
DCP/NDCP						○
TEMP						○
ACQ PLAN/ACQ STRAT						○
RAR/DSF						○
NAVY TRAINING PLAN						○
LOGISTIC SUPPORT PLAN						○
PRR						○

_________ PROGRAM PRODUCTION READINESS

- PRR PLAN: (SCHEDULED FOR ISSUE/ISSUED) ON________
- MILESTONE III DECISION IS PLANNED FOR__________
- CURRENT RISK ASSESSMENT:

PRODUCT DESIGN ------------------------------ ○
INDUSTRIAL RESOURCES ------------------------ ○
PRODUCTION ENGINEERING AND PLANNING --------- ○
MATERIAL AND PURCHASED PARTS ---------------- ○
QUALITY ASSURANCE --------------------------- ○
LOGISTICS ----------------------------------- ○
CONTRACT ADMINISTRATION --------------------- ○

LOGISTIC STATUS

	REQMTS	FUNDING	SCHEDULE
ILS PLAN	○	○	○
MAINTENANCE PLAN	○	○	○
SUPPLY SUPPORT	○	○	○
LOGISTIC TECH DATA	○	○	○
SUPPORT & TEST EQUIP	○	○	○
TRAINING & TRAINING DEVICES	○	○	○
MANPOWER/PERSONNEL	○	○	○
PACKAGING, HANDLING, STORAGE, & TRANSPORTATION	○	○	○
FACILITIES	○	○	○
COMPUTER RESOURCES SUPPORT	○	○	○
ILS AUDIT			
[illegible]			

FIGURE 1

analysis to meet program objectives, there is no uniform policy or guidance that requires the implementation of a standard quantitative risk assessment program/system.

QUALITATIVE AND QUANTITATIVE CONSIDERATIONS

Figure 1 represents some sample formats extracted from the NSAT system which are to be used by NAVMAT Acquisition Managers for the purposes of reporting their status during specific phases of an acquisition. Basically, for overall appraisal, NSATS utilizes a three point estimate - green, yellow and red. Green indicates the program element is essentially on plan, yellow indicates there is potential for significant deviation from plan, and red indicates there has been a significant deviation from the plan. These measures are subjective in nature with no specific threshholds established to define what is significant and what is not. It should be noted that the NSATS requirements do not provide a tool or method to assess and/or control risk. NSATS is a reporting format.

Essentially, these reporting requirements of program status are qualitative unless the manager has at his disposal the tools which allow him to quantify his program status in terms of technical, schedule, and cost factors. Only through use of such tools is the manager able to accurately measure progress against the plan. A quantifiable methodology permits a clear and measured definition of what is and what is not significant.

The program manager in order to quantify actual program status does not generally require additional information. The astute manager already has the preponderant planning and execution information at his disposal. Each program manager has his own plan for meeting program objectives. The plan normally entails what has to be done (activities), how long it takes to do a particular activity (the duration), how much it costs, the sequence of events, the logic associated with activities in the program, and the start and end dates. The program manager given this basic data has a strong, firm foundation upon which to add, at a reasonable cost to him in time and money, the ability to conduct quantitative risk management on his program.

Uncertainty is a key factor to be considered in the application of risk management. There are two types of uncertainty: first, the type most people call "unknown-unknowns" or "unk-unks". These are unpredictable variances. An example of an "unk-unk" would be damaging a component thus requiring it to be returned to the factory for rebuild. There are no systems which predict "unk-unks" but there are a number of variable factors that are in fact statistically predictable. For example, within an organization standard operating procedures state it will take 120 days from proposal receipt until a contract is awarded. From a procedural point of view and from a documentation point of view that's all well and good; however, a review of the records in their contracting office may show it actually has taken from 90 to 165 days with an expected duration of 120 days. The use of the 120 day figure alone would induce error where an estimate of 90 to 165 days with an average of 120 days is statistically more valid.

Secondly, within an overall program there is predictable uncertainty in varying degrees related to each individual activity. In order to manage the predictable uncertainty and risk in a program, it is necessary to determine those activities whose uncertainty must be controlled and those which do not need to be controlled. The list of activities that must be controlled changes as progress is made in a program. The attributes of a system capable of handling uncertainty and risk are several. First, such a system must have a deterministic base to allow a program manager to load his program plan. Secondly, it must have the ability to handle stochastic or probabilistic elements of uncertainty in each activity. Thirdly, it must facilitate updating on a continuing basis during the evolution of the program in order that progress can be recorded against the original plan. In quantifying progress vs. plan the most important aspect is that the assessment be objective and reflect true progress. An example of the absence of true status assessment, or objective assessment, is assuming that 50% of an activity is complete when 50% of the manhours originally planned for the activity have been expended. In perpetuating this error many industrial activities report only the beginning of an activity and the completion of an activity in a truly objective way and any intermediate progress is a function of the expenditure of manhours against the plan. The reason the objective assessment of current status of a program is so critically important is that if one waits until reported completion (having missed a milestone) one has in fact missed the opportunity to take early corrective action. The fourth attribute required is the ability to make predictive projections in a way that permits one to determine whether or not they are still capable of meeting schedule and what degree of risk is associated with achieving it. The final attribute is the ability to play "what if" games thus permitting the manager to handle the effects of something happening that is not in the plan, e.g., the unexpected. These capabilities must be part of a system that is capable of modelling the program as the program manager perceives it. The manager must be able to tailor the system to his specific program, not vice-versa.

THE ORIGIN OF QUANTITATIVE RISK MANAGEMENT IN NAVSEA

The Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) were developed in the 1950's. The strong point of CPM was incorporation of networking. PERT additionally accounted for estimating bias. Both required the development of a careful plan from beginning to end. Prior to PERT/CPM, managers had mainly used bar or GANTT type charts. The ability to conduct simulations had been available since the 1880's and with the advent of structured networking and improved computer capabilities probabilistic network simulation became a reality.

The Naval Sea Systems Command became involved in risk management with respect to shipbuilding in the 1960's. NAVSEA initiated development of a system that permitted probabilistic risk analysis of ship acquisition projects. The product became known as PROMAP and was delivered to the Naval Sea Systems Command in the early 1970's. As a result of numerous applications to ongoing ship programs and lessons learned, there followed the development of the Schedule Management System (SMS). SMS has significant capabilities beyond those of early PROMAP. These improvements include a capability to compare probabilistic projection to plan in such a manner as to tell the program manager if his project is on schedule; and if not, what management action he can take to get it back on schedule.

DETERMINISTIC AND PROBABILISTIC METHODS

There are three principle factors that comprise the difference between deterministic and probabilistic analysis. These factors are: 1) estimating bias, the difference between the estimate given by planners and estimators, and the value expected to be realized after the activity has been completed; 2) nodal bias, the phenomenon that occurs at each node in a network where the completion distributions of the predecessor activities overlap; and 3) criticality, the probability that any particular activity will be on the path that ultimately drives the network. These three factors coupled with network logic generate three sets of results from the analysis of a network. These results are: 1) the schedule or planned dates for the network; 2) the deterministic projections resulting from having simulated the network deterministically; and, 3) the probabilistic projections resulting from having simulated the network probabilistically. Figure 2 shows that these three results can occur in three possible configurations on the time line. The first configuration, on the left of Figure 2, is that in which both the deterministic and probabilistic results indicate that the network will complete prior to the schedule date. This particular condition has little risk of not completing on schedule, and the program is considered to be in condition green. This is consistent with the NSATS condition green which is defined as being "essentially on plan". The second configuration of these three projections is shown in the middle of Figure 2. In this configuration the deterministic projection indicates that the schedule can be met, while the probabilistic projection shows that completion is expected to exceed schedule. This is defined as condition yellow and is considered to have acceptable risk. This is consistent with the NSATS yellow condition which is defined as having a "potential significant deviation from plan" - that is, the deterministic results show that in fact the program can meet its schedule but the probabilistic results indicate there is potential for exceeding the program schedule. The third configuration, on the right of Figure 2, is that in which both the deterministic and probabilistic projections predict that completion will exceed schedule. This is defined as condition red and is considered to have unacceptable risk. This definition is also consistent with the NSATS definition of red which is defined as being a "significant deviation from plan". In this third case, even if the program were to follow the originally planned sequence and durations it will complete on the deterministic projection, and will have experienced a significant deviation from the original plan which is reflected in the schedule dates.

RISK MANAGEMENT

A manager must understand which condition of risk his program is in. Reference to Figure 3 shows

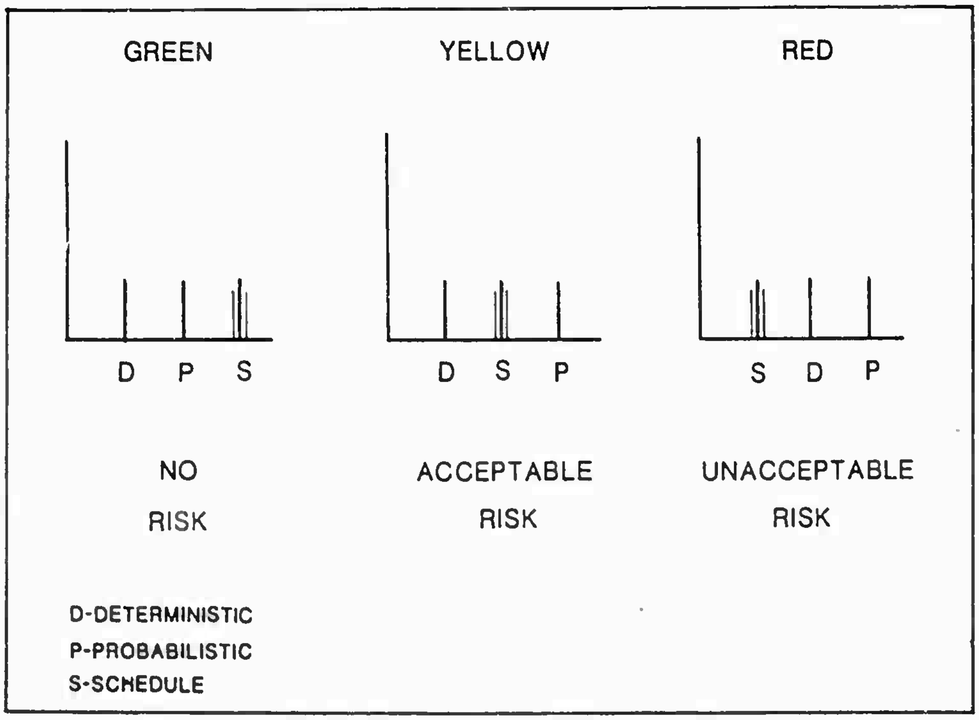

FIGURE 2 THREE CONDITIONS OF RISK

the three program conditions of risk at the top. In condition green the system output is a critical path network and tabular listing of each activity's start and complete dates. The management action at this point is simply to monitor the program because as long as it continues to follow plan (meet deterministic dates), even with the uncertainty aspects taken into account, the schedule will be met. Optionally, as a management action, the program manager might consider a reschedule of the program due to the slack, which the workforce has a tendency to expand to fill.

In the second condition, condition yellow, the system output is more extensive. A critical path network is generated which depicts those activities which have some probability of impacting on the schedule. Additionally, a watch list is provided. The management action required in this condition is to insure that the program does not track along the probabilistic predictions, since they inevitably lead to late completion. This is done by a means of the watch list. The watch list is simply a tabulation of the minimum number of activities, beginning with those currently underway, that must be held to their deterministic dates in order to ensure that there is sufficient slack in the remaining portions of the program to accommodate the uncertainty without being late. This is essentially a list of the activities that must be held to their dates. The list is then subdivided into time periods and functional areas so that each subordinate is given a short list of specific items to be controlled during the next reporting period. The advantage of this approach is to conserve management resources by directing attention only to those activities with potential to cause deviation from plan.

In the third condition, condition red, the system output is in the form of a man-machine interface permitting workaround plan development and evaluation through user interaction with the simulation model. This is necessary to accommodate the management action necessary to intervene in the network and take overt action to bring the program back under control. In the

ANALYSIS • REDUCTION • CONTROL

CONDITION	GREEN	YELLOW	RED
SYSTEM OUTPUT	CRITICAL PATH NETWORK	CRITICAL PATH NETWORK & WATCH LIST	WORK AROUND DEVELOPMENT
MANAGEMENT ACTION	MONITOR OR RESCHEDULE (OPTIONAL)	CONTROL	INTERVENTION (REQUIRED)

FIGURE 3

process of condition red gaming, the system generates a list of those activities that impact on the network in an adverse way, the manager or analyst selects a potential corrective action and applies it to that list of activities, tests that action interactively with a simulation and determines the impact of his action. The system red module then determines if sufficient action has been taken to bring the network back into a yellow condition. If so, this is considered an alternative; if not, additional impacting activities are listed and other alternative actions are identified, an action is selected and tested, and the process is repeated until sufficient corrective action is taken to bring the program back into condition yellow. When this is done it's identified as an alternative and documented by the system. At the end of each alternative developed the analyst or manager is given the opportunity to reset the scenario and replay the system red analysis to generate a different alternative.

After a number of these alternatives have been generated, the program manager then may select a specific alternative. Those overt actions selected in that alternative are documented as the revised plan in the system, the simulation is run and a critical path and a watch list are generated from the resultant condition yellow status. The documented alternative then becomes the manager's directed action to bring the program back on schedule.

The condition red workaround capability can also be applied to conditions other than red and forms the basis for a general "what if" gaming capability.

CURRENT APPLICATIONS

NAVSEA has a number of program managers that currently use the Schedule Management System. Most significant are the CV SLEP program manager, the High Energy Laser Research and Development program manager, the Mine Counter Measure Acquisition program manager, and the Amphibious Ship Acquisition program manager. SMS is also being used by the Marine Corp in the LVT(X) program with regard to logistics support. NAVAIR is currently using the cost oriented TRACE concept on a number of programs.

SUMMARY

In summary, it should be noted that there is certainly every indication from the review of a large number of DoD major acquisitions that the ability to control projects within cost and schedule is a problem. The most significant element in trying to control a schedule problem is to identify and understand it, followed by timely determination of exactly where and how much specific intervention is required to bring the program under control.

There is a Navy policy which directs managers' attention to evaluation and control of risk but there is no official position on how this is to be done. Currently, the closest approximation to actual control is a requirement that subjective reporting be done in accordance with the NSATS program manager appraisal requirements. However, the Navy Acquisition Research Council is sponsoring, through the Defense System Management College, the development of a Risk Assessment Management Handbook.

The Naval Sea Systems Command has over the years been involved in the development of risk analysis tools and has been involved in the application of these tools to major programs. SMS is one of these tools that is successfully used on a number of NAVSEA programs. It permits the manager to incorporate his plan in a network format, and, by application of progress vs. plan reporting by qualified, experienced people the manager is able to accurately assess program status. One of the most important elements of any quantitative analysis scheme is the grass roots technical knowledge of the program in order to assign deterministic schedules and to assign probabilistic range values for any activity. The Monte Carlo simulation identifies those areas of uncertainty which have the potential to impact program objectives, quantifies this impact, and directs management attention to those minimum areas that must be controlled in order to maintain schedule adherence. In the situation where activity progress is no longer contained within the plan, the system indicates whether that lack of containment will directly contribute to an overall project overrun of schedule. In those cases where objectives are not effected management action is not required, in all other cases management action is required. Where action is required the system permits the manager to experiment and simulate various management actions thus developing alternative solutions to the problem considering elements of cost, time and feasibility. The program manager can select the best alternative and insert the appropriate changes into the model. The system then documents new dates that become his new schedule direction to the program staff.

In conclusion, it can be stated that although quantitative risk analysis is being used by some program managers, it is apparent that many program managers neither support nor appreciate the total benefits which would accrue with the application of quantitative risk management to their program. If quantitative risk analysis is to be used cost effectively as a management tool, it requires high level technical and management support and involvement. There can be little doubt that given the Carlucci initiatives and congressional sensitivity to cost overruns associated with major acquisition programs, that the trend for acquisition program managers is toward the utilization of quantitative risk management.

REFERENCES

1 - Carlucci Initiative No. 4 Increase Program Stability in the Acquisition Process. April 30, 1981.

2 - NAVMATINST 5200.43B of 13 December 1982. Subject: NMC Selected Acquisitions Tracking System (NSATS).

3 - NAVSEAINST 5000.3B of 1 June 1983. Subject: Acquisition Program Appraisal within the Naval Sea Systems Command.

Procedures for Modelling TRACE-P Estimates

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ABSTRACT

TRACE-P, Total Risk Assessing Cost Estimate for Production, is intended as a contingency-funding vehicle for the first three years of production of designated systems. TRACE-P extends the TRACE concept of RDTE to Production, and serves to quantify risks in terms of their cost impact on designated systems. A mechanism is proposed here for generating such risk costs. It extends the use and application of the contractor's Work Breakdown Structure (WBS) in identifying risk prone areas, and combines the WBS with probabilistic networking techniques to create a data structure which generates risk costs for the designated program.

PURPOSE

The purpose of this paper is to show how the Venture Evaluation and Review Technique ~~(VERT)~~ networking model can be combined with the contractor Work Breakdown Structure in a way that provides the Program Manager with a powerful tool in determining potential risk costs to his program.

INTRODUCTION

TRACE-P, Total Risk Assessing Cost Estimate for Production, is intended as a contingency-funding vehicle for the first three years of production of designated systems. TRACE-P continues the TRACE concept of RDTE, and serves to quantify risks in terms of their cost impact on designated systems. The proposed mechanism for generating such risk costs involves no new reporting format. In fact, it merely extends the use and application of an existing reporting vehicle, the contractor's Work Breakdown Structure (WBS). The reasons for using the WBS are plain:

1. Virtually all risk-prone activities are performed by the contractor, not Government. Government is responsible for managing programs with risk; contractors encounter risk in actual execution of these programs.

2. The WBS hierarchy is a very convenient format to use in identifying those contractor activities which are more risk-prone than others. Thus, use of documents such as the contractor's Production Plan, Development Test/Operational Test reports, Production Readiness Reviews, Technical Data Packages, etc. in conjunction with the WBS will allow simple identification of risk prone areas.

The WBS is seen to be a powerful means of isolating risk to those pertinent work areas. However, the WBS in and of itself provides an incomplete picture of any contractual effort. This is because although the WBS shows the hierarchial organization of tasks, it does not show the manner in which these tasks are executed, nor the relation of the tasks to each other from a schedule network perspective. The full potential of the WBS as an analytical tool is therefore limited if we restrict our use of it to its hierarchial form.

POLICY CONSIDERATIONS FOR THE WBS

At present, the contractor's WBS is used by the government as the basis for tracking contractor cost and performance. In fact, Cost/Schedule Control Systems Criteria (C/SCSC) reporting is essentially one of the few uses to which the CWBS is applied in project management. In many instances, an examination of contractor schedules show that activities and milestones often relate to Contractor Data Requirements List items more than they do to the WBS. This lack of correlation can lead to needless confusion. Further, because schedule information does not track with the WBS, any projections addressing schedule or cost uncertainty will of necessity come from two diverse sources - the contractor's schedule and the WBS work packages, respectively. What is needed is a means of tying cost and schedule considerations together, and this objective can be readily obtained by a change in the use of the contractor's WBS and schedule network data.

It is proposed that contractors be required to submit schedule network diagrams of their activities and milestones so that the following minimum criteria are met:

(1) Each WBS element corresponds to one arc at an appropriate level. The coarsest level of detail should be level 3, and where specified by the government, should be 4 or lower if finer detail is required.

(2) For each arc, the contractor must provide its expected cost and duration, with all costs expressed in common units and all times expressed in common units. The expected cost should be readily available because in most cases that will correspond to the value of some work package.

(3) The network should be structured so that time phasing of activities and milestones will be readily apparent; the interrelationships between activities and milestones (i.e., network logic) also should be readily apparent.

(4) Activities which cannot be included as part of the WBS but which do affect time and cost must be included in the network.

(5) The network must span a period of time covering contract award to last delivery, and the sum of the costs for all arcs in the network must equal the contract cost or appropriate financial measure.

A few comments are in order here. First, the use of the WBS as the basis for a schedule network to be submitted by the contractor is certainly achievable. The imposition of such a requirement on him should not be any great hardship, because such information must already be at hand. For example, the contractor must know how his work is organized and he must have a fairly good idea of how much time and money each piece of the work will require. From the government perspective this is a very reasonable expectation. However, we must next consider the contractor's concerns. Often the WBS is devised in such a way that it simply does not make sense to use the WBS for presenting schedule data. Consequently, the contractor is forced to present schedule data in a manner different from the WBS. If the method proposed here is to work, government managers must choose and devise WBS elements in such a way that their portrayal in schedule format becomes feasible. One way this can be accomplished is if the WBS is not strictly bound to the hardware/software configuration of a system and its corresponding subsystems. If instead the WBS is portrayed to have as its subelements the activities associated with any particular subsystem, then it will be a simple matter for the contractor to provide the WBS-derived schedule. For example, if a piece of electronics equipment were to be developed, the WBS for that equipment might include subelements headed "Design", "Breadboard", "Test". In this way all WBS elements will be included in the schedule network. It is again stressed that if this concept is to work, government and contractual management alike are going to have to view the WBS as a vehicle for other than CSSRs, CPRs and the like. The WBS concept in the presently proposed form is expanded to provide total contract and, therefore, total project representation in a manner which unifies cost and schedule considerations. That is why the policy regarding the use of the WBS as well as the means of reporting schedule and cost needs to be reviewed and changed. Only then will the benefits that the remainder of this report discusses be realized. Extending the use of the WBS will as a minimum provide the government with a data base for its TRACE-P analyses.

THE WBS DATA BASE AND VERT

Many current tools of generating risk costs involve analysis of the WBS in its tabular form, or at best a bar chart schedule which lists each activity in a more or less standalone fashion. The Venture Evaluation Review Technique (VERT) eliminates these deficiencies by allowing program activities to be linked together in a symbolic network which is then probabilistically exercised for many (several hundred) iterations, dynamically testing program activities and their interfaces. Unlike other networking techniques which have fixed input data, VERT allows for functional relationships to be defined, i.e., the cost of one activity may be a function of the time-or manpower-loading of that activity, or of other related activities. This allows a more realistic modelling to be conducted of the contactor's work, thereby providing a refined measure of the associated risk costs compared to other analytical tools. The only additional requirement that use of the VERT techniques would impose on contractor personnel is that they provide WBS schedule data in network form, similar to PERT-type diagrams. We repeat our assertion that these data should be readily available from the contractor because the various cost account managers have to know how they are spending money on the work being performed. Once the data are provided to the Government in this format, the Government analyst can structure the VERT network and conduct the necessary activities needed in preparing the numerical data to be exercised by the network logic. VERT would then generate histogram data on cost and time which would predict the contractor's performance based on the input data.

SAMPLE CASE TRACE-P USING VERT

To illustrate the application of these procedures to generating TRACE-P estimates, we consider the hypothetical System X whose WBS and production schedule are shown in Figure 1. System X has four major subsystems which are produced in parallel, and then integrated and tested before delivered to the government. In the past, a TRACE-P estimate for System X would have been generated by having personnel with appropriate expertise examine each WBS element or else each risk element, and quantify the risk for each element in the form of a numeri-

Syetem X

WBS (Down to Level 1 Only)

X

XA

XB

XC

XD

Typical Schedule

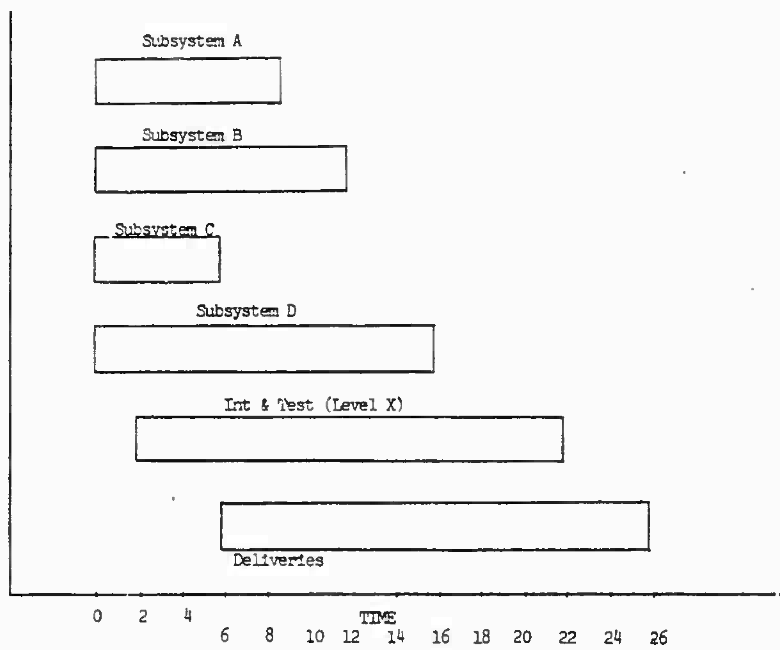

Figure 1.

cal multiplier. For example, if element XA costs $1 and it is determined that a risk multiplier of 1.25 is appropriate for XA, then XA's contribution to the TRACE-P is $1.25. The full TRACE-P would be the sum of all such products. In this manner, each element contributes its portion to the TRACE-P in the form of a point estimate; the TRACE-P for System X is also a point estimate which is the sum of the point estimates for each WBS element. So although the risk factor method is useful in identifying risk areas and their contributions to TRACE-P, nevertheless the outcome of this type of approach is one number, a point estimate.

In the method proposed here, the contractor would provide the Government schedule information on the WBS in the network form of Figure 2. Each arc in the network corresponds to an element of the WBS, and therefore the associated cost with that element can be readily provided by the contractor. Uncertainties in cost and schedule can now be examined in the light of this network representation; for example, in the network for Systems X's WBS, integration and test cannot begin until after unit #1 for each subsystem has been fabricated; this in turn affects the start of production deliveries. If there is a stretchout in the production schedule, the cost associated with that affected portion of the schedule can be modelled in VERT as a function of time, and the spread in time values will provide a more

System X WBS Network

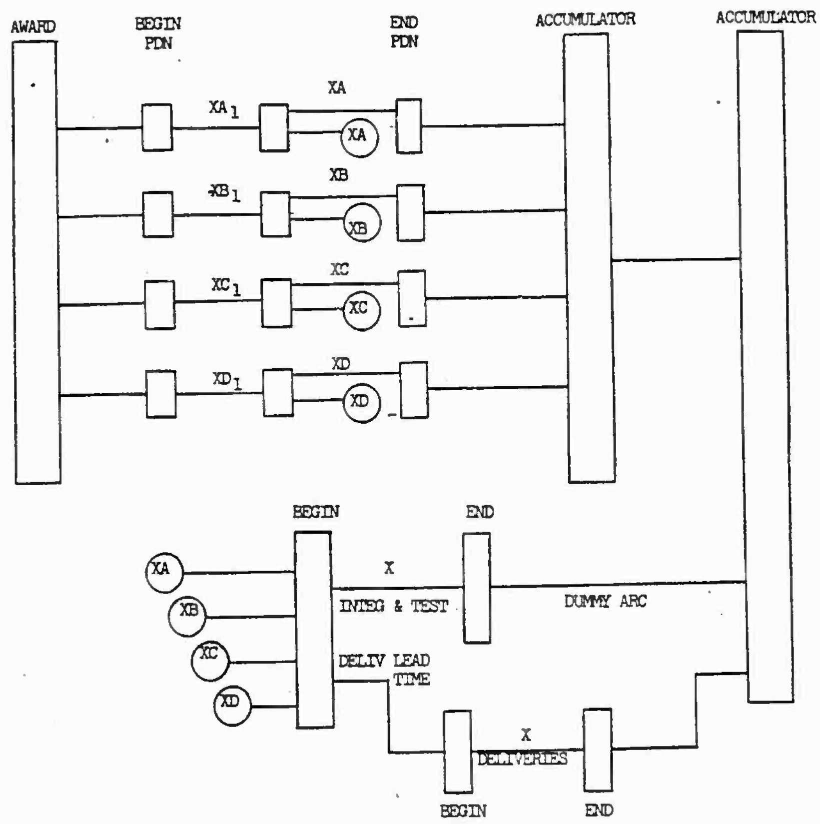

Figure 2.

deterministic basis for the TRACE-P generated. The spreads in time and cost can be determined by consultation with Government technical and contractual experts familiar with the WBS element under scrutiny. The analyst can incorporate this information in the VERT data base, and then by exercising the WBS network with VERT, a measure of System X's TRACE-P costs can be obtained.

Table 1 is a list of hypothetical input values for time and cost that VERT would use in simulating System X's project. The time parameters are given in a form suited to the use of the triangular probability density distribution; however, VERT permits the use of many distributions, and if another distribution were more applicable for modelling time, such as the exponential, normal or binomial, the data applicable to their use could be easily formatted for execution by VERT. Regardless of the distribution used, the data would have been obtained from detailed conversations with area specialists so as to assure inclusion of their expert opinions in forming the VERT data base. The same would also apply to the costs being modelled.

Cost distributions are the central issue when it comes to discussing TRACE-P, and for the WBS elements of System X, it was decided to choose their representative costs as being linear functions of the time required to complete each activity, thereby illustrating the great flexibility of the VERT system in generating TRACE-P figures. To further clarify, consider

System X WBS Network
Input Data

		TIME		
		MIN	MOST LIKELY	MAX
X(INIT + TEST)		20.0	20.0	24.0
X(DELIV LEAD TIME)		4.0	4.0	4.0
X(DELIVERIES)		20.0	20.0	22.0
XA_1	1st PDN UNIT	1.0	1.0	2.0
XB_1		2.0	2.0	4.0
XC_1		1.0	1.0	2.0
XD_1		3.0	3.0	4.0
XA	PDN UNITS 2-END	8.0	8.0	10.0
XB		10.0	10.0	12.0
XC		5.0	5.0	6.0
XD		13.0	13.0	15.0

		COST
X(INT + TEST)		$500 + 100\ \{(T_{XB_1}-2) + (T_X-20)\}$
XA_1	1st PDN UNIT	$100 + 200\ (T_{XA_1}-1)$
XB_1		$100 + 250\ (T_{XB_1}-2)$
XC_1		$100 + 100\ (T_{XC_1}-1)$
XD_1		$250 + 150\ (T_{XD_1}-3)$
XA	PDN UNITS 2-END	$900 + 200\ (T_{XA}-8)$
XB		$900 + 250\ (T_{XB}-10)$
XC		$500 + 100\ (T_{XC}-5)$
XD		$750 + 150\ (T_{XD}-13)$

Table 1.

the cost expression for the first unit production of subsystem A. The expression is:

$$C = 100 + 200\ (T_{XA_1} - 1).$$

The time data for subsystem A indicates a most likely and also a minimum requirement of 1 month to produce the first unit before it is sent forward for integration and test. The cost relationship here is structured in such a way that if the time required to produce subsystem A's first unit exceeds 1 month, a penalty of $200K times the excess measured in months exceeding 1 month will be incurred. This would correspond to a real world situation where the contractor would need to hire many highly skilled workers, or make additional capital investments to assure minimal schedule slippage. However, if there is no slippage, no cost penalty is incurred. Each subsystem has its own cost penalty. As VERT exercises the System X WBS network, random time values for the respective WBS subelements are incurred for each iteration of VERT, thereby generating different cost penalties.

If the contractor were 100% certain of meeting his schedule, there would be no variability in time and hence no cost penalties. The total contractual cost would be $4100K, which is the sum of the constant parts of all the WBS subelement costs in Table 1. However, there is schedule uncertainty, which is reflected in the fact that the time data for each subelement of System X is described by a probability distribution. This in turn causes various cost penalties to be incurred for each iteration of the

System X network by VERT. After the number of iterations is completed, VERT will generate histograms of cost data - by sequential time period and for the program's full duration - which the Program manager/analyst may use in selecting an appropriate risk level for TRACE-P funding. Figures 3-6 are histograms generated by VERT for months 0-12, 12-24, 24-36, and 0-36 of the program, providing the PM with anticipated yearly costs as well as anticipated program costs. If, for example, the Program Manager of System X wishes to be conservative during the first year of the program, he might pick the 90% point of the histogram for months 0-12. This can be found by interpolating the cumulative distribution function values, which bracket the 90% point, and comes out to $4404K for year 1. The meaning of this choice is simply, that of all the cost values generated by VERT for year 1 of System X, the value $4404K was exceeded only for 10% of those iterations, and therefore, it exceeded 90% of the cost values generated for that year. By selecting a large number of iterations we can be statistically confident that costs will fall within this arena, providing we have an accurate representation of subelement costs and schedules. Use of the WBS helps to assure this aspect of getting an accurate handle on TRACE-P.

Analagous choices of percentile points can be made for years 2 and 3 of System X. In this manner, the risk funding level may be lowered for years 2 and 3 if the PM feels such actions are warranted. The overall program risk funding level may be found by summing costs for years 1, 2 and 3 and reading the value obtained off the overall program cost histogram, Figure 6. To again illustrate, the 90% point for year 1 was found to be $4404K. For year 2 (months 12-24), let us read directly off the histogram. The 81.8% point is $941K, and let us suppose the PM is satisfied with this figure, i.e., of the cost generated by VERT for year 2, they did not exceed $941K for 81.8% of the total iterations. For year 3, suppose the PM selected the 73.3% point which reads as $56K. The sum of these 3 figures, 4404 + 941 + 56, is $5401K, and this corresponds to an overall program risk funding level of about 90%, as shown in Figure 6. That is to say, in order to be 90% confident that System X's contractor costs will not exceed his budget, the PM would need to have on hand $5401K, or 31.7% above the initial projected cost of $4100K. Whether or not such a contingency funding level is appropriate for a system entering production will not be discussed here. The example chosen had purposely built-in severe cost penalties to illustrate the nature of TRACE-P issues. If the PM wished to be less conservative in this example, he might be willing to go for a 70% confidence level. The new total cost as read from Figure 6 would then be $5190K, or 26.6% above the contract budget. The TRACE-P deferral for the 3 years would be $1090K ($5190K - 4100K). The PM could then allocate the TRACE-P deferral among each program year, verifying that when the deferral is added to the baseline for all three years, they sum up to the $5190K. Whatever course is taken, the WBS network approach permits the PM to make difficult decisions with more useful information at his disposal. With cost becoming an increasingly scrutinized arena, the VERT-WBS methodology for generating TRACE-P estimates cannot be ignored.

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POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF       0.0  -       12.00

                    CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
          3823.2524 I----I----I----I----I----I----I----I----I----I----I MIN
                    I                                                   0.0
          3823.2524 I
                    I*                                                  0.012
          3863.0930 I
                    I*                                                  0.018
          3902.9336 I
                    I**                                                 0.046
          3942.7742 I
                    I****                                               0.078
          3982.6147 I
                    I*******                                            0.132
          4022.4553 I
                    I**********                                         0.200
          4062.2959 I
                    I*************                                      0.258
          4102.1328 I
                    I******************                                 0.354
          4141.9727 I
                    I***********************                            0.470
          4181.8125 I
                    I****************************                       0.568
          4221.6523 I
                    I*********************************                  0.654
          4261.4922 I
                    I**************************************             0.754
          4301.3320 I
                    I*****************************************          0.828
          4341.1719 I
                    I********************************************       0.876
          4381.0117 I
                    I**********************************************     0.918
          4420.8516 I
                    I***********************************************    0.940
          4460.6914 I
                    I************************************************   0.966
          4500.5312 I
                    I*************************************************  0.980
          4540.3711 I
                    I**************************************************0.992
          4580.2109 I
                    I**************************************************0.996
          4620.0508 I
                    I**************************************************0.998
          4659.8906 I
                    I**************************************************1.000
          4699.7461 I
                    I**************************************************1.000
          4699.7461 I----I----I----I----I----I----I----I----I----I----I MAX

                    NO OBS------------      500  STD ERROR-          155.6463
                    COEF OF VARIATION-     0.04  MEAN------         4200.5117
                    KURTOSIS (BETA 2)-     2.83  MEDIAN----         4196.2227
                    PEARSONIAN SKEW---     0.24  MODE------         4162.9375
```

FIGURE 3

```
POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF     12.00 -       24.00

                 CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
      589.7739 I----I----I----I----I----I----I----I----I----I----I MIN
               I                                                  0.0
      589.7739 I
               I*                                                 0.012
      616.8157 I
               I*                                                 0.020
      643.8574 I
               I**                                                0.050
      670.8992 I
               I****                                              0.088
      697.9409 I
               I*******                                           0.148
      724.9827 I
               I***********                                       0.226
      752.0244 I
               I****************                                  0.318
      779.0662 I
               I*********************                             0.426
      806.1079 I
               I*************************                         0.496
      833.1497 I
               I******************************                    0.600
      860.1914 I
               I**********************************                0.688
      887.2332 I
               I**************************************            0.766
      914.2749 I
               I*****************************************         0.818
      941.3167 I
               I********************************************      0.880
      968.3584 I
               I**********************************************    0.912
      995.4001 I
               I**********************************************    0.928
     1022.4419 I
               I***********************************************   0.948
     1049.4836 I
               I************************************************  0.964
     1076.5254 I
               I************************************************* 0.982
     1103.5671 I
               I**************************************************0.998
     1130.6089 I
               I**************************************************0.998
     1157.6506 I
               I**************************************************1.000
     1184.6953 I
               I**************************************************1.000
     1184.6953 I----I----I----I----I----I----I----I----I----I----I MAX

               NO OBS------------      500  STD ERROR-         111.3275
               COEF OF VARIATION-     0.13  MEAN------         839.4507
               KURTOSIS (BETA 2)-     2.88  MEDIAN----         834.1758
               PEARSONIAN SKEW---     0.47  MODE------         787.0784
```

FIGURE 4

```
POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF      24.00 -        36.00

                  CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
         0.2695 I----I----I----I----I----I----I----I----I----I----I MIN
                I                                                    0.0
         0.2695 I
                I*******                                             0.135
         6.4551 I
                I************                                        0.237
        12.6406 I
                I****************                                    0.313
        18.8262 I
                I********************                                0.402
        25.0117 I
                I************************                            0.485
        31.1973 I
                I****************************                        0.569
        37.3828 I
                I*******************************                     0.617
        43.5684 I
                I**********************************                  0.682
        49.7539 I
                I*************************************               0.733
        55.9395 I
                I***************************************             0.782
        62.1250 I
                I*****************************************           0.825
        68.3105 I
                I*******************************************         0.852
        74.4961 I
                I********************************************        0.871
        80.6816 I
                I*********************************************       0.900
        86.8672 I
                I**********************************************      0.930
        93.0527 I
                I***********************************************     0.946
        99.2383 I
                I************************************************    0.968
       105.4238 I
                I************************************************* 0.976
       111.6094 I
                I************************************************* 0.984
       117.7949 I
                I************************************************* 0.989
       123.9805 I
                I**************************************************0.997
       130.1660 I
                I**************************************************1.000
       136.3516 I
                I**************************************************1.000
       136.3516 I----I----I----I----I----I----I----I----I----I----I MAX

                NO OBS------------      371  STD ERROR-          30.8206
                COEF OF VARIATION-     0.79  MEAN------          39.2381
                KURTOSIS (BETA 2)-     2.94  MEDIAN----          33.1992
                PEARSONIAN SKEW---     1.10  MODE------           5.2579
```

FIGURE 5

POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF 0.0 - 36.00

```
                   CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
        4419.7148 I----I----I----I----I----I----I----I----I----I----I MIN
                  I                                                    0.0
        4419.7148 I
                  I                                                    0.002
        4486.7969 I
                  I*                                                   0.012
        4553.8789 I
                  I*                                                   0.030
        4620.9609 I
                  I***                                                 0.062
        4688.0430 I
                  I*****                                               0.098
        4755.1250 I
                  I********                                            0.154
        4822.2070 I
                  I*************                                       0.250
        4889.2891 I
                  I******************                                  0.350
        4956.3711 I
                  I***********************                             0.462
        5023.4531 I
                  I****************************                        0.562
        5090.5352 I
                  I*********************************                   0.656
        5157.6172 I
                  I*************************************               0.744
        5224.6992 I
                  I****************************************            0.808
        5291.7812 I
                  I********************************************        0.876
        5358.8633 I
                  I**********************************************      0.912
        5425.9453 I
                  I***********************************************     0.940
        5493.0273 I
                  I************************************************    0.956
        5560.1094 I
                  I************************************************    0.970
        5627.1914 I
                  I*************************************************   0.978
        5694.2734 I
                  I**************************************************0.996
        5761.3555 I
                  I**************************************************0.998
        5828.4375 I
                  I**************************************************1.000
        5895.5234 I
                  I**************************************************1.000
        5895.5234 I----I----I----I----I----I----I----I----I----I----I MAX

                  NO OBS------------     500   STD ERROR-        255.8068
                  COEF OF VARIATION-    0.05   MEAN------       5069.0469
                  KURTOSIS (BETA 2)-    3.02   MEDIAN----       5045.9609
                  PEARSONIAN SKEW---    0.31   MODE------       4989.9102
```

FIGURE 6

PANEL SESSION

ON

BUDGETING AND CONTRACTING RISK

CHAIRMAN

MICHAEL FIORILLO

NAVAL AIR SYSTEMS COMMAND

AD P002303

RISK ASSESSMENT FOR DEFENSE ACQUISITION MANAGEMENT

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INTRODUCTION

The problem of dealing with cost growths in its acquisition of weapon systems has haunted the Defense Department for years and probably will continue to do so until either drastic changes* are made in the acquisition process or until we just stop keeping track of costs. Since neither of these is likely to occur, the problem of defense systems acquisition costs exceeding original estimates and budgets is probably here to stay. Nevertheless, there are a number of actions that can be taken to improve the process and to reduce the magnitude of future cost growths.

This paper deals with just one of these actions as it describes a research project conducted by the Defense Systems Management College (DSMC) to develop a handbook designed to assist acquisition management personnel in selecting and implementing risk assessments. The purpose of this paper is: 1) to briefly describe that research project and its primary product - the handbook and 2) to share some of the findings from this research that, while inappropriate for inclusion in the handbook, should nevertheless, be of interest to acquisition management personnel. The objective of sharing this other information is to suggest areas whereby risk assessments can become a more effective tool in fighting the problem of cost growth.

BACKGROUND

One of the primary thrusts of the Department of Defense Acquisition Improvement Program (AIP) was to develop specific actions whose implementation would reduce the number of weapon system programs experiencing cost growths. One such action was AIP Action Number 11. This action addressed the problem of program budgets failing to adequately account for the technological risks inherent in the development and production of today's complex weapon systems. This action, commonly referred to as "Budgeting for Technological Risk," recommended that efforts within the Department of Defense to quantify risk be increased and that the use of budgeted funds to deal with uncertainty be expanded. Specifically, this action directed that the Services budget funds for risk and that "each Service should review the TRACE (Total Risk Assessing Cost Estimate) concept and either adopt it or propose an alternative for their use." (1 p. 12)

Today, the issue of budgeting for risk is continuing to receive emphasis at the highest levels in DoD. Deputy Secretary of Defense Thayer has included "Budgeting for Technological Risk" in the list of actions he has recently consolidated into six areas for increased management attention. (2) The actions were selected for inclusion in this consolidated list because of their importance to the overall defense mission. The Services, along with the designated "lead office" within the Office of the Secretary of Defense, will develop more detailed objectives and actions for each consolidated area. The designated "lead office" for "Realistic Budgeting" (the consolidated area now containing AIP Action Number 11) is the Assistant Secretary of Defense, Comptroller. Progress in implementing the more detailed actions will be reviewed on a regular basis by Deputy Secretary Thayer during meetings of the DoD Council on Integrity and Management Improvement.

In an attempt to assist the implementation of the "Budgeting for Technological Risk" action, in the fall of 1982 DSMC embarked on a contracted effort to develop a Handbook of Risk Assessment/Budgeting Techniques. The objectives of this project

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*Examples of the magnitude of the changes we are referring to are: 1) the creation of a permanent, professional, civilian organization to manage the acquisition of weapons systems for all the services and 2) the extension of the budget cycle from one year to two.

were to identify the risk assessment techniques actually being used by defense acquisition management activities and to describe these techniques along with their advantages and disadvantages in a handbook. The handbook was also to include information to help the user select and implement a technique chosen for his particular application. This, then, establishes the background and rationale for the DSMC research effort.

RESEARCH APPROACH

In the next few paragraphs, the approach taken in this research project will be described to form a basis for understanding the findings and recommendations contained later in this paper.

Under the DSMC-managed research contract, the first step taken was to conduct an extensive search of the existing literature in the areas of risk assessment and budgeting for risk. The purpose of this search was to identify the available techniques, discover where and how they were being employed and commence the development of a bibliography to assist the ultimate users of the handbook in pursuing areas of particular interest.

After review of the data collected through the literature search, it was determined that a survey of acquisition management activities was necessary to get a better indication of on-going risk assessment activities. A plan listing the Program Management Offices (PMOs) to be surveyed was developed using the following criteria - Service, type of PMO (i.e., size, degree of matrix support, etc.), type of weapon system and status of the program. This led to a plan to research over 50 PMOs at some 15 different defense activities. The plan also included interviews of the appropriate functional support offices, in addition to the PMOs, at the various activities visited.

Preliminary evaluation criteria were developed for the purpose of determining the "usefulness" of the risk assessment techniques in use. These criteria formed the basis of the questions asked during the survey. The initial set of criteria included - soundness of theory, availability of necessary data, resources required, availability of software, speed of the solution, perceived value to the decision-making process and credibility of the technique.

After completing the survey, the collected data were analyzed to categorize the techniques discovered and to describe their advantages and disadvantages as identified by the personnel interviewed. A refined set of evaluation criteria was used. Some of the preliminary criteria were dropped and some new ones were added resulting in the following list - soundness of theory, resources required and value as a decision aid (a subjective evaluation of several factors by PMO personnel).

A draft version of the handbook was developed based on the results of the data analysis and technique evaluation efforts. This handbook draft was reviewed in detail by individuals representing a broad cross-section of the acquisition management community and modified accordingly. The revised handbook has been published by DMSC and distributed to various acquisition management offices, including of course, those who assisted in the survey. Incorporation of the handbook into the Defense Technical Information Center (DTIC) is in process.

HANDBOOK DESCRIPTION

In the following paragraphs, a description of the contents of the handbook will be given. The purpose of this description is to give the reader of this paper a general understanding of the type of material contained in the handbook and its organization, but not to provide a comprehensive summary of its contents.

The handbook was prepared with basically two major sub-divisions. The first section of six chapters was written to give the acquisition manager a concise, easy-to-read, management-level overview of risk assessment and what it should mean to him.* The purpose of this first section was to interest the manager in applying risk assessment to his program and to give him the background to do so through the use of the second section of the handbook - the Appendices. The Appendices were developed to provide the interested user with more details in selected areas to aid implementation of a risk assessment technique.

The entire handbook, and particularly the first six chapters, was written assuming the prime user would be a manager within the PMO who either had been charged

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* Whenever in this paper "man," or "men," or their related pronouns appear, either as words or parts of words, they have been used for literary purposes and are meant in their generic sense.

with the responsibility of assessing his program's risk or who felt that his program (or project) could benefit from a risk assessment. It was assumed that the targeted user would be experienced in acquisition management, but would be relatively unfamiliar, or at least not current, in the details of conducting risk assessments such as the modeling or interviewing techniques required. Hopefully, the experienced analyst will also find some of the Appendices of interest. It was not the intent of the handbook, however, to provide stand-alone, detailed instructions on "how to implement" any one risk assessment technique. The Bibliography provides references for details associated with all of the techniques discussed.

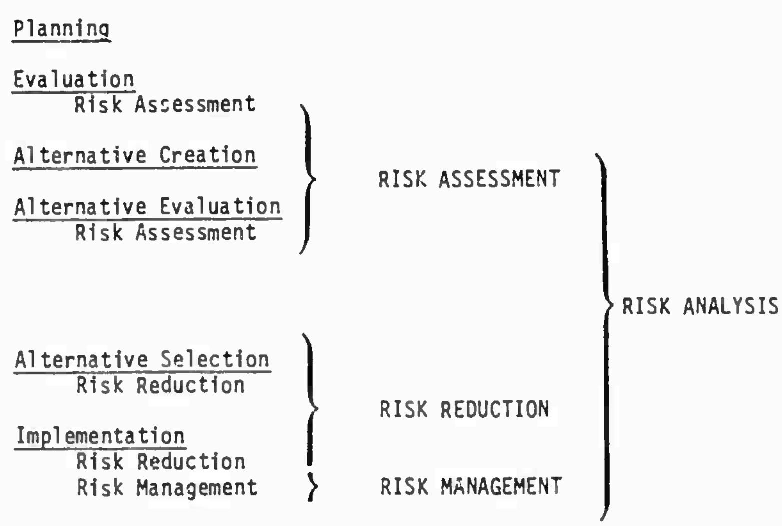
The first six chapters lead the user through 1) an Introduction - a description of the handbook's purpose and scope, 2) a discussion of what risk assessment means, including a very limited review of some elementary concepts in probability, 3) a general analysis of the costs and benefits of conducting risk assessments and a discussion of why a manager should consider conducting one, 4) a presentation and brief description of the techniques available, 5) information to assist in the selection of a particular technique and, finally 6) a discussion of where a manager could find support and/or assistance in implementing a technique on his program. The second section of the handbook is made up of a number of Appendices that provide amplifying details in several areas. In addition to the Bibliography, Definition of Terms and List of Acronyms, there are Appendices that: 1) address the problem of quantifying the opinions of experts and using this data in risk assessments, 2) provide a further level of detailed description of the available techniques, 3) describe the DoD and Service policy statements associated with risk assessment and 4) discuss the budget policy concept that specifically incorporates risk assessment, i.e., TRACE.

RESEARCH FINDINGS

The findings reported in this section result from the analysis of the data collected during the survey of Army, Navy and Air Force system acquisition management offices in December, 1982 and January, 1983. Interviews were successfully completed in a total of 46 PMOs and 9 functional support offices using a questionnaire briefly described in the RESEARCH APPROACH section of this paper. The findings have been categorized and will be discussed in the following areas: the extent of use of risk assessment, the techniques being used and their reported advantages and disadvantages.

A. Extent of Use of Formal, Quantitative Risk Assessments

Before describing where formal, quantitative risk assessments were found in use, a working definition for these terms must be established. As used in this research effort, in the handbook and in this paper, risk analysis can be thought to consist of the three activities - risk assessment, risk reduction and risk management as shown in Figure 1 below taken from (6). Risk assessment then, consists of



COMPONENTS OF RISK ANALYSIS

FIGURE 1

evaluating an existing plan and any alternative plans that may be subsequently developed. A formal assessment is considered to be one that utilizes the classical system analysis approach by attacking complex problems through analyzing the individual elements that make up the problem, determining the relationships among these elements and then formulating a model of the problem to study. A quantitative assessment attempts to develop mathematical descriptions of the relationships that exist among the problem's elements; i.e., to formulate a model in mathematical terms.

Where then, were formal, quantitative risk assessments found to be in use? Of the 46 PMOs surveyed in the Army, Navy and Air Force, 20 reported having used risk assessment techniques that could be called formal and quantitative. The majority of the PMOs reporting the use of formal, quantitative techniques were from the Army. In fact, 12 of the 18 Army PMOs contacted reported the use of such techniques. The Air Force PMOs contacted were much more likely to use qualitative assessment methods than quantitative with the Navy falling between the two other Services.

For the purposes of this study and the handbook, three levels of program/project management organization were defined. At the top was the "Self-Contained" (or SC) Program Management Office, an organization frequently staffed by more than one hundred people who execute all the major functions of program management. The intermediate level of Program Management Office strength was called the PM. This was intended to represent an office of less than 100 people, who carry out the top level management, engineering, and business functions. This office level is usually supported for the majority of the daily detail engineering, planning, and analysis tasks by support organizations within the host command. The lowest level of PMO strength was called the PC and could be the project engineer, program coordinator or product manager. The PC represents an office consisting of one, or at most, three people, who would usually be subsystem development engineers. The host command generally would be expected to provide support to these offices, however, command priorities often leave this PMO level with little in the way of analytic support.

The 20 PMOs that reported using quantitative techniques were made up of the following:

3 of the 5 surveyed in the SC category
16 of the 34 surveyed in the PM category
1 of the 7 surveyed in the PC category
20

It was found that of the 20 PMOs reporting that quantitative assessments had been used, 4 had actually accomplished the assessments within the PMO, 13 had their assessments done by functional support groups within the host matrix organization, 2 used a support contractor, and the final 1 used a PMO/Support Contractor team. None had used their prime contractor for quantitative assessments.

The survey revealed that these 20 PMOs had actually made a total of 47 applications of formal, quantitative techniques. The decision categories that these applications were intended to serve and the number of applications in each category are shown in Figure 2 below.

Decision Category	No. of Applications Reported
Tech. Alternative Selection	11
Planning	14
POM Development/Budgeting	14
Source Selection	1
Acquisition Strategy	5
Management Control	2
	47

APPLICATIONS OF FORMAL QUANTITATIVE ASSESSMENTS

FIGURE 2

During all the interviews conducted in this survey an attempt was made to determine the highest level within the chain of command at which results of the risk assessment were reviewed. The highest review level for the 47 applications of formal, quantitative techniques is shown in Figure 3 below.

Highest Level of Review	No. of Applications Reported
PMO	22
SYSCOM	5
MATCOM	3
SERVICE HQ.	13
OSD	4
	47

REVIEW LEVEL FOR ASSESSMENTS
FIGURE 3

B. Techniques Being Used

The survey of the PMOs and the associated support offices revealed that the formal, quantitative techniques actually in use could be grouped into the following 4 categories:*

- Network Analysis
- Decision Analysis
- Estimating Relationships
- Risk Factors

These and three other techniques are described in some detail in the handbook. Since the primary purpose of this paper is to discuss the findings of the research rather than to describe how to conduct a risk assessement, the techniques will only be briefly described here.

The networking techniques identified during the survey were of the classical type that have emerged from the PERT approach. In most cases computer simulation techniques were being used to develop probability statements. Network models were found in use throughout the Army to support program milestone decisions at In-Process Reviews, ASARCs and DSARC reviews. Some Navy program offices were found to be using network - based approaches to conduct risk assessments and were taking them one step further to serve as program control and management systems. This application will be addressed in more detail in the RECOMMENDATIONS section of this paper.

The category designated as decision analysis techniques consists of the approaches that examine overall program decisions by breaking them into sequences of more elemental decisions with their associated uncertain occurrences. The resulting sequences often are depicted as decision trees, but other approaches such as probabilistic event analysis are also possible. The two applications found during preparation of the handbook followed the concept of the decision tree approach and established schedule and cost probability distributions around anticipated problems and then utilized a computer model to perform simulation exercises. These applications were used to aid the planning process in Army programs.

The estimating relationships technique is used by Air Force Commands to develop estimates of management reserves necessary to accommodate contract cost risks in much the same manner as cost estimating relationships are used in parametric cost estimating. Based on historical data, curves have been developed that display the appropriate management reserve corresponding to various judgementally assessed levels of the following factors - engineering complexity, degree of system definitization, contractor proficiency/experience and multiple users. To use this technique, a contract is described by program management personnel and rated relative to the existence of these factors. The existing curves are then used to identify recommended management reserves.

The risk factor method is also used to estimate cost risks. This method starts with a work breakdown structure of program elements. Baseline cost estimates (BCE) are developed for each program element. Risk factors for each element are then developed using any of the judgemental approaches described in (4). These risk factors are then multipled times the program element BCE to determine the amount to be added to the budget for accommodating technical risk. This is the technique most commonly used within the Army to develop TRACE budget estimates.

Figure 4 on the next page reports the number of times a particular technique was reported in use during the survey, categorized both by the technique type and by the program activity being supported by the application of that technique. It can be seen that networks were most often used and were largely applied to assisting the selection of program technical alternatives and for program planning. The risk factor technique was the second most used technique. Its primary use was to assist budgeting decisions, specifically the development of TRACE estimates.

C. Reported Advantages and Disadvantages

This section will attempt to report and summarize various statements and opinions received during the survey as a result of asking the users to describe the advantages and disadvantages of the various techniques. Very often these user comments are focused on the resources required to use a particular technique, but other comments are also included.

1) Networking Techniques - The networking techniques in use were found to require up to 6 man-months of analyst effort at the GS-12 to GS-14 level to build the program network for a large program of the type having a

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*The handbook actually addresses three other techniques which have potential for use by the defense program manager.

	TECH. ALT. SELECTION	PLANNING	POM/ BUDGET	SOURCE SELECTION	ACQ STRATEGY	MGT. CONTROL
NETWORK	9	12	2	-	4	2
DECISION ANALYSIS	-	2	-	-	-	-
ESTIMATING RELATIONSHIPS	-	-	2	-	-	-
RISK FACTORS	2	-	10	1	1	-

REPORTED APPLICATIONS OF RISK ASSESSMENT TECHNIQUES

FIGURE 4

designated program manager (PM type program). Much of this time was consumed in defining activity inter-relationships and gathering experts' estimates of activity risk. In nearly every case, this effort was more difficult and time consuming than orginally anticipated. Several managers reported that the time required to build the network created a "catch-22" situation since the longer it took it create the network and complete the analysis, the more changes that occurred in the program, in turn, requiring more time to correct the network. A few managers reported that the networks and analyses became so complicated and took so long that they were not completed in time to support the decision-making process. In these cases, the assessments turned out to be little more than paper exercises used to substantiate decisions already made.

Although numerous comments were received that objected to the time and resources required to use the networking techniques, it was also acknowledged that the by-products of the process - e.g. better program planning, definition of interrelationships and more complete understanding of the whole program and its parts - were extremely valuable. It was also reported that the results of the network analyses had a relatively high degree of credibility with analysts, managers and reviewers.

2) Decision Analysis Technique - While there are various levels of detail and rigor that can be applied in using the methods that fall in this category, the only applications found during the research survey tended toward a rather sophisticated approach. These applications required analysts essentially at the same level and for the same duration as the network technique would require for a comparable program. Again, the collection of the necessary program data to provide as input to the technique was the most difficult and time consuming task.

Although improved program planning was gained as a by-product to the actual risk assessment, the detailed understanding of activity sequencing and interrelationships that result from the development of a program network is not as direct a result with the decision analysis technique.

3) Estimating Relationships - The time consuming part of the effort associated with this technique was the collection and analysis of the historical data necessary to develop the contract "factor"/ management reserve relationship. Once established, this relationship allowed the estimate of management reserves by mid-level analysts with only a few days of interviews of program personnel.

As currently applied, this method has been used only for establishing reserves for specific contracts not for program cost estimates. This technique is, of course, not technically rigorous since, unlike the technique of cost estimating relationships, the "data" used to establish the relationships are subjective and are not comparable in terms of scales of measurement and are not even scalable.

4) Risk Factors - In this technique, as with all the others, the collection of input data was the most demanding task. With the risk factor method, mid-level analysts can develop the necessary estimates of risk for each program element cost through interviews with program management personnel. There are several different approaches suggested for generating these risk factors. However, all of them can be used to develop reasonable estimates in a relatively short time. This method is very straight-forward and understandable and thus, holds significant appeal for many management personnel.

The point estimate of a risk factor for a particular element cost, of course, tends to ignore the uncertainty existing in the defense acquisition environment. Again, the advantages afforded by the networking techniques of improved program planning and understanding are lacking in the risk factor method.

CONCLUSIONS

Many of those familiar with this research effort were surprised with the finding that as many as 20 of the 46 PMOs surveyed reported that they had employed formal, quantitative risk assessment techniques. It had been expected that fewer PMOs would have used these techniques and that there would have been fewer than the reported 47 total applications supporting the 6 decision categories (Figure 2). Despite this better-than-expected showing for the use of quantitative assessments, if the survey that was conducted is representative of the state of the rest of the defense acquisition community, there remains substantial room for improvement.

In the face of encouragement from high levels to conduct quantitative risk assessments, such as the AIP action that inspired this research effort, and the basic scientific logic that instills the belief that quantitative is "better" than qualitative, why is it that fewer than half of the defense system acquisition programs (according to the survey) employ formal, quantitative risk assessment techniques? The authors believe that there are three reasons which are supported by the data collected during this research project.

First, there must be interest and support for risk assessments at command levels above the PMO. It is obvious without further elaboration -subordinate activities will concentrate their efforts on items of interest to the boss.

Command level interest and support of a defense acquisition issue is typically demonstrated by the issuance of policy and procedure directives. AIP Action Number 11 recommended that efforts within the DoD to quantify risk be increased and directed that the Services adopt TRACE or an alternative concept to budget funds for risk. Despite this emphasis, the most recent revisions to the primary DoD acquisition policy documents (DoDD 5000.1 dtd 29 Mar 82 and DoDI 5000.2 dtd 8 Mar 83) add little in the area of requiring the quantification of program risks. A detailed review of the Service regulations was made during this research project to locate requirements related to risk assessments. Appendix H of the handbook consists of a collection of excerpts from these Service regulations. While these regulations generally encourage the use of risk assessments at various points within the acquisition process, with two exceptions, none of them clearly state the need for formal, quantitative assessments. These two exceptions are the Army directives for implementing TRACE. (4) and (5) This failure of the system of directives and regulations to specify the use of quantitative techniques indicates to the authors and more importantly to the program managers a lack of interest and support at the highest management levels within DoD.

Another indicator of command-level interest in risk assessments is the regularity at which the assessments that are done are reviewed by these higher levels. As was shown in Figure 3, the data collected in this survey indicates that only about one half of the assessments completed are reviewed above the PMO level. Additionally, none of the survey respondents reported that any review of a formal, quantitative assessment resulted in controversy over inputs, methods, assumptions or results. The contrast of this situation compared to that of cost estimates is so great that a lack of interest and concern about the results of formal, quantitative assessments at the higher DoD management levels is clearly indicated.

The second reason why more acquisition programs don't employ formal, quantitative techniques is that the program manager must first believe that there is "something in it for him" and in many cases, in today's environment, there is little reason for him to hold this belief. For example, the program manager is under continual pressure from various sources to "buy in" to overly optimistic schedules. He may be well aware of the risks of doing so and even may be able to quantify them, but this knowledge usually carries little weight when compared to user requirements and budgetary constraints. If the results of risk assessments are largely ignored, then program managers are not going to waste management attention on them, and will perform then perfunctorily at best.

Another example results when assessing cost risks. At every level, the review of a program manager's budget appears to be an effort to force him to reduce his budget. The quantification of his cost risks and the subsequent identification of funds to accommodate this risk is viewed by program managers as an open invitation to budget reviewers to make cuts. This occurs at all levels in the review process and can even happen at the highest level as evidenced by Congressional action on the Navy's FY 83 budget. As acknowledged by the House Appropriations Committee (HAC) in their report on the FY 83 DoD Appropriation Bill (7), the Navy responded to AIP Action Number 11 by identifying funds required for management reserves in several R,D,T&E and Procurement program budget requests. The HAC recommended reductions in these management reserves totalling over $500 million based on their determination that "the factors being used by the Navy in arriving at the fund requests for these cost elements were not appropriate and reasonable; the funds provided were being used for other than purposes intended, and the newly established management reserves are creating excessive program management flexibility or another source of funding that can be drawn on as the needs of a program arise." (7 p. 101) While the approach taken by the Navy in calculating and presenting the requests for these reserves may be questioned, the fact remains that this is another example of funds budgeted for management reserves once identified, becoming very vulnerable.* Army programs using the TRACE approach for budgeting for risk have been much more successful in sustaining their risk estimates in their budgets and those budgeting efforts were, in fact, acknowledged in the HAC reports. This will be further addressed in the RECOMMENDATIONS section of this paper.

A third reason why more system acquisition programs don't use formal, quantitative risk assessment techniques is that the techniques don't appear "useable" to the program manager. The term "useable" is intended to include the concepts that the techniques are neither timely, convincing nor affordable.

For a risk assessment to be "timely" it must provide its output at a point in time that will allow the manager to analyze the output, assess his alternatives and make the required decision within the time allotted. Several of the program management personnel interviewed during the survey indicated that many of the issues they were dealing with would have benefitted from risk assessments, but there wasn't sufficient time to conduct such an assessment and still meet the deadline for the decision. There were also cases reported where the data collection portion of the assessment effort task took so much longer than originally anticipated that the assessments were completed too late to support the decision-making process.

The need for the risk assessment technique to be "convincing" comes from the program manager's desire to use the results of the assessment to influence decisions made at levels above him. For a technique to be "convincing" it must be theoretically sound and most importantly, understandable and logical to the reviewers approving the decision. This says that, no matter how sophisticated the actual analysis may become, for a technique to be considered convincing, it must be explainable in terms understood by managers and reviewers who may be totally unfamiliar with risk assessment concepts.

The need for a risk assessment technique to be "affordable" refers to the availability of personnel with the necessary capabilities for the time period required, whether these people come from the PMO itself, the functional support groups of the host

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*It should be noted that a portion of the management reserves requested by the Navy (for the TRIDENT and CV-SLEP programs) were eventually restored by the Conference committee. (8 p. 127) command or a contractor. This concept of "affordability" includes the analysts involved in conducting the assessment as well as the individuals within the PMO and elsewhere who will serve as the subject matter experts and who will fulfill the critical function of providing the input data. In addition, "affordability" of a risk assessment must consider the availability of the program manager himself, who must be involved to give direction to the assessment, to agree to necessary simplifying assumptions, to make critical choices as the assessment progresses and to apply the results of the assessment. In several cases during the survey, program managers indicated that this issue of "affordability" was the most critical problem for them. This was particularly true, of course, with the more sophisticated techniques such as networking and decision analysis.

RECOMMENOATIONS

The recommendations resulting from this study are aimed at several different levels within the defense acquisition management community. For the policy-making levels within the Office of the Secretary of Defense and the Services, it is hoped that they will recognize that the perception of their attitude is critical for setting the tone for all the risk assessment activities that occur within DoO. This perception is developed from the policy directives and regulations that are issued and the extent of interest demonstrated in reviewing the results of risk assessments. Thus, the specific recommendations in this area are: 1) revise the tree of appropriate directives and regulations (starting with OOOD 5000.1 and OOOI 5000.2 and continuing through the Service regulations) to explicitly require that formal, quantitative assessments be conducted and under what circumstances they are required and 2) critically review and utilize the results of such risk assessments as decisions are made at appropriate points in the fiscal and life cycles of programs.

One of the conclusions discussed in the preceding section promotes the concept that a program manager will not expend the resources necessary to conduct a formal, quantitative risk assessment unless "he sees something in it for him" or for his program. If increasing requirements to conduct risk assessments are going to be placed on program managers, then procedures must be clearly established so that the various review points recognize and honor the estimates of risk. This does not mean that estimates resulting from a quantitative assessment should be accepted without questioning the technique. To the contrary, all elements of the assessments, that is, the input, techniques, assumptions and the conclusions should be questioned and explored.

What this does mean however, is that assuming it's determined that a reasonable, justifiable approach has been taken in developing the risk estimates, the funding requirements then identified to accomodate the risk (in the case of cost risk) should not be arbitrarily viewed as the discretionary budget line that is the first to be cut when it comes time to squeeze more programs into the overall budget.

Congress, of course, is one of the key review points that must agree and be part of any attempt to increase the use of quantitative assessments. At the same time that it was recommending reductions to remove management reserves from the Navy's FY83 ROT&E and Procurement requests, the HAC acknowledged the "need for management reserves to provide the necessary flexibility to address unforeseen circumstances." While they addressed the need for reserves, the HAC also reported that they "found little evidence to support, or otherwise validate the appropriateness and reasonableness of the factors being used, or the resultant amounts being included in the Navy's budget requests." (7 p. 101) Clearly, the Services and OSD should develop a logical, justifiable approach to assessing risks, estimating the cost associated with these risks, presenting the budget requirements necessary to accommodate these risks and managing the funds appropriated for these risks. This approach must then be negotiated with the key committees in Congress.

This recommended approach would seem to be so simple and straight-forward that it would appear that it must be naively overlooking some insurmountable obstacles. However, this is basically the approach that the Army has taken in using the TRACE concept to budget for risk in selected ROT&E and now Production programs. As viewed by the Army program manager, the TRACE concept certainly "has something in it for him" since his estimates for technical risk are routinely funded in the Army budget process.

The final reason discussed in CONCLUSIONS for the limited application of formal, quantitative techniques was the need for the program manager to find the technique "useable". To provide assistance in this area is a real challenge to the developers of these techniques. From the data collected during the survey, it is clear that acquisition management personnel have at least some appreciation for the value of the information that can result from implementing the more sophisticated techniques of networking and decision analysis. But, because of the resources (dollars, people and time) required, these techniques are only well-suited for major decisions that can be anticipated far in advance on resource-rich programs.

A number of recommendations evolve from this conclusion. First, the networking techniques in use should be extended to perform on-going program control functions in addition to risk assessments. Once the time and effort has been invested to create the original network and to apply computer software in order to conduct the risk assessment, this effort should be capitalized on by maintaining the network for program control. Commercially available software packages have been used in this manner on some Navy shipbuilding programs.

Another recommendation in this area is to educate program managers and upper level managers throughout the community on the very real and valuable by-products to be gained from employing any quantitative technique - especially the more rigorous network and decision analysis techniques. These by-products - such as improved program planning, identification and recognition of responsibility for all program activities and better understanding of the sequencing of these activities - in many cases may be much more important then the originally stated purpose of generating an estimate of program risk. This is presently not understood or appreciated by managers at many levels within the DoD.

Where the availability of dedicated, analytical support is the primary factor limiting the conduct of risk assessments, upper level management should consider the establishment of such offices within the functional support matrix. While this can be expensive (in terms of both dollars and billets) there are many advantages to developing an "in-house" capability for conducting program sensitive risk assessments.

The final recommendation centers on encouraging the development of techniques that the manager of any size program can find "usable" to assist the decisions he must make with advance warning of perhaps days rather than months. Techniques that are timely, easy to understand, convincing and affordable are desperately needed. To become convinced that such techniques will be used, if available, one need only look at the number of times the risk factor method has been employed to develop TRACE estimates.

REFERENCES

1. Deputy Secretary of Defense (Frank C. Carlucci) Memorandum, Subject: Improving the Acquisition Process, Pentagon, Washington, D.C., 30 April 1981.

2. Deputy Secretary of Defense (Paul Thayer) Memorandum, Subject: Priority Defense Management Initiatives, Pentagon, Washington, D.C., 5 May 1983.

3. Jordan, H. R. and Klein, M. R., "An Application of Subjective Probabilities to the Problem of Uncertainty in Cost Analysis," Office of the Chief of Naval Operations, Systems Analysis Division (OP-96D), Pentagon, Washington, D.C., November, 1975.

4. "Letter of Instruction (LOI) for Implementation of RDT&E Cost Realism for Current and Future Development Programs," Office of the Deputy Chief of Staff for Research, Development and Acquisition, Washington, D.C., 6 March 1975.

5. "Letter of Instruction (LOI) for Implementation of the Total Risk Assessing Cost Estimate for Production (TRACE-P)," Headquarters, U.S. Army Material Development and Readiness Command, Alexandria, VA., 6 October 1982.

6. Lochry, R. R. Col., USAF, et.a., Final Report of the USAF Academy Risk Analysis Study Team, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, August, 1971.

7. U.S. Congress, House of Representatives, Report No. 97-943, Department of Defense Appropriations Bill, 1983, December 2, 1982.

8. U.S. Congress, House of Representatives, Report No. 97-980, Conference Report, December 20, 1982.

TOTAL RISK ASSESSING COST ESTIMATE FOR PRODUCTION (TRACE-P): WILL HISTORY REPEAT ITSELF?

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A key milestone in the life cycle of an Army weapon system is the decision to enter production. Milestone III--the production decision point--occurs years after concept exploration begins, but only a small percentage of the total expected program life cycle cost has been incurred up to this point. Most of the program funds remain to be expended during the Production/Deployment Phase following Milestone III and in the operational phase. Typically, R&D accounts for approximately 15% of the program cost, production 30%, and operation and support the remaining 55%.[1] Therefore, it is prudent that the risks of entering production be understood as clearly as possible before the program is committed further.

In spite of the Army's efforts to prepare for production and to control cost through Producibility, Engineering and Planning (PEP) and Production Readiness Reviews (PRR), a weapon system typically experiences problems during the transition period from R&D into Production which eventually contribute to substantial increases in program cost. Figure 1 shows the extent and alarming trend of the total increase in RDT&E and Procurement appropriations for Army systems reported in the Selected Acquisition Report (SAR).[2] Excluding inflation, there still has been a 28% increase in the procurement appropriation from the first quarter of FY 78 through the third quarter of FY 81 compared to 15% increase in RDT&E during the same period.

Although DOD may attempt to shift production risk to a defense contractor through the use of firm, fixed price (FFP) contracts, the Army Procurement Research Office (APRO) has shown in earlier work that this has little impact on cost growth. "FFP contracts suffered a net 53% cost growth - almost identical to the entire sample cost growth."[3] Nearly all of the FFP contracts were for production. The need for more attention to production and for better planning and control of initial production uncertainties is clear. Also, a methodology is needed to analyze the uncertainties of entering production and to account for the risk impacts in the program plan. By planning and budgeting for risks, program disruptions and resulting cost increases can be minimized.

The magnitude and trend of transition problems have been studied in terms of budgetary impact. In 1979, Augustine reported that, for 38 DOD programs from 1962-1976, program cost growth of 9% occurs after R&D is complete, adjusting for inflation and quantity changes.[4] Factoring out the R&D cost, procurement cost growth for these SAR programs was about 12%.

To evaluate current programs, APRO and the Army Logistics Management Center (ALMC)

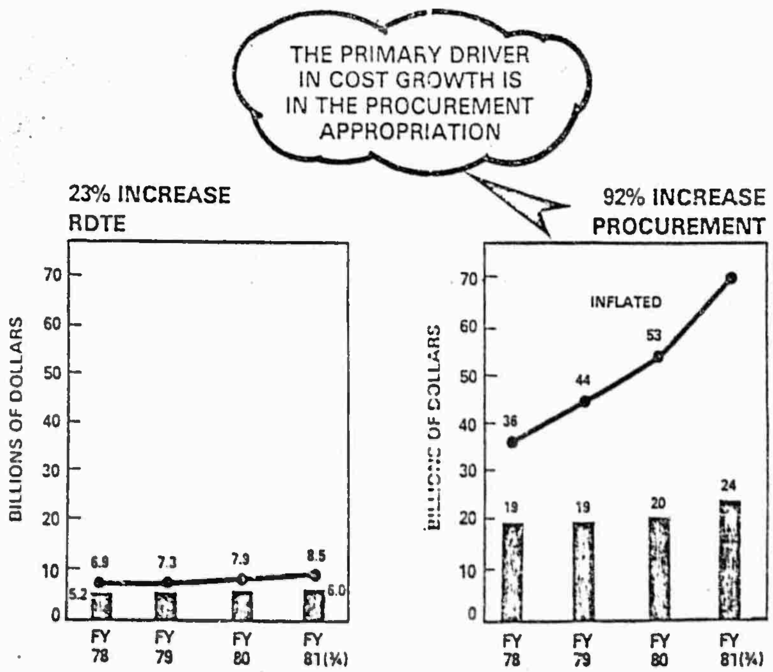

FIGURE 1 ARMY WEAPON SYSTEM COST GROWTH
(SOURCE: STUDY OF ARMY LOGISTICS, 1981, AND ARMY SAR'S)

analyzed 11 Army SAR systems that have recently undergone transition from R&D to production to determine procurement cost growth during early production.[5] SAR Procurement cost data in constant dollars was adjusted for quantity changes with a baseline taken at the quarterly SAR three to six months prior to ASARC III. The magnitude of growth, averaging 35.5% and totaling over $5 billion, indicates an unfavorable trend of higher growth in recent years as shown in Figure 2. Most of the overall 35.5% growth occurs in the first 24 months of the time period considered, with very steep rises between 3-9 months (ASARC III time frame) and 18-24 months (1-1 1/2 years after ASARC III). The timing of reported growth seems to correlate with the updated cost estimates prepared for ASARC III (t = 6 months) and the annual contract negotiation and award cycles.

Multi-year Procurement, #4 - Program Stability, #5 - Capital Investment, #7 - Economic Production Rates, #8 - Appropriate Contract Type, #10 - Reduce Administrative Cost and Time, #13-14 - To Reduce "Red Tape," #15 - Funding Flexibility, #18 - Budget for Inflation, #19 - Forecasting Business Base, #20 - Improved Source Selection, #22 - Design to Cost and others are management actions that will reduce and control risks associated with the transition of systems from R&D into production. Others, like #6 - Budget to Most Likely Cost, and particularly #11 - Budget Funds for Technological Risk, are designed to help minimize the adverse impacts of problems when they do occur. In requiring the services to budget funds for risk, the initiative pointed out:

"Material development and early production programs are subject to uncertainties. Program managers who explicitly request funds to address these uncertainties usually find these funds deleted either in the DOD PPBS process, by OMB, or by Congress. Then, when such uncertainties occur, undesirable funding adjustments are required or the program must be delayed until the formal funding process can respond with additional dollars.

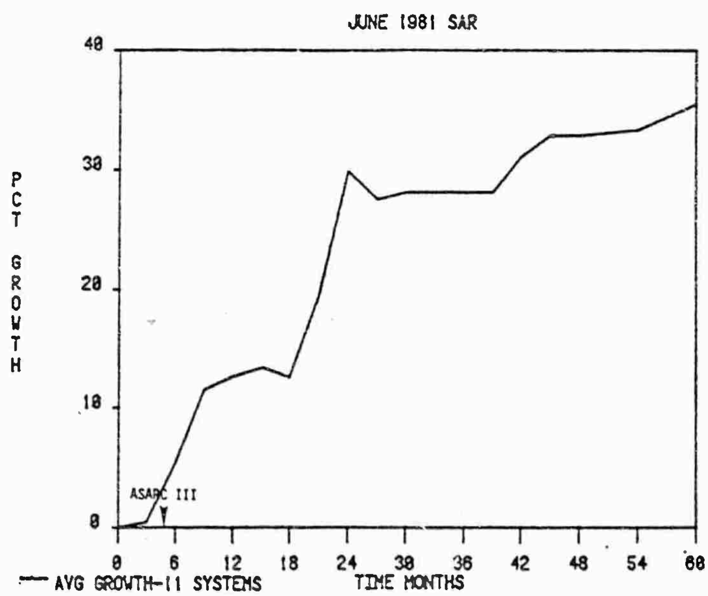

FIGURE 2 CUMULATIVE AVERAGE PROCUREMENT COST GROWTH FOR ARMY SAR SYSTEMS

The cost growth pattern exhibited by the aggregate of the 11 systems is not evident when analyzing each individual system. Some programs grow from the beginning, others delay growth until later in the production cycle, and others have experienced little growth. This is consistent with the notion of uncertainty and probabilistic occurrences. Statistical techniques, although applied to individual programs, are more meaningful on an aggregate basis.

To address this problem and some other shortcomings in the DOD acquisition process, on 30 April 1981, the DEPSECDEF, Mr. Carlucci, directed a series of initiatives to change for the better some of the policies of the past. Such initiatives as #1 - Management Principles, #2 - Pre-Planned Product Improvement, #3 -

The Army has initiated, and Congress has accepted, a Total Risk Assessing Cost Estimate (TRACE) to explicitly address program uncertainties in the development of RDT&E budget estimates. The Army is studying the application of this concept to early production cost estimates. The other Services lack a similar concept to justify reserve funds for dealing with developmental uncertainties."

Shortly thereafter, in a Vice Chief of Staff Army Memorandum, 22 Jul 81, on Cost Discipline, a directive to implement the concept of a management reserve fund for procurement with emphasis on the transition phase between engineering and production was issued. Thus, the Army started a program to budget funds for production risks and included such funds for programs like the Remotely-Piloted Vehicle, Apache and other programs at subsequent ASARC reviews. The process was formalized on 6 Oct 82 when the Comptroller, US Army Materiel Developments and Readiness Command (DARCOM) issued a Letter of Instruction (LOI) on Total Risk Assessing Cost Estimate for Production (TRACE-P). Therefore, the Army has adopted policies that seek to reduce, control and manage risk in R&D and production, with the knowledge from experience that even the best managed program may develop foreseen and unforeseen circumstances that will increase cost. Funding for these risks will permit timely resolution and minimize resultant cost increases.

PURPOSE AND OBJECTIVE

This paper is designed to compare the Army efforts of TRACE versus TRACE-P. In doing so, the TRACE process, methodology, history and results will be highlighted. Secondly, the evolution of TRACE-P will be discussed with primary focus on an APRO/ALMC study effort that took place from June through December 1981. Characteristics of TRACE and TRACE-P will then be compared and contrasted. Based on the experiences of TRACE during its early years (1976-1979) and the similarities between TRACE and TRACE-P, some predictions will be made concerning the use of TRACE-P in FY 84 and beyond. Thus, the TRACE-P program will be presented as a logical extension of TRACE into a problem area of high risk, with the expectation that many of the experiences with TRACE will be repeated with TRACE-P.

TRACE FOR R&D

In a memorandum, "RDTE Cost Realism," dated 12 July 1974, Mr. Norman Augustine, ASA (R&D) formulated the TRACE concept to provide realistic cost estimates and thereby minimize subsequent disruptive reprogramming actions. It was designed to minimize cost overruns without resorting to gross overbudgeting. Specific emphasis is on allocation of funds to reduce the cost growth effects resulting from the occurrence of events that could not be programmed because of the lack of certainty that they would materialize.[6]

It is impossible to exactly predict the cost of a project. In reality, the final cost of a project will fall somewhere within a distribution as shown in Figure 3. TRACE is a point estimate selected from that distribution such that its probability of being exceeded is at an acceptable level. Figure 3 shows the TRACE as having an equal (50/50) probability of underrun and overrun. When the Baseline Cost Estimate (BCE) is placed on this distribution of possible costs, it will fall to the left of the TRACE. The BCE is calculated from engineering estimates of specifically programmed activities, and although it generally includes some contingency, it does not include consideration for many uncertain activities that are statistically probable.

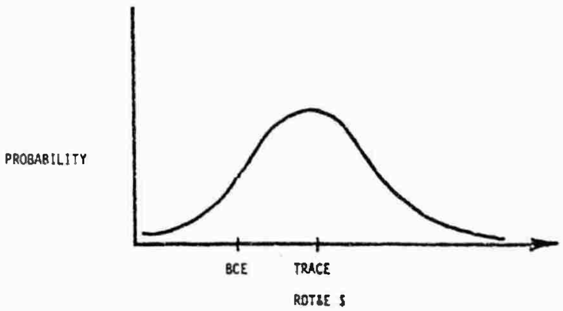

FIGURE 3 POTENTIAL RDT&E COST DISTRIBUTION

The PMO calculates a BCE and a TRACE and submits them through channels to Headquarters, Department of the Army (HQDA). The BCE represents project target cost. The TRACE is used for programming/budgeting and as the cost entry in the Five Year Defense Plan (FYDP). Upon budget approval by DOD/Congress, the BCE amount is released to the PM for program execution. The remainder, known as "TRACE deferral or Risk Cost," is retained by HQDA to serve as a source of funds for the PM to draw upon, when justified, to accomplish additional uncertain activities.

The retention of TRACE deferral funds by HQDA allows for managerial control and possible cost savings. These deferral funds are on a line item and fiscal year basis, and each year's funds are available for obligation for two years. During the fifth quarter of availability, the PMO must decide whether to release the funds to HQDA for reprogramming. The funds will be automatically reprogrammed if no action is taken by the seventh quarter. Any request by the PM to obtain deferral funds must be accompanied by sound justification within established guidelines. For example, funds will not be used to offset costs of major requirements changes which instead will be accommodated by restructuring the program and recomputing the TRACE. The list of exclusions includes the following occurrences for which TRACE deferral funds may not be used:

1. Program changes based on requirements changes.

2. Inflation-related cost increases.

3. Congressionally enacted pay raises.

A survey of 20 Army PMO's that had TRACE experience found that three principal methodologies were used to compute TRACE, with some unique variations.[7] The three methods were classified as Risk Percentage, Risk Factor, and Probabilistic Network Models. A fourth method called Probabilistic Event Analysis or Risk Tabulation was not found to be used by any PM. These four methodologies are as follows:[8]

1. Risk Percentage

The Risk Percentage method is an undocumented procedure in which the TRACE is computed by adding a percentage (10-15%) to the BCE at a summary level. The percentage is subjectively determined by experts based on past experience, risk assessment and judgment. Time phasing is accomplished subjectively or assuming proportionality to the RDTE effort. This method, although used, has not been formally approved because of similarities to contingency fund or management reserve concepts.

2. Risk Factor

The Risk Factor approach described in a 1975 LOI [9] computes TRACE by assigning risk factors to discrete Work Breakdown Structure (WBS) elements of the BCE. After estimating WBS element costs as part of the RDTE BCE, each element is assessed for uncertainty by experts. Historical data on previous similar systems is used when available, but most risk factors are subjectively determined. A factor represents the cost increase expected for a WBS element as a result of technical uncertainty associated with that particular element plus the interrelated uncertainties associated with other WBS elements that interface with it. By multiplying each WBS cost by its risk factor, a TRACE is computed. Time phasing is subjective or assumed proportional to BCE time phasing.

Advantages of this approach are: (1) analysis does not require a high analytical skill level; (2) analysis can be performed quickly and inexpensively in comparison to computer modeling; (3) analysis can be easily understood; and (4) quality of analysis can be easily evaluated by management.

The most serious disadvantage of this approach is in the determination of the risk factors. Because of the apparent simplicity of the approach, there might be a tendency to use the risk factor as simply a "fudge factor." To handle the factor in such a manner would reduce the credibility of the cost estimate. In addition, the factor is implicitly assumed to be constant for each element throughout duration of the project.

3. Probabilistic Network Modeling

Probabilistic Network Modeling is a combined approach using Program Evaluation and Review Technique (PERT) principles and Monte Carlo simulation techniques. Various computerized models can be used for this application, including VERT, RISCA, and RISNET.[8] An R&D program is first displayed as a network of interrelated events and activities. Cost, schedule and technical uncertainties associated with the various activities are then estimated. The model iterately simulates the activities and events to produce time-phased cost and schedule distributions for the program. The analyst can adjust the TRACE to levels reflecting desired probability of cost overrun vs. cost underrun. This method is the most rigorous and resource demanding, but it is the most precise and risk inclusive.

Advantages of this approach are: (1) explicit consideration is given to activity interaction; (2) the TRACE may be selected from the total cost distribution as output; (3) the form and collection of output is flexible; (4) the model can be easily modified and rerun to answer "what-if?" questions; (5) the network can estimate the BCE by fixing schedules and removing uncertain/contingency/fallback activities; (6) the network can serve as a management tool to track and control, as well as predict time and schedule; and (7) the network can be used to satisfy the Decision Risk Analysis requirement.

Disadvantages of this approach include: (1) a high skill level is required to build the network and collect data; (2) the output can be sensitive to the network logic; (3) it is difficult to reconcile this approach with the WBS; (4) the cost is initially high; and (5) it requires considerable data collection.

4. Probabilistic Event Analysis

Probabilistic Event Analysis, or Risk Tabulation, was developed by John M. Cockerham and Associates, Inc. to correct perceived deficiencies in the Risk Factor approach[10]. Risk for each WBS element is separated into two categories in an effort to assess interactive effects between WBS elements. Internal (stand alone or isolated) risks are assessed as well as the external (interactive) risks. Using conditional probability theory, the overall program cost risk is tabulated. Uncertainties assessed as probability values are determined essentially in the same manner as risk factors. Time phasing can be incorporated into the calculation by estimating when the various risks will occur for each WBS.

Advantages of this approach are that it is relatively easy to use, and it addresses interaction between elements so it should give better results than the Risk Factor approach. Disadvantages are (1) it is highly dependent upon the skill of the analyst to identify and account for the various interdependencies; (2) it is sensitive to errors in subestimates and; (3) the TRACE uses the BCE as a basis and is subject to the same bias as the BCE.

TRACE for RDT&E has been applied by the Army since the 6 March 1975 "Letter of Instruction (LOI) for Implementation of RDTE Cost Realism for Current and Future Development Programs."[9] Between FY 76 and FY 84, TRACE has been applied to 31 programs. As of FY 81, TRACE has been credited with avoiding 17 reprogramming actions and avoiding 27 Congressional approvals.[11] The number of programs using TRACE and the amount of TRACE funding have increased as shown in Figure 4. Those programs that have more recently used TRACE have relied on TRACE as a greater percentage of RDTE funding in the TRACE-funded years than earlier TRACE programs, as shown in Figure 5. Thus TRACE for R&D has become generally accepted and useful.

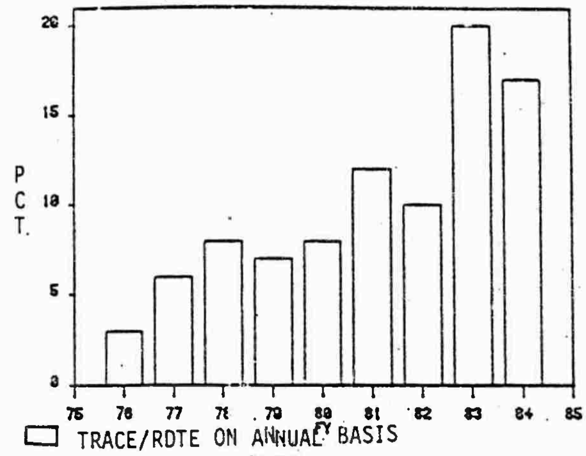

FIGURE 5

TRACE for R&D has experienced some problems:

1. Initially, PM's were hostile to the concept of project funds being held in reserve by DA.[12]

2. In theory, approximately one-half of the programs using TRACE should not need all of their programmed TRACE funds and the other half should need more than the amount programmed. In reality though, very few (5 times out of 88 potential) programs from FY 76-FY 81 have turned in unused TRACE funds in a fiscal year. Two possible explanations are

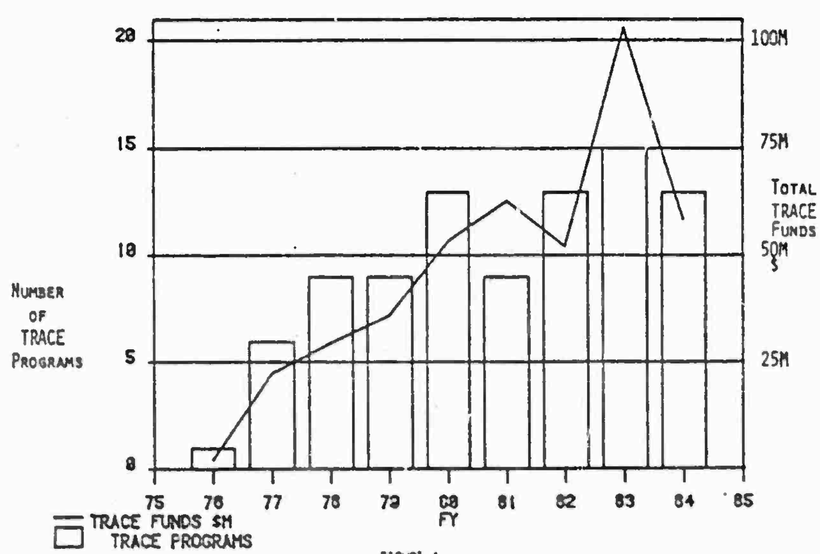

FIGURE 4

that TRACE may have been historically underestimated (or underfunded) or that TRACE becomes a "self-fulfilling prophecy."

3. TRACE methodology has been criticized as too subjective, too resource demanding, too restrictive, and too inflexible.[7]

4. TRACE has not eliminated RDTE overruns.[12]

TRACE-P

As stated earlier, TRACE-P within the Army was catalyzed by the April 1981 DEPSECDEF memorandum followed by a July 1981 Vice Chief of Staff memorandum. The first Army effort at estimating risk funds for production was completed in the spring of 1981 for the Remotely Piloted Vehicle (RPV) by the Directorate of Plans and Analysis at the U. S. Army Aviation Research and Development Command. A methodology for estimating management reserve for production for this system was developed. A similar approach was used for the Apache helicopter later that summer. Concurrently, the Army Procurement Research Office began a formal study of TRACE-P from June through December 1981. A methodology similar to the RPV approach was developed and tested on an historical system for validation. The APRO model was further modified by HQ DARCOM and institutionalized in the 6 October 1982 LOI. Thus, TRACE-P has evolved into a formal policy and procedure.

Capitalizing on the experience of the TRACE for R&D, the mechanics for implementing TRACE-P parallel almost identically the TRACE process. In the 6 October 1982 DARCOM LOI, TRACE-P is defined as the median or 50/50 point on the cost distribution for procurement funds during the first three years of "significant quantity production." Specifically excluded from the TRACE-P are procure-funds for long lead items and cost increases caused by:

Quality changes
Performance changes to meet an increased threat
Poor management
Inadequate funding in the early years
Inflation in excess of rates predicted
Unknown-Unknowns

Eight risk categories are allowed to control and focus the analysis of risk in early production. Cost increases covered by the TRACE-P umbrella are:

Threat uncertainty
Management
Materials/Purchased Parts
Facilities/Equipment
Labor
Design changes
Producibility
Performance

These risk categories are defined and examples are provided in the LOI.

The management and organizational policies for TRACE-P are also similar to TRACE. The PM is responsible for providing the TRACE-P estimate in conjunction with the Baseline Cost Estimate. Upon approval, TRACE-P becomes the program estimate and is submitted to DA to be included in the weapon system procurement line item. The difference between the TRACE-P and BCE will be identified as the Risk Cost or TRACE-P funds which will be held by the DCSRDA and released to the PM only upon approval by DCSRDA based on a written, validated request with justification.

The following methodologies have evolved for TRACE-P:

1. Investment Phase Management Reserve (IPMR) was the first known analysis to attempt to quantify the cost of production risks during the transition period. Developed for the Remotely Piloted Vehicle program, IPMR defines uncertainty elements or categories that are separate from the BCE structure. The link between the risk elements and the BCE is the Design to Unit Production Cost (DTUPC) value. The impact of the risk elements on the DTUPC is estimated as a triangular distribution based on experts' assessment of the nature of the risk and its cost impact. Then, the distributions are convolved using Venture Evaluation and Review Technique (VERT) which produces a single distribution for cost based on Monte Carlo techniques. The uncertainty elements in IPMR are labeled Production, Performance, Sizing, Technology, Resources, Management/Control, Higher Management and Other.

2. Employing a similar approach, APRO and ALMC developed an alternate methodology called Production Risk Assessing Methodology (PRAM) based on a survey of 10 PM offices, 3 Defense Contractors and several DOD experts. Linked directly to the BCE are 11 risk categories based on an analysis and synthesis of problems cited in historical systems during the transition period. The 11 risk categories were further grouped into 3 major groupings as shown in Figure 6. For each risk category an assessment is made on the possible impacts on the affected portions of the BCE as a cost distribution such as triangular, uniform, normal or other distributions. The pertinent BCE value is then subtracted from each distribution to form a distribution of risk costs which can then be combined, assuming independence, by Monte Carlo-based techniques such as VERT

or by application of the Central Limit Theorem.

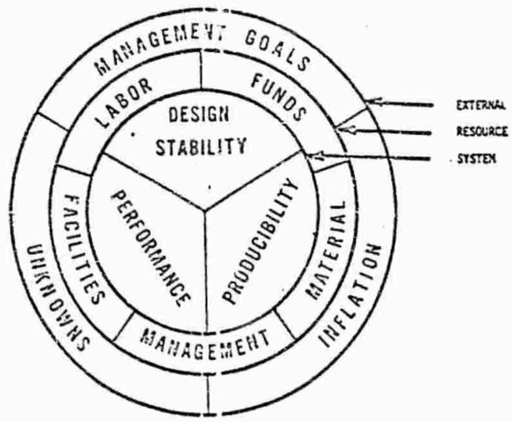

FIGURE 6 . HEIRARCHY OF INITIAL PRODUCTION RISK .

3. TRACE-P methodology outlined in the 6 October 1982 LOI was developed as a modification to PRAM. Two risk categories were eliminated, one redefined and the hierarchy or structure eliminated. The estimation of cost distributions as specified in the LOI calls for the direct estimation of risk cost or delta costing, although the BCE value is to be identified. The approved risk categories for TRACE-P are defined and examples provided as Threat Uncertainty, Management, Materials/Purchased Parts, Facilities/Equipment, Labor, Design Changes, Producibility and Performance.

4. An effort to develop a network-based TRACE-P methodology is in progress at the U. S. Army Communication and Electronics Command at Fort Monmouth, NJ. This model is similar to the Probabilistic Network Modelling technique used for TRACE.

Since TRACE-P is so recent, little experience and data would be available to evaluate the effectiveness of the program. TRACE-P methodology was tested by reconstructing an historical system BCE, applying TRACE-P to the pre-production estimate and comparing the revised estimate to the actual production costs of the system (M735 ammo). The revised estimate was extremely close to the total actual cost and also matched the yearly breakout of costs very well. However, it was not possible to track whether or not the actual cost increases matched the risk category predictions because of data limitations on the actual costs. Also, the experts who made the TRACE-P estimate were familiar with the program and knew what the actual problems were, facilitating the correlation of revised estimates to actuals.

Because the TRACE-P methodology is relatively straightforward and easy to apply, many recent systems have submitted TRACE-P as part of the program estimate for the POM process. Time will tell if the estimates are accurate and the methodology sound. Regardless, TRACE-P will increase the estimates of early production costs and therefore result in fewer cost overruns and improved management of the acquisition of systems.

COMPARISON OF TRACE AND TRACE-P

As the name indicates, TRACE-P is a natural extension of the TRACE program from Research and Development into the initial phases of production. Since there is a carry-over effect of technological risk in the transition phase, the TRACE-P initiatives have been designed and patterned after the earlier TRACE program. Essentially, some of the same risks associated with R&D remain and some new risks develop whenever a new product is produced for the first time in a production environment, rather than under prototype conditions.

Thus there is a great deal of similarity between TRACE and TRACE-P in the policies and implementation guidance. Both programs are implemented through a LOI as opposed to a regulation. Each program has a defined scope of uncertainties, i.e., types of uncertainties that are included or excluded. In fact, many of the exclusions are common to both. Each program is administered the same way. The PM develops both estimates, HQ DARCOM approves the estimates and validates the justification for release of funds. DCSRDA holds the risk funds, manages them and has approval authority for their release to the PM. Above the DA level, the TRACE and the TRACE-P become part of the weapon system line item. DOD and Congress see a single unified estimate that contains the sum of the BCE and the risk cost.

In addition, there is a great deal of similarity between the analytical techniques used in TRACE and TRACE-P. Both estimates rely heavily on expert judgment and the use of probability theory to quantify risks. The early TRACE methodology, application of risk factors to Work Breakdown Structure elements, is comparable in rigor to the TRACE-P methodology (neither is complex, data intensive and time consuming). Both estimates suffer from analytical problems stemming from the interaction of risks or interdependence which is difficult to quantify.

The differences between TRACE and TRACE-P are more obscure, apart from the differences associated with the different funding appropriations involved. Theoretically, TRACE-P should be a smaller percentage of the procurement program than TRACE is for the RDTE program because it only applies for the first three years and because technological risk should be a less critical factor in production. On the other hand, other forms of risk besides technical barriers may tend to dominate in the production transition. These risks, identified in the TRACE-P LOI, are generally related to the disruptions to the production process and planning caused by a broader scope of uncertainties than those encountered in R&D. The cumulative effect of the many small nagging problems associated with initial production that frustrate production management is the justification for the need to budget funds for the timely resolution of some of these problems. It should be noted, however, that TRACE-P, like TRACE, does not cure the illness; it only relieves some of the symptoms. Some production risks cannot always be resolved by an infusion of additional funds in a timely manner. A smooth transition reouires diligent management and planning, beginning in the early stages of R&D regardless of the availability of TRACE-P funds.

PROGNOSTICATIONS

With the knowledge that the subject is controversial and subject to widely divergent opinions within and among the servides, a projection of the future of TRACE-P will be made based on the Army experience with TRACE. Predictions (based on the premise that, because the programs are so similar, the experiences of TRACE will also apply to TRACE-P) are:

1. Acceptance - The Army will implement TRACE-P, slowly at first, then routinely for major systems. Project Managers will be generally supportive of the program. The Navy and the Air Force will also fund for initial production risks, but will use different models and procedures to do so.

2. Improved Methodologies - Alternate, more sophisticated methodologies will be developed to overcome resistance from "budget-cutters" and "optimists." These models will nonetheless be limited by the nature of the subjective data inputs. A useable risk data base will never be developed to enable analysts to rely less on expert judgment.

3. Results - Programs will continue to experience problems and cost overruns during the transition from R&D into production. However, the track record will be improved. The rate of overrun which had averaged over 35% in constant dollars during this phase will be reduced to less than 10% because of TRACE-P and other acquisition reforms.

4. Criticism - There will continue to be critics who believe that risk funds will be "self-fulfilling prophesies," slush funds to cover management errors, or analytical empire-building schemes. They will be supported by the inconsistency of programs to not use their risk funds (violating the 50/50 principle). This criticism will result in tighter management of TRACE and TRACE-P reserve funds, denial of release requests when justification is inadequate and rewards to PM's who do not use all of the risk funds.

5. Expansion - In the long term, there will be other applications of the concept of budgeting for risk. Potential areas are initial spare parts, military construction projects, procurement of foreign systems, etc.

In summary, the Army is aggressively pursuing the policies of budgeting for risk. It has done so for R&D with the TRACE program since budget year 1976 and has begun a follow-on program, TRACE-P, to budget for risk in initial production in FY 82. The two programs are similar in concept, policy and methodology. Thus, for the Army, history does seem to be repeated in the TRACE-P program.

Acknowledgement: This paper was written in part from a report entitled "Production Risk Assessing Methodology," APRO 81-2, May 1982, written by Monte Norton, Army Procurement Research Office, AMSAA; Richard Abeyta, now at the Logistics Studies Office, AMSAA; and Paul Grover, Army Logistics Management Center.

REFERENCES

1. Baer, John L. and P. Chernoff, "Engineering for Producibility," Army Research, Development and Acquisition Magazine, HQ DARCOM, Alexandria, VA 22333, July-August 1981.

2. Study of Army Logistics, 1981, HQ DARCOM, Alexandria, VA 22333 (Section 6 - The Materiel Acquisition Process), 30 August 1981.

3. Launer, Robert L., Harold F. Candy, and Shirley H. Carter, "Contract Cost Growth in Major Army Programs," Army Procurement Research Office, Fort Lee, VA 23801, May 1973.

4. Augustine, Norman R., "Augustine's Laws and Major System Development Programs," Defense Systems Management Review, Vol. 2, No. 2, Spring 1979.

5. Norton, Monte, Richard D. Abeyta, and Paul E. Grover, "Production Risk Assessing

Methodology (PRAM)," Army Procurement Research Office, May 1982.

6. "Total Risk Assessing Cost Estimate (TRACE)," Army Logistics Management Center, Fort Lee, VA 23801, ALM-63-4476-LC, June 1979.

7. Grover, Paul and Major George D. Schneickert, "Total Risk Assessing Cost Estimate (TRACE): A Field Survey," Army Logistics Management Center, Fort Lee, VA 23801, March 1981.

8. USALMC, "Army Programs Decision Risk Analysis (DRA) Handbook," US Army Logistics Management Center, Fort Lee, VA 23801, DARCOM Handbook 11-1.1-79, 29 October 1979.

9. "Letter of Instruction (LOI) for the Implementation of RDTE Cost Realism for Current and Future Development Programs," 6 March 1975, Department of Army-DCSRDA.

10. "Total Risk Assessing Cost Estimate (TRACE) Guide," John M. Cockerham and Associates, Inc., Huntsville, AL 35805, September 1979.

11. DAMA-RA letter, Subject: Total Risk Assessing Cost Estimate for Procurement (TRACE/P), 11 March 1981, with DRCDE-PC 1st Ind, 8 April 1981.

12. Ventzke, LTC Gene A., "Implementation of Risk Assessment in the Total Risk Assessing Cost Estimate (TRACE)," US Army War College, Military Studies Program Paper, 25 May 1977.

13. Simonich, Michael L., "TRACE: Effectiveness to Date," Florida Institute of Technology, Fort Lee, VA 23801, Research Paper, undated.

MANAGING RISK: THE RPV PERSPECTIVE

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ABSTRACT

This paper reviews formal efforts used to identify and measure risk in the Remotely Piloted Vehicle (RPV) Program. Formal means are contrasted with informal efforts which also surface risk areas, yet are designed for other purposes. Discussions follow to emphasize specific actions taken by the Project Manager (PM) to minimize identified risk.

PART ONE

During the course of the RPV Program, various attempts have been made to quantify the risk associated with the Full Scale Engineering Development (FSED) Phase and the Investment Phase. In mid-year 1979, a Total Risk Assessing Cost Estimate (TRACE) was estimated that equalled 15% of the total RPV FSED program cost. This estimate was based upon a comparison with the Advanced Attack Helicopter (AAH) and Target Acquisition Designation System (TADS) Piloted Night Vision System (PNVS) weapon systems and should be assessed in light of the RPV program's lack of maturity at that time.

In June of 1981, when the Army was considering the value of a TRACE concept for the Investment Phase of the Life Cycle Cost Estimate (LCCE), a report was submitted which described the analysis performed in calculating a risk assessment of the RPV's Investment Phase. This "Management Reserve" as it was called, categorized risk into the following categories:

- Production
- Performance
- Sizing
- Technology
- Resources
- Politics
- Other

This report identified the Air Vehicle, Mission Payload, and Modular Integrated Communications Navigation System (MICNS), as having high production risk. It assigned MICNS as high risk in terms of performance, sizing, and technology. The Mission Payload also ranked high in sizing. Politics was a significant risk area for the recovery subsystem; probably because the recovery system is supplied by a foreign company. Overall, the analysis recommended setting aside 18 percent of the investment cost for Management Reserve.

Department of the Army (DA) formed a team in August 1982 to discuss preliminary issues then being considered by a formal risk team, whose purpose was to recommend a cost position to the Army System Acquisition Review Council (ASARC) Chairman. The items that posed some degree of risk included:

- Changes in the Organizational and Operational (O&O) concept.
- Environmental protection requirements (nuclear hardening, etc.).
- Composite optic's producibility.
- Semiconductor availability.
- Transition from FSED to production.
- Production facilities move from California to Austin, Texas.
- Funds stability.

A short time after the DA Risk Team completed their evaluation, a Total Risk Assessing Cost Estimate-Production (TRACE-P) ad hoc team convened to incorporate the findings into an updated TRACE-P estimate. The DA Risk Team assigned high risk to the Data Link; the move to Austin; Lockheed Missile and Space Company's (LMSC's) production planning and their technical ability to integrate the system; LMSC's ability to provide the necessary composite optics and software independent verification and validation; and also the need to obtain a larger Ground Control System (GCS) computer. The team, using a statistical program to define cumulative distributions, placed the risk team's concerns into the following categories:

- Threat Uncertainty
- Management (i.e., Funding)
- Materials/Purchased Parts
- Facilities/Equipment
- Labor
- Design Changes
- Producibility

The highest risk, in terms of expected cost, was under the Facilities/Equipment category. The basic cause of this high potential cost was the possible requirement to open the acquisition of the Air Data Terminal to competitive bidding and, also, the possibility of having different subcontractors work in the production phase. The composite optics was responsible for the high risk assigned to Materials/Purchased Parts and to a lesser extent, the risk assigned to Producibility. The move to Austin generated risk associated with Labor. The concern here was the possible growth of burdened labor rates and a possible facilities contract with the Government.

Another effort was being undertaken during the same timeframe to assess the risk associated with the FSED Program. The resulting document represented a Decision Risk Analysis (DRA) for the RPV PMO. Its purpose was to determine the performance, cost, and schedule risks in the Research and Development (R&D) Phase.

Out of forty-two parameters identified representing performance, six were assigned high risk:

- Video Downlink (MICNS)
- Displacement
- Air Vehicle Design Gross Weight
- Forward Looking Infrared (FLIR) Weight
- Mission Payload Weight
- Electrical Optical Augmentation Test Program Sets

Cost risks were separated into three types:

- Cost Uncertainty
- Fixed Cost Growth
- Variable Cost Growth

Significant risk items influencing the schedule were:

- Number of Test Program Sets (TPSs)
- Electrical Optical Augmentation
- Mission Payload Redesign
- MICNS Slip (Redesign and Integration)
- TPS Development
- FLIR

The DRA indicated eight percent of FSED costs for the TRACE deferral. In February 1983, an update to the DRA was accomplished that considered only a revision to the RPV schedule. Performance and cost were assumed unchanged.

PART TWO

Drawing upon the results of the studies and reports examined in Part One, the Project Manager (PM) recognizes the high, moderate and low areas of risk in his program. He evaluates the status of his program, determines whether adequate funding is available, and takes appropriate steps to reduce his program risk level.

Risk can be identified by informal and formal means. The informal means are those activities that surface risk areas, but are not designed for that particular purpose. Some examples are:

- The PM and the prime contractor meet regularly on a monthly basis to discuss current problems and other issues relevant to the program.
- An Informal Technical Review (ITR) which is a command unique concept where the PM sends out a team to the subcontractors in order to initiate schedules, monitor progress, and assist in problem areas, may also surface risk.
- Factfinding teams can also surface areas although this is not its intended purpose.

Formal means, on the other hand, are those studies, teams, and other efforts devised specifically to identify risk areas. Examples of the observable actions, formal and informal, taken by the RPV PM to manage his program's risk as brought out in Part One will be examined.

Most of the actions taken by the PM to minimize risk involves the relationship that he has developed with the prime contractor. If the PM has earned the respect of the contractor; if he has convinced the contractor that he, the PM, represents the Army and wants what is best for the Army; if he has been fair and capable in the past, then the effort exerted by the prime contractor should be satisfactory in reducing risk, as long as the risk areas remain monitored by the PM. However, there are times when the PM has accomplished all of the above and the prime's efforts still do not reduce the level of risk to the PM's satisfaction. Consequently, there are necessary actions that the PM must take to resolve intolerable levels of risk in his program.

Soon after the contractor had begun work on the RPV contract, the PM directed the effort that culminated in the June 81 report. The findings indicated to the PM that MICNS was high risk in terms of getting it to operate satisfactorily at the dimensions required. In fact, size was perhaps the PM's greatest concern at that time for both MICNS and the Mission Payload. In addition, due to the business conditions at the responsible subcontractor, concern was expressed about the level of risk in the Air Vehicle. Such conditions were unfavorable labor practices, lack of production capacity, and poor management.

To alleviate these risks, the PM took three observable actions that have paid off:

- The subcontractor for the airframe was switched from the prime contractor's sister company Georgia Lockheed (GELAC) to Hitco.
- The program was stretched out from 43 to 52 months.
- Dual second tier subcontractors were

established to develop and integrate mission payload composite optics.

These actions significantly reduced the risks documented in the Management Reserve Study.

Approximately a year later, the program was again assessed for the purpose of reducing risk. The DA Risk Team and the TRACE-P Team, who conducted a follow-up study, identified their areas of concern for that period of time. These concerns, which have been listed above, shed light on some of the special actions taken by the PM which have greatly alleviated the level of risk. For example, the DA team noted that funding perturbations, which marked the program in early FY82, had considerable risks associated with it and questioned how the PM would minimize any future funding swings. One technique used by the RPV PMO is a heavy reliance on the Baseline Cost Estimate (BCE) in executing the budgetary process. By utilizing the BCE in this way, even before the Carlucci Initiatives required it, the PM recognized the implications of budget swings on his program and, thus, could take appropriate actions. With regard to the other risk areas, the PM set up TIGER teams who were sent to the subcontractors to initiate schedules, monitor progress, and assist in problem areas. The PM also set up Informal Technical Reviews (ITRs) which keeps the PMO and the contractor in close communication. As a further example of PM action, he is smoothing the transition from FSED to Investment by establishing an early operational capability program which provides a RPV section to a US Division. Also, through a Producibility Enhancement Initiative (PEI), he is providing for units to be built with hard tooling during the transition phase between R&D and Production. A final example of actions taken, relative the DA Risk Team, is the phasing out of engineers from Sunnyvale, California to Austin, Texas. Originally, it was planned to move all of the engineers to Austin by a certain date; however, to minimize disruption, only those whose work is finished at Sunnyvale are allowed to move to Austin.

Next, the TRACE-P Team applied a statistical analysis of the risk areas identified by the DA team. A point known to the DA team and emphasized firmly by the TRACE-P Team concerned risk associated with the Test Program Sets (TPSs). Because newly developed weapon systems are often highly complex in terms of their construction and capability, and rely heavily on software either in operation or testing for faults, the strategy taken by the RPV PM is to develop about 15% of the TPSs during FSED and to construct the remaining sets after FSED is completed. Having workable computer programs developed in this way should minimize program risk considerably in terms of reducing computer reprogramming, often necessitated by engineering changes in the hardware being developed during FSED.

The last risk study under consideration here is a Decision Risk Analysis (DRA). The data base for this effort was a questionnaire on which the responsible PMO engineer described the risk level for one of 42 parameters and the plan formulated to manage the associated risks. A review of the responses underlines the PM's obvious concern for risk items and the reduction in risk resulting from actions which the PM has taken. For instance, the PM performed tradeoff studies to evaluate Organizational and Operational (O&O) concepts, which impact displacement, and simultaneously allows the PM to plan for potential scenarios. Test Program Sets (TPSs) remain a concern and are continually monitored by management and technical personnel, as noted above. In addition, programs written for TADS/PNVS are being studied for application to the RPV program's test sets.

SUMMARY

The key to managing the RPV Program's inherent risk is early identification of the problem areas. The PM augmented the usual means of assessing risks, e.g., Initial Production Readiness Reviews (IPRRs), factfinding, standard reviews, and monthly status meetings, with studies designed specifically for identifying and, to some extent, quantifying program risk. Like so many other state-of-the-art weapon system programs, the areas of risk change and the levels of risk tend to diminish as the program matures. The RPV, however, insures that its program endures only minimum risk by early identification and good management practices. Those risk areas identified in the recent DRA are indeed different from those identified in June 1981. Moreover, the level of risk for each item is considered to be substantially reduced.

PANEL SESSION

ON

COMPUTER AIDS IN DECISION MAKING

CHAIRMAN

GERALD MOELLER

US ARMY ARMAMENT MATERIEL READINESS COMMAND

INTERACTIVE RISK ANALYSIS

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ABSTRACT

This paper presents a brief description of a computer program which is available to perform calculations needed in a risk analysis. The model discussed in this paper is one which allows a user to estimate the risk associated with any number of variables and to display the distribution of any arithmetic (addition, subtraction, and (or) multiplication) combination of the variables.

The mode of operation is designed to be similar to a calculator. Rather than entering in a single number, the user must supply a low, most likely and high for each variable. Variables can be added, subtracted, or multiplied; intermediate calculations can be stored; and the distribution of the total can be displayed at any time.

INTRODUCTION

Many point estimates of totals (e.g., project completion time, cost of weapon systems, etc.) involve simple addition, subtraction and multiplication which can be performed on a hand calculator. Commonly, point estimates are made for each subcomponent and totals are calculated. Problems arise when there is uncertainty about the value of the individual component because of lack of information or the inability to accurately forecast the subcomponent. The affect of this uncertainty on the total is captured by risk analysis.

To determine the amount of uncertainty in a total, an analyst would not only estimate the most likely value for each subcomponent but also estimate the probability of different outcomes for each subcomponent. From this information, probabilities of different totals could be calculated. This is exactly what is done in statistical risk analysis. The only difference is in the way that an analyst supplies information about the uncertainty in subcomponents and how this information is used to make probability statements. The complexity of the calculations required make the use of a computer almost a necessity.

Most computer programs available to assist an analyst in performing calculations required in a risk analysis are designed with a particular area of application in mind or require a relationship between the different variables involved to be defined in advance. Either of these requirements limit the flexibility of the software and hence applications.

The computer program discussed in this paper was designed such that

- -no formal training is required on the modeling technique employed,
- -no mathematical equations need to be defined,
- -the operation is similar to a calculator, and
- -the results can be displayed immediately.

The program can be used in numerous areas of applications including, but not limited to, quality control, scheduling, inventory control, and cost analysis.

Interactive Model

The computer program being discussed, accepts three estimates for each subcomponent and allows the user to combine the subcomponents using any sequence of addition, subtraction and multiplication. The three points required are a most likely value (i.e., the value with the highest probability), a low value (i.e., a value which will be underrun only 1% of the time), and a high value (i.e., a value which will be overrun only 1% of the time). When the user has combined the subcomponents in a meaningful fashion the probability of different totals can be requested.

The user has the following commands available:
- -ADD for addition
- -SUB for subtraction
- -MUL for multiplication
- -STO for storing intermediate calculations
- -RCL for recalling stored information
- -INP for inputing the three point estimates
- -CON for displaying the contents of storage
- -DIS for displaying probabilities
- -BYE to end program.

Note, there is no hierarchy of operation (i.e., 1 added to 2 and then multiplied by 3 would be 9 not 7).

EXAMPLE

In order to illustrate the interactive risk program, a simple example will be used. The problem is to add two variables together and then to multiply by a third variable. The data for the three variables is shown below.

Variable	Low	Most Likely	High
1	300	400	600
2	100	300	900
3	.1	.3	.5

The actual input and output is shown below. The use of the STO command was not necessary but was used to demonstrate how intermediate calculations can be stored. The underlined portion is the user input.

INTERACTIVE RISK ANALYSIS EXAMPLE

```
COMMAND (mul, add, sub, dis, inp, sto, rcl, con, bye)
? inp
Low, Most likely, and High ? 300,400,600

COMMAND (mul, add, sub, dis, inp, sto, rcl, con, bye)
? add
COMMAND (inp, rcl)? inp
Low, Most likely, and High ? 100,300,900

COMMAND (mul, add, sub, dis, inp, sto, rcl, con, bye)
? sto
Enter numeric storage location? 21

COMMAND (mul, add, sub, dis, inp, sto, rcl, con, bye)
? inp
Low, Most likely, and High ? .1,.3,.5

COMMAND (mul, add, sub, dis, inp, sto, rcl, con, bye)
? mul
COMMAND (inp, rcl)? rcl
Enter Numeric Storage Location? 21

COMMAND (mul, add, sub, dis, inp, sto, rcl, con, bye)
? dis
   PROBABILITY          TOTAL          Most likely value= 2.0194662D+02
   OF EXCEEDING         VALUE                      Mean = 2.4066549D+02
          0.01 5.0070685D+02
          0.05 4.1430178D+02
          0.10 3.7006158D+02
          0.15 3.4109697D+02
          0.20 3.1865877D+02
          0.25 2.9986448D+02
          0.30 2.8337811D+02
          0.35 2.6845837D+02
          0.40 2.5464213D+02
          0.45 2.4161250D+02
          0.50 2.2913463D+02
          0.55 2.1702022D+02
          0.60 2.0510498D+02
          0.65 1.9323140D+02
          0.70 1.8123174D+02
          0.75 1.6890555D+02
          0.80 1.5598177D+02
          0.85 1.4203856D+02
          0.90 1.2628802D+02
          0.95 1.0673596D+02
          0.99 8.1682755D+01
```

The program will allow for up to 100 distributions of intermediate calculations to be stored. The number of inputs and calculations is unlimited.

SUMMARY

An interactive risk analysis program, which is not tied to a particular application and does not require modeling knowledge of the user, has been described in this paper. The ability to perform risk calculations in a manner similar to using a calculator makes the program easy to use and adds flexibility.

The program is currently available on two brands of micro computers and will be on COPPER IMPACT in the near future. For more information concerning the program or its usage contact the author or

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A MANAGER ORIENTED MICROPROCESSOR HOSTED RISK ASSESSMENT PROGRAM

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ABSTRACT

This paper describes a microcomputer program that is used at Martin Marietta Denver Aerospace (MMDA) to perform quantitative risk assessment and to assist in program risk management. Examples are presented to illustrate its use for analyzing technical, schedule, and cost risks. The program has been developed to require minimal training in order to provide a tool that program managers can and will use. The functional capabilities of the program for monitoring and managing risk data are described including examples showing user interaction.

I. Introduction

This paper describes a microcomputer hosted risk assessment program that is designed for direct use by program managers or systems engineering leads even though they may have no previous experience using computers. The software is part of a risk analysis methodology developed and being implemented by the Systems Engineering Department of MMDA. The program has been named RAMP, for Risk Assessment and Management Program. It should not be confused with a similarly named program developed by the USAF in the 1970's.

RAMP provides an easily used tool to maintain program risk data and to analyze program technical, cost, and schedule risks. Using RAMP, managers may interactively compare alternative program strategies proposed to mitigate risks and identify effects of potential problems. The ability to rapidly evaluate risks for program alternatives is a desirable capability in today's acquisition environment. A recently completed USAF study indicates that in the 1970's the major sources of program problems are funding instability, external management impact, and technical complexity. Each of these effects will modify requirements and program hierarchies, introducing new uncertainties thus requiring development of new program strategies and increasing the need for quantitative risk assessment. An interactive risk assessment tool can permit managers to quickly identify effects of such potential program perturbations.

Another attractive feature of RAMP lies in the security of program data inherent with use of a microcomputer for sensitive programs or for sensitive managers.

The MMDA risk analysis approach that incorporates RAMP is shown in Figure 1. A fundamental feature is

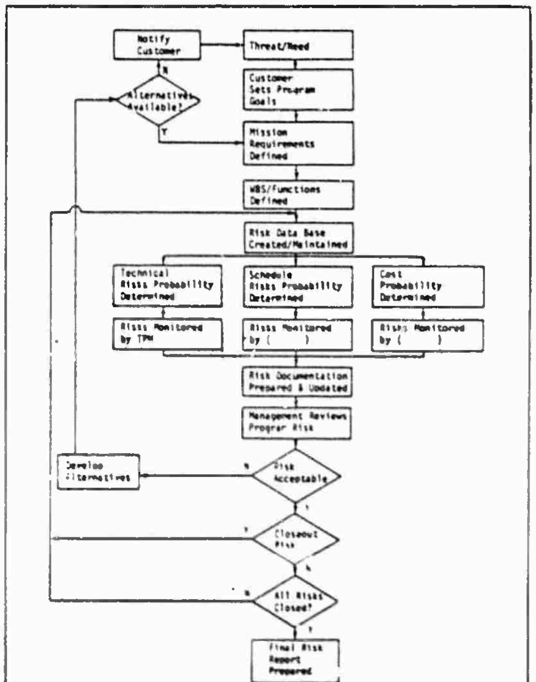


Figure : Overall Risk Analysis Flow Diagram the continuing assessment of all program risks from preproposal activities through program completion. Early in a program, risk assessment provides inputs for deriving cost and schedule estimates that include risk induced by technical uncertainties. Just as important, the risk assessment methodology helps identify inconsistent or deficient requirements. It is impossible to make estimates for technical risk parameters without well defined performance requirements. As shown in Figure 1, the customer is involved in the overall risk management process since risks may sometimes have to be balanced against mission goals or need of a weapon system to counter a threat. Figure 2 shows how systems engineering utilizes the RAMP data base to ensure that all disciplines involved in program performance, monitoring, estimating, and planning use consistent and timely risk data.

Following sections describe key features of RAMP and present examples to illustrate its application.

II. RAMP Description

RAMP has been implemented on both IBM PC and APPLE II+ microcomputers. It has also been recently converted and implemented on a VAX 11/780 computer for use by some programs which do not have access to microcomputer systems. Some of the calculation algorithms were initially developed on an HP-85 desk top computer and were modified for the IBM PC.

RAMP provides "manager-friendly" executive control, data base management, risk calculation using Monte Carlo simulation, and tabular and plotted output display of risk effects in the form of cumulative probability functions for risk parameters. It does not incorporate network models of programs. Rather, it is intended to identify a range of values for a single program risk parameter that is not uniquely defined because of some program uncertainty or combination of uncertainties. Examples of risk parameters that have been assessed for programs are required lines of software code, system mass, time required to complete sets of tasks, engineering manpower and associated cost, probability of program success (or overall program risk), and relative complexity or technical state of the art increase required for a program.

Following are paragraphs which discuss the RAMP executive, data architecture, and data manager.

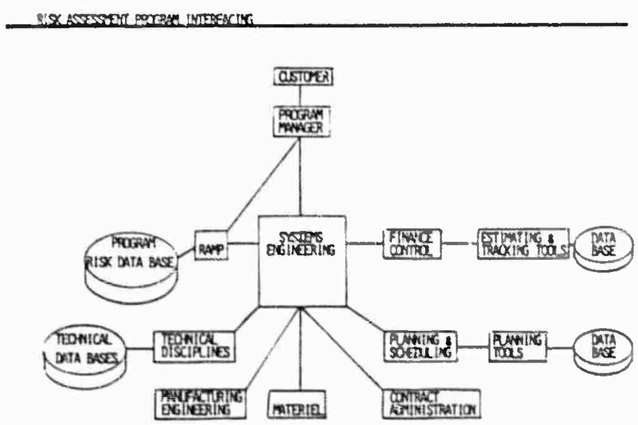


Figure 2 MMDA Risk Methodology Interfaces

II.1 RAMP Executive Approach

The basic objective is simplicity of use, both with respect to minimizing training required for use and eliminating ambiguity in user prompts. Experience indicates that managers most likely will not use computer tools that require a learning process or relearning if time passes between uses. For this reason, the RAMP executive software is based on menu selection and unambiguous prompts requiring either YES/NO answers, user defined file names, or user defined parameter names. All user inputs are protected against inadvertent input errors or reading through end-of-data. Preliminary testing has shown that RAMP may be used effectively with less than 10 minutes training. The Main Menu display shown in Example 1 permits a user to identify and select the desired risk assessment function.

```
Select Risk Assessment Function:
1-Enter new risk
2-Modify current risk
3-Delete risk element
4-Display risk data
5-Create risk calculation file
6-Calculate and Plot risk effect
7-Stop

Function choice ? 1
Enter Risk DB File Name ? PAPERDB
```

Example 1 RAMP Main Menu

II.2 RAMP Data Management

The data base stores those data required for the quantitative risk assessment. The data are obtained by a cooperative effort including systems engineers, technical leads, cost estimators, etc. as shown previously in Figure 2. Data relating to rationale for the risk assessment, when made and by whom, and information relevant to risk management are presently maintained on hardcopy forms used to acquire data. Only data required for the RAMP calculation is entered into the program data base.

RAMP Data Architecture

Each RAMP data base record contains:

1) a task identifier (e.g. WBS number);
2) a risk type identifier where
   1 = performance risks
   2 = supportability risks
   3 = schedule risks
   4 = cost risks;
3) a risk parameter name;
4) a probability density function type where
   1 = uniform
   2 = triangular
   3 = normal
   4 = fixed value;

5-7) values corresponding to the density function.

All risk data for a program are stored in a program unique data base using a host computer random access file. When calculation of a cumulative function is desired for a risk parameter, a calculation file is created. The calculation file is a host sequential file containing the density type and values for each record of the specified risk parameter.

RAMP Data Management

The first 5 Main Menu choices are data management functions. Choice 1 is used to create a new data base or to add new risk records. Choice 2 permits individual risk data records to be modified while choice 3 permits deletion of a risk record from the data base, either of which might happen as a program matures and risks are closed out. A typical use of these functions would result if a manager desired to tradeoff risk resulting from alternative approaches to mitigate risks. A second use is to determine the effects if estimates are believed to be verly pessimistic or optimistic.

Choice 4 is used to display risk data records. The submenu shown in Example 2 allows selective display of:

1) all data records;
2) all records of a single WBS or for a single function;
3) all records of a single risk parameter;
4) all records of a risk type.

```
Function choice ? 4
Enter Risk DB File Name ? PAPERDE

Would You Like A Hard Copy? N
Select Risk Data Display Mode
1-Display all data
2-Display by WBS
3-Display by risk parameter
4-Display by risk type
5-Return to MAIN MENU

Display Choice?
```

Example 2 RAMP Data Display Menu

A user prompt is issued at the start of the display function to control display for a printer or display monitor. If a printer is not used the display will proceed one risk record at a time. A record display and prompt to continue is shown in Example 3. When the selected display function is completed the display menu is again presented for further display or return to the Main Menu.

```
-----------------------------------------
RECORD # 7

WBS#2.0
Cost risk

Parameter--DIRECT LABOR

Distribution Type Is Triangular( 2 )
Lower Limit            4400
Upper Limit            5700
Most Likely Value      4800

-----------------------------------------
To Continue, Type Any Key, Then Return
To Stop,Just Return? E
```

Example 3 Risk Data Display

Choice 5 creates a sequential data file to be used during risk calculation. The file is created by user input of the desired risk parameter as shown in Example 4. The data base is searched for all records of the parameter and the parameter name, probability density function type, and risk parameter data are written to the calculation file. Several calculation files can be created at this time before entry to the calculation section of RAMP.

```
Function choice ? 5
Current DB Name Is PAPERDB Use This DB?
? Y
Name Of Calc. or Multiplication Distribution File To Be Created?? ORAUL

Calculate Cumulative Risk Distribution
Select Risk Type
1-Performance
2-Supportability
3-Schedule
4-Cost
CHOICE"? 2

Risk Parameter Is"? MTBO-RPR

File named ORAUL created '
```

Example 4 Create Calculation File

RAMP Risk Calculation

RAMP calculates risk effects using the probability density function of each risk record. At present calculation algorithms are included for uniform, normal, and triangular distributions. An algorithm for Beta distributions could easily be added if desired. The increased accuracy in fitting a density function to a Beta distribution is probably insignificant when compared to the uncertainty in the risk data estimates. The ability of triangular functions to incorporate skewed estimates is considered sufficient for the RAMP analyses. When the calculation section is entered the user is prompted as shown in Example 5 to select the risk dependency mode that best reflects the program and the particular parameter being analyzed. The choice will be for either dependent risks or independent risks. The variance for dependent risks will be greater than for independent risks. In reality, some program risks will be independent and some interdependent. By performing an analysis using each mode, it is possible to estimate a value between the two when appropriate. This will result in a better definition of the actual parameter variance for most programs.

Calculations are performed using a Monte Carlo simulation. The user defines the number of passes through the algorithm. Table 1 shows the expected average error in generating random numbers as a function of number of passes for the IBM system. The random numbers are seeded by using the minute and second values of the internal clock function. The random function for the Apple system does not require explicit seeding. Tests show the same level of expected error for the Apple as for the IBM.

```
RISK CALCULATION FILE NAME IS ? MASSFIL

RISK PARAMETER IS? MASS
IS THIS THE DESIRED RISK PARAMETER ? Y

SELECT SIMULATION MODE

1-DEPENDENT RISKS
2-INDEPENDENT RISKS
USE MODE ? 2

NUMBER OF PASSES? 200
```

Example 5 Prompts for Calculation Mode

Table 1 Average Error in Random Number Generation

# Passes	% Error
50	6.2
100	5.4
200	3.5
500	1.2
1000	0.6

The required execution time is a function of the number of risk records, the type of probability density function, and the specified number of passes. Test cases run indicate execution time of about 1 second per pass on the IBM PC and slightly longer on the APPLE II system when using interpreter BASIC. Using a BASIC compiler with the IBM decreased run time by 4 1/2 times for an identical case. In addition, the advances being made in speed of processor chips for microcomputers will further decrease execution time in the future.

After calculations are completed the range of the parameter and cumulative probability function are output in tabular and plotted form. After each calculation and output is completed, the user is permitted to calculate compound risk effects by the prompts shown in Example 6.

```
DO YOU WISH TO COMPOUND DISTRIBUTION FACTORS TO THE CUMULATIVE CURVE ? Y
STORING CUMULATIVE CURVE FOR CALCULATIONS. WILL BEEP WHEN COMPLETE
COMPOUND DISTRIBUTION FACTOR FILE NAME (TYPE 'CAT' FOR LIST OF FILES'? SECSURD

RISK PARAMETER IS? SEC. SUBO
IS THIS THE DESIRED RISK PARAMETER ? Y

SELECT SIMULATION MODE

1-DEPENDENT RISKS
2-INDEPENDENT RISKS
USE MODE ? 2

NUMBER OF PASSES? 200
```

Example 6 Risk Convolution Prompts

II.3 RAMP Applications

Following are some examples of how RAMP has been used to determine a range of values for technical parameters, manpower requirements, and program costs.

Evaluating Risk of Staying Within Mass Budget

Figure 3 shows 4 component mass estimates and the resulting cumulative probability function obtained by RAMP execution. The total mass budget was 190 kilograms resulting in an initial risk of 25%. As the program is performed the mass estimates are continually updated and the mass risk recomputed. The risk can be plotted vs. time as shown in Figure 4. Ideally, the risk should decrease as the program matures. If not, management action can be pursued earlier than would be probable without benefit of the quantitative risk assessment. Similar analyses can be performed for any technical parameter to predict and monitor technical risk. As will be discussed later, the results can be normalized to evaluate overall program risk.

Quantitative risk assessment can also improve the ability to tradeoff alternative designs. Figure 5 shows the risk data and predicted mass for a case where the mass estimates for components 3 and 4 are changed to represent a different system design. For the new design the initial mass risk is <5%. Now, however, other factors such as increased complexity must be traded off as well.

Evaluating State-of-the-Art(SOA) Risk

Figure 6 shows the result obtained for predicting a range of technical complexity figures for input to a cost estimating model. (This points out a valuable use of RAMP--its use to provide datareflecting program uncertainties for use in existing tools.)

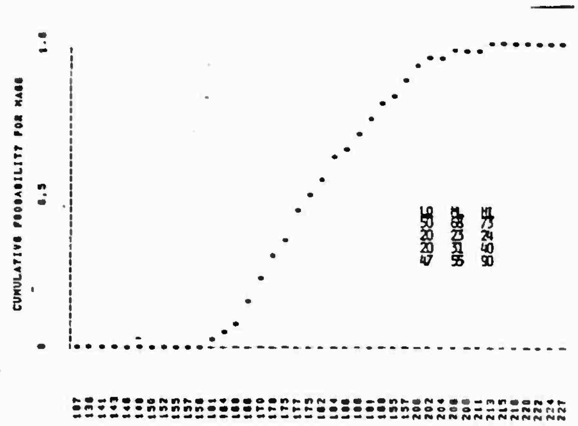


Figure 3 Cumulative System Mass Function for Initial Design Configuration

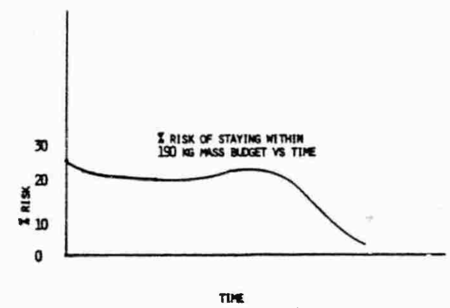


Figure 4 Risk of Meeting Mass Budget

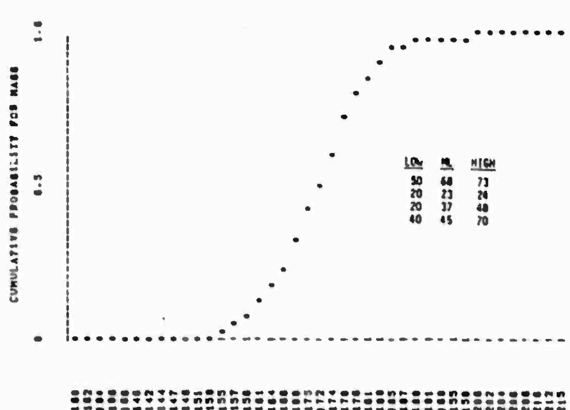


Figure 5 Cumulative System Mass Function for Alternative Design

Each of 6 WBS task were analyzed to estimate relative complexity factors on a scale from 0.2 (easy) to 3.3 (most difficult). Cardinal weights were also defined for each task to relate their relative importance to the program. These values are shown in Table 2.

Table 2 Technical Complexity Risk Data

WBS	Weight	Low	Most Likely	High
1.0	4	0.2	0.3	0.4
2.0	8	0.7	0.8	0.9
3.0	12	0.2	0.2	0.3
4.0	3	0.6	0.6	0.8
5.0	3	1.0	1.0	1.0
6.0	3	0.4	0.4	0.6

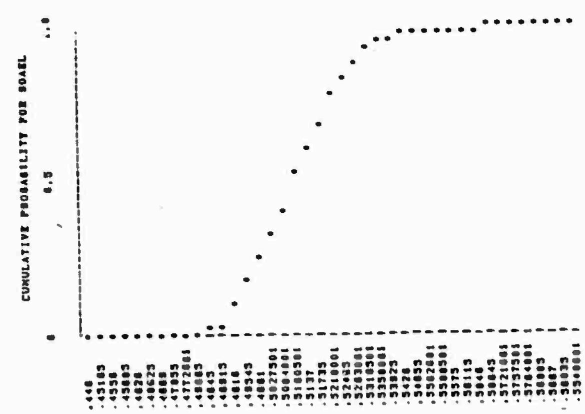


Figure 6 Cumulative Function for Assessing Program Technical Complexity

Estimating Engineering Labor Cost

A method was desired to estimate engineering labor cost considering uncertainty in the total hours required to perform a set of tasks by different labor grade mixes. Figure 7 shows the probable direct cost obtained from the estimates of Table 3. The labor burden density function was applied to this result to give the burdened cost estimate shown in Figure 8. Finally, the G&A density function was applied resulting in the total probable cost function shown in Figure 9. This type of analysis provides data for a rational selection of price of labor.

Table 3 Probability Density Function Data for Manpower Cost Estimate

RAMP APPLICATION—MANPOWER COST ESTIMATION WITH BURDENS

WBS #	LOW VALUE HRS	LOW VALUE RATE	MOST LIKELY HRS	MOST LIKELY RATE	HIGH VALUE HRS	HIGH VALUE RATE
1.0	1500	$27	2000	$22	2500	$18
2.0	4400	22	4800	20	5700	17
3.0	3200	23	3200	23	4500	17

ENGINEERING LABOR BURDEN

LOW	MOST LIKELY	HIGH
1.01	1.04	1.10

G & A BURDEN

LOW	MOST LIKELY	HIGH
1.09	1.09	1.17

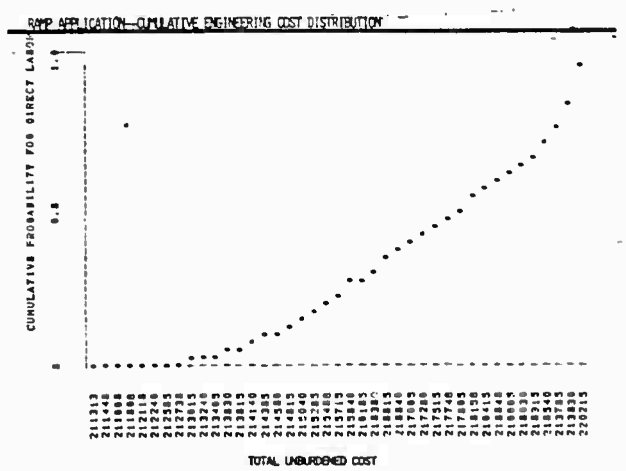


Figure 7 Unburdened Manpower Cost Function

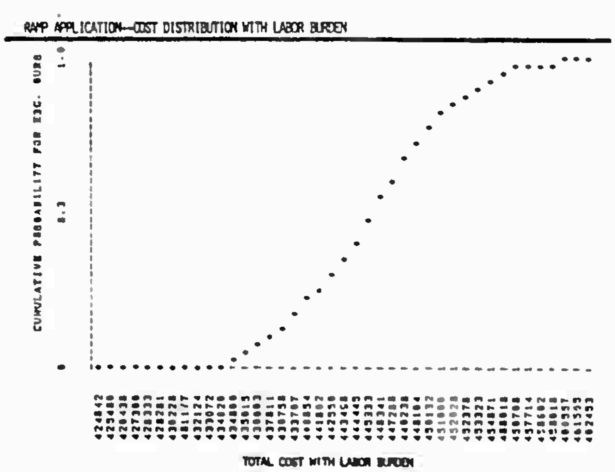


Figure 8 Burdened Manpower Cost Function

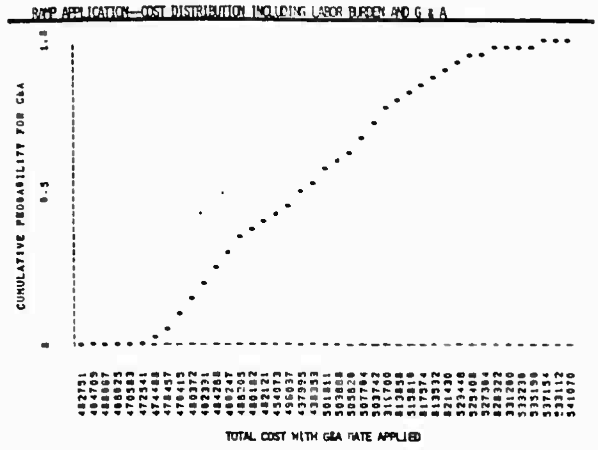


Figure 9 Cumulative Cost Function With G&A

Evaluating Program Performance Risk

Tradeoff of alternative program approaches requires evaluation of overall risk based on allocated resources. A typical risk analysis scenario first uses the risk assessment methodology to predict cumulative schedule and cost requirements. Consider the case represented in Figure 10. Using RAMP, an initial cost prediction was obtained for the listed 6 top level functions. A baseline price of $86M was selected based on results. The $86M was then allocated to the tasks as shown under column "V". These allocated values were then used to go back into the data base to determine a risk for each task based on its allocation. The resultant risk for each task and an overall weighted risk for the program were calculated and output as shown. It now is easy to respread the initial allocation to reduce risk for individual tasks or to minimize overall risk.

Another way RAMP can be used to predict overall program risk is to use estimates of probability of success from program task leads after initial resource allocation. Each lead provides low, modal, and high

RAMP APPLICATION—PROGRAM TECHNICAL RIS

BASELINE COST SELECTED FROM CUMULATIVE COST DISTRIBUTION—[illegible] M

WBS	DISTRIBUTION	LOW	ML	HIGH
1.0	TRIANGULAR	$20	$28	$41
2.0	NORMAL	3	17.5	--
3.0	TRIANGULAR	3	7	8.9
4.0	UNIFORM	6	--	10
5.0	TRIANGULAR	4.2	5.6	6.9
6.0	FIXED	--	4.9	--

RISK ELEMENT	LO	ML	HI	[illegible]	RISK
[illegible] SOFTWARE	20	20	31	[illegible]	.02298
[illegible] SYSTEMS	2	17.5		10.[illegible]	.32059
[illegible] DESIGN	[illegible]	7	[illegible]	[illegible].2	.04271
[illegible] QUALITY	[illegible]		10	[illegible]	.28
[illegible] TESTING	4.2	[illegible]	[illegible]	[illegible].4	.07122
[illegible] TESTING		4.[illegible]		[illegible]	[illegible]

WEIGHTED RISK = SUM(PARAMETER VALUE * RISK) / SUM(PARAMETER VALUES) *100%

=12.13402 %

Figure 10 Evaluation of Overall Program Risk After Allocating Funds

probability values. A weighting factor reflecting task importance is assigned by the manager with the sum of weights equal to 1. In RAMP, these estimates are entered as performance risks with a required parameter name "NORMED". The calculation produces a cumulative program risk combining different types of risk parameters.

Evaluating Schedule Risk

While RAMP does not include ability to create network models, it can be used to perform first order schedule risk analyses or to simplify network models. Figure 11 shows a simple program schedule network. RAMP could be used to determine an equivalent cumulative function for each loop resulting in the simplified network shown in Figure 12. The final step would be to use RAMP to determine a cumulative function for both remaining paths and using the results to predict risk of meeting the program milestone. For programs in early stages this might provide a means to reduce effort required when program hierarchies change frequently, as is common with high technology programs.

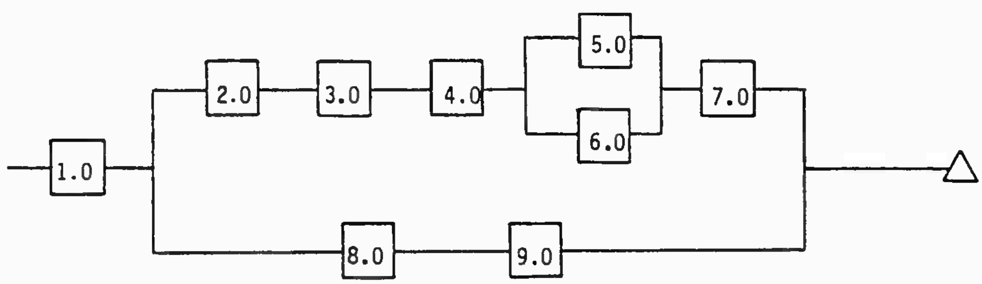


Figure 11 Initial Network Model

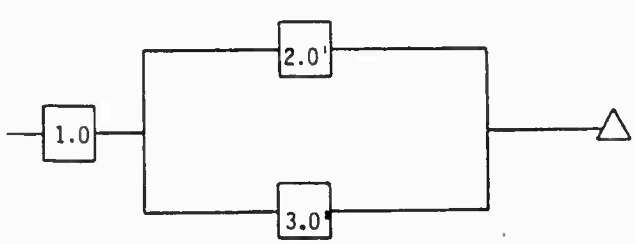


Figure 12 Reduced Network Model

IV. Summary

RAMP was developed to meet a functional requirement for a risk assessment methodology that can readily used to improve planning and management of acquisition programs. The methodology emphasizes acquiring, maintaining, and communicating risk data to aid both the customer and contractor managers. The calculation capabilities of RAMP could be supplemented by more esoteric algorithms if so desired. The present capabilities are considered adequate for now.

The risk assessment methodology, including RAMP, is currently being used on several programs and is being included in several proposals as the approach to be followed to perform risk assessment. The examples presented here represent only a fraction of the potential application to program management. The methodology can be applied to any program that needs to determine effects of program uncertainties. The ease of use of RAMP coupled with the low cost and portability of microprocessors make it an attractive alternative to previously developed risk assessment programs. It may also serve to increase acceptance of the use of quantitative assessment techniques by managers by making them more transparent to the user.

CAUSAL-INTEGRATIVE MODEL

I. A. Somers, Ph.D.
Hughes Aircraft Company

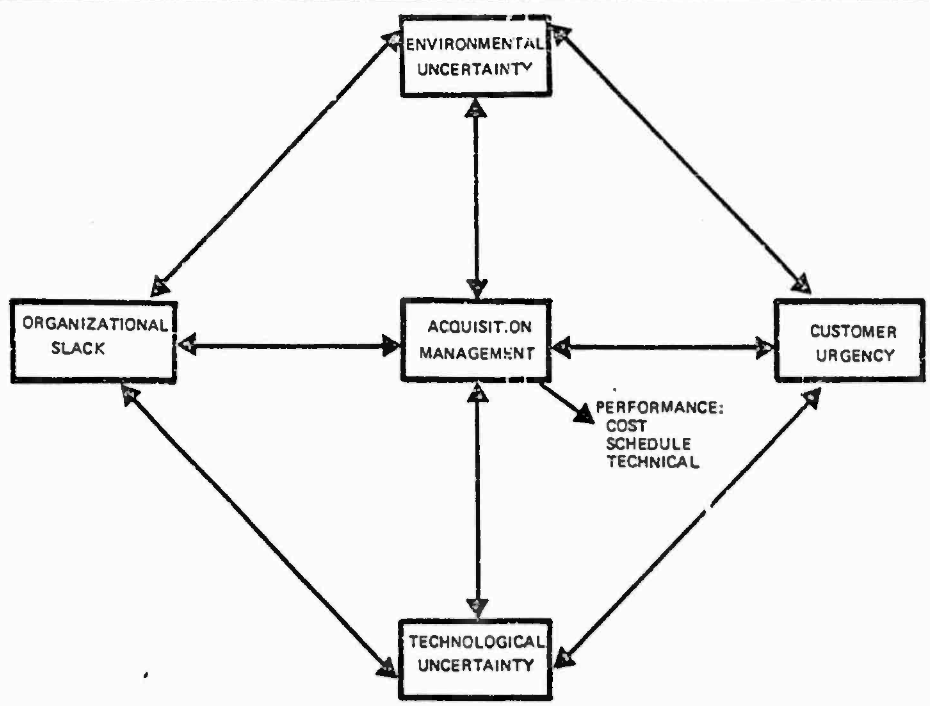
CAUSAL-INTEGRATIVE MODEL

HUGHES
HUGHES AIRCRAFT COMPANY

- INVOLVES E. B. COCHRAN'S CONCEPT OF DISRUPTION THEORY
- EVOLVED FROM RESEARCH AT UNIVERSITY OF SOUTHERN CALIFORNIA (COCHRAN, ROWE)
- FIRST PRESENTED FEBRUARY 1981 (ROWE, SOMERS)

AGGREGATED CIM VARIABLES

HUGHES
HUGHES AIRCRAFT COMPANY



ACQUISITION MANAGEMENT PROCESS

DEFINITION OF VARIABLES

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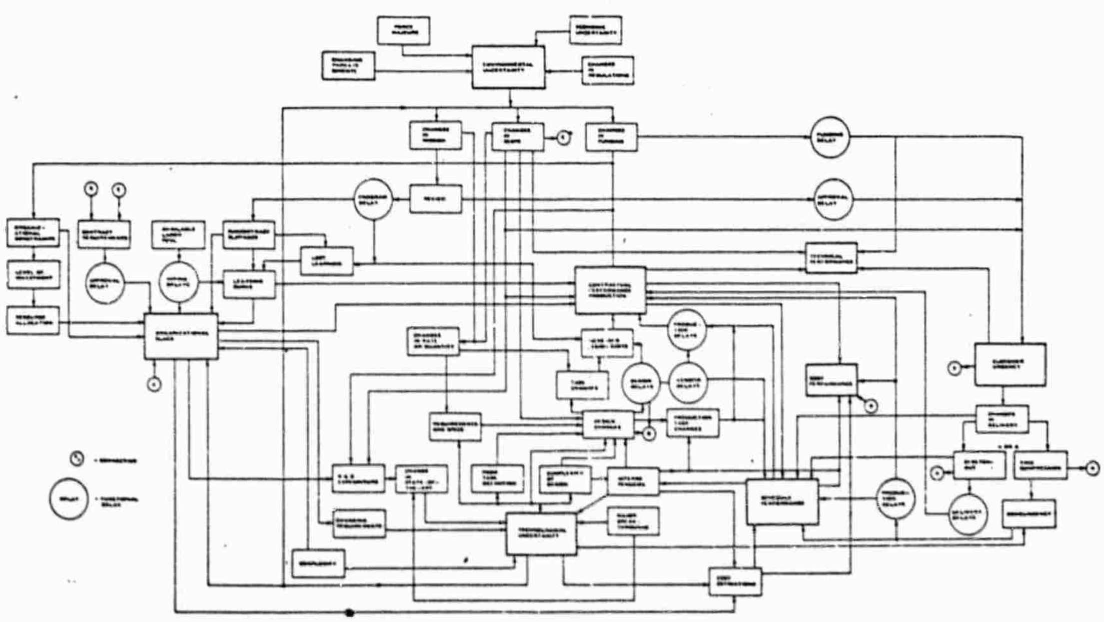
- **ENVIRONMENTAL UNCERTAINTY** — EXOGENOUS VARIABLES THAT CAUSE DISRUPTIONS
- **TECHNOLOGICAL UNCERTAINTY** — MEASURE OF SOA AND DEGREE OF INTERDEPENDENCY AMONG COMPONENTS
- **CUSTOMER URGENCY** — TIME COMPRESSION, STRETCH-OUT, CONCURRENCY, CHANGES IN SCOPE
- **ORGANIZATIONAL SLACK** — MEASURE OF ORGANIZATION'S ABILITY TO PERFORM TASK REQUIREMENTS

CAUSAL-INTEGRATIVE MODEL

HUGHES
HUGHES AIRCRAFT COMPANY



ORGANIZATIONAL SLACK RELATIONSHIPS

HUGHES
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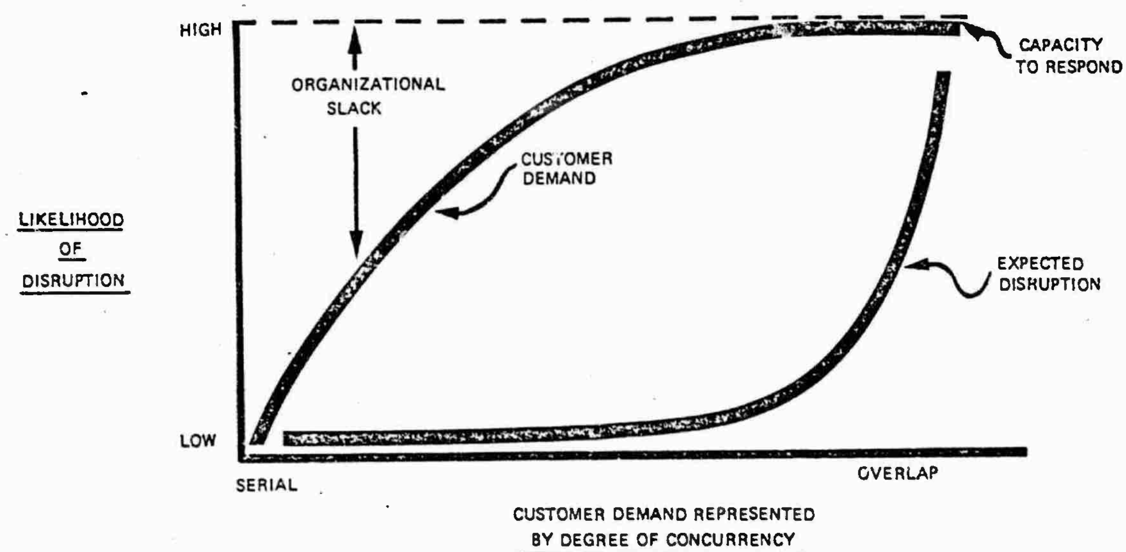
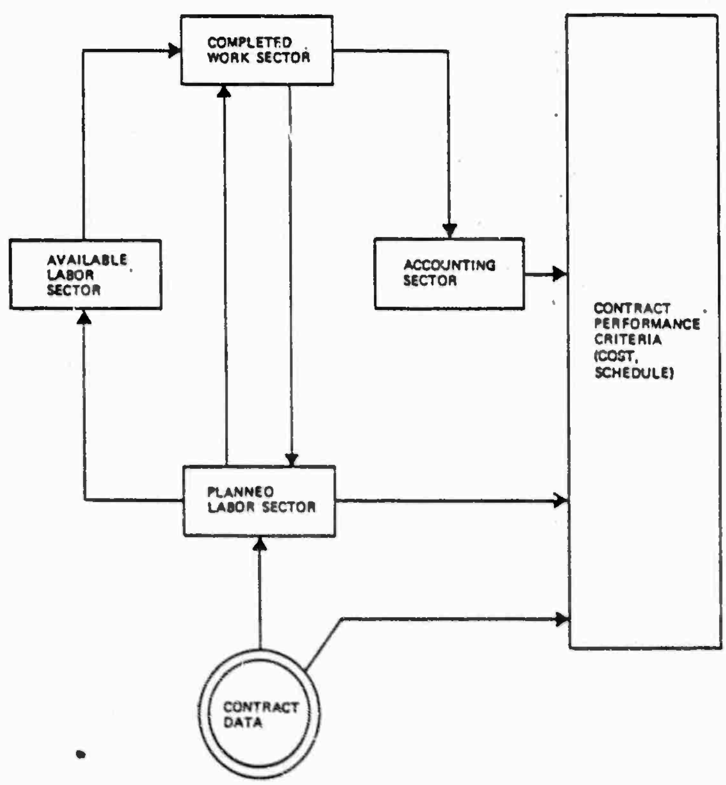




HUGHES
HUGHES AIRCRAFT COMPANY

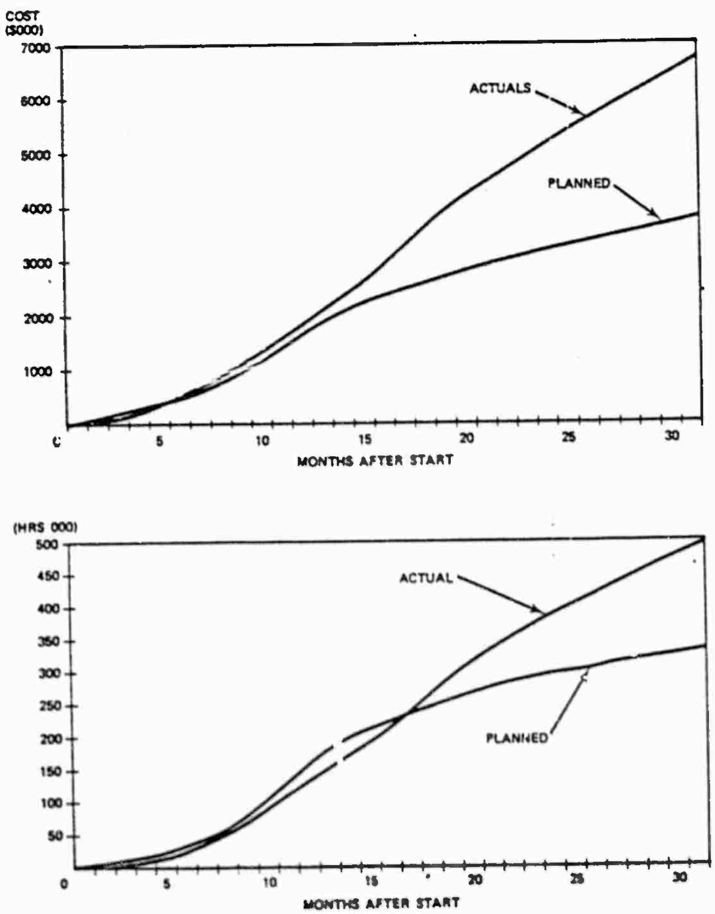
ORGANIZATIONAL SLACK SECTORS

LIMITATIONS

HUGHES
HUGHES AIRCRAFT COMPANY

- DEVELOPED FOR ONE-PROGRAM ORGANIZATION

- SOFTWARE



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ACTUAL COST DATA

SIMULATED COST DATA

HUGHES
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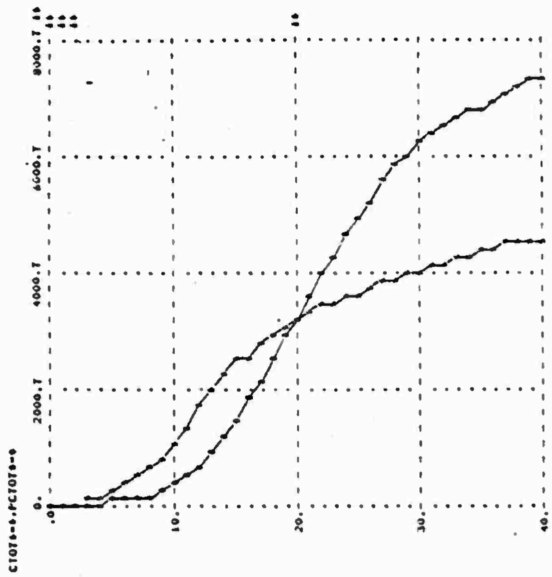
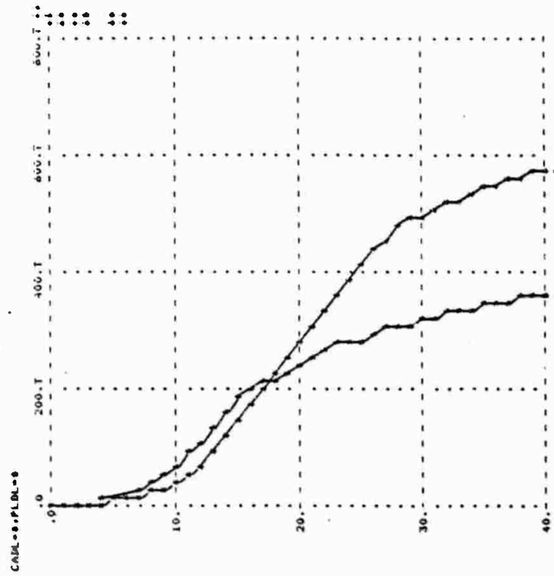




USES OF MODEL

HUGHES
HUGHES AIRCRAFT COMPANY

- PROGRAM CHANGES
- CONTRACTUAL RELIEF
- PROGRAM PLANNING/CONTROL

PANEL SESSION

ON

MANAGEMENT VIEW OF ACQUISITION RISK I

CHAIRMAN

JOHN D. S. GIBSON

AIR FORCE SYSTEMS COMMAND

ADDRESSING RISK AND UNCERTAINTY IN COST ESTIMATING

GUY E. JETTE

Aeronautical Systems Division
Air Force Systems Command
United States Air Force

INTRODUCTION

The function of the Directorate of Cost Analysis at the Aeronautical Systems Division (ASD) of the Air Force Systems Command (AFSC) is to prepare and present cost estimates for weapon systems in various stages of acquisition. Frequently these estimates take the form of Independent Cost Analyses (ICAs) performed to test the reasonableness of the program office estimate or Most Probable Costs (MPCs) developed in support of Source Selection Evaluations.

Perhaps the most significant problem in predicting such future costs is the risk and uncertainty inherent in predicting the future. Although ASD has not had a breakthrough in measuring the cost impact of risk and uncertainty, a number of approaches have been developed, adopted, or refined to address risk in cost estimating. These techniques or methods which have been incorporated into cost estimating are as follows:

- Learning Curve Adjustments
- Technology Indexing
- ECO Model
- Proposal Analysis
- Range of Estimates
- Confidence Indexes
- Risk/Uncertainty Assessments

These several techniques will be addressed below.

LEARNING CURVE ADJUSTMENTS

The first place an analyst must address risk/uncertainty is within the basic estimate. For several years ASD has been using adjustments to the learning curve to reflect and account for certain aspects of risk and uncertainty.

Development in general is found to contain flatter learning curves than follow-on production. There are several reasons for this. First, development programs are for the most part small quantities of hardware produced over a several month or perhaps several year period. This low production rate will flatten the slope. This is a commonly accepted effect and has been addressed in the pertinent literature. In addition, development hardware is manufactured in a prototype-development environment with associated disruptions because of constant change based upon feedback from the design, development and test effort. Both the low rate and prototype environment create a situation with less opportunity to learn and greater opportunity to forget.

An additional effect which serves to flatten learning curve slopes is concurrency. Concurrency is defined as an overlap between production and development. To the extent that production occurs prior to flight test completion there will be increased Engineering Change Orders (ECOs) to accommodate configuration revisions. A high change volume will likely be generated by the simultaneous "build and test" environment. Concurrency also has a retarding effect upon production learning. Not only will learning disruption occur on those items or elements being directly affected, but there is a collateral impact on those areas which are not directly involved in the changes.

For several years ASD has been using adjustments to the learning curve to reflect and account for these aspects of program risk and uncertainty. Specifically learning curves are flattened for concurrent programs where disruptions are high, production rates low, and rework potential significant. A definite quantifiable relationship has been shown to exist between prototype and production T_1's (first unit costs). In particular this relationship has been studied and documented extensively by Tecolote.

Figure 1 shows an example of how the manufacturing labor was estimated for the KC-135 Re-Engine Modification ICA. The composite T_1 value is in hours and production learning curves emanate from it. The T_1 was based on current contractor experience on analogous programs which were very similar in weight, scope and complexity of effort. The underlying learning curve was calculated using the same actuals used to calculate T_1. However, to take into consideration the slower rate of learning which would be occurring during the period of concurrency, the initial production quantities were projected on the flatter learning curve slope shown. It was felt that three months after flight test completion all changes would be final with concurrency no longer impacting production. It was at this point in time that twenty five units would be complete or in process and would be affected by a lessening of learning due to the change-traffic and manufacturing concurrent with development and flight test. Therefore this flatter slope was extended through the twenty-fifth unit. The degree of flattening from the underlying slope (6 percentage points) was based upon judgment as well as ASD experience. Beginning with the twenty-sixth unit the estimate would pick up where the underlying learning curve would have been if there has been no concurrency between development and production. From that point on, the manufacturing labor estimate proceeds down the underlying learning curve.

Figure 2 portrays the manufacturing labor methodology of the recent B-1B ICA. The first four B-1A aircraft were test aircraft manufactured in a prototype environment. The actual costs of these four aircraft were used to derive the prototype T_1. Because of the production gap between these aircraft and the B-1B production a complete loss of learning was anticipated. Because the initial phase of the B-1B production will also be in a prototype environment, this T_1 was used as the first production aircraft estimate. The early phase of B-1B production will occur simultaneous with the establishment of a viable production line including extensive tooling build-up/implementation, facilities modernization, and capital-type rehabilitation. This will be a period of turmoil for the first few B-1Bs produced. In addition the B-1Bs will be produced at a relatively low production rate with relatively long flow times. It was estimated that this prototype environment will affect the first nine aircraft, therefore this prototype T_1 was extended on the learning curve shown through unit nine.

Beginning with unit ten the estimate drops to an underlying slope (same learning curve slope but lower T_1) which projects from a production T_1. This production T_1 was derived from a separate methodology than the prototype T_1 and assumes a full production capability and environment. The prototype-production relationship (production T_1 is approximately 80% of prototype T_1) is consistent with the Tecolote research previously referenced as well as ASD experience.

If the B-1B were to proceed into a full production environment the manufacturing labor would be projected from the production T_1 down the underlying slope which is the steeper of the two shown in Figure 2. However, because the B-1B program is 50% concurrent the underlying slope will not be attained until unit twenty six. In other words between unit nine and twenty five, the labor estimate is projecting from a production T_1 on a concurrency-flattened slope. As apparent from the figure the first nine "prototype-environment" aircraft are also on this concurrency-driven flatter slope. Normally with a 100% concurrent program, the concurrent slope would be 6% flatter than the underlying slope. But in this case the flattening is only 3% because concurrency is 50% rather than 100%. Percent concurrency is measured as the number of months between production contract award and flight test completion divided by the number of months between development contract award and flight test completion. In the case of B-1, concurrency would have been 100% except for the fact that previous development had occurred and a large percent of the aircraft was common design. Thus the denominator of the concurrency equation was increased to reflect the previous development months of the common design.

TECHNOLOGY INDEXING

TEMPER COST is an acronym which refers to a temporal, performance and cost methodology which allows an analyst to relate cost to increases in technology (performance) over time. There are several major assumptions or premises which need to be established before explaining this method. First - technology growth occurs over time. Second - performance is one of several proxies for technology. Third - performance (technology) increases over time at some growth rate. Fourth - an increase in performance over time equates to one of three conditions as relates to cost: 1 - at the "given" technology growth rate over time greater performance is achievable at equal cost (to todays performance), 2 - at less than the "given" growth rate, greater performance is achievable at lower cost, 3 - at greater than the "given" growth rate, greater performance is achievable at higher cost.

Figure 3 graphically portrays this concept. A technology index is shown along the Y or dependent axis with time along the X or independent axis. The premise of course is that technology growth or our proxy, performance, is a function of time. This technology growth as a function of time is a result of total national resources (government, industry, scientific, etc.) being brought to bear over time. It is assumed that these resources are so large in total that no one single effort (such as a large government R&D effort) can change the position of the technology growth line. As technology growth compounds over time along this line, the technology reached over the time continuum is available at equal cost (excluding inflation).

If in four years a technology growth or performance increase of 2.0 is required and the technology growth will be at 2.5 plus as shown in Figure 3, then the required technology of 2.0 will be available at a lower cost than current technology. As a matter of fact the technology required in four years will be available in slightly less than three years (along the equal cost-technology growth line). Therefore the difference between the required technology of 2.0 and the technology growth line at 4 years represents a cost benefit or savings over current levels of technology.

On the other hand if 3.5 is the required technology level in that same time period, but the technology has not yet arrived (along the technology growth line), then it is achievable only at a cost penalty or premium as shown. Only in 5 1/2 years could the 3.5 level of technology be available at equal cost, i.e. that technology will arrive in 5 1/2 years.

The greatest uncertainty in this method is probably the determination of the rate of technology growth, as shown bounded by the dashed lines emanating from the origin on the graph.

A hypothetical example using Figure 4 will further clarify this concept and show how the analysis was used in a recent estimate. System Z is a current program using 1983 technology to achieve a performance normalized to a value of 1.0. Actual production costs are available for this program. It is now required that the production costs for a very similar system, system Z-4, be estimated. System Z-4 requires a performance of 3.0 (normalized to Z performance). This increased performance (read: technology) is required in 1987, four years hence. The industry has been surveyed and the growth rate for this technology or performance is estimated to be 20% per year based on past trends and growth patterns. Plotting this given technology growth on Figure 4 results in the 20% ISO-Cost Curve shown. Given this 20% growth, a 3.0 performance increase will arrive, as shown, in 6 years. This calculates as the log of 3.0 divided by the log of 1.2. Of course, given the theoretical construct, to acquire such a capability sooner will cost more than current performance costs and to acquire it later will cost less. At the time we need the performance increase, i.e. 4 years hence, at the 20% growth rate, equal cost technology will only have achieved a performance increase of 2.0. The performance increase required, 3.0, divided by the performance increase achievable at the required time (at equal cost), 2.0, yields a 1.5 TEMPER Cost factor. Therefore to achieve this capability two years "ahead of its time" will cost 50% more than the current technology. The application of this 1.5 factor to the cost of System Z will result in our best estimate of System Z-4 in four years, excluding the impact of inflation and assuming Z-4 and Z are identical except for the performance increase.

ECO MODEL

ASD has developed an ECO (Engineering Change Order) Model. This model, previously called the ASD Unencumbered Funds Model, estimates ECOs and management reserve (MR) required for a program. These ECOs and management reserve are funds for unanticipated, but within scope requirements. This model provides a systematic approach which enhances estimator judgment in arriving at an ECO/MR estimate. Although judgment is still required to establish the input parameters, that judgment is now in the context of a consistent, logical and procedural process.

Ideally a statistically derived cost estimating relationship (CER) would be derived which quantitatively related ECO/MR cost to pertinent independent variables. However, the unique nature of ECO/MR funds preclude this type of cost method. Subsequent to a program's completion no historical data is available which identifies the required ECO/MR. Funds set aside for such contingencies are later allocated to whatever use they are needed and thus appear within the respective cost element in the actual record of cost. On the other hand initial estimates may have included estimates for such contingencies, either explicitly or implicitly. To further compound this problem very few data points exist while a large number of causative factors can be addressed. Thus a CER approach to estimate ECO/MR could not be used.

The data base used for the generation of this model includes the following weapon system programs:

F-15	C-5A	F-5E	F-15 Nav Subsys
F-16	F-111	SRAM	B-52 SRAM MOD
A-10	F-4E	MAVERICK	F-15 FCS
B-52 Phase VI ECM Mod			F-15 Avionics

Again the data provided by these systems was sketchy and subject to the limitations stated above. Based on this data as well as discussions with cost analysts, engineers, and program managers the factors affecting unencumbered funds were identified. The identified factors which drive the magnitude and direction of ECO/MR are shown below.

1. Degree of Certainty of Configuration at Time of Contract Award

2. Concurrent Development and Production

3. Risk Due to Technical Advancement

4. Program Length

5. Multi-Service Participation

6. Multi-Purpose Systems

7. Contractor Proficiency

8. Scope of Total Production Program

9. Development Schedule Compression

From this set of applicable factors it was determined that two separate and distinct common denominators existed, program complexity and program schedule impact. An attempt was made to derive a composite measure of complexity from the appropriate factors. In addition the concurrency between development and production was quantified as well as the impact of a compressed development schedule.

A group of ASD analysts reviewed all the data from the systems previously listed and discussed the aforementioned factors and how these logically relate to ECO/MR. They then made several composite judgment estimates for ECO/MR as a percent of production costs, as a function of program complexity, schedule impact and overall program nature. The established cause and effect logic was then extended to develop step-by-step procedures for estimating ECO/MR.

The other consideration in the development of the ECO Model was that the nature of the data led the analyst to a procedure which separately addresses New Aircraft Systems, New Avionics Systems and Aircraft Modification Programs.

The first step in establishing an ECO estimate using the ECO Model is to complete the Complexity Score Computation Worksheet (Table 1) This worksheet develops a program complexity score (S) by summing scores for six individual categories of "pertinent" factors. Each factor is scored by matching the program characteristics to the most appropriate description for each factor. These worksheets should be completed based on discussions and inputs from cost analysts, engineers and program managers.

The second step is to establish the percent concurrency between development and production. This percent concurrency is the number of months between first production contract award and completion of flight tests divided by the number of months from development (FSD) contract award to completion of flight test. This calculated percent shows the percent of development which is overlapped by production.

The third step is to determine, based on judgments from engineers and program managers, if the development schedule is compressed.

Step four entails going to Table 2 with the results of each of the first three steps. Table 2 shows the "UF Requirement Percent Program Data" for New Aircraft Systems. As mentioned earlier there is a different table for each of three different types of systems/programs. Using the complexity score, S, as well as the percent concurrency either under the normal or compressed schedule column, an ECO/MR percent can be read from the table. (As shown in Table 2 the percent concurrency from either column can be translated into a "t" value which when combined with the "S" value will give an ECO/MR percent from the table.)

The final step is to estimate the total unencumbered funds dollar requirement by multiplying the percent ECO factor by the recurring production costs. Finally the ECO/MR funds which have been estimated need to be spread by fiscal year. This fiscal year spreading requires estimator judgment as well as awareness of program peculiar characteristics. In general the ECO funds will show a decrease as a percent of recurring production each year. Usually the first year percent is lower than the second year. Yearly rates must be established by trial and error in order to maintain the integrity of the total percent calculated as well as following a logical decreasing profile.

PROPOSAL ANALYSIS

During a Source Selection Evaluation an independent Cost-To-The-Government panel makes an independent estimate of the contractor proposal. This estimate is called an MPC or Most Probable Cost. This MPC for the instant contract must be analyzed in light of the proposed values and with consideration of the ECO Model just covered. Table 3 shows several possible scenarios for an FPI contract. If the MPC exceeds the ceiling of the proposal, which of course is the limit of government liability for that potential contract, the MPC would have to be adjusted down to that ceiling value. However, assuming the MPC is accurate and represents the cost which will actually be incurred, the contractor would be buying-in and using his own funding to pay for the costs incurred in excess of ceiling. The risk here is that the contractor will attempt to get well or recoup his losses in follow-on efforts. So there is a risk that he will "roll-over" these costs to later phases or contracts. To the extent that it can be quantified these "additional" costs should be reflected on estimates of the follow-on activities. Even with an FFP contract where ceiling is target, a contractor can buy-in with hopes of getting well either on follow-on effort or if out-of-scope changes are negotiated to the FFP contract.

If the MPC falls below the proposed target value then it would be wise to reevaluate the MPC to determine why it falls short of the target. It would also be appropriate to review the contractor's past performance on relevant contracts. For example, if the contractor has consistently come in under target and if the MPC is within the range of these final contract values (as a percent of target), then the MPC could be used without adjustment. The converse is of course also true, i.e. an adjustment of MPC to target is appropriate if the contractor rarely if ever falls under target.

Most likely the MPC will fall somewhere between target and ceiling. In this case the MPC is indicating that the final cost will be at this value above target but below ceiling. Again past performance should be analyzed as a test of the reasonableness of the MPC in relation to target/ceiling values. It is also here that the ECO Model can play a role in the proposal evaluation. Specifically the difference between the MPC and the contract target could be used to estimate the additional ECO/MR required as a result of the unrealistically low proposal value, i.e. the buy-in. Where a proposal is being evaluated without benefit of an MPC estimate additional ECO costs can be developed by using the "Other Factors" category of the ECO Model. An approach would be to run the ECO Model with and without the "buy-in" consideration, the delta being the estimated impact of the "buy-in." This represents one facet of ECO while the balance of the ECO is for "normal requirements."

In all cases, contract share ratios should be considered in deriving final MPC values, i.e. the MPC must be consistent with the contractual terms and conditions of the proposal.

RANGE OF ESTIMATES

Most frequently in cost estimating, point estimates are required, whether for budgeting purposes or to test the reasonableness of program office estimates. These point estimates, as most probable costs (thus the "MPC" of source selection), have a very small chance of being the right number; rather they represent the 50% probability position in a range or band of estimates. For example if the MPC or ICA estimate is 7.4 billion dollars, what is really meant is that there is a 50% probability of the cost being less than 7.4 and a 50% probability of the cost being greater than 7.4. However, without some bounding of the range or band we have little indication of the uncertainty surrounding 7.4 billion, i.e., is there a 90% probability that the cost will be between 7.0 and 7.8 billion or does the 90% probability fall between 6.0 and 9.0 billion. The latter estimate of 7.4 has more uncertainty than the former estimate of 7.4. A great deal has been written about confidence intervals around estimates but very little has been put into practical use.

An estimating range around a point estimate can provide a quantification of the uncertainty which surrounds that point estimate. This estimating range need not be related to a statistical probability of specific value. On several recent Independent Cost Analyses (ICAs) an estimating band of reasonableness was established. To the extent the program office estimate (being tested for reasonableness) fell within the band, the program office estimate was considered reasonable. Whereas the point estimate involves a set of fixed assumptions, a range of estimates or band of reasonableness can allow certain critical assumptions to vary and thus depict the cost sensitivity of differing values for these critical assumptions. For example the C-5B ICA had a Range of Expected Costs based upon several different assumptions - an FFP constrained estimate, an estimate with an additional 2% ECO, and estimates with two levels of abnormal inflation. Table 4 portrays these estimates. Although an ICA point estimate of 8513 was established, the range of varying assumptions resulted in a band of reasonableness from 7986 to 8695 with the program office estimates (FY84 President's Budget) falling within the reasonableness band. Traditionally the ICA value of 8513 compared to program office estimate of 8284, a difference of less than 3%, would result in the conclusion that the 8284 is a reasonable estimate.

The IIR Maverick ICA developed a band of reasonableness based on varying one critical assumption, competition scenario. The ICA estimate methodology was sensitive to this competition strategy in terms of percent splits of buys between the competitors and buy-out years where the winner competes for the balance of FY buys. Because the program office estimate was not sensitive to these competition parameters (they assumed there would be a 10% reduction in cost due to competition, without regard to different split percents) it was impossible to choose a competition scenario for the ICA to serve as a test of reasonableness of the program office estimate. The only logical alternative was to determine if the program office estimate was within the band of estimates generated by various competition scenarios. Although Table 5 only shows three scenarios or strategies numerous were estimated, with the three shown being representative of low, middle, and high values for the range. Because the program office estimate fell within the range it was considered to be a reasonable estimate, and in fact the ICA adopted it as its own ICA estimate.

CONFIDENCE INDEXES

An AFSC Regulation (AFSCR 173-2) established as AFSC policy the use of cost estimate quality ratings for cost estimates. This technique, developed at ASD, provides for management the basis of the estimate and the confidence in the estimate. Once management understands the index system, all estimates being presented can readily be compared in terms of methods and data used, i.e. overall quality.

The confidence index has two parts, the methods used and the data availability. The methods used fall into four categories from I. Detailed to IV. Parametric and Factors. The data availability fall into seven categories, from A-Actual cost of significant quantities for system being estimated to G-Limited cost data and limited physical and technical definition. Therefore the range of the confidence index can be from "IA", where the confidence level of the estimate is highest to a "IVG" where the confidence index is the lowest. There are of course numerous confidence levels in between. When estimates are thus rated by the analyst it is clearly established that not all estimates are of the same quality. A "IA" estimate has the least uncertainty being based on detailed methods and actual data, whereas a IVG estimate has the greatest uncertainty being based on parametric methods with limited available data. It would be expected that a "IA" estimate would have a narrow estimating range around it while a "IVG" would have a wide range of estimating probability or error. Likewise a "IA" should have a smaller ECO/MR percent than a "IVG" estimate, because of the differences in uncertainty. It should be mentioned that because of method/data differences between development and production estimates, they are usually assigned different index ratings.

The four methods addressed in the index are described below.

Detailed - This method of estimating involves detailed grassroots calculations. It includes industrial engineering standards which measure labor hours and dollars for discrete tasks at a low level of detail. Frequently this type of estimate is done on a functional labor basis, i.e. engineering, manufacturing, quality control and tooling, for lower levels of the work breakdown structure (WBS).

Analogous - This method involves drawing comparisons with similar systems where costs have already been incurred. Costs of the analogy are adjusted according to weight, performance, or complexity differences in order to estimate the cost of the system being estimated.

Parametric - This method involves an estimate that uses statistically derived cost estimating relationships which are developed from actual cost and performance data. Such relationships are expressed as equations which have cost/hours as the dependent variable and physical/performance parameters as the independent variables. Parametric estimates are usually performed at higher levels of detail than the detailed method.

Factors - Cost factors are used to estimate cost as a percent of another cost based upon similar systems or a historical data base.

Realizing that an estimate will seldom be composed of just one of these methods, or data availability for that matter, the following indexes have been established:

METHODS USED

I. Detailed

II. Detailed and Parametric

III. Analogous and Factors

IV. Parametric and Factors

DATA AVAILABILITY

A. Actual cost of significant quantities for the system being estimated arrayed by functional and WBS breakout.

B. Actual cost for development hardware for the system being estimated arrayed by functional and WBS breakout.

C. Actual cost by function or WBS for analogous systems.

D. Firm contractors' proposals with detailed backup or negotiated prices.

E. Contractor budgetary estimates with program office adders (factors, ECO, management reserve, etc.)

F. Limited cost data but good descriptions of physical, technical, and performance characteristics.

G. Limited cost data and limited physical, technical, and performance descriptors.

RISK/UNCERTAINTY ASSESSMENTS

Most of our comprehensive estimates include a risk analysis section where areas of risk and/or uncertainty are as a minimum identified and where possible cost impacts to the basic estimate are shown. Specific areas addressed may include inflation rates, overhead variations due to fluctuating business base, methodology assumptions such as learning curve sensitivities, competition impacts, technical-difficulty assessments, concurrency, material shortage potential, technology availability, schedule risk, plant capacity, etc. These considerations may or may not be addressed in other ways by the estimate as discussed heretofore. The Risk section of an ICA briefing will usually contain several charts which address the Confidence Index, a chart showing sensitivity to various inflation rates which are always a critical assumption, and a chart or two addressing any other areas of concern. For example the KC-135 Re-Engine Modification ICA briefing summarized risk as follows:

- Development
  - Hours Sufficient
  - Purchased Equipment - Existing Design
  - Critical Design Review Completed
    - No Design Problems - State-of-the-Art
  - Production
    - Engine Long Lead
    - Concurrency - Minimum Impact
  - Overall Assessment - Low Risk

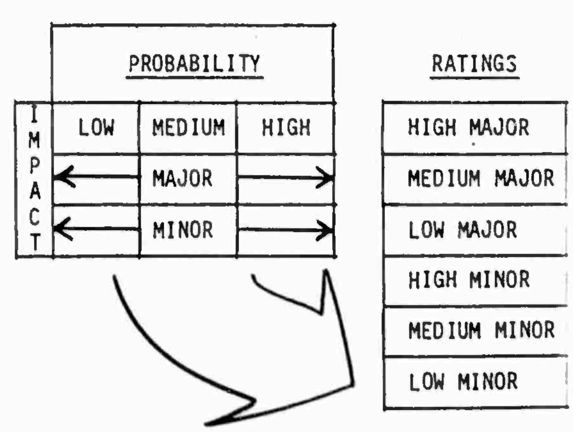
This was a program completing development and about to go into production. A different example would be the ASALM (Advanced Strategic Air Launched Missile) Independent Cost Study. This program was very early in its development with only a propulsion system validation having been completed.

The Technical Risk and Uncertainty addressed in the study are shown below.

- Technical Risk
  - System
    - Integration
  - Guidance
    - Air-to-Air Anti-Radiation Homing
    - Active Radar
  - Propulsion
    - Limited Integral Rocket Ramjet Experience
    - Ramburner Insulation
  - Airframe
    - High Temperature
    - RCS Reduction
- Uncertainty
  - Carrier Aircraft
    - Force Structure/Roles
  - Ultimate Performance/Design Requirements
  - IOC To Be Specified
  - Nature of Program to be Directed
    - Only Subsystem Demo Validation Phase Directed
    - Limited Industrial Base

A more comprehensive approach to addressing risk/uncertainty is the Independent Schedule Assessment (ISA), an independent assessment of the reasonableness of the program office master integrated program schedule. The ISA, performed as a complement with the ICA, evaluates general schedule risk, identifies critical paths, and determines specific pacing schedule events. Once specific areas of concern are identified the potential for cost impact can be quantified.

The Next Generation Training ICA included a comprehensive ISA which incorporated as the basis for evaluation a novel two-dimensional risk assessment. This assessment considers two levels of schedule impact, major and minor. Each of these impacts has three levels of probability of occurrence, low, medium and high. This matrix shown below results in six schedule risk assessment ratings as shown.



A specific rating assigned to an area would have to be explained in terms of the potential impact. In addition this impact could also be quantified, i.e. if the impact was realized specific additional dollars would be incurred by the program. Probability theory could also be used to estimate the expected cost impact of all the identified risks.

SUMMARY

There are a number of methods currently being used in addressing risk and uncertainty in cost estimating. These techniques are by no means the final word on risk/uncertainty, as other ideas can and surely will be developed. Perhaps these concepts will be further refined or even serve as the seeds for creating new approaches to deal with risk and uncertainty in weapon system acquisition.

BIBLIOGRAPHY

1. AFSC Regulation 173-2, 2 October 1978, Confidence Levels of Cost Estimates (Cost Analysis)

2. AFSC Regulation 800-35, 31 January 1979, Independent Schedule Assessment Program (Acquisition Management)

3. The Relationship Between Development and Production Hardware Costs in Military Weapons Systems, September 1976, Tecolote Research, Inc.

4. Advanced Strategic Air Launched Missile (ASALM) Independent Cost Study, November 1979.

5. KC-135 Re-Engine ICA, May 1981

6. Long Range Combat Aircraft (B-1B) ICA, September 1981

7. Next Generation Trainer (NGT) ICA, October 1982

8. IIR MAVERICK ICA, February 1982 and February 1983

9. ASD ECO Model Users Guide, March 1983, J. Gibson, Directorate of Cost Analysis, ASD, Wright-Patterson AFB, Ohio

10. C-5B ICA, April 1983

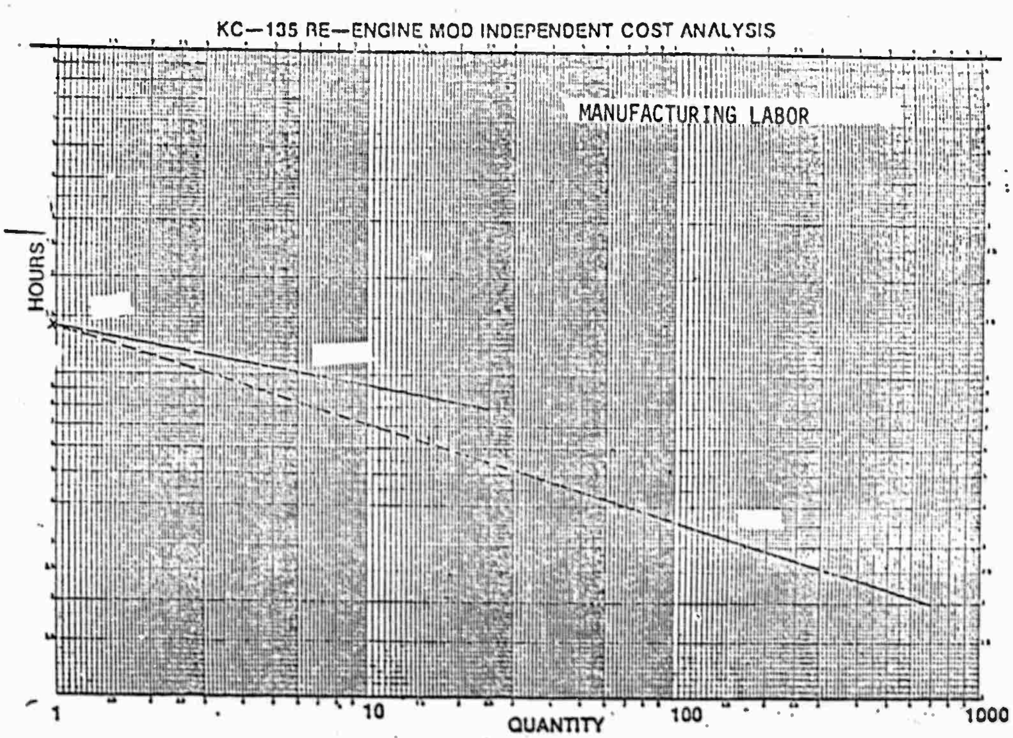


FIGURE 1

INDEPENDENT COST ANALYSIS

MANUFACTURING LABOR

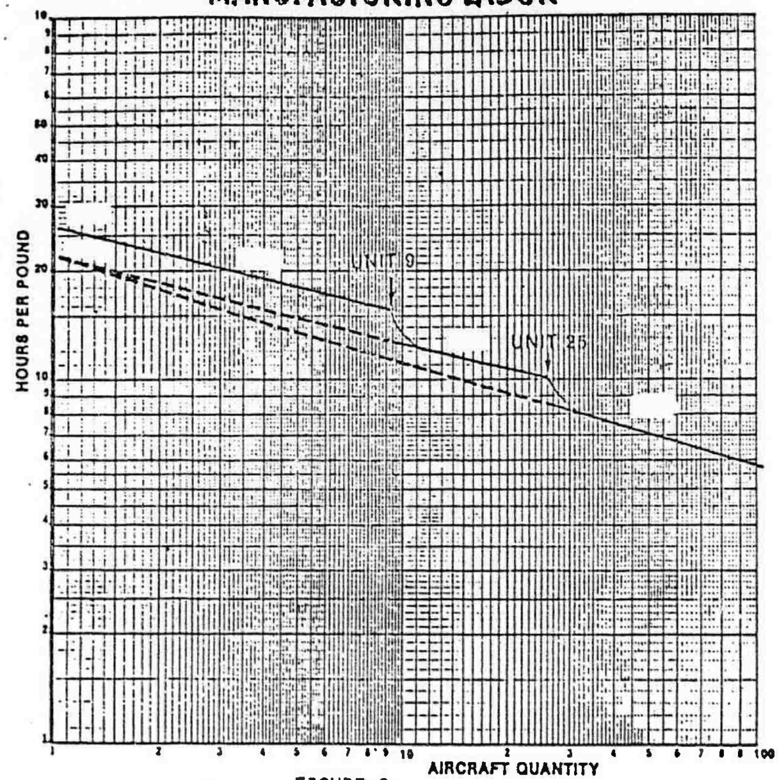


FIGURE 2-

TECHNOLOGY GROWTH

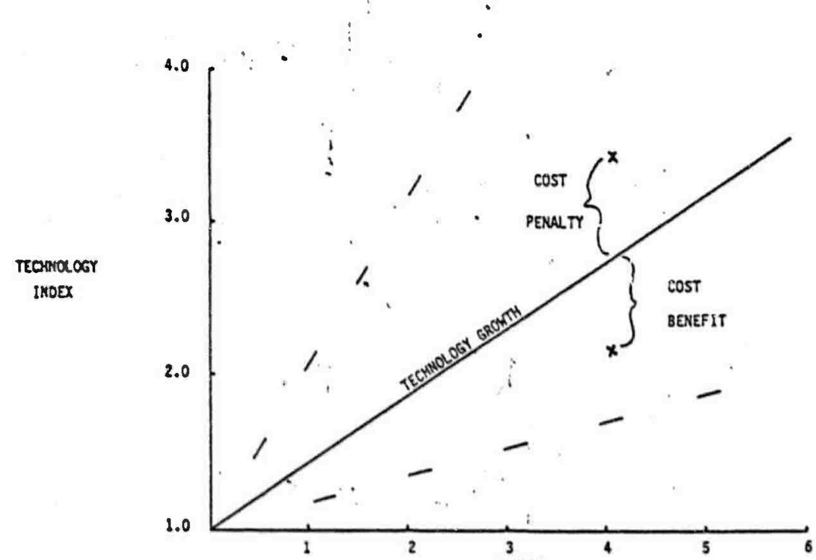


FIGURE 3

"TEMPER COST FACTOR"

EXAMPLE OF DERIVATION

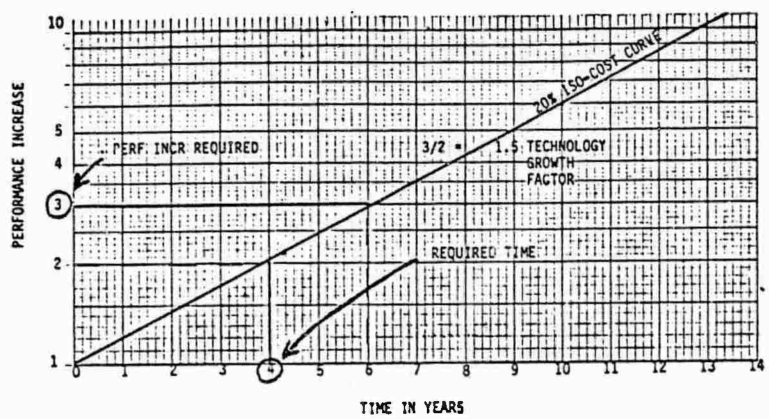


FIGURE 4

TABLE 1

COMPLEXITY SCORE COMPUTATION WORKSHEET AND INSTRUCTIONS

SYSTEM PROGRAM: ____________________

1. DEGREE OF CERTAINTY OF DESIGN CONFIGURATION

(-1) Very Firm (Chinese Copy)
(0) Typical
(1) Modest Uncertainty
(2) Major Uncertainty

2. RISK DUE TO TECHNICAL ADVANCEMENT:

(-1) Low
(0) Routine
(1) Difficult
(2) Complex

3. MULTI-SERVICE PARTICIPATION:

(0) USAF Only
(1) Multi-Service

4. MULTIPURPOSE SYSTEMS:

(0) No
(1) Yes

5. CONTRACTOR PROFICIENCY:

(-1) Better Than Average
(0) Typical or Average
(1) Less than Average
(2) Significantly Less Than Average

6. OTHER FACTORS

(-1) Positive Impact Reducing Risk
(0) No Impact
(1) Minor Negative Impact Increasing Risk
(2) Medium Negative Impact Increasing Risk
(3) Large Negative Impact Increasing Risk

TABLE 2

UF REQUIREMENT PERCENT PROGRAM DATA

NEW AIRCRAFT SYSTEMS

SCHEDULE IMPACT INDEX (t)			COMPLEXITY SCORE (S)						
% CONCURRENCY									
NORMAL FSD SCHEDULE	COMPRESSED FSD SCHEDULE	(t)	-2	-1	0	+1	+2	+3	+4
20	0	1	1	1	1	1	1	+2	2
30	15	2	1	1	1	1	2	2	2
40	25	3	1	2	2	2	2	3	3
50	35	4	2	2	2	3	3	4	4
60	45	5	3	3	3	4	4	4	5
70	55	6	3	4	4	5	6	6	6
80	65	7	4	4	5	6	7	7	8
90	75	8	4	5	6	6	7	8	10
100	85	9	5	5	7	7	9	10	12
-	100	10	5	6	8	9	10	11	12

TABLE 3

PROPOSAL ANALYSIS

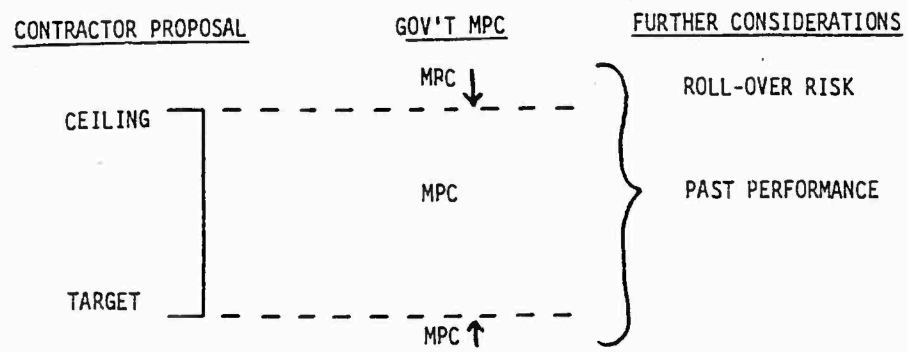
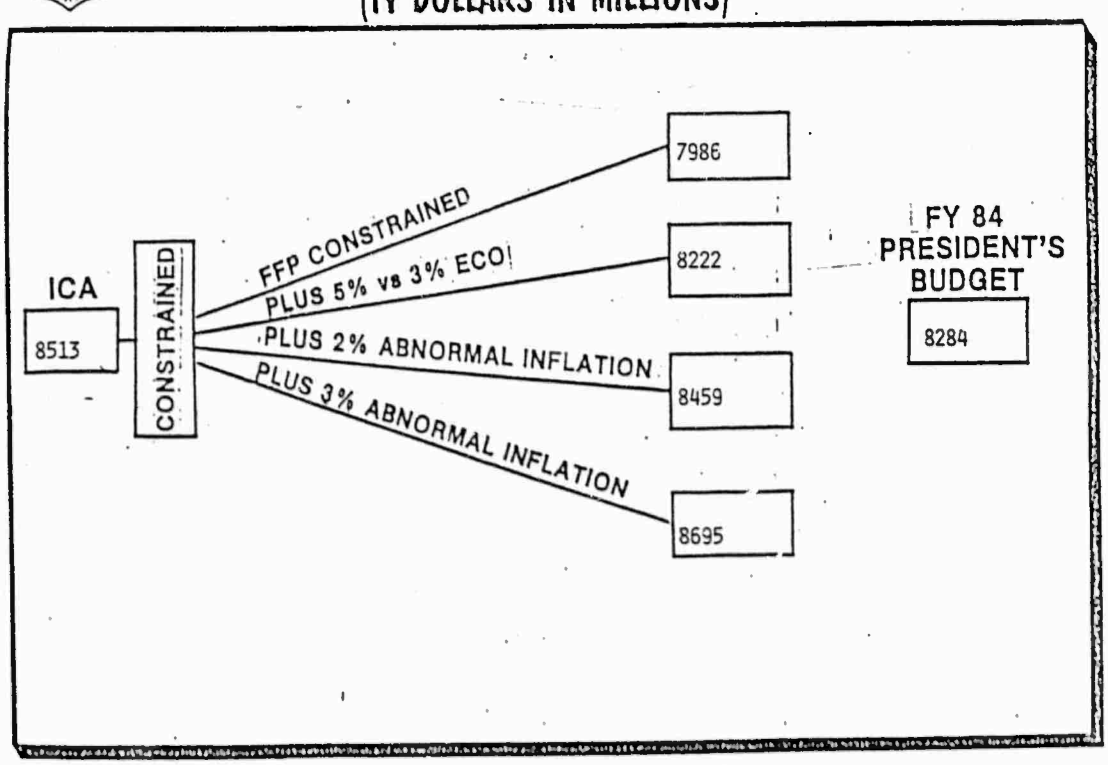


TABLE 4

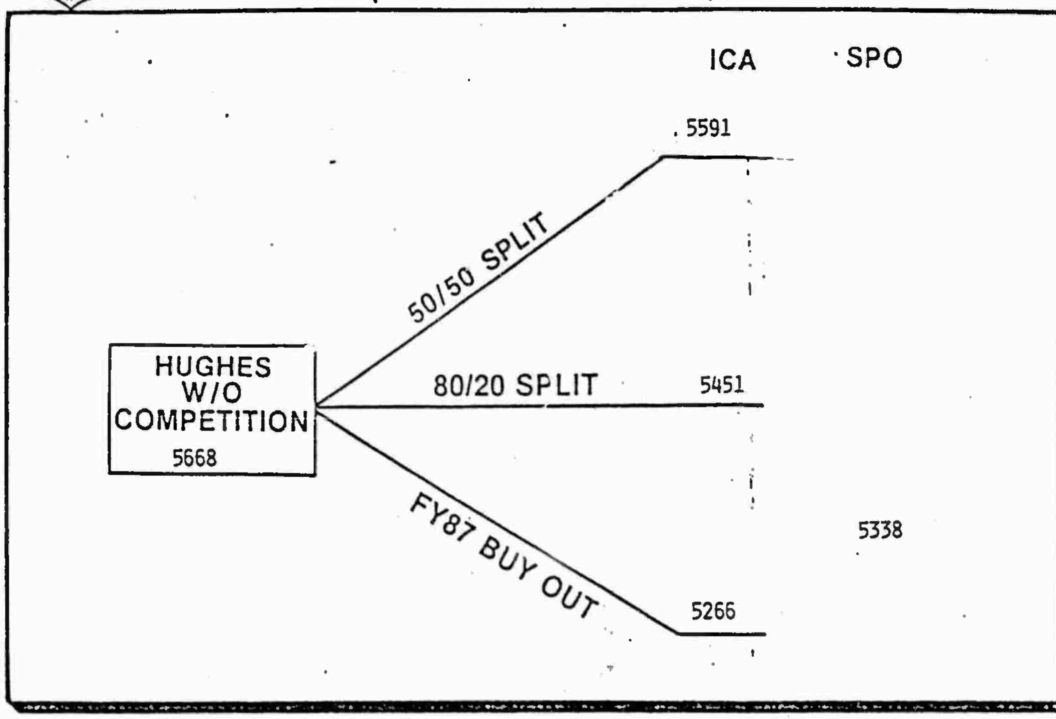
C-5B INDEPENDENT COST ANALYSIS
RANGE OF EXPECTED COSTS*
(TY DOLLARS IN MILLIONS)



*ALL COSTS HAVE BEEN ADJUSTED AND DO NOT REFLECT ACTUAL ESTIMATES.

TABLE 5

IIR MAVERICK INDEPENDENT COST ANALYSIS
COST COMPARISON *
(TY DOLLARS IN MILLIONS)



* ALL COSTS HAVE BEEN ADJUSTED AND DO NOT REFLECT ACTUAL ESTIMATES.

WEAPON SYSTEM COST RISK REVIEWS

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There is always a considerable cost risk associated with weapon systems. This is because weapon systems have life cycles which often run more than 20 years, and they must be technology and threat reactive. Therefore, there can be no progress without taking risks. The term "life cycle" suggests a process with a beginning, an ending and a series of phases in between. Weapon systems have five phases: (1) concept exploration, (2) demonstration and validation (Milestone I), (3) full scale development (Milestone II), (4) production (Milestone III), (5) deployment which includes disposal. Of greatest concern are Milestones I, II, and III. There is the need to evaluate the cost risk at each of these milestones.

The Army has adopted a cost risk review approach as systems move through these three miletones. The purpose of the cost risk review process is to determine the cost risk associated with the weapon system acquisition programs and to recommend a cost position to the Chairman of the ASARC. There is a general officer level executive committee which decides which weapon system programs will be subject to "cost risk review." The principle criteria will be those systems scheduled for ASARC; however, other systems can be selected on an "as required" basis. The second tier of the cost risk review structure is the Cost Risk Review Field Team which reports their findings to the Executive Committee. The Field Team is kept relatively small and with highly experienced, functionally oriented individuals.

The presentation described the modus operandi of the Cost Risk Review Field Team, and in general terms, case results.

BUDGETING FOR TECHNOLOGICAL RISK IN PROCUREMENT

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ABSTRACT

This paper presents the results of the Army's effort to quantify risk and to budget funds for the technological uncertainty in the procurement of weapons systems. This effort is known as Total Risk Assessing Cost Estimate for Production (TRACE-P). This paper describes the model and methodology used to quantify this uncertainty. It discusses implementation of the system and the results experienced to date.

BACKGROUND

The US Army Materiel Development and Readiness Command (DARCOM) sets challenging goals for the development and procurement of major weapons systems. These success-oriented programs entail risk and the seemingly inevitable occurrence of unfunded contingencies. It is no easy task to retain our optimistic funding, schedule, and performance goals while presenting a fully executable program with adequate funding for technological risks. Requests for funding of contingencies must survive the budget process. What is required is a systematic, organized, credible approach to provide realistic cost estimates. It should provide assurance that funds for technological risk are adequate but not excessive. To address the problem the Army developed the TRACE concept.

INITIATION OF THE TRACE CONCEPT

The original concept to budget for the uncertainty in research and development (R&D) was initiated by the Army in 1974 under the guidance of Mr. Norman A. Augustine, then Assistant Secretary of the Army for Research and Development[1]. A good overview of this Total Risk Assessing Cost Estimate (TRACE) concept is found in a recent paper by LTC John D. Edgar, Defense Systems Management College[2]. Extension of the concept to budgeting for the technological risk in production was approved on 30 April 1981 by then Deputy Secretary of Defense Frank C. Carlucci[3]. This extension, known as TRACE-P, supports Carlucci initiatives 6 and 11:

Initiative No. 6: Budget to Most Likely Cost
Initiative No. 11: Budget Funds for Technological Risk

Further, on 22 July 1981, the Vice Chief of Staff, Army, stated a decision to implement the concept of funding to cover uncertainties in production[4]. The Army Cost Discipline Advisory Committee monitors the progress of this and other high level initiatives.

DEVELOPMENT OF TRACE-P

Shortly after the Carlucci initiatives were promulgated, a test case for TRACE-P was performed on the Remotely Piloted Vehicle (RPV) by Ralph Tate at the US Army AVRADCOM[5]. In June 1981, the US Army Procurement Research Office (APRO) at Fort Lee, Virginia was directed to study the applicability of this concept to all weapons systems entering production. The APRO report[6] submitted to HQ, DARCOM identified the sources of production risks during the transition into production and grouped them into generalized risk categories. APRO developed the theory for TRACE-P and refined the analytical techniques used to quantify and summarize the budgetary impact of risks. Based on the APRO report, HQ, DARCOM refined the methodology by limiting the risks to the eight specific categories shown in Figure 1. Eliminated were risk areas which should be corrected by good management or by other Carlucci initiatives. The methodology was verified by testing the model on the M735 round using historical data. The results obtained from the TRACE-P model approximated the actual costs incurred.

Analysis of M735
Test Results (FY 82 $ In Millions)

BCE	$228.82
BCE + Risk	282.50
Actual Cost	289.05

In February 1982, the TRACE-P concept was briefed to and approved by the CG, DARCOM. Subsequently, the DARCOM methodology was briefed to HQDA staff principals as a recommended approach.

TRACE-P CONCEPT

TRACE-P is a budget policy designed to improve the capability of a Project Manager (PM) to minimize the impact of technological risk on his program. TRACE-P provides the PM with a disciplined method of costing for risk as well as providing higher authorities with a scientific money management system. TRACE-P identifies and promotes understanding of the risks involved. TRACE-P aids the PM in coping with those risks by the early and judicious application of funds. These funds provide an early resolution of avoidable risks and a funding solution for unavoidable risks. TRACE-P is used to identify and budget the funds required at the .5 probability level (i.e., 50/50 chance) to accommodate the known technological risks during each of the first three years of significant quantity production. Three distinct actions are required to quantify risk and expand the use of budgeted funds to deal with uncertainty:

1. Identify the funds required for risk, i.e., prepare the TRACE-P estimate. The model used is described below.

2. Budget the funds required for risk. The budgeting process for TRACE-P is outlined below.

3. Manage the program. A separate paper[7] given at this workshop discusses how the Remotely Piloted Vehicle (RPV) Project Manager (PM) is using TRACE-P to manage his program.

THE MODEL

Seven basic techniques in use to analyze acquisition program risk are described in "Risk Assessment Techniques, A Handbook For Program Management Personnel"[8]. The TRACE-P model can best be described as a Work Breakdown Structure (WBS) simulation. The procedure used to determine the funds required for technological risk during procurement of a weapons systems is as follows:

1. Identify the major subsystems of the weapons system using the WBS. For each subsystem, identify the unfunded technological risks and uncertainties. Each risk is assigned to one of eight risk categories. These categories provide the framework for applying conventional cost estimating techniques to the technological risks and uncertainties.

FIGURE 1

RISK CATEGORIES INCLUDED IN TRACE-P	UNCERTAINTIES EXCLUDED FROM TRACE-P
• THREAT UNCERTAINTY	• QUANTITY CHANGES
• MANAGEMENT	• PERFORMANCE IMPROVEMENTS
• MATERIALS/PURCHASED PARTS	• POOR MANAGEMENT
• FACILITIES/EQUIPMENT	• INADEQUATE FUNDING
• LABOR	• INFLATION
• DESIGN CHANGES	• CIVILIAN PAY ADJUSTMENTS
• PRODUCIBILITY	
• PERFORMANCE	

2. Determine a cost estimate and its distribution for each contingency. Adjustments are made to the data if necessary to assure that the technological risks are stochastically independent.

3. Next, the probability of occurrence of each contingency and its cost distribution are input into the VERT computer program[9]. Using a Monte Carlo technique, the program derives a single cost distribution for all the known contingencies.

4. Apply inflation factors and display results.

5. Include the results in the Baseline Cost Estimate (BCE) and Army Materiel Plan (AMP) by fiscal year.

TRACE-P is an objective, systematic, organized, and credible approach. It identifies specific technological risks and their costs. By including these risks, it provides a better initial cost estimate. TRACE-P will lessen cost growth in the investment phase of weapons systems life cycle.

One other risk assessment technique that shows significant promise for deriving TRACE-P estimates is described in, "Procedures for Modeling TRACE-P Estimates", by Vincent Alfieri[10]. This CECOM approach extends the use and application of the contractor's Work Breakdown Structure (WBS) in identifying risk prone areas, and combines the WBS with probabilistic networking techniques to create a data structure which generates risk costs for the designated program. This approach has the potential to consider and integrate a wide range of inputs. A strong point of Mr. Alfieri's model is the analysis of schedule interactions and the impact of schedule slips on the total cost and schedule. At the present time, the output in terms of technological risk cost has been limited, considering mostly cost estimating uncertainty and schedule slippages. While it is more sophisticated and has greater potential than the current TRACE-P model, it requires more detailed knowledge of the system schedule and imposes data requirements on the contractor. By comparison, the present TRACE-P model is simple, transportable, and demonstratable. Both models produce an audit trail.

BUDGETING

After the TRACE-P estimate is prepared and approved, the TRACE-P value is to be included in the investment portion of all cost and budget estimates. The PM submits the TRACE-P estimate with the BCE for required review and approval. He also enters it in the Army Materiel Plan (AMP). The Major Subordinate Commands (MSC) and HQ, DARCOM must enter the estimated risk cost in their normal programs and budgets within the Planning, Programing, Budgeting and Execution System (PPBES). The TRACE-P estimate becomes part of the budget requirements and must survive budget cuts. The budget process is fraught with difficulties. Figure 2 illustrates the barriers encountered by the initial seven systems.

STATUS OF TRACE-P

In March 1982, the Comptroller, DARCOM assumed responsibility for TRACE-P. A management concept and budgeting methodology were

FIGURE 2

STATUS OF TRACE-P SYSTEMS

SYSTEM	TRACE-P	COMMENTS
XM-833	FY 84 BUDGET POM FOR FY 85, 86	AWAITING CONGRESSIONAL ACTION
RPV	POM FOR FY 86, 87, 88	RESULT OF ASARC
PII	-	FY 84 $65M SHORTFALL ABSORBING ALL FY 85 RESERVE
AHIP	-	USOFA CEILING
SINCGARS-V	-	CUT IN PROGRAM
STINGER/POST	-	CUT IN PROGRAM
MCS	-	CUT IN PROGRAM

developed. Instructions and guidelines were prepared and published in a DARCOM Letter of Instruction[11] on TRACE-P promulgated on 6 October 1982. TRACE-P requirements were computed for the XM-833, the Remotely Piloted Vehicle (RPV), the PERSHING II, the Advanced Helicopter Improvement Program (AHIP), SINCGARS-V, the Maneuver Control System (MSC), and STINGER/POST. A summary is shown in Figure 3. The budget request for the XM-833 projectile was submitted to HQDA on 25 May 1982. The TRACE-P requirements for the remaining six systems were submitted to HQDA on 1 April 1983. HQDA has prepared a draft of a new Army Regulation on TRACE. It outlines the TRACE objectives, policies, responsibilities and procedures. It includes both TRACE-P and TRACE-R (RDTE).

The FY 84 budget contains a request for TRACE-P funds for the XM-833. The Army staff has included TRACE-P funds in the FY 1985-89 POM for the XM-833 (FY 1985-86) and the RPV (FY 1986-88). All TRACE-P fund requests will be reviewed during the Army Materiel Plan (AMP) and post AMP processes prior to the 1985 Office of the Secretary of Defense (OSD) submit for the 1985 budget. HQ, DARCOM's recommendations will be used to determine which weapons systems will get additional TRACE-P funds from the total obligation authority (TOA) of the Army. The total budget request will remain the same. The FY 84 Budget request for the XM-833 has been approved by the House Armed Services Committee (HASC) and the Senate Armed Services Committee (SASC).

The House Appropriations Committee (HAC) believes that there is a need for management reserves to provide the necessary flexibility to address unforeseen circumstances. The Committee is of the opinion that excessive management reserves should be avoided and if additional funds are needed for a particular development effort, specific requests should be submitted to Congress. If it should become necessary to establish management reserves, the Committee expects to be informed of the size of such reserves, the project involved and the reasons for the establishment of such reserves.

FIGURE 3

RESULTS TO DATE

SYSTEM	INITIAL 3 YRS PROCUREMENT	TRACE-P	TRACE-P AS % OF PROC
XM-833	270M	25.3M	9.4%
AHIP	1001	135.2	14.2
RPV	804	111.2	13.7
PERSHING II	1235	63.5	5.2
STINGER/POST	1243	58.4	4.7
MCS	104	11.6	11.2
SINCGARS-V	446	37.6	8.4

REFERENCES

1. Norman A. Augustine, memorandum, subject: "RDTE Cost Realism -- Future Development Programs." 12 July 1974.

2. LTC John D. Edgar, USAF, "Controlling Murphy: How to Budget For Program Risks," Concepts, Summer, 1982.

3. Frank C. Carlucci, memorandum for the Secretaries of the military departments and others, subject: "Improving the Acquisition Process," 30 April 1981.

4. Memorandum, Vice Chief of Staff of the Army, 22 July 1981, subject: "Cost Discipline."

5. Ralph O. Tate, "Remotely Piloted Vehicle (RPV) Management Reserve for the Investment Phase," September 1981.

6. Monte Norton, Richard Abeyta and Paul Grover, "Production Risk Assessing Methodology (PRAM)" May 1982, LD Number 49786A.

7. Claire Jacobs, Donald MacVittie, and Bill Waymire, "Managing Risks: The RPV Perspective," Defense Risk and Uncertainty Workshop, 13 July 1983.

8. Defense Systems Management College, "Risk Assessment Techniques, A Handbook for Program Management Personnel," July 1983.

9. Gerald L. Moeller, "Venture Evaluation and Review Technique (VERT)" U.S. Army Logistics Management Center, Fort Lee, VA, November, 1979, ALM-63-6260-H2.

10. Vincent Alfieri, "Procedures for Modeling TRACE-P Estimates" Defense Risk and Uncertainty Workshop, 13 July 1983.

11. Letter, DRCCP-ER, HQ, DARCOM, 6 October 1982, subject: "Letter of Instruction (LOI) for Implementation of the Total Risk Assessing Cost Estimate for Production (TRACE-P)."

PLENARY PAPER

THE EQUITABLE SHARING OF RISK BETWEEN DEFENSE AND INDUSTRY

THE EQUITABLE SHARING OF RISK BETWEEN
DEFENSE AND INDUSTRY

Jack L. Bowers
CEO, Sanders Associates, Inc.

EQUITABLE SHARING OF RISK AND UNCERTAINTY

Why is this an issue?

- There is a Public Record of Program Failure
- There is a history of attempted solutions
- Regardless of Progress Made—

  There remains a perception of weakness and need for improvement

V-83-0280-001

EQUITABLE SHARING OF RISK?

(Not just because it is fair)

With intelligent recognition of risk Human Beings will perform better

Sharing of Risk will make both the Buyer and the Seller do better

V-83-0280-002

WHY NOT THE COMMERCIAL WAY?

In commercial endeavors seller assumes risk

Outstanding successes!

- Automobiles
- Aircraft Engines
- Computers

V-83-0280-003-1

Three Answers:

1. The Military Market is not Predictable
   - Changes in Threat
   - Changes in DOD Policy
   - Changes in Congressional Policy
2. Procurement Regulations do not allow supplier to recover preincurred costs
3. Advanced State of the Art

V-83-0280-003-2

HISTORY OF RISK IN MILITARY ACQUISITION

1950'S CPFF Era

- Technically oriented
- Cost atmosphere
- Many successes
- Emerging Problems

1960'S "Contract" Era

- Shift to Fixed Price, Multiple incentive contracts
- Total Package Procurement
- C-5A
- Navy Shipbuilding claims (into 70's)

V-83-0280-004-1

Lesson Learned:

Contract form alone is not the Answer

Conclusion:

We need tools to help the manager control the process

Not a Process to control the Manager

V-83-0280-004-2

HISTORY OF RISK IN MILITARY ACQUISITION

The Management Era:

1970 Packard
DOD Instruction 5000.1
DOD Instruction 7000.2

1980—Carlucci Initiatives

V-83-0280-004-3

RISK IN MILITARY ACQUISITION—THE FUTURE

Thesis:

If We:

1. Follow guidance of Packard
2. Implement Carlucci Initiatives
3. Improve Planning and Budgeting
4. Train Industry and Military Managers

We Will:

1. Improve Procurement Process
2. Learn to Manage Risk
3. Establish basis for equitable sharing of risk

V-83-0280-005A

WHAT ARE THE SOURCES OF RISK AND UNCERTAINTY?

1. Advanced technology
2. Attaining satisfactory Reliability and Quality
3. Integration of complex systems
4. Availability of manpower
5. Availability of facilities
6. Instability of Programs
   a. Cancellation
   b. Change in schedule
   c. Change in requirements (threat)
7. Inadequate Budgeting

V-83-0280-006

"BUDGETING TO MOST LIKELY COST"

(NAVAL AVIATION INDUSTRIAL COUNCIL STUDY)

Causes of Unrealistic Pricing during Advocacy Phase

- Low Defense Budgets following VietNam
- Micromanagement—program instability
- Understated Inflation
- Production of too many systems
- Noneconomic production rates

V-83-0280-007

KINDS OF ACTIONS CONSIDERED IN DEALING WITH RISK

- Identifying Risk and Uncertainty
- Minimizing Risk by Careful Planning
- Acceptance of Individual Risks
- Risk Sharing Plan at Contract Inception
- Managing Risk sharing during Contract
- Long Range Actions to improve Risk Environment

V-83-0280-008

ACTIONS TO LIMIT AND EQUITABLY SHARE RISK

- Prepare sound Procurement Plan
- Review Plan with Industry (Modify)
- Select Proper form of Contract
- Increase use of Award Fee Contracts
- Increase use of Multiyear Contracts

V-83-0280-008-1

ACTIONS TO LIMIT AND EQUITABLY SHARE RISK (CONT)

- Establish Capital Investment Incentives
- Eliminate multiple Best and Final Offers
- Increase use of VECP's
- Make Cost/Performance Tradeoffs
- Improve Military/Contractor Business Relationship

V-83-0280-009-2

PREPARE SOUND PROCUREMENT PLAN (ASPR)

- Performance Requirements
- Reliability, Quality and Maintainability
- Evaluation of Risk
- R&D Plan
- Test and Evaluation Plan
- Production Plan
- Schedules
- ILS Plan
- Estimated Cost

V-83-0280-010

REVIEW PLAN WITH INDUSTRY

Review Plan

- Technical
- Schedule
- Contract Form

Modify Plan

- Specifications
- Schedule
- Contract
- Estimate of most likely cost

V-83-0280-011

SELECT PROPER FORM OF CONTRACT

- DOD Instruction 5000.1 states that Contract Form should be consistent with risk
- Use simple—straightforward contract forms
- Contract Form should not be used for negotiating tool
- Strict Contract forms should not be used to eliminate inexperienced contractors

V-83-0280-012-1

SELECT PROPER FORM OF CONTRACT (CONT)

"Contract Types inconsistent with inherent technical risks, stage of production, nature of task, or which do not recognize economic reality are not in best interest of government or contractor"

V-83-0280-012-2

INCREASE USE OF AWARD FEE CONTRACTS

- Profit Incentive frequently used
- Award fee adds performance review
- Pride of Contractor personnel becomes involved
- Responsibility of Military P/M is emphasized
- Risk sharing is negotiated on real time basis

V-83-0280-013

INCREASE USE OF MULTIYEAR CONTRACTS

- Military Receives Lowest price—Low Risk
- Industry Gains Stability (Offsetting Price Risk)

But:

- Loses Budget Flexibility—Bad?
- Inhibits Technical Change—Bad?

V-83-0280-014

ESTABLISH CAPITAL INVESTMENT INCENTIVES

- Productivity improvement needed
- Capital Investment expensive
- Stability of Future Government Procurement
- Contractor Investment Risk should be balanced with Profit incentive
- Exploratory work in process

V-83-0280-015

ELIMINATE MULTIPLE BEST AND FINAL OFFERS

- Multiple Best and Final Offers should be eliminated (Contractors are encouraged to submit unrealistic offers)
- Justification should be demanded of any cost change
- Cost changes should be allowed only in areas of competitive discussion
- Risk will be reduced—both parties

V-83-0280-016-1

"The Government's interest is best served by a negotiation to the lowest attainable cost by a viable contractor, not in driving the earnings of the selected contractor to the lowest level"

V-83-0280-016-2

INCREASE USE OF VECPs

VECPs are not clearly understood or used effectively

Contractor and Military risk will benefit thru wider use

V-83-0280-017

MAKE COST/PERFORMANCE TRADEOFFS

Unknown factors usually drive cost up

Performance requirements are usually rigid

Tradeoffs will reduce and balance risk

V-83-0280-018

IMPROVE MILITARY—CONTRACTOR BUSINESS RELATIONSHIP

- Nonadversarial
- Program Managers should work together from same data
- Both loyal to the program
- Each loyal to their own organization
- The contract should be written to resolve conflict
- Only good management can produce equitable sharing of risk

V-83-0280-019

PANEL SESSION

ON

METHODS AND MODELS II

CHAIRMAN

KNEALE T. MARSHALL

NAVAL POSTGRADUATE SCHOOL

APPROXIMATELY BOUNDED RISK REGIONS

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ABSTRACT

In conventional WBS-oriented costing, each WBS element cost is estimated, and the total cost is taken to be the sum of the element costs. In assessing the overall uncertainty, the element cost is treated as a random variable, and the characteristics of the random variable estimated. The overall cost is then expressed as another random variable by appropriate summing of the element variables.

The conventional analytical approach is to assume that the element costs are independent. Under this assumption, the additive (A) moments of the element random variables are determined, and added to determine the A moments of the sum. A curve is fitted to the sum's A moments to represent the cumulative distribution function of the total cost.

We now make the alternative assumption that the elements are linearly dependent, and develop a set of D moments that have the same additive properties of the A moments under the independence assumption. In similar fashion to the A moment procedure, element D moments are determined and added to yield the D moments of the total cost. A curve is fitted to these moments to represent the cumulative distribution function of the total cost. These two curves may be considered the boundaries of a probability risk region.

Working on risk analysis with project management personnel has shown the need for a quick, easily implemented method tc calculate this risk region. Based on these needs programs have been developed that are suitable for use on a handheld calculator. For convenience they are presently programmed for the TI-59. Like the methodology discussed previously, they use moments to approximate distributions. Procedures have been developed for both the independent and dependent cases.

INTRODUCTION

A Grass Root estimate consists of dividing a complete project into identifiable activities which taken together include all required tasks — a Work Breakdown Structure (WBS). The cost to complete each activity is separately estimated, usually based on a mixture of experience and analogy with previously completed similar tasks. These WBS element estimates are then added to become a total cost estimate. Usually manhours are estimated and dollars are found by applying the rates applicable to each skill code. Also various additional factors are also included, such as indirect allocations, G&A and fee. These factors add some computing complication but do not change the basic approach, so they will be ignored here.

An uncertainty analysis covers the same ground. It uses the same WBS. However, the cost estimates of the individual WBS elements are expressed as probability distributions rather than point estimates. Then it adds the distributions to obtain a total probability function. This resulting function expresses the range of possible costs in terms of their probabilities of being achieved.

INPUT DENSITY FUNCTIONS

Since we have stated that our estimates are to be expressed as probability distributions rather than point estimates, it is necessary to determine what form our input probability density function should take. If we assume that the project is technically feasible, then for each element:

- There is a greatest lower bound for the resources required for the task to be accomplished with a probability of zero
- There is a least upper bound for the resources required for the task to be accomplished with a probability of one.

The actual shape of the density function is, in reality, unknown, and probably unknowable. We can, however, assign characteristics to it that would be logical.

1. It should have fixed, positive upper and lower bounds
2. It should not be necessarily symmetric
3. It should be unimodal
4. It should be computationally simple.

Many density functions meet all or most of these criteria. Perhaps the most widely used is the Beta distribution suggested by the pioneering work of Dieneman (3), and used by Klein (5, 6) and many others. McNichols (8) uses a Weibul distribution, which does not require the strict feasibility assumption since it is open-ended at the top. In this paper, we will use the triangular distribution. It is completely characterized by three points, low (l) with an associated probability of zero, mode (m) the most likely, or modal value, and high (h) with an associated probability of one. We usually assign the modal value to the nominal or point estimate. This distribution meets the criteria mentioned above, and a very useful characteristic is that its inverse transform is closed form and quite simple, making it very convenient for Monte Carlo or other simulations.

The requirement, then, is for three estimates for each element; l, m, and h. In some cases the analyst may feel uncomfortable with trying to estimate the zero and one probability points. In this case, we ask for a low estimate (l') and an associated probability of underrun (s), the mode (m) and a high estimate (h') and a probability of overrun (p). The l and h values are calculated easily as shown in Reference (12).

In some instances it may only be possible to assign bounds to the estimate. In that case, we use the uniform distribution. The characteristics of the triangular and uniform distributions are described in detail in References (9) and (10).

INDEPENDENT ELEMENTS

If it can be assumed that these estimates, or WBS elements are independent, then our normal approach is to use the method of moments. This approach follows the general approach of McNichols (7) and is described in detail in References (9), (10), and (11). For this reason, only a brief summary is included.

If x is a random variable with mean μ (first origin moment) and using the nomenclature $\mu^{(i)}$ to signify its i^{th} central moment, then its additive moments A_i are as follows:

$$A_i = \mu$$
$$A_2 = \mu^{(2)}$$
$$A_3 = \mu^{(3)}$$
$$A_4 = \mu^{(4)} - 3\,(\mu^{(2)})^2$$

The useful property of these A moments is that, for all independent x_i's, the A moments of the sum of the x_i's is the sum of the A moments of the individual x_i's.

To perform the analysis, we determine the four A moments of each WBS element and add them to determine the output distribution's A moments. We then fit a Beta distribution to these four moments [Reference (1)] and assume that it represents the output density function. We have developed a library of FORTRAN subroutines to determine these for triangular and uniform distributions and for the Beta fit.

A main program is written to input the data, call out the required subroutines. and supply required formatting. These programs are also written in BASIC for the HP 9830.

Use of the four additive moments enables us to shape the output density function, since a function of A_4 and A_2 defines the kurtosis, or peakedness, and a function at A_3 and A_2 defines the skewness. The output Cumulative Distribution Function (CDF) is easily found by a simple numerical integration, and the output probability statements obtained.

By examining the element results, useful insights may be obtained into the risk elements of the project. The risk drivers are those elements with the greatest variance, while the cost drivers are those with the greatest means. They are not necessarily the same.

DEPENDENT ELEMENTS

The assumption of complete independence among project elements is often troublesome. Perhaps its wide use is due more to ease of analytical or simulation solutions than to practical applicability. In most cases, it is not intuitively pleasing to assume complete independence, since poor results in one project element do tend to ripple through related elements. The independence assumption, due to operation of the Central Limit Theories will likely have a relatively steep CDF, hence may tend to understate the variability or risk. This represents an optimistic view of the possible outcomes. It is our opinion that the assumption of independence is seldom completely valid.

If we make the opposite assumption, i.e., that there is complete linear dependence among the project elements, in effect we say that any problem with any element will be reflected in all elements, and conversely any "good luck" will be similarly reflected. This assumption may not be valid in many situations, but we feel that it is closer to reality than the independency assumption, and the region between the two assumptions may be considered to bound the set of intermediate outcomes.

Under the assumption of complete linear dependence, a set of "D" moments is developed that have the same additive characteristics as the A moments under the independence assumption. Thus, the k^{th} D moment of the sum of n dependent variables is the sum of the k^{th} D moments of the n elements.

As shown in Appendix A, the k^{th} D moment is the k^{th} root of the k^{th} central moment, $k□1$. The first D moment is the first origin moment, or mean, and is therefore equivalent to the first A and M moments.

As shown in Appendix A, there is a simple relationship between the various moments. Using the following notation,

D_k = dependent additive moment
A_k = independent additive moment
C_k = central moment ($k□1$)

$$A_1 = C_1 = D_1 = \mu$$
$$A_2 = C_2 = D_2^2 = \sigma^2$$
$$A_3 = C_3 = D_3^3$$
$$A_4 = C_4 - 3C_2^2$$
$$C_4 = D_4^4$$

For an analytical solution, the existing library of FORTRAN subroutines was modified to solve for the additive D moments. Curve fitting of the Beta distribution uses the original routines after making the D to A transformation at the summary level.

To illustrate these techniques, a hypothetical project is shown with six additive elements. Input variables were all triangular distributed; three transformed by Cost Estimating relationships of the form $y = a + bx^n$, and three unchanged by a CER, i.e., $a = 0$, $b = n = 1$. The input data are shown in Table 1. The example was solved for the independent case by our standard method of moments technique, Reference (9). For the dependent case, both the analytical method of D moments, and a 100,000 iteration simulation were used. The simulation used the "SLICE" technique described in Reference (2) with calculated means.

ELEMENT	LOW	MODE	HIGH	a	b	n
1	9	12	16	14	6	0.86
2	14	18	26	23	8	0.31
3	8	9	14	17	2	1.2
4	31	38	55	0	1	1
5	27	29	37	0	1	1
6	40	45	54	0	1	1

1043-1G

Table 1 Example Input Data

The results are tabulated in Table 2. The moments shown in the table are the conventional A moments for ease of comparison. In the dependency cases these were found by transforming the summary D moments using the equation described above. The values of the exponents α, β of the fitted Beta distribution are also shown as well as their end points and ranges.

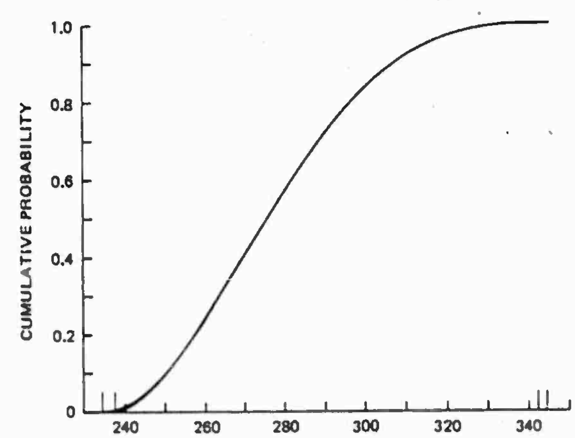
	DEPENDENT CASE		INDEPENDENT CASE
TECHNIQUE/ PARAMETERS	SIMULATION	ANALYTICAL	ANALYTICAL
A_1	2.777E2	2.777E2	2.777E2
A_2	4.459E2	4.473E2	9.168E1
A_3	3.214E3	2.833E3	1.437E2
A_4	-1.224E5	-1.182E5	-1.241E3
SKEWNESS	0.341	0.300	0.164
KURTOSIS	2.384	2.409	2.852
α	0.841	1.142	10.284
β	1.968	2.313	16.879
LOW	237.6	234.5	235.9
RANGE	104.7	110.0	108.0
HIGH	342.3	344.5	343.9

1043-2G

Table 2 Example Results

It can be seen by inspecting the table that the simulation results are a very close approximation of the analytical approach using the additive D moments. As expected, the independent case has a smaller variance, is less positively skewed, and its kurtosis is close to that of a normal distribution.

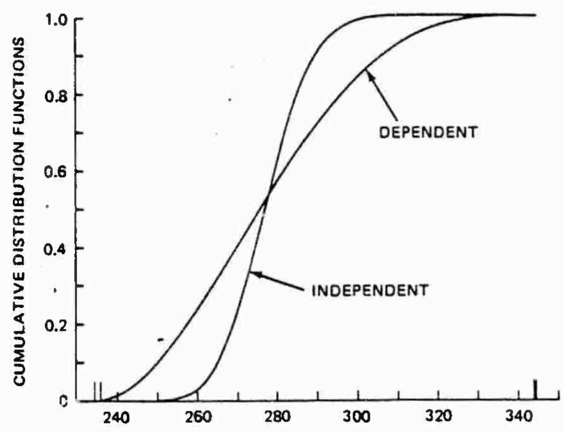
In Figure 1, the CDFs for the analytical and simulation dependent approaches are plotted. It can be noted that the curves for dependent simulation and analytical approaches are indistinguishable.



1043-3G

Fig. 1 Cumulative Distribution Functions: Simulation & Analytical

Figure 2 illustrates the bounded region within the curves of the dependent and the independent cases. It is a matter of judgement to determine where in this area the "truth" lies. The author's preference is to use the dependent case.



1043-4G

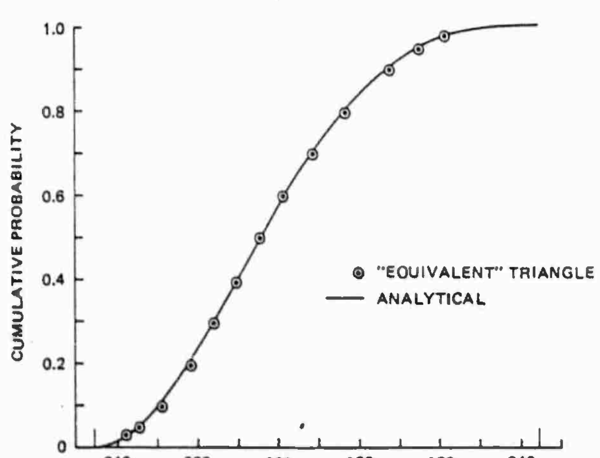
Fig. 2 Cumulative Distribution Functions

"EQUIVALENT TRIANGLE APPROXIMATIONS"

It has been noted empirically that the kurtosis of a triangular distribution is 2.4, and a proof is given in Appendix B. It was also noticed that the kurtosis of the sum of dependent triangular distributions is also 2.4. A proof of this is offered in Appendix C.

These relationships indicate that a good approximation for the sum of dependent triangular distribution might be a triangular distribution having the mean, variance, and skewness of the calculated summary dependent moments.

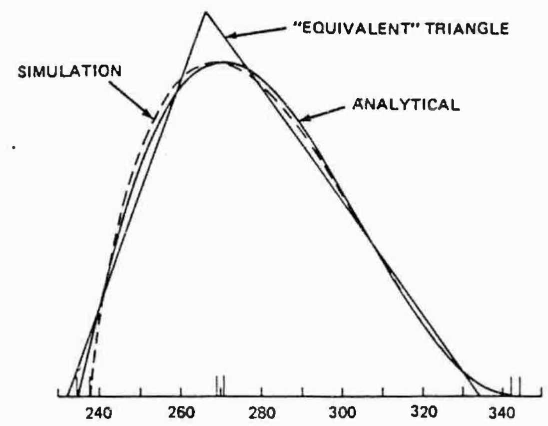
Following the procedure outlined in Appendix D, the "equivalent" triangular model for the illustrative example is l = 232.32, m = 266.64, h = 334.14. The results of the simple area determination to calculate points on the CDF curve (Figure 3) are shown by the "X" values for this dependent curve, plotted on the analytically determined CDF. The density functions



1043-5G

Fig. 3 Cumulative Distribution Functions

derived analytically and by simulation are shown as Figure 4, as well as the "equivalent" triangle.



1043-6G

Fig. 4 Probability Density Functions

For the case of summed triangular distributions, the entire analysis may be done quickly using programs written for the TI-59 handheld calculator. Programs are available for calculating moments of triangular distributions (A, M, and D) and for the area calculation for determining points on the CDF to determine confidence limits for the dependent case. A good approximation for the independent case is to add the means and variances, and assume normality per Central Limit Theorem (as long as a reasonable number of roughly equal estimates are being considered).

CONCLUSIONS

The extension of the method of moments to include additive D moments offers a relatively simple and straightforward solution to determining the cost risk associated with a WBS-oriented program when the independence assumption cannot, or should not be made. The solution is, we think, bounded by the CDF representing the independence assumption, an optimistic approach, and the CDF represented by the complete linear dependence assumption, a pessimistic approach. The methodology is simple enough so that most analyses may be performed by a programmable handheld calculator, such as the TI-59, or when CER transforms exist, a desk-top computer (HP9830 or HP9845) will usually suffice.

For large problems, a library of FORTRAN subroutines has been prepared, and these may be assembled by a suitable main program.

REFERENCES

(1) Black, R. *Fitting a Beta Distribution from Moments.* Grumman Aerospace Corporation, PDM-OP-79-115, 12 June 1979.

(2) Black, R.L. & Wilder, J.J. *Probabilistic Cost Approximation When Inputs Are Dependent.* Grumman Aerospace Corporation, PDR-OP-1382-01. Presented at the 1982 ISPA Conference.

(3) Dienemann, P.F. *Estimating Cost Uncertainty Using Monte Carlo Techniques.* The Rand Corporation, RM-4854PR, January 1966.

(4) Haese, Edward J. *Cost Uncertainty/Risk Analysis.* USAF System Command, March 1976.

(5) Klein, Michael R. *Treating Uncertainty in Cost Analysis; The Beta Distribution.* U.S. Navy CNO Resources Analysis Group, March 1973.

(6) Klein, Michael R. & Jordan, Harley R. *An Application of Subjective Probabilities to the Problem of Uncertainty In Cost Analysis.* U.S. Navy CNO Resources Group, November 1975.

(7) McNichols, G. *On the Treatment of Uncertainty in Parametric Costing.* PhD Dissertation The George Washington University Program In Logistics, 2 February 1976.

(8) McNichols, G.R. *Treatment of Uncertainty In Life Cycle Costing.* Proceedings 1979 Annual Reliability & Maintainability, Symposium, IEEE.

(9) Wilder, J.J. *An Analytical Method For Cost Risk Analysis.* Grumman Aerospace Corporation, PDR-OP-T79-12, 27 June 1977.

(10) Wilder, J.J. *A Simplified Approach to Monte Carlo Cost Risk Evaluation.* Grumman Aerospace Corporation, PDR-OP-T73-27, 11 July 1973.

(11) Wilder, J.J. & R. Black. *Using Moments in Cost Risk Analysis.* Proceedings of "Management of Risk and Uncertainty in the Acquisition of Major Program," U.S. Air Force Academy, February 1981.

(12) Wilder, J.J. & R. Black. *Determining Uncertainty in Bottoms-Up Estimating.* 1982 Federal Acquisition Research Symposium, George Washington University, Washington, DC, 5-7 May 1982.

APPENDIX A*

DERIVATION OF "D" MOMENTS

$m_k(x) = E(x-\mu_x)^k \qquad m_k(y) = E(y-\mu_y)^k$

If x and y are linearly dependent, then

$y = A + Bx$, and $\mu_y = A + B\mu_x$

$$\begin{aligned}(x-\mu_x) + (y-\mu_y) &= (x-\mu_x) + (A + Bx - A - B\mu_x)\\ &= (x-\mu_x) + B(x-\mu_x)\\ &= (1+B)(x-\mu_x) \qquad (1)\end{aligned}$$

$$\begin{aligned}m_k(y) = E(y-\mu_y)^k &= E\,(A + Bx - A - Bx_\mu)^k\\ &= B^k\,(x-\mu_x)^k\\ &= B^k\,m_k\,(x)\end{aligned}$$

$$\sqrt[k]{m_k(y)} = B\sqrt[k]{m_k(x)} \qquad (2)$$

$$\begin{aligned}m_k(x+y) &= E((x-\mu_x) + (y-\mu_y))^k\\ &= E((1+B)\,(x-\mu_x))^k && \text{from (1)}\\ &= (1+B)^k\,E\,(x-\mu_x)^k\\ &= (1+B)^k\,m_k\,(x) && \text{by definition}\\ &= ((1+B)\sqrt[k]{m_k(x)})^k\\ &= (\sqrt[k]{m_k}\,(x) + B\,\sqrt[k]{m_{k}\,(y)})^k\end{aligned}$$

$$m_k(x+y) = (\sqrt[k]{m_k}\,(x) + \sqrt[k]{m_{k}\,(y)})^k \qquad \text{from (2)}$$

then

$$\sqrt[k]{m_k}\,(x+y) = \sqrt[k]{m_k}\,(x) + \sqrt[k]{m_k}\,(y)$$

It is clear by induction that

$$\sqrt[k]{m_k}\,\Sigma\,x_i = \Sigma\sqrt[k]{m_k(x_i)}$$

We will use the following notation:

$\sqrt[k]{m_k}\,(x) = D_k$ for dependent additive moments

A_k for independent additive moments

C_k for k^{th} Central Moment (k□1)

$C_1 = \mu$

$D_1 = \mu$

then

$$\begin{aligned}A_1 &= C_1 = D_1 = \mu\\ A_2 &= C_2 = D_2^2 = \sigma^2\\ A_3 &= C_3 = D_3^3\\ A_4 &= C_4 - 3C_2^2\\ C_4 &= D_4^4\end{aligned}$$

*Derivation suggested by Dr. R. Dowd, Operations Analysis Technical Staff

APPENDIX B

DERIVATION OF THE KURTOSIS OF A TRIANGULAR DISTRIBUTION

$K = \dfrac{C_4}{C_2^2}$ (C_K is the K^{th} Central Moment)

Consider the Δ (0, m, 1)

$$E[x^4] = \frac{1 + m + m^2 + m^3 + m^4}{15} \qquad \text{(1) Ref (9)}$$

$$E[x^3] = \frac{1 + m + m^2 + m^3}{10} \qquad (2)$$

$$E[x^2] = \frac{1 + m + m^2}{6} \qquad (3)$$

$$E[x] = \frac{1 + m}{3} \qquad (4)$$

$$C_2 = E[X^2] - E[X]^2$$

$$= \frac{1 - m + m^2}{18}.$$

Substituting (3) and (4)

$$\text{then } C_2^2 = \frac{1 - 2m + 3m^2 - 2m^3 + m^4}{324}$$

$$C_4 = E[x^4] - 4E[x^3]E[x] + 6E[x^2]E[x]^2 - 3E[x]^4$$

Substituting (1), (2), (3), (4)

$$C_2 = \frac{1 - 2m + 3m^2 - 2m^3 + m^4}{135}$$

$$\text{then } K = \frac{C_4}{C_2^2} = \frac{324}{135} = 2.4$$

APPENDIX C

KURTOSIS OF THE SUM OF DEPENDENCY TRIANGULAR DISTRIBUTIONS

$$K = \frac{C_4}{C_2^2} = \left(\frac{D_4}{D_2}\right)^4 = 2.4 \text{ for any } \Delta \text{ distribution as shown in Appendix B}$$

$$KD_2^4 = D_4^4$$

$$K^{1/4} D_2 = D_4$$

then summing:

$$K^{1/4} \Sigma D_{2i} = \Sigma D_{4i}$$

$$K^{1/4} = \frac{\Sigma D_{4i}}{\Sigma D_{2i}} =$$

$$K = \left(\frac{\Sigma D_{4i}}{\Sigma D_{2i}}\right)^4$$

Thus, the kurtosis of the sum of dependent triangles is shown to be 2.4.

APPENDIX D

DETERMINATION OF THE "EQUIVALENT" TRIANGLE

Since the kurtosis of the distribution resulting from the addition of dependent triangular distributions is always 2.4, this suggests that a good model of this distribution might be a triangle with skewness, variance, and mean corresponding to the summed D moments.

We first determine a value m, the mode of a Δ (0, m, 1).

From Reference (9) it is shown that for the xΔ (0, m, 1)

$$A_3 = \frac{2m^3 - 3m^2 - 3m+2}{270}$$

and

$$A_2 = \frac{m^2 - m+1}{18}$$

Coefficient of Skewness

$$\gamma_1 = \frac{A_3}{A_2^{1.5}}$$

The TI-59 was programmed to find γ_1 from a manually entered value of m, and an iterative search performed to find a value of m corresponding to the desired γ_1. (A more elegant search routine will be written as time permits.)

With this value of m, we have a Δ (0, m, 1) with the desired skewness. We now want to find a similar triangle (0, km, k) with the required variance if $V[\Delta]$ = required variance, and $V[.]$ is the variance of the Δ (0, m, 1)*, then

$$k = \sqrt{\frac{V[\Delta]}{V[.]}}$$

and our Δ with the required variance is

(0, km, k)

$$*V[.] = \frac{1-m+m^2}{18}$$

We now need to shift the triangle along the X axis to give us a triangle L, $L+km$, $L+k$, and all we need now is the value of L:

$$\mu = \frac{L+M+H}{3} \quad \text{definition}$$

$$\mu = \frac{L+L+km+L+k}{3}$$

solving for L:

$$L = \mu - \frac{k(m+1)}{3}$$

and our "equivalent" triangle is

L, $L+km$, $L+k$

A QUANTITATIVE METHODOLOGY FOR ESTIMATING TOTAL SYSTEM COST RISK

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I. INTRODUCTION

A. BACKGROUND

Virtually all cost estimates - whether for private, commercial, or governmental systems - are presented as fixed point estimates without qualification, and are commonly assumed to possess a high level of certainty. However, even a cursory examination of the nature of costs reveals that they are intrinsically highly variable. Unless the cost of a commodity or system element is artificially fixed, it will vary locally, regionally, nationally and, to compound the variability, temporally. Raw material costs, labor costs, utility costs all vary, if not locally, then regionally and nationally.* Complex systems are essentially the results of labor (managerial, engineering, manufacturing, etc.), equipment, and energy applied to raw materials. If the costs of these elements possess an inherent variability, then the resulting aggregated cost of the systems created would likewise display a corresponding variability. The foregoing sources of cost uncertainty are further compounded by uncertainties inherent in both the specific details of the system being costed, and in the amounts of labor and materials that will be required.

Regardless of what technique may be used to generate system cost estimates, the variability inherent in the cost of the system elements, when combined with the intrinsic uncertainty in the cost-impacting details of the system together with such factors as inflation impacts, should make any unqualified point cost estimate highly suspect. A cost estimate at best is only an approximate representation of the expected system cost rather than the precise price that it is too commonly assumed to be.

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* According to the 1980 Dodge Manual, published by McGraw Hill, the wage rates for laborers in Raleigh, N.C. was $6.06 per hour, whereas 430 air miles away in Cleveland, Ohio, it was $17.79 per hour or 190% greater. Salaries of professional engineers likewise show considerable variability as reported in Professional Engineer Income and Salary - 1981, published by the National Society of Professional Engineers. Based on samples of hundreds of professional engineers, the difference in median salary between engineers in Columbus and Detroit (a distance of less than 200 miles) was more than 20%. A 20% median salary differential was also shown between hundreds of professional engineers in Houston and San Antonio, approximately 200 miles apart. In the summer of 1980, the residents of Atlanta paid 4.25 cents per kilowatt-hour of electricity, whereas New Yorkers paid 11.77 cents per kilowatt-hour, or 177% more. During the same period, the rate per kilowatt-hour in Indianapolis was 4.96 cents while 175 miles away in Columbus it was 7.77 cents or 57% more. (Based on a survey by the National Association of Regulatory Utility Commissioners). Material costs depend on extraction and processing labor costs, processing energy costs, and transportation costs, all of which are variable geographically and temporally.

B. PURPOSE/OBJECTIVE

This report presents quantitative methodologies for identifying the cost variability within the individual system elements, a methodology for aggregating the estimated uncertainties in the costs of the system elements, and a methodology for depicting the system cost uncertainty by a range of system costs with their associated probabilities of occurrence. Thus, the inherent uncertainties prevailing in a system and in its costs would be reflected by a cost-probability relationship rather than as an ambiguous point cost estimate.

Two basic techniques are currently used for generating the desired cost-probability relationships: the Monte Carlo approach and the Method of Moments approach.[1,2,3] Both of these methods, however, are of such complexity that the use of a computer (or at least a programmable calculator) is essential. Approximately 500 computer iterations are required by the Monte Carlo method in order to generate a relatively smooth cost-probability relationship. The need for a simple, straightforward technique for generating a quantitative estimate of the cost uncertainty (risk) has long been recognized. The objective of this report is to describe, in detail, the direct, quantitative methodologies developed for deriving subsystem cost uncertainties, aggregating these uncertainties into a total system cost uncertainty, and finally deriving a probability-related cost estimate.

II. CONTENTS AND SCOPE

The subsequent methodology for determining total system cost risk consists of three distinct sequential steps or areas. The first area focuses on methods for estimating the uncertainty associated with the cost of individual system elements. Methods are developed and illustrated for determining these cost uncertainties when the cost estimates are derived by any of the four basic costing approaches: parametric, engineering (bottom-up/grass roots), analogy, or constant multiplier (factor). The major sources of uncertainty that are ultimately manifested in cost uncertainty are treated within each costing approach. These sources of cost uncertainty are identified in Table 1 for each of the four costing approaches. In the parametric costing approach, the two major sources of uncertainty considered are the uncertainty in the independent parameter (e.g., subsystem weight*) and the uncertainty in the cost estimating relationship (CER). In the engineering approach, the uncertainty in the man-hours (or quantity of material required) is considered as well as the uncertainty in the corresponding wage rate (or cost per unit quantity of material). In the analogous or scaling approach, the uncertainty in the system parameter (e.g., weight, power) and the uncertainty in the scaling exponent are considered. In the constant multiplier or factor approach, the only source of uncertainty is in the estimate of the system parameter which is multiplied by a fixed factor to obtain the estimated cost.

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* Weight really is a dependent variable, but because cost is often highly correlated with it, it is frequently used in CERs as an expedient surrogate for a normalized mix of independent system parameters, which are also highly correlated with it.

Table 1. Major Sources of Cost Uncertainty for Four Basic Costing Approaches

	System Element Costing Approach	Equation	Sources of Uncertainty
1.	Parametric	$Cost = a + bP^c$	- System parameter P - Cost model (std. error of est.)
2.	Engineering	Cost = (MH) x (Rate) Cost = (Mat) x (Price)	- Man-hours required - Rate (skill level) - Material required (quantity) - Price (per unit quantity)
3.	Analogy	$\frac{Cost_1}{Cost_2} = \left(\frac{P_1}{P_2}\right)^Y$ or $Cost_1 = Cost_2\left(\frac{P_1}{P_2}\right)^Y$	- System parameter P_1 - Scaling exponent Y
4.	Factor	Cost = P x K	- System parameter P

Factors contributing to cost uncertainty, such as technological developments required, funding stretch-out or schedule slippage, and design changes are not specifically considered. However, they are intrinsically incorporated in a normalized manner within the historic data points on which the parametric CERs are based and also in a similar manner, in the known system cost (C_2), and within the exponent in the analogous system costing approach.

The second area in the overall methodology development presents a procedure for aggregating the individual system element cost uncertainties that were derived by one of the four approaches. The result of the aggregation is a composite uncertainty that reflects the uncertainty (risk) associated with the total system cost. Application of the aggregation methodology developed is illustrated by an example.

The third area presents a methodology for developing a cost versus probability relationship. It also includes some guidelines for deriving a meaningful, specific, R-ACE from the cost-probability relationship for program funding purposes. The methodologies developed are then summarized, and future efforts for enhancing cost estimating methodologies are identified.

III. METHODOLOGIES FOR ESTIMATING COST UNCERTAINTY WITHIN SYSTEM ELEMENTS

The methodologies for estimating the cost uncertainty within the individual system elements under the four approaches shown in Table 1 depend on estimates of the mean $\bar{x}$ and standard deviation σ of the cost-driving parameters. The following section describes two techniques for generating values for the mean and standard deviations from engineering estimates of the cost-driving parameters. The two are the beta distribution and the triangular distribution techniques.

A. TECHNIQUES FOR GENERATING QUANTITATIVE ESTIMATES OF COST-DRIVING VARIABLES AND THEIR UNCERTAINTIES

1. BETA DISTRIBUTION TECHNIQUE

This technique traces its origin to PERT (Program Evaluation and Review Technique) where it was widely used to generate time estimates for events in a scheduling network. In the beta distribution technique as used here, three estimates of a system cost--driving parameter are solicited from the knowledgeable engineering specialist most knowledgeable about that system: low, most likely, and high. The low, or optimistic, estimate should correspond approximately to a value that would be realized only under the most fortuitous circumstances - a subjective probability somewhere in the 0.01 to 0.10 range. The most likely estimate is just that - the mode. The high, or pessimistic, estimate should correspond to a value that reflects the ultimate working of Murphy's Law - a subjective probability in the 0.99 to 0.90 range. Thus, if the three values are:

a = low estimate
m = most likely estimate
b = high estimate

then the mean value $\bar{x}$ can be estimated by

$$\bar{x} = \frac{1}{6}(a + 4m + b) \qquad (1)$$

and the standard deviation about the mean can be estimated by:

$$\sigma_x = \frac{1}{6}(b - a) \qquad (2)$$

2. TRIANGULAR DISTRIBUTION TECHNIQUE

The triangular distribution technique is generally preferred over the more common beta distribution technique.[4] In the triangular technique, the identical estimates - low (a), most likely (m), and high (b) - estimates of the cost driving parameter (e.g., weight) are obtained from the knowledgeable system/subsystem specialist. The mean $\bar{x}$ can then be estimated by

$$\bar{x} = \frac{1}{3}(a + m + b) \qquad (3)$$

and the standard deviation σ by

$$\sigma = \sqrt{\frac{1}{18}\left[(b - a)^2 + (m - a)(m - b)\right]} \qquad (4)$$

Generally, subsystem characteristics, performance requirements or design constraints enable the knowledgeable subsystem specialist to readily arrive at the low and high estimates. The most likely estimate usually presents the greatest difficulty because of a significant degree of uncertainty (indifferance) in the broad mid-range area. The nature of the computations for $\bar{x}$ and σ, however, tends to be forgiving and reduces the percentage of error in estimating m. Figure 1 shows the general uncertainty or indifference in providing an estimate of the most likely value, m.

A measure of the sensitivity of $\bar{x}$ and σ to the selection of m may be seen from an analysis of the three triangular distributions shown in Figure 2. It assumes that curve A is selected when the actual correct values are depicted by curves B or C. Table 2 shows the sensitivity of the calculated values of $\bar{x}$ and σ with respect tothe assumption of m.

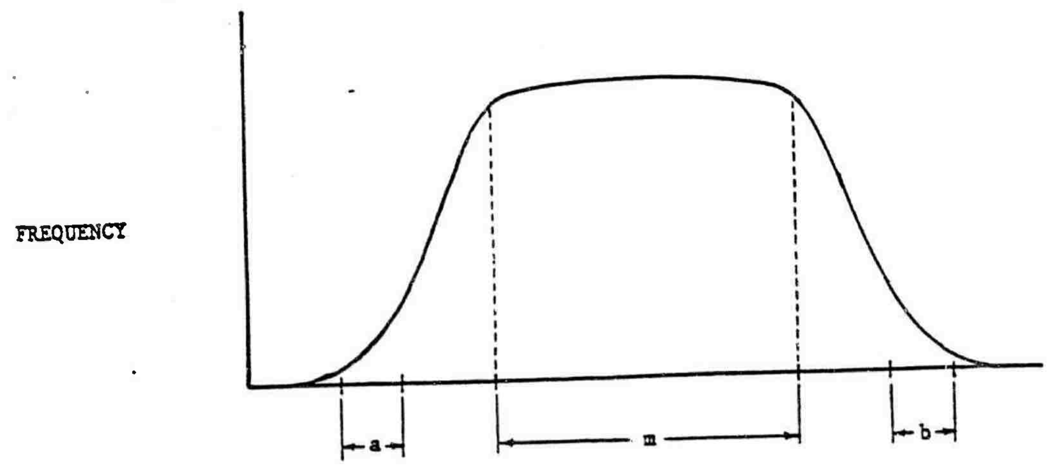

Figure 1. Schematic of General Uncertainty in Estimating the Most Likely Value

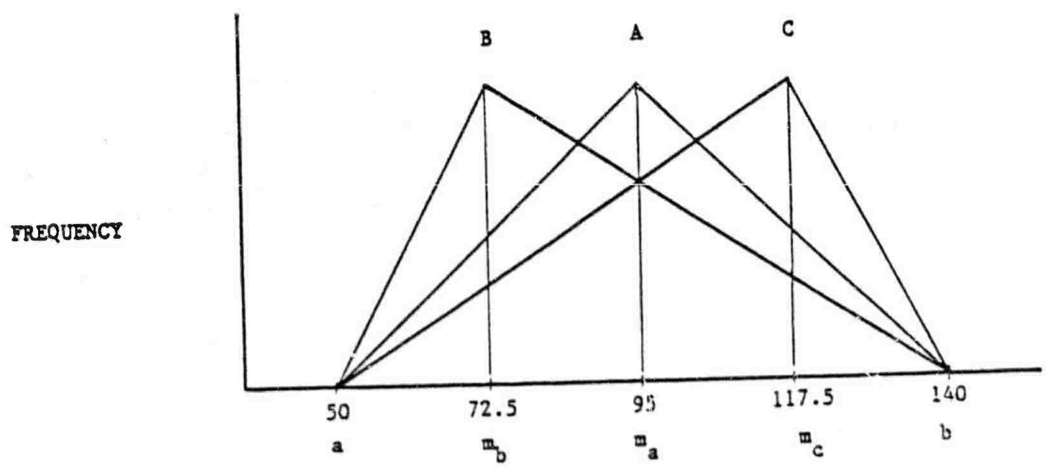

Figure 2. Assumption of Most Likely Values at 25%, 50%, and 75% of Range

Table 2. Sensitivity of Calculated $\bar{x}$ and σ with Respect to Assumption of m

Curve	a	m	Δm	b	$\bar{x}$	$\Delta \bar{x}$	σ	$\Delta \sigma$
A	50	95	0	140	95	0	18.4	0
B	50	72.5	+ 31.0%	140	87.5	+ 8.6%	19.1	3.7%
C	50	117.5	- 19.1%	140	102.5	- 7.3%	19.1	3.7%

The refinement of intentionally incorporating substantial skewness into the distribution by the estimate of the most likely value does not appear to be warranted. However, if there are recognizable and justifiable reasons for estimating the most likely value at other than approximately the mid-range point, this certainly should be done.

B. PARAMETRIC COSTING APPROACH

This section describes and illustrates an algebraic technique for estimating the uncertainty within a parametrically derived cost estimate.

1. PROBLEM

Parametrically derived cost estimates generally have two major sources of uncertainty: the uncertainty inherent in the parametric descriptor of the system (e.g., weight), and the uncertainty associated with the cost-estimating regression equation, which uses the parametric descriptor to derive the cost estimate. The interrelationship between these two basic sources of uncertainty is shown in Figure 3.

The essence of the problem is how to propagate the uncertainty in the independent parameter that is used to predict the cost, through the uncertainty in the cost estimating equation, so as to obtain an estimate of the resultant composite uncertainty in the derived cost estimate.

2. ASSUMPTIONS/REQUIREMENTS

The following assumptions are implicit in the proposed methodology:

a. An estimate of the uncertainty in the independent variable (e.g., weight) can be generated (usually by beta or triangular distribution techniques such as described in the preceding section).

b. A measure of the uncertainty in the cost-predictive regression equation is obtainable in terms of the standard error of estimate.[5,6,7,8]

c. The uncertainty distributions associated with both the independent variable and the regression equation are symmetrical. (Neither the Monte Carlo approach nor the Method of Moments approach is restricted to this assumption.)

d. The independent variable is within the predictive range (bounds) of the regression equation. Extrapolation

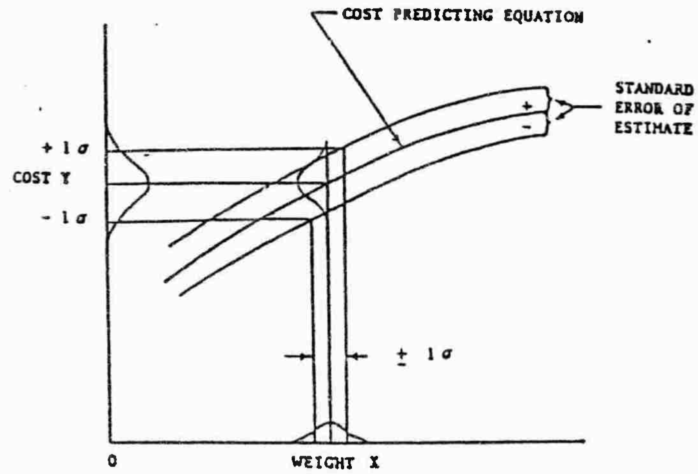

Figure 3. Schematic Illustration of the Uncertainty Propagation Problem

beyond the bounds of the regression equation could introduce significant additional sources of uncertainty that are not treated here.

e. The cost-predictive equation is of the general form:

$$Y = a + bx^c$$

For example,

$Y = a + bx^c$

$Y = bx^c$ (a, the Y intercept is equal to zero)

$Y = a + bx$ (c is equal to 1)

$Y = bx$ (a is equal to zero, and c is equal to 1).

3. METHODOLOGY FOR DETERMINING THE UNCERTAINTY IN A PARAMETRICALLY DERIVED COST ESTIMATE

The application of the algebraic relationship requires the following data:

a. For the independent variable (e.g., system weight), an estimate of the mean value $\bar{x}$, and an estimate of the standard deviation σ_x.

b. A cost predicting regression equation (of the general form $Y = a + bx^c$) together with an estimate of the standard error (SE) about the regression curve.

Knowing both the mean and standard deviation of the independent variable (e.g., weight), as well as the regression line equation with its standard error of estimate. Then the standard deviation of the dependent variable (e.g., cost) σ_Y can be estimated by the relationship:*

$$\sigma_Y^2 = SE^2 + \frac{b^2}{4}\left[(\bar{x} + \sigma_x)^c - (\bar{x} - \sigma_x)^c\right]^2 \quad (5)$$

It should be noted that this relationship is independent of a (the Y intercept) and so will hold true for regression equations of the form $Y = bx^c$. In the linear case $Y = a + bx$, it reduces to a standard result. The application of this methodology is illustrated by the following example.

4. APPLICATION OF PARAMETRIC COST UNCERTAINTY DETERMINATION

The following example is based on the Telemetry, Tracking and Command (TT&C) subsystem data for generating first unit cost and was extracted from the Unmanned Spacecraft Cost Model, SD-TR-81-45, dated June 1981 which was prepared by Air Force Space Division/ACC. The TT&C subsystem design weight of 81.6 lb found on page VII-3 of the subject document was modified by the data for triangular distribution parameters shown in Table D-1, page D-4, as follows so as to represent typical data that might be encountered in an actual case:

Basic design weight: 81.6 lb	
Low estimate (- 50%)	40.8 lb = a
Mode or most likely estimate (+ 2.9%)	84.0 lb = m
High estimate (+ 58%)	128.9 lb = b

The mean value, assuming a triangular distribution, can be derived by Eq. (3), so that the mean weight in this case is

$$\bar{x} = 1/3\ (40.8 + 84.0 + 128.9) = 84.6 \text{ lb}$$

Likewise, the standard deviation for a triangular distribution can be estimated by Eq. (4), which in this case is

$$\sigma_x = \left[1/18[(128.9 - 40.8)^2 + (84 - 40.8)(84 - 128.9)]\right]^{1/2} = 18.0 \text{ lb.}$$

The first unit cost-predicting regression equation for TT&C is given on page IV-11 of the referenced document to be

$$Y = 42.43 + 35.93x^{.93}$$

where Y = First unit cost in thousands of FY 79 dollars
and
x = TT&C weight in pounds

By substituting the mean weight of 84.6 lb for x in this equation and solving, an estimated first unit cost of $Y = 42.43 + 35.93(84.6)^{.93} = \$2270.4$ is obtained. The standard error of estimate (SE) for this equation is reported as 713.9. By inserting the corresponding values into the cost uncertainty estimating equation (5), the standard deviation for the TT&C first unit cost is found to be

$$\sigma_Y^2 = 713.9^2 + \frac{35.93^2}{4}\left[(84.6 + 18.0)^{.93} - (84.6 - 18.0)^{.93}\right]^2$$

* R. H. Huddlestone, Prediction Error Statistics for a Nonlinear Cost Risk Model, The Aerospace Corporation, Interoffice Correspondence (13 January 1982). (Not available for public distribution).

or

σ_Y = \$839.2

The contribution of the uncertainty in the weight (σ_x = 18.0 lb) resulted in an increase in uncertainty of

$$\frac{839.2 - 713.9}{713.9} \times 100 = 17.6\%$$

over that attributable to the standard error of estimate alone.

C. ENGINEERING (BOTTOM-UP/GRASS ROOTS) COSTING APPROACH

The engineering approach is probably the most widely used technique for preparing cost estimates of systems that are in the latter stages of development.

1. PROBLEM

Engineering cost estimates focus primarily on labor and material costs and secondarily on energy and processing costs. Cost estimates of system elements are usually derived by multiplying the quantity estimated to be required times a unit rate (e.g., man-hours times dollars per hour; pounds times dollars per pound, units times dollars per unit). In this case, the two major sources of uncertainty are the uncertainty in the estimate of the required quantity (e.g., man-hours, pounds), and the uncertainty in the estimate of the cost per unit (e.g., dollars per man-hour, dollars per pound). The essence of this problem is how to combine the uncertainty in the quantity required with the uncertainty in the dollar rate per unit quantity so as to obtain an estimate of the uncertainty in the product cost.

2. ASSUMPTIONS/REQUIREMENTS

The following are required for the implementation of this uncertainty propagating methodology:

a. An estimate of the quantity required a along with a measure of the uncertainty in this estimate in terms of the standard deviation σ_a. The estimated standard deviation can be derived by either beta or triangular distribution techniques as previously described.

b. An estimate of the rate per unit quantity b together with an estimate of its standard deviation σ_b. This too can be derived by beta or triangular distribution techniques as previously mentioned.

c. The uncertainty distributions associated with both the quantity estimate and the rate per unit quantity are symmetrical.

d. The quantity and rate per unit quantity are assumed to be independent.

3. METHODOLOGY FOR DETERMINING THE UNCERTAIN-UNCERTAINTY IN AN ENGINEERING (BOTTOM-UP/GRASS ROOTS) COST ESTIMATE

As stated in the assumptions, in order to apply this methodology, it is necessary to have estimates of the quantity (mean) a and its standard deviation σ_a, as well as the rate per unit quantity (mean) b and its standard deviation σ_b. These values are used to calculate the coefficient of variation (called the "fractional standard deviation" by some authors) for both the quantity and the rate. The coefficient of variation S is the standard deviation divided by the mean. Thus,

Coefficient of variation for quantity:

$$S_a = \frac{\sigma_a}{a} \qquad (6)$$

Coefficient of variation for rate:

$$S_b = \frac{\sigma_b}{b}$$

The cost is, then, the product (P$) that results from multiplying the quantity a times the rate per unit quantity b

$$P\$ = a \times b$$

The standard deviation σ_p about the product P$ is then found by:

$$\sigma_p = ab\sqrt{S_a^2 + S_b^2} \qquad (7)$$

4. APPLICATION OF COST UNCERTAINTY DETERMINATION IN THE ENGINEERING APPROACH

If 5000 diverse engineering man-hours a were expected to be required to develop a specific element with a standard deviation σ_a of 500 man-hours, and the mean burdened rate per engineering man-hour b was estimated to be $60 per hour with a standard deviation σ_b of $10 per hour, then the estimated cost of developing the element is

$$P\$ = a \times b$$
$$P\$ = 5000 \times 60$$
$$P\$ = 300{,}000$$

The coefficients of variation are

Quantity: $S_a = \frac{\sigma_a}{a} = \frac{500}{5000} = 0.10$

Rate: $S_b = \frac{\sigma_b}{b} = \frac{10}{60} = 0.167$

and the standard deviation for the product of a times b is

$$\sigma_p = ab\sqrt{S_a^2 + S_b^2}$$

$$= 5000 \times 60\sqrt{0.10^2 + 0.167^2}$$

$$\sigma_p = \$58{,}400$$

Whereas, the individual coefficients of variation were 0.10 and 0.167, the coefficient of variation in the resulting product is

$$\frac{\sigma_p}{P\$} = \frac{58{,}400}{300{,}000} = 0.195$$

or greater than that of either of the factors.

D. ANALOGOUS (SCALING) COSTING APPROACH

The analogous or scaling costing approach is used in cases where sufficient historical data are lacking so that meaningful/valid CERs cannot be developed by statistical (regression) techniques, but where there is a close similarity between the system (subsystem) being costed and an existing system (subsystem) whose cost is known. This approach is widely used in the chemical process industry to generate preliminary cost estimates for new chemical plants or equipment based on the known cost of a pilot plant or smaller scale installation. It is commonly referred to in the literature as the "six-tenths factor" costing approach even though scaling factors other than 0.6 are often used.

1. PROBLEM

In the analogous costing approach, a system similar, or as the term implies - analogous - to the one being costed exists. Key characteristics (e.g., weight, output), proven by experience to be highly correlated with cost, are known for both systems - the analogous system and the system being costed. Thus, the variables in the cost estimating equation are

C_N = cost of the new system (sought)
C_O = known, actual cost of old, analogous, existing system
P_N = cost-correlated characteristic of new system
P_O = known, cost-correlated characteristic of old, analogous, existing system
K = experientially based scaling exponent

and the cost estimating relationship is

$$\frac{\text{Cost of New System}}{\text{Cost of Old System}} = \left(\frac{\text{Characteristic of New System}}{\text{Characteristic of Old System}}\right)^{\text{Exponent}}$$

Thus,

$$\frac{C_N}{C_O} = \left(\frac{P_N}{P_O}\right)^K \tag{8}$$

or

$$C_N = C_O\left(\frac{P_N}{P_O}\right)^K$$

The characteristic P_O and cost C_O of the analogous, existing system are precisely known (no uncertainty). The two sources of input uncertainty in this approach are associated with the characteristic of the new system being costed P_N, and with the uncertainty in the scaling exponent K.

A perusal of exponents used to cost chemical industry elements reveals exponents ranging from approximately 0.1 to over 3.0, although most fall between 0.4 and 0.9.[9] Scaling exponents for fighter or transport aircraft subsystems generally range from 0.70 to 1.0, with most falling between 0.8 and 0.9.[10]

2. ASSUMPTIONS/REQUIREMENTS

The following assumptions and requirements underlie the application of the costing by analogy approach:

a. An estimate of the mean value of the cost-correlated characteristic P_N (e.g., weight, power output) of the new system or subsystem is required along with an estimate of the uncertainty about the mean value in terms of the standard deviation σ_{PN}.

b. An expected value of the scaling exponent K is required together with its uncertainty in terms of the standard deviation σ_K.

c. The uncertainty distributions associated with the characteristic P_N and with the exponent K are both assumed to be symmetrical.

3. METHODOLOGY FOR DETERMINING THE UNCERTAINTY IN A COST ESTIMATE DERIVED BY THE ANALOGY (SCALING) APPROACH

This methodology, developed by Dr. R. H. Huddlestone*, differs from those previously presented in that the uncertainty in the cost is not uniquely determined by a specific equation, but rather by a procedure as follows: The two key sources of uncertainty in the analogy method are (1) the estimate of the new system's characteristic, and (2) the estimate of the scaling exponent. Estimates of these, along with their standard deviations as measures of their uncertainty, need to be obtained, which can be done by the beta or triangular distribution techniques as described in Sections III A 1 and III A 2.

The standard deviations are then applied to the mean values of P_N and K so as to obtain + 1 and − 1 standard deviation values for each of the two parameters − four points in all.

$P_N + 1\sigma_{PN}$

$P_N - 1\sigma_{PN}$

$K + 1\sigma_K$

$K - 1\sigma_K$

These values are then used to determine four estimates of the cost C_N, where

$$C_N = C_O\left(\frac{P_N}{P_O}\right)^K$$

The four values of C_N are obtained by substituting the following four sets of values into the preceding equation and solving for C_N:

1. $P_N - 1\sigma_{PN}$, $K - 1\sigma_K$
2. $P_N - 1\sigma_{PN}$, $K + 1\sigma_K$
3. $P_N + 1\sigma_{PN}$, $K - 1\sigma_K$
4. $P_N + 1\sigma_{PN}$, $K + 1\sigma_K$

The mean of the four C_N values is then obtained, and the standard deviation of the four values of C_N from the mean C_N is generated. The best estimate of the cost of the new system is the mean value, and the standard deviation thus calculated is the sought estimate of the uncertainty in the system cost.

4. APPLICATION OF COST UNCERTAINTY DETERMINATION IN THE ANALOGY APPROACH

A system analogous to the one being costed was known to have weighed 200 lb (P_O) and cost $10 million ($C_O$). The new system is expected to weigh 800 lb (P_N) with a standard deviation of 200 lb (σ_{PN}). The expected scaling exponent K_E is estimated to be 0.6 with a standard deviation σ_K of 0.2. Thus,

C_O = \$10 M

P_O = 200 lb

P_{NL} (low, $-1\sigma_{PN}$) = 600 lb

P_{NE} (expected) = 800 lb, σ_{PN} = 200

P_{NH} (high, $+1\sigma_{PN}$) = 1000 lb and

K_L (low, $-1\sigma_K$) = 0.4

K_E (expected) = 0.6, σ_K = 0.2

K_H (high, $+1\sigma_K$) = 0.8

* R. H. Huddlestone, Estimated Error in Costing by Analogy, The Aerospace Corporation, Interoffice Correspondence (7 January 1983). (Not available for public distribution.)

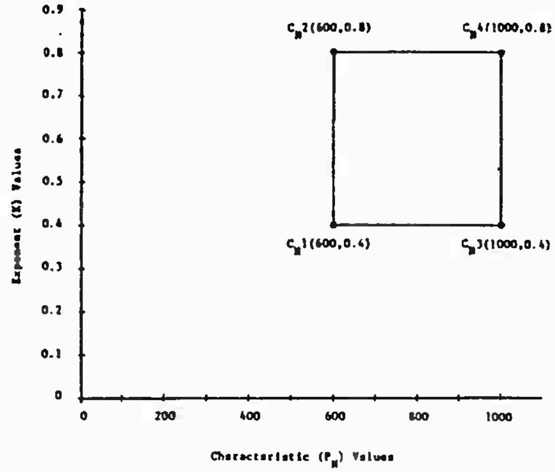

Figure 4. Schematic of Bounds of System Cost C_N

By using the equation

$$C_N = C_0\left(\frac{P_N}{P_0}\right)^K$$

and the four preceding sets of values for P_N and K, four estimates of C_N are obtained. The best estimate of C_N can be shown to lie within the bounds of these four points, as illustrated in Figure 4. An estimate of the standard deviation σ_{CN} can be obtained by determining the standard deviation of the value of C_N for these four points from the mean C_N, as shown in Table 3.

Thus, the estimated cost of the new system C_N is $23.7 million with a standard deviation σ_{CN} of $7.8 million.

Table 3. Illustrative Data and Computational Results for Determining Estimated Cost and Cost Uncertainty by the Analogy Approach

Point	P_N		K		Calc. C_N	Dev. (D) From Mean C_N	D^2
1.	Low	600	Low	0.4	15.52	8.20	67.24
2.	Low	600	High	0.8	24.08	0.36	0.13
3.	High	1000	Low	0.4	19.04	4.68	21.90
4.	High	1000	High	0.8	36.24	12.52	156.75
			Total C_N =		94.88	Total D^2 =	246.02
			Mean C_N =		23.72		

$$\text{Then, } \sigma_{CN} = \sqrt{\frac{\Sigma D^2}{N}} = \sqrt{\frac{246.02}{4}} = 7.84$$

E. CONSTANT MULTIPLIER (FACTOR) COSTING APPROACH

In some instances, the cost of subsystems can be estimated by multiplying the cost estimate of a related system element by a fixed factor(s). The factor might reflect a spares cost factor, inflation factor, learning curve factor, or some other fixed parameter.

1. PROBLEM

In this approach, the factor is fixed - by edict or mathematical principles. The cost, which is multiplied by the factor, however, does possess uncertainty - either actual historical variability or developed estimated cost uncertainty. The problem in this approach is to ascertain the variability in a cost developed by multiplying a cost estimate, that has some level of uncertainty by a fixed constant.

2. ASSUMPTIONS/REQUIREMENTS

The following are required for the implementation of the constant multiplier (factor) costing approach:

a. An estimate of the historical or previously generated (expected) cost of the subsystem/element, along with a measure of the uncertainty about the expected cost as expressed by the standard deviation.

b. The uncertainty distribution about the expected cost is symmetrical.

3. METHODOLOGY FOR DETERMINING THE UNCERTAINTY IN A COST ESTIMATE GENERATED BY A CONSTANT MULTIPLIER

The methodology for propagating the uncertainty in a variable when it is multiplied by a constant is well established,[11,12] and is presented here for completeness. The methodology consists of multiplying the standard deviation of the original, independent variable by the constant in order to obtain the standard deviation in the resulting, dependent variable. Thus, if the initial cost is C, its standard deviation σ, and the constant multiplier K, then the new cost C_2 and its standard deviation σ_2 are found by:

$$C_2 = KC_1 \qquad (9)$$

and

$$\sigma_2 = K\sigma_1 \qquad (10)$$

4. APPLICATION OF COST UNCERTAINTY DETERMINATION IN THE CONSTANT MULTIPLIER APPROACH

If a system was estimated to cost $850 million in some past-year's dollars with a standard deviation of $200 million, and the inflation factor to bring the past costs to current-year dollars is 1.3, then the new (current-year) cost and its standard deviation are obtained as follows:

K = constant (e.g., inflation factor)
C_1 = cost in past-year dollars
C_2 = cost in inflated current-year dollars
σ_1 = uncertainty associated with the cost expressed in past-year dollars
σ_2 = uncertainty associated with adjusted-for-inflation cost

$$C_2 = KC_1$$
$$C_2 = 1.3 \times \$850 \text{ million}$$
$$C_2 = \$1105 \text{ million}$$

and

$$\sigma_2 = K\sigma_1$$
$$\sigma_2 = 1.3 \times \$200 \text{ million}$$
$$\sigma_2 = \$260 \text{ million}$$

Thus, the cost in current-year dollars is found to be $1105 million, with a standard deviation of $260 million.

IV. METHODOLOGY FOR AGGREGATING THE COST ELEMENT UNCERTAINTIES

In the preceding section, methodologies were presented for developing cost uncertainties when individual system elements are costed by one of the four basic costing approaches. The costs of the individual system elements are obviously aggregated by adding, but it is not clear how the uncertainties (e.g., σs) associated with the system element costs should be combined to reflect the uncertainty in the aggregated cost. This section identifies a methodology, along with its rationale, for aggregating the cost uncertainties.

A. FALLACY IN APPLICATION OF CLASSICAL/CONVENTIONAL STATISTICS

Conventional statistics holds that if variables are additive, then their variances (the square of the standard deviation or σ^2) are also additive. Thus, the variance about the sum of a series of variables, each with its own variance, is found by adding the variances as follows:

Variable	Standard Deviation	Variance
a	σ_a	σ_a^2
b	σ_b	σ_b^2
c	σ_c	σ_c^2
d	σ_d	σ_d^2
Sum S		

The variance about the sum σ_S^2 then, is

$$\sigma_S^2 = \sigma_a^2 + \sigma_b^2 + \sigma_c^2 + \sigma_d^2$$

The standard deviation about the sum σ_s may then be derived by taking the square root of both sides of the equation; thus,

$$\sigma_S = \sqrt{\sigma_a^2 + \sigma_b^2 + \sigma_c^2 + \sigma_d^2}$$

This is the conventional root-sum-square (RSS) relationship.* What happens, however, when this relationship is applied to system cost data?

Suppose a system is composed of three independent elements, each with a cost of 50 and a standard deviation about the cost

* A refinement of the RSS technique focuses on the independence or nonindependence of the variables being aggregated. If they are indeed all independent, then the conventional, straightforward RSS equation applies. However, if they are nonindependent (correlated), then an additional complexity arises - covariance term(s) need to be added to the sums of the variances.**

** R. H. Huddlestone, Estimated Error in Total System Cost, The Aerospace Corporation, Interoffice Correspondence (30 November 1982) discusses this issue. (Not available for public distribution.)

equal to 10% of the cost, or 5. The total system cost and its standard deviation would be derived thusly:

Element	Cost	Standard Deviation
1	50	5_1
2	50	5_2
3	50	5_3
Total cost = 150		

The standard deviation about the total cost computed by applying the RSS approach would be

$$\sigma_s = \sqrt{5_1^2 + 5_2^2 + 5_3^2} = 8.66$$

The standard deviation, which initially amounted to 10% of the cost of each element is, by the application of the RSS technique, reduced to 5.8% of the sum.

Now, if the system were twice as large and consisted of six rather than three like elements, each of which again had a standard deviation equal to 10% of the mean, thus,

Element	Cost	Standard Deviation
1	50	5_1
2	50	5_2
3	50	5_3
4	50	5_4
5	50	5_5
6	50	5_6
Total Cost = 300		

then, the standard deviation about the total cost using the RSS approach would be

$$\sigma_S = \sqrt{5_1^2 + 5_2^2 + 5_3^2 + 5_4^2 + 5_5^2 + 5_6^2}$$

or 12.25. This is but 4.1% of the sum.

If the system were truly gigantic and complex, such that it consisted of 24 statistically independent elements under the above assumptions, then the total cost would be 1200, and the standard deviation using the root-sum-square approach would be 24.49, or now only 2.0% of the total cost! These examples, which show the effect of applying conventional RSS techniques, are summarized in Table 4 below.

Table 4. Potential Impact of Using RSS Technique for Cost Uncertainty Aggregation

No. of Elements	Total Cost	Uncertainty σ	Uncertainty σ % of Total Cost
3	150	8.66	5.8
6	300	12.25	4.1
24	1200	24.49	2.0

These data show that as the system becomes larger, (e.g., more expensive and complex) the percent uncertainty tends to decrease! This is contrary to all costing experience. Something is wrong. An examination of what is actually occurring will reveal the source of this fallacy.

B. SOURCE OF INAPPLICABILITY OF CONVENTIONAL STATISTICS

1. NATURE OF COMPETITIVE PROCUREMENT PROCESS

When proposals for the development and/or production of a system are received from several qualified contractors, cost is invariably a criterion for selecting the winner. Not necessarily the lowest cost - but rather a reasonable, credible cost. This obviously puts pressure on the competitive bidders to develop low but realistic bids. However, in most system procurements, there is a significant element of uncertainty. This is reflected by the inclusion of prototype development and tests into the program. The tests are in essence demonstrations to ascertain whether the manifold uncertainties pervading the system have been successfully resolved. Tests are expensive. How many tests will be required reflects just one aspect of contractor optimism. Some level of optimism (confidence in the engineering staff's technical competence) must be displayed. A bid based on pessimistic outcomes would surely lose to a more success-oriented competitor. On the other hand, the compulsion to submit a low bid based on substantial optimism would be prudently balanced by experientially derived knowledge of the existence of a potentially malevolent reality (Murphy's Law!). Consequently, modest reserves for a limited number of adverse events are usually incorporated into the bid. Thus, the nature of the competitive procurement process results in bids that (1) tend to be somewhat low, based on both an optimistic view of the contractor's technical competence and prevailing competitive forces, and (2) belong to a two-tailed distribution inasmuch as the cost could be lower if the program were so successful that the reserves were not needed; or higher, if the amount of reserves were inadequate. Invariably, the uncertainties surrounding the costs of all of the individual elements that are aggregated to produce the final bid are two-tailed, even though some tails may be highly skewed.

Thus, in aggregating the costs and their uncertainties, a root-sum-square approach would appear valid. The high-tailed cost uncertainties would be offset by the low-tailed cost uncertainties. The population would tend towards normality, and the Central Limit Theorem would hold.

2. MANAGEMENT PRINCIPLES/DECISION DRIVERS

Once a contract is awarded, what was up to that point a "normal" distribution becomes a truncated (one-sided) distribution, and the root-sum-square approach to aggregating the uncertainties is no longer valid. That portion of the cost distribution which lies below the mean or expected cost disappears, so there are no offsetting values for the high portion of the distribution. The reason for this is based on program management motivators or decision drivers. The program manager is acutely aware that the systems being procured have a higher intrinsic value than what is reflected in their cost (or else their acquisition would be uneconomic and imprudent). Both his and his company's reputation depend on the reliable performance of the developed system over its expected life - but in the case of space systems - with stringent weight and/or volume constraints. The anticipated reliability is substantiated by failure mode analyses which pinpoint weak links. Engineers responsible for elements of the space system invariably identify changes that would enhance reliability and improve the system, but usually at an increase in cost, weight, and/or volume. Thus, if the cost is underrunning, a prudent manager would opt to use the available funds to eliminate the ever-present weakest link and so enhance the system's reliability, life, or other key attributes.* It is virtually inconceivable that a program manager would decide to come in below the contract cost while weak links exist that could jeopardize the total success of the system. (How much testing and reliability is enough?)

Furthermore, the level of contractor optimism evoked by a competitive procurement process operates to reduce the probability of such a highly successful program that a cost underrun would result. (Some sole source procurements without cost-depressing competitive pressures have resulted in underruns, but this is deemed to be due to the submittal of a more realistically high bid than would normally be the case in a competitive procurement.) The pressures on the program manager personally and on the contractor in general to deliver the "best" possible system, coupled with the ubiquitous weak links, preclude cost underruns. Consequently, the system costs incurred are not governed by, nor display, randomness about the contract awarded amount. The RSS technique in which variances are summed, assumes a randomizing nature at work, or an "averaging" of the high side values with those below the expected (i.e., mean) value. This does not occur here. There are no "low" values. If the costs of the elements were normally distributed so that some were higher than expected while others were lower (thus producing a bell shaped histogram or curve), then the conventional RSS approach might apply, but this is not the case. The awarded amount - usually the bid price (slightly modified during contract negotiations) - which was two-tailed in its development, becomes a floor once the award is made. The two-tailed, chance element that underlies the RSS technique no longer prevails. Root-sum-squaring should not be used. It generates wrong estimates of the standard deviation because "averaging" does not occur.

The foregoing assessment of the program manager applies equally down the organizational line to the subsystem project engineers and subcontractors. Once a cost goal has been set or subcontract award made (based again on a measure of optimism), that then becomes the cost floor. The best subsystem possible will be developed for the designated cost. However, any adversity encountered, beyond that anticipated in preparation of the proposed bid, will likely result in cost overruns. Thus, the bid/award cost will not be underrun. It can only be met or overrun.. This negates the applicability of the root-sum-square technique for aggregating system cost uncertainties.

C. RECOMMENDED APPROACH

The independent parameters (e.g., subsystem weight, CER standard error of estimate) on which cost estimates are based

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* Major General Jasper Welch, USAF, Assistant Deputy Chief of Staff for Research, Development and Acquisition, writing in the December 1982 issue of Electronic Business (pages 55, 56) admonished contractors for merely meeting rather than substantially exceeding negotiated MTBF specifications.

possess an inherent two-tailed probability distribution (± σ). The beta and triangular distribution techniques described provide methods for estimating a two-tailed uncertainty about a mean or expected value. The methodologies described for propagating the uncertainties in the independent variables within the four costing approaches result in the development of two-tailed uncertainty distributions about each element or subsystem cost derived. Now, the purpose of aggregating the element/subsystem costs and their uncertainties is to arrive at a total, composite cost along with its uncertainty that will reflect actuality - what really may occur. Conventionally, aggregation of two-tailed uncertainties is validly done by means of the RSS technique - RSS alone if the variables whose uncertainties are being aggregated are independent, RSS plus a covariance factor if the variables are nonindependent. But, as described in the preceding section, forces prevail that eliminate the lower tail, thus negating the applicability of a RSS approach. The one-sidedness of the cost incurrence is the basis for the recommended approach. Specifically, in aggregating the uncertainties associated with one-sided cost elements, the uncertainties as reflected in the standard deviation associated with each of the aggregated cost elements should be added to arrive at a standard deviation for the aggregated cost.*

D. APPLICATION OF AGGREGATION METHODOLOGY

The following example is based on an actual space system concept. High, low, and most likely weight estimates were obtained for each subsystem element from the respective subsystem specialists. The triangular distribution methodology (discussed and demonstrated in Section III A 2) was used to generate the expected value (mean) and estimated uncertainty (i.e., standard deviation, σ) for each of the subsystem elements. Parametric cost models were used to determine the subsystem element costs. The standard deviations of the weight estimates were combined with the standard error of estimate of the CERs by means of the parametric error propagation equation (5), thereby providing an estimate of the standard deviation (uncertainty) in the system element cost. Tables 5 and 6 show the subsystem costs by cost element along with the standard deviation for the non-recurring costs and recurring costs, respectively. The coefficients of variation or fractional standard deviations are also shown as a percentage. The standard deviations are aggregated by summation into a total system standard deviation. The standard deviations that would be obtained if RSS techniques were used are shown for comparison.

The total system acquisition cost, not including launch or operations and support costs, is shown in Table 7, along with the aggregated cost uncertainty as reflected by the standard deviation.

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* This conclusion is supported by analyses performed by Dr. R. H. Huddlestone and presented in Estimated Error in Total System Cost, The Aerospace Corporation, Interoffice Correspondence (30 November 1982). (Not available for public distribution.)

Table 5. Aggregation of System Non-Recurring Costs and Their Uncertainties

Non-Recurring Cost in FY 82 Dollars

System Element	Parametric Cost Est. M$	Estimated Std. Dev. σ M$	Coefficient of Variation %
Mission Equip. (M.E.)			
Element A	50.0	3.0	6.0
Element B	225.4	33.2	14.7
Element C	36.3	2.7	7.4
M.E. Subtotal	311.7	38.9 (33.4 RSS)	12.5 (10.7% RSS)
Spacecraft (S/C)			
Structure & Mech.	12.2	2.1	17.2
Thermal Control	3.6	2.1	58.3
Electric Power	14.9	2.9	19.5
Trk., Tel. & Comm'd	53.1	2.6	4.9
Stab. & Control	19.0	7.8	41.1
Aux. Propulsion	3.0	0.9	30.0
S/C Subtotal	105.8	18.4 (9.3 RSS)	17.4 (8.8% RSS)
Integration	15.6	1.9	12.2
Qual. & Space Proto.	472.1	53.4	11.3
Ground Support Equip.	9.6	1.0	10.4
Fee	64.0	8.0	12.5
Total Non-Recurring	978.8	121.6 (64.2 RSS)	12.4 (6.6% RSS)

Table 6. Aggregation of System Recurring Costs and Their Uncertainties

Non-Recurring Cost in FY 82 Dollars

System Element	Parametric Cost Est. M$	Estimated Std. Dev. σ M$	Coefficient of Variation %
Mission Equip. (M.E.)			
Element A	36.3	3.8	10.5
Element B	269.4	28.4	10.5
Element C	63.6	6.4	10.1
M.E. Subtotal	369.3	38.6 (29.4 RSS)	10.5 (8.0% RSS)
Spacecraft (S/C)			
Structure & Mech.	19.2	3.6	18.8
Thermal Control	4.8	3.4	70.8
Electric Power	66.6	8.3	12.5
Trk., Tel. & Comm'd	95.4	6.3	6.6
Stab. & Control	34.8	7.2	20.7
Aux. Propulsion	6.6	0.3	4.5
S/C Subtotal	227.4	29.1 (13.6 RSS)	12.8 (6.0% RSS)
Integration	18.6	1.9	10.2
Launch Site Support	8.5	1.1	12.9
Fee	43.7	4.9	11.2
Total Recurring	667.5	75.6 (32.8 RSS)	11.3 (4.9% RSS)

Table 7. System Acquisition Cost and Cost Uncertainty (σ) (In FY 82 Dollars)

Procurement Phase	Estimated Cost M $	Estimated Std. Dev. σ M $	Coefficient of Variation %
Non-Recurring	978.8	121.6	12.4
Recurring (6)	667.5	75.6	11.3
Total	1646.3	197.2	12.0

V. COST-PROBABILITY (COST RISK) RELATIONSHIP

The objective of system cost risk analysis is to portray the financial resources required to acquire a given system in a concise yet realistic manner. A point cost estimate, although concise, does not realistically represent the actual uncertainties that prevail. A cost-probability curve for the given system can depict the measure of cost risk associated with the acquisition of the system.

A. METHODOLOGY FOR GENERATING A COST-PROBABILITY CURVE

The expected (mean) total system cost and its standard deviation - whose generation was described and illustrated in the previous section - are sufficient for the development of a cost-probability curve. The expected cost corresponds to a 0.5 probability. If a normal probability distribution is assumed, reference to cumulative probability tables shows that the expected cost, + 1 standard deviation, corresponds to a 0.841 cumulative probability. This means that the probability is 0.841 or 84.1% that the cost will be less than the amount corresponding to the expected cost, + 1 standard deviation. The expected cost plus twice the standard deviation corresponds to a cumulative probability of 0.977 or 97.7%. Similarly, the expected cost, - 1 standard deviation, corresponds to a 0.159 probability and the expected cost, - 2 standard deviations corresponds to a 0.023 probability. The cost probability curve can be generated by plotting the above points for cost versus probability on standard probability paper and connecting them with a straight line.

The three prerequisites for generating a cost-probability curve are:

1. The availability of the expected (mean) cost with its standard deviation.

2. The assumption of normality (for at least the upper tail of the distribution, as discussed in Section C below).

3. The following table of cumulative probabilities versus standard deviations (σ):

	Cumulative Probability	%
Expected Cost - 2σ	0.0228	2.28
Expected Cost - 1σ	0.1587	15.87
Expected Cost (mean)	0.5000	50.00
Expected Cost + 1σ	0.8413	84.13
Expected Cost + 2σ	0.9772	97.72

B. EXAMPLE OF COST-PROBABILITY RELATIONSHIP DETERMINATION

A cost-probability relationship will be developed for the total system cost $1646.3 million, and standard deviation $197.2 million developed in Section IV D and shown in Table 7. The cost probability curve can be developed by plotting the following cost versus percent probability values on probability paper, as illustrated in Figure 5:

	Cost	% Prob.
Expected Cost	1646.3	50.0
Expected Cost + 1σ:		
[1646.3 + 197.2 =]	1843.5	84.1
Expected Cost - 1σ:		
[1646.3 - 197.2 =]	1449.1	15.9
Expected Cost + 2σ:		
[1646.3 + 2(197.2) =]	2040.7	97.7
Expected Cost - 2σ:		
[1646.3 - 2(197.2) =]	1251.9	2.3

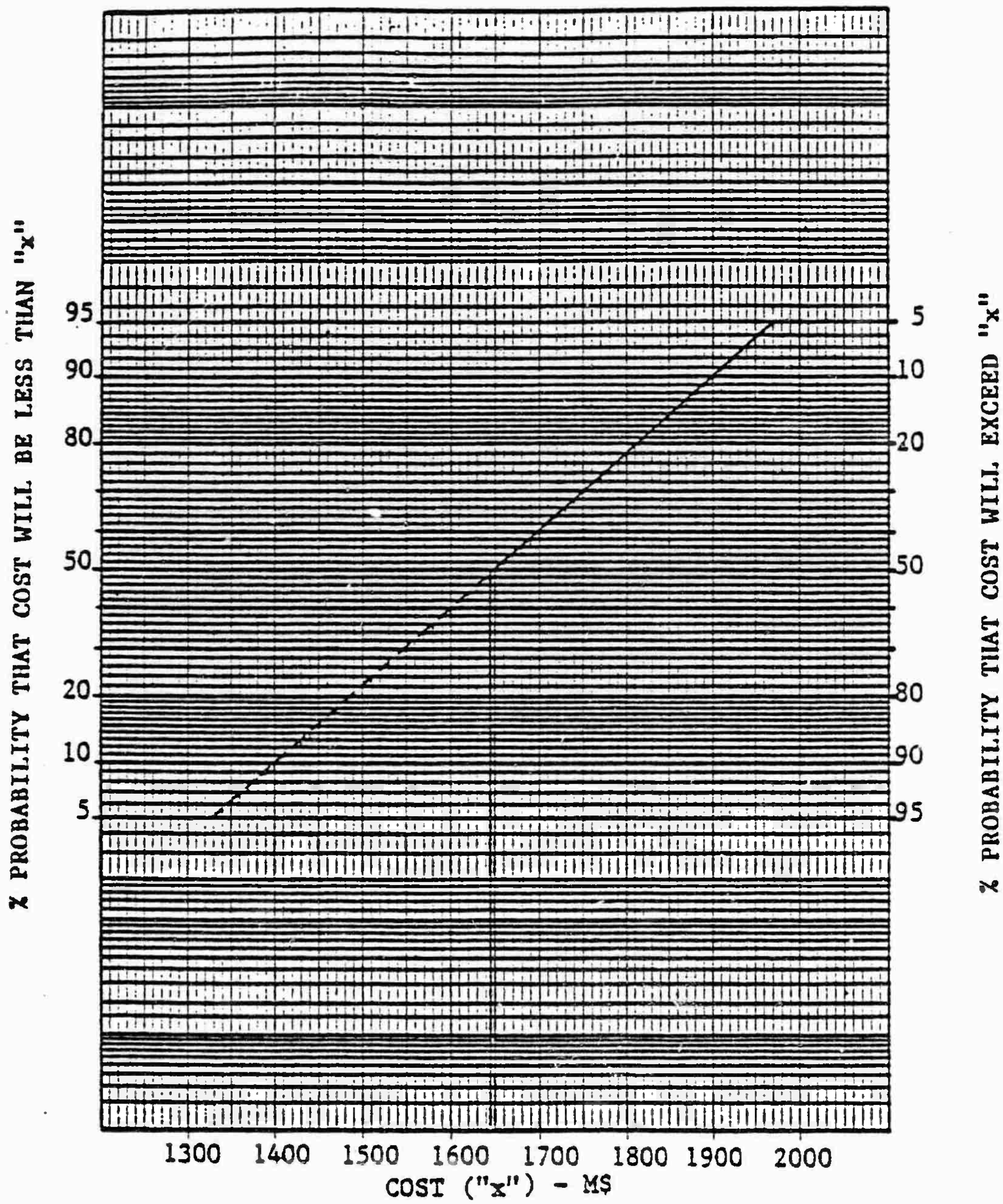

Figure 5. System Cost vs Probability Relationship

The steeper the slope of the curve (i.e., relatively narrow cost range about the expected cost), the less the cost risk; the shallower the slope of the curve (i.e., relatively wide/broad cost range about the expected cost), the greater the cost risk.

C. TRUNCATION RATIONALE

The two basic reasons why system costs are estimated are (1) to aid in determining whether the anticipated benefits warrant the expenditures necessary to acquire the system, and (2) to determine the funding that will be required for its acquisition. A key characteristic of most advanced systems is their relatively large cost - developmental, production, and operations. The funding of a system indicates that the anticipated benefits are judged to be substantially larger than its costs, or else its development would be irrational. The premature loss of the benefits of a key system could have calamitous consequences. Thus, program managers responsible for the acquisition of systems have to balance the dire consequences of diminished performance or premature failure against the expenditures incurred in system acquisition and, as discussed in Sections IV B 1 and IV B 2, would likely opt for enhancing the weakest link(s) rather than underrunning. Consequently, the expected cost (0.5 probability) constitutes a floor on the system cost; therefore, it is recommended that the cost-probability curve be viewed as credible only upward from the expected cost (0.5 probability point).

D. FUNDING LEVEL (RISK-ADJUSTED COST ESTIMATE: R-ACE) DETERMINATION

Although the cost-probability curve is a more valid portrayal of the prevailing reality than a point cost estimate, the budgetary process is incapable of treating a probabilistic spectrum of costs. Therefore, the probabilistic costs depicted on the cost curve need to be translated into a meaningful fixed value for budgetary requirements. A basic guideline for accomplishing this is to use the cost associated with a probability that reflects the level of novelty inherent in the system - the risk-adjusted cost estimate (R-ACE). For example, the cost corresponding to a 0.6 to 0.7 probability level could be used for systems with a substantial legacy from prior systems versus a cost corresponding to a 0.8 to 0.9 probability level for systems incorporating a substantial technological advancement. Major architectural and engineering firms tend to favor a 0.85 probability level for cost risk estimates of new major construction projects.

The source of the cost increase being compensated for by the R-ACE is usually some aspect of actual or potential technological deficiency(s). The presence of a technological deficiency is often referred to as "technical risk." Major categories of technical risks are those that are associated with both the RDT&E phase of a system as well as with its production phase. A prerequisite to the initiation of a successful RDT&E phase (or its cost estimation) is that the physical laws and principles on which the functioning of the system will rely, must be in hand. It is foolhardy to even attempt to estimate the cost of achieving a technical breakthrough. Any cost estimate of a system for which the basic technology is not in hand is meaningless. The history of the nuclear powered aircraft program is brought to mind.

The technical risks in the RDT&E phase are usually associated with the efficient and reliable implementation of known physical laws and principles through engineering design. Even then, substantial risks are occasionally encountered as in the case of the success-eluding program for developing an active refrigerator for cooling spacecraft payload sensors (cryocooler). A nominal measure of the impact of the technology implementation risk is recognized as being incorporated within the historically-derived subsystem RDT&E CERs and their standard errors of estimate that constitute the cost estimating data base.

The second area of potential technological deficiencies that create technical risk is associated with production, specifically that stemming from a lack of manufacturing or testing know-how or both. For example, it is one thing to develop and produce a demonstration-of-principle mosaic focal plane containing 16 or even 200 detectors under laboratory conditions; it is quite another to mass produce an operational version with say 10 million detectors. (The "development" of the production facilities may present an even greater technical challenge than the actual development of the detector.)

The resolution of technical risk (i.e., the elimination of technological deficiencies) is accomplished through the acquisition of new knowledge, which may be viewed as a function of time (schedule) and funding (cost). Technical risk per se has no unique intrinsic substance; it manifests itself through some combination of cost and schedule risk - cost, through the focusing of additional skilled scientific and engineering talent on the surmounting or elimination of the impeding deficiencies; schedule through the application of the scientific and engineering talent over a longer period of time or more intensely, which again is basically a cost impact. (Either acceleration or stretch-out of a program from a normalized, baselined schedule usually results in increased costs because of increased labor requirements.) Cost impacts, although they capture the major essence of schedule changes, omit the initial operational capability (IOC) consideration or program criterion. Nevertheless, cost impacts capture most of the essence of schedule risk. Thus, cost impacts constitute an acceptable surrogate for technical risk. This is borne out in the testimony given by Deputy Secretary of Defense, F. C. Carlucci, on 9 February 1982 before the House Committee on Armed Services[13] in which he reported the increases in the FY 83 DOD budget for the technical risks associated with the RDT&E phase of 12 major programs. The average percent funding increase for "technical risk" for the 12 programs was 21.1%. (The median was between 17.7 and 21.1%). Thus, in the absence of other data on which to establish a R-ACE, a cost increase on the order of 20% may be the best estimate possible under the circumstances. However, experience gained from the application of the R-ACE technique would soon provide guidelines for selecting probability levels (and hence costs) commensurate with the inherent uncertainties, nature, and characteristics of the system being costed.

The difference between the cost corresponding to the selected risk probability level and the expected cost should go into a program reserve, possibly such as that recommended in the Total Risk Assessing Cost

Estimate (TRACE) concept.[14] Whereas, the budgetary funding request would correspond to the cost associated with the estimated risk probability level, the procurement contract and any incentive/award fees should be based on the proposed, "expected" cost. Were the contract award to be made at say the 0.85 probability cost level, the manifold pressures prevailing on the program management to produce a reliable, high quality system would assure that the incremental (reserve) funds would be committed to eliminating weak links and enhancing the system, thereby raising the probability of insufficient funds being available to overcome any unexpected adversities late in the program. The likely net result would be an overrun of the R-ACE amount. To preclude this, the reserve should be in the tight control of the system program office or, in the case of major system contracts, in the control of a top level DOD service board, but not in the control of the contractor, who should endeavor to meet his initial cost estimate.

VI. ADDITIONAL CONSIDERATIONS IN APPLICATION OF METHODOLOGY

A. INFLATION UNCERTAINTY

Although the cost risk methodology presented has described and demonstrated (1) techniques for estimating the cost uncertainty associated with the various cost elements, (2) a recommended methodology for the aggregation of the cost uncertainties, (3) a methodology for the generation of cost-probability curves, and (4) some initial guidelines for the selection of a risk-adjusted cost estimate, consideration of inflation has been excluded to this point for clarity of presentation. All treatment of costs and cost uncertainties has been in base-year dollars. Cost estimates for budgetary requirements generally need to reflect the impacts of inflation and be expressed in then-year dollars. This can be accomplished as described below.

The RDT&E and production costs along with their uncertainties (i.e., standard deviations) can be spread by the use of historically derived spread factors, programmatic schedules, or by other means, over the years in which they are expected to be incurred. To do this, the prorated, or allocated cost estimate as well as its uncertainty estimate for a given year can be generated by multiplying the total RDT&E or production costs and its cost uncertainty σ by the appropriate spread factor. The prorated costs together with the cost uncertainties thus generated for each future year can then be multiplied by the expected inflation factor (e.g., Office of the Secretary of Defense (OSD) inflation factor) for that year. This procedure corresponds to that described under the constant multiplier approach in Section III E 3. Thus spread (allocated) and inflated cost estimates as well as their uncertainties can be generated by direct multiplication by the spread factors and inflation factors.

B. ALTERNATIVE AGGREGATIONS AND COST-PROBABILITY PLOTS

Once the costs and their uncertainty estimates have been spread across the corresponding years and inflated, the final steps are (1) to aggregate the costs and their uncertainties (by adding the standard deviations), (2) generate cost-probability plots, and (3) select R-ACE values. The direction of aggregation and the resulting plots depend on the cost estimates that are being sought. For example, if annual funding requirements are desired, the aggregation will be by year; if, on the other hand, funding by program phase is desired, aggregation will be by RDT&E phase, production phase, etc.; if total program cost is desired, all costs as well as their associated uncertainties need to be aggregated. After the sought costs, for example annual funding requirements and their uncertainties, are totaled by year, then cost-probability curves can be generated by year and provided to the contracting agency for R-ACE selection of funding requests.

VII. SUMMARY

The over-all methodology presented for determining total system cost risk is judged to constitute a significant advance in the area of cost risk determination. Although it admittedly favors pragmatic results over "noncost-effective" statistical rigor, it is basically sound. The fundamental value of the methodology is that it recognizes explicitly and derives analytically impacts on cost of the uncertainties prevailing in both system element estimates and in cost estimating relationships - uncertainties that were formerly ignored, but which contribute significantly to cost estimating "error." Methodologies are presented for arriving at the uncertainty surrounding system element costs that are derived by alternative costing approaches (e.g., parametric, engineering, analogy, and constant multiplier).

It is shown that the uncertainties in the costs of the system elements cannot be validly aggregated by the conventional technique of adding the variances (root-sum-squaring). The proposed approach - which is recognized as being conservative in that the errors are not diminished by the process of error aggregation - consists of adding the standard deviations associated with the costs of the system elements. Pragmatically, the estimate of the total cost error tends to be "reasonable." By generating a cost-probability curve (truncated), the cost risk involved can be perceived. However, for budgetary purposes, a risk-adjusted cost estimate (R-ACE), corresponding to a probability level commensurate with the novelty of the system, needs to be selected. The risk-adjusted cost thus selected should be used for the determination of budgetary requirements. A management reserve base on the difference between the R-ACE and the expected cost (0.5 probability) should be established inasmuch as the expected cost is virtually certain to be exceeded.

By compiling data on the results of the application of this methodology, particularly on the resultant accuracy of the selected R-ACE values, specific guidelines or relationships for selecting probabilities commensurate with the novelty of systems can be established. Complex, first generation systems might necessitate a R-ACE at the 0.9 probability level, whereas fifth generation systems might be accurately estimated at the 0.7 probability level.

Identification of such probability-determining guidelines could further improve the accuracy of system cost estimating.

The presentation of this methodology is but the first step. Its application together with documentation of results, will permit the identification and correction of any deficiencies. Toward this end, the methodology developed for propagating error (uncertainty) in the parametric costing approach together with the methodology for aggregating the cost uncertainty have been incorporated into the Air Force Space Division computerized version of the Unmanned Spacecraft Cost Model.*

The potential applicability of this methodology or its elements extends beyond cost risk estimation per se. The methodology for the identification of errors, their propagation through mathematical relationships and ultimate aggregation appears to be applicable to technical fields other than cost estimating.

By continuing identification, reduction, and eventually elimination of sources of cost estimating error, more accurate cost estimates will be achieved. The methodology developed and described herein is a step in that direction. Consistently accurate system cost estimates, however, should realistically be viewed as an elusive goal because of the inevitable presence of inherently random or uncontrollable events that impact costs. (Even with complete estimating accuracy at all steps, a 0.9 probability level cost will be exceeded 10% of the time because of random influences.) Nevertheless, significant, further improvements can be achieved through better understanding of the sources of cost errors and the decisions that influence the procurement of the system being costed.

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VIII. FUTURE EFFORT

In examining areas of deficiencies in cost analysis, two appear to be outstanding and so constitute prime candidates for future effort. The first is the replacement of the method of least squares by the method of least distance for generating cost estimating relationships. When relationships developed by the method of least squares are used to predict costs in the upper ranges of the independent variable, the results are significant underestimates. The method of least distance, which will be described and illustrated in the subsequent effort, does not possess this deficiency.

The second area of deficiency is in the estimation and quantification of key aspects of schedule risk. Results of progress on these two efforts will be reported at the meetings of the Space Systems Cost Analysis Group (SSCAG).

* Jose Gutierrez of The Aerospace Corporation was responsible for modifying the cost model (on the Hewlett-Packard 9845) such that both numerical results and cost-probability plots would be generated.

IX. REFERENCES

1. J. J. Wilder, Space System Cost Analysis Group (SSCAG) Cost Risk Study, PDM-OP-81-128, Grumman Aerospace Corporation (13 November 1981) (Method of Moments).

2. J. J. Wilder, An Analytical Method for Cost Risk Analysis, PDR-OP-B78-2, Grumman Aerospace Corporation (12 July 1978) (Method of Moments).

3. P. F. Dienemann, Estimating Cost Uncertainty Using Monte Carlo Techniques, RM-4854PR, The Rand Corporation, (January 1966).

4. R. D. Archibald and R. L. Villoria, Network-Based Management Systems (PERT/CPM), John Wiley and Sons, Inc., New York (1967).

5. H. Arkin and R. R. Colton, An Outline of Statistical Methods, Barnes and Noble, Inc., New York (1949).

6. A. J. Duncan, Quality Control and Industrial Statistics, Richard D. Irwin, Inc., Homewood, Illinois (1952).

7. W. A. Spurr and C. P. Bonini, Statistical Analysis for Business Decisions, Richard D. Irwin, Inc., Homewood, Illinois (1967).

8. V. E. Cangelosi, P. H. Taylor, and P. F. Rice, Basic Statistics: A Real World Approach, West Publishing Company, St. Paul, Minnesota (1979).

9. H. C. Bauman, Fundamentals of Cost Engineering in the Chemical Industry, Reinhold Publishing Corporation (1964).

10. M. E. Earles, Factors, Formulas and Structures for Life Cycle Costing, Eddins-Earles (1981).

11. S. L. Meyer, Data Analysis for Scientists and Engineers, John Wiley and Sons, Inc., New York (1975).

12. A. Barry, Errors in Practical Measurement in Science, Engineering, and Technology, John Wiley and Sons, Inc., New York (1978).

13. House of Representatives, Hearings on Military Posture and H.R. 5968, U.S. Government Printing Office, Washington, D.C., (1982), p. 790.

14. U.S. Army Aviation Research and Development Command (USAAVRADCOM), Total Risk Assessing Cost Estimate (TRACE), An Evaluation, Report 79-8 (February 1979).

PANEL SESSION

ON

BEHAVIOR UNDER RISK AND UNCERTAINTY

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COGNITIVE BEHAVIOR AND INFORMATION PROCESSING UNDER CONDITIONS OF UNCERTAINTY

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Over the past decade, research and synthesis of findings on decision making have led to the unequivocal conclusion that earlier conceptualizations about the decision process were either overly simplistic or lacking in veridicality. The nature of the decision task, and the conditions under which it is performed have a profound influence on the decision process. These effects include the decision maker's view of the process, and (probably) information processing strategies which the decision maker may be unaware of having chosen. Further, there is a growing body of literature which suggests that the nature of the decision process is strongly influenced by the organizational level at which the decision maker is located, i.e., what his critical functions in the organization are, and the nature of the cognitive skills he therefore must bring to the task. The purpose of the present paper is to present some of these data, together with some possible implications they have for decision making under conditions of uncertainty, and for risk management.

These latter considerations will have particular relevance for program managers, for the following reasons. If we assume that program managers are differentially effective, then it is reasonable to assume that part of the variance in effectiveness is ad hominum and part is environmentally determined. To some extent, ad hominum variance can be controlled through individual assessment and selection, though this is an expensive venture. However, environmental engineering offers much more promise. It seems highly likely that environments can be made more adaptive for effective decision performance with relatively little cost to organizations. If this is a correct assumption, then interesting new approaches to improving decision performance under conditions of uncertainty will become available.

First, the following definitions of risk and uncertainty seem useful (Lopes, 1983):

- Risk defines the condition under which the possible outcomes of a decision are known, and so are the probabilities attached to each.
- Uncertainty defines the condition under which the outcomes are known but the probabilities are not. (Further, there may be conditions of extreme uncertainty under which not all the outcomes are either knowable, or anticipated if knowable.)

The essence of this distinction is between a condition of rationality or one of, at best, bounded rationality. The problem is that a substantial amount of the early work on decision making, and many of the early conceptualizations, addressed risk to a far greater extent than uncertainty, as thus defined. However, most of the decision making done by humans at senior levels of responsibility, either program managers or executives, is not done under conditions of risk, as defined, but rather under conditions of uncertainty.

Three useful reviews of the decision literature have appeared during the past six years (Slovic, Fischoff, and Lichtenstein, 1977; Einhorn and Hogarth, 1981; Payne 1982). In the first of these, Slovic, Fischoff, and Lichtenstein included a substantial treatment of decision aiding, but at the same time noted some emerging general findings that challenge rational decision theories, i.e., those which have as a basic assumption maximization of expected value (EV), expected utility (EU), or subjective expected utility (SEU). First, information load consistently has shown strong impact on information acquisition utilization strategies. Second, strategies for search and evaluation may vary from one stage of a decision problem to another, a finding which repeatedly occurs and which confounds rationality assumptions. Payne's review adds a third general finding: decision makers seem to have some kinds of learned rules which are probably context bound and generalized across situations (that is, they are ways of dealing with decision requirements) whether it is appropriate to generalize them or not. Payne noted that Abelson's scripts and Pitz's production systems are good examples.

The second of the three reviews cited earlier had a broader objective:

> "...to place behavioral decision theory in a broader perspective, emphasizing importance of attention, memory, cognitive representation, conflict, learning, and feedback."

As does Payne, Einhorn and Hogarth challenge normative models:

> "Judgement and choice are strongly influenced by seemingly minor changes in task and context. And information search and evaluation strategies are interdependent. A variety of strategies exists, and little is known about criteria for rule taking, rule shifting, and the choice of evaluation strategy."

Uncertainty arises from the environment, from equivocal cue-criterion relationships, inconsistentcy in individual information combination strategies, and the question of how cues should be weighted in relation to their predicitiveness. Finally, they note that there is limited learning capacity in humans, and that humans paradoxically show learned confidence in judgement despite obvious low validity of judgement.

While human decision performance even in simple conditions is subject to characteristic biases and errors, a good case can be made that performance becomes worse as task complexity increases. Payne (1982) focuses on the impact of task complexity, noting that as complexity increases, information load presumably also increases, and several predictable impacts reliably are found:

- Compensatory strategies shift to conjunctive or elimination-by-aspects strategies.
- Response variability increases and choice quality decreases.
- Decision makers rely more on negative information to reduce complexity (with increases in time pressure).
- Risk propensity is reduced by a more constrained time horizon.
- Decision makers tend more strongly not to transform information but rather to use it in the form conveyed, which reduces cognitive strain but does little to enhance quality of decisions.

In addition, decision makers are systematic in violation of some rationality assumptions, but nonsystematic in violation of others. For example, there is apparently systematic tendency to be risk aversive for gain and risk seeking for losses. However, Lopes (1983) seeks to explain this systematic violation of rationality assumptions in terms of psychological variables such as the decision maker's status and long term goals, which of necessity are idiosyncratic. Payne makes a similar point, that decision makers operate in terms of a psychologically relevant outcome space (problem space) which may or may not conform either to reality or to the outcome space of other decision makers.

Finally, Payne notes that little is known about how decision strategies are learned. Heuristics are widely used, and the evidence suggests that they are context-dependent. However, once learned, they can be very enduring. A great deal more needs to be learned about how they are acquired, and how feedback processes operate to mediate their retention over time.

As was noted by Payne, Braunstein and Carroll (1978), decision research to date has focused more on outcomes than on processes. In order to understand decision performance better, we need better data on how decision makers acquire and use information, the information that eventually is used, and the conditions under which it is used. If decision making is viewed more from the perspective of information processing benavior, focusing on search/acquisition, evaluation, and feedback/learning, avenues may well be found to improve decision performance through attention to environmental and individual factors that influence these processes. The remainder of this review will focus on these issues. Three broad categories will be addressed: (a) the information processing characteristics of the human decision maker, (b) the nature of the function served by decisions within the organizational context, and (c) the form taken by the requisite information in relation to the decision function served and the cognitive skills of the decision maker.

Broadbent, among many others, has contributed substantially to an understanding of the characteristics of human decision makers in terms of the basic processes involved. In a seminal article, he (Broadbent, 1977) described research on control systems which mediate throughout processes in human information processing. Processing tasks were defined in two ways:

- Closed tasks - open-chain sequences which require no check with the environment for execution.
- Open tasks - unpredictable sequences of actions in relation to unpredictable series of events, which requires continuing check with environment.

In a series of experiments, Broadbent demonstrated that human information processing occurs at least at two levels, and that these levels may correspond to the type of tasks performed. One control system operates in an open chain fashion, accepting input and producing output, without any feedback loops. A second control system can be visualized as an integrating, feedback operated processor, with a capacity for both rewriting the rules used by the open chain processor, and for providing it with inputs. Broadbent visualized these as "lower" level and "upper" level, respectively. A key assertion is that lower level processes can operate in parallel, as long as they do not require the same input sensory modality, but that upper level processes cannot. Perhaps of even greater interest, he theorized that control of the total information processing task shifts from one level to another, depending on context, task, and feedback.

Awareness of differential processes such as these is not reflected in the methodology reported in much of the current literature. Many findings are based on laboratory tasks which probably elicit use of lower level processors, while others are based on tasks requiring upper level processors. Specifically, repeated responding in a simple lottery could conceivably be accomplished by a lower level processor. In such tasks, it would not be surprising to find the use of quite different search/acquisition and evaluation strategies in those which activate upper level processors. Further, it would not be surprising to find that the switching control system levels is contingent on such variables as information load, with upper level systems operating under conditions permitting the longer processing times probably required, and switching processing to lower level systems when available processing times are inadequate for the functioning of upper level systems. More research correlating control systems with tasks by conditions is needed for developing understanding of human information processing characteristics of the nature of decision tasks.

In preparation of this review, no research was found on information processing requirements for program managers. However, there is a growing body of knowledge about decision and information processing behavior of senior executives. If it can be assumed that similar behaviors are required of senior executives and managers of complex programs, conclusions can be drawn from analysis of that literature.

Two interesting recent publications are relevant (Kotter, 1982; Draft and Lengle, 1983). The first is one of a growing number of works in which the on-the-job behavior of senior managers is reported and analyzed. The second is an analysis of the information-processing task of the senior executive. In it, the authors assert that the managerial task is to make sense out of complex decision making - and it can be argued that this is a central part of complex decision making - and to coordinate internal activities within the organization. They then advance the concept of information richness, which is defined as the information carrying capacity of data.

- Situations of greater uncertainty (equivocality) require data of greater richness, and
- Media can be scaled in terms of their richness into five categories from most to least rich: face-to-face, telephone, letter, memorandum and computer printout. (Scaling is accomplished through use of the variables of channels utilized, feedback capability, source and language used.)

In essence, simple phenomena can be managed with simple rules, and with information of low richness; complex phenomena require rich information, and probably yield more easily, in general, to the use of heuristics than to more mechanical computational procedures. But Kotter showed convincingly that the phenomena of concern to senior executives in his sample were indeed complex. He further provides evidence concerning their sources of information that strongly supports the Draft and Lengel hypotheses. Senior executives obtain most of their information from "rich" sources. Similar support is contained in Mintzberg's (1973) observational data on the job of the senior manager. Senior managers make little use of low richness sources, and the extent to which they do so decreases with increases in uncertainty. Not only are their most critical tasks focused on fuzzy problems, but also some of the relevant data are essentially political (Brightman, 1978). Draft and Lengle concluded:

- The best form for an organization to take is one which addresses its information processing needs best.
- Management information systems designers lack a coherent theory of manager needs and manager behavior.

To this might be added the need for decision making models relevant to executive function under such conditions, and the unique information processing skills of good decision makers.

Streufert (1970, 1981) addresses these skills from a cognitive complexity perspective in research dealing with information search and the impact of load stress in complex decision making. His research shows that decision makers at senior levels perform better if they engage in cognitive processes of differentiation and integration of their information dimensions, and then use these dimensions in their subsequent decisions. As expected, work pressure/ laod reduces the capacity to do this. However, individuals who characteristically do more differentiation and integration under light loads are less impacted by load increases. Further, predispositions to multidimensionality are trainable, though with difficulty, perhaps paralleling Payne's observation about problems in the learning of decision strategies. As a final point, Struefert notes another finding paralleling decision research findings on feedback acquisition and use. In his experiments, he found that the amount of information needed to change a decision exceeded that needed to make one. One might therefore conclude that unidimensional information processors will not discover bad decisions as effectively as do multidimensionals. If a correct inference, cognitive complexity then relates to search/ acquisition and evaluation in complex tasks, though of necessity it would not in simple tasks not requiring cognitive complexity.

Thus far, select findings on the characteristics of human decision makers and the relation of cognitive skills to information requirements and decision outcomes have been presented. A final issue is the time horizon (perspective) of the decision maker. Jaques (1976) has developed a theory of organizational structure which identifies levels of performance requirements and relates them both to the time frames within which action must be planned by level. For practical purposes, seven levels are defined, as shown in Figure One. They can be broken into three more general sets, strategic, general management, and operational execution. If these levels are cross-matrixed with Streufert's cognitive complexity categories, and if successively more complex program development and management activities are located logically within the matrix, the cell entries shown in Figure One emerge. These, of course, are only theoretical. However, if the theory is accurate, there are several strong implications. First, the information processing requirements of successively higher levels of organization (and management of successively more complex programs) should increase in volume and complexity. A diagonal from lower left to upper right in the matrix coincides with the direction of increasing information load. Second, if Jaques is correct about the critical functions of incumbents by level, the degree of concreteness of required information and the form it should take change from level to level. More complex problem situations, as shown on Figure One, require the use of more abstract information, i.e., consolidated rather than individual elements, transformed to show trends as opposed to sums second derivatives rather than first derivatives, and so on. Finally, executives and program managers at the more senior levels should have longer time horizons than shorter, and should have demonstrated capacity for multidimensional integration information processing skills.

The research base thus far available is not large, and very substantial effort is now being applied to the creation of executive development technology, using the logic of the above. Findings from this research will enable substantially more confidence in the drawing of conclusions than now is possible. However, it seems clear that some improvements in organizational performance (and probably program management) can be achieved. One fruitful direction is assessment of potential executives and program managers. If cognitive complexity and the capacity for functioning over extended time periods (10-20 years) are requirements at the most senior levels, assessment programs to permit early identification and development of talent would seem to be a good investment. Training and development activities could then be purposefully tailored to permit career management against known executive skill performance requirements. A second fruitful approach is engineering of the information environment. Given that load decreases decision quality and limits the multidimensionality of senior executive performance, organizationally imposed information loads, to the extent they exceed optimum levels, impact on organizational performance. However, in bureaucracies, there frequently is little filtering of the content of imposed loads in relation to organizational priorities. Further, rules proliferate in bureacuracies, and performance is audited by a variety of "seniors" to include one's formal boss. However, the perspectives of the "audit" frequently vary from one auditor to another, and in some cases do not directly reflect awareness of organizational priorities and the requirements for effective organizational performance. In terms of level of performance, an axiom might be that the greater the number of rules, the less integration the incumbent can show, and the lower the quality of decision outcomes will be, outside some boundary condition. Another might be that the greater the load, e.g., through imposition of performance requirements established by an organizational rule-making subsystem (such as personnel), the lower will be the integrative quality of decision outcomes. Finally, organizational structure probably influences decision quality outcomes. For complex decision making and the processing of information under conditions of substantial uncertainty, mechanistic organizations (like bureaucracies) probably impose upper limits on the quality of executive (and program manager) performance.

If these inferences are correct, progress toward higher quality decisions and higher organizational performance probably can be realized through selection and development of early talent; systematic review of rules and procedures to ensure simplicity and consistency in complex environments (in simple environments it does not matter); systematic auditing of the information loads imposed on critically important senior executives and program managers to ensure they are not burdened by requirements generated by suboptimizing subelements; and tailoring of organizational structure to match the complexity and time frame of the level of performance required.

REFERENCES

1. Broadbent, Donald E. Levels, Hierarchies, and the Locus of Control. Quarterly Journal of Experimental Psychology. 1977, 29, 181-201.

2. Brightman, H. J. Differences in Ill-structured Problem Solving along the Organizational Hierarchy. Decision Sciences, 1978, 9, 1-18.

3. Draft, Richard L. and Lengel, Robert H. Information Richness: A New Approach to Managerial Behavior and Organizational Design. TR-ONR-DG-02, May 1983.

4. Einhorn, Hillel J. and Hogarth, Robin M. Behavioral Decision Theory: Processes of Judgement and Choice. Annual Review of Psychology, 1981, 32, 53-88.

5. Jaques, Elliott. A General Theory of Bureaucracy. New York: Halstead Press, 1976.

6. Kotter, John P. The General Managers. New York: Three Free Press, 1982.

7. Lopes, Lola L. Observations. Some Thoughts on the Psychological Concept of Risk. Jounal of Experimental Psychology, 1983, 9, 137-144.

8. Mintzberg, H. The Nature of Managerial Work. New York: Harper and Row, 1973.

9. Payne, John W. Contingent Decision Behavior Psychological Bulletin, 1982, 92, 382-402.

10. Payne, John W., Braunstein, Myron L., and Carroll, John S. Exploring Predecisional Behavior: An Alternative Approach to Decision Research. Organizational Behavior and Human Performance, 1978, 22, 17-44.

11. Slovic, Paul, Fischhoff, Baruch, and Lichtenstein, Sarah. Behavioral Decision Theory. Annual Review of Psychology, 1977, 28, 1-40.

12. Streufert, Siegfried. Complexity and Complex Decision Making: Convergencies between Differentiation and Integration Approaches to the Prediction of Task Performance. Journal of Experimental Social Psychology, 1970, 6, 494-509.

13. Struefert, Siegfried, and Struefert, Susan C. Stress and Information Search in Complex Decision Making: Effects of Load and Time Urgency. ONR Technical Report 4, August 1981.

FIGURE 1

COGNITIVE COMPLEXITY AND TIME HORIZON

	COMPLEXITY		
CAPACITY	UNIDIMENSIONAL	MULTIDIMENSIONAL	
		DIFFERENTIATOR	INTEGRATOR
STRATEGIC VII (20 Years +) VI (20 Years)		Cross Program Tradeoff Analysis -- Investment Strategy Determination	Future Force Concept Development
OPERATIONAL MANAGEMENT V (10 Years) IV (5 Years) III (2 Years)	SINGLE PROGRAM MANAGEMENT	MULTIPLE PROGRAM MANAGEMENT - ANALYTIC	MULTIPLE PROGRAM MANAGEMENT -- CROSS PROGRAM INTEGRATION
OPERATIONAL EXECUTION II (1 Year) I (0-3 Mo)	PROGRAM ELEMENT ADMINISTRATION	PROGRAM ADMINISTRATION	MULTIPLE PROGRAM COORDINATION

THE CONTRIBUTION OF CARDINAL UTILITY TO REAL LIFE DECISIONS

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We shall start this discussion of cardinal utility theory in general and measurement of risk attitudes in particular by limiting ourselves to situations in which the construct of economic man - one who is driven solely by financial considerations - is reasonably valid. A fair mount of research has been done here. We will now go on to discuss risk attitudes in situations which are not controlled by economic considerations. Unfortunately, almost no research exists in this area.

For many years, most writers who considered probabilistic environments assumed that decisions would be made based on expected values. This is not always true. For example, it was assumed that having to choose between a sure dollar and a 50-50 gamble on either five dollars or nothing, one would choose the gamble, since its expected value is $2.50. Experiments show that almost all people would indeed make this choice. However, with choosing between a sure million dollars or a 50-50 gamble on five million or nothing, most people opt for the sure million. We demonstrated the truth of these statements in our talk. The fact that the gamble would lead to an expected value two and a half times greater than the million swayed almost none of our audience.

In the 16th century, in his famous St. Petersburg paradox, Daniel Bernouli demonstrated that in at least one case, respondents were unwilling to base decisions on expected values. Philosophies, logisticians, statisticians and economists have discussed this paradox for years. But it was not until 1946, when VonNeumann and Morgenstern published their monumental Theory of Games and Economic Behavior, that a formal treatment of risk attitudes would allow decisions made in risky situations to be predicted. They showed that, given certain reasonable assumptions, decision makers will optimize on the expected value of what the authors defined as utility. This formed the basis of cardinal utility theory, and enabled us to quantify risk attitudes. It also led to much confusion. A number of people, most notably Allais, constructed counter examples in which most people would not choose the alternative having the greatest expected utility. Many took the attitude that these counter examples destroyed utility theory. Others, including myself, felt that this enhanced its usefulness. We take the position that only when normative, or prescriptive, theory is at odds with descriptive behavior that the theory is useful beyond its ability to massage one's prejudices.

An example of such use occurred in a study reported in the Harvard Business Review. In this study, I found that many decision makers, employed by very large companies, would not recommend investing in a bid which offered a 50-50 probability of a net present worth of either a gain of $200,000 or a loss of $20,000.

Since such companies have many many opportunities of this kind, and have very large resources, it is easy to show that it would have been in the company's interest to take such risks.

Members of the audience hypothesized that an explanation of the difference between the choices that should be made and those that were made lay in control procedures which penalized one recommending a course of action leading to a $20,000 loss. My research tends to confirm this hypothesis. For several of my respondents asked, perceptively, if I had not asked what they would do rather than what they should do. When I told them yes, I had, they replied that they would not recommend the bid, even though they were aware it would be to their company's interest to do so. When I was discussing this in Norway I was told that I had simply rediscovered and verified an old Norwegian proverb. It says "It takes ten times as much profit to get a pat on the back as it does loss to get a kick in the tail."

The question was then raised as to whether or not similar risk averse attitudes would tend to be held by civil servants. Unfortunately, no research exists to settle this question, but it is surely an important one to ask. Likewise, we can offer no research findings on the possibility of changing employee risk attitudes. I do, however, have evidence that in one company, lower management perceived upper management to be far more risk averse than it really turned out to be, and that they felt that the proper risk attitude for the company, and therefore themselves, was far less risk averse than they actually were.

Because of the active participation of the audience in discussing these matters, we had to conclude after a brief discussion of a partially successful study Jerry Selman and I made on risk attitudes held by military officers.

PANEL SESSION

ON

RISK ANALYSIS: IMPLICATIONS FOR ACQUISITION

CHAIRMAN

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AD P002311

RISK ANALYSIS FROM A TOP-DOWN PERSPECTIVE

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Most risk analyses begin by considering the behavior of the lowest and most detailed level of all possible events that can be identified in the system under study. Next, risk estimates are made for each event-consequence relationship and aggregated upward to obtain a total risk estimate of the process under study. The aggregation process propagates the errors contained in the detailed risk analyses, and often results in risk estimates whose error ranges are too wide to provide useful information. An alternative approach starts at the highest level of the problem, and identifies the crucial decisions, decision makers, alternatives and parameters. Agreements regarding specific decisions and subsequent actions are sought at the beginning, and "what if" situations and conflicts are identified in case agreement cannot be reached. The "what if" situations provide the framework for more detailed and focused studies in critical areas. A variety of analyses, such as a localized version of the bottom up risk analysis approach and sensitivity analysis, focus on these open ended cases to resolve them. Unresolvable decision conflicts include value judgments which risk analysis cannot solve; however, by making these conflicts visible, the focus on differences such as these can often force resolution at a higher management level.

Definitions

Several definitions should be provided as a basis for discussion:

Risk: The downside of a gamble; the potential for harm.

Bottom-up Risk Analysis: Taking each event that can occur in a system and analyzing the pathways leading to the range of possible consequences, and aggregating these over the total spectrum of events and their associated probabilities.

Top-down Risk Analysis: Determining the critical parameters of a decision and forcing the underlying factors among alternative choices to become visible and understandable.

Joint Approach: Using a top-down approach to scope a problem and specific bottom-up approaches to provide quantification where needed.

In order to illustrate these approaches, a hazardous waste disposal example is provided. Two different cases are shown because they each illustrate the methodologies, as well as represent actual cases.

Bottom-Up Risk Approach For A Hazrdous Material Site

Consider an inactive waste disposal site owned by a coroporation, which is suddenly suspected of containing previously unidentified hazardous wastes (as defined by the Resource Conservation and Recovery Act of 1976 (RCRA)). The case under consideration is an actual case which has been modified for use as an illustration here. Identifying the case is not important, nor are the conclusions drawn necessarily valid for the particular case in question.

An old, uncontrolled disposal site on a farm in the midwestern United States, consisting of an unlined pit in which an estimated 150 drums of waste material were buried around 1970, was brought to the attention of EPA. EPA performed a two-week field study from which they determined that the wastes came from a company-owned hexachlorophene manufacturing process and which contained 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD) as well as other materials, such as trichlorophenol (TCP) and ethyleneglycol. Bore holes were taken to determine leakage, and the disposal pit was partially excavated, uncovering 13 drums —some empty, others ranging from near empty to full. Samples confirmed the presence of TCDD from 29 mg/kg (ppm) to 100 mg/kg of materials in the barrels and soils. Based on the field investigation, excavation, and results of the sampling, the EPA further concluded that immediate action was necessary to protect human health and the environment. This decision necessitated the development of a short-term response program to minimize and/or prevent the release of contaminants from the site until a method permanently ameliorating the hazard could be implemented. An immediate and temporary measure was taken by the EPA. The disposal trench was capped with an impermeable membrane. Surface water was diverted from the site. At this point, EPA contracted with an independent contractor to undertake a three-month study to determine how to deal with the problem. This study will be used to illustrate the process.

The objective of the study was to clean up the site or, at least, to ensure it would not impose risks to the public. As a result of the initial study, it became evident that no methods were presently available for final treatment or disposal which met even minimum criteria. Several methods were in the experimental stage, but several years would be needed to demonstrate their capability. As a result, the following conclusions were established:

a. There is no method for final disposition at the present time;
b. Temporary storage is required until suitable final disposal methods are available.

Four general alternatives were considered:

1. Leave buried;
2. Leave buried, but install and maintain a ground water monitoring system;
3. Excavate and store material on-site in a newly (to be) constructed temporary repository;
4. Excavate and transport drums via truck to an alternate disposal site (and store).

The contractor then attempted to develop the criteria required for each remaining alternative. Not unexpectedly, the risk determination caused the most significant problem:

> "The major hazard to human health due to the wastes at the site is assumed to be the toxicity of dioxin (TCDD); for simplicity, only this hazard is considered. An "exposure" is considered to occur whenever a person comes directly in contact with TCDD in high enough concentrations that the dose of TCDD to his body exceeds an assumed safe level, which is taken to be 1 part per trillion (ppt) of body weight. The level of effect, that is, severity of health impairment, produced in the exposed person by this dose of TCDD cannot easily be predicted, and therefore, the person is counted as potentially subject to some adverse health effect. Depending on the actual magnitude of the dose, which in turn depends on time duration of the contact and other pharmacological factors, the actual level of effect suffered may range from a mild and probably reversible case of chloracne to cancer of the liver.
>
> In order for exposure to TCDD from the trench at the site to occur, a certain amount of TCDD must escape from the trench, spread from the site via some physical environmental pathway and ultimately enter the human body directly. An effort has been made to systmatically consider all possible pathways and to identify those exposure scenarios which are most credible for four alternative actions."[1]

At this point, the contractor made two assumptions upon which his analysis was based: (1) since human risk to TCDD cannot be quantitatively determined, any exposure has negative impact and that impact is simply measurable by counting the number of people potentially exposed to any amount of TCDD from the site, and, (2) the probability of exposure scenarios and the number of people potentially exposed could be estimated.

Table 1 summarizes the scenarios which were considered, the estimated probability of occurrence and the maximum number of people exposed, as well as approximate costs of each alternative over five years. The exposure estimates are worst-case estimates. Table 2 summarizes the data, and shows the results of the expected risk computations in the last three columns, i.e., the maximum number of people exposed multiplied by the probability of occurrence of possible events. Alternative 3, the most expensive, turns out to have the lowest expected risk, but only by a very small difference at the third significant figure. The rest of the report delineates the design criteria necessary for a facility to satisfy this alternative. It is obviously not the cost-effective alternative; but, is it the lowest risk alternative? Since both the probability and consequence estimates were only very rough estimates, the results of this approach do not provide very satisfactory answers.

The difficulty with this approach is that all the errors aggregate along with the basic data; since they are large and, to great extent, multiplicative, they dominate the analysis. This same kind of problem exists in all bottom up analyses, especially those using fault and event tree approaches to probabilistic risk analysis.

Top-Down Analysis For A Hazardous Waste Decision

One cannot do a total, in-depth top-down or bottom-up risk analysis for the same problem -- at least in the cases studied thus far. If a bottom-up analysis has already been done, the top-down analysis looks like second guessing (after all the data has been gathered). In reality this happens; in fact, the analysis undertaken

TABLE 1

ABBREVIATED SUMMARY OF CREDIBLE EXPOSURE SCENARIOS

Alternative Action (Cost Estimate)	Exposure Scenario	Estimates of Probability of Occurrence	Maximum Number of People Exposed
1. Leave buried ($1,000)	A. Sinkhole - contents of 150 drums to ground water	0.01	1,446 pop.-4.3 miles of site
	B. No sinkhole - gradual leak to ground water	0.90	119 pop.-1.2 miles of site
2. Leave buried Install and maintain monitoring system for ground water ($10,000)	A. Monitoring systems works for both cases above	0.98	0
	B. System fails	0.03	379 - sinkhole 119 - leak
3. Excavate and store on site ($2,500,000)	A. Common accident	0.20	2 - 3 workers
	B. Tornado strikes during operation	3×10^{-5}	50
	C. Leach of residuals after removal	.95	0
	D. Sinkhole effect on residuals	0.04	67
	E. Worker contaminated by human failure	0.025	40 workers 120 off-site
4. Excavate and Transport ($1,500,000)	A. Same as A-E above for alternative 3		
	B. Truck accident on road	3.5×10^{-7}	1 - 2 workers
	C. Truck accident at facility	3.5×10^{-7}	10 workers

TABLE 2

SUMMARY OF ESTIMATED RISKS
MAXIMUM AND AVERAGE NUMBERS OF PEOPLE EXPOSED TO DANGEROUS CONCENTRATIONS OF TCDD

Alternative Remedial Action	During Short Term: Workers on site	During Short Term: Public off site	During Long Term: Workers on site	During Long Term: Public off site	Total on site	Total off site	Combined Total exposures
1. Leave buried	0	1446 max 14.46 ave	0	119 max 107.10 ave	0	121.6 ave	121.6 ave
2. Install & maintain a groundwater monitoring system	0	379 max 0.13 ave	0	119 max 53.55 ave	0	53.7 ave	53.7 ave
3. Excavate & store material on site	43 max 20.6 ave	170 max 25 ave	0	67 max 2.7 ave	20 ave	27.7 ave	48.3 ave
4. Excavate + transport drums via truck to Syntex facility in Verona, Mo.	45 max 21.0 ave	180 max 25 ave	0	67 max 2.7 ave	21.0 ave	27.7 ave	48.7 ave

a "Average" is the maximum number multiplied by the estimated probability of occurrence; see Table B-2

b "Dangerous" means high enough to lead to a dose of 1 ppt or greater in the average human body; in drinking water, this threshold concentration is 0.035 ppb.

c "Short term" means during excavation period, approximately 1 month.

d "Long term" means greater than 1 year (assumes no other future actions are taken which lead to increased worker exposures).

above was reanalyzed by an informal top-down analysis, which led to the rejection of the chosen alternative and the adoption of a totally different strategy. However, this would not serve to introduce the top-down approach. In cases where a top-down approach is initially undertaken, there is no need to gather all the data and then do a bottom-up analysis. Thus, the case presented here is merely to introduce and illustrate the top-down approach, not to compare the two methods.

This case involves a large chemical company which produces hazardous waste, and which must find the means to dispose of these wastes in order to keep their primary production processes in operation. Neither the Environmental Protection Agency (EPA), nor local authorities with jurisdiction over land fills and land farms, have issued new commercial hazardous waste site permits for several years. The existing capacity, as it is used up by the large number of waste disposers, can result in large cost escalations for using the remaining capacity. Moreover, liability for failure of hazardous waste facilities, under the Resource Conservation and Recovery Act (RCRA), make all participants in a site liable for environmental and health impacts for disposal system failures, regardless of how much and what kind of waste a particular disposing organization committed to the disposal site. Other details will be brought out in the discussion.

Top-Down Risk Analysis Procedure

Table 3 lists the procedural steps necessary to undertake a top-down risk analysis and Figure 1 provides a diagrammic view of this process. Each step will be explained in reference to the above-mentioned problem.

Step 1: Identify a Minimum Set of Critical Variables — Initially, five critical variables were identified: regulatory climate for obtaining permits, cost, environmental damage and liability, work stoppage and strike potential, and transportation. The last two were found to be of lesser importance, and were omitted in the minimization process.

Step 2: Provide Gross Scales for these Variables -- Scales of high, medium and low were used, and the meaning of each classification is shown in Appendix 1, but summarized in Table 4.

Step 3: Generate a Set of Scenarios from the Combination of the Intersections of the Variable Conditions -- There are three variables, each with three levels of value, leading to 27 separate scenarios.

TABLE 3

TOP-DOWN RISK ANALYSIS
PROCEDURAL STEPS

1. IDENTIFY A MINIMUM SET OF CRITICAL VARIABLES
2. PROVIDE GROSS SCALES FOR THESE VARIABLES
3. GENERATE A SET OF COMBINATION SCENARIOS OF THE INTERSECTIONS OF THE VARIABLE CONDITIONS
4. DEVELOP A SET OF ALTERNATIVE STRATEGIES FOR SOLUTION AND A PROBLEM STRUCTURE
5. IDENTIFY THE CRITICAL DECISION MAKERS
6. HAVE EACH (OR GROUP OF) DECISION-MAKER DETERMINE HIS CHOICE OF ALTERNATIVES FOR EACH SCENARIO OR NEEDED INFORMATION TO MAKE A CHOICE
7. IDENTIFY SCENARIOS IN WHICH DECISION-MAKERS:
   A. ALL AGREE AS TO SELECTION OF ALTERNATIVES
   B. HAVE IRRESOLVABLE CONFLICTS
   C. REQUIRE FURTHER INFORMATION
8. FIND MEANS TO RESOLVE CONFLICTS, IF POSSIBLE. IF NOT, STOP
9. SPECIFY AND CONDUCT REQUIRED STUDIES TO OBTAIN REQUIRED INFORMATION
   - WHAT INFORMATION
   - LEVEL OF PRECISION REQUIRED
   - DECISION POINT - IF KNOWN
10. ANALYZE THE RESULTS.

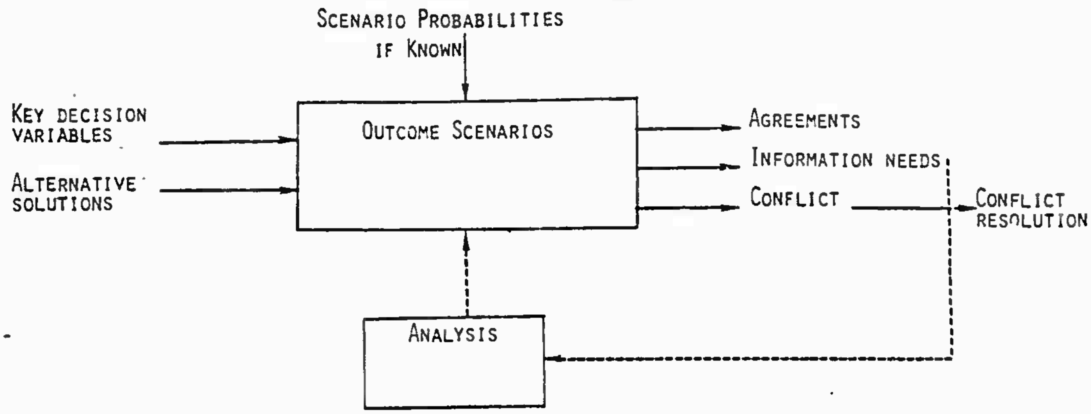

FIGURE 1. DIAGRAMMIC VIEW OF TOP-DOWN RISK ANALYSIS PROCESS.

TABLE 4

SUMMARY OF SCENARIOS

SCENARIO	OWNERSHIP	TECHNOLOGY	
1. A,a,i	Company	HT	
2. A,a,ii	Company	UND (Cost vs Liability Study)	
3. A,a,iii	Company	LF	
4. B,a,i	Company	HT	
5. B,a,ii	Company	UND (Cost vs. Liability Study)	
6. B,a,iii	Company	LF	
7. C,a,i	Company	HT	
8. C,a,ii	Company	HT	
9. C,a,iii	Company	HT	
10. A,c,i	Company	(Cost vs. Liability Study)	
11. A,c,ii	Off-site	LF	
12. A,c,iii	Off-site	LF	
13. A,b,i	Company	UND (Cost vs. Liability Study)	
14. A,b,ii	Company	LF	
15. A,b,iii	Company	LF	
16. B,b,i	Company	UND (Cost vs. Liability Study)	
17. B,b,ii	Company	LF	
18. B,b,iii	Undecided	LF	
19. B,c,i	Company	UND	
20. B,c,ii	Off-site	LF	
21. B,c,iii	Off-site	LF	
22. C,b,i	Company/Off-site	HT/LF	Difficult to get permit
23. C,b,ii	Off-site	LF	
24. C,b,iii	Off-site	LF	vs.
25. C,c,i			Value of continuity
26. C,c,ii			
27. C,c,iii			

This combinational problem requires that the number of assigned variables and values be kept low. Scenarios were developed for each combination, for which three were trivial and eliminated. The scenarios are short descriptions of the outcome, and only two are reported here to provide illustration -- the rest are not included here because of lack of space. Note, that at this step, likelihoods of occurrence have not been assigned to the scenarios.

Scenario 1: Optimistic Regulatory Climate, High Cost Escalation, High Environmental Impact - A,a,i

The regulatory system has stabilized and permits are obtained with reasonable effort. However, existing capacity for the next five to 10 years is inadequate, causing contractors to raise disposal costs at very high levels of escalation. Moreover, the management of these facilities has been less than adequate, and major site leaks can be expected to occur at one or more sites involving wastes which may not be the company's, but which are, nevertheless, indistinguishable. Thus, the company could share in liabilities resulting in temporary and/or permanent closure. The fact that permits are easy to get that, in the long run, competition will make adequate capacity available at reasonable costs. The timing of such availability in the proper locations is a key issue which must be compared to the amortization period for any company-owned facility. In either case, the potential for high environmental impact by land fill makes the high technology operation attractive on its own.

Critical Factors:

- Years to high capacity, competitive contractors availability vs. amortization period of high technology investment.
- Cost escalation factor and estimate of potential liability vs. cost of high technology alternative.

Scenario 2: Optimistic Regulatory Climate, High Cost Escalation, Medium Environmental Impact - A,a,ii

This scenario is similar to Scenario 1, except that the environmental impact and attendant liability is greatly reduced. The high cost escalation in the short run makes contractor ownership unattractive and the company can obtain permits for their own land fills.

Critical Factors:

- Increased cost of high technology operation vs. land fills must be compared to cost escalation factors and potential liability of medium environmental impact.

The company ownership decision is also dependent on the years to high capacity, and competitive contractors availability vs. the amortization period.

Step 4: Develop a Set of Alternative Strategies for Solution and a Problem Structure -- The following three alternative strategies have been proposed:

1. High Technology Facility - HT
   On-site
   Objective: Maximize destruction of waste
   Incinerator and other processes
   Minimum land disposal
   High investment
   Company owned and operated

2. Off-Site Disposal (current) - LF Off-site
   Land intensive
   Off-site
   Land farming -- land fill
   Low investment
   Contracted

3. Company Land-based System - LF
   Company-owned
   Land intensive
   On-site
   Company operated and owned
   Incinerate some wastes

The problem is basically a sequence of two decisions plus some contingency alternatives in the face of uncertainty in several critical, uncontrolled states of the regulatory environment.

Decision Level One: Use contractor waste facilities or develop and operate company-owned facilities.

Decision Level Two: If the company develops and operates its own facility, should it be a land fill operation or a high technology operation?

Contingency Alternatives

1. Level One: Contractor Facility --Should the company develop a land fill site for use as a contingency if contractor operations are to be interrrupted?

2. Level Two: Company-owned Land Fill Operation -- How many such sites are there, and

where should they be located?

3. Level Two: Company-owned High Technology Operation — What kind of technology, capacity, and location is required? Should remaining land fill needs be fulfilled by the company on-site, by a contractor, or by some combination of these?

This decision problem is illustrated in Figure 2. It should be noted that Level 1 and Level 2 decisions are not totally decoupled since the cost of technology, and its performance capability at Level 2, affects the choice of Level 1, i.e., the choice between contractor or company ownership.

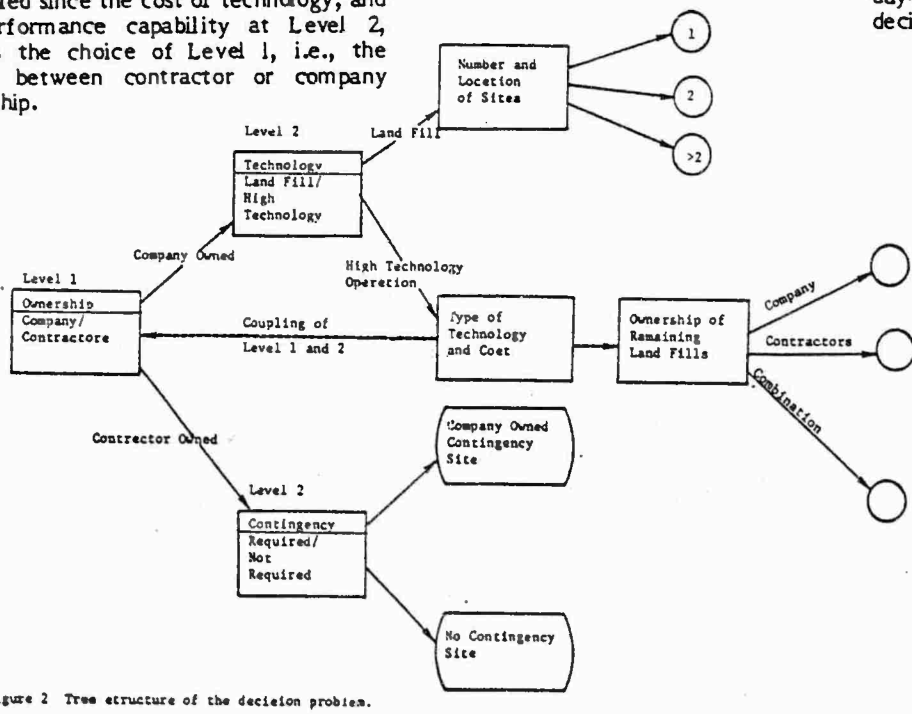

Figure 2 Tree structure of the decision problem.

Step 5: Identify the Decision Makers — There are many decision makers, but the division manager will make the final judgment. The array of decision-makers are as follows:

Division Manager	Final decision responsibility
Production Management	Need for continuity of capacity
Engineering Management	Design of on-site waste facilities and hazardous waste stream identification
Environmental Department	Environmental requirements and relations with Federal, state and local agencies
Legal Department	Liability and legal ramifications
Risk Analysis Team	Team responsible for conducting the analysis and making day-to-day decisions

Step 6: Have each (or group of) decision maker determine his choice of alternatives for each scenario or the information required in order to make a choice. The results of this effort are shown in Table 4 for each of the 27 scenarios. Each scenario is assigned a number in column 1, identified by the coded combinations as shown in column 2. Column 3 shows the ownership decision, column 4, the technology decision or information required to make the decision.

Step 7: Identify Scenarios in which Decision-Makers: (a) all agree as to the selection of alternatives; (b) have irresolvable value conflicts; (c) require further information. In this case, no conflicting situations were found which could not be resolved; however, two studies (a cost vs. liability study and permit difficulty vs. value of continuity study) were identified for the undecided cases, UND, for the technology decision. The one undecided case for the ownership decision is only for landfills and is a lower level decision.

Step 8: Find Means to Resolve Value Conflicts — There were no value conflicts which could not be resolved in order to select the preferred alternative for a given scenario, except for the outcome of the two studies to be conducted. Some unresolvable conflicts can be eliminated if the probablity for a scenario, where a conflict exists, is so low as to be of little concern. The probability of a scenario depends upon the joint probability of each value for each scale. Approximate probability classes are usually adequate for this purpose as long as the participants in making assignments understand and agree on the meaning of such assignments (precision of the scale), although the choice of values may differ (accuracy of the measurement). Classes and probability values might be assigned as follows:

Value Assignment	Probability Range	Probability Value Used
High	0.8-1.00	0.9
Moderate	0.2-0.8	0.5
Low	0.01-0.2	0.1
Very Low	Less than 0.1	0.01

The joint probability of the values of the critical parameters are found by multiplying the three values together, one for each parameter, to obtain the probability of the scenario. Probabilities less than one in a thousand, with respect to the highest probability scenario, might be considered insignificant (if the consequences are catastrophic even, lower probabilities should be considered). Note: in the top-down approach, this is the only method in which probabilities are used, i.e., the probability of a scenario occurring.

If unresolvable value conflicts survive at this stage, no further technical studies will aid in resolving the conflict. A decision involving political power is the only way to resolve such issues.

Step 9: Specify and Conduct Studies to Obtain Required Information — Two studies, described in Step 7, must be specified, and then carried out. In each case, the required information must be identified, as well as the level of precision of the required information, and the decision point, if it is known.

Cost vs. Liability Study — Since the high technology option involves higher capital and operating costs than the lowest technolgy options, these costs must be offset by a significant reduction in liability. It was determined that engineering estimates for capital and operating costs only had to be precise to one significant figure, and that time discounting of money flow was not required. The cost estimates for contractor facilities are already provided in the parameter scales (shown in Appendix 1). Using similar cases and trends, the legal department made estimates of possible levels of liability for a range of impacts for each alternative. These estimates were only necessary to an order of magnitude of one significant figure for very large sums of money. In addition, the legal department made a relative risk estimate of the likelihood of liability claims from each alternative to about one order of magnitude. No decision points were developed for this study, except to express the scarcity of capital funds.

Difficulty of Getting a Permit vs. Value of Continuity Study — This was a two-part study aimed at how long the production operation could run if no land fill capacity was available, and what short term fixes could be undertaken, such as interim permits or special appeals. These studies were strategic, rather than tactical, and were, except for the production run time to shutdown, qualitative in nature.

Step 10: Analyze the Results — The results of these studies are then added to the analysis. The format for the results of the cost vs. liability study is shown in Table 5. This is then used to perform an indifference analysis as shown in Table 6. This indifference analysis shows the probability balance point where the actual estimate of probability of scenario occurrence is compared, leading to a choice of one scenario over the other. The indifference probability is the calculated decision point as opposed to the specified decision point (if it is specified *a priori*).

In addition, the relative likelihood of costs and libilities can be found, as shown in Table 7. Note that the numeric results of the analysis are not given, since the actual values used were proprietary. A similar, but abbreviated analysis, was conducted for the second, yet qualitative study.

All the surviving scenarios are then grouped by the three alternatives, and the sum of the probabilities of the scenarios leading to each alternative is determined.

This is the probability of selecting that alternative and having made the right decision. A "what if" analysis, as shown in Table 8, can then be used to determine the cost of being wrong. The decision is made by maximizing the correctness and minimizing the cost of being wrong. A dominant solution is one whose probability of being correct is higher and whose cost of being wrong is lower than another alternative, which is dominant. For the case involving multiple dominant strategies, the propensity for risk of the decision maker can be considered in terms of minimax or maximin choices.

TABLE 5

ANALYSIS 1

COSTS AND ENVIRONMENTAL LIABILITY

ALTERNATIVES	COST PROJECTIONS			SIZE OF LIABILITY			PROBABILITY OF ENVIRONMENTAL DAMAGE
	High	Mod	Low	High	Mod	Low	
Company - Land Fill	C_{11}	C_{12}	C_{13}	L_{11}	L_{12}	L_{13}	P_1
Company - Land Farm	C_{21}	C_{22}	C_{23}	L_{21}	L_{22}	L_{23}	P_2
Company - Incinerator	C_{31}	C_{32}	C_{33}	L_{31}	L_{32}	L_{33}	P_3
Contractor - Land Fill	C_{41}	C_{42}	C_{43}	L_{41}	L_{42}	L_{43}	P_4

Costs and Liabilities are Over the Operating Life of the Facilities - Liabilities Can Extend Further.

TABLE 5

STEP 1 INDIFFERENCE ANALYSIS 1 (CONTINUED)

P_4 IS THE PROBABILITY OF DAMAGE CLAIMS OF A CONTRACTOR LANDFILL OVER ITS LIFE. WE DO NOT KNOW THE VALUE OF P_4 EXACTLY. WE DO HAVE SOME ESTIMATES OF RELATIVE RISK OF THE OTHER OPTIONS IN RELATION TO P_4, I.E.,

$P_1 = A_1P_4$ — A_1 IS THE RELATIVE IMPROVEMENT IN RELIABILITY DUE TO COMPANY TOTAL CONTROL OVER A LAND FILL.

$P_2 = A_2P_1$

$P_3 = A_3P_2$ — A_2 IS THE RELATIVE IMPROVEMENT IN RELIABILITY OF A LAND FARM OVER A LAND FILL.

$P_1 = A_1P_4 = A_{14}P_4$ — A_3 IS THE IMPROVEMENT OF AN INCINERATOR OVER A LAND FARM.

$P_2 = A_1A_2P_4 = A_{24}P_4$

$P_3 = A_1A_2A_3P_4 = A_{34}P_4$

THE INDIFFERENCE PROBABILITY IS FOUND BY TAKING ANY TWO OPTIONS AND $C_{IJ} + P_IL_{IJ} = C_{KL} + P_KL_{KL}$

(NOTE: P_4 MUST ALWAYS BE POSITIVE, I.E., HIGHER COST CASES MUST HAVE LOWER LIABILITY EXPECTATION.)

THIS CAN BE SOLVED FOR ALL COMBINATIONS OF COST AND LIABILITIES TO FIND THE RANGE OF DECISION VALUES OF P_4 FOR EACH COMBINATION OF ALTERNATIVES, I.E., NINE CONDITIONS FOR EACH COMPARISON OF ALTERNATIVES.

TABLE 7

STEP 2 <u>RELATIVE LIKELIHOOD OF COSTS AND LIABILITIES</u> ANALYSIS (CONTINUED)

IF INFORMATION ON THE RELATIVE LIKELIHOOD OF COSTS ARE AVAILABLE, THEN AN AVERAGE COST CALCULATION COULD BE TRIED.

$$C_I = B_{I1}C_{I1} + B_{I2}C_{I2} + B_{I3}C_{I3} \text{ WHERE } B_{I1} + B_{I2} + B_{I3} = 1$$

A SECOND METHOD IS TO ORDER THE NINE CALCULATIONS IN ORDER OF THEIR RELATIVE LIKELIHOOD WITH A CALCULATION BESIDE EACH SHOWING THE RELATIVE LIKELIHOOD.

THIS CAN ALSO BE DONE FOR LIABILITIES, SUCH THAT

$$L_I = c_{I1}L_{I1} + c_{I2}L_{I2} + c_{I3}L_{I3} \text{ WHERE } c_{I1} + c_{I2} + c_{I3} = 1$$

THEN, WHEN ORDERED BY RELATIVE LIKELIHOOD, THE ORDER IS CALCULATED BY $B_{IJ}c_{KL}$.

TABLE 8

ANALYSIS 3

WHAT IF? ANALYSIS

THE COSTS OR OPPORTUNITIES INVOLVED IN SELECTING AN ALTERNATIVE I BASED UPON MORE FAVORABLE CONDITIONS FOR ALTERNATIVE, K (SEE ANALYSIS 1).

$$WIC_{IK,JL} = C_{IJ} - C_{KL} - (L_{KL} - L_{IJ}) + \text{OTHER COSTS, IF ANY.}$$

THERE ARE NO PROBABILITIES INVOLVED SINCE THE SCENARIO HAPPENS.

THERE ARE 9 x 6 = 54 SUCH COMBINATIONS. BUT, ONLY THOSE COMBINATIONS MADE FEASIBLE BY A CHANGE IN REGULATORY CLIMATE OR SITING CLIMATE SHOULD BE INVESTIGATED. MOREOVER, AFTER A SPECIFIC ALTERNATIVE IS CHOSEN, THE WHAT IFS REDUCE TO 9 x 3 = 27.

In each case, the studies which were undertaken were relatively imprecise estimates made by knowledgeable personnel with a minimum of expended resources for acquiring data. The subsequent manipulation of the data was to extract the maximum available information from it. The indifference analysis provided the decision point where the probability estimates of scenarios could be ascertained. Emerging dominant strategies force a decision. In other cases, the final choice, involving the propensity for risk of the decision maker, is presented in decision-making terms which decision makers at all levels can understand.

The dominant feature of the approach is to focus, very early, on the critcal decision factors and only obtain bottom-up type data for the UND conditions to a limited level of precision and a limited data gathering effort. The use and manipulation of data for maximum information for the decision is stressed rather than acquiring data before its utility in the decision process is ascertained. Gathering precise data is expensive, manipulating small amounts of imprecise data is not.

A major advantage of the approach is that it forces the decision analyst to communicate with the decision participants in mutually understandable language. This is accomplished by developing understandable, mutually exclusive and collectively exhaustive, and descriptive, scale values, outcome scenarios, alternatives, and probability assignments. This process is built in, and may be the most useful aspect of the approach

On the other hand, the process is designed for organizations whose various facets have the same objectives yet different perspectives on how best to achieve these objectives. The identification of conflicts for outcome scenarios can otherwise bring out hidden agendas. For organizations which have goal conflicts and internecine antagonisms, this process might be quite upsetting.

Use of the Top Down Approach in the Defense Department Acquisition Process

Because the process is top-down, its use must be made in the same manner, i.e., starting from the top. It will best be used at the beginning of the acqusition in order to determine performance, cost, and schedule requirements for all users, many of whom may have conflicting requirements (as opposed to conflicting agendas). Conflicting requirements can be evidenced by developing scenarios for different outcomes of performance level, schedule and cost combinations, and a range of alternatives. Conflicting agendas may become visible, and this may either help to provide compromises or exacerbate the situation.

The top-down approach promises a better rapport between the users, decision analyst, and decision makers. This promise can only be ascertained by attempting to use it on several tests or real cases.

Footnotes

[1] "Technical Study and Remedial Action for Denny Farm Site 1, Aurora, Missouri" (Final Report), Document No.: EFSR80-09-0105, TDD: F7-8006-01, EPA Contract No.: 68-01-6056, Ecology and Environment, Inc., September 15, 1980, p B-1.

APPENDIX I

MEANING OF VALUE ASSIGNMENTS TO CRITICAL VARIABLES

1. THE REGULATORY CLIMATE FOR ALLOWING PERMITS FOR HAZARDOUS WASTE SITES

The Environmental Protection Agency, under RCRA, is responsible for permitting hazardous waste disposal sites. This, in turn, can be modified by state and local regulations and pressures. Three different scenarios exist for alternate regulatory conditions in the future. At the present time, the outlook for permits is very confusing and obtaining permits is very difficult. EPA is in a transition status and a permitting program with definitive criteria does not yet exist. Obtaining new permits under the present case is either difficult or non-existent.

CASE A: Optimistic Outlook
EPA comes out, in the very near future, with reasonable regulations and criteria for obtaining permits for hazardous waste sites. The criteria may be exacting and sometimes difficult to achieve, but the means for meeting the criteria are unambiguous and straightforward and, when met, permits are issued. Permitting could even be easier to obtain than indicated above, i.e., the climate could be even more optimistic, but this would not have much affect on the decision criteria here.

CASE B: Less Pessimistic Outlook
EPA regulations on permits and criteria for obtaining permits are issued, but the means for meeting the criteria are ambiguous, hard to predict, lengthy, and unduly subject to public and other pressures. Permits can be obtained, but the predictability of when, and under what conditions, permits are issued is uncertain. However, the regulatory climate is improved over the present situation.

CASE C: Pessimistic Outlook
The present situation continues. Permits are nearly impossible to obtain and the confused conditions remain, at least, for the next few years.

2. COST ESCALATION OF CONTRACTOR DISPOSAL FEES

Contractor disposal fees are bound to escalate when there is inadequate capacity for disposal, such as at present. Unless the disposal field becomes intensively competitive for wastes of the type the company produces, it is unlikely that contractor costs for disposal will be reduced.

CASE a: High Cost Escalation
Costs of disposal escalate at rates which are increasing fast enough to offset the investment costs in the high technology operation. At the present status of this study, the investment and operating costs have not yet been ascertained, nor are the present escalation rates greater than 50% per year. However, this scenario accepts that upon completion of cost studies escalation will exceed the high technology investment costs, making such investment feasible on an economic basis alone.

CASE b: Moderate Cost Escalation
The costs escalate at a rate more than enough to offset the costs of investment and operation for a company land fill operation (cost yet to be determined), but not nearly enough to offset the high technology case.

CASE C: Low Cost Escalation
The costs escalate at or near the inflation rate. This is quite different than present trends.

3. ENVIRONMENTAL DAMAGE AND LIABILITY

Whether at a contractor site or a company site, accidents or leaks occur requiring remedial action, fines, and/or liability claims.

CASE i: High Environmental Impact Occurs
A major off-site leak or accident occurs which represents a serious departure from requirements. Costly remedial actions, fines, and liability for the off-site public may be involved. In addition, negative publicity may affect corporate image and may result in site closure or restrictions.

CASE ii: Moderate Environmental Impact Occurs
Leaks and accidents occur on-site with minor off-site problems. Remedial actions may be necessary and fines may be levied, but liability would be minimal. Adverse publicity and pressures on site operation might occur.

CASE iii: Negligible Environmental Impact Occurs
The site performs to requirements and all accidents and leaks are retained on-site, using normal procedures. Problems occur, but are within the normal scope of operations.

4. SITE CLOSURE SUSCEPTIBILITY

This variable is important, but only becomes critical after the first three variables have been determined. There are two cases: susceptible and less susceptible. Some of the reasons for closure are regulatory changes, loss of permit, strikes, public pressure for closure, and capacity limit reached. For each of these reasons the choices of Level 1 and 2 decisions become more or less susceptible to closure. Only differences among alternatives need be considered.

5. TRANSPORTATION OF WASTES

Transportation of wastes, some of which may be hazardous, becomes a problem in only two respects: (1) interruption of transportation by state or local governments, strikes, etc., and (2) long distances to travel which provide exposure for accidents and higher transportation costs. The basis of the transportation decision factors is whether there are single or multiple waste sites and their locations. The comparative transportation problem is made by comparing the distances and routes among the technical alternatives and determining the relative differences in distance and localities and state lines crossed. The risks of transport per mile are low, but can be assessed as an additional parameter for consideration as will the costs.

SUCCESSFUL ACQUISITION RISK MANAGEMENT: A CONCEPT

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ABSTRACT

Risk analysis is a mathematical field based in gambling, investments and certain types of insurance (life, health and accident.) Attempts to adapt analogous rationales and analytic methods to public and environmental safety issues with risky technological projects like dams, nuclear power plants and marine shipments of hazardous substances have sometimes been of dubious value. The author, based on experience in maritime safety/pollution risk analysis, has recently been advocating a shift from a focus on risk assessment and risk acceptance analysis towards risk management. The purpose of this paper is to adapt that same reasoning to acquisition risk analysis. It may or may not be true that some acquisition risk analysis studies are misdirected at non-existent decisions or at decisions that do not depend on the degree of risk. Similarly, it may or may not be true that some acquisition risk managers fail to realize their true and productive role in the risk management process. Finally, it is possible that the Deming management philosophy underlying his quality control conepts can be adapted to aid more effective DoD systems acquisition risk management.

INTRODUCTION

Risk is one of those brief, everyday words which is convenient because it is widely and commonly understood. That very convenience is dangerous, however, because it relies on imprecision.

Risk most commonly refers to personal danger and the taking of chaces with personal safety. There is personal risk in skiing, hang gliding and race driving which may be compensated only by the accompanying thrill or sense of accomplishment. There is for many an exquisitely heightened perception of risk, with little real risk, in riding roller coasters. Risk frequently includes the connotation of an unnecessary danger, as in trying to jump a motorcycle over a canyon, involving an apparent chance of a sudden and spectacular death. That association leads to a common popular impression that risky ventures are unnecessary and careless.

For many centuries, maritime commerce was considered risky due to the hazards of the sea, storms and pirates. The economic concept of risk most probably arose in maritime insurance, wherein dangers to the safety of ships, goods, and crews were compensated by money from a fund set aside from the profits of several risky ventures. As in the 1600's, today's maritime insurance underwriters do not rely on mathematical or statistical risk analysis to decide on the acceptability and premiums for hull insurance. Instead, they consider the specific vessel, its seaworthiness, its management, its registry, trade and crew.

Other types of insurance lend themselves to risk analytic (actuarial) methods, such as life, health, auto and accident insurance. In such cases, there are very large, fairly homogeneous populations of insureds which display stable patterns of loss experience over time.

Risk management in insurance generally means diversification of risks geographically, by age and sex of insured and by type of insurance to minimize the chances of catastrophic loss experience in a single year. For large, single risks, such as a chemical ship or a nuclear power plant, the risks are managed by spreading them over numerous underwriters.

Having moved from a concept of danger to life and health to one of compensating the loss of life or health with money, it is but a small step to view risk in purely economic terms. In gambling, one risks some amount of money in the hope of obtaining more money, but with a generally greater chance of losing some or all of the amount ventured on any single "play." This context also contributes to the notion that risk-taking is foolhardy.

Similarly to gambling, one can apply risk concepts to investments - in securities, in new plants and equipment, or in new sales territories for an existing product line. These contexts have led to specialized forms of analysis such as portfolio management, utility analysis, and multiattribute decision analysis. Such tools are well suited to situations where there is a single decision-making individual or cohesive group having commensurate utility functions, where the factors bearing on the decision are known and can be systematically described, and where there actually is a definable decision point in time after which the gamble wins or loses, the product succeeds or fails or the insured lives or dies. Systems acquisition cost risk management shares some of the attributes of these economic contexts.

Continuing the leaps of analogy, a person or organization may take a professional, social or political risk by associating with any activity wherein the outcome is not known with certainty. Success of the venture may be presumed to enhance the reputation, career, credibility and attractiveness of the backer whereas failure will have the opposite consequences.

To complete the circle, the taking of political or social risks involves dangers analogous to personal safety dangers in that failures may dramatically affect one's quality of life and one's livelihood. Even worse, in the DoD systems acquisition environment, a backer of a weapons system procurement may later have his/her life (along with many others) at risk in battle, relying on the practical combat effectiveness of the system procured.

Having explored the various informal connotations of risk, let us now turn to risk assessment and risk management issues in weapons systems acquisition.

LIMITATIONS OF SINGLE DECISION RISK ASSESSMENTS

In the context of safety/environmental risk for large technological projects, it has been argued that:

Risk acceptance is a myth.

The estimation methods used are inappropriate.

The risk acceptance concept is inappropriate to the intended decision support.

The decision context often does not exist at all.

"Risk acceptance" decisions are not even theoretically appropriate. (1)

There is no question that appropriate environments do sometimes exist for assessing the technological and/or cost risk of a prospective DoD acquisition to determine whether or not the risk is acceptable. However, the appropriate context does not always exist. The following questions may be useful in determining whether an acquisition risk assessment is worthwhile.

Is there a decision to be made? If the locus (jurisdiction) and timing are well known and the decision options have not been foreclosed, then some form of decision analysis may well be appropriate. There should, however, be some decisiveness to the decision. Tentative, easily modifiable or reversible decisions generally do not justify as extensive or solid analytic support as more definite decisions.

Is risk a factor in the decision? Even if a definite acquisition decision is to be made, the decision may not be greatly influenced by any conceivable value of risk. The decision for the Apollo space program considered technological risk, but it was not a serious factor in the decision. If the Soviets could get a Sputnik into orbit in 1957, by golly, we could surely get a man onto the moon before 1970. The decision issues were philosophical and political. What set of values would prompt us to want to put a man on the moon? Was it appropriate to spend large amounts of the national treasure on a venture with little assured practical value to humanity when there were so many obvious and pressing human needs that could certainly be met by alternative allocations of funds and of scientific and engineering brainpower?

The point is this: not all risky ventures are decided upon on the basis of their risk. If no conceivable outcome of a risk assessment could affect the decision, then why do the risk assessment? If a quick and dirty, even a qualitative, risk estimate is all that is needed, why do an elaborate quantitative analysis?

Systems acquisitions require a certain degree of service, JCS/OSD and Congressional support just to get to the starting line. It can be argued that unless some minimal degree of support is evident, any extensive risk assessment is premature. Conversely, if the political support is absolutely rock solid, that may be because of considerations such as the distribution of probable employment by Congressional district - or some other factors distinct from DoD mission concerns. In such cases, technological risk may play little role in a decision.

Given that there exists a decision context and that "risk" is in some sense a factor that may affect the decision, it does not automatically follow that risk assessment will be helpful. At this point, we have to leave the layman's loose appreciation of risk to consider its scientific meanings. Historically, risk analysis arose out of insurance. It addresses the probability of loss and the magnitude of loss. Within the DoD systems acquisition risk community, however, there is not a widespread adherence to the root meaning of risk. Some analyses address the uncertainty on either side of expected values of time, cost or technical performance. The positive, beneficial possibility is not, in any classical sense, a risk. Other analyses address only the probability of failing to meet a goal, but do not address the consequences. Other studies address only the range of consequences that may occur, but not the likelihoods associated with each. Finally, some of the studies considering a range of possibilities address only the mean estimates or expected values out of a distribution.

Rather than insist that only one definition of risk can be used (a futile pursuit indeed!), it is more pertinent to note that whatever is to be analyzed in a decision risk study ought to be relevant to the decision to be made. Some decisions require high assurance that some boundary of cost, time or performance not be violated, but are then quite insensitive to potential values of that same cost, time or performance measure within the threshold.

If the probabilities associated with various values of cost, time or performance are to be analyzed, several issues should be explored. Is there an appropriate objective measure of the criterion of interest? Must a composite measure be used or will a single measure do the job - thrust-to-weight ratio for an aircraft, for example, rather than simply thrust? Is there some reason to believe that a specific probability distribution applies or should alternative candidate distributions be tested?

If the potential consequences of a decision are to be analyzed, similar considerations apply. Is the measure of consequence appropriately defined? Is a point, interval or distributional estimate desired? Should the probability and consequences be estimated separately with different probability distributions? (In the case of marine oil spills, various researchers have determined that spill frequency is best represented by the negative binomial probability distribution, but that the size of spill, given a spill, can be well described by either a log-normal or a gamma distribution.)

Once the appropriate type and measure of risk to support an analysis have been determined, it is still not assured that a risk assessment will be of any value. Some risks are dominated by their uncertainties. There are cases where risks are uniformly distributed or where the boundary values of greatest interest lie well within a single standard deviation of the mean. In such cases, it is not at all clear that the information produced by a risk assessment will be of any use in the decision. Sometimes a rough estimate can show this to be true, avoiding an elaborate, unproductive analysis.

Finally, let us assume that you have thought out all of the above factors and determined that a decision context does exist, that the decision could be swayed by a sound and elaborate risk estimate, that the apropriate measures and distributions are known, and that the risk is not likely to be dominated by its uncertainties. Is a decision risk assessment now known to be a warranted effort? Not quite.

Even the best justified and soundly prepared risk estimate is subject to misuse. How do you expect the risk estimate to be used? Can it be presented clearly to the decision-maker? Will its use in the overall decision analysis be structured or unstructured? Will the form of the estimate support the structure in which it is to be used? How much of the information relevant to the decision will be passed along to each successive level of command? Regardless of how much relevant information is produced, how much will actually reach the decision-makers? If caveats are vital to the decision input, will they survive the transmittal process? Such questions may be viewed as beyond the purview of the analyst or the staffer who orders a risk assessment but if it is totally foreseeable that the valuable components of a risk assessment product will not enter the decision process what is the justification for the analysis?

One advantage of writing this paper after the workshop was held is that it is feasible to refer to remarks by another speaker. The above comments at the workshop were grounded outside the DoD systems acquisition process. Any fear that they might not be relevant, however, was dispelled by Donald Hurta, who indicated that a great many analyses conducted for decision support fail ever to reach a decision-maker or to be used in a decision. He urged us to consider, as project officers buying such analyses or as performers of such analyses, why we continue to be parties to the generation of unused studies. There are many answers, of course, but there are no comfortable answers.

SUCCESSFUL ACQUISITION RISK MANAGEMENT

Just as there are various criteria that must be met for a risk assessment study to be useful in decision-making, there are also criteria which can help to determine whether formal risk management analysis may be useful.

Above all, one has to define what is wanted in order to manage the risk of not getting what you want. This step is perhaps the hardest of all. Does a systems acquisition have defined requirements? Of course, there is some stated operational requirement in the file, but that may not be relevant to risk management. A requirement is, properly, some criterion that must not be redefined, compromised, violated or ignored. If a criterion were truly a requirement of a procurement, the procurement would be terminated if it became apparent that the criterion would not be met.

A design goal, unlike a requirement, can be compromised or violated if necessary. If a vehicle is desired to have twice the payload, range and reliability of its predecessor but only half the specific fuel consumption, that is unlikely to be a true requirement, whatever wording is used in the documentation. One would have to expect that some compromise would be needed at some point of the acquisition.

Given that a compromise is likely, are there some clear indications of acceptable contingency positions? Are there priorties established for competing criteria? In short, is there sufficient definition of achievable goals to make it plausible that formal analytic support would aid the risk management process?

If the cost risk is to be managed, will it in fact be feasible to "freeze" the design at some point? Will the producer have contractual motivation to stay within cost, be motivated to exceed originally estimated cost, or be motivated to contribute toward the sort of extensive redefinition of the specification that would justify throwing out the cost ceiling?

Given that there is some definitive criterion to manage to, and that a genuine risk of failing to meet that criterion exists, is there a real feasibility of recognizing and accepting the failure early enough to realize a substantial savings? In general, does the managerial discretion exist within the procurement system to allow the risk to be managed?

Given that the requirements, goals, contingencies, and managerial authority exist, is there a defined management team which is properly motivated to monitor and control risk? At times the recognition that a gamble (risk) has been lost or that some realignment of design goals is necessary can be painful to accept. Historically, bearers of bad news have occasionally been shot by their kings. In any specific acquisition, will manager(s) will be rewarded for taking the right action, regardless of what right action may be dictated by the facts of the situation?

Given that properly motivated risk managers exist and are defined, do they have the authority and resources to be administratively capable of sound risk management? Are they in a position to be able to monitor the risk as required to support timely action? Do the risk managers have the necessary training and analystic tools to manage risk?

Given that a capable risk manager is closely monitoring a risky acquisition, are there operational definitions of risk actualization triggers? (Let's paraphrase that.) Risk is a potential for a glitch. How would the manager recognize the glitch if it happened? Are appropriate data gathered? Does the management team know how to analyze and interpret them? Are suitable threshold criteria defined?

Given that manager detects a trigger signal, can he/she select and implement the right actions? Are the actions of each of the other parties helpful or harmful toward the motivation and capabilities of the defined risk managers?

DOERs VERSUS INFLUENCERs

One of the most useful recent insights into (safety) risk management is the recognition that risk managers can be logically divided into two categories: doers versus influencers.

Doers have been defined in marine safety analysis as: first, the ship masters, pilots and watchstanders who have direct hands-on control of the vessel and, secondly, those ship operating company executives off-ship who make available (or fail to make available) the resources and policy options required in the hands-on management of risk.

Influencers are everybody else whose actions or inactions affect the risk. Specifically, in the marine safety case, there are the government authorities who regulate the ships and people, others who provide channel maintenance and aids to navigation, insurers, naval architects and ship equipment designers, shipbuilders, equipment manufacturers, professional societies, labor unions, schools, and anyone else who affects the capability and motivation of the doers toward risk management.

The key point is that only the doers can directly manage risk. Everybody else can only influence the management of risk. To the extent that the influencers think of themselves as direct risk managers, they are likely to be ineffective or, quite possibly, counterproductive. To be effective, they must actively consider the probable impacts of their efforts on the capability and motivation of the doers.

To illustrate the case, bridge structural engineers have recently had to devote explicit consideration to the design of bridges so as to minimize the risk of a ship accidently damaging the bridge. Where such accidents cannot be absolutely prevented (as by placing the supports well clear of the navigable waters) then the role of the bridge designer in managing this risk is to maximize the capability and motivation of the ship master or pilot to manage the risk. This concept is as vital as it is revolutionary.

A parallel has to exist in systems acquisition risk management, but it is not easy to draw the analogy in a workable manner. It may be well to question, however, whether after contract award the doers may not be limited to the prime and subcontractor program managers. If this is true, it has important implications for the government program managers. If DoD program managers are the doers, they should seek to manage the risk directly. If they are influencers, then it becomes important that they not seek to manage the risks directly; they are likely to foul up the efforts of the actual (contractor) doers. Instead, they must act consistently to maximize both the motivation and the capability of the doers to manage risk. Most of that motivation and capability has to be established in the contract, including the risk management resources provided for in the contract.

Before award, there may be a succession of doers at various stages, most likely culminating in the assigned DoD program manager for some period prior to actual award. Even at that stage, however, it will be extremely important for the DoD program manager to so structure the contract and to so influence selecting the contractor that the doer functions will be smoothly and effectively transferred to the contractor after award.

If this analogy has merit, it suggests that the following are all Influencers and should carefully rethink their roles in that light:

-DSARCs

-DoD Program Managers

-Congress

-Writers of Military Standards and Military Specifications

-Professional Societies

-Schools that train the Doers

DEMING's 14 POINTS

W. Edwards Deming is famous for the impact of his approach to the use of quality control statistics on the subsequent growth of Japanese productivity and competitiveness after his methods were introduced. Dr. Deming does not attribute the success to the statistical methods themselves (nor to quality circles and other phenomena which become involved in an applied quality management program.) He views the success of his program as being due to some fundamental realizations and to certain managerial practices. (2) The current author is attempting to develop extensions of the Deming approach outside the basic context. Paratheses are used in this section to distinguish those thoughts from the better established principles of Deming's work.

The fundamental realization must be tha quality and productivity are not in conflic but in harmony, in a properly managed enterprise. The inevitable consequence of lack of quality is waste, and waste is counterproductive.

(It seems logical, then, that Deming's concept could be extended into safety risk management. By analogy, safety and productivity should not be in conflict. Accidents waste time and resources and, if they impact quality, that impact is adverse. Thus, lack of safety is counterproductive. The idea that efforts devoted to safety detract from productivity must be due to faulty management.)

(Having already extended Deming's basic principle somewhat tenuously, can we stretch the analogy even further to acquisition risk management? In the grand view, it seems inevitable. Over a large number of systems acquisitions, the better acquisition risk is controlled, the more productive in terms of DoD mission capability will be the systems acquired. Presumably, this is consistent with having higher quality weapons systems than under conditions wherein acquisition risk is less well managed.)

(It is less apparent how to adapt the Deming principles to the prevention of specific accidents or to the management of risks in a specific systems acquisition.) The reference context in which Deming has worked has been a repetitive industrial production environment where parts and materials purchased from other companies are further processed, packed, shipped and marketed. He has readily extended the applications to bank teller operations and to hospitals.)

(Some of the ways the reader is urged to consider Deming's philosophy is for adaptation to generic guidelines and control systems for DoD systems acquisitions or as a contract requirement, somewhat different from current quality control regulations, to be enforced upon production lines of Defense contractors.)

What distinguishes Deming's approach from other theorists and applications authorities in quality control is the 14 point management schema which Deming insists is necessary to create the conditions under which a quality control program can flourish and be consistent with high productivity. They are summarized briefly here; the reader is encouraged to read reference 2.

1. Long range goals are more important than short range goals. (Keep your eye on what you are really after - effective, affordable national security.)

2. Managements must become less tolerant of waste and "business as usual." (Never mind that Defense contracts may display a stubborn tendency to 109% cost growth; you will not allow it.)

3.-4. Demand and enforce statistical evidence of process quality control in incoming materials; this will reduce the number of contractors willing to deal with you, which is good.

5. Constantly improve the system of production and service; you cannot do this except through statistical monitoring.

6. Modernize training. Use statistical quality control methods to monitor training effectiveness.

7. Improve supervision, mainly by letting the supervisor inform upper management concerning conditions that need correction. Do not allow supervision to mean forcing the staff to work with whatever is available, regardless of how poorly it is suited to the work or how poorly it is maintained.

8. Drive out fear. Especially, let people ask questions without fear of reprisal or humiliation. Let managers not fear to ask workers what the job is and how to tell whether it is being done correctly or not. Let the workers not fear to ask more than three or four times what work is acceptable and what is not. Let a crew not fear to shut down a production line for crucial repairs before a catastrophic failure.

9. Break down barriers to communication between staff areas: operations and maintenance, engineers and technicians, plant personnel and logistical/clerical staff, research, design, recruiting, training, public relations.

10. Eliminate numerical goals. Slogans such as "Zero Defects", "improve productivity", "100 days without a lost time accident", are motherhood goals. Nobody could disagree with them. The problem is that they do not enhance the capability or the motivation of anyone to do a better job. They advertise instead that management does not know <u>how</u> to achieve desirable goals so it is depending on the work force to find some way to do it.

11. Eliminate counterproductive work standards and quotas. For various reasons, it is usually undesirable for a workforce to exceed a quota or even to meet it with ease. For that reason, the quota becomes an upper limit. If management and workers are cooperating to make the system work at its best, why impose an upper limit on the improvement?

12. Allow the staff pride of workmanship by defining quality work measurably and meaningfully and appraising it consistently. People who are rated inconsistently for the same quality of output will retain neither their quality standards nor their pride. Because systems and people are variable, output is variable. Quality, output and productivity can only be meaningful if they are defined statistically and evaluated by consistent statistical methods.

13. Institute a vigorous program of education and training. Everybody's job is changing over time. When statistical quality (and risk) control methods are instituted, that process alone changes all managerial and engineering jobs. Among other training, provide all of these people training in at least the rudimentary statistical methods needed for monitoring and control.

14. Institutionalize the new philosophy so that it gets a continual push. Embedding this concept of quality and risk control is not a one-time effort. Every one of these principles will run out of steam unless the commitment to them is renewed.

THE BOTTOM LINE

Risk management should mean a continuing commitment to the requirements, design goals, costs and schedules in a project. That cannot be directly accomplished by anyone other than the direct operating managers at any acquisition stage. Others can only influence their capability and motivation toward risk control. Risk management must be made consistent with high quality and high productivity. Achieving any or all of these requires that certain management principles be in force. Deming has suggested a set. It is up to us to adapt or replace his set toward defining workable principles for systems acquisition risk management.

REFERENCES

1. Gardenier, John S. "Successful Risk Management: A Concept", Presented on May 28, 1983 at the Annual Meeting of the American Association for the Advancement of Science, Detroit, MI. Publication pending. This paper is a (substantial) adaptation.

2. Deming, W. Edwards Quality, Productivity and Competitive Position (MIT Center for Advanced Engineering Study, 1982)

PANEL SESSION

ON

MANAGEMENT VIEW OF ACQUISITION RISK II

CHAIRMAN

DAVID D. ACKER

DEFENSE SYSTEMS MANAGEMENT COLLEGE

A RISK MANAGEMENT MODEL FOR THE DEFENSE SYSTEM ACQUISITION PROCESS

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ABSTRACT

This paper presents a risk management model that is designed to identify, assess, and manage risk for Defense weapon system acquisitions. The model provides a detailed, disciplined process that establishes baseline definitions, principles for risk management, and diagrams which support the risk management process.

BACKGROUND

Risk management for the DoD system acquisition process is not an exact science. There is no common or standard DoD sanctioned practice, technique, or procedure for identifying, assessing and managing risk. Furthermore, there is no universally accepted definition of risk. The most common form of risk management is to quantify the probability of loss in dollar values, much like the insurance industry. Dollar values, or costs, are only one-third of the risk problem for DoD Project managers. The other two factors are system performance (quality) and schedule (time) for producing the system. Therefore, a valid requirement exists for a disciplined process that will facilitate the uniform treatment of risk variables and allow understanding of risk as it applies to the DoD system acquisition process.

PURPOSE

This paper provides a risk management model that can be used to identify, assess, and manage the risk of the three areas of the system acquisition process -- cost, schedule, and performance. This risk management model was specifically tailored for the full scale engineering development of a major surveillance system.

DEFINITIONS

The introduction of terms that differ from generally accepted definitions is necessary to establish the baseline for the system acquisition risk management model. These terms are defined below.

a. Risk - The resultant product of the probability of failure and the consequence of that failure for any preset goal (expressed in terms of performance, cost, and/or schedule criteria).

b. Probability of Failure - The assessed value of the likelihood of not meeting the goal or criterion for an activity. The probability of failure is best expressed numerically, but may be expressed in qualitative terms. Figure 1 may be used to convert qualitative terms to numeric values.

c. Uncertainty - Insufficient knowledge (information) to assess risk in concrete terms. (Uncertainty is often confused with risk and used incorrectly as a synonym for risk.)

d. Risk Assessment - A comprehensive and disciplined process for assigning factors of risk (probability and consequence of failure) to particular activities; also the product of the foregoing process.

e. Risk Management - Developing and implementing alternate courses of action to reduce factors of risk.

f. Risk Analysis - A procedure for the division of a project into activities and the uniform examination of these elements to determine the probability and consequence of failure; also the product of such a process.

g. Failure Identification - The process of determining areas of probable failure within an activity for subsequent analysis, assessment, and management.

h. Consequence of Failure - The quantifiable loss of money, time or quality resulting from the failure to meet a goal or criterion.

i. Risk Threshold - The upper limit of risk that will be accepted by the project manager for any activity or element of a project.

Order of Likelihood	Qualitative Terms	Adjectival Rating	Chances in 10	Probability/ Percent
Near Certainty of Failure	Virtually (almost) certain We are convinced, Highly probably Highly likely	Very High	9	.99/99 .90/90
Probably Will Fail	Likely We believe We estimate Chances are good It is probable that	High	8 7 6	.60/60
Even Chance of Success or Failure	Chances are slightly better than even Chances are about even Chances are slightly less than even	Medium	5 4	.40/40
Improbable Failure	Probably not Unlikely We believe . . . not	Low	3 2	.10/10
Near Impossibility of Failure	Almost impossible Only a slight chance Highly doubtful	Very Low	1	.01/1

Figure 1. ESTIMATIVE TERMS, DEGREES OF PROBABILITY, AND PERCENTAGES

PRINCIPLES OF RISK MANAGEMENT

Risk management entails a disciplined process that operates within the scope of four major principles.

a. Risk is present in the system acquisition process only when there are established goals, objectives, or criteria.

b. Risk must be assessed on elements, or activities, of the total system acquisition for management of the parts.

c. The risks assigned to elements, or activities, cannot be summed and averaged for risk to the total system acquisition.

d. Uncertainty limits the ability to assess risk (i.e., probability of failure and consequence), but does not increase the risk.

RISK MANAGEMENT MODEL

The risk management model addresses more than the elements of risk, and works in concert with commonly accepted project management practices, procedures and techniques. The model is designed to fit within the current management structure as a complementary tool rather than replacement for or addition to existing techniques. The model uses the outputs from the work breakdown structure and networks such as PERT, CPM or PDM.

Figure 2 depicts the overall diagram of the risk management model. This is a comprehensive overview of the work required to establish the risk identification, assessment, tradeoff activities, and finally, the end management of risk during project implementation. The flow of activity is shown by arrows and lines in a logical

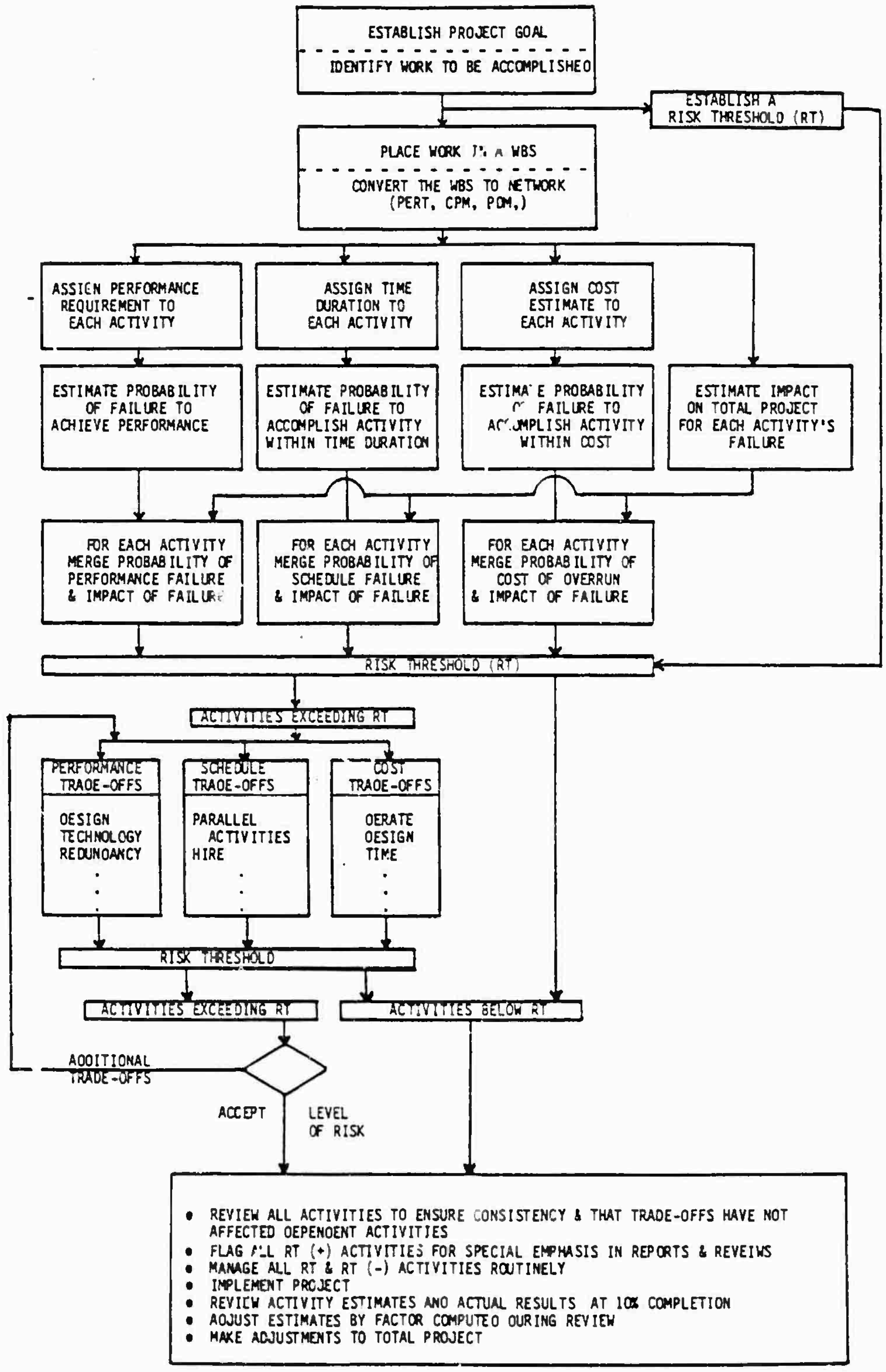

Figure 2. RISK ASSESSMENT DIAGRAM

sequence from top to bottom. The activities are specifically ordered from top to bottom as a natural sequence for addressing each one and to limit biases by establishing thresholds prior to the estimating process. The procedures for using this model are as follows:

Project Goal. The goal of the system acquisition is often stated in the Project Office charter or another document that describes the authority and responsibility of the project manager. If there is no stated goal, one must be developed prior to proceeding. The goal provides the focus for development of subsequent work.

Project Work. Identify all the work to be accomplished from start to finish (with the knowledge that subsequent changes will normally be required). The totality of the identified work, even in large packages, will provide an upper bound for resources required.

Risk Threshold. Before proceeding further, establish the degree of risk that is acceptable for any one activity in cost (money), schedule (time), or performance (quality). This designation of the Risk Threshold (RT) is a predetermined criterion from which all activities will be measured (see Figure 3). It provides a uniform, unbiased standard that will cause acceptance, rejection, or reassessment of activities.

Consequence of Failure	Probability of Failure				
	Very High	High	Medium	Low	Very Low
Very Severe	.9	.8	.7	.6	.5
Severe	.8	.7	.6	.5	.4
Moderate	.7	.6	.5	.4	.3
Little	.6	.5	.4	.3	.2
Very Little	.5	.4	.3	.2	.1

Figure 3. RISK QUANTIFICATION MATRIX

NOTES: (1) The decision to accept or reject any risk is the function of the project manager. The decision may, for example, be made to accept any risk of 0.4 or less without tradeoff studies, and to conduct tradeoffs on all risks greater than 0.4. If tradeoffs cannot reduce the risk to 0.4, then the project would be deferred pending approval of the sponsor.

(2) To determine value (measure of success) for any activity, use the formula of 1 - risk. For example, a very high probability of failure intersecting with a severe consequence is: 1 - 0.8 = 0.2. Thus, the value of this activity is 0.2.

(3) The use of colors may assist in identifying the zones of acceptable, marginally acceptable, and unacceptable risk. Red may be used for 0.7 through 0.9, yellow for 0.4 through 0.6, and green for 0.1 through 0.3.

Activity Number	PERFORMANCE				TIME				COST			
	Assigned Value	Probability of Failure	Consequence of Failure	*Risk Value	Assigned Time	Probability of Failure	Consequence of Failure	*Risk Value	Assigned Cost	Probability of Failure	Consequence of Failure	*Risk Value

Figure 4. SAMPLE VALUE ALLOCATION

*Value derived by using Figure 3 to obtain the intersection of probability of failure and consequence of failure.

Work Packages. The total work is divided into the work packages that represent well defined activities of a work breakdown structure for managerial purposes. MIL-STD-881A should be used as a guide for standardization and to ensure all support items are included.

Network. Convert the work breakdown structure to an interdependent network to place activities in the proper sequential interrelationship. This network, in addition to establishing interrelationships, facilitates the computation of the total time required to complete the project. Another advantage of the network is the capability to predict the start and finish of individual activities.

Allocation of Performance, Time, and Cost. Allocate each activity in the network a performance criterion, a time for completion, and a cost value. These baseline figures for each activity are the values which will be used to assess the probabilities of achieving the individual values. Record the performance, time, and cost values. A format similar to Figure 4 may be used for this purpose.

Probability of Failure for Activities. The values previously assigned for cost, time, and performance are evaluated using Figure 5 and a probability value (number between 0.0 and 1.0) assigned for each area and each activity. The estimative terms of Figure 1 may be helpful in making the evaluation. This evaluation and assignment of probabilities should not be accomplished by the same individual who made the allocation of values. Record the probability of failure data. (See Figure 4.)

Consequences of Failure for Activities. Following the assessment for the probability of failure, a consequence of failure must be derived for each activity. The criterion for consequence of failure is outlined in Figure 6. Record the consequence of failure data (See Figure 4.)

Risk Threshold. Using Figure 3, determine the risk value for performance, time, and cost in each activity by determining the intersection of the probability and consequence of failure. The resultant value can be compared to the Risk Threshold established previously. Each performance, time, and cost for each activity that is equal to or less than the Risk Threshold can be temporarily set aside. Areas of activities that exceed the Risk Threshold must be evaluated for trade-off options.

Probability of Failure Character	Criteria
Very High	- The activity has not been done before. - Technology is not readily available to accomplish the activity. - There is little experience in this type of work.
High	- One or more major portions of the activity have not been done before. - Experienced people are not available to complete most of the activity.
Low	- The activity has been done before. - People are available to complete the activity.
Very Low	- The activity has been done before. - Experienced people are available to complete the activity.

Figure 5. PROBABILITY OF FAILURE

Note: Probability of Failure is the reciprocal of the probability of success.

Consequence Character	Criteria
Very Severe	A failure of an activity, in itself, that will cause the project to be cancelled.
Severe	A failure, in combination with the failure of one or more activities, that will cause the project to be cancelled.
Moderate	A failure, in itself, that will cause a major impact on cost, schedule and/or performance of the system/project.
Little	A failure, in itself, that will cause only a minor impact on cost, schedule and/or performance.
Very Little	A failure, in combination with the failure of one or more activities, that will cause only a minor impact on cost, schedule and/or performance.

Figure 6. CONSEQUENCE OF FAILURE

Trade-Off Options. The trade-off options are too numerous to list. A few examples will serve to highlight selected options and provide the incentive to generate feasible options within the scope and constraints of redesign, new or old technology, or redundancy. Schedule trade-offs could include redesign of the network to permit parallel activities or add more people to the job. Cost trade-offs could include acceptance of less in performance, accept a lesser design, or extend the time required to accomplish an activity. The exact and best trade-off can only be made in context of all resources and limiting factors.

Risk Evaluation. There will be some activities that cannot be reduced to the established Risk Threshold. These activities must be evaluated to determine their impact on the total project. Will the failure of one or more of these activities cause the project to fail? Will the failure of one or more of these activities reduce the system equipment to a non-usable system? Will the failure of one or more of these activities increase the cost to a level unacceptable for production? Will the failure of one or more of these activities extend the engineering development phase by one, two, three or more years? If the answer to any of these questions is yes, a complete reassessment of the project feasibility must be made.

Risk Acceptance and Management. If there is a lesser degree of risk than that outlined in the paragraph above, the Project Manager may decide to accept and intensively manage the high risk activities. This management may include ongoing studies of means to resolve the probability of failure or the consequences of failure for the activity. In addition, periodic reports of high risk activities may be required which would include any progress in the area of risk reduction. As a minimum, an individual should be appointed to monitor and report the risk reduction progress.

SUMMARY

The risk management model provides a disciplined methodology for identifying, assessing, and managing risk. The model is compatible with and complementary to commonly accepted project management techniques. It provides the means for a project manager to uniformly address the risk in a project, to minimize the risk through tradeoffs, and to recognize high-risk activities in the project prior to conduct of the activity. An added benefit of this approach is that the individuals conducting the risk identification and assessment become intimately familiar with the detailed requirements of the project.

ACKNOWLEDGEMENTS

This paper has been developed, updated, and refined over the past three years from ideas and concepts obtained from a variety of sources. Although there are no known direct quotes, three prime sources of ideas or concepts are greatfully acknowledged: Campbell, Robert P., A Guide to Automated Systems Security, Global Printing, Inc., Springfield, VA, 1980; Martin, M.D., Alan J. Rowe, and Harold A. Sherman, Ed. Proceedings Management of Risk and Uncertainty in the Acquisition of Major Programs, USAF Academy, Colorado Springs, CO, February 9-11, 1981; Rowe, William D., An Anatomy of Risk, Wiley-Interscience, 1977.

APPLICATION OF RISK ANALYSIS: RESPONSE FROM A SYSTEMS DIVISION

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ABSTRACT

A review of theoretical literature reveals that most technical aspects of risk analysis have become a reasonably well-defined process with many sophisticated techniques in existence. A major conclusion from this review is, however, that a primary need exists to develop a better understanding of risk analysis in order to enhance its application. Also needed are better tools to enhance use of both subjective judgment and group decision processes. A major concern in using the group decision and consensus building techniques seems to be the need to eliminate undue influence of persuasion, previous expressed opinion, majority opinion and higher level arm twisting. Many researchers suggest training to improve use of available techniques in the hope that it would lead to increased application of risk analysis in the acquisition process.

Responses to a survey questionnaire within an Air Force Systems Command Product Division indicate that very little use is being made of risk analysis and almost no use is being made of the more sophisticated techniques. Over half of the respondents had used PERT, but only one had used VERT, four had used dynamic modeling and three had used causal integrative modeling. Where risk analysis is used it is based mostly on subjective assessment with group rather than individual decisions being used in most work areas. For those surveyed, engineering and program management were the work areas which appeared to provide the most effective input for risk analysis. But, a high level of need exists for risk analysis in both scheduling and cost estimating as well as in engineering and program management. A high level of interest was expressed for formal risk analysis training.

INTRODUCTION

The technical aspects of risk analysis are a fairly well understood process with many sophisticated techniques in existence (1 and 2). Nevertheless, a review of the literature reveals that practical application remains at an almost nonexistent level. Results of a survey on application of risk analysis within an Air Force Systems Division confirm the lack of use of risk analysis and provide some insights into potential areas for increased application.

DESCRIPTION OF TECHNIQUES

A great deal of effort has been devoted to development and understanding of the technical aspects of risk analysis and numerous examples exist of the application of risk analysis to problems of a specific nature and generally within a narrow area of interest. The first category of models is the stochastic/probabilistic group which includes PERT, VERT and a Risk Analysis Model (2, p. 53). The second category is general models. Within this category, parametric cost estimating has been the primary costing methodology for DOD. Dynamic modeling is a third category and is based on a complex system of mathematical models and works well for complex, continuous systems. The last category is the causal integrative model which is used to determine how a change in economic uncertainty affects the level of mission, scope and funding uncertainty.

These above modeling methodologies are fairly well-developed and each of these methodologies has been applied in a limited sense. A primary conclusion is that even though technical aspects have been well-developed, a primary need exists to develop a better understanding of risk analysis in order to enhance application of these methodologies (2). The review of literature indicates that only a limited number of individuals involved in acquisition of major weapons systems have been adequately involved in application of risk analysis.

A corollary need as an important part of the decision process is to develop tools for the use of intuition and subjective judgment (3). Statistical probabilities as limits of relativ frequencies of events and occurrences are usec routinely in risk analysis techniques. But, i many cases, available probabilities are not relevant to a decision process because the dat base is outdated or the current system does nc have a close counterpart upon which to base estimates. Subjective probability then becom the valid concept where probabilities must be formulated from the opinion and experience of experts and specialists.

Certain inputs can only be supplied on a subjective basis by a select group of individual In acquisition this group generally includes engineers, budgeting, pricing, cost estimator buyers, contract personnel and various level of program management. It is generally believed that these subjective judgments are used in almost all cases throughout the acquisition organization. However, documentation on evaluation of the application of group decisions and use of consensus building techniques to develop subjective judgments are almost nonexistent (4).

In order to use group opinion in the estimation process, analysts find themselves faced with the problem of aggregating probability assessments of group opinion. Recent research has clearly demonstrated that groups have repeatedly outperformed individuals at these estimation and assessment tasks. Fischer found general agreement that subjective probability distributions can be substantially improved by aggregating the opinions of a group of experts rather than relying on a single expert (5). Consequently, methodology must be refined for using group opinions as entering estimates in risk and uncertainty analysis.

The combining of individual judgments into a group consensus is a formidable task. Very little information exists anywhere that directly addresses group behavior in certain decision environments such as the acquisition process. Information is available, however, on several behavioral interaction techniques. But the major concern in using these techniques to arrive at a decision is to eliminate undue influence of persuasion, previous expressed opinion, majority opinion, higher level arm twisting, or views of very forceful individuals.

Researchers agree that in order to improve group consensus the training of experts specialists, decisionmakers, and managers at all levels in probabilistic thinking and consensus building could lead to significant improvement in the use of the techniques and the application of risk analysis (6). Not all agree on how to do this task. Assumptions about expertise in a given subject area may not be the important factor in performance of a probabilistic task. Maybe the ability to deal with probabilistic thought is what produces good probabilistic assessments (7).

OVERALL SURVEY RESULTS

In order to evaluate the actual application of risk analysis a survey questionnaire was administered to members of an Air Force Systems Command Product Division. Responses were received from five operational units and represented five primary work areas:

work area	number of responses
engineering	5
budgeting & cost estimating	11
program management & scheduling	10
contracting	9
pricing	5

Of the 40 respondents, 83 percent had received some formal training in statistics and 63 percent had formal training in use of computers. But, only 30 percent had received formal training in risk analysis techniques. There were two major exceptions to these averages. In program management all 10 persons interviewed had training in statistics, 9 had training in use of computers and 7 had training in risk analysis. The opposite was the case for engineering. Four of 5 had training in statistics but only one had training in use of computers and none had training in risk analysis.

Of the many available risk analysis techniques only the program evaluation and review technique (PERT) had been used by a majority of the respondents. Sixty percent had used PERT but not necessarily in their current work area. Of the other techniques, one had used the venture evaluation and review technique (VERT), four had used dynamic modeling and three had used causal integrative modeling. Obvieusly, almost no use is being made of these more sophisticated techniques.

The limited use of the more sophisticated techniques was concentrated in a unit or a work area. In budgeting, two had used causal integrative modeling and one had used dynamic modeling. The four using dynamic modeling were all in an airlift and training group and the three using causal integrative modeling were all in a reconnaissance and warfare unit. The five in pricing had not used any of the listed techniques.

Most respondents thought risk analysis was important to their program areas. Thirty-two percent thought it was very important and an additional 55 percent said it was of average importance. Nevertheless, 45 percent said risk analysis is not being used very much in their program area even though most felt it was important to their area.

Seventy percent of the respondents said the risk analysis which was used in their work area was based on subjective assessment rather than statistical modeling or a combination of the two. All in engineering and most in program management said their risk analysis was based on subjective assessment. Over half said group decisions rather than individual decisions were used to arrive at the subjective assessment.

Sixty-five percent said group decisions rather than individual decisions were used for all risk decisions. Program management and engineering indicated a high level of use of group decision processes such as panels of experts. Sixty-three percent said the program manager generally initiated the group effort. On the other hand, over half of those in pricing said the group process was never used.

Responses on who has influence within group decisions are fairly consistent with the published literature. Only 24 percent said that group decisions depend very much on equal weight of all participants. Over 50 percent said group decisions depend very much on undue influence or persuasion of one or more participants. About 38 percent said group decisions depend very much on each of previous expressed opinion, majority viewpoint and higher level arm twisting. Sixty percent said decisions depend very much on program manager's desires.

An important factor for an educational program is to know how each unit feels about its own input into the risk analysis process as well as feelings about other units' input. Of the total group, 42 percent said engineering provided the most effective input for risk analysis. Another 32 percent said program management provided most effective input. Of those in program management 7 of 10 believed their own areas provided the most effective input. Four of 5 in engineering said engineering had the most effective input. But, 6 of 9 in contracting said engineering had the most effective input. Also only one of 11 in budgeting said budgeting had most effective input.

Training in risk analysis appears to be a key issue for getting increased application in DOD. Most respondents said a high level of need exists for risk analysis in engineering and program management. Overall the split was about even between a high need and a low need for pricing, budgeting and contracting. In individual areas those in program management saw a high need for risk analysis in all areas except pricing and contracting. Those in contracting saw a high need for risk analysis in all areas except budgeting. Those in engineering saw a high need in all areas except contracting. Only in budgeting did they see a low need in their own area as well as in pricing and contracting.

A high level of interest was expressed for formal risk analysis training. Most respondents indicated that education in procedures to aggregate individual preferences and subjective judgments was very much needed. Those in engineering saw little need for education while those in pricing were split on the need: two of five said it was needed very much and three of five said not at all.

Seventy-two percent responded that expertise in subject area was most important in performance of risk assessment and the others thought the ability to deal with probabilistic thought was most important. All in engineering said expertise in subject area and three of five in pricing said ability to deal with probabilistic thought was most important.

WORK AREA OBSERVATIONS

The analysis of specific work areas reveals some interesting observations. In engineering five of five gave average importance (as opposed to very important or not very important) to risk analysis in their area and all indicated a high need for risk analysis in their area. Also, engineering was identified as a most effective input into the process. Yet, three of five in engineering said a low need existed for training in risk analysis and none of the five had used a technique other than PERT nor had they had any training in risk analysis.

In follow-up discussions, engineering work area personnel emphasized the need for a very clear distinction between the traditional risk analysis that is involved in everyday engineering activities and the more recently initiated efforts to develop sophisticated program level risk analysis techniques. In their opinion, risk analysis is already a part of formal engineering courses and engineers already have a sufficient knowledge base to understand the results of any risk assessment that may be necessary as input into activities of their work area. On the other hand, very few engineers have a working knowledge of program-type risk analysis techniques.

The follow-up discussions disclosed a need for a specifically designed course on program-type risk evaluation. The course content would include an evaluation of techniques that had been successfully applied to projects which were similar to the systems command products. The course content should also include suggestions as to whom to contact for program risk evaluation.

Since these particular engineers are working mostly on first time, unique requirements, they all expressed the overriding problem of identifying up-front the big driver items. In their opinion, reliance on experience outweighs use of sophisticated techniques for this important function. Engineers tend to be "very specific" and therefore are generally uncomfortable with things they do not totally understand or have not previously experienced. Therefore, with respect to the new techniques, they must first see how the ultimate user can make use of it and how effective it is. Otherwise gut feeling based on subjective judgments will continue to prevail. They would, however, like to improve these subjective inputs.

In the opinion of engineering management, techniques such as PERT have been a burden to use. Information from such techniques is generally months behind on-going activities and any problems have already been corrected as they occurred and well before the information becomes available. The techniques end up being a tracking system, not a decision system.

The engineers believe a need exists for them to get back into cost estimation. The in-depth knowledge of the sensitivity of engineering requirements is needed for risk assessment in cost estimation. Thus, a better understanding through courses or seminars on risk and cost estimation would be helpful. Engineers would then have more confidence in risk evaluation estimates. An evaluation of experiences in parallel development with other areas would be helpful.

The engineers believed that subjective assessment would continue to depend mostly on individual experiences but, as now, continue to be tempered by opinions of other engineers. In those few cases in engineering where group consensus is sought, a leader always emerges. Enough opportunity already exists for this type consensus building training.

The respondents in budgeting had used some of the more sophisticated techniques. Yet, as a group they said risk analysis had little importance to their work area nor was it needed. Yet, they saw very much need for training in risk analysis in their area. Only one of eleven said budgeting was a most effective input into the process.

In the opinion of budgeting and cost estimation managers, most individuals in budgeting and cost estimating have a sufficient background in statistics and business. All have received training in cost effectiveness and cost estimating but most often risk analysis has not been distinguished as a separate topic. All have been introduced to such techniques as learning curves and quantitative methods. All have sufficient background to understand results of risk analysis and most would be comfortable with use of techniques. Courses are available but the lecturers change very frequently. Consequently, not everyone gets exposed to the same approaches. A seminar series with participation by the many who work together would aid in the use of available techniques.

According to the program control managers, the available techniques, particularly the sophisticated ones, are not being used because of the traditional syndrome of wanting to continue doing things the way they have always been done and of only allowing a few days or a few weeks for a cost estimate. Only when higher level decisionmakers are educated to the need for use of sophisticated techniques and direct the use of those techniques will they be used. To coincide with these directives, appropriate evaluation time must be built into the system.

Use of subjective assessment is the normal procedure in budgeting. The group consensus process could be improved, however, if documentation could be provided on best procedure for specific projects with evaluation of how successful such techniques have been for similar product groups.

In contracting, three of eight said risk analysis was very important to their area and the other five said it was of average importance. Eight of the nine said there was a high need for risk analysis in contracting and that training in risk analysis was needed. Yet, only two of eight had training in risk analysis and they indicated a limited use of PERT with only one having used a more sophisticated technique.

In follow-up discussions, contracting managers insisted that risk analysis is not being used in contracting because the need does not exist. According to them, all risk analysis should have been completed before the requirements are submitted to contracting. A better knowledge of risk assessment would be helpful, however, during the first steps of the negotiation team process in which the core team (configuration, engineering, product, etc.) all have input. It would be helpful in the determination of whether the potential contractor can meet the requirements (perform) and in determining contract type and profit level. This type knowledge should be provided in currently available contracting courses.

As with other work areas, time and cost constraints generally prevent sophisticated analysis. Therefore the greatest need is to maintain better the weighted guidelines which are now being used. Up-to-date values and coefficients would help contracting personnel evaluate the completed technical assessments which are submitted as requirements.

In pricing, four of five said risk analysis was of only average importance to their work area and three of five said there was a low need for risk analysis in pricing. Consistent with that view was the fact that only one of five had training in risk analysis and none of the five had used any of the risk analysis techniques. The analysis indicates that either risk analysis is not needed in pricing or that the respondents did not understand risk analysis and therefore were unaware of its advantages as an aid to decisionmaking.

According to the pricing work area managers, most pricing personnel are not interested in gaining further knowledge in statistics or risk analysis. Although most have the knowledge bases necessary to understand what risk models are being used for, they would not understand the concepts well enough to evaluate them. Procedures which are provided must be easy enough for everyone to use.

Existing models seem to be useful in pricing only as a tool to evaluate judgment and the output is good only until the first day of negotiation. At that time the numbers start changing and subjectivity of individual decisionmakers takes over. Thus, higher level management must understand the techniques as only tools to evaluate judgment rather than ends unto themselves.

The same traditional way of making price estimates has been used by pricing personnel for years and these personnel reject any suggestion of using models for fear that the models will replace them. Consequently, models will be used only if mandatory and if enough time is built into the decision process to allow for their use. To gain acceptance, models should be developed by working within the work area and then tested by outside evaluation before management will use them.

General courses in risk analysis are available to pricing personnel. But, pricing managers believe a course is needed to show how the analysis can best serve the work area and it should include an analysis of limitations on application of a given model.

Overall, those in program management had considerably more training in risk analysis and all had used some of the risk analysis techniques. Likewise, they indicated a high level of use of subjective assessment, multiple attributes, and group consensus decisions.

In follow-up discussions with program managers, the view emerged that overall cost risk for new programs is minimized because a ceiling has been established for total program cost. The scheduled delivery date then becomes the primary driver of the program. Each work unit is concerned only with supportability of that schedule and not cost risk.

While most people in program management are willingly involved with some form of program risk analysis, tradition is hard to change and managers must gain confidence in any new methods or techniques. Higher level managers must be educated on the validity of specific models not in the application of those models. Also, risk assessment models seem to be most beneficial in the software rather than in the hardware area.

An analysis of success rates on use of models and examples of successful application would be more beneficial to program management personnel than actual training in use of risk analysis. But, most managers want to guard against overanalysis of what can be done with existing experience.

In program management, group consensus just happens. An approach is put forth and you can stay with it or change the baseline. In group consensus you just learn to use available methods.

SUMMARY

The mechanical aspects of risk analysis are fairly well understood. But, a primary need exists to develop an awareness and a better understanding of the subject in order to enhance its application in the total acquisition process. Also, better tools are needed for inclusion of group decisions and subjective judgment into the process.

Survey respondents had very little formal training in risk analysis even though most had some formal training in statistics and the use of computers. Most respondents recognized the importance of risk analysis to their work areas but the extent of use of the analysis was very limited. Where risk analysis was used, PERT was the most often used technique, although respondees in program management and budgeting had used some of the more sophisticated techniques.

A high level of need for risk analysis was perceived for engineering, program management and the cost of estimating part of budgeting. A high level of interest was expressed for training in risk analysis and in procedures to aggregate individual preferences into group decisions.

REFERENCES

1. G.E. Fisher and E.P. Gay. An Approach to Risk Analysis: A Process View, Air Force Studies and Analysis (June 1981).

2. M.D. Martin, et al. Management of Risk and Uncertainty in the Acquisition of Major Programs, Proceedings of a Conference, February 9-11, 1981, at Colorado Springs, Colorado, University of Southern California (1981).

3. Ralph Strauch. "Risk Assessment as a Subjective Process," The Rand Paper Series, Rand Corporation, California (March 1980).

4. D. Rippy and P. Sweeny. Behavioral Aspects of Decisions Under Uncertainty During Weapon System Acquisition, DTIC, AD A098 934 (January 1980).

5. Gregory Fisher. "An Experimental Study of Four Procedures for Aggregating Subjective Probability Assessments," NTIS, AD A020 455 (December 1875).

6. Based on personal interviews within an Air Force Systems Command Product Division during 3-5 November 1981 and 12-13 May 1983.

7. Ward Edwards, et al. Research on the Technology of Inference and Decision, DTIC AD A056921, 1978.

EXPERIENCES AND LESSONS LEARNED IN PROJECT RISK MANAGEMENT

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ABSTRACT

The paper describes a state-of-the-art computer-based project risk analysis technique which has been in widespread use since 1970. The technique has been used to assist in management of project risks on over a hundred projects worldwide, with a total value of over $55 billion. PROMAP V* resembles conventional deterministic project management tools only in that it uses the conventional critical path network as the framework for a project risk model. The model is then analyzed to determine the interrelated schedule and cost risks resulting from time, cost, and technical performance uncertainties. At the same time, the model serves in the usual way the routine functions of project estimating, planning, scheduling, resourcing, costing, and control.

BACKGROUND AND INTRODUCTION

In 1963 and 1964, as a consequence of a number of significant Defense program overruns, the RAND Corporation investigated the analytical assumptions of the PERT project management tool which had been utilized on an increasing number of DOD programs over the previous five-year period. The results of the research 1.) revealed that a major shortcoming of the critical path technique is that because it is deterministic it does not adequately account for the impact of uncertainties on project time and cost performance. As a consequence, PERT-based schedules and time-related estimates of costs are inherently optimistic, and project overruns are being inadvertently built into the project plan from the very start.

Almost twenty years later, the Defense systems acquisition community now finds itself in the very peculiar circumstance of continuing to support widespread use of deterministic project management tools on one hand, while on the other, attempting to cope with the problems of increasingly complex acquisition programs by sponsoring development of a proliferation of special-purpose analytical tools designed specifically to deal with project risks and uncertainties.

1.) See References 5, 9, 10 and 11.

*PROMAP V is a service mark of Log/An, Inc.U.S.A.

Project management has been employed on DOD programs for some time, but until recently, it has been largely non-rigorous. The original PERT was intended to rigorously deal with uncertainties affecting project time and cost performance, and at that time, it was described as a "stochastic" technique because it accepts range estimate inputs which account for uncertainty. But, the range values are reduced to a single "expected" value and the subsequent critical path analysis is deterministic. Hence, the benefits of probabilistic analysis are not realized.

At UCLA, in 1966, we started development of a probabilistic network analysis package designed specifically for projects where uncertainties are significant. By 1968, we were applying the first operational versions of PROMAP (Project Risk Management and Planning) on Navy ship overhaul projects. Early application results were reported in the Navy Management Review, April/May 1969 issue.

Navy applications continued on ship acquisition, modernization, and repair projects and in 1975, at the Fourth Annual DOD Procurement Research Symposium at Colorado Springs, I described the PROMAP approach and compared it with conventional deterministic techniques with the aid of explicit results.

The following year, the PROMAP technique was included in the Naval Sea Systems Command project management handbook, Reef Points. Later in 1976, I presented a paper at the Fifth Annual DOD Procurement Research Symposium at Monterey, covering application of PROMAP to government contract claims analysis.

Further applications on DOD and non-Defense projects in aerospace, energy, transportation, and construction fields led to continuing improvement in the PROMAP approach, and in 1981 as Panel Chairman at the Air Force Risk and Uncertainty Workshop at Colorado Springs, I discussed the advanced features of the latest version, PROMAP V.

Over the 15 years since it became operational, the PROMAP V technique and its predecessors have been successfully applied to ovcr a hundred large, complex Defense and non-Defense projects, with a total value in excess of $55 billion.

THE PROMAP V* APPROACH

The foundation of the PROMAP V* approach is the Project Risk Model which is in effect, the conventional critical path activity network, modified to include logic and data accounting for uncertainties in (see Figure 1):

Internal Factors

- Planning (including contingency planning)
- Technical performance
- Time performance
- Resource performance
- Cost performance
- System support readiness

External Factors

- Economic factors
- Funding
- Environmental factors
- External deliverables

By accounting for the various types of uncertainty in a single model, the computer analysis accomplishes the intricate correlations among the different uncertainty factors and schedule and costs, which is so necessary for a reliable assessment of project risks. Data inputs are accepted from a variety of reliable data sources and estimating approaches, including empirical data and parametric, engineering, analogy, factor, and subjective estimating techniques.

In conducting a project risk analysis with PROMAP V*, the project model is "run" (simulated) in the computer as many as several hundred times; each run representing a complete project realization from start to end, with activity paths, activity durations, resource requirements, and costs sampled from distributions contained in the input data.

The results include project schedules and schedule risks, costs and cost risks, and resource requirements, together with data on critical activities, diagnostics, graphics, and other management information.

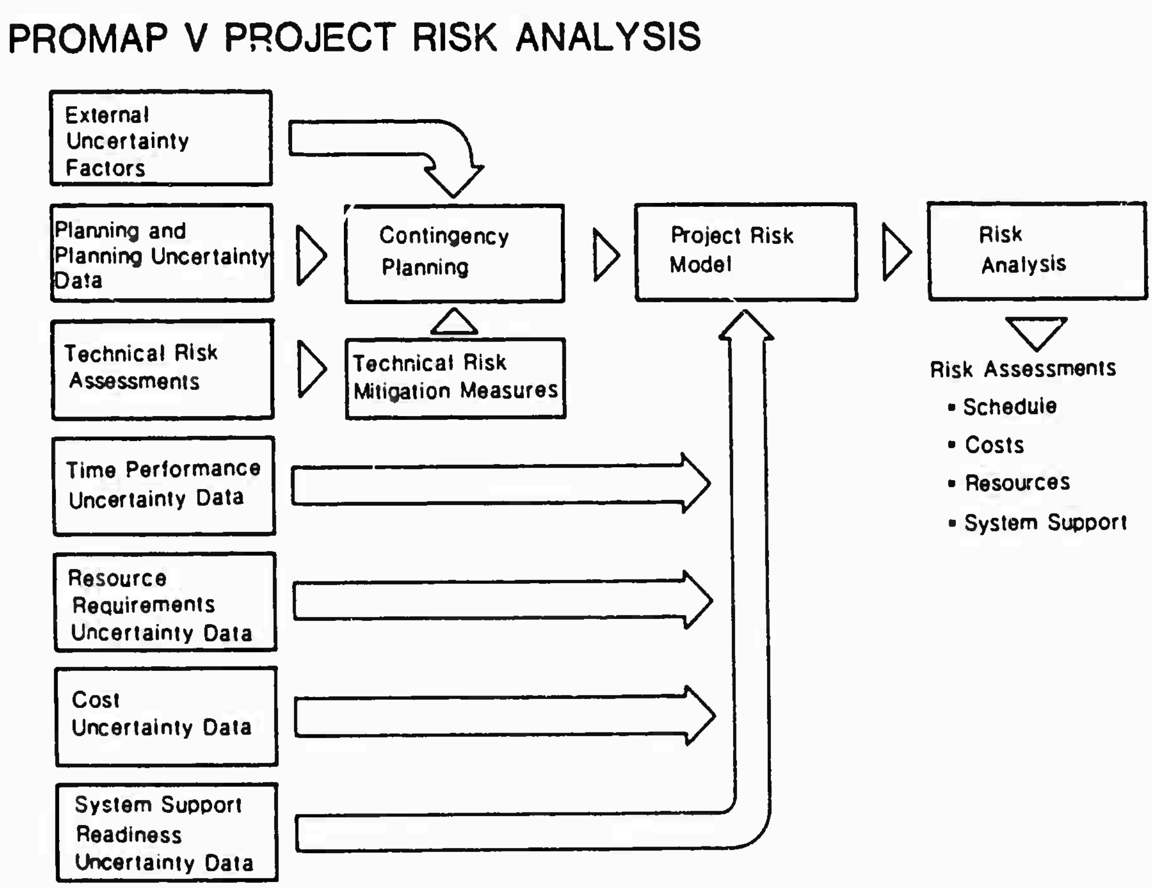

Figure 1. PROMAP V* PROJECT RISK ANALYSIS

A. Planning and Contingency Planning

The conventional critical path network (project plan), identifies all project activities from start to completion. Activities are arranged in proper sequence of performance, depicting their interrelations and interdependencies. Conventional, deterministic techniques are limited to representing each activity at a 100 per cent likelihood of occurrence.

A key feature of the PROMAP V* technique is its ability to account for uncertainty in the project plan. For example, a set of operational specifications may or may not be returned to the preparer for revisions. Or certain software design features may or may not be rejected by the Project Manager and returned for modification; a "backup" plan may be undertaken to substitute a less advanced state-of-the-art system feature should the primary design effort prove to be unsuccessful; or weather may delay an important field test.

If the program plan, schedule, costs, and resource requirements are to be realistic, such uncertain actions must be accounted for in terms of their likelihood of occurring.

As an example, Figure 2 illustrates a project plan incorporating a contingency plan consisting of Activities 5 and 8, representing a "back-up" in the likelihood that upon completion of Activity 2, the primary plan to develop an advanced state-of-the-art system feature (Activities 4, 7) will be assessed to be too risky. At the start, it is assessed that the primary plan has an 80% probability of technical success. Accordingly, the "back-up" plan is assigned a 20% probability of being implemented. This is referred to as "Contingency Planning."

As another example, suppose Activity 6 is a key test of a critical subassembly. Based on past experience, it is estimated that there is a 90% chance that the test will be successful (Activity 9) and a 10% likelihood that it will fail and the subassembly will have to undergo some modifications and retest (Activity 10). This situation is depicted by showing Activity 9 as having a 90% probability of occurring, and Activity 10 a 10% probability of occurring.

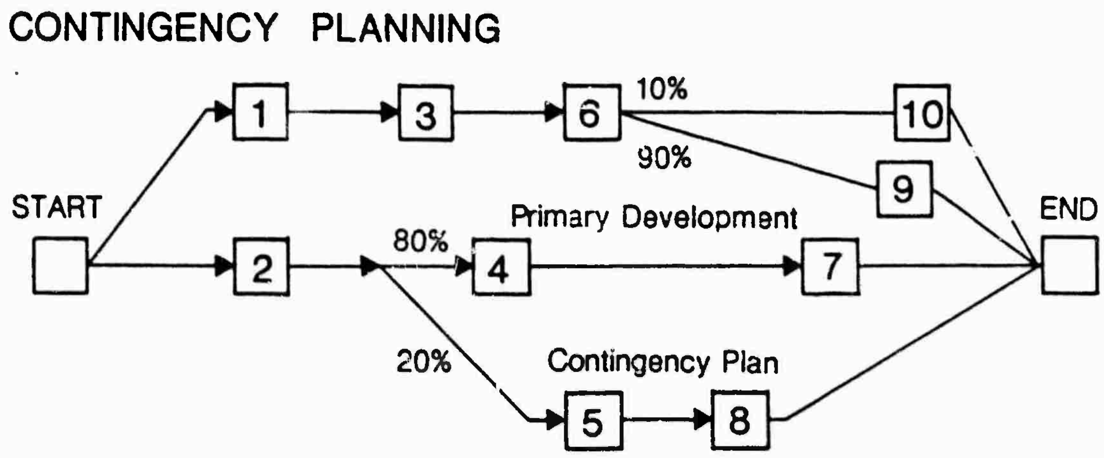

Figure 2. Contingency Planning

B. Technical Risk Management

Uncertainties and risks inherent in technical or software development can have major impact on the likelihood of attaining project objectives.

In the typical case, the technical risk elements are identified and the risks assessed. Conventionally, for technical risk elements which are critical to project success, management attention is directed at minimizing the impact on project performance. With PROMAP V*, "contingency" plans designed to mitigate the risks are developed and included as part of the overall project model. Typically, contingency planning may include measures such as early starts, allocation of additional resources, redundancy, and substitution of proven state-of-the-art technology.

During the course of the project, as the technical development proceeds, periodic reviews are made to obtain a current risk assessment of the technical risk elements.

It is normally expected that the risk level for an individual development item will decrease as the work progresses. However, should the updated risk assessment indicate that the technical risk level has not adequately decreased since the previous assessment, the appropriate measures are taken to accelerate implementation of related contingency plans; the objective is to provide assurance that project objectives are attained despite the continued existence of technical risks.

C. Schedule Risk Analysis

Schedule risk analysis results include the range of times covering the span between the earliest and latest possible dates for project completion and individual milestones, with accompanying detailed activity schedules and schedule risks. Figure 3 illustrates the range of project completion times for an example project. The results show that the project might be completed in from 240 to 330 workdays. The cumulative plot presents the probabilities of project duration between the two extremes. For example, there is a 90% probability that the project will be completed in 300 workdays or less, a 60% probability in 280 workdays or less, and so forth. The results show that there is an 85 per cent chance of overrunning the schedule target of 260 workdays.

Activity Criticality

One of the misleading aspects of conventional deterministic methods is the assumption that there is a single "critical" (longest time) path which determines the duration of the project. The designated critical path then becomes a focal point for project management.

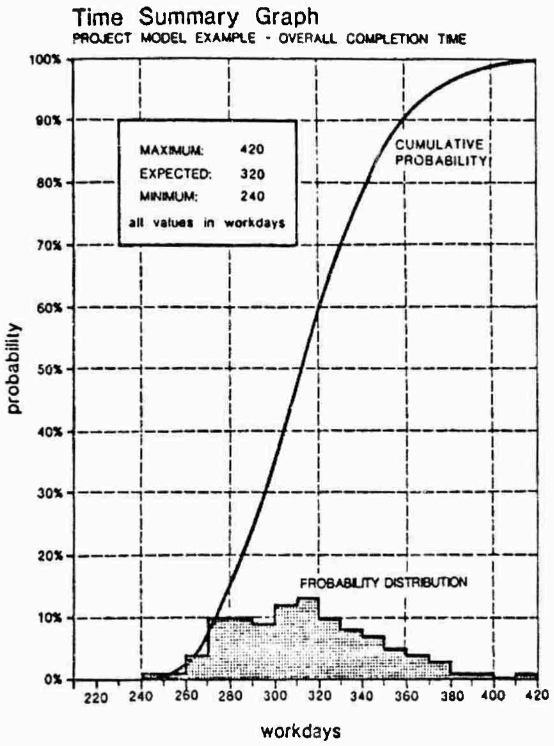

Figure 3. Time Summary Graph

However, when uncertainty factors are accounted for, there can be a number of different network paths which have significant probability of becoming critical during the course of the project. In fact, a probabilistic analysis will usually demonstrate that the "longest time" path of the deterministic technique has significantly less than a 100% probability of becoming critical.

For the sake of precise project monitoring and control, risk analysis focuses on activity "criticality"; the higher the criticality value (in per cent) - which is an output of the analysis - the more sensitive the activity, with regard to overall project schedule performance.

Accordingly, the activities requiring close managerial attention are those with the most criticality. On some projects, as many as 35 to 50 per cent of the project activities have a significant level of criticality.

D. Resource Risk Analysis

Schedules and budgets are not realistic unless the resources required to accomplish the individual project activities are available when needed. Resources may include personnel, materials, documentation, equipment, facilities funds, or suitable environmental conditions.

Most projects suffer from some scarcity of resources--the net effect can be to significantly delay the project completion and add to the project cost.

PROMAP V* provides the project manager with resource requirements, taking into account the variable start and finish dates of the activities.

Figures 4 and 5 show the difference between deterministic and probabilistic resource analyses. The deterministic results in Figure 4 show a one-day peak requirement of nine General Maintenance Men; Figure 5 shows a probabilistic requirement of none for as long as twenty days. The difference is due to the cumulative impact of uncertainties in the probabilistic case.

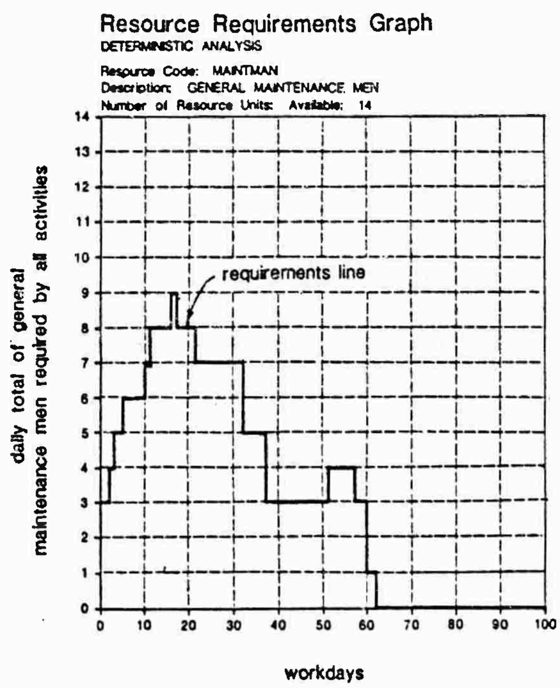

Figure 4. Deterministic Resource Requirements

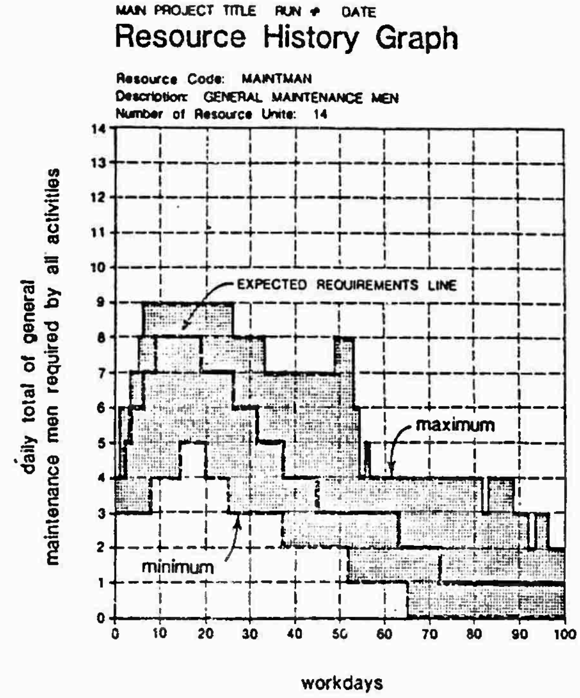

Figure 5. Probabilistic Resource Requirements

E. Cost Risk Analysis

Conventionally, cost estimates are deterministic; that is, costs for the individual line items of a project budget, or for individual project activities of a network, are expressed as single values representing perhaps the "best" 1./ estimate. However, where there is uncertainty, the use of range estimates allows a "cost risk analysis" which combines the uncertainties for the different cost elements and determines the overall range of project costs between minimum and maximum and as well as the risks of overrunning project cost targets.

1./ The practice varies considerably: "best", "most likely", "average", "normal", or no special designation at all may be given to the estimate. On many projects, there is no specific standard discipline applied to the estimating process.

Typical results of a cost risk analysis are shown in Figure 6. The range of total project costs is given together with the probabilities of different cost outcomes between the two extreme values. For example, it is shown that there is a 60% probability of expenditures reaching the amount of $60 million (hence, a 40% probability of exceeding that amount, and by as much as $12.5 million).

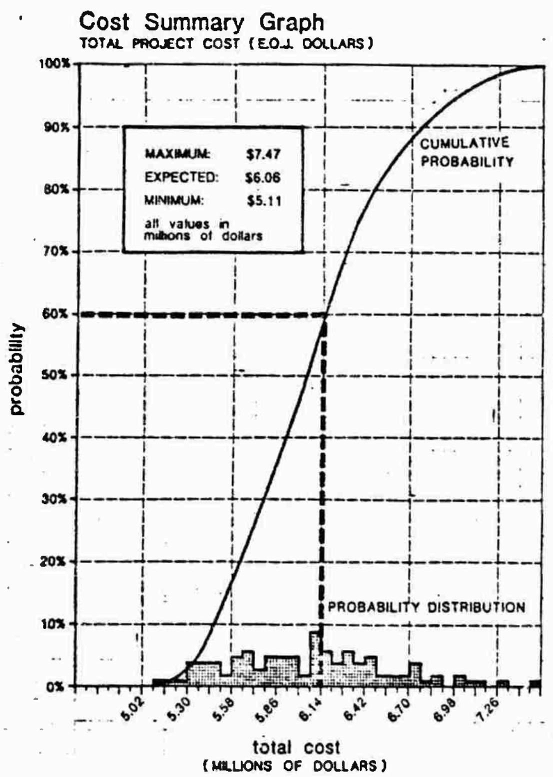

Figure 6. Cost Summary Graph
Total Project Cost (E.O.J. Dollars)

F. Cost/Schedule Analysis

Figure 7 shows a PROMAP V* cost/schedule graph for a typical project. The projection to completion incorporates the uncertainties regarding future events and produces a "projected outcome area" which includes all completion possibilities between the extremes in time and cost performance. A specific cost/schedule target value may be selected as representing any specified level of risk acceptable to management. In Figure 7, the target value shown is the "expected" cost/schedule value, which has an average likelihood of being realized.

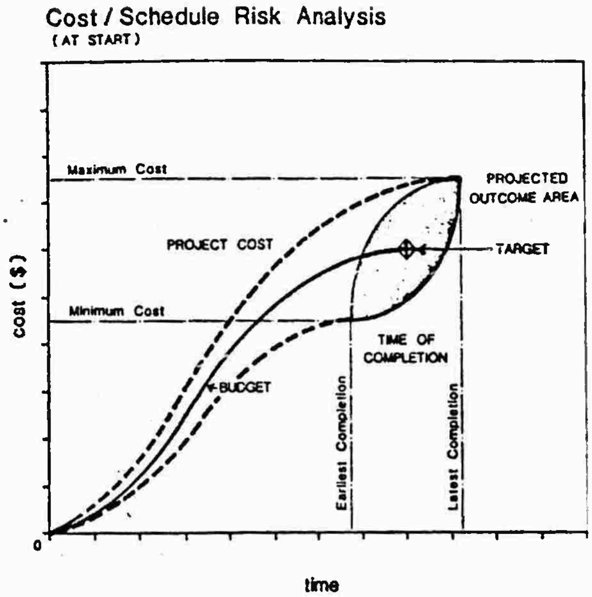

Figure 7. Cost/Schedule Projected Performance

Figure 8 shows the cost/schedule performance at a later stage of the project. Typically, the size of the projected outcome area decreases as certainty replaces uncertainty as the work proceeds. A major task in project risk management is to assure that the expected value of the projected outcome area does not materially deviate from the target value, as is shown in Figure 8.

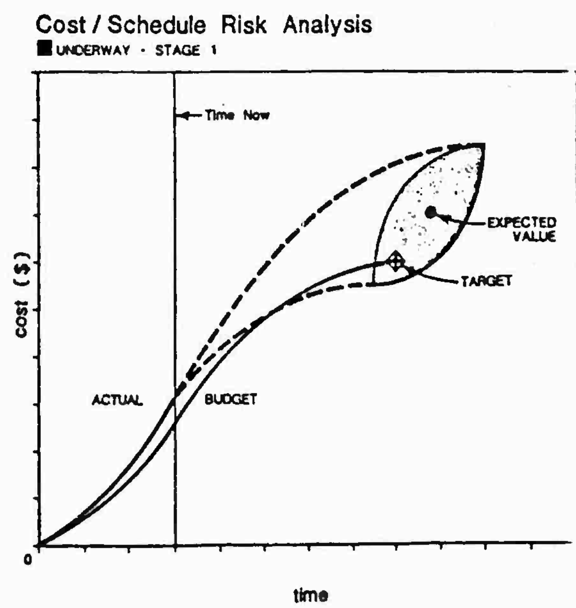

Figure 8. Cost/Schedule Risk Analysis

PROMAP V* provides the diagnostics to allow the project manager to make the specific adjustments to bring the projected outcome area into an acceptable risk range (as shown in Figure 9).

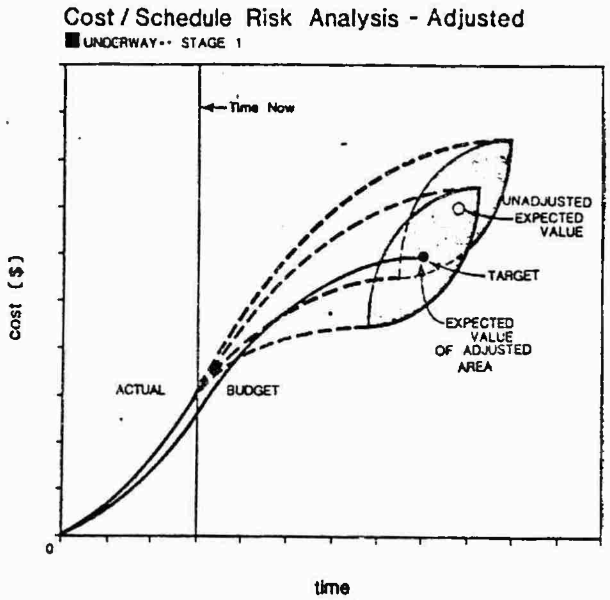

Figure 9. Cost/Schedule Risk Analysis-Adjusted

LESSONS LEARNED

1. Budgets and schedules should be based on the results of risk analyses with "expected" values chosen for the project targets and the use of a contingency allowance or management reserve should be avoided. In practice, the contingency allowance is set-aside to cover the impact of uncertainties on project cost performance. However, project uncertainties generate "minus" as well as "plus" possibilities; events may turn out better than expected. Because the conventional contingency allowance covers just the "pluses", there is no planning to take advantage of the "minus" instances when they occur. Adopting "expected" values and contingency planning will reduce the risks and with effective project risk management, overrun possibilities will be minimized.

2. A baseline risk analysis should be conducted early in the program and updated as appropriate during the pre-award period, assuring the availability of a current risk baseline at the time of source evaluation.

3. The system acquisition RFP should specify that the bidder support its presentation with the following data:

a. Identification of the cost, schedule, and technical risk elements.

b. Description of contingency plans designed to reduce risks on critical technical elements to manageable levels.

c. Results of a risk analysis covering cost, schedule, and technical risks.

d. Explanation of the risk assessment justification supporting the bid price.

e. Description of the bidder's risk management plan covering cost, scheduling, and technical risks, together with the details of procedures and system for implementing the risk management plan.

4. As part of the bid evaluation, the government should compare the bidder's risk analysis results with the government's baseline values. Any significant difference should be analyzed.

5. Once the contract is awarded, the government should continually monitor project risks and risk trends, the latter providing a very sensitive indicator of problems ahead. The periodic reviews of contractor performance should encompass cost, schedule, and technical risk considerations in addition to the standard requirements of DOD I 7000.2.

REFERENCES

1. A.M. Feiler, "Panel Reports: 1. Assessment of Risk and Uncertainty, 2. Taxonomic Concepts, Proceedings, Conference on Management of Risk and Uncertainty in Major Acquisition Activities", USAF Academy, Colorado Springs, February 8, 1981.

2. A.M. Feiler, "Investigation of Implementation of DODI 7000.2 Criteria on Navy Shipbuilding Project, Proceedings, Seventh Annual DOD Acquisition Research Symposium", Hershey, Pennsylvania, May 31, 1978.

3. A.M. Feiler, "Project Risk Management," Proceedings, 23rd International Meeting, The Institute of the Management Sciences (TIMS) Athens, Greece, July 25, 1977.

4. A.M. Feiler, "Assessment of Project Impact of Changes," Proceedings, Fifth Annual DOD Procurement Research Symposium, Monterey, California, November 19, 1976.

References (continued)

5. A.M. Feiler, "Project Management Through Simulation," UCLA Report ENG-76119, December 1976.

6. A.M. Feiler, "Project Management Through Simulation" Proceedings Fourth Annual DOD Procurement Research Symposium, Colorado Springs, October 17, 1975.

7. A.M. Feiler and G. Jurges, "PERA(CV) Project Risk Management," UCLA Report ENG-7445, June 1974.

8. A.M. Feiler, "Project Risk Management," Proceedings, INTERNET 72 Congress, Stockholm, Sweden, May 17, 1982.

9. A.R. Klingel, "Bias in PERT Project Completion Time Calculations for a Real Network," Management Science. 13(4): B-194-201, 1966

10. K.R. MacCrimmon and C.A. Ryavec, "An Analytical Study of the PERT Assumptions," Operations Research. 12.(1): 16-37, 1964.

11. R.M. Van Slyke, "Monte Carlo Methods and the PERT Problem, "Operations Research. 11(5): 839-860, 1963.

PANEL SESSION

ON

ADVANCED THEORY

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ENGINEERING RESEARCH ASSOCIATES, INC.

A LINGUISTIC APPROACH TO THE CONSTRUCTION OF EXPERT SYSTEMS

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Introduction

An expert system is a computer program that provides expert level solutions to important problems. In [1] Buchanan and Duda provide an excellent introduction to the principles of rule-based expert systems. In [2] Buchanan provides a comprehensive bibliography on expert systems. A particularly well cited example of a rule based expert system is MYCIN [3,4].

Some essential features required of such an expert system are seen to be the following:

1. It has the ability to reason and to make inferences under new situations.

2. It can use judgmental as well as formal knowledge.

3. It provides explanations of its reasoning process and answers questions about its knowledge.

4. It has the ability to easily and modularly add new knowledge.

It should be noted that the first characteristic is what substantially differentiates an expert system from an information system.

The structure of an expert system can be seen to consist of the following items:

1. A set of rules.

2. A set of data.

3. An inference mechanism.

The set of rules provide the knowledge base of the expert system. It is with these rules that one captures the knowledge of the expert in the computer system. Typically these rules are of the form of conditional statements of the type

$$\text{If } V_1 = A \text{ then } V_2 = B.$$

In this form V_1 and V_2 are variables and A and B are values. By use of these types of statements we can capture the informal knowledge of an expert. A typical example of one such rules would be

"if the response type is rapid then the destruction is minimal"

The set of data generally contains the information particular to the problem at hand. A general form for the data would be

$$V_1 = C$$

The basic mechanism for reasoning in these first generation expert systems such as MYCIN is modens pollens.

For example, from the rule "if the response time is rapid then the destruction is minimal" and the data "the response time is rapid" we can conclude that the destruction is minimal.

The use of this approach for reasoning provokes at least two questions

1. Does the user and the designer (expert) mean the same thing by fast?

2. What if we know that the response time is "about five minutes," can we say anything about the destruction?

Future implementations of expert systems must extend the concepts pioneered by the developers of MYCIN and other first generation expert systems to include semantics for natural language so as to handle the above situations.

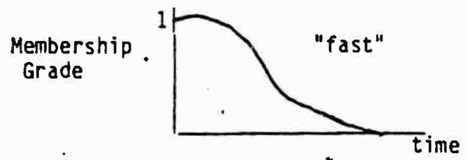
Fuzzy set and possibility theory provides a mechanism for representing the meaning of words, values in an expert system, in a manner that allows for the implementation of expert systems which can allow the necessary reasoning operations to be performed in such a manner as to take into account the semantics of natural language.

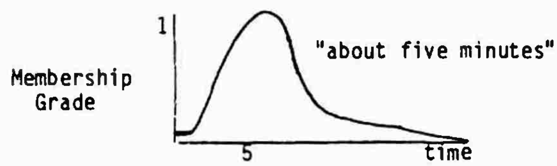
Fuzzy Sets in Expert Systems

The concept of a fuzzy subset introduced by L.A. Zadeh [5] provides a generalization of the idea of a set. In particular it allows for the partial inclusion of elements in subsets. With the aid of this idea one can very naturally represent the types of values associated with the variables found in expert systems. In particular if X is a set of elements, a fuzzy subset A of X is associated ciated with a membership function

$$A: X \text{ -----> } [0,1]$$

such that $A(x)$, for $x \varepsilon X$ indicates the degree to which x satisfies the concept defined by A. For example, in our previous illustration we could represent the concepts of "fast" and "about five minutes" as fuzzy subsets of the real line representing time.





Thus with the use of fuzzy subsets a designer of an expert system can provide semantics for the values used in the system. Likewise a user of such a system could provide semantics for his responses to the systems questions. A typical dialog could be seen as follows:

System: What is the response time?

User: Fast

System: What do you mean by fast?

User: (at this point the user could draw in his membership function for fast)

The theory of approximate reasoning [6] provides a mechanism for making inferences in situations in which the information is given in terms of fuzzy subsets. The rule of fuzzy compositional inference plays the analagous role to the law of modens pollens.

Assume we have the following situation:

$V_1 = A$

If $V_1 = B$ then $V_2 = C$,

where A and B are fuzzy subsets of X and C is a fuzzy subset of Y. Using the theory of approximate reasoning we proceed as follows:

$V_1 = A$ translates into a possibility distribution such that $\Pi_{V_1}(x) = A(x)$

The statement

if $V_1 = B$ then $V_2 = C$

translates into the conditional possibility distribution

$$\Pi_{V_2|V_1}(x,y) = \text{Min}\ [1, 1-B(x) + C(y)]$$

By use of the rule of fuzzy compositional inference we obtain

$$\Pi_{V_2}(y) = \underset{x \varepsilon X}{\text{Max}}\ [\Pi_{V_1}(x) \wedge \Pi_{V_2|V_1}(x,y)] \quad (\wedge = \text{min})$$

Then the inferred value of V_2 is the fuzzy subset D such that

$$D(y) = \Pi_{V_2}(y).$$

In the remainder of this short paper we would like to discuss some issues related to the construction of expert systems using fuzzy set theory.

In particular we shall briefly discuss four issues:

1. Handling of large knowledge bases

2. Inclusion of certainty/belief associated with knowledge

3. Complex production rules

4. Validation of expert systems

In many cases of expert systems the number of rules necessary to capture the expert's knowledge become very great. In [7] Yager has suggested a method using the concept of knowledge trees to provide an organized method for processing the information necessary for an expert system to answer any questions.

MYCIN and other expert systems have been concerned with the issue of belief or certainty factors associated with the data and the rules in an expert system.

In many cases we have information of the type

$V_1 = A$ with α_1 certainty

If $V_1 = B$ then $V_2 = C$ with α_2 certainty

A method has been suggested by Yager [8] for the inclusion of certainty factors in a manner consistant with Zadeh's theory of approximate reasoning. In particular Yager has suggested that the statement

$V = A$ with belief α, where $\alpha \varepsilon [0,1]$

can be translated into the statement

$V = A^*$ (implicit belief one)

where A and A* are fuzzy subsets of X such that

$$A^*(x) = \text{Min}\ (A(x), \alpha) + (1-\alpha)$$

The formulation of the experts rules generally are more complex than the simple conditional statements described above. A more representative example of the types of rules experts use are:

"In at least about 50% of the cases if most of $V_1 = A_1$, $V_2 = A_2$, . . . $Vn = An$ are satsified, then $U = B$."

Methods have been developed within the framework of the theory of approximate reasoning for the inclusion of such statements [8].

An expert system as any forecasting type system must be subject to some validation procedure. We desire two properties for an expert system to be a good forecaster:

1. Correctness of the answer.

2. Specificity of the answer.

Assume a system forecasts

$$V = B$$

and the actual value is

$$V = x^*$$

then $B(x^*)$ measures the degree of correctness of the system

The specificity of the system relates to the following situation. Assume a weather forecaster predicts that the high termperature tomorrow will be greater than 10°. While this system will almost certainly have been correct, its lack of being specific has rendered it totally uninformative.

In [9] Yager has introduced a method for measuring the specificity of a fuzzy subset

$$Sp(B) = \int_0^1 \frac{1}{Card\ (B\alpha)}\, d\alpha$$

where $B\alpha = \{x \mid B(x) \geq \alpha\}$ and

Card $B\alpha$ is the number of elements in $B\alpha$.

Conclusion

We feel that in the future expert systems based upon the theory of fuzzy subsets will play a significant role in the decision making process involved in systems acquisition.

References

(1) Buchanan, B.G. and Duda, R.O., "Principles of rule-based expert systems," Fairchild Technical Report No. 626, Lab for Artificial Intelligence Research, Fairchild Camera, Palo Alto, Ca., 1982.

(¯) Buchanan, B.G., "Partial Bibliography of Work on Expert Systems," Segart Newsletter, No. 84, 45-50, 1983.

(3) Shortliffe, E.G., Computer-Based Medical Consultations: MYCIN, American Elsevier, New York, 1976.

(4) Davis, R., Buchanan, B.G., & Shortliffe, E.G., "Production Rules as a Representation of Knowledge-Based Consultation Program," Artificial Intelligence 8, 15-45, 1977.

(5) Zadeh, L.A., "Fuzzy Sets," Information and Control 8, 338-353, 1965.

(6) Zadeh, L.A., "A Theory of Approximate Reasoning," in Hayes, J.E., Michie, D. and Kulich, L.I. (eds). Machine Intelligence 9, 149-194, John Wiley & Sons, New York, 1979.

(7) Yager, R.R., "Quering Knowledge Base Systems with Linguistic Information via Knowledge Threes," International Journal of Man-Machine (to appear 1983).

(8) Yager, R.R., "Approximate Reasoning as a Basis for Rule Based Expert Systems," Machine Intelligence Institute Technical Report, Iona College, 1983.

(9) Yager, R.R., "Measuring the Quality of Linguistic Forecasts," International Journal of Man-Machine Studies (to appear).

RISK MANAGEMENT IN A MULTIOBJECTIVE DECISION-MAKING FRAMEWORK

AD P002317

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ABSTRACT

The thesis of this paper is grounded on the premise that the analysis of risk and uncertainty—and ultimately the management of risk—can be meaningful and effective only when considered as an integral part of the decision-making process. Five major elements or steps that encompass the risk assessment process—risk identification, risk quantification, risk evaluation, risk acceptance and risk management—are discussed. The risk assessment is shown to ultimately lend itself to a multiobjective decision-making process. The surrogate worth trade-off (SWT) method (a multiobjective optimization method) and four risk assessment methodologies—the multiobjective statistical method (MSM), the partitioned multiobjective risk method (PMRM), the risk/dispersion index method (RDIM), and the uncertainty/sensitivity index method (USIM)—are briefly discussed.

1. Introduction

The thesis of this paper is grounded on the premise that the analysis of risk and uncertainty—and ultimately the management of risk—can be meaningful and effective only when considered as an integral part of the decision-making process. To avoid common ambiguities of terms and terminologies associated with this subject, the following definitions will be used—not as universal definitions, but as a useful means of communicating with the reader (Haimes, 1981).

Risk situations—those in which the potential outcomes can be described by reasonably well-known probability distributions.

Uncertainty situations—those in which potential outcomes cannot be described in terms of objectively known probability distributions.

Risk assessment—a complete process that encompasses all of the following five elements or steps: risk identification, risk quantification, risk evaluation, risk acceptance and aversion, and risk management. The term "risk" will be generically used in most parts of this paper to connote situations of both risk and uncertainty.

Risk identification—identification of the nature, types and sources of risks and uncertainties. The end products of this stage are a complete description of risky events and elements of major concern along with their causative factors and mechanisms.

Risk quantification—formulation of appropriate measures of risk and estimation of the likelihood (probability) or occurrence of all consequences associated with risky events as well as the magnitude of such consequences.

Risk evaluation—selection of an evaluation procedure (i.e., optimizing expected value; trade-off analysis) and analysis of various possible impacts of risky events.

Risk acceptance and aversion—decision making regarding both an acceptable level of risk and its equitable distribution. This stage of risk assessment also involves the development of risk control (i.e., methods to reduce or prevent risk).

Risk management—formulation of policies, the development of risk-control options (i.e., methods to reduce or prevent risk), and the execution of such policy options.

The last two stages of the risk assessment process—risk acceptance and aversion and risk management—overlap to a large extent and require the subjective judgment of the appropriate decision makers in trading-off the noncommensurate beneficial and adverse consequences resulting from the ultimate "acceptable risk" decision. The existence of these fundamental trade-offs among conflicting and noncommensurate multiple objectives and attributes demands the consideration of risk management as an integral part of the overall decision-making process—which is the imperative premise assumed in this paper.

In summary, from a multiobjective decision-making perspective, the risk assessment process consists of two major phases that partially overlap:

a) Information is quantitatively processed and evaluated through well-developed procedures and methodologies, including the quantification of risk and uncertainty and the development of alternative policy options. The methodologies of risk assessment are the techniques utilized in the scientific approach of estimating probabilities and performing risk assessment (excluding the explicit application of value judgments).

b) Value judgment is introduced, within the overall decision-making process, concerning what risks and their associated trade-offs are acceptable, what selections are preferred, what policies are desirable, what constitutes the ultimate decision (the best-compromise solution), and what actual actions should be taken.

It is worthwhile to note that the setting of value judgment is critically important; it is an integral part of any decision-making process and thus is integral to the risk assessment process itself. This process also serves as an educational medium to the decision makers in their interaction with the analysts; it can help identify and articulate the issues upon which there is an agreement among decision makers and also those for which there is no agreement; it also helps to make the implicit explicit (doing this, however, at the expense of embarrassing decision makers under certain circumstances).

Given the welter of theories and methodologies that have been developed over the last decade on multiple-criteria (objective) decision making (MCDM), "risk management" should not be considered a new field; rather, it is a special case of MCDM—albeit a very important one—as well as an extension of it. In the remainder of this paper, a brief summary of four risk assessment methodologies that have been developed within a multiobjective decision-making framework at Case Western Reserve University will be presented. These are (i) the uncertainty/sensitivity index method (USIM) (Haimes et al. 1975 and Haimes and Hall 1977), (ii) the multiobjective statistical method (MSM) (Haimes et al. 1980), (iii) the risk/dispersion index method (RDIM) (Rarig and Haimes 1983), and (iv) the partitioned multiobjective risk method (PMRM) (Asbeck and Haimes 1983).

An important aspect or component of risk management within a multiobjective decision-making framework is that of solving a multiobjective optimization problem. The concepts of Pareto optimality and trade-offs are so fundamental and germane here that prior to discussing the above risk assessment methodologies, we will concentrate (in the next section) on an effective multiobjective optimization method that plays a critical role in all of the above methods, namely, the surrogate worth trade-off (SWT) method (Haimes and Hall 1974).

2. The Surrogate Worth Trade-Off (SWT) Method

The surrogate worth trade-off (SWT) is a multiobjective optimization method (Haimes and Hall 1974) that is especially well suited for risk assessment.

Fundamental to multiobjective analysis is the concept of the noninferior solution (also known as efficient solution or Pareto-optimal solution). Qualitatively, a noninferior solution of a multiobjective problem is one where any improvement of one objective function can be achieved only at the expense of degrading another.

To define a noninferior solution mathematically, consider the following multiobjective optimization problem (MOP):

$$\min_{\mathbf{x} \in X} [f_1(\mathbf{x}), f_2(\mathbf{x}), \ldots, f_n(\mathbf{x})] \quad (1)$$

where X is the set of all feasible solutions defined as

$$X = \{ \mathbf{x} \mid g_k(\mathbf{x}) \leq 0, \ k = 1,2,\ldots,m \} \quad (2)$$

The functions $f_j(\mathbf{x})$ and $g_k(\mathbf{x})$ are well-defined objective functions and constraints, respectively, and $\mathbf{x}$ is a N-vector of decision variables.

Definition. A decision $\mathbf{x}^*$ is said to be a noninferior solution to the problem posed by the systems (1)–(2) if and only if there does not exist another $\mathbf{x}$ so that $f_j(\mathbf{x}) \leq f_j(\mathbf{x}^*)$, $j = 1,2,\ldots,n$, with strict inequality holding for at least one j.

The original version of the surrogate worth trade-off method is, in principle, noninteractive and assumes continuous variables and twice-differentiable objective functions and constraints. It consists of four steps: 1) generate a representative subset of noninferior solutions, 2) obtain relevant trade-off information for each generated solution, 3) interact with the decision maker to obtain information about preference expressed in terms of worth, and 4) retrieve the best-compromise solution from the information obtained. Extensions of the surrogate worth trade-off method that include multiple decision-makers, an interactive mode, dynamic systems, and nondeterministic systems have been published in the literature (see, for example, Chankong and Haimes 1983).

The ε-constraint approach (Haimes et al. 1971), which constitutes an important component upon which the SWT is based, transforms a multiobjective optimization problem into a mathematically equivalent single-objective optimization problem by converting (n-1) objectives into constraints. The problem resulting from the ε-constraint formulation may be denoted $P_k(\varepsilon)$:

$$\min \ f_k(\mathbf{x}) \quad (3)$$

subject to

$$\mathbf{x} \in X, \quad (4)$$

$$f_j(\mathbf{x}) \leq \varepsilon_j, \ j = 1,\ldots,n, \ j \neq k \quad (5)$$

Although there is no rule to specify which objective should be chosen as a reference, a dominant objective or one in familiar units (such as dollars) that yields a meaningful trade-off analysis is recommended.

To generate an ad hoc representative subset of noninferior solutions we simply select a reasonable number of values for each ε_j and solve $P_k(\varepsilon)$ for each combination of these values ($j \neq k$). The equivalence between problems (1)–(2) and (3)–(5) is proved in the equivalence theorem by Haimes et al. (1971).

The Lagrangian function $L(\mathbf{x}, \lambda)$ is constructed for the following ε-constraint problem:

$$\min_{\mathbf{x} \in X} \ f_k(\mathbf{x})$$

subject to

$$f_j(\mathbf{x}) \le \epsilon_j,\ k \neq j,\ j=1,\ldots,n \qquad (6)$$

where each $\epsilon_j > 0$ will be varied parametrically in the process of constructing the trade-off function. Form the generalized Lagrangian, L, to the system (6):

$$L(\mathbf{x},\lambda) = f_k(\mathbf{x}) + \sum_{j \neq k} \lambda_{kj}[f_j(\mathbf{x}) - \epsilon_j] \qquad (7)$$

where λ_{kj}, $j \neq k$ are generalized Lagrange multipliers. The subscript kj in λ denotes that λ is the Lagrange multiplier associated (in the ϵ-constraint vector optimization problem) with the j^{th} constraint, where the objective function is $f_k(\mathbf{x})$.

By considering one objective function as primary and all others at minimum satisfying levels as constraints, the Lagrange multipliers related to the (n-1) objectives as constraints will be either zero or positive. The set of positive Lagrange multipliers can be shown to represent the set of trade-off ratios between the principal objective and each of the constraining objectives, respectively. Clearly, these Lagrange multipliers are functions of the optimal level attained by the principal objective function as well as the level of all other objectives satisfied as equality (binding) constraints. Consequently, these Lagrange multipliers form a matrix of trade-off functions.

In general, we consider only those noninferior solutions whose associated multipliers $\lambda_{kj}(\mathbf{x})$ are all strictly positive. In effect, we have limited ourselves here to considering only solutions that are proper and noninferior. In this case, if the primary objective is changed from f_k to f_i, the trade-offs λ_{ij}, $j \neq i$, can be determined from the λ_{kj}s by using the formulas

$$\lambda_{ij} = \lambda_{ik}\lambda_{kj} \quad \text{for all } i \neq j \qquad (8)$$

and

$$\lambda_{ik} = 1/\lambda_{ki} \qquad (9)$$

The decision maker is supplied with trade-offs and the levels of all corresponding objectives. He then expresses his preference for wiether or not (and by how much) he would like to make such a trade at that level. The surrogate worth function is then constructed from this information.

The decision maker is asked, "How (much) would you like to improve f_k by $\lambda_{kj}(\mathbf{x}^0)$ units per one-unit degradation of f_j while all other objectives remain fixed at $f_\ell(\mathbf{x})$, $\ell \neq j,k$? Indicate your preference on a scale of +10 to -10." The decision-maker's response is recorded as $W_{kj}(\mathbf{x}^0)$, called the <u>surrogate worth</u> of the trade-off between f_k and f_j at $\mathbf{x}^0$. At a particular noninferior solution, there will be n-1 questions to obtain $W_{kj}(\mathbf{x}^0)$ for each $j \neq k$. In order to measure $W_{kj}(\mathbf{x}^0)$ on an interval scale, we define the surrogate worth scale for measuring W_{kj}s, using the following conventions:

$W_{kj} > 0$ when λ_{kj} marginal units of $f_k(\mathbf{x})$ are preferred over one marginal unit of $f_j(\mathbf{x})$, given the satisfaction of all objectives at level ϵ_k.

$W_{kj} = 0$ when λ_{kj} marginal units of $f_k(\mathbf{x})$ are equivalent to one marginal unit of $f_j(\mathbf{x})$, given the satisfaction of all objectives at level ϵ_k.

$W_{kj} < 0$ when λ_{kj} marginal units of $f_k(\mathbf{x})$ are not preferred over one marginal unit of $f_j(\mathbf{x})$, given the satisfaction of all objectives at level ϵ_k.

These conventions define the scale for measuring W_{kj} (Chankong and Haimes 1983).

Intuitively, one would expect that a particular noninferior solution $\mathbf{x}^*$ is the best-compromise solution if the decision maker is indifferent to all trade-offs offered from the current point $\mathbf{x}^*$. In other words, $\mathbf{x}^*$ is the best-compromise solution if

$$W_{kj}(\mathbf{x}^*) = 0 \quad \text{for all } j \neq k \qquad (10)$$

We can apply condition (10) to retrieve the best-compromise solution. If at some generated noninferior solution all the corresponding W_{kj} vanish, that generated point can immediately be chosen as the best-compromise solution. Otherwise we use multiple regression to construct, for each j=k, the surrogate worth function W_{kj} relating W_{kj} to f for all $\ell \neq k$. Then the system of equations

$$W_{kj}(f_1,\ldots,f_{k-1},f_{k+1},\ldots,f_n) = 0 \quad j \neq k \qquad (11)$$

is solved to determine $\epsilon^* = (f_1^*,\ldots,f_{k-1}^*,f_{k+1}^*,\ldots,f_n^*)^T$. The best-compromise solution $\mathbf{x}^*$ is then found by solving $P_k(\epsilon^*)$.

The corresponding trade-offs $\lambda^* = (\lambda_{k1},\ldots,\lambda_{k,k+1},\ldots,\lambda_{kn})$ can also be found. Note that in practice there usually exists an indifference band around a neighborhood of λ^* within which the W_{kj}s, $j \neq k$, do not change. The decision maker may be asked additional questions to obtain the indifference band and to improve the accuracy of λ^*.

3. <u>Risk Assessment Methods</u>

The following summaries of four risk assessment methodologies are taken from Haimes (1983).

3.1. The multiobjective statistical method (MSM)

The multiobjective statistical method (MSM) was developed for the U.S. Army Corps of Engineers (Haimes et al., 1980) to account for the risk of floodings in the design and management of interior drainage systems. The method is an integration of multiobjective optimization (SWT method) and statistical simulation models (Stanford-type stream flow simulation models) to assess the probability of risk events and their consequences. The risk functions in the MSM are first constructed as functions of two state variables—pond duration and pond elevation of interior floodings. These two state variables are then related to the system's decision variables, $\mathbf{x}$, using Stanford-type streamflow simulation models. Historical records associated with two random variables—precipitation and stream flow—are then used to generate conditional and joint probabilities (as appropriate) for the ultimate development of the expected value of the appropriate risk functions. The set of ordered pairs of the expected value of the j^{th} risk function, $f_j(\mathbf{x}^k)$, $j = 1,2,...,J$, and its associated policy decision $(\mathbf{x}^k)$ for $k = 1,2,...,K$, is used to generate the needed functional relationship $f_j(\mathbf{x})$ through a regression analysis technique. The completion of this last step yields to quantifiable risk functions amenable for optimization via the SWT method, where Pareto optimal policies and their associated trade-offs are generated as part of the risk assessment process.

3.2. The partitioned multiobjective risk method (PMRM)

Central to the partitioned multiobjective risk method (PMRM) is the premise that the expected value concept used for the construction of risk functions suffers from the same flaw associated with commensurating multiple objectives via constant weights (Asbeck and Haimes, 1983). In the expected value approach, extreme events with low probability of occurrence are given the same proportional weight or importance regardless of their potential catastrophic and irreversible impact. In the PMRM, on the other hand, the frequency spectrum of the random variables is partitioned, for example, to three ranges—low, medium and high frequency. Conditional expected value risk functions are then constructed for each range in addition to the "business as usual" unconditional expected value risk function. The SWT method is then utilized for the completion of the risk assessment process. The PMRM has been used for the study of acid rain (Haimes, 1982).

3.3. The risk/dispersion index method (RDIM)

The heart of the RDIM is the construction of a sensitivity measure that accounts for the effects of variations in the nominal values of the random variables α. It is assumed that α_j's are independent random variables with known finite means and variances. The sensitivity measure Ω, called the dispersion index, which is interpreted as a first-order approximation to the standard deviation, is then incorporated in a multiobjective optimization formulation. The dispersion index can also be interpreted as a measure of the size of the neighborhood about the nominal optimal solution in which the actual solution is most likely to occur. The method also derives a sensitivity trade-off (when using the ϵ-constraint formulation with the SWT method), which gives an explicit representation of the trade-offs between the sensitivity measure Ω and the other objective functions. Since the RDIM incorporates the SWT method, it generates all needed Pareto optimal solutions to the multiobjective risk problem (see Rarig and Haimes, 1983).

The dispersion index is particularly useful in decision making. The information that Ω conveys to the decision maker(s) can be readily understood: the larger the value of Ω, the greater the possibility that the actual solution will deviate significantly from the nominal solution. Since Ω is a scalar-valued quantity and is independent of the number of objectives, any decision maker who desires to minimize Ω will not be confused by a deluge of sensitivity information that needs to be analyzed at each prospective solution point (alternative policy option).

Note that the fundamental difference between the RDIM and the USIM is that the former generates a sensitivity index on the basis of probability distributions (conditions under risk), whereas the latter generates a sensitivity index without any reference to probability distributions(conditions under uncertainty).

3.4. The uncertainty sensitivity index method (USIM)

The uncertainty sensitivity index method (USIM) is an effective method for quantifying uncertainty functions in terms of sensitivity indices (see Haimes and Hall, 1977). The method constructs an uncertainty—sensitivity function for each random variable α_j (for which respective probability distribution functions cannot be assumed to be reasonably well-known) Such a function, $f_j(\cdot)$, can take the following basic form:

$$f_j(\mathbf{x};\hat{\alpha}) = [\,\partial y(\mathbf{x};\alpha)/\,\partial\alpha_j]^2|_{\alpha_j} = \hat{\alpha}_j \qquad (12$$

where $\hat{\alpha}$ represents the assumed nominal value of $\boldsymbol{\alpha}$; and $y(\cdot)$ is the system's output.

Basically, minimizing the function $f_j(\cdot)$ posed by eq. 12 is equivalent to minimizing the variation of the model's output [or the cost function if $f_1(\cdot)$ replaces $y(\cdot)$] that might be caused by the random variation of α_j. If eq. 12 is considered to be an objective function to be minimized along with $f_1(\cdot)$ and maybe other objectives, a vector optimization problem of the form of (1) results. For example, if $f_1(\cdot)$ replaces $y(\cdot)$ in eq. 12 and the random vector α is a scalar α_1, ten the following bicriterion problem results:

$$\underset{\mathbf{x}\,\epsilon X}{\text{Min}}\ \{f_1(\mathbf{x};\alpha_1),\ f_2(\mathbf{x};\alpha_1)\} \qquad (13$$

where

$$f_2(\mathbf{x};\hat{\alpha}_1) = [\,\partial f_1(\mathbf{x};\alpha_1)/\partial\,\alpha_1]^2\,|_{\alpha_1} = \hat{\alpha}_1 \qquad (14$$

It has been shown elsewhere that, for a given model, a major variation in α_1, say +25%, would yield only up to 3% change in the cost function $f_1(\cdot)$ when the most conservative policy $\mathbf{x}$ is followed, but it would yield to as much as a 50% change in the cost function $f_1(\cdot)$ when the business-as-usual policy $\mathbf{x}^*$ is followed (see Haimes et al., 1975; Haimes and Hall, 1977).

4. References

Asbeck, E. and Y. Y. Haimes, "The Partitioned Multi objective Risk Method", Report No. LSS&PA83-

Case Western Reserve University, 1983.

Chankong, V. and Y. Y. Haimes, Multiobjective Decision Making: Theory and Methodology, Elsevier-North Holland, New York, 1983.

Haimes, Y. Y., L. S. Lasdon, and D. A. Wismer, "On the Bicriterion Formulation of the Integrated System Identification and Systems Optimization," IEEE Trans. Syst., Man, & Cybern., Vol. SMC-1, pp. 296-297, 1971.

Haimes, Y. Y., W. A. Hall and H. T. Freedman, Multiobjective Optimization in Water Resources Systems: The Surrogate Worth Trade-off Method, Elsevier Scientific Publishing Company, The Netherlands, 1975.

Haimes, Y. Y., and W. A. Hall, "Multiobjectives in Water Resources Systems Analysis: The Surrogate Worth Trade-off Method," Water Resources Research, Vol. 10, no. 4, pp. 615-624, Aug., 1974.

Haimes, Y. Y., and W. A. Hall, "Sensitivity, Responsivity, Stability, and Irreversibility as Multiple Objectives in Civil Systems," Advances in Water Resources, Vol. 1, no. 2, 1977.

Haimes, Y. Y., K. A. Loparo, S. C. Olenik, and S. K. Nanda, "Multiobjective Statistical Method (MSM) for Interior Drainage Systems," Water Resoures Research, Vol. 16, no. 3, pp. 467-475, 1980.

Haimes, Y. Y. (Editor), Risk/Benefit Analysis in Water Resources Planning and Management, Plenum Publishing Company, New York, 1981.

Haimes, Y. Y., "Risk Analysis for Transport Air Pollutants," Report prepared for the Office of Technology Assessment, U.S.Congress, July 1982.

Haimes, Y. Y., "Integrated Risk and Uncertainty Assessment in Water Resources within a Multiobjective Framework," Journal of Hydrology, Special Ven Te Chow Issue, 1984.

Rarig, H., and Y. Y. Haimes, "Risk Dispersion Index Method in a Multiobjective Framework," IEEE Trans. Syst., Man, & Cybern., Vol. SMC-13, no. 3, pp. 317-328, May/June, 1983.

A MEASURE OF UNCERTAINTY IMPORTANCE IN FAULT TREES

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(OR. ORAKE'S TALK WAS BASED ON THE FOLLOWING OISSERTATION ABSTRACT BY VICKI M. BIER OF M.I.T.)

The primary product of this work is the development of a measure of "uncertainty importance." This measure ranks the components in a fault tree in terms of their contributions to the overal uncertainty about the probability of system failure. For sufficiently small fractional change in the variance of a given component failure probability, the uncertainty importance of tha component is defined to be the resulting fractional change in the variance of the system failur probability divided by the fractional change in the variance of that component's failure probability.

We present a general algorithm for computing the uncertainty importance of any component in system. This alogrithm can be applied not only in the case where all component failure probabi lities are assumed to be mutually independent, but also in the case where some components hav perfectly correlated failure probabilities. We also propose a model for use in analyzing partia correlation among component failure probabilities. Our algorithm is implemented using MACSYMA a research-oriented programming language which is designed to perform symbolic manipulatio of expressions (e.g., symbolic differentiation) as well as numerical operations.

We also develop a simple approximation to our measure of uncertainty importance. This approximation is reasonably accurate in a wide variety of typical cases, and can be computed at littl cost beyond that involved in estimating the variance of the system failure probability. Th development of this approximation also provides an improved understanding of the factors whic influence importance of any given component depends more on the variances of the failure probabilities of the minimal cut sets in which that component appears than on the variance of the component failure probability itself.

Our work is illustrated by several numerical examples. We also apply the techniques which w develop to an analysis of the reactor protection (SCRAM) system in a pressurized water reactor. This analysis is based on the fault tree for the reactor protection system presented in the Reactor Safety Study (1975). One result of our analysis is an estimate of rods contributes to th overall uncertainty about the probability of SCRAM failure.

PANEL SESSION

ON

ISSUES IN RISK AND UNCERTAINTY

CHAIRMAN

RICHARD D. ABEYTA

US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY

IMPLEMENTATION OF RISK INFORMATION INTO THE DoD DECISION MAKING STRUCTURE

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The time has arrived for accurately predicting programmatic cost and schedule risk on large weapon system projects. Management science and operations research techniques coupled to power of today's computer provide timely decision information for sophisticated budgetary and scheduling strategies. However, the time for using this information in a systematic fashion has not arrived. This document discusses the problem.

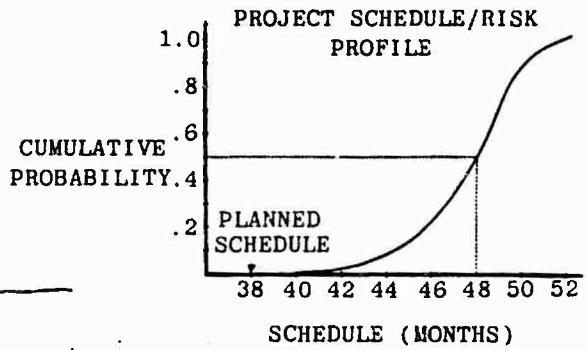
Some years ago, I was working on the cost/schedule budgets and risks for a major weapon system development. I was suddenly summoned by the newly appointed Project Manager. Upon arrival he promptly asked "Mr. Cockerham, what is the probability that I will bring this program in on schedule?" With surgical precision, I replied "Zero, Sir." He asked "What is the probability that I will bring this project in within costs?" Again, my reply, "Zero, Sir." He raised his voice and asked "Well then, what is the good news?" I answered, "That was the good news!" In looking back at the exchange, the Project Manager was just trying to learn something about his program risks and I was of the mind set to simply answer the question and no more. This was a rather meaningless exchange in that probability alone did not indicate the risks nor help the Project Manager better understand his program.

To illustrate the point a risk profile for the schedule of project is shown on Figure 1.

An Appropriate Statement of Risk:

"There is a (.5) probability that the program will take up to ten (10) months additional time to complete than planned."

FIGURE 1



This does not mean that the Planned Schedule should be rescheduled to forty eight (48) months. On the contrary, the thirty eight (38) month Planned Schedule is used to drive the program to the earliest possible conclusion. This strategy, in fact, serves a useful purpose but unfortunately, total program dollars are often tied to a zero probability schedule which of course yields a zero probability budget. Such is just one of the numerous examples of the difficulties in communicating with probabilistic information. Even when these difficulties are overcome at the program level, the Project Manager is, at best, reluctant to communicate this information to higher levels. This can be easily understood when one looks at some of the type information yielded from a probabilistic analysis. The following examples are true statements concerning some well planned programs.

"Probability of meeting the schedule is zero."

"Probability of meeting the planned cost is zero."

"Incremental funding of some long lead items for production should be initiated prior to the development program."

"$100M of RDT&E funding is needed for the planned program two years after the IOC."

"There are negative cost risk in the middle years of the Engineering Development."

"The cost risk is greater than the planned project budget."

Although there are inherent difficulties in communicating risk information, the primary difficulties in DoD are presented by a system of compartmental decision making that is steeped in tradition, power structures and resistance to change. Although frustrating at times, it is recognized that the aspects of our system that give reasons to problems, also give reasons to much success. Nevertheless, there are substantial problems in implementing risk information to the DoD decision making process.

The problem begins at the Congressional level in that there are no requirements for uncertainty or risk information to support the Congressional responsibility of deciding which programs are funded and how much. Moreover, the Congressional decisions are intertwined with the political process which customarily yields compromised results. Such decisions are largely based upon qualitative assessments and political values. There are no management science or operation research methods to describe the Congressional process. However, it is my contention that it is better to know the program's planned cost and risks than to know only the program's planned cost.

At DoD there has been no shortage of words written and words spoken to the need to analyze, plan and budget for program uncertainties. Lacking in these words are firm instructions, guidance, requirements and the propensity to use the information.

The Defense Acquisition Initiatives have stimulated some thinking and action by the Services. However, the action has been tenative and lacking in application. This is understandable in that there is no coordinated push from DoD, nor has Congress expressed any approval, disapproval or even knowledge of the efforts to budget and plan for risk. Congress is hardly to blame since there has been no DoD spokesman on the subject and service projects mask the risk cost in their budgetary submissions to Congress.

The following discussion addresses the Lessons Learned concerning the Implementation of the TRACE Concept for the Navy. The lessons learned are based on experience from the Army's TRACE program and the Navy's experience since September 30, 1981. The information was generated by this author under a contractual effort for the Pilot Application of the TRACE Concept for the Navy, February, 1983. The lessons are generally applicable to DoD interest and are categorized by the following areas:

Navy TRACE Implementation Lessons Learned

* Fiscal Management
* Training/Education
* Manpower
* Methodology
* Application
* Project Management
* Resources

The nature of the lesson is described as an observation with support rationale and followed by recommendations. The subject areas are addressed independently but are in fact interrelated. Therefore, the acceptance/rejection of the observations and recommendations should also be viewed collectively.

Fiscal Management

Observation:

The Navy has not developed the fiscal management methods to systematically incorporate the elements of the TRACE concept. There is confusion and doubt on behalf of Project Managers on how to prepare budgetary submissions with the Risk Cost Estimate (RCE) and what adverse effect may result when compared to previous budgetary submissions.

Support:

The Army developed a management system in conjunction with the methodology of the TRACE concept. The management system described the who, what, when and how the Army RDT&E monies would be managed. Organizational infighting and confusion were completely avoided. Though the Army system has some shortcomings, the TRACE concept has survived largely due to a comprehensive management system from the onset. The Navy's approach has been overly cautious to not make changes until there is certainty that the TRACE deferral monies will not be rejected by Congress. The Army has already provided the lesson that Congress will not remove the TRACE deferral monies when properly presented. However, the Navy has not determined the method of presentation nor the means for managing the money thereafter. Navy policy on these matters should not be mutative and chance failure at each level of budgetary review. Instead the lesson learned by the Army should be heeded and Navy policy established accordingly to Navy needs.

Recommendation:

Immediate action should be taken to establish the Navy's management system of RDT&E and production TRACE deferral funds. This effort should include how the funds are established, updated, processed, authorized, expended and tracked.

Training/Education

Observation:

Training and education at all levels in the Navy is currently needed.

Support:

The lessons learned by the Army were:

1. TRACE was initially successful due to a comprehensive educational and training program. Congressmen, Senators, professional staffers, and top management at DoD, DA and DARCOM were given 15-20 minute individual presentations on the concept. Every Commanding General, Deputy Commander, Project Manager and Deputy Project Manager was individually given a 20-30 minute briefing. Management staffers at all levels were briefed in groups of twenty (20) or less for approximately one hour. Cost and system analysts were given two (2) day courses. All training was provided by the same training team to insure consistent and exacting information.

2. As TRACE was initially successful on a short term basis due to the educational program, TRACE was equally unsuccessful on a long term basis due to a major extent, to the lack of follow-on training.

Recommendation:

The Navy should initiate an intensive training and educational program to introduce the science and management methods associated with the TRACE concept. This short term training should be coordinated with a Navy handbook and be similar in scope to the Army's initial training program. The training should be accomplished in no more than six months at a cost of less than $100K. Subsequent to the initial training, a plan should be developed for a long term in-house training capability. This could be incorporated into the mission of Navy or DoD schools.

Manpower

Observation:

Currently, no significant manpower capability has been manifested within any service to apply the scientific methodology supporting the TRACE concept.

Support:

From Army, Navy and major contractor experience there is no organization or job function or job code that can readily be used to perform TRACE type analyses. The problem is independent of any lack of training or education on the subject. The problem can be visualized in that virtually all organizations are divided functionally in elements, (i.e., cost, schedule, program plans, program management, test, logistics, quality assurance, procurement, personnel, etc.). However, a TRACE analysis requires that detailed analysis be performed across all elements as relates to cost, schedule and uncertainties. Furthermore, all elements are modeled and analyzed together. This is all possible due to the advancements in computer hardware/software technology. However, traditional organizational elements are not structured to take advantage of computer technology promoting integrated analysis and decision making.

Recommendation:

On a trial basis with a lead command, the Navy should detail a group of four to six individuals to do acquisition planning. This group of acquisition planners would work on multiple projects and cut across functional boundaries. Within six to twelve months a credible and useful in-house capability for acquisition planning and TRACE analyses could be established.

Methodology

Observation:

Methodologies in support of probabilistic analysis for the TRACE concept have not been established by the Navy.

Support:

For the analysis and distribution of TRACE deferral RDT&E monies the Navy has used an interactive network analyzer known as RISNET and methods of risk enumeration. These have been accomplished on a contractual basis and the Navy has not taken steps to endorse nor establish an in-house capability. Having the methodology in-house is the most essential part of establishing a capability. The computer hardware/software and operator's instructions must be made available and accessible for any significant utilization.

For TRACE production, there has been no effective methodology developed by any Service. The areas of production cost, cost overruns and production risks are matters of great national concern, regularly voiced through the Congress and the news media. However, there is no concerted effort to develop the methodology to accurately predict production costs and cost risk.

In summary, the RDT&E methodology exists and is available to the Navy. The production methodology does not exist.

Recommendations:

1. The Navy acquire the hardware/software for RDT&E TRACE analysis and make it available to all commands.

2. The Navy initiate an applied research program on production cost risk analysis for a ship, aircraft, and missile system.

Application

Observation:

The planned applications for Navy projects are insufficient to support the implementation of the TRACE concept.

Support:

The Carlucci initiative requires the services to implement TRACE or a TRACE type system. The explicit implication is that the TRACE concept is to be applied to all projects at all commands. The Navy has initially had good experience in applying the methodology, but only at one command and on one project. Application to programs must be significantly increased if the implementation of the TRACE concept is to be a serious consideration.

Recommendations:

1. Building on the NAVAIR experience, the S-3B application should be continued in order to demonstrate the maintenance of the technology and usefulness on a continuing basis. In addition, two new applications should be initiated. The projects should be selected based on a need for detailed planning and costing. If possible, the projects should be of high complexity and early in the conceptual or development phase.

2. In conjunction with lessons learned in Training/Education, Methodology, Manpower and Application, the technical

responsibility for the application of the TRACE methodology should be identified within NAVAIR.

3. One application of probabilistic network analysis should be initiated for an R&D program at each Navy command.

4. One application of TRACE for production (TRACE-P) should be initiated for a lead command. This would be an applied research effort and should be performed on a pilot project for lessons learned.

Project Management

Observations: S-3B Experience

1. S-3B Project experience with complete RISNET analysis was judged favorable and cost effective.

2. S-3B PMA used the network model as a vehicle of communication with the prime contractor to baseline the program (i.e. program logic, milestones, deliverables, critical path, costs, and uncertainties). The network continues to provide a framework for programmatic communication between the PMA, Lockheed, NADC, and JMCA.

3. The prime contractor used the network to better define the activities and interrelationships of the program. The prime contractor was receptive and helpful in the application of the RISNET methodology.

4. The S-3B PMA used the network model and RISNET data to successfully defend the project's baseline budgets and schedules.

Support:

The TRACE budget determination is just one by-product of interactive network analysis. The value to the Project Manager encompasses all aspects of the TRACE methodology to include:

Master Network Display
Sub-network Display
Schedules
* Barcharting
* Milestone/Deliverables
* Critical and Near Critical Paths
* Uncertaint..s/Risks
* Tracking and Control
Costs
* Baseline Costing by Fiscal Yea.
* Cost Risks by Fiscal Year
* Budget Allocating
* Multiple Cost Functions
Joint Cost and Schedule Analysis
Alternatives and Trade-off Analysi

Recommendation:

The Navy should expanc applications of the TRACE methodolog: for Project Managers. (See Application Recommendations).

Resources

Observation:

Insignificant resources have been committed to the application of the science embodying the TRACE concept.

Support:

Between 1972 and 1977 the Army spent $14,000 for the TRACE Guidelines. In 1978, $200,000 was used to purchase RISNET software and training for all Army RDT&E commands. Since 1981, Army in-house expenditures are estimated at $200,000 for the purpose of establishing a methodology for analyzing production cost uncertainties. Since the Carlucci Memorandum in April 1981, Navy expenditures total approximately $200,000. All resources expended on methodology and training is equivalent to approximately 5-6 man years since 1972. This is less than one-half man per year for a concep credited to save millions of dollars Each year the Government spends ten of millions of dollars on conferences, seminars, and symposium to address the problem of cos estimating for weapon systems. Yet the most promising field of cos planning, predicting and budgetin receives virtually no funding yea after year. TRACE methodology is a the leading edge of the computer aided decision sciences and should be pursued aggressively.

Recommendations:

1. DoD, through a lead Service, should commit a minimum of five million dollars in FY84/85 for the specific advancement of TRACE methodology for RDT&E and production; procurement of computer hardware and software; and education at all levels.

2. DoD, through a lead Service Command, should initiate a study to define a physical facility of computers, visual screens, graphic terminals, plotters, communication equipment and software that would provide state of the art planning, costing and control of programs. The system definition should address the schedule and resource requirements for the facility, security, computer hardware, data base and operational software, documentation, training, implementation and cost for duplicate facilities.

Many problems face the practical implementation of risk information into the decision process. However, the last year has produced greater progress than all previous years. Request for proposals are requiring risk information and in at least one case, cost realism was evaluated equal to the total cost. DoD top management, on several occasions, has mentioned the TRACE concept to Congress in testimony regarding the improvements to the acquisition process. Prime contractors are using risk methodology to enhance their proposals and risk management methods to better control their projects. At least one of the services is actively reviewing selected programs explicitly for cost risk. Most significantly, the reviews are conducted by the Office of the Under Secretary.

Heretofore, the exclusion of formal risk information in the decision process has been the greatest shortfall in DoD and Congressional planning. Changes have begun and are inevitable because the knowledge of risk has been proven not only useful but absolutely necessary.

ISSUES INVOLVING UNCERTAINTIES IN DEFENSE ACQUISITION AND A METHOD FOR DEALING WITH THEM

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ABSTRACT

This paper analyzes two work processes involved in defense acquisition which are replete with uncertainties. These are the proposal phase and the architectural design phase. Both phases involve a vendor designing alternative system in response to a set of stated (and perceived,) requirements, followed by the government agency's final selection of a preferred system design (and a preferred contractor). Since these efforts many times occur during the preliminary phases of the acquisition process, many uncertainties are present, including: technological uncertainties, uncertainties in the timely availability of inputs, workload uncertainties, and equipment reliability and maintainability, all of which lead to performance, schedule, and cost uncertainties.

Several issues involving these uncertainties are identified:

1) Do government agencies provide vendors with sufficient information to enable them to design their most cost-effective systems with respect to these uncertainties?

2) What additional information should be provided which will enable vendors to do so?

3) What credible evidence should vendors provide in their proposals and system designs which can increase the government's confidence that the system being proposed will in fact be delivered within the schedule and cost estimated?

Finally, a systems evaluation methodology is described and illustrated, providing a recommended way of dealing with these issues.

OVERVIEW

Defense systems are composed of elements which inherently involve various uncertainties, including technological uncertainties, transportation uncertainties, equipment unreliability. In general, we know how to deal with these factors. This paper focuses on certain deficiencies in the systems acquisition process itself, which prevent the government from obtaining the most cost-effective system meeting the needs and constraints. The paper also presents a method of overcoming these deficiencies.

The specific parts of the system acquisition process to be focused upon are:

- The proposal phase from RFP to Source Selection

- The architectural design phase in which a preferred preliminary design best meeting the government agency's needs and constraints is provided.

The specific improvement I have in mind is an increased involvement of the Government agency in the two processes being treated.

This paper analyzes the work process involved in systems design in which a set of user requirements and environmental constraints are converted into alternative system designs and a preferred design selected. It identifies some basic problems encountered when a systems design organization is used to initiate this process of designing a new system for a client organization. These problems fall into two major classes: 1) how to properly state the requirements and constraints which the system must meet, and 2) how to properly evaluate the systems proposed by the system designers. A major thesis of this paper is that the systems planning process is a cooperative effort between the client and the designer. If the latter is to properly design a system he must not only thoroughly understand the requirements, but also develop an evaluation procedure which is acceptable to the client and meets his needs.

An analysis of various evaluation methods used is also provided. The factors often used for evaluation include: 1) System Performance or other Technical Factors, 2) Date of Availability of the System, 3) System

Cost, 4) Risks (in performance, schedule and cost which arise when all system components are not available "off the shelf," but some have to be developed), and 5) other miscellaneous factors. Generally the values of each key factor for various alternatives are assembled in matrix form for validation and comparison purposes. Unfortunately, it is rare that one alternative is superior to all others for all descriptors (often the alternative offering superior performance is more costly or has higher risk). Thus some means of relating all of the evaluation factors must be used. This is frequently done by applying weighting factors (generally selected heuristically), which causes the final "score" to be highly dependent on the values of the weights. Furthermore clients often have difficulty in defending this approech to others requiring such justification.

This paper examines in deteil the basic process of specifying requirements, creating design alternatives, and evaluating them against a set of criteria. It describes e number of key pitfalls faced by the systems designers as well as the evaluators which normally occur and which should be avoided during a systems planning effort. An improved evaluation process avoiding these pitfalls is presented for use by the evaluetion team, allowing them to select the preferred alternative in a more rational, defensible fashion. Finally, a method of presenting evidence which supports and enhances the preferred design alternative is described.

While the main focus of the paper is on the architectural design process in which there can be close cooperation between the system designers and the client, many of the techniques described also apply to the systems design effort which occurs during a proposal generation effort when such cooperation does not exist. Thus the paper is extended to show how to deal with these problems during a proposal effort.

This paper builds on work in source selection of EDP systems previously performed by the author for the Assistant Secretary of the Air Force (Financial Management). The evaluation process presented now includes the element of developmental uncertainties which was not required in the original work. While the paper has greatest value for contractors and Government agencies involved in the design of large, complex systems requiring development, it is also applicable to smaller projects in the private sector as well.

PART I. PROBLEM DEFINITION

PART I reviews the architectural systems design process, indicating the various work functions involved, and the information required by a systems designer if he is to provide a preferred system design to a client. Some of the difficulties in obteining this information ere described.

1. INTRODUCTION

A major objective of this paper is to identify a number of pitfalls which can prevent a systems designer from proposing and designing the most cost-effective system for a client, taking into account risks and uncertainties, and to indicete ways of avoiding such pitfalls.

At the heart of these problems is that the entire work process is generally divided among those major contributors, each of whom contributes his own expertise to the process:

- o The system user, who will operate and support the system once it is completed, provides e statement of his needs (and desires), es well as the environmentel constreints which are present.
- o The system designer (generally a contractor experienced in this erea) who trensletes the user needs into a set of feasible design alternatives making whatever trade-offs are necessary, end recommends the preferred system.
- o The procurement organization which serves as the point of contect with the system designer, generally is heavily involved in the eveluation of the design elternatives in terms of the trade-offs of performance, cost, availability date and risk, and makes the ultimate decision regarding the preferred system selected.

For purposes of this paper we shall define these participants in the following way:

- o The term "Client" will represent the procurement organization who is funding the architectural study. The client will be responsible for obtaining the specifications from the users. Since the client knows the budgetary constraints, he plays a large role in the ultimate systems evaluation function leading to the selection of the preferred system.
- o The term "Designer" represents the systems analysis and design organization who has been contracted to perform the design study.

Although a systems designer works with the client under varying circumstances, this paper concentrates on two disparate situations which bound most of the set. The first example is an architectural design effort in which the designer maintains a close interface with the client. In the second example, the systems designer is a vendor proposing a system design to a client. In this situation there is generally minimal contact with the client during preparation of the design proposal.[1]

2. WORK PROCESS INVOLVED

Both situations involve a common work process which typically includes these functions (Figure 1):

- o Client sets system specifications, including desired performance, system availability date, and constraints.
- o Designer proposes one or more design alternatives potentially meeting the system specifications.
- o Designer develops an evaluation model based on his understanding of the job to be done and his perception of the evaluation model to be used by the client.
- o Designer uses the evaluation model to evaluate alternative system design configurations and selects the preferred system design.
- o Designer submits his proposed system design to the client for his evaluation.
- o Client validates that all specifications have been met, and in a design competition, evaluates all proposals submitted by vendors, and selects the preferred proposal.
- o Client makes final selection of the preferred system.

[1]This situation is quite common in the development of systems for the government, particularly the Department of Defense.

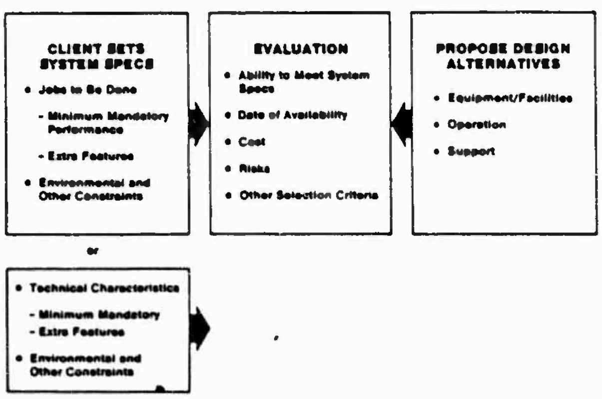


Figure 1. Systems Planning Work Process

Having presented an overview of this process, we shall now examine each of the steps in greater detail, focusing on some of the pitfalls which may arise.

3. POTENTIAL PITFALLS IN THE WORK PROCESS

It should be obvious that the two major drivers of the design effort are the designer's understanding and perception of: 1) the client's specifications, and 2) the client's evaluation model. Unless the designer understands what the client has specified, the final system design may be configured to produce the wrong system. Specifically, unless the designer knows and understands the evaluation model to be used by the client, the designer will not be able to properly make his performance, cost, availability, and risk trade-offs to produce the "optimal" system desired. During an architectural design effort, there are usually opportunities to meet with the client to obtain a good mutual understanding of what the client really desires (the "real" system specifications), as well as the proper evaluation model which should be used. Unfortunately, this type of information is generally not available from the client during a proposal effort. Thus in the next four sections we shall describe a process for providing designers with a better understanding of system requirements and the system evaluation process, using the case of an architectural study as an example. We shall then consider the analogous planning problem which should occur during a proposal effort.

4. UNDERSTANDING THE SYSTEM SPECIFICATIONS

The first part of a client's specifications typically describes characteristics needed by the designer to synthesize the system. Sometimes these descriptors indicate the concept of operation, the missions, functions and jobs to be done, and the performance characteristics (e.g., speed of response, reliability and maintainability) required. Sometimes these descriptors consist of a set of technical or design characteristics (e.g., core size and number and type of displays for a data processing system).

The second part of the specifications may consist of a set of environmental or operational constraints that must be observed. This set could include operational temperature, humidity, shock and vibration, as well as specifications which must be met so that this system can interface with other systems. In addition, the set of requirements should include the date when the system must be operational.

These specifications are generally stated in two ways. The first is a set of minimum mandatory requirements that must be met or else the design will be considered nonresponsive to the specifications. Sometimes the client indicates a desire for additional capabilities if they are available. These "desirable features" are not made part of the mandatory requirements since the designer may not be capable of providing these.

Early in the planning effort, the designer should review the system specifications. Any questions about these should be resolved during a conference with the client early in the design study effort.

5. UNDERSTANDING THIS EVALUATION MODEL

Having established a mutual understanding of the initial system "requirements" as the baseline for the architectural design study, the next step is to obtain a mutual agreement with the client of the evaluation model to be used. Here we are concerned with three major points:

- o The evaluation model or method should be explicit so that the designer can perform various cost-performance trade-offs to arrive at a preferred solution.
- o The evaluation model should be rational, credible and defensible.
- o The evaluation model should be agreed to by the client. If not, the final results obtained may not be acceptable.

With the preceding discussion in mind, let us now examine various evaluation methods which are used by various government agencies, and describe how designers may respond to each.[1] This will be helpful in determining whether such responses are desirable, or if the evaluation method should be modified accordingly to produce the results desired.

5.1 The "Extra Performance Is Overkill" Evaluation Method

The first evaluation method examined, illustrated in Figure 2, operates as follows:

- o All evaluation factors and their minimum mandatory requirements as contained in the Statement of Work (SOW) are listed in column form.
- o The actual values provided by each alternative system being evaluated are then listed and validated by the evaluator that these values each meet its requirement.
- o Any system characteristic which is over the minimum level specified can be considered "overkill", and has no additional value as compared to the minimum level.
- o The selection criterion used is as follows: choose that system whose characteristics individually meet or exceed all constraints and minimum specifications, and whose Present Value Life Cycle Cost (PVLCC) is least among all alternatives under consideration.

The main advantage of this approach is that it explicitly states the "rules of the game". Ideally each system would be designed to exactly equal the design specifications since any larger values would generally result in higher cost. In this case the evaluator might select as the preferred system alternative the one which has the least PVLCC.

Unfortunately system components come in discrete units rather than from a continuous array, and the specifications of similar units generally differ from vendor to vendor. Thus to be entirely responsive to the specifications which have been issued, the only feasible design solution may be to use components which individually meet or surpass the minimum requirements which have been stated. In this case, excess performance may be provided, and the key deficiency of this approach is that extra performance is ignored. It should not be. There may be justification in giving some extra credit for

EVALUATION MATRIX

Descriptors/ Evaluation Factors	Minimum Values	System A	System B
Technical Factors			
—Required Throughput			
—Capacity			
—Response Time			
Performance and Other Factors			
—Capability Requirements			
—Reliability			
—Maintainability			
—Availability to User			
—Date of Availability (IOC)			
—Schedule Risk			
—Performance Risk			
—Upward Compatibility			
—Growth Potential			
—Flexibility			
Cost Factors			

Validate That Each Vendor Meets All Minimum Requirements
Excess Performance Is "Overkill"
Choose by PVLCC

Pitfalls:

- Excess Performance Has Worth
- Trade-Offs Among Factors Are Possible

Figure 2. Evaluation Method 1

[1]While this discussion specifically applies to government contracts, it also applies to many non-government contracts as well.

extra performance to counter balance the additional cost which generally accompanies extra performance.

If extra credit cannot be given for excess performance, the designer might be permitted to compensate for a performance deficiency by providing excess value of some related characteristic. For example, the same probability of kill for a missile could be obtained by either having a highly accurate guidance system and a low yield warhead, or having a lower accuracy guidance system and a higher yield warhead. Thus it may be possible to achieve the same end result at lower cost to the client by using a component which may not quite meet an "arbitrary" minimum specification if another related, higher value component is used as compensation. The designer can best make such determinations since the designer usually knows the relationship between performance characteristics and cost, and hence can decide which set of his available characteristics can best perform a defined job (within constraints) at lowest total cost.

Thus the major improvements which can be made to the "Extra Performance is Overkill" method are to define the jobs to be done at the mission or functional level and allow intersystem trade-offs to be made within a constrained set of boundary conditions. Note that the system design task will also permit trade-offs between quality and quantity. Thus, in the case of a missile system, if the probability of kill of one missile is greater than another, it may be possible to configure both systems to achieve a given level of target destruction, in which a lower performance missile will require the use of more missiles to do the same job than a higher performance missile. The PVLCC calculations will determine the preferred system. To protect the client against unacceptable design features (such as the proposal of a very low performance missile in the previous example), the client can specify a minimum value that must be provided for any characteristic (such as the missile probability of kill must exceed 0.5).

5.2 The "Point Scoring" Evaluation Method

Another disadvantage of the previous evaluation method is as follows. The client may have in mind a minimum level of capability, but may desire additional capability if obtainable at a reasonable cost. Thus, some way must be found to give "additional credit" to those vendors which can provide these desirable features or superior characteristics beyond the minimum specifications. This can be accomplished by using the so-called "point scoring" method, illustrated in Figure 3. In this method the key evaluation factors are listed again as one dimension of the evaluation matrix, and their values for each alternative constitute the other dimension. As in the previous evaluation method, the next step in this evaluation method is to validate that each of the mandatory requirements has been met. Then each of the key factors where a value other than a fixed mandatory value is desired is assigned two numbers which will translate its value into a point score. The first number (V in Figure 3) translates the extra amount of performance provided into a normalized value (say from 0 to 10 to normalize the worth of each factor). The second number (W in Figure 3) provides the Weighting Factor or relative worth of this factor compared to all of the other factors involved. For example, cost may constitute 60% of the total score possible. Choosing the latter as 1000 points, the value of W for cost may be chosen as 600 points. Thus the lowest cost design could be given a V = 1, and each design would receive a V equal to the ratio of the cost of the lowest cost design to the cost of the design under consideration. Thus if one cost were twice as much as another alternative, the lowest cost system would receive 600 points and the other system would receive 300 points. These numerical values chosen for V and W would be based either on available operational data or on the judgment of the technical evaluators.

Each system alternative would then be evaluated with respect to each factor in order to determine how many of the maximum points allocated would go to each of the proposed alternatives. A total score for each alternative is then obtained by summing each of its factor scores.

This method does have the advantage of providing credits for extra performance.

EVALUATION METHOD 2

POINT SCORING METHOD

Dimensions/ Evaluation Factors	Weight	System A	System B
Technical Factors			
–Required Throughput	W_1	$W_1 \cdot V_{1A} = P_{1A}$	$W_1 \cdot V_{1B} = P_{1B}$
–Capacity	W_2	$W_2 \cdot V_{2A} = P_{2A}$	$W_2 \cdot V_{2B} = P_{2B}$
–Response Time	–	–	–
Performance and Other Factors	–	–	–
–Capability Requirements	–	–	–
–Reliability	–	–	–
–Maintainability	–	–	–
–Availability	–	–	–
–Date of Availability (IOC)	–	–	–
–Schedule Risk	–	–	–
–Performance Risk	–	–	–
–Upward Compatibility	–	–	–
–Growth Potential	–	–	–
–Flexibility	W_n	$W_n \cdot V_{nA} = P_{nA}$	$W_n \cdot V_{nB} = P_{nB}$
Cost Factors			
		Score A	Score B

Give Credits for Excess Values
Choose by "Highest Score"
Pitfalls:

- Can Not Agree on Weights and Value Coefficients
- Adding Points Is Artificial

Figure 3. Evaluation Method 2

However, it also has several difficulties. First, while the key factors contributing to the worth of a system may be identified, the use of value and weighting factors (V and W) as the method of combining factors is always subject to challenge by other evaluators or decisionmakers. Thus, what is needed is a more defensible way of combining the factors listed.

The second difficulty inherent in the point-scoring method is, even more serious. This method combines cost values with the technical or performance values through the vehicle of points. Yet while selecting the preferred system based on highest score is intuitively sound, there is no scientific justification for the use of such a "figure of merit" approach. There are two more widely accepted methods of selecting a preferred alternative. The first is to select that system alternative which will perform the operational functions and meet all constraints at the lowest total cost to a defined organization (i.e., pivoting on equal effectiveness). The second approach is to select that alternative which will yield the highest performance of the operational functions at a fixed total cost (i.e., pivoting on equal cost). Such a method must also take into account the risks and uncertainties involved.

Lastly, experience has shown that when a large list of factors are included in the evaluation, the final score for each system is often very close to one another, rendering this evaluation method ineffective. One reason for this closeness in score is because the value of most of the large number of factors being added together are fairly close to one another since most values correspond to the minimum mandatory requirements. These values overpower value of the few remaining factors which describe the real differences among the system alternatives. Thus, while these "matrix evaluation methods" enable the evaluator to rapidly focus on the relative differences among systems, they have basic flaws as positive selectors of the preferred system.

PART II. GENERATING AN IMPROVED EVALUATION METHOD

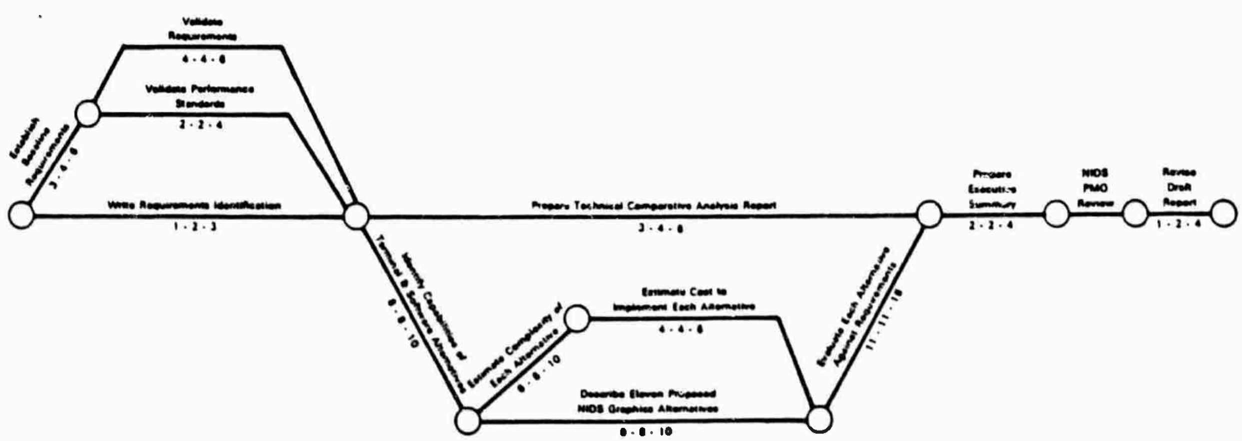
PART II returns to fundamentals and analyzes the key factors which represent the results of an effort of developing and constructing a system which involves components that are either beyond the state of the art or are not readily available "off-the-shelf" and thus have to be developed. From this scenario we develop an improved method for evaluating proposed system alternatives.

6. CONSIDERATION OF DATE OF AVAILABILITY AND ITS UNCERTAINTY

The previous discussion of the two commonly used evaluation methods and their deficiencies concentrated on the two key evaluation factors of system performance (getting the jobs done) and cost. In this section we shall consider two other evaluation factors which must be considered when the design contains elements which must be developed. In this case the system designer (and client) must also consider technological or developmental uncertainties which are further reflected into:

- The date when the system will be available for use
- The final system cost
- The system performance achieved

To perform this analysis we need to consider the entire effort of developing and constructing the system as a work process which can be modeled as a series-parallel network as shown in Figure 4. This network indicates



Include All Work Elements: RDT&E, Procurement, Installation, Operations, Maintenance, Support
Indicate Required Deliverables
Indicate Completion Time and Their Uncertainties

Figure 4. Project Activities Network

that this entire work effort (defined as "the project") consists of a group of work activities arranged in a preferred sequence or order. Some of these activities (when completed satisfactorily) produce outputs or deliverables required as part of the Statement of Work. Each of the activities requires time and the expenditure of manpower and other resources. Thus using Critical Path Scheduling techniques the network can be analyzed and the project completion time can be calculated (based on the sum of the times of those activities along the "critical path"). In addition, the man-hours required can be summed and converted into manpower costs and total costs.

Having described the project effort as a work process, two observations can be made. First, the entire project effort can be completed in an acceptable fashion only if all of the various work activities shown in figure 4 are completed in the sequence shown, resulting in the completion of the various required deliverables. It can be assumed that if an activity is not completed satisfactorily, the project effort cannot continue and it will be aborted, unless a complementary activity which should also be shown in the network can be completed as a substitute.

Secondly, given that an activity is completed satisfactorily, the time and man-hours required for such completion can rarely be estimated exactly for all development type activities. This uncertainty in completion time can best be represented by a three-point estimate: the most likely value, and the limits of uncertainty at the 5th to the 95th percentile, as illustrated in figure 5a. The completion time of the entire project will similarly have a range of uncertainty as illustrated by the probability distribution of figures 5b and 5c.

6.1 Evaluation Calculations to be Made

To simplify the calculations involved, it will be assumed that the project activity network constructed describes exactly the work process to be employed. Since this assumption will be applied to all alternatives, the relative accuracy of the evaluation should not be greatly impaired. Here are the calculations to be made:

- Determine the level of acceptability for each activity in the network. Assign the planned resources to each activity and provide a three-point estimate of the time required to complete each activity in an acceptable fashion using these resources.
- Estimate the maximum time each activity will be permitted to continue before the activity, and hence the project, will be terminated. If desired, parallel paths can be inserted into the network to reduce the chance of project termination.
- From the individual probabilities of activity failure, calculate the probability of project termination (failure). Then calculate the project completion time as a probability distribution when the project is successful, as illustrated in Figure 5c.
- Using the same time estimates, calculate the manpower cost and other

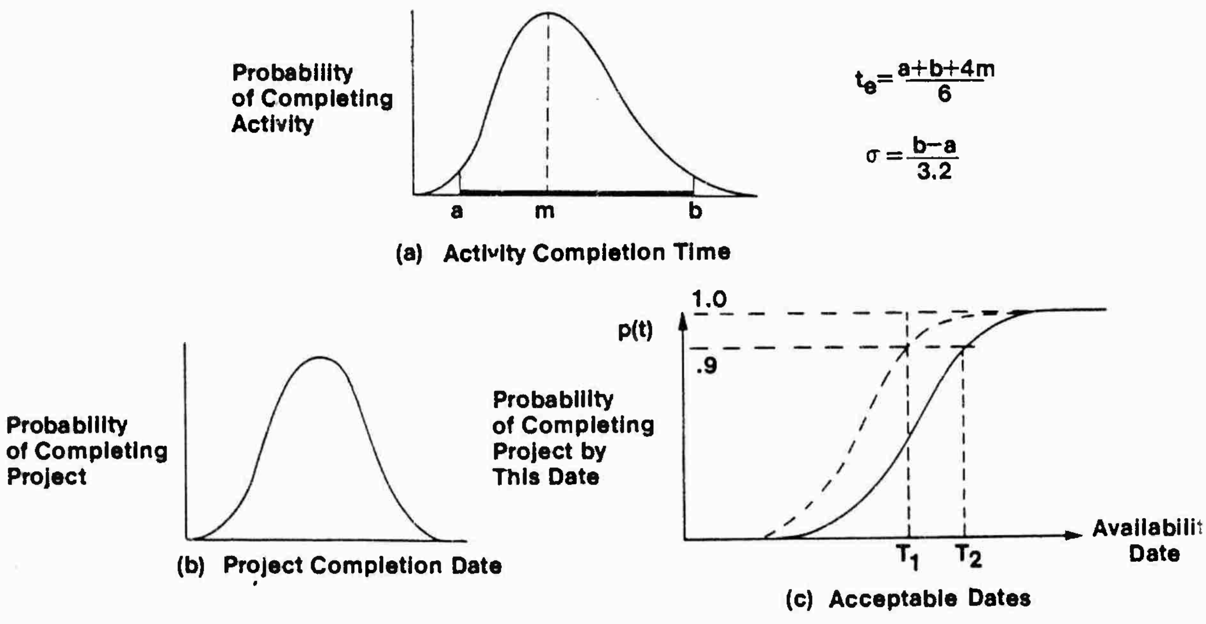


Figure 5. Schedule Risk (From Developmental Uncertainties)

costs associated with each activity and the entire project as a probability distribution. This will be similar to Figure 5b.

6.2 Representing the Project Results

From the previous calculations, the key evaluation characteristics of the project may be expressed as a three-dimensional probability distribution, as illustrated in figure 6. This figure should be interpreted as illustrating the statistical set of results of performing all development activities a large number of times. Each vector (having one of the end points shown) represents one of the results described by each of those coordinates: 1) the system capability of meeting the entire set of mandatory specifications, 2) the date when the system will become available, and 3) the total cost required to obtain the results. Applied to these results are two threshold levels of acceptability of: 1) minimum level of system capability, and 2) maximum allowable availability date. Applying these levels of acceptability (to both the project deliverables and to the system implementation process itself as it progresses), from a statistical point of view, it can be seen that certain of these "trials" are defined as being "unsuccessful", since they do not meet the minimum level of acceptability. These trials result in zero system capability, but do consume both time and cost, as represented by the cluster of points on the YZ plan (zero system capability). Note that the times spent on the project vary from early cancellation of the project to later cancellation. Costs of the unsuccessful project "trials" are also shown. The other points of Figure 6 represent the results of the successful "trials." Note that all successful trials meet at least the minimum level of system capability and all trials complete the project in less than the maximum acceptable date. The resulting capabilities, dates, and total costs are as shown in the three-dimensional, bell-shaped set of points.

This method of analyzing and evaluating results shows that performance risk can be defined as the probability of meeting the minimum set of requirements. By making the assumption that all activities (of the project network) are independent of one another and each must be completed by some specified date (or the entire project will be terminated), the probability of project success can be calculated as the joint probability that all activities will be successful (the product of the probabilities of success of all activities).[1]

Schedule Risk and Cost Risk will be treated in a later section.

7. DEFINING THE EVALUATION OBJECTIVE

Having defined the analytical structure for the evaluation approach, we can now explicitly define the selection objective as follows:

"To select a proposed system which performs a set of future required jobs at given work load levels and meets all required constraints including maximum availability date at the lowest total cost, taking into account all uncertainties."

This objective includes the following three major concepts:

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[1]Note that if the assumption of activity independence is not acceptable, a similar, but more difficult, analysis can be made taking the pertinent dependencies into account.

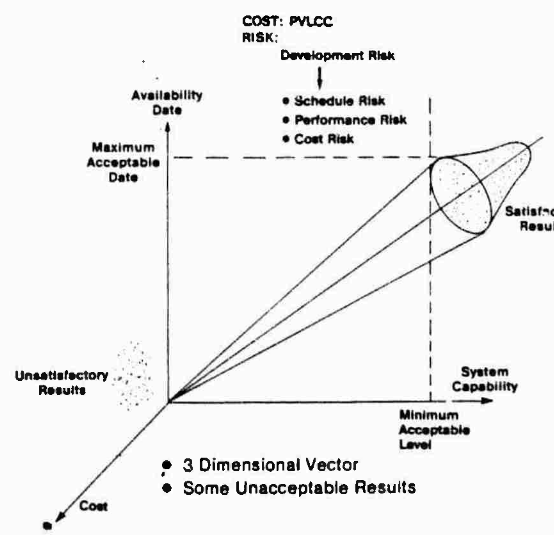

Figure 6. Measuring Project Output

a. The contractor must show that each of his system alternatives can perform all of the future jobs and meet all the constraints.

b. Lowest total present value life cycle cost should be the selection criterion.

c. Development and job uncertainties are the key factors which make the evaluation selection process a difficult one.

8. SUMMARY OF SYSTEMS PLANNING APPROACH

Figure 7 summarizes the steps to be followed in an architectural design study:

a. The client will define one or more sets of mandatory system requirements in terms of jobs to be done and constraints to be met. The client will also specify a set of desirable features over and above the mandatory requirements which they would like to obtain, if possible, and a set of jobs which would use such desirable features.

b. The designer will design a number of system alternatives which meet each set of mandatory requirements, on or before a specified availability date, at a level of risk specified by the client.

c. The designer will calculate the present value life cycle cost (PVLCC) of meeting the stated set of requirements at a level of risk specified by the client.

d. The designer will also provide total cost data relevant to providing and operating each desirable feature he provides, as embedded in the representative jobs for which the desirable feature is to be used.

e. Based on this data, the designer will calculate the cost of performing the set of jobs associated with each Desirable Feature proposed by the designer. This cost will be compared against the cost of performing the set of jobs if the proposed Desirable Feature were not available. For each of these sets of jobs, the least costly way of performing these jobs will be chosen and this cost added to the cost of performing the mandatory jobs.

f. These results (the preferred system for each level of system capability) will be shown to the client.

g. The client will select the final preferred system based on a comparison of the incremental cost to the incremental gain for increasing levels of system capability.

PART III. APPLYING EVALUATION METHOD IN AN ARCHITECTURAL DESIGN STUDY

PART III amplifies the description of the design approach by showing how to apply the approach in an architectural design study.

9. AN EXAMPLE OF THIS PROPOSED APPROACH

Having described the approach to be followed, we shall now consider an example of how the approach would operate in practice. The example used is that of an architectural design study of an information system.

9.1 Client Issues the Total Set of Requirements

As mentioned previously, this would include:

- The basic system workload (as characterized by a representative set of EDP jobs), in terms of the mandatory

1. Client will specify alternative sets of design requirements in terms of jobs to be done, performance and constraints.
2. Client will specify minimum mandatory requirements and extra features desired.
3. Constrain designers to provide alternative designs which meet the set of system requirements, including maximum availability date and level of risk.
4. For each alternative, calculate the present value life-cycle cost (PVLCC).
5. Determine the worth of any significant extra performance.
6. Select the system which meets the set of requirements and constraints at lowest PVLCC to client while accounting for risks and uncertainties.
7. Show preliminary results to client and trade-off specifications with feasible system results.
8. Designer assists the client in finalizing on Preferred System.

Figure 7. Summary of Architectural Design Approach

capabilities to be met over time, as illustrated in Figure 8

- All mandatory constraints to be met

- A statement of Desirable Features (or extra capability desired), and a statement of the set of jobs for which each desirable feature would be used if provided by the designer

9.2 Consideration of Mandatory System Capability

The first step which the designer must take is to configure one or more system alternatives which will meet or exceed the minimum mandatory workload requirement. Figure 8a shows the "input demand function" (in this case a workload which will be increasing over time). The increase shown is expected to be gradual from start until t_1, when a large increase is expected. The workload then continues to increase gradually until t_2 when a second large increase will occur. After t_2 the increase is again gradual. The planned system life is five years, which occurs at t_3.

In the example being presented, the objective of the system is to provide sufficient capability to process the forecasted daily workload within a 24-hour period. However, as shown in Figure 8b, the 24-hour period must also include time for Rework to correct all errors detected, and Down Time (for both preventive and corrective maintenance). With this in mind we shall define the term "Reli-ability" to represent the frequency of malfunctions, and "Maintainability" to represent the amount of time when the system has reduced capability due to required repairs or replacement. Thus the system designer must make certain that the net system capability will enable the workload to be processed in the required time.

These failure and down time considerations are illustrated in Figure 9. System Availability is defined as the proportion of Up Time to Total Time. The set of these factors may be treated in the following way:

a. Make certain that the total down time and associated reduction in system capability is taken into account when designing the system to meet the required workload.

b. Frequency of failure or system availability may also be treated as a system constraint, i.e., the maximum frequency of failure that can be tolerated.

c. All of the maintenance factors finally result in added cost, and will be accounted for in the Present Value Life Cycle Cost (PVLCC) analysis of each system.

9.3 Dealing With an Uncertain Workload

The previous analysis of system capability was based on the assumption that the input workload was known exactly, as illustrated in Figure 8a. Sometimes the assump-

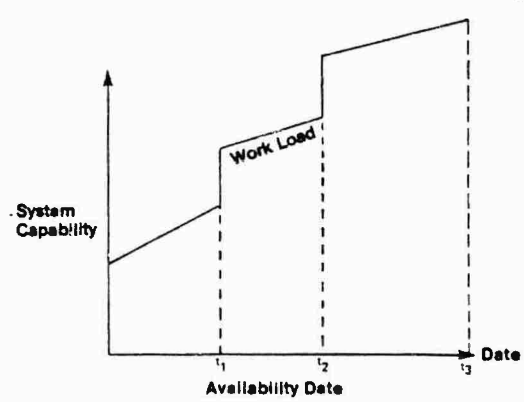

Figure 8a. Meeting the Workload

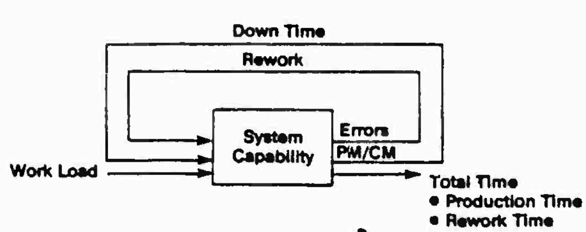

Figure 8b. Factor Affecting Time to Complete Workload

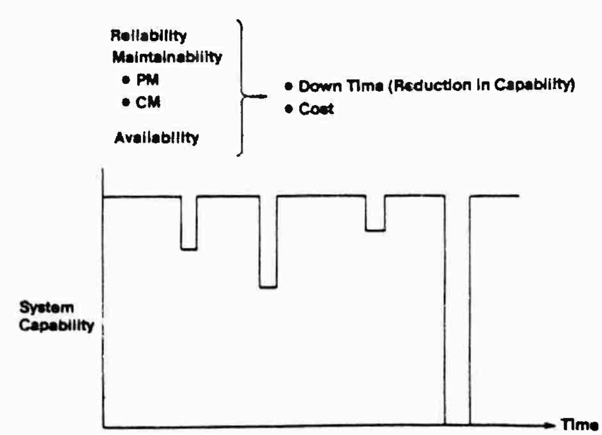

Figure 9. Down-Time Considerations

tion is made that this is the minimum mandatory workload but that extra credit will be given for systems having the capability greater than the minimum. The designer's problem is, how much extra capability is desired over time? Many times the client cannot accurately predict what the actual workload may be. However, some limits must be set if appropriate guidance is to be given to the designers.

One way of dealing with this uncertainty is to express the workload as a probability distribution as shown in Figure 10. Setting the upper limit is fairly straightforward, since this can be set as an arbitrary design limit beyond which additional capability is assumed to have no value. Intermediate probability values can then be inserted, as shown in Figure 10, using whatever data the client has available (either statistical data or judgmental estimates).

Based on this assumed workload, the designer must then design the system to be able to meet the entire range of workload levels, over time, adding additional system increments whenever required. In the illustration of Figure 10, the designer proposed System A_1 as the initial system. This system will "absolutely" meet the workload requirement in Years 1 and 2 and will "absolutely not" meet the requirement in Year 5. However, the designer proposed to add an additional capability to A_1, to yield System A_2, whenever A_2 is needed. Generally two constraints are placed on the designer for purposes of design and evaluation:

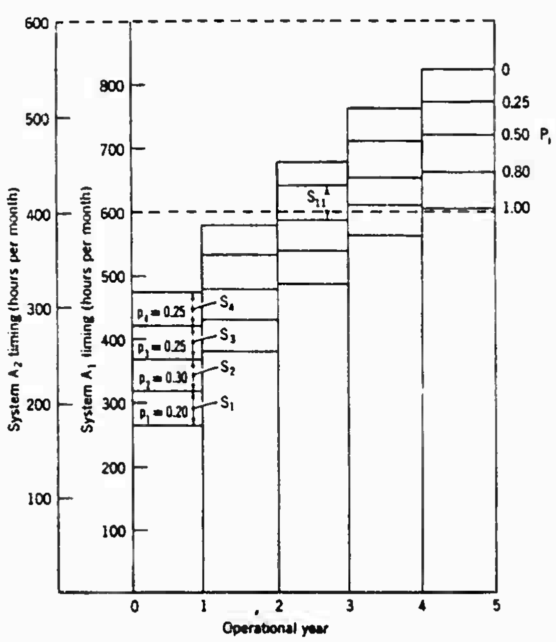

Figure 10. Designer Response to Meeting Workload Probabilities

- o No more than one or two growth additions will be permitted to keep disruptions within acceptable limits.

- o An addition will be required whenever the operational hours per month reaches some upper limit (say, 600 hours per month as shown in Figure 10). This will permit sufficient time for corrective and preventive maintenance. Alternatively, this limit could be a function of the system's demonstrated maintainability.

Providing such system "upgrades" during its operational life saves the user money since it prevents the user from having to buy more capability than is required (like A_2) at the beginning of system operations rather than when it is actually needed.

Finally the designer should provide "credible evidence" for the client that the preferred system can in fact meet the entire defined workload (as shown in Figure 10) over its entire levels, as well as all constraints. For off-the-shelf systems, this could be validated by live test demonstrations. For development type projects this could be shown by simulation or analysis.

9.4 Availability Dates and Schedule Risk

Given that each system has been designed to provide the required net productivity to meet the incoming workload specified in Figures 8a or 10, we shall now describe how the designer plans the development effort to meet the required availability dates (t_1 and t_2) and provides the necessary data to the client, enabling him to perform his validation function. Recall that Figure 4, which displays the project work process in network form and the time estimates of the activities along the critical path, was used to calculate the project completion date as the normal distribution of Figure 5c. In the example shown, there is approximately a 40% chance of successfully completing the project by date T_1 (60% chance of schedule overrun). However, the client may not be comfortable with this degree of risk. Thus, the system designer must find out what risk of overrun the client is willing to accept. Assume a 10% risk is acceptable. As shown in Figure 5c, for this 10% risk the project would be completed on or before T_2 which is later than T_1 and hence unacceptable. Thus, the system designer must reconfigure the project plan to reduce completion date. Generally this is done by adding more resources on one or more activities on the critical path until the new completion date probability function satisfying the requirement (10% chance of overrun at time T_1) is obtained, as shown in Figure 5c.

In summary, Schedule Risk is defined as the probability that the project will overrun a required delivery date. For purposes of the planning and evaluation efforts, the value of Schedule Risk acceptable to the client should be provided to the designer at the beginning of the study. Then it is up to the designer to construct the project work plan accordingly and provide the project activities network plus all time calculations to show that the completion date, as a probability function, satisfies both the time and risk requirements.

9.5 Consideration of Total Cost

The project activities network (Figure 4) is also the starting point for the cost calculations. From this network the cost of all work and cost elements (RDT&E, procurement, installation, operations, maintenance, and support) borne by the client must be calculated for each year.[1] Here the standard formulas for calculating the cost of an activity are used (e.g., labor cost equals the product of man-hours and labor rate). When the activity time is expressed as a three-point estimate, these times must be converted to an expected value and a standard deviation (as shown previously in Figure 5a). These values for time are then converted to labor cost values by multiplying each by the labor rate. Costs are then accumulated by year, and the expected value of cost and the cost variance for each year are calculated as follows: The expected total cost for the year is equal to the sum of the expected costs. The total cost variance for each year is equal to the sum of the squares of the individual standard deviations for that year.

When a probabilistic workload is assumed (as discussed in the previous section), each yearly cost must be handled as a frequency distribution. Operations, maintenance, or leasing costs must be calculated for each probability segment. Using Figure 10 as an example, first calculate the cost of segment S_1 as a function of its operating time. Using the time of the mid-point of the p_1 segment, and using the pricing data supplied the designer as well as the user labor cost, calculate the cost associated with this mid-point time. This cost has the probability $p_1 = .20$ associated with it. Make a similar calculation for the other segments, S_2, S_3, and S_4. Then calculate the expected value and standard deviation for these four probabilities. These terms are then added as part of the sum of the other expected values and the squares of the standard deviations of the cost terms of that year as described previously.

The expected value and standard deviation of cost for each year must then be incorporated into a present value analysis in the following way. First, apply the appropriate discount rate to each of the yearly expected values of cost. The sum of this result is the present value of expected cost. The present value standard deviation is calculated as follows:

- Find the standard deviation of cost for each year as the square root of the variance of cost for each year.
- Apply the appropriate discount factor to each year's standard deviation. This yields the present value of each year's standard deviation.
- Square each of these factors to obtain the present value of each year's variance.
- Sum each of these present value variances.
- Take the square root of this sum. This is the standard deviation of total cost.

A lease-versus-buy calculation can also be made by including the purchase cost of the system. But this must also be handled on a probabilistic basis. In the example of Figure 10, there is a 100% chance that System A_1 will be required for the initial installation. As seen in Figure 10, there is a 56% chance that System A_2 will be needed in Year 3, 85% chance in Year 4, and 100% chance in Year 5. Using this data, the probability of purchasing A_2 is each year (given that it was not purchased previously) can be calculated. This data can be converted into an expected value and standard deviation of purchase price for that year and these values added to the other yearly expected values and standard deviations as described previously.

Having calculated the present value of the expected value and standard deviation of cost, the PVLCC can be obtained as a normal distribution, similar to Figures 5b and 5c. Now the factor of cost risk can be introduced in the same way as schedule risk was treated. Namely, the client should indicate the cost risk they are willing to assume, where cost risk is defined as the probability of cost overrun. For example, the expected value of cost has a 50% chance of overrun and this may be unsatisfactory to the client. If the client is only willing to assume a 10% chance of overrun, for example, this amount is applied to the cost probabilistic values, as

[1] In this section we assume that the cost of all work performed by the client and the user is included in the analysis. If other organizations or the public also perform work or bear any of the costs, such costs must also be factored into the analysis.

illustrated in Figure 5c, and the value of cost obtained. For this example of a 10% chance of overrun, the value of cost = C_e + 1.28.

where C_e = expected value of cost

σ = standard deviation of cost

Values of cost for other values of risk may be similarly calculated using data from a standard normal probability distribution.

9.6 Consideration of Growth Factors

Here are three other related factors which often arise in an evaluation:

- o Upward Compatibility
- o Growth Potential
- o Flexibility

Here is a description of how they would be treated under this evaluation method.

The first step is to understand and define what the client means by these terms. Generally the term "Upward Compatibility" is used to connote that the system can be reconfigured to provide greater capability by adding additional elements. That is, it can be modified by using all or part of the original system, thus providing the greater capability at less cost and disruption than if a second, totally new system were used.

"Growth Potential" is quite related to the previous definition of Upward Compatibility. In this case the size of the job may be "growing" or increasing, and hence a larger capability may be needed.

"Flexibility" generally means that the set of jobs may change, and the client would like the original system to be sufficiently general-purpose so that its capabilities are sufficient to perform the new set of jobs rather than just the original set of jobs.

Thus, all three of these terms suggest that the client has some other set of jobs in mind besides the originally defined set of jobs. In keeping with the evaluation approach described, here is how these terms may be included in the evaluation. First, explicitly define a representative set of other jobs which may be required to be performed by the system. Second, indicate both the dates when these jobs will be performed (such as in Years 4 and 5) and the probability that the jobs will occur. This may be a subjective estimate of the probabilities. Thus both sets of workloads now become the total requirement. And the designer is required to configure his system design to accommodate the total set of jobs. In general, the design and evaluation approach used is the same one used in the case of job uncertainties (Figure 10). That is, the client will validate that the total system, including changes, is capable of handling the total workload, with proper response times, if it should occur. In addition, the client's evaluator will calculate the total cost on a probabilistic basis and apply the cost risk factor to estimate the total cost to be used in the evaluation.

9.7 Consideration of Superior Characteristics

The recommended evaluation approach described thus far can be summarized as follows:

- o All systems have been designed to perform the same set of operational jobs and to meet all specified constraints.
- o All systems will become available at the specified date(s), taking into account an acceptable risk of schedule overrun.
- o The preferred system is the one which requires the lowest cost (PVLCC), taking into account an acceptable risk of cost overrun.

However, sometimes a designer provides one or more characteristics (generally at greater cost) which are clearly superior to the lowest cost system alternative. Now the question raised is, are these incremental superiorities provided worth the difference in cost?

The key factor to be analyzed is, have these superior characteristics been considered in performing the operational jobs which have been evaluated? Or are there other jobs which would demonstrate each of the superior system's characteristics? In the former case, a system's superior characteristics may have already been accounted for in the cost calculations. Hence, no further "credits" need be given to that system. In the latter case, the evaluator can calculate the additional "credits" to be given as follows:

- o Clearly define all other jobs to which these superior characteristics would apply.
- o Estimate how much additional cost would have to be paid by the client if the lowest cost system were used for these jobs rather than the superior system. This cost is obviously a function of how often each job is performed during the system life cycle, or the probability of its being performed. This additional cost should be added to the lowest cost system to determine what the true PVLCC would be for all systems.

Note that what we have done is to enlarge the set of operational jobs to be done, and enlarged the total costs required to do them. Thus this new total cost can be the basis of the system selection.

PART IV. APPLYING EVALUATION METHOD TO A PROPOSAL

The previous sections presented a method for performing an architectural design study (involving systems analysis, synthesis and evaluation of alternatives) in an environment where there is close contact with the client. A proposal effort fundamentally involves the same systems planning functions as described for the architectural study. However, instead of the designer synthesizing and evaluating all of the system alternatives and selecting the preferred one, a set of competing designers each designs a proposed system and submits these to the client evaluators for their selection. Here are the differences which make it more difficult to "optimize" a system in a proposal effort than in an architectural design study:

- o First, the system requirements are generally in the form of technical specifications with firm mandatory requirements. This may force the designer to provide extra capabilities if the off-the-shelf entities to be employed do not exactly match the mandatory requirements.

- o The second and most important difference is that there generally is little opportunity to make contact with the client prior to submission of the proposal, and hence it is more difficult to "optimize" the design in terms of the client's desires. Thus it is very important that the designer review the Request for Proposal and make certain that he understands what the client is requesting and the details of the evaluation method to be used. There should be an opportunity for the designer to obtain clarification of any fact which is ambiguous to him.

With these differences in mind, we shall now describe how to apply the previous systems planning approach to the client proposal process.

10. APPLICATION OF METHOD TO A TECHNICAL CHARACTERISTICS TYPE OF PROCUREMENT

In this scenario it is assumed that the client provides the system requirements primarily in the form of technical specifications rather than operationally oriented jobs. The system design and evaluation approach now recommended will still be based on the approach previously presented but with the following changes as indicated.

- o Technical specifications are again presented as two levels: 1) a mandatory minimum, and 2) desirable features.

- o An additional aid to the designers would be the inclusion of operationally oriented information regarding the operational use of the system (jobs and functions to be performed).

- o All desirable features will be described, and the value of providing each of these features will be provided to all designers. These values will be derived from the architectural design studies which were performed at some previous time, and which were the basis of the technical specifications. Based on the architectural studies, the client should also provide the designers with evaluation functions indicating the worth of exceeding the mandatory minimum requirements. That is, what is the value of exceeding a minimum mandatory requirement in terms of its dollar savings somewhere else. As described previously, each of these values is equal to the lowest additional cost of performing the jobs needing these functions (or providing additional performance) if the functions (or additional performance) were not provided.

- o Each designer would then attempt to design a system exactly meeting each mandatory requirement. However, the designer will also consider if it is possible to make trade-offs among related parameters which will meet a joint requirement at lower cost than the cost of meeting (or exceeding) the requirements singularly, taking into account the value of the additional features or performance.

- o Ideally, the client would provide the designer with the value of exceeding the mandatory requirements. Each designer could then properly "optimize" his proposal in terms of meeting all requirements at lowest PVLCC to the client, taking into account the value of desirable features as well as all significantly superior characteristics. However, if the client does not provide these values and the designer finds he must include these "extras" in his design, he should estimate its value using the method described previously.

- o In either case the client should also validate such calculations and select that designer which meets all requirements and performs all jobs at lowest total PVLCC.

- Developmental uncertainties as reflected into schedule risk and cost risk would be treated in the same way as previously described.

PART V. CONCLUSIONS

In this paper we have presented several potential pitfalls which can occur in the process of designing, evaluating and selecting the preferred system for clients. Some are fairly obvious; some are not. These pitfalls and other conclusions reached in this paper can be summarized as follows:

a. Unless the requirements of the job are clearly stated and understood by the designers, they will not be able to design their systems appropriately. Thus, some means should always be available for further discussion and clarification of these requirements prior to the start of system design efforts. This opportunity is generally available to designers, and should be utilized early in the design process.

b. Unless an objective procedure for evaluating system alternatives is provided to the designers by the client, designers will not be able to perform their cost-performance trade-offs effectively to arrive at the system design preferred by the client.

c. The system requirements should be stated in a way that will enable the designer to provide what is desired by the client at lowest total cost. In architectural studies where the client desires the designer to make systems engineering trade-offs among the key design parameters, it is preferable that the requirements should be stated as operational jobs to be done rather than a set of detailed system characteristics. If the client also wishes to include a set of technical characteristics as mandatory minimum requirements, with additional desirable features, it would be helpful to list each design constraint in two ways: 1) a design goal, indicating the client's mandatory minimum value which must be equalled or surpassed, and 2) the worth of exceeding this minimum value. By doing this the designer should be permitted to make appropriate trade-offs among design parameters and thus be better able to satisfy the user needs at lowest cost. The same approach should be used in proposal efforts.

d. Credible evidence of the accuracy and reliability of the proposed work plan should be provided to the client as part of the architectural design study and proposal efforts. Such evidence includes: 1) performance validation through live test demonstrations, simulations or analysis; 2) reliability, maintainability data, when available; 3) schedule analysis, including critical path analyses; 4) cost analyses; and 5) risk analyses.

RISK ANALYSIS TRAINING WITHIN THE ARMY: CURRENT STATUS, FUTURE TRENDS

by Joseph G. King
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The analysis of technical risk was to have become a way of life for Army program managers back in 1970 when the US Army Materiel Development and Readiness Command (DARCOM) established a program called "Program for the Refinement of the Materiel Acquisition Process" (PROMAP-70). One task of PROMAP-70 was to improve the analysis of technical risk so that cost growth did not result from prolonged development or from changes required to overcome technical problems. However, 13 years later, risk analysis is still not commonplace. Some systems are fielded without risk being formally addressed. Articles are still being written about DOD waste and mismanagement of acquisition programs. An Army course in advanced decision risk analysis was developed and then canceled. DARCOM even considered deleting the regulation that requires the performance of a risk analysis for major system acquisitions.

What has happened since 1970? Has DOD directed that formal risk analyses are a waste of time and are not to be performed? No. In 1969, Deputy Secretary of Defense David Packard sent a memorandum to all military departments highlighting problems in major system acquisition. This memorandum was what prompted the Army to develop PROMAP-70. In 1981, Deputy Secretary of Defense Frank Carlucci, III, published a memo titled "Improving the Acquisition Process." One of the "initiatives" requires DOD action to increase the visibility of technical risk in budgets of weapon system acquisition programs.

What is the problem? Should there be more regulations? In DARCOM, the existing regulation is often ignored and, where it is followed, the people doing the analysis wonder if the study has any bearing on decisions made. Is the study being done just because the regulation says to do it?

Specialized training may be an answer. The purpose of this paper is to outline what is done by the Army to train people in risk analysis. Since risk analysis training in the Army is provided by the Army Logistics Management Center (ALMC), my focus is on the courses offered there. After providing a brief history of how ALMC became involved in risk analysis training, I review all risk analysis-related training done in any course at the Center. I provide information on the student population of each course, what risk subjects are taught, approximately how much time is spent on the subject, and how the students are expected to use the training. Then the future trend in risk analysis training is presented. I outline new courses, course changes and hardware/software changes that will make risk analysis more palatable.

HISTORY

ALMC has been involved in risk analysis instruction since 1970. The Center was tasked with developing a capability to train students to analyze technical risk as part of PROMAP-70. ALMC was not prepared to meet this task without impacting adversely on other courses, so the instruction was contracted out to Mathematica, Inc., of Princton, NJ. Mathematica put together a one-week course called Introduction to Risk Analysis. They also developed a simulation model called MATHNET which evolved into models such as SOLVENET, RISCA, and VERT. Within a year, ALMC's staff took over the instruction of the course. Workshops were added to the course and the course length was extended by a week, giving a format similar to what is presented today in the Decision Risk Analysis Course (DRAC).

A second course in risk analysis was also developed in March 1973. ALMC was urged by DARCOM to initiate a second course in risk analysis geared to logisticians. This course developed into Decision Risk Analysis for Logisticians (DRALOG) which is still taught today. An Advanced Decision Risk Analysis Course was also developed. This course was to go beyond the basics as taught in the other courses. It was canceled in 1982 due to low class fill. ALMC also included some risk instruction in five other classes.

PRESENT INSTRUCTION

Today, there are still five courses in which risk analysis is taught. Project Management Development Course (PMDC) is a 5-week course of which 8 to 10 hours are devoted to risk analysis. The student receives a brief history of formal risk analysis in the Army. They discuss the reason for risk analysis and the process called Decision Risk Analysis. They are also exposed to one of the most advanced risk analysis tools called Venture Evaluation Review Techniques (VERT). These students return to their project management shops informed about the basics of risk analysis. If they desire to use the tools mentioned in class, they have to send people to be trained further in the risk analysis techniques.

ORSA MAC I is a 12-week course of which approximately 56 hours are devoted to risk analysis-related subjects. Fifty hours are spent on decision trees, multiattribute decision analysis, utility theory, and 6 hours are spent on VERT. The graduates of this course are mostly military who are enroute to an SC 49 (ORSA) assignment. Because they are ORSA-trained, they are expected to know a myriad of tools and techniques. Risk analysis is one of many tools with which they are equipped.

ORSA MAC II is a 3-week course with about 15 hours of risk instruction. The bulk of the time is spent on decision analysis techniques with 3 hours devoted to VERT. The student in this class comes from the same population as those who attend ORSA MAC I; however, the MAC II students have prior ORSA training. Since they all come to the class after working in a non-ORSA job, this course is used to refresh their ORSA skills prior to returning to an ORSA assignment.

This brings me to the only two classes offered in the Army (and possibly DOD) which are entirely devoted to decision and risk analysis--DRAC and DRALOG. Decision Risk Analysis for Logisticians is a 2-week course geared to reach an audience who have a non-quantitative background. These students' duties involve them in all aspects of logistics management. The purpose of the class is to give the student a detailed introduction to the concepts of risk analysis so that they can use risk analysis in the logistics or readiness areas. Graduates are capable of initiating action with their systems analysis people to do a risk analysis, or participating in risk analysis studies that require their expertise. To accomplish this, the students spend 4 hours discussing why risk analysis is important and how it developed within the Army. They are exposed to 12 hours of quantitative techniques used in risk analysis starting with SET theory and moving through probability distributions. They are taught 8 hours of decision analysis techniques to include decision trees, simple ranking techniques, and utility theory. Another 4-hour block of instruction is used to explain risk analysis in general and to introduce the student to concepts modeling and Monte Carlo simualtion. Eight hours are devoted to a specific Monte Carlo simulation technique called RISCA III. The remaining 4 hours of the first week are used to address how subjective estimates are used in the analysis. The second week of the course is devoted to workshops. The class is presented a case each day to work on where they are to analyze the risk and choose the "best" alternative after the risk for each alternative has been developed. The last two cases in this course are structured to show that risk analysis is not just for R&D ventures, but is also useful to analyze policy in the readiness arena.

The Decision Risk Analysis Course is also a 2-week course but it is designed for OR Analysts, Engineers and Scientists. The majority of the subject areas taught in the first week of DRAC are similar to DRALOG. The major differences between the courses are the pace and the amount of material covered. DRAC goes into more detail in the same amount of time used in DRALOG, so the pace is faster in DRAC. Another difference is the simulation model taught. In DRAC the student learns VERT instead of RISCA III as in DRALOG. The second week of this class is devoted to workshops as with DRALOG; however, all of the cases in DRAC are R&D, test and evaluation oriented. By the end of the class, these students become quite proficient at using VERT to analyze risk. This class is a must for anyone in the Army who plans on doing risk analysis.

FUTURE TRENDS

The future of risk analysis training holds a number of changes. The changes are due to a study that was conducted by Dr. Erwin Atzinger, Chief, Special Studies and Activity at AMSAA. In 1982, Dr. Atzinger studied the use of systems analysis techniques at the DARCOM subordinate commands. As part of this study, he looked at the use of Decision Risk Analysis and the perception of the training being offered in this area. The results showed that the training was well received, but it is not enough to overcome the resistance that exists against the use of the tool. Also, there was some comment that there is not enough taught on how to do a qualitative risk analysis. Some felt there was too much emphasis on VERT, while others would like to see more VERT. Since Dr. Atzinger is also the proponent for the risk courses at ALMC, he passed the comment on to us so the changes could be evaluated. As a result, the following actions are planned by ALMC.

ALMC will offer a 2- to 4-hour briefing targeted toward the highest management people within the Army and possibly DOD. The purpose will be to explain to the chiefs of each command what tools are available to them in the risk analysis area and how these tools can benefit them. It will be tailored to be offered to commanders and their staffs or at conferences such as the Project Managers' conference. This briefing should be available early in FY 84.

DRAC will be modified by eliminating SET theory and some of the VERT workshops to make room for more qualitative risk analysis instruction and more subjective estimation. SET theory will be put into a programmed text that the student will be expected to review prior to coming to ALMC. The VERT workshops will have to give way to qualitative risk analysis workshops and decision analysis workshops. Shifting from VERT in DRAC is due to the perceived overemphasis now in the present course. Sixty percent of the present DRAC is either VERT instruction or VERT workshops. When a student leaves the class, he/she is ready to use VERT at his/her duty station, but VERT is not available everywhere. The shift from VERT will give the student tools that are not so computer dependent and more readily used.

To handle the request for more VERT instruction, we plan to offer a 1-week VERT seminar. This course will cover more VERT features than are presently taught in any government course. Due to the present emphasis on the Total Risk Assessing Cost Estimate (TRACE) procedure, this course shows how VERT can be used to do a TRACE study. This course will be offered on a trial basis about a year from now to see if there is a demand for it.

ALMC is also looking at ways to improve the input of data into the VERT program. VERT requires formatted cards or formatted card images as input which are a challenge to work with. We are studying the possibility of using highly portable micro-computers that can be used to elicit data from students, store it formatted for VERT input and transmit it to a host computer for processing. When this becomes available, it would help ease the problem with data entry which discourages all but the most persistent from using VERT.

CONCLUSIONS

Thirteen years have gone by since risk was identified at the highest level of DOD as a cause for cost growth, schedule slippages or performance degradation. The problems still persist. Will training solve the problem? I really cannot answer that yet, but whatever the solution is, training will have to be a part of it and the Army through ALMC is ready.

PLENARY PAPER

UNCERTAINTIES OF THE FUTURE

MARVIN J. CETRON

FORECASTING INTERNATIONAL

The workshop dealt primarily with the uncertainties we perceive today. This talk looked to the future - what uncertainties will we have to address in acquiring future systems?

PLENARY PAPER

PROBLEMS IN APPLICATIONS

DONALD W. HURTA

NAVAL WAR COLLEGE

PROBLEMS IN IMPLEMENTING RISK TECHNIQUES

DONALD W. HURTA

NAVAL WAR COLLEGE

[SUMMARY NOTES FROM DR. HURTA'S PRESENTATION]

1. There is confusion over the meaning of terms (risk, uncertainty, etc.) not only outside th analytical community but within it. And although there may be some merit to leaving things unde- fined, the harm far outweighs the good (if there is any). Remember Humpty Dumpty: "When I us a word, it means what I choose it to mean, neither more nor less." If we can't agree on defini- tions, at least let's define our terms in a common sense way whenever we speak, write, repor ...on our subject.

2. As a community we must improve our communication skills - to be able to relate better t each other, but much more importantly to the manager/s decision makers we prefer to help. This i crucial. We must be able to translate our expertise into terms managers/decision makers can easi- ly understand. Don't expect or wait for them to learn our language - the burden is on us to lear theirs.

3. Back off ever so slightly on the precision we may desire in our results. Increase the effi- ciency of our processes which maintaining sufficient effectiveness. Don't gold plate the analy- sis. It's better to be approximately right than exactly wrong.

I believe that consideration of items 2 & 3 would tend to encourage confidence on the part o managers/decision makers in the analyst and analytic process.

4. We must become more manager/decision maker-oriented. We must remember that our work usuall is not on end in itself (our end), but rather a means to an end (his).

5. We should work to bring the manager/decision maker more into the process. Most of the pro- blems we work on aren't ours, they are theirs. This must be accomplished through a more humble interpretation of our role as well as by pursuading the manager/decision maker how crucial his role is to the analytical process.

6. The state of the art of our theories has far outstripped their implementation. Implementatior is where the next great payoffs are. Although great progress comes from invention, I believ that far more progress comes from thinking of applications for or adapting inventions.

7. Learn some new skills. Don't tend to do tomorrow what you did yesterday, just because you dic it yesterday. No model/tool can be used on all problems.

8. Find out what tool the manager/decision maker likes, or is comfortable with. This may cal upon you to use a technique which, from the analytical perspective, is not the best one. But. remember, there's more than the analytical perspective.

PAPERS NOT PRESENTED

(SOME HIGH QUALITY PAPERS WERE RECEIVED THAT, FOR VARIOUS REASONS, DID NOT FIT INTO THE REGULAR PROGRAM. WE ARE PROUD TO PRESENT THEM HERE.)

AD P002321

DECISION RISK ANALYSIS (DRA) FOR THE REMOTELY PILOTED VEHICLE (RPV)

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ABSTRACT

The topic of this is the DRA performed to support the Army's RPV Development Program. The basic analytical tool utilized was the Army's Venture Evaluation and Review Technique (VERT) computer model. The paper addresses the general methodology utilized in performing the DRA, including (1) a brief discussion of VERT, (2) procedures used to identify risk areas, and collect the associated data necessary to assess their impact, and (3) problems encountered in adapting certain peculiar situations to the VERT methodology. It concludes with lessons learned.

The Directorate for Plans and Analysis, AVRADCOM, was tasked to perform a Decision Risk Analysis to determine the performance, schedule, and cost risks inherent in the Remotely Piloted Vehicle Research and Development (R&D) Program. In addition, the project manager requested that the analysis results be utilized to generate a year-by-year TRACE estimate. TRACE stands for "Total Risk Assessing Cost Estimate" and should represent ".... expected total cost over a specified period of a materiel development program ... including specific provision for the statistical estimation of probable program costs otherwise indeterminate. TRACE should be that estimate having a 50/50 chance of producing either a cost overrun or an underrun."

In approaching the problem, it was determined that the areas of performance risk were too diversified to attempt a quantitative assessment; thus a qualitative approach was used. Some 42 system parameters, ranging from the boresight accuracy of the FLIR to the System Displacement time were evaluated by system engineers. The vehicle used was a Risk Assessment Questionnaire. For each parameter, the engineer was asked to provide: a risk level, a brief explanation for the rating, a list of problem areas, and a "fallback" position (should the risk prove to be unacceptable). While this approach has limited decision making value, it is useful for: providing a good "over-all view", identifying problem areas, and putting the various risk areas in proper perspective.

In evaluating schedule and cost risks, the Army's VERT model was used. VERT is a simulation model designed for network evaluation. The model requires construction of a basic flow network consisting of nodes (Milestones/normal activity completion points) and arcs (activities) initiating and terminating at nodes.

Each arc can be assigned three parameters - a time, a cost and a performance parameter. Generally, the time and cost parameters represent the resources consumed in performing the activity, while the performance parameter represents the "capability" gained for that expenditure.

As activities are completed (or partially completed) their resource expenditures and performance gains are accumulated. Thus, for each pass through the network (each iteration in the simulation), total cost, time, and performance are determined.

Each node is assigned an input and output logic - the input logic setting the conditions on the incoming arcs that must be met before the output logic is executed, and the output logic determining which outgoing activities are triggered. Examples of logic are:

AND: All incoming activities must be completed before the output logic is initiated.

PAND: All incoming activities must be either completed or terminated (with at least one completed) before output logic is initiated.

OR: One completed incoming activity initiates output logic without waiting for a determination on the remaining incoming activities.

Examples of output logic are:

ALL: All outgoing activities are triggered.

MONTE CARLO: Each outgoing activity is assigned a probability of occurence (total 1) and the activity triggered is chosen on a probabilistic basis by generation of a random number.

FILTER: Each outgoing activity is assigned a range of values for time, cost and/or performance. If the respective parameter value(s) accumulated at this point in the network lie within these ranges, the activity is triggered.

Nodes may also be assigned what is called a unit logic, rather than separate input and output logic. These nodes have N input arcs which mate with one of N output arcs to enable direct transmission of the network flow from a given input arc to a given output arc.

Nodes, in themselves, are not assigned specific time/cost/performance values (since they are not activities); however, the model does accumulate, at each node, the total time expended, cost incurred and performance generated to process all the arcs encountered along the path the network flow followed in order to complete the processing of the node.

Time is the basic parameter controlling network flow, and it determines not only the values accumulated at each node but other pertinent information such as critical path. The data (time, cost, performance) for each activity can be assigned in four ways:

(1) Direct Input

(2) A mathematical relationship involving either data from previously processed arcs or nodes or the remaining data for the activity itself.

(3) As a random variable or

(4) A combination of (1) thru (3).

This maximizes the realism that can be built into the network. VERT provides 37 transformations to aid in structuring mathematical relationships and 14 statistical distributions to facilitate the modeling of random variables.

Other features which make VERT a very flexible analytic tool are:

(a) Use of a random number seed which allows duplication of results

(b) Histogram input capability

(c) Printout of intermediate results

(d) A pruning option which permits accumulation of partial costs

(e) Accumulation of data at pre-selected time intervals

(f) Inflation/Discount

(g) Detailed, explicit error messages

In establishing the basic network for evaluating the RPV schedule and cost risk, technical personnel provided a flow diagram identifying the major technical milestones for each subsystem, as well as a low, most likely, and high estimate of time required to complete each activity. For lack of better information, each activity's time was treated as a random variable using triangular distribution. In addition to the technical aspects of the R&D effort, the support (ILS) impact on schedule was also considered. Since the ILS effort did not necessarily coincide with the technical flow, it was decided to evaluate where, in the basic network, the ILS effort could affect the schedule; this impact was then addressed as a low, most likely, and high schedule slippage anticipated at that point due to ILS problems. Again a triangularly distributed random variable was assumed. Using 1000 iterations, a cumulative distribution of probable months to complete the R&D effort was derived. This distribution was used to analyze the probability that the program would be completed within the time frame expected by the Project Manager. We also provided the mean (expected value), median (50/50 chance), and "90% confidence" times-to-complete to the PM.

For assessing cost risk, the PM's Baseline Cost Estimate (BCE) was used to represent the most likely cost associated with his most likely schedule. Cost analysis personnel were then asked to quantify cost risks in three different areas:

(1) Cost uncertainty - those costs associated strictly with potential estimating error and involving no change in scope of work nor schedule impact.

(2) Fixed Cost Growth - Costs associated with a change in the scope of work which is not time sensitive (e.g., adding an additional training course to be conducted simultaneously with those scheduled), and

(3) Variable Cost Growth - Additional costs resulting from schedule slippage. In addressing cost uncertainty, a high and low factor (to be applied to the BCE estimate) were obtained for each major subsystem. This was input to the model and, using a triangular distribution, resulted in a single "distribution factor" for each subsystem and each iteration. This factor was then applied to the BCE estimate (as well as the fixed and variable cost growth estimate) to generate the cost associated with that particular iteration.

Fixed cost growth values were directly input to the model (at the appropriate point), utilizing arcs with zero time. Variable cost growth was addressed on an arc by arc basis by applying a "cost per month" (for every month beyond the most likely) using a mathematical relationship.

Again 1000 iterations were run, and cumulative cost distributions were derived for the total program, as well as (using the model's partitioning and pruning options) each fiscal year.

These results were then used to address cost risk and develop the year-by-year TRACE estimate.

In performing the DRA, several situations arose which required some manipulation of the model to achieve realism.

In trying to run both schedule and cost risk simultaneously, it was necessary to introduce a "BCE Cost Path" with times incremented at 12 month intervals (fiscal years). To prevent this path from dominating the schedule erroneously (in those instances where the program may come in under schedule), the total path time was subtracted at the very end. But the model, being time driven, will <u>subtract</u> cost whenever it backtracks in time. This then would misrepresent the cost assessment. This dilemma could have been avoided if the BCE estimate could have been broken down by activity; however, such detail was not available so that cost and schedule had to be run separately.

In superimposing ILS schedule impact on the basic technical network, it was necessary in some cases to give the ILS impact "credit" for schedule slippage already assessed for technical problems. This again necessitated using negative time. To avoid a cost problem, a dummy arc was inserted in the network parallel to the ILS portion. This insured that the time "coming out" of this section was never less than the time "going-in", yet the use of negative time still properly diminished the ILS impact when appropriate.

A final, though minor, problem concerned cost distribution factors. Since all cost risk was evaluated using basic BCE data and since the BCE methodology did not logically get any better or worse by fiscal year, it was felt that a single uncertainty distribution should be used (for each subsystem) rather than an independent one for each activity and/or fiscal year. This was accomplished by means of a (previously unused) performance arc early in the network.

In performing the RPV DRA, I came to several conclusions:

(1) The VERT is an excellent, highly flexible, realistic tool for risk assessment.

(2) The DRA is a valuable management tool. This particular effort resulted in the identification of potential schedule problems and budgetary inconsistencies.

(3) To continue to provide the PM with this type of assistance, it should be updated semiannually. I am pleased to say that this is the current intent of the RPV Project Manager.

I also formulated a philosophy for "selling" the DRA concept to reluctant managers:

(a) Realize that, at least initially, the relationship will be adversarial; this is normal - the analyst is looking for problem areas, the program manager doesn't like problem areas.

(b) Keep everything out in the open - explain exactly what you are trying to do, what data you need, and exactly how it will be used.

(c) If possible, deal with a supervisor common to those providing data. This makes conflict resolution much easier.

(d) Make sure the data collected realistically reflects the situation being modeled; then <u>let the data determine the results</u>. Frequently the temptation is to adjust, and rationalize, the data in such a way that preconceived results are obtained.

(e) Most important - have a firm conviction of the value that such an analysis can be to the project manager.

BRIDGING THE MANAGEMENT INFORMATION GAP AT THE BEGINNING OF A PROGRAM

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INTRODUCTION

The purpose of this article is to share the preliminary results of a schedule analysis performed on a major Air Force systems acquisition program. The program is in Full Scale Development (FSD). Portions of the FSD program are concurrent with the production program. The time span for both developing and manufacturing qualification test hardware is shorter than normal. The schedule analysis was performed with the assistance of a computer program, called PREDICT 2000. PREDICT 2000 enabled both engineers and managers to more accurately quantify their experiences so that a working schedule could be established prior to the development of the contractor's formal scheduling system.

The results of the schedule analysis were used by the Air Force contractor to modify initial schedules and change the make/buy structure to meet overall program milestones. While the final results of this approach will not be known until January, 1984, the preliminary results look quite good and it appears that the approach used in this paper may be a key factor in the contractor achieving contractual milestones which would have otherwise been missed.

CONCURRENCY, RISK AND UNCERTAINTY

The beginning of a major program tends to be the point of maximum risk. The engineering design is normally incomplete and the management systems which will be used to control the program are in the process of being developed. These factors tend to increase the risk and uncertainty associated with a systems acquisition. However, it is also during the initial stages of a program that the most flexibility exists to make changes in make/buy strategies and internal schedules so that overall program milestones can be met.

The risk inherent in the beginning of a program can be increased by program concurrency. Many DOD programs face a substantial amount of concurrency because it is necessary to shorten the time span from the conceptual idea to the fielded system. Concurrency makes it necessary to release engineering designs before they have been completely proven. The press to design a product meeting specifications tends to reduce the interaction among the manufacturing and the design engineers which assures a producible product. The lack of mature engineering designs also reduces the ability of manufacturing engineers and managers to plan, control, and assess the manufacturing processes, costs and schedules. Risk and uncertainty is quite frequently compounded because it takes several months to input data into the management systems so that they can work effectively. Thus, scheduling early in a program is usually based upon parametric approaches or experience.

An Air Force parametric analysis of historical data for similar programs showed that there was a low likelihood that the contractor would successfully achieve the schedule for completing full scale development(FSD) on this program. The FSD schedule is driven by the stated initial operating capability(IOC) date. The IOC date must be achieved for the acquisition program to be considered a success. Thus, it was necessary for the program office to emphasize the need for good schedule analysis early in the program. In mid-November, five months after the completion of source selection, the time for completing the engineering design of the 62 most critical parts in the acquisition program was analyzed using PREDICT 2000. The input for PREDICT 2000 was provided by the design engineers responsible for completing the design. Prior to the analysis using PREDICT 2000, the company had established a schedule for completing the design of 62 critical parts; this schedule had estimated that the design would be complete by mid-January. The analysis using PREDICT 2000 estimated the design completion the end of the last week in February. The last week in February was identified by the Air Force in November as the time frame for conducting a schedule analysis of the remaining manufacturing tasks; the results of that analysis will be discussed in the last section of this paper. With the exception of four items which had to be redesigned, the design of the critical items was completed by the last week in February. It appears that the engineers' ability to estimate design times was substantially improved using the computer aid.

PREDICT 2000- AN AID IN ESTIMATING

PREDICT 2000 solves a major operations research problem which concerns how one generates an appropriately shaped probability density function when only sparse data is available. PREDICT 2000 can generate cumulative probability distributions based upon the thirty-seven different generic shapes shown in Figure 1 from experiential data. Although each of the twenty-five group II shapes is shown unskewed (that is, 50% of the function is on each side of the mode), each shape can assume any level of skewness.

The PREDICT 2000 computer software interacts with the user through a mini-computer. It uses one measure of central tendency (the mode) and two measures of dispersion(a 100% percentile range and another range specified by the user) to provide its output. The mode was chosen as the PREDICT 2000 measure of central tendency both because people can estimate the mode more accurately than the mean and because the mode has analytical importance in determining the probability density function's shape. The ranges are also easy for people to estimate and provide a basis for determining the shape of the probability function. In summary, PREDICT 2000 requires eight pieces of data to provide an output:

(1) The variable's name which is used to identify the output.

(2) The variable's dimension which is used to label the output.

(3) The user defined percentile range. This percentile range is symbolized by R and lies between the points R_1 and R_2. These points are identified by the user. The value of R is used to define the area below R_1 and above R_2. N has the value of (R+((1-R)/2)x100)%.

(4) The lowest possible value.

(5) The value associated with R_1. This is the value above which N% of the distribution is found.

(6) The most likey value(mode).

(7) The value associated with R_2. This is the value below which N% of the distribution is found.

(8) The highest possible value.

Given this information, PREDICT 2000 generates the complete cumulative probability function and calculates the mean value for the function. Normally, when addressing the problem of scheduling a production program, it is the mean value which one desires to use.

The determination that the design would be complete the last week in February was based upon the mean time to complete design. However, the same analysis also considered the likelyhood of values above the mean. The four items whose design had not been completed fell into the risk range identified in the analysis.

FIGURE 1. PREDICT 2000 SHAPES

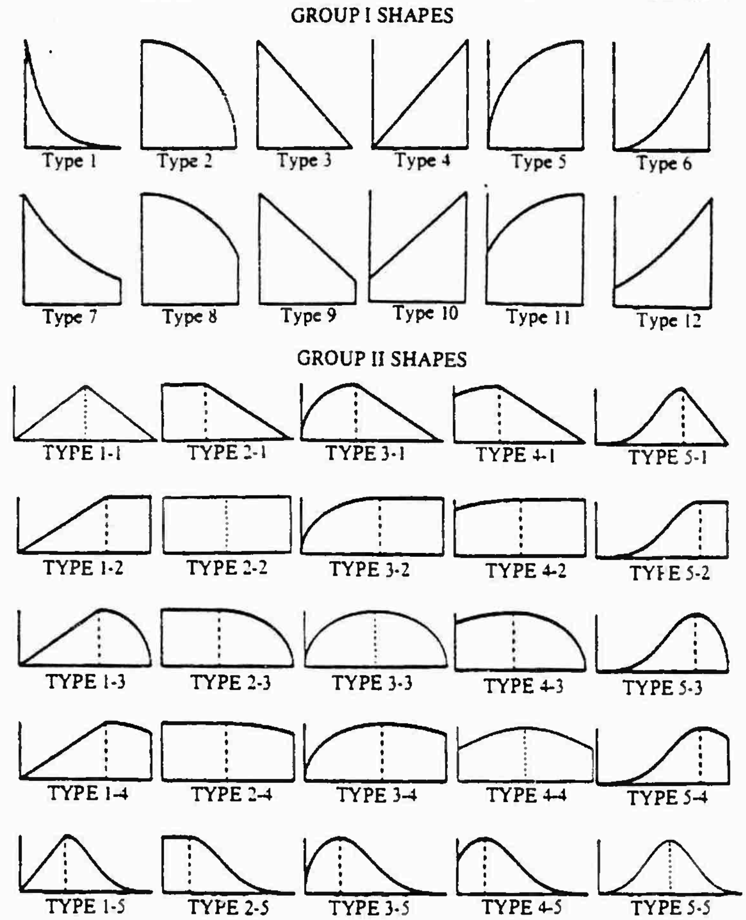
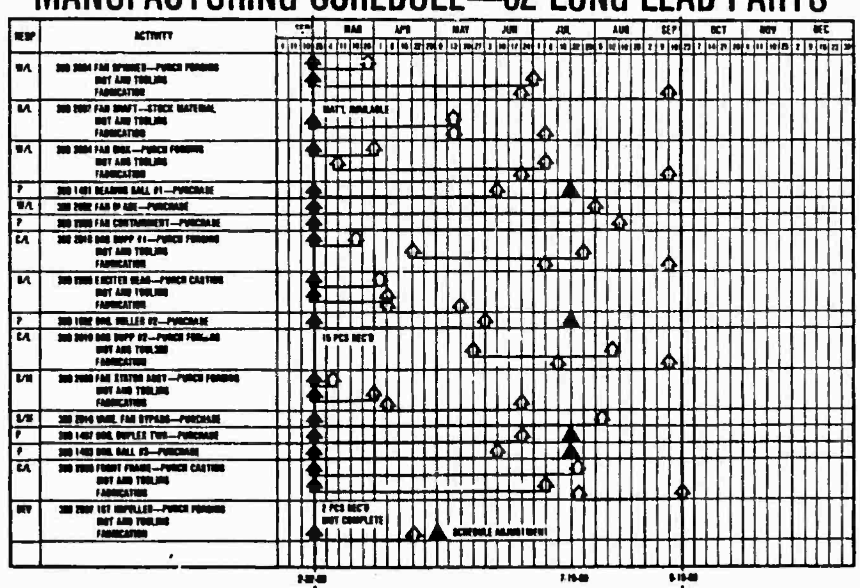


FIGURE 2.

MANUFACTURING SCHEDULE—62 LONG LEAD PARTS



ANALYZING THE MANUFACTURING SCHEDULES

The development of an estimate of when the engineering would be complete was not a matter of idle curiosity. The manufacturing tasks can not be successfully begun until the majority of the engineering is complete. This causes what is often referred to as the bow wave effect. The majority of the engineering tasks are completed at about the same time. Upon their completion, the manufacturing planners, schedulers, tool designers, and procurement specialists can begin their efforts to turn the design into hardware. The completion of the engineering tasks at nearly the same time causes the next tier of tasks for each new specialty to be grouped together. If the overall schedule is tight, then this bow wave will continue onto the production floor. Thus, a slip in the engineering design schedule can cause problems throughout the entire program. Moreover, the manufacturing tasks which result in the production of the hardware can not be begun until the design for each piece of hardware is complete.

The sixty-two parts which were identified as critical were parts which are typically found on the critical path of PERT/CPM networks of this type of product. Experience had shown that those parts were the schedule drivers. Thus, they were chosen as the parts to track prior to the development of a formal tracking system.

It should also be noted that this contractor has an excellent formal scheduling system. However, this system was not fully established until June 1983. The time frame from March through May 1983 was crucial for making schedule adjustments. The schedule analysis using PREDICT 2000 showed that all of the available slack time would have been gone and the schedule would be unattainable for all practical purposes if the analysis had been deferred until June 1983.

PREDICT 2000 was used to estimate the mean times for procurement of material, manufacturing operations and tooling sheet development and tool manufacturing, and part fabrication. Parts had to be fabricated by the end of September to meet a November internal schedule. The contractual date for the first unit to begin qualification test was the end of December. The time allowable for concurrency between material procurement and fabrication and manufacturing operations sheet development and tooling manufacturing and fabrication was determined and included in the analysis. The final result of the analysis was depicted on a traditional Gantt chart showing procurement of materials, manufacturing planning, and fabrication of the parts. One month was allocated for assembly. The desired schedule was planned to include contingency time of between one and two months. The analysis shown in Figure 2 provided the contractor with insights into the overall schedule at the end of February 1983 which would otherwise not have been available until June 1983. The contractor took management action based upon the PREDICT 2000 schedule analysis which resulted in an adjusted schedule meeting the contractual requirements. The PREDICT 2000 schedule analysis took approximately three people three mandays to accomplish.

Currently, the program appears to be on schedule. The final proof of the merit of this approach will be if the contractor can actually build qualification test article on schedule. The preliminary results do suggest that PREDICT 2000 can improve the quality of schedule estimates.

AD P00232[illegible]

QUANTITATIVE TECHNIQUES FOR DARPA PROGRAM RISK MANAGEMENT

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ABSTRACT

Meridian Corporation has developed an approach to risk assessment and contingency reserve allocation which draws upon numerous statistical and empirical techniques to evaluate contractor performance. The approach is motivated by the need to anticipate, at the highest levels of program management, potential cost overruns so that corrective or pre-emptive actions may be initiated early in the development cycle. This paper discusses the nature of the analytical tools used to assess the risk of cost growth and describes the application of these tools to an individual DARPA program.

The approach presented in this paper is intended to supplement rather than to supplant traditional methods of contract cost analysis. It is oriented toward the needs of senior level decision-makers who must evaluate in the aggregate the requirements for contingency reserves and who have ultimate responsibility for the successful completion of the program within established cost, schedule, and technical constraints. It is designed to be used in conjunction with the more detailed management analyses of specific projects to illuminate trends in cost growth and to provide a comparison to heuristic models and empirically-derived cost distributions.

The approach consists of a series of risk assessment indicators which collectively address the potential for short-term, mid-term, and long-term cost growth. The outputs range from short-term projections of an "envelope" of future costs by WBS element to long-term estimates of total contract cost and probabilities of attaining budget targets. Finally, results obtained from applying this approach to an actual DARPA program are presented. Scenarios for how the outputs can be assimilated into the program review and budget allocation process are described, and issues to be considered in the implementation of the approach are identified.

OVERVIEW OF PROGRAM RISK MANAGEMENT TECHNIQUES

The general problem of assessing risk and uncertainty in major programs has received considerable attention in the risk analysis literature. Numerous attempts have been made to analyze the reasons for cost overruns, although contributions to the state-of-the-art in risk analysis have originated from a wide variety of sources.

Meridian's review of the state-of-the-art in risk analysis undertaken at the outset of the project has yielded some interesting insights into the thrust of previous efforts. Previous publications concerning cost growth risk may be broadly characterized as falling into one of three categories:

- o Analyses of structural deficiencies which indirectly cause cost overruns.
- o Analyses of causal factors which were directly responsible for incurring cost overruns.
- o Descriptions of models which attempted to assess the likelihood and impact of cost overruns.

None of the previous analyses adequately addresses the particular circumstances and requirements of the DARPA Program Management Office (PMO), although valuable lessons can be learned through the study of such analyses. Analyses undertaken in each of the three groups of analysis are summarized in Meridian's final report to DARPA. (see Reference)

Relationship to PMO Requirements

From the outset, a primary concern of the PMO was the need for a mechanism to gauge the likelihood of a project requiring additional funds due to unforeseen circumstances and to assess the magnitude of such additional funds. Such requirements had arisen historically and had a significant disruptive impact on DARPA's ability to pursue its mission successfully. However, the role of PMO analysts is broad program oversight and budgetary control, and the analyses undertaken at the PMO level are generally oriented toward financial rather than technical management. Consequently, information of a technical nature is of limited utility since engineering trade-off analyses are the predominant responsibility of the Technical Offices, which also have responsibility for technical risk assessment. As a result, the inputs which may be used in PMO risk assessment must be limited to information which is readily available at the PMO and the risk assessment mechanism applicable to a diverse set of projects and technologies. Also, it was recognized that any mechanism proposed to assist in identifying potential program risk areas must be sensitive to the workload already imposed on PMO analysts.

Therefore, the PMO risk assessment procedure must be easily administered by existing staff members without requiring excessive data collection and reduction efforts.

In developing procedures for use by DARPA to address these general agency requirements, two sets of characteristics were identified — conceptual and organizational. These characteristics represent the basis for the structure of the risk assessment tools described in later sections.

Conceptual characteristics of the approach to program risk assessment include the following:

- o The approach must be sufficiently general to be applicable to a wide range of heterogeneous projects.
- o The approach should utilize data available at the PMO so as not to impose additional reporting requirements on contractors or DARPA agents.
- o The approach should be relatively easy to implement and to operate on a regular basis.
- o The algorithms should ideally be transparent to the users, preferably being contained in a "user-friendly" interactive minicomputer program.
- o The approach should permit the PMO analyst sufficient flexibility to interpret results and to draw independent conclusions concerning future risk mitigation alternatives.

Organizational characteristics of the approach include the following:

- o The approach should be executable by existing PMO staff and should not require additional personnel to operate.
- o The approach should be sufficiently expeditious to permit timely interface with other budget cycle activities.
- o The approach should complement rather than supplant the project management activities of the Technical Offices.

As mentioned previously, analyses conducted by Meridian indicate that none of the techniques identified as currently available adequately address the special needs and environment of the PMO. An examination of models for risk analysis showed that most were oriented toward program-specific cost growth. Cost growth models of this genre are appropriate and useful for the management of programs at the level of the Technical Offices, since technical risk and cost growth risk are generally analyzed by component in these models rather than in the aggregate. Unfortunately, the detail which makes these models useful at the component level tends to make them ineffectusl for the Program Management Office due to their specificity, their cost, and the amount of data required to run them.

For all these reasons, the approach focused on the identification of risk assessment indicators which could be used by PMO analyst to gain an understanding of potentially risky areas at a higher level of aggregation than afforded detailed causal models. The risk assessment indicators, while not designed to provide definitive answers concerning eventual cost, are oriented toward revealing trends in costs incurred to date. In this manner, areas of likely cost growth can be flagged early enough to permit a detailed examination of the reasons for cost growth an to permit intervention by PMO analysts and Technical Offices to forestall cost overruns through active or passive risk reduction measures.

Several analytical techniques were investigated by Meridian in connection with the development of risk assessment tools. Meridian has characterized these tools according to the time horizon that costs are projected through, i.e. short term, mid term, an long term. Short term refers to a period les than six months in the future. Mid term projections are for a period 1/2 to 1-1/2 years in the future, and long term refers to period greater than 1-1/2 years. A description of these tools and how they may be applied to th analysis of DARPA programs follows.

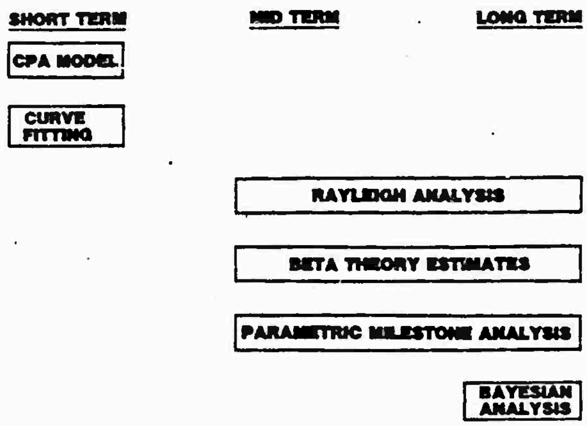
Through the analysis of techniques with potential applicability to DARPA program risk assessment, it became apparent that no single risk assessment tool could satisfy all of the requirements of the PMO. Some tools appeared to be valid for predicting short-term fluctuations in project costs, but lacked accuracy for long-range forecasts. Others provided good indications of likely long term cost performance, but did not provide acceptable shor term estimates. The methodology presented in this paper is comprised of several techniques, each oriented toward a different facet of program risk assessment. The differing emphases of these techniques is illustrated i Figure 1.

As will be discussed below, these techniques, while individually not capable of addressing all risk assessment concerns, collectively provide a firm indication of the relative status and financial risks of the programs subjected to the analysis. The theory behind each of the component risk assessment indicators will be described individually with reference to results obtained from applying these indicators to an ongoing DARPA program.

RISK ASSESSMENT INDICATORS

As indicated in Figure 1, the risk assessment

Figure 1
RISK ASSESSMENT INDICATORS



indicators can be distinguished by the time horizon of their applicability. The indicators would be provided to the program analyst who would assess the requirements for short-term, mid-term and long-term risk management activities. In order to facilitate an understanding of how the risk assessment indicators will be utilized collectively, the following sections will first describe the rationale behind each of the indicators separately. The methodology for analyzing the collective output of the indicators is then presented.

Cost Performance Analysis (CPA) Model

The Cost Performance Analysis (CPA) model was developed by Captain Douglas Tyler of the Air Force Weapons Laboratory. It is currently operational at DARPA and is significant for several reasons. First, the model uses data from the contractor's Cost Performance Report (CPR) as inputs as the other tools Meridian developed were constrained to do. Second, the risk assessment tools developed by Meridian were intended to complement the existing cost analysis procedures already in place at DARPA. Therefore, the tools that Meridian developed were oriented toward providing information not adequately addressed by the CPA model. As a result, a brief review of the CPA model and its areas of applicability and validity is necessary as part of an integrated analysis of DARPA's program risk analysis capabilities.

The CPA model is an automated tool resident on DARPA's HP 3000 that automatically generates data and ratios of interest to the program analyst. In addition, the model estimates cost at completion utilizing trend extrapolation of a variety of these ratios. The CPA model computes a number of contract status indicators, based upon inputs from the contractor's monthly reports, primarily in the form of ratios between these data elements and differences between the current month and a previous time period (e.g. last month, three months ago, project initiation). The contract cost status indicators are summarized in Figure 2 with similar indicators developed for schedule status. Utilizing these indicators, the CPA model then computes estimated costs at completion and determines the variances (absolute and percentage) between those estimates and the total budget at completion plus management reserves. The model then provides an assessment of the condition of the contract (e.g., condition red, yellow, green, or blue).

Figure 2
CPA MODEL CONTRACT COST STATUS INDICATORS

INDICATOR	CONCEPT	FORMULA
1. COST VARIANCE ($)	OVERRUN	$BCWP - ACWP$
2. COST VARIANCE (%)	PERCENT OVERRUN	$\frac{BCWP - ACWP}{BCWP}$
3. MANAGEMENT RESERVE INDEX	RATE OF RESERVE DEPLETION	$\frac{\left(\frac{\text{REMAINING MGT. RES.}}{\text{INITIAL MGT. RES.}}\right)}{\frac{BAC - MR0 - BCWP}{BAC - MR0}}$
4. COST PERFORMANCE INDEX (CPI)	EFFICIENCY: WORK DONE FOR RESOURCES EXPENDED	$\frac{BCWP}{ACWP}$
5. % SPENT A. (BAC - MRREM)	AMOUNT SPENT VIS-A-VIS PERFORMANCE MEASUREMENT BASELINE	$\frac{ACWP}{BAC - MRREM}$
B. CONTRACTOR'S LRE	AMOUNT SPENT VIS-A-VIS CONTRACTOR'S LRE	$\frac{ACWP}{\text{CONTRACTOR'S LRE}}$
6. ACWP RATE	AVERAGE EXPENDITURES PER MONTH	$\frac{\text{CUMULATIVE ACWP}}{\text{\# OF MOS.}}$
7. MONTHS LEFT (ACWP)	TIME REMAINING AT ACWP RATE	$\frac{BAC + MR0 - ACWP}{\text{ACWP RATE}}$

The estimates at completion (EAC) are computed seven ways, each of which gives a slightly different indication. The seven EAC values are based on:

- o contractor's LRE (Latest Revised Estimate)
- o current month CPI (Cost Performance Index)
- o 3 month CPI
- o cumulative CPI
- o ACWP (Actual Cost of Work Performed) regression
- o weighted SPI/CPI (Schedule Performance Index/Cost Performance Index)
- o trend weighted SPI/CPI

The sources and uses of the seven EAC values are summarized in Figure 3.

The CPA model has been used by DARPA for program cost analysis for some time and is useful for certain fundamental program management responsibilities, including both accounting verifications as well as performance verifications. For example, the CPA data indices are useful for:

- o insuring that ACWP, BCWP, AND BCWS are less than or equal to budget at completion (BAC) or EAC,
- o insuring that program cost data for the period are less than or equal to cumulative

data,

- o insuring that cumulative program cost data are less than or equal to EAC's,
- o monitoring cost and schedule variances above either a dollar or percentage of cost threshold for either cumulative or periodic cost account data,
- o monitoring slippages on the critical path,
- o flagging cost performance anomalies,
- o analyzing contractor's LRE and predicted EAC values.

Figure 3

CPA MODEL EAC PROJECTIONS

ESTIMATE BASED ON:	SOURCE	USE
CONTRACTOR'S LRE	CONTRACTOR'S CPR	CONTRACTOR'S LATEST ESTIMATE
CURRENT MONTH CPI	BAC-MR / CURRENT MONTH CPI	TREND INDICATOR
3 MONTH CPI	BAC-MR / 3 MONTH CPI	TREND INDICATOR, PREDICTOR IN FINAL MONTHS
CUMULATIVE CPI	BAC-MR / CUMULATIVE CPI	PREDICTOR IN THE ABSENCE OF SCHEDULE RECOVERY
ACWP REGRESSION	LINEAR EXTRAPOLATION OF ACWP VS. BCWP PLOT	PREDICTOR IN THE ABSENCE OF SCHEDULE RECOVERY
WEIGHTED SPI/CPI	ACWP + ESTIMATE TO COMPLETION BASED ON NECESSARY SCHEDULE RECOVERY	PREDICTOR WHEN SCHEDULE RECOVERY IS ESSENTIAL
TREND WEIGHTED SPI/CPI	ACWP+ESTIMATE TO COMPLETION BASED ON RECENT TREND IN PERCENT COST VARIANCE	PREDICTOR WHEN SCHEDULE RECOVERY IS ESSENTIAL

Unfortunately, the predicted EAC values and the contract condition indicator utilized in the CPA model depend to a significant extent on ratios which contain baseline costs. Moreover, two of the time-weighted EAC projections require six and eight months of data. Consequently, when a contract baseline change occurs, the EAC projections are confounded and an erroneous indication of contract status is generated.

The limitations of the CPA model in the context of baseline changes motivated considerable research into techniques for short-term risk assessment and long-range risk management. The results of the research into short-term techniques are embodied in the curve-fitting module, while the other risk assessment indicators are oriented toward longer range concerns. Collectively, these risk assessment indicators compensate for some of the inadequacies of the CPA model when contract conditions invalidate the CPA model methodology.

Curve Fitting Algorithm

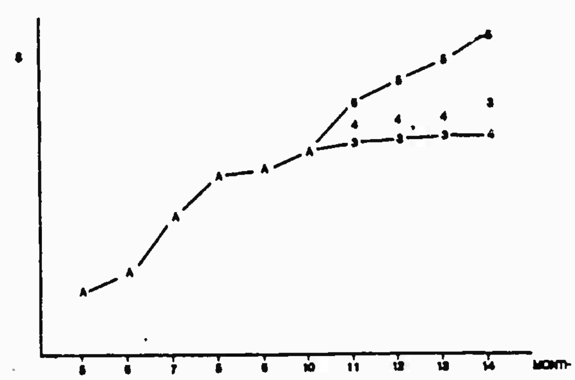
The curve fitting algorithm was developed in response to the need for a mechanism to assess short term cost growth which is not dependent upon cost performance ratios. Consequently, the algorithm was designed to utilize recent ACWP data to provide a clear and useful display of near term future cost variability.

The approach taken to the quadratic curve fitting algorithm consisted of the projection of ACWP for 1, 2, 3, and 4 months into the future. Three separate projections were prepared for each month based on the contractor's ACWP as reported in the previous 3, 4, and 5 Cost Performance Reports. Three separate projections were deemed appropriate because the methodology needed to be sensitive to relatively long term indications of stability and yet be responsive to short term fluctuations which may be indicative of rapidly rising costs.

It was reasoned that the more months upon which the projection is based, the more stable the projection will be, i.e., the less responsive the projection will be to singular cost surges or plunges. On the other hand, cost projections based on fewer months of past ACWP data are more sensitive to recent cost fluctuations. Hence, the dispersion or envelope of cost projections derived from various time horizons is an indicator of recent cost growth variability, in addition to providing estimates of short term costs. An example of the type of output which the algorithm provides is shown in Figure 4. As shown, the series of projections which the algorithm generates form an envelope which bounds the range of future costs.

Figure 4

EXAMPLE: CURVE-FITTING ALGORITHM



The generation of this envelope is useful for three distinct functions. First, as a measure of relative uncertainty, an analysis of the widths of the envelopes surrounding the projections of individual WBS elements can assist the PMO in identifying particularly volatile cost elements which merit closer technical observation. In addition, such an analysis would also necessarily indicate recent cost growth variability within the WBS element. Second, the curve fitting algorithm provides useful basis for comparison with the contractor's baseline plan. Cost projections in excess of the baseline plan should provide an early warning signal to the PMO, especially i two or more of the projections are above the baseline. Third, utilizing the outputs of the algorithm retrospectively, the PMO can assess significant deviations between ACWP and the previous month's projections. If the deviations show higher than projected costs, the causes for such cost growth should be examined. Alternatively, if the ACWP figures fall below projections, a further comparison with the baseline should be made. ACWP below baseline may be indicative of either a schedule slippage or an extremely high baseline plan. Also, the previous month's projections should be monitored for changes in the designators of the lower and upper bounds. In general, a period of steadily increasing ACWP will give rise to 5-month projections forming the upper bound and 3-month projections forming the lower bound. However, recent significant cost surges will create a situation in which the 5-month and 3-month projections switch temporarily. This switch can be utilized as an early warning signal by the PMO, who may alert the Technical Office to the cost growth and promptly implement procedures for cost control.

The curve fitting algorithm was tested against data obtained from the Teal Ruby Program. The results confirmed that the size of the cost prediction envelope varied with cost element uncertainty. Moreover, it was found that the envelope bounded future costs in 77% of the cases. An analysis of the wrong predictions indicated that a substantial majority (81%) were associated with significant changes to the contract baseline. Consequently, in the absence of baseline changes, the curve fitting algorithm was shown to bound the future ACWP in 95% of the cases. For comparative purposes, a second cost envelope was constructed by taking as bounds the contractor's baseline plus or minus 10%. This envelope was capable of predicting future ACWP in only 61% of the cases.

A significant result of this analysis was the behavior of the algorithm in the region surrounding baseline changes. As indicated earlier, baseline changes have historically rendered the projections and assessments resulting from the CPA model erroneous due to the confounding effect on the model's regressions. This confounding effect lingers for several reporting periods after the baseline changes, since some CPA model indicators utilize up to eight periods of historical data. In contrast, the curve fitting algorithm was able to compensate for baseline changes within a period of 2-3 months. Consequently, although baseline changes account for nearly all the erroneous predictions of the curve fitting algorithm, the algorithm is sufficiently resilient to recover from such changes within a relatively short period of time.

Finally, it should be noted that the output of curve fitting algorithm cannot be analyzed without regard to other contract indicators, such as the narrative portion of the Cost Performance Report (CPR). By realizing that a baseline change is imminent, the PMO can adjust the interpretation of the algorithm's output in recognition of the changing baseline. In such a case, less emphasis would be placed on the cost envelope per se, with a corresponding increase in emphasis on the retrospective analyses described earlier.

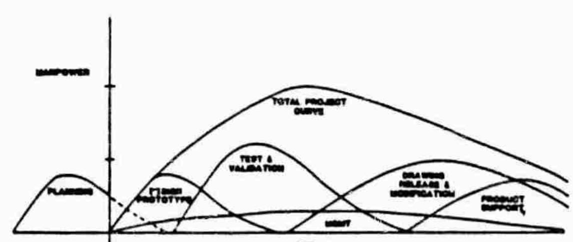
Rayleigh Analysis

The Rayleigh equation describes a random statistical process where many complex interactions drive the unpredictability of the process outcome. This theory has been used to project software system cost based upon parameters of development time, system difficulty, and number of source statements. It has also been used to dynamically track manpower and cash flow over project duration. R&D projects are thought to exhibit similar patterns of manpower loading and interactions as those of software development, where frequently, software itself is an integral part of R&D projects. Preliminary research has indicated that a potential exists for the application of Rayleigh theory to contract costs.

Each cycle, or variable, which makes up part of the total process exhibit a pattern of a sharp initial rise in manpower, a peak, and then gradual tailing off. Figure 5 illustrates the interactions of each of the R&D

Figure 5

R & D LIFE CYCLE CURVE WITH SUBCYCLES



life cycle phases and the resultant total project curve. The total project curve tends to demonstrate the Rayleigh theory also, though not as pronounced as the individual cycles.

The mathematical model which represents this curve and has been successfully used for both individual cycles and overall time varying behavior is given by:

$$Y = k/t_d^2 \cdot t \cdot e^{-t^2/2t_d^2} \quad (1)$$

where

Y = manpower at any time t
K = area under the curve and represents total life cycle effort in man years
t_d = development time in years (time of peak manpower)
t = elapsed time since initiation of project

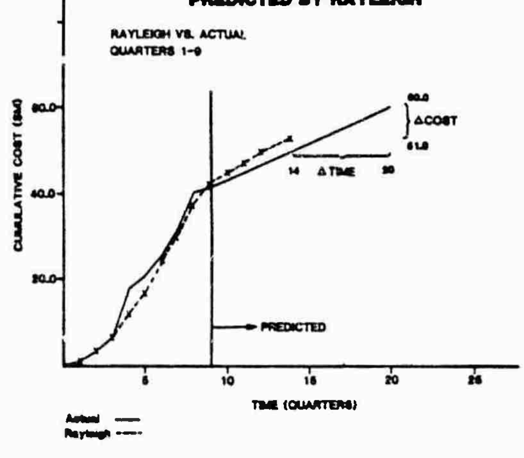
The results of exercising this model allow one to make projections of manpower and time requirements given a few early actual data points. These projections can be used as a basis for comparison with actual project values in the later stages. If actual figures exceed the established bounds surrounding the projection, program management may be alerted that some corrective action is needed to bring the project back into line.

When the Rayleigh theory provides a good explanation for varying contract costs, the PMO can use this methodology to predict total cost as well as next period costs and period of greatest cost expenditure. As actual cost data becomes available for each period, the model can be updated and all prior data elements used to predict desired parameters. A close watch should be kept on previous predictions versus actual costs as they occur so that program management is alerted in a timely manner of a potential problem.

The best use of the Rayleigh model is as a predictor of total project costs. Applying the Rayleigh theory to Teal Ruby data showed the greatest utility of Rayleigh theory appears to be in projecting cumulative project costs. Figure 6 graphically shows the

Figure 6

CUMULATIVE COSTS PREDICTED BY RAYLEIGH



the project cumulative costs versus the cumulative and final total costs predicted by the Rayleigh curve. The graph illustrates the costs at the end of quarter 9. Nine quarters of data were input to the model and an expected total cost of 51 million dollars spent by the expected completion at quarter 14 resulted. This compared to the contractor's estimate of 60.2 million (BAC) spent by an expected completion at quarter 20. The variance in cost and completion time between the actual and predicted curves give an early warning signal of potential problems. In the Teal Ruby case, there were in fact at least two baseline changes after quarter 9. The potential for the increases created by the baseline change are evident upon examination of these graphs.

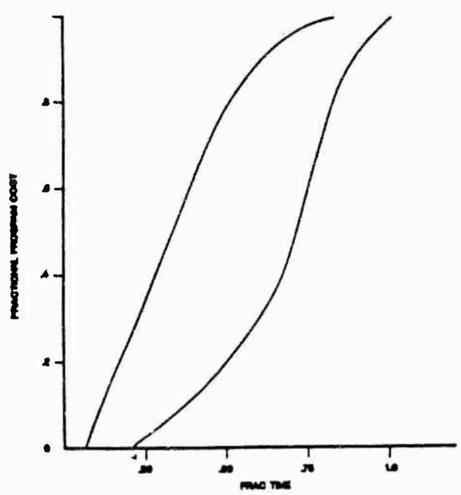
The Beta Distribution Model

The Beta distribution curve has been successfully used as a model for spreading or simulating costs across time. The variables in th application are fractional time versus fractional cost expended or, the ratio between resources expended and time consumed. The Beta curve has proved useful in spreading total program costs for budgeting and scheduli purposes as well as a powerful tool for monitoring on-going projects by calculating expected cost at completion (EAC). This information provides managers with timely feedback on their progress in meeting cost objectives as they occur.

The cost spreading function used with the Be model was developed by NASA cost analysts at the Johnson Space Center. It has been used extensively by NASA to project EAC at successive time periods during ongoing projects. This particular model gives an envelope of cumulative cost curves, as shown in Figure 7,

Figure 7

BETA DISTRIBUTION ENVELOPE OF CUMULATIVE PROGRAM COSTS



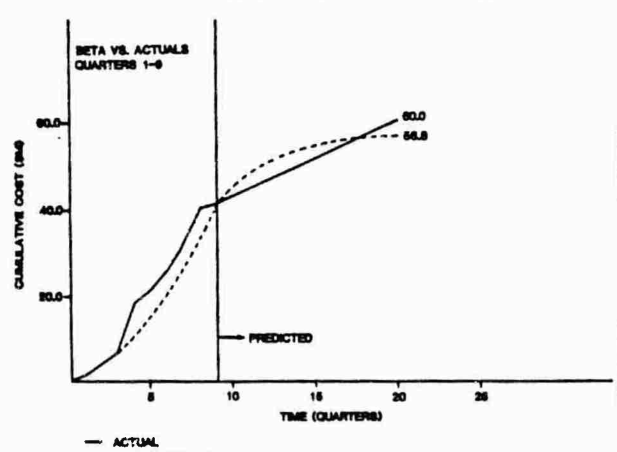
that can be expected. The model best fits, by least squares, the actual project data collected to date to a Beta curve within thi envelope. The parameters calculated for developing the curve are then used to project an EAC given the project data to this point.

The most attractive feature of this model is its simplicity of use. Data inputs are project start date, project end date, current period date and cumulative cost to date. Once input, the model calculates EAC. This EAC can then be compared against the contractor's LRE and against other estimates of EAC from other sources.

The output from this model is valuable for two reasons. First, it provides an estimate of total cost based upon actual project duration and the rate of cost expended to date. This can be compared to the contractor's Latest Revised Estimate (LRE) which is based upon the same length of project time. Second, it provides an additional estimate of EAC based upon different parameters than the Rayleigh model uses. Although the Rayleigh model also evaluates rate of costs expended, it calculates and uses its own expected project duration time. Because the Beta model projects EAC based upon different inputs, it provides an "independent" assessment of EAC for comparative uses. This allows the LRE to be assessed from two different points of view.

The model was applied to the Teal Ruby data base and produced a fit of the data to the Beta distribution. This model is sensitive to project duration estimates and as the length of the project is revised, the estimates of EAC become more reasonable. Figure 8 show the cumulative Beta curve estimates at

Figure 8
TEAL RUBY DATA APPLIED AGAINST BETA



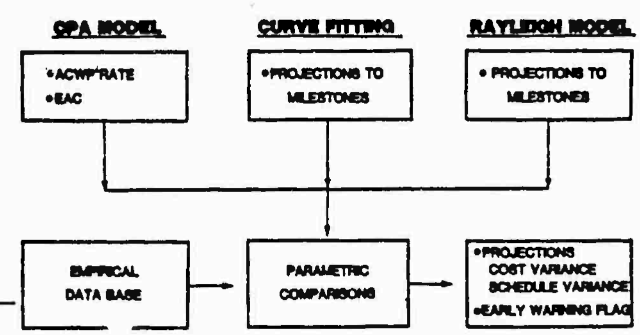
the midpoint of the data base. Used in conjunction with the output from the Rayleigh model, the Beta distribution model provides a different assessment of total expected cost. The output also provides an assessment of the reasonableness of project duration time. If values of EAC projected with early data points are considerably higher than LRE, there is an indication that based upon the rate of early expenditures, the project will either have to be extended or cost overruns will be large. This can be an early warning signal to expect extended project duration, increased LRE, or both.

Parametric Milestone Analysis

Parametric milestone analysis refers to a procedure whereby ACWP data are systematically compared to 1) projections yielded by other techniques in the risk assessment package, and 2) empirical data collected on other high risk R&D programs. The purpose of the parametric milestone analysis is to indicate to the PMO how the progress — and the projected progress — of the contractor compares to the progress attained by other contractors conducting similar R&D programs. The progress reported by the contractor is measured with respect to the achievement of key project milestones (e.g., Critical Design Review, Functional Configuration Audit, etc.). The cost projected to be incurred by the contractor at the milestone as a percentage of total contract cost is then compared to the percentage figure actually incurred on contracts of a similar nature.

Parametric milestone analysis is not intended to provide a rigid normative model of how costs necessarily must be incurred, but rather, is most useful as an early warning indication that contractor performance may be out of line with other historical experience. In such circumstances, the analysis can serve as a catalyst to the closer examination of individual cost elements which lie outside the nominal range.

Figure 9
PARAMETRIC MILESTONE ANALYSIS



As shown in Figure 9, outputs from the CPA model, curve fitting algorithm, and Rayleigh analysis model are used as inputs to the parametric milestone analysis, in addition to the contractor's baseline plan (which, of course, appears in the curve fitting module and is implicit in the CPA model). If in any given month no milestones appear within the range of the curve fitting module, then the output from that module is not utilized for parametric analysis in that month. The project these sources are then compared to empirical data on the cumulative percentage expenditures required to attain the corresponding milestones on similar projects. The output of the parametric milestone analysis is a structured listing of projections from each of the data sources. This listing also provides an assessment of the cost variance and the schedule variance predicted by each of the four methods. The ultimate value of the report lies in its ability to provide an indication of potential problems based upon the cost and schedule variances which it computes.

An example of how the parametric milestone analysis may be applied is shown in Figure 10. Although the data shown were obtained

Figure 10
PARAMETRIC MILESTONE ANALYSIS

		EMPIRICAL DATA BASE						
	WBS 1.4	DOTY	THAYER	SAFEGUARD B.M.S.	DALY	IDEAL	ESTIMATORS RULE OF THUMB	AGGREGATE
ANALYSIS	12	6	11	20	10	30	40	11
DESIGN	27	16	33	20	40			26
CODING & CHECKOUT	27	28	24	17	18	40	20	24
INTEGRATION & TESTING	34	52	32	43	36	30	40	39

from the contractor's baseline plan, the procedures for analysis of actual data would be identical. In addition to the actual cumulative data, parametric milestone analysis contains columns for estimates derived from short term CPA model forecasts, curve fitting projections if the milestones fall within the range of the algorithm's predictions, and Rayleigh theory analysis extrapolated to the individual milestones.

The results of the parametric milestone analysis showed that the phase costs for software were remarkably consistent to the empirical data base. However, when compared to the Rayleigh theory estimates for software development, the technical software milestones as specified in the baseline plan appeared to be more optimistic than the corresponding milestones proposed for the experiment as a whole. Moreover, a disproportionate percentage of the optimism in the proposed software plan concerned the scheduling of the later software milestones. The implication of this parametric milestone analysis, when viewed in conjunction with the results of the Rayleigh model estimates, is that a specific WBS element could be identified as very likely to cause a slippage in the baseline plan. In addition, the analysis indicated that software was likely to become a limiting activity on the critical path. Based upon this analysis, the Technical Office was able to focus the direction of further risk management activities and initiate an active risk reduction program.

Bayesian Analysis

The purpose of Bayesian analysis is to provid the PMO with information on the uncertainty surrounding the estimated costs at completion Bayesian analysis explicitly recognizes the uncertainty in cost estimates, and rather tha attempting to pinpoint a single estimate of cost at completion, it instead characterizes the range of possible values which the cost a completion may include.

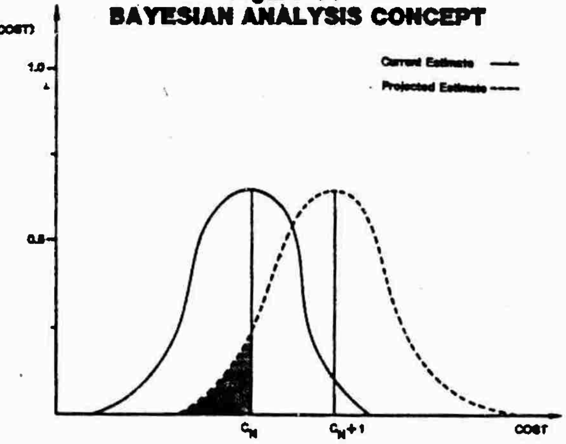
The Bayesian analysis algorithm postulates a probability distribution surrounding initial cost estimates. The characteristics of this probability distribution will vary depending on the nature of the cost element under consideration, but in all cases may be defined i terms of the mean, μ, and the variance, σ^2 Utilizing the properties of Bayesian statistics, the empirical data for the cost element as reported by the contractor on the Cost Performance Report (CPR) are used to update the characteristics of the probability distribution. Based upon this new information as reported in the CPR, the parameters of the distribution are updated, including both the mean and the variance.

The outputs of this analysis are updates of the initially postulated distributions. Thes updates permit three distinct analyses to be performed. First, a new mean for the distribution will be provided. Under commonly used distributions, the mean also corresponds to the value with the highest probabililty of occurrence. Therefore, the new mean may be construed as indicating a new estimate at completion.

Second, the new mean will also have a probability distribution surrounding it. Utilizir this distribution, the Bayesian analysis algorithm establishes confidence intervals or the mean. The higher of these confidence intervals less the value of the mean may be interpreted as the level of contingency reserve allocation necessary to achieve a give confidence level on the estimated cost at co pletion. The PMO may then alter the width o the confidence interval to decrease (or increase) the amount of contingency reserves required, and incur a corresponding decrease (or increase) in the confidence level of the estimate at completion. In this manner, the PMO may trade off risk reserves versus the increased uncertainty in remaining within th budget at completion.

Finally, the new probability distribution may be compared with the previous distribution. The essence of this analysis is illustrated in Figure 11. This comparison is useful for three purposes. First, the PMO may compare how the estimated mean has changed from month to month. The magnitude of this change will indicate the level of increase in expected cost at completion from the previous month. Second, the PMO may analyze the change in the variance from the previous month. An increase in the variance will indicate greater uncertainty in the cost estimates. Conversely, a decrease in variance will indicate that the estimate at completion is becoming firmer. Such a development might occur near project completion. The third purpose this comparison serves is to show the new probability of attaining an actual cost at completion which is less than or equal to the previous month's estimated cost at completion. The probability is represented by the shaded area in Figure 11. Such an analysis shows that, as new estimates at completion are developed, the probability of achieving the former estimates at completion diminishes. This in turn may indicate that previously allocated management reserves are not sufficient and that a baseline change is necessary.

Figure 11
BAYESIAN ANALYSIS CONCEPT



UTILIZATION OF THE RISK ASSESSMENT TECHNIQUES

As emphasized previously in this report, the techniques presented for DARPA program risk assessment are oriented toward the special needs of the PMO to identify, to analyze, and ultimately to manage risk. The techniques were designed to be used as tools in conjunction with other information available to the PMO. Taken individually, none is an infallible indicator of program cost and cost growth risk. Taken collectively, they yield a reasonably comprehensive assessment of program risk from numerous different perspectives.

The applicability of each of the program risk assessment techniques is summarized in Figure 12. As shown in this figure, the techniques

Figure 12
SUMMARY OF APPLICATIONS

	EARLY WARNING SIGNAL			COST AND SCHEDULE PREDICTIONS	
	SHORT TERM COST GROWTH	MID-COURSE REASONABLENESS CHECK	LONG RANGE CONFIDENCE INTERVALS	SHORT TERM	LONG TERM
CPA MODEL	X				X
CURVE FITTING	X			X	
RAYLEIGH ANALYSIS		X			X
BETA THEORY		X			X
PARAMETRIC MILESTONE ANALYSIS		X			
BAYESIAN ANALYSIS			X		X

have two fundamental purposes. First, they are intended to serve as early warning signals to the PMO to alert management in a timely manner to the possibility of unexpected cost growth. Second, the techniques are intended to provide an estimate or an indication of the likely magnitude of a cost overrun or schedule slippage. As a result, the analytical framework recommended for DARPA program risk assessment consists of three principal elements which focus on short term, mid term, and long term concerns. Within each of these elements, the outputs of two or more of these techniques may be synergistically combined.

Short Term Analysis

Short term analysis can be accomplished through use of the CPA model and the curve-fitting algorithm, giving cost prediction and early warning signals. These outputs permit the following analyses to be performed:

- o Evaluation of earned value data. CPA model output contains ratios that permit the evaluation of recent past contractor performance in terms of ACWP vs. BCWP (cost overruns) and in terms of BCWP vs. BCWS (schedule slippage). Deviations greater than 3% generate early warning messages.
- o Cost prediction. Curve fitting algorithm projects near-term future cost and enables comparison of projection to contractor's baseline. Significant deviations generate early warning message.
- o Cost analysis. Curve fitting algorithm enables a "backward look" at the actual cost data to permit a comparison to previous predictions. Overruns or underruns command management attention to control costs (or increase the baseline) in the case of the former or to examine data for schedule slippages in the case of the latter. This analysis should be done in conjunction with CPA model indicators.

element, permits the identification of those cost elements with the largest projected cost envelope. This is in turn indicative of those cost elements which have shown the greatest short term cost variability in recent months.

Mid Term Analysis

In the mid term, the risk assessment indicators focus less on the prediction of costs and more on the assessment of the reasonableness of the expenditure patterns vis-a-vis theoretical and empirical models. From the theoretical perspective, comparisons with the Rayleigh theory of expenditure patterns are possible for any reporting period in the life of the project. At certain other points, the contribution of Beta theory analysis is applicable. From the empirical perspective, parametric milestone analysis can provide a benchmark based on historical experience against which progress may be measured. In a limited number of cases, the curve fitting module will have applicability through its impact on the parametric milestone analysis output. In summary, the mid term risk indicators have applicability as follows:

- Cumulative cost analysis. A project's cumulative costs versus milestones are compared to historical experience to indicate significant deviations. Reasons for large deviations (either positive or negative) should be explained in detail to the PMO as they may indicate either a compressed time frame or the imminent need for baseline revisions.
- Expenditure pattern analysis. Expenditure pattern analysis refers to analyses of long term trends in expenditures as opposed to short term expenditures which may fluctuate with the business cycle. Basically, expenditure pattern analysis entails comparison to Rayleigh theory predictions for the pattern of expenditures and the Beta theory estimates. In addition, this analysis includes the examination of costs at the WBS level and indicates which cost elements are experiencing recent changes from established patterns.

Long Term Analysis

Long term analysis includes all of the estimates at completion as determined through the individual techniques plus confidence intervals. The following analyses may be performed using the risk assessment indicators:

- Estimate at Completion (EAC). The CPA model provides seven estimates at completion including the contractor's latest revised estimate (LRE). Bayesian analysis, while constrained by assumptions, does provide a maximum likelihood estimate of EAC based upon a contractor's monthly reports of ACWP. In addition, the Rayleigh model provides an EAC based upon the development times of the program, and Beta theory provides an EAC based upon the starting date, ending date, and cumulative cost to date. These estimates may be compared and contrasted to yield an assessment of long term cost growth risk.
- Confidence limits. Bayesian analysis also provides a confidence interval for the estimate at completion. The width of this interval indicates the confidence one may have in the estimate, or conversely, the relative risk that the actual cost will not be near the EAC.
- Probability estimates. These estimates are derived from the Bayesian analysis, and permit the PMO to assign a probability to achieving a final cost less than or equal to a given value (e.g., contractor's LRE, contractor's LRE + 10%, etc.). Conversely, these estimates also permit the PMO to assess the amount of contingency reserves necessary to bound a confidence interval of some desired percentage (e.g., $3 million reserves necessary to achieve 90% confidence interval).

SUMMARY AND CONCLUSIONS

This paper has described an innovative approach to risk assessment for use in the DARPA Program Management Office. The approach focuses on the prediction of costs in the short run and the indication of risk over longer time horizons. It employs a quadratic curve-fitting algorithm to estimate short term cost fluctuations, and it uses theoretical and empirical cost models both to estimate the cost at completion and as well as to gauge the reasonableness of the expenditures to date. The components of the approach are intended to be utilized collectively to yield a balanced appraisal of cost and schedule risk of a program over the remaining phases of the R&D cycle.

In summary, this report has documented the initial steps which have been taken to provide DARPA PMO with an augmented analytical risk assessment capability. The basic risk assessment tools have been developed and are now available for use by the PMO. The adoption of the methodology will assist DARPA in assessing the cost and schedule risk of high risk R&D programs, and will provide the foundation for future PMO activities in risk management and control.

Reference: "Analysis of Quantitative Techniques for DARPA Program Risk Management". Interim Report under Contract No. MDA903-82-C-0139, Meridian Corporation. May 19, 1983.

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TWO MODES OF DECISIONMAKING

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ABSTRACT

Brain research has grown into an acceptable area for management awareness. Learning facts about the brain hemispheres has yielded powerful tools for decisionmakers, allowing them to become literate about brain functions, to utilize the "fact" that the two sides of the brain are entirely independent with regard to learning and retention. A new paradigm incorporating consciousness technology may better serve the decisionmaking processes of our rapidly-changing society.

INTRODUCTION

The purpose of this paper is to put the emerging consciousness technologies into a managerial perspective. The on-going brain research which has resulted in three Nobel Prizes in 1981 to American-based researchers, focused on specialized higher split-brain functions.

The first part of this paper explains the underlying theory of split-brain research, indicating the more significant developments for the mechanisms of decisionmaking. The second part reviews significant implications of the research contributing to a new paradigm for this current era of profound change.

THE TWO MODES OF DECISIONMAKING

Decisionmakers have been aware that there are many different paths to problem solving. When queried about the mental process by which the "right" answer was selected, the decisionmaker cannot track the logical process. Darwin, Copernicus, and Newton are examples of the revolutionary scientific work that involves shifting to a new paradigm.

Several erroneous assumptions in Nineteenth Century science have oriented our cultural philosophy in the direction of rational mechanical thinking:

- All known forms of energy have been discovered.
- Our ordinary consciousness of time/space is necessarily the correct view.
- Men live as separate and autonomous individuals.
- The existence of the physical body is the essence of man.

Concentrating on the verbal (left) side of our brains we produced things we know how to analze and measure. Our mute (right) brain remained uncharted. Current research is directed to discovering how the right hemisphere thinks and how it might be educated, and more important what its contribution is in the complex art of creativity.

Split-Brain Research

It is well known that the left hemisphere of the brain (the "dominant" or "major" hemisphere) controls movements on the body's right side, and the right hemisphere (the "subordinate" or "minor") controls movements on the left.

Other research indicates that the left hemisphere also contains the logical thinking processes for most people. These processes are mainly linear -- processing information sequentially, one bit after another, in orderly analytical fashion -- line mathematics or language. The right hemisphere in contrast, is specialized for simultaneous processing; i.e., it functions in a more holistic, relational way -- like comprehension of visual images. The Dichotomy, quoted in Linstone and Simmonds' book on Futures Research: New Directions [9], shows a schematic comparison of the split-brain halves and their biological-behavioral patterns.

TABLE 1. The Dichotomy

Left-Brain Hemisphere

Sequential thinking
Reductionist
Analytic
Well-structured problems
Problem solvers
Sensation (Jung)
Perceptual, external experience

Right-Brain Hemisphere

Spatial thinking
Holistic
Synthetic
Ill-structured problems
Problem formulators
Intuition (Jung)
Conceptual, internal experience

The human being can be thought of as an organism composed of components having both psychological ("receptive mode" to receive the environment) and biological dimensions ("action mode" to manipulate the environment). In his Harvard Business Review article, Henry Minzberg [13] stated

> ... scientists have further found that some common human tasks, activate one side of the brain while leaving the other largely at rest. For example, a person's learning of a mathematical proof might evoke activity in the left hemisphere of his brain, while his conceiving a piece of sculpture or assessing a political opponent might evoke activity in his right.

Robert Ornstein [15] points out that the "esoteric psychologies" of the East (Zen, Yoga, Sufi, etc.) have focused on right-hemispheric consciousness, while Western psychology has been almost exclusively concerned with left-hemispheric consciousness, with logical, rational thought.

Inside each of our skulls, we have a double brain with two ways of knowing; each half with its own way of perceiving external reality. Each of us has two minds, two consciousnesses, mediated and integrated by the connecting cable of nerve fibres (corpus callosum) between the hemispheres. The two hemispheres can work together in a number of ways. Each half can cooperate with the other by contributing its special abilities, and taking on the peculiar part of the task that is suited to its mode of information processing. At other times, the hemispheres can work singly; with one half "on", the other half more or less "off". The hemispheres may also conflict; one half attempting to do what the other half "knows" it can do better. It may even be that each hemisphere has some way of keeping knowledge from the other hemisphere!

As each of the hemispheres gather in the same sensory information, each half may handle the information differently: the task may be divided between the hemispheres, each handling the part suited to its style. Or one hemisphere, often the dominant left will "take over" and inhibit the other half. The left hemisphere analyzes, abstracts, counts, marks time, plans step-by-step procedures, verbalizes, makes rational statements based upon logic. On the other hand, the right hemisphere mode is a second way of knowing. We "see" things in this mode that may be imaginary, or recall events that may be real. We see how things exist in space, and just how parts go together to make up the totality, the gestalt. Using the right hemisphere, we understand metaphors, anagrams, dreams; we create new combinations of "Eureka"-type ideas, we use intuitions and have leaps of insight and "peak" experiences. Most of our training -- home, school, business, social -- has been designed to cultivate and prize the verbal, rational, on-time, left-half -- while virtually neglecting right-half processing.

George M. Prince of Synectics, Inc., saw this "split-brain" discovery as the key to unlocking the creative process. Reasoning that the key to creativity lay in suppressing the left (or logical) hemisphere, he encouraged his clients to become comfortable with their right brains, the so-called "storehouse of ideas". In his "encounter" sessions he came up with techniques like that of Goal-Wishes -- in which an aspiring inventor would fantasize about how his problem might be solved if there were no fiscal or technical constraints. From this list the client was instructed to select such an absurd method of achieving his goal that he would fear dismissal if he seriously proposed it at work. This "get-fired solution" was one that could, in many cases, be refined into an imaginative yet workable answer.

In attempting to repress the left-brain, Dudley Lynch used such techniques as playing soft, rhythmic music while gazing at a glass coffee pot onto which a series of colored lights are projected. Another area of research has been with the use of drugs designed to chemically suppress the working of the left hemisphere; on the theory that with that side out of the way, the thoughts of the right-brain will come forth. Other psychologists are convinced that the key to understanding creativity in decision making can be found through the techniques of brain-scan and biofeedback. The Greens, at the Menninger Foundation, using biofeedback have been able to achieve and prolong the theta state (and stimulate creativity), which occurs in the immediate pre- and post-sleep stages. Professor Eugene Gendlin, University of Chicago has developed a technique of "focusing", in which, he claims, a person can reach theta state and remain there indefinitely through a process akin to self-hypnosis, where the subject makes a connection between the brain halves.

It seems that the nature of the task at hand may induce a particular hemisphere to "accept" and/or "control" the job, while repressing the activity of the other hemisphere. "Scientists postulate," stated Betty Edwards in her Drawing on the Right Side of the Brain [5] "that the hemispheres either alternate being 'on' --- an 'on' condition in one hemisphere causing an 'off' condition in the other --- or they are both 'on', but with one hemisphere controlling the action (the overt behavior)." What factors determine which hemisphere will be "on" and/or controlling? She concludes that scientists believe that the control question can be decided mainly in two ways:

> One way is speed: which hemisphere gets to the job the quickest? A second is motivation: which hemisphere cares most or likes the task the best? And conversely: which hemisphere cares least and likes the job least? Since drawing a perceived form is largely a right-brain function, we must keep the left-brain out of it. Our problem is that the left-brain is dominant and speedy and is very prone to rush in with words and symbols, even taking over jobs which it is not good at. The split-brain studies indicated that the left-brain likes to be boss; so to speak, and prefers not to relinquish tasks to its "dumb" partner unless it really dislikes the job -- either because the job takes too much time, is too detailed or slow or because the left-brain is simply unable to accomplish the task.

Figure 1, taken from Bartfeld, Selman and Selman [2] illustrates a suggested decision-making matrix for forecasting purposes. In cases where both brain-sides are in agreement, there is no problem. In case of disagreement, recent past personal experience will suggest the acceptable course of action; if not, or if experience is insufficient, the more conservative "Don't do it" prevails.

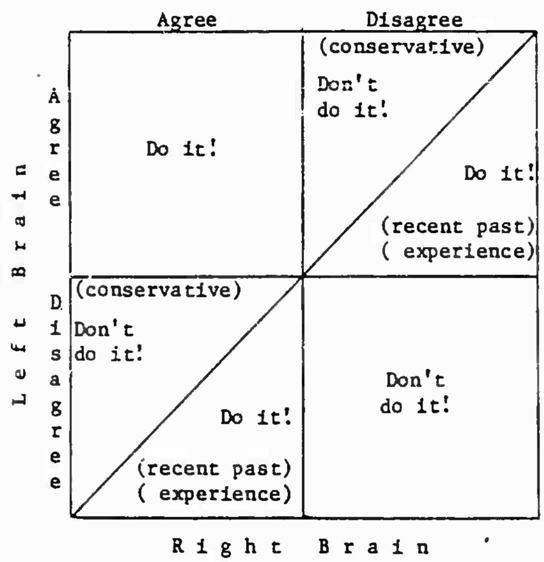

FIGURE 1. Decision Matrix

How does one use "past experience" pramatically? By comparing the positive experience gained in similar circumstances when following intuition or hunches (like betting on numbers), versus positive experience gained by following an analytical approach (like betting on probabilities), the decisionmaker can select that course of action proven most profitable for him in the long run.

David Loye [11] believes that the study of the functions of the forebrain, the so-called "frontal lobes", has been almost as neglected as the study of the right-brain functions.

Forebrain functions are of three main types:

- Foresight, including detection of change patterns.
- Systems thinking -- the ability to cognize in wholes.
- Self-regulation -- the ability to control behavior that shapes one's own future by interposing something that governs behavior, something that says: "Yes, I will do this", or "No, I won't do that."

To the above forebrain powers, psychobiologist David Goodman adds holos, the social sense, and prognos, the sense of the future.

After identifying the three separate mind functions as concepts, the next question is: How do they work together? David Loye in his article "The Forecasting Mind", in The Futurist, speculates on the working together of the Right-, Left-, and Forebrain, and how they relate:

> Think of the forebrain as the mind's manager through whom all questions involving decisionmaking must pass. Under forebrain monitoring and guidance, the left brain, primarily through consciousness, processes the information received from the phenomenal world --- or the world of "appearances" --- much as a computer with pattern recognition equipment would. It scans the data; if it then detects anything with which it is programmed, it will predict future events.
>
> Also with forebrain monitoring, the right brain, primarily through unconsciousness, processes information from ... the noumenal as well as the phenomenal world. In other words, the right brain receives information whose "reality" is unlike that of the phenomenal world ...

From these two sources, information bearing on the future flows into the forebrain. Here, the forebrain must decide what is sense, and what is nonsense, and what should be done about it --- what actions to take, or what actions not to take. David Loye in his pioneering work, The Knowable Future [10], uses the following example to illustrate the integration of the left-, right-, and forebrain.

> It seems evident, then, that our capacity for foreknowledge derives from pooling and processing by the forebrain of the rational left-brain information and intuitive right-brain information. In other words, it is as if the forebrain acts like a field general to whom two lieutenants bring in reports in the heat of battle. One lieutenant, representing left brain rationality, is spotlessly uniformed, clicks his heels and rattles off his information like a computer. The other, representing right brain intuition, silently slips in clad in his spy's gypsy disguide and mumbles and rambles through his account. The forebrain as field general then sifts the perceptions of both lieutenants and decides what is the likely shape of the future course of battle, and what is to be done about it.

William J.J. Gordon [7], author of Synectics, contends that the left, or logical, part of the brain is more involved in the creative process than many other researchers believe. In Gordon's view, the formation of creative ideas is actually an oscillation between the right and left hemispheres, with the right hemisphere continuously making free associations and the left performing rapid judgments on them and sending them back to the right brain for more work. Niles Howard [8], in his "Business Probes the Creative Spark", in Dun's Review concludes that:

> In creativity tests on individuals of all ages, creativity scores invariably drop about 90%, between ages five and seven, and by age forty, an individual is only about 2% as creative as he was at age five. This suggests to many psychologists that the almost total emphasis on logical thought in education may effectively suppress creativity.

The expectation of further "split-brain" research is that what has been trained out can be trained back in. A creativity test designed by Eugene Raudsepp (Princeton Creative Research, Inc.)is included as Appendix A, How Creative Are You?

UNCERTAINTY

The work "futurology" was coined to describe the scientific study of the future. Before then, images of the future include frequently speculation, guesswork and mysticism. Prediction is a revelation of what can happen, given certain conditions and occurrences. Forecasting allows influencing outcomes, by changing and impacting one or more variables involved. It permits society to preview and discuss possible outcome options and to select alternatives. Newly emerging methodologies for Decision Risk Research included approaches remote from conventional Western epistemology to problem-solving, which was primarily built on the notions of the "hard" sciences of replicable experiments, and "objective" truth. Looking now towards a complex and fuzzy future with uncertainties, discontinuities, and unknowns, surprise-free extrapolations of the past and present become rather limited and restricted tools for forecasting. There is no fail-safe, risk-free future. Viewed in game-theoretic concepts, pre-industrial society was a zero-sum game against nature; industrial society, a game against "rational man", and post-industrial society, and n-person game. Daniel Bell [3] suggested coming changes in sociological terms. He notes:

> Yet, in an intangible way, there may be more -- a change in consciousness and cosmology, the dark tinge of which was always been present at the edges of man's conception of himself and the world, whic now moves to the phenomenological center.

H.A. Linstone and W.H.C. Simmonds [9] suggeste specifically a fundamentally different approac to analyzing future problems than the more common emphasis on more numbers, more causal related techniques:

> "... move beyond the objective, analytic, reductionist, number-oriented, optimizin and fail-safe approaches to future proble and learn to think with equal fluency in more subjective, synthesizing, holistic, qualitative, option-increasing, and safe-fail ways."

Using split-brain concepts, David Loye [10] accepted the validity of qualitative information and the use of judgmental or value-based decisionmaking for forecasting processes. Th is can be inferred that less analytical metho may have a significant place in forecasting processes.

In order to assist this process, a group of of the most common forecasting techniques li by Mitchell [11] was reclassified by Bartfel Selman and Selman [2] into three groups acco ing to brain function: left-, right-, and mixed, and are listed in the Reference. Per of the list clearly indicates the prepondera of left-brain based methodologies which woul explain some of the dissatisfaction voiced b Armstrong [1] and others with the poor recor of decisionmakers and forecasters in our fast-changing environment.

Another emerging technique which may become in the future increasingly important is "metamodeling".

"Metamodeling" can be described as a formal framework for future modeling, which utilizes both human subjective assessments and conventional mathematic models as in synergistic Decision Support Systems. Future modeling of such complex areas as weapons acquisition and environmental systems can be approached by the use of fuzzy variables and possibility theory in the creation of future scenarios. This holistic framework attempts to combine human judgment into the structured modeling process, according to J. Fiksel [6].

SUMMARY

It is clear today, looking at the unsettled state of the world, and the quantum changes taking place continually, that the customary decisionmaking tools are not adequate to permit timely predictions. In particular, single consequence actions forecasted by conventional models do not work. More importantly, conventional models yield a single output for multiple inputs, which do not enable predicting higher-level and derivative consequences for that action. In order to improve the decision risk process it is suggested that higher-order consequence models as proposed by J. Coates [4] be adapted for integrated split-brain holistic decisionmaking and forecasting. More research and development into such models would greatly improve our decisions to forecasting for an uncertain future.

This report attempts to make the intelligent use of the conscious mind more palatable, and of the unconscious mind more respectable. David Loye states: "... Separation of the function and status of the incredible single power of the human mind is a disturbing reflection on the disjointedness of our lives, thoughts, and times."

REFERENCES

[1] Armstrong, J.S., Long-range Forecasting: From Crystal Ball to Computer (New York, NY: Wiley-Interscience, 1978)

[2] Bartfeld, C.L., Selman, V., and Selman, J., "Crystal-Balling the Future: Methodologies for the Study of the Future Perspective", Proceedings: International Congress on Applied Systems Researoh and Cybernetics, Acapulco, MX (December 1980)

[3] Bell, D., The Coming of Post-Industrial Society (New York, NY: Basic Books, Inc., 1973

[4] Coates, J.F., "Technology Assessment", The Futurist, Vol. 5, pp. 225 - 233.

[5] Edwards, B., Drawing on the Right Side of the Brain (Los Angeles, CA: J.P. Tarcher, Inc., 1979)

[6] Fiksel, J., "Computerizing the Crystal Ball: Toward a Metamodeling Capability", Technological Forecasting and Social Change, Vol. 17, pp. 201 - 210

[7] Gordon, W.J.J., Syntectics: The Development of Creative Capacity (New York, NY: Harper and Row, 1961)

[8] Howard, N., "Business Proves the Creative Spark", Dun's Review, Vol. 115, pp. 32 - 38

[9] Linstone, H.A. and Simmonds, W.H.A., Futures Research (Reading, MA: Addison-Wesley, 1977)

[10] Loye, D., The Knowable Future: A Psychology of Forecasting and Prophecy (New York, NY: Wiley-Interscience, 1978)

[11] Loye, D., "The Forecasting Mind", The Futurist, Vol. 13, pp. 173 - 177

[12] Makridakis, S., Forecasting: Methods and Applications (New York, NY: John Wiley and Sons, 1978)

[13] Mintzberg, H., "Planning on the Left Side and Managing on the Right", Harvard Business Review, Vol. 56, pp. 49 - 58

[14] Mitchell, A.M. et al., Handbook on Forecasting (Menlo Park, CA: SRI, 1973)

[15] Ornstein, R.E. (ed), The Nature of Human Consciousness (San Francisco, CA: W.H. Freeman and Co., 1973)

APPENDIX A

HOW CREATIVE ARE HOW?

Researchers have developed a number of tests to determine whether someone is predisposed to think creatively. The following test was designed by Eugene Raudsepp of Princeton Creative Research, Inc. after studying characteristics of highly creative people. To take the test, indicate after each statement whether you: (A) agree, (B) are in-between or don't know, or (C) disagree. Answer as accurately and frankly as possible, trying not to guess how a creative person might respond. There is no time limit.

1. I feel that a logical step-by-step method is best for solving problems.
2. It would be a waste of time for me to ask questions if I had no hope of obtaining answers.
3. I always work with a great deal of certainty that I'm following the correct procedures for solving a particular problem.
4. I concentrate harder on whatever interests me than do most people.
5. When trying to solve a problem, I spend a lot of time analyzing it.
6. I occasionally voice opinions in groups that seem to turn some people off.
7. I spend a great deal of time thinking about what others think of me.
8. Complex problems and situations appeal to me because I find them challenging.
9. It is more important for me to do what I believe to be right than to try to win the approval of others.
10. People who seem unsure and uncertain about things lose my respect.
11. More than other people, I need to have things interesting and exciting.
12. On occasion I get overly enthusiastic over things.
13. I often get my best ideas when doing nothing in particular.
14. I rely on intuitive hunches and the feeling of "rightness" or "wrongness" when moving toward the solution of a problem.
15. I sometimes get a kick out of breaking the rules and doing things I'm not supposed to do.
16. I like hobbies that involve collecting things.
17. I feel I have capacities that have not been tapped as yet.
18. Daydreaming has provided the impetus for many important projects.
19. I like poeple who are objective and rational.
20. I see myself as more enthusiastic and energetic than most people I know.
21. I can get along more easily with people if they belong to about the same social and business class as myself.
22. I have a high degree of aesthetic sensitivity.
23. I have a highly developed capacity for self-instruction.
24. I like people who are most sure of their conclusions.
25. Inspiration has nothing to do with the successful solution of problems.
26. When I'm engaged in an argument, the greatest pleasure for me would be for the person who disagrees with me to become a friend, even at the price of sacrificing my point of view.
27. I tend to avoid situations in which I might feel inferior.
28. In evaluating information, the source of it is more important to me than the content.
29. I resent things being uncertain and unpredictable.
30. I like people who follow the rule "business before pleasure."
31. One's own self-respect is more important than the respect of others.
32. I feel that people who strive for perfection are unwise.
33. I prefer to work with others in a team effort rather than solo.
34. I believe that creativity is restricted t specialized fields of endeavour.

35. It is important for me to have a place for everything and everything in its place.

36. Sometimes I'm sure that other people can read my thoughts.

37. The trouble with many people is that they take things too seriously.

38. I have a great deal of initiative and self-starting ability.

39. I have retained my sense of wonder and spirit of play.

40. I can maintain my motivation and enthusiasm for my projects, even in the face of discouragement, obstacles or opposition.

41. People who are willing to entertain "crackpot" ideas are impractical.

42. I'm more interested in what could be rather than what is.

43. Even after I've made up my mind, I often can change it.

44. I enjoy fooling around with new ideas, even if there is no practical payoff.

45. I think the statement, "Ideas are a dime a dozen," hits the nail on the head.

46. I don't like to ask questions that show ignorance.

47. Once I undertake a project, I'm determined to finish it, even under conditions of frustration.

48. I sometimes feel that ideas come to me as if some external source and that I am not directly responsible for them.

49. There have been times when I experienced an "avalanche" of ideas.

50. I try to look for ways of converting necessities to advantages.

51. It is wise not to expect too much of others.

52. I am able to more easily change my interests to pursue a job or career that I can change a job to pursue my interests.

53. Many creative breakthroughs are the result of chance factors.

54. People who are theoretically oriented are less important than are those who are practical.

55. I feel it is important to understand the motives of people with whom I have to deal.

56. I can see things in terms of their potential.

57. When brainstorming in a group, I am able to think up more ideas more rapidly than can most others in the group.

58. I am not ashamed to express "feminine" interest (if man), or "masculine" interests (if woman) if so inclined.

59. I tend to rely more on my first impressions and feelings when making judgements than on a careful analysis of the situation.

60. I can frequently anticipate the solution to my problems.

61. I often laugh at myself for my quirks and peculiarities.

62. Only fuzzy thinkers resort to metaphors and analogies.

63. When someone tries to get ahead of me in a line of people. I usually point it out to him.

64. Problems that do not have clear-cut and unambiguous answers have very little interest for me.

65. I usually work things out for myself rather than get someone to show me.

66. I trust my feelings to guide me through experiences.

67. I frequently begin work on a problem that I can only dimly sense and not yet express.

68. I frequently tend to forget things such as names of people, streets, highways, small towns, etc.

69. I have more capacity to tolerate frustration than does the average person.

70. During my adolescence I frequently had a desire to be alone and to pursue my own interests and thoughts.

71. I feel that the adage "Do unto others..." is more important than "To thine own self be true."

72. Things that are obvious to others are not so obvious to me.

73. I feel that I may have a special contribution to give to the world.

74. I find that I have more problems than I can tackle, more work than there is time for.

75. Below is a list of adjectives and terms that describe people. Indicate with a check mark ten (10) words that best characterize you.

energetic	factual
persuasive	open-minded
observant	tactful
fashionable	inhibited
self-confident	enthusiastic
persevering	innovative
forward-looking	poised
cautious	acquisitive
habit-bound	practical
resourceful	alert
egotistical	curious
independent	organized
good-natured	unemotional
predictable	clear-thinking
formal	understanding
informal	dynamic
dedicated	self-demanding
original	polished
quick	realistic
efficient	modest
helpful	involved
perceptive	absent-minded
courageous	flexible
stern	sociable
thorough	well-liked
impulsive	restless
determined	retiring

ANSWERS TO CREATIVITY TEST

Scoring instructions: To compute your score, add up the points assigned to each item. For each question, the first value is for A (agree) the second is for B (in-between or don't know) and the third is for C (disagree).

1.	-1, 0, 2	38.	2, 0, -1
2.	0, 1, 2	39.	2, 0, -1
3.	0, 1, 2	40.	2, 0, -1
4.	3, 0, -1	41.	-1, 0, 1
5.	2, 1, 0	42.	2, 1, 0
6.	2, 1, 0	43.	2, 1, 0
7.	-1, 0, 2	44.	2, 1, 0
8.	2, 1, 0	45.	-2, 0, 1
9.	2, 0, -1	46.	-1, 0, 1
10.	-1, 0, 2	47.	2, 0, -1
11.	2, 1, 0	48.	2, 0, -1
12.	3, 0, -1	49.	2, 1, 0
13.	2, 0, -1	50.	2, 0, -1
14.	3, 1, 0	51.	1, 0, -1
15.	2, 1, 0	52.	-2, 1, 0
16.	-1, 0, 1	53.	2, 1, 0
17.	2, 1, 0	54.	-2, 1, 0
18.	3, 0, -1	55.	2, 0. -1
19.	-1, 0, 1	56.	2, 0, -1
20.	2, 1, 0	57.	2, 0, -1
21.	-1, 0, 1	58.	2, 1, 0
22.	3, 1, 0	59.	1, 0, -1
23.	2, 1, 0	60.	2, 1, 0
24.	-1, 0, 1	61.	2, 0, -1
25.	-2, 0, 2	62.	-2, 0, 2
26.	-1, 0, 1	63.	2, 1, 0
27.	-1, 0, 1	64.	-1, 0, 1
28.	-2, 1, 2	65.	1, 0, -1
29.	-1, 0, 1	66.	2, 1, 0
30.	-1, 0, 1	67.	2, 1, 0
31.	2, 1, 0	68.	2, 0, -1
32.	-2, 0, 1	69.	2, 1, 0
33.	-1, 1, 2	70.	2, 0, -1
34.	-1, 0, 1	71.	-1, 0, 1
35.	-1, 0, 1	72.	2, 1, 0
36.	-2, 0, 2	73.	1, 0, -1
37.	-1, 0, 1	74.	2, 1, 0

75. The following have values of 2: energetic, observant, persevering, resourceful, independent, dedicated, original, perceptive, courageous, enthusiastic, innovative, currious, dynamic, self-demanding, involved, flexible.

The following have values of 1: self-confident, forward-looking, informal, thorough, open-minded, alert, restless, determined.

The rest have values of 0.

Scoring:	125-150	Exceptionally Creative
	90-124	Very Creative
	55-89	Above Average
	35-54	Average
	15-34	Below Average
	-56-14	Noncreative

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