

RISK AND DECISION ANALYSIS PROJECT
AT LOCKHEED-GEORGIA

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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

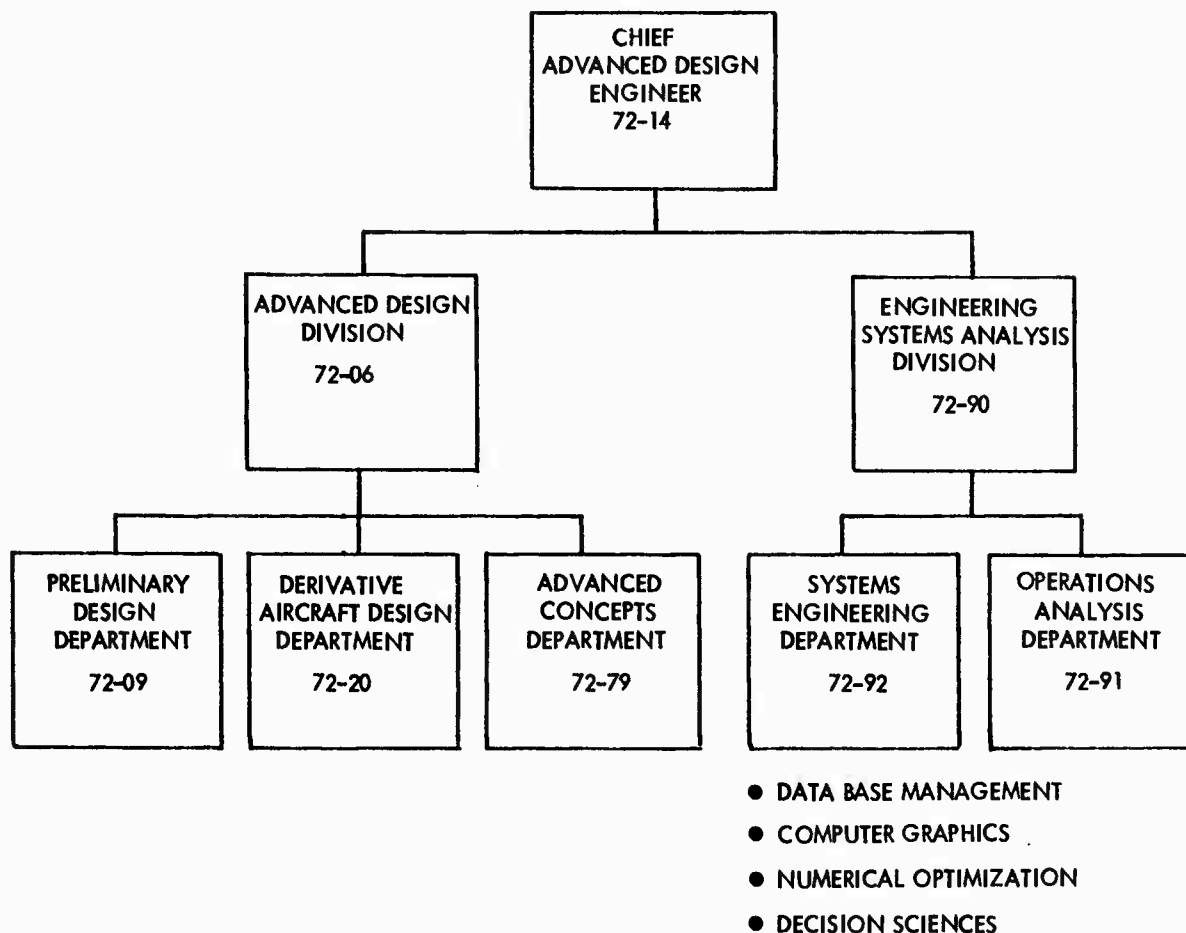


Figure 1. Immediate Project Environment

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

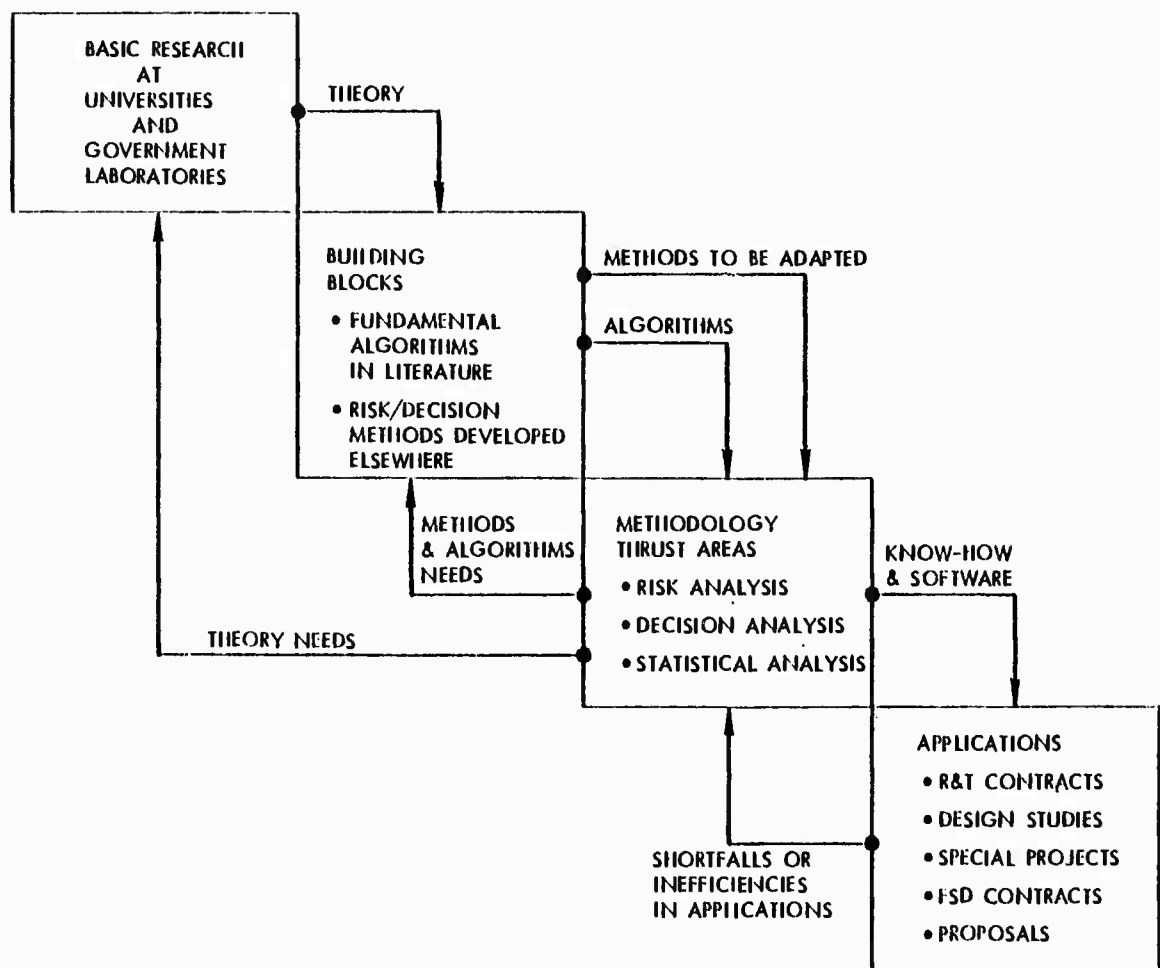


Figure 2. Applied Research Approach Employed by Project

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

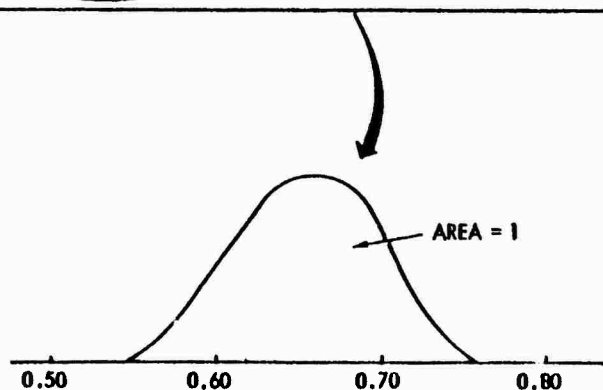


Figure 3. Conversion of Questionnaire Responses to Beta Distribution

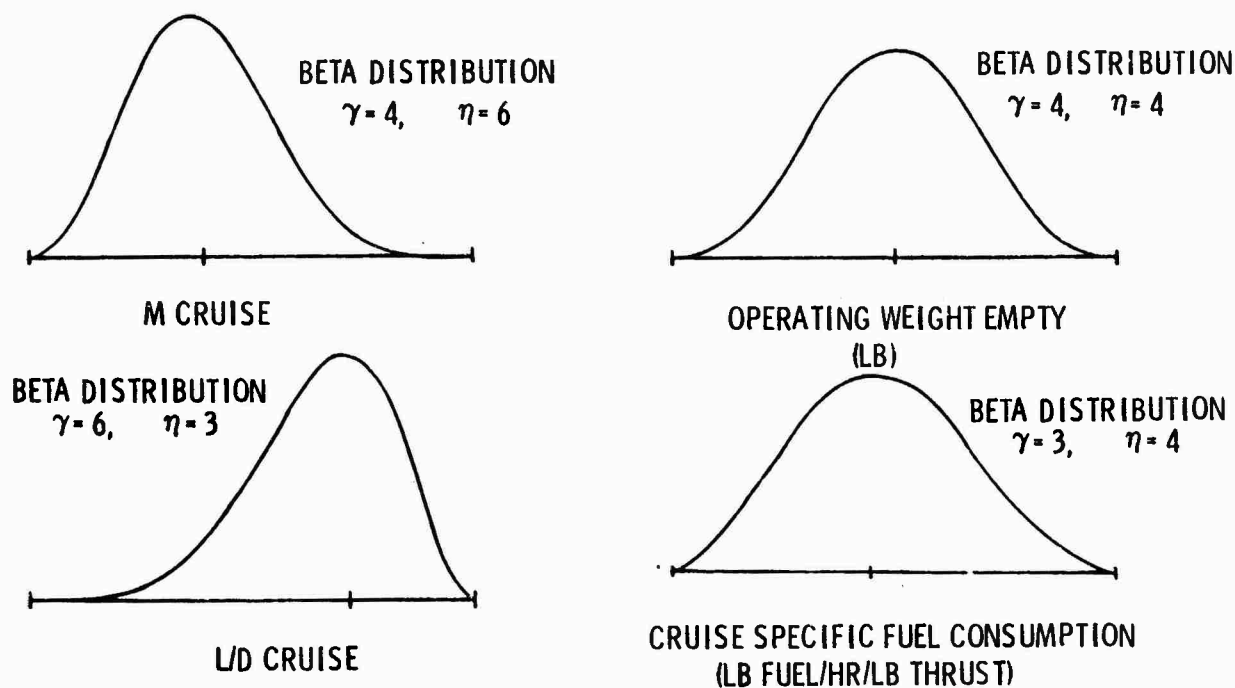


Figure 4. Probability Distributions for Variables Upon which Range is Dependent

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

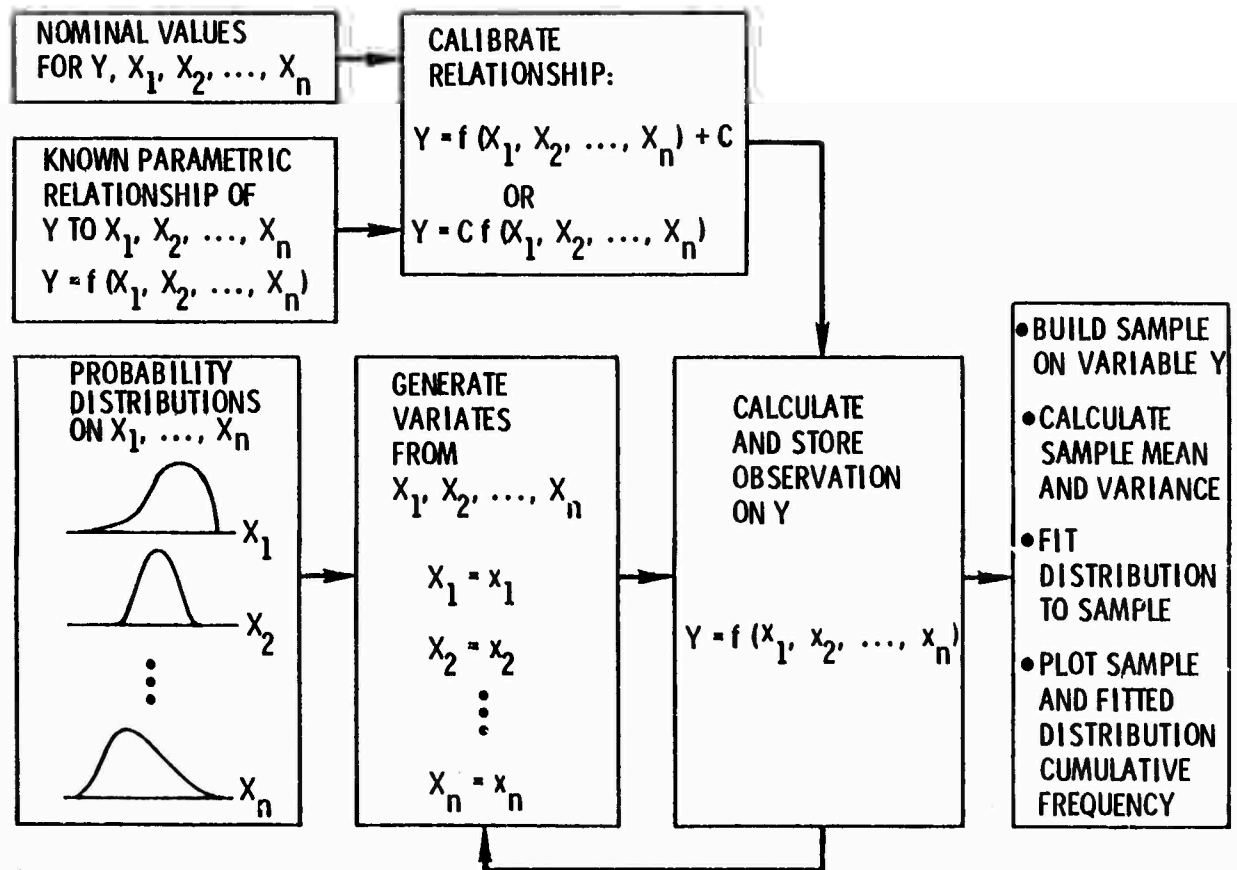


Figure 5. Flow Diagram for Quantitative Uncertainty Analysis

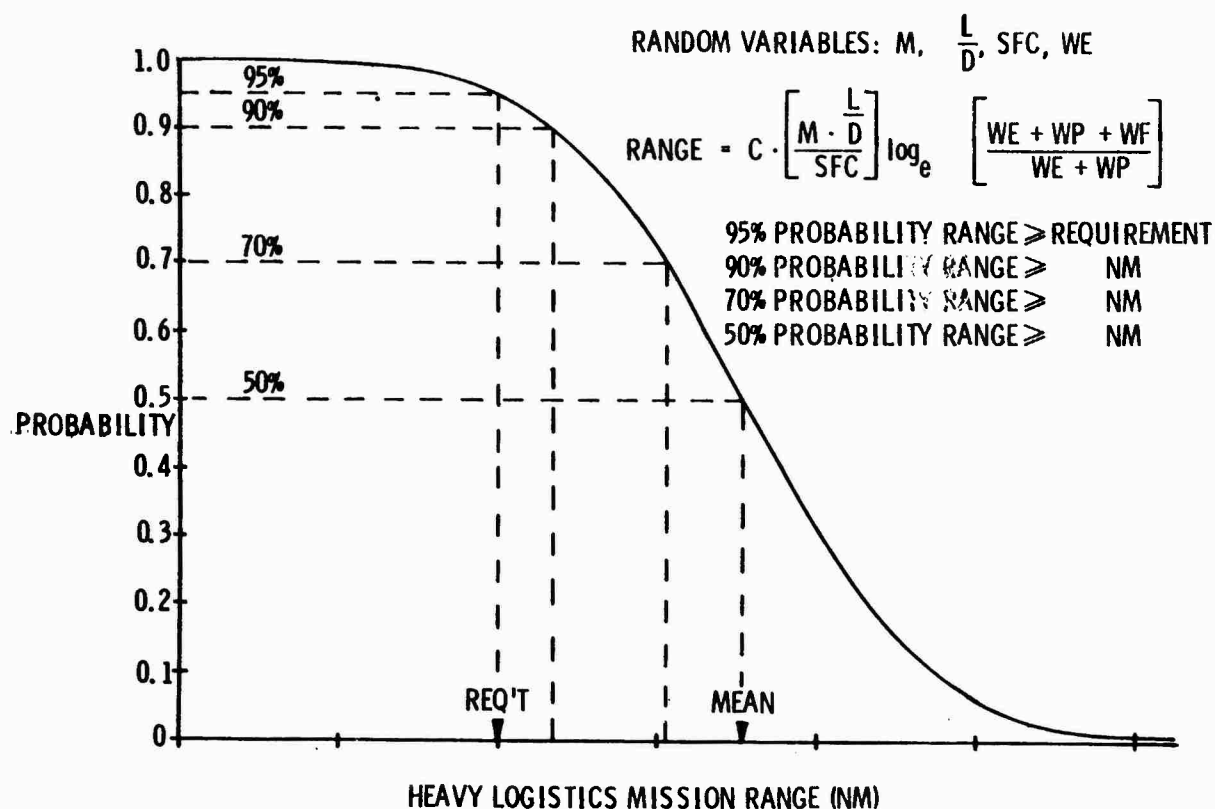


Figure 6. Uncertainty in Aircraft Range

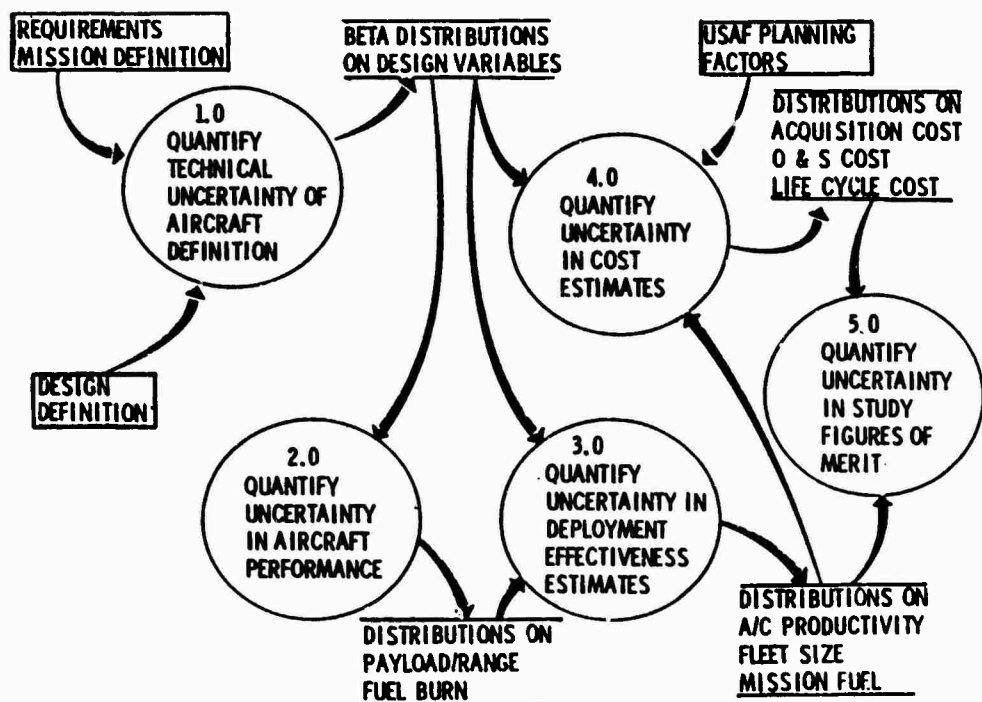


Figure 7. Data Flow Diagram for AFCUE

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

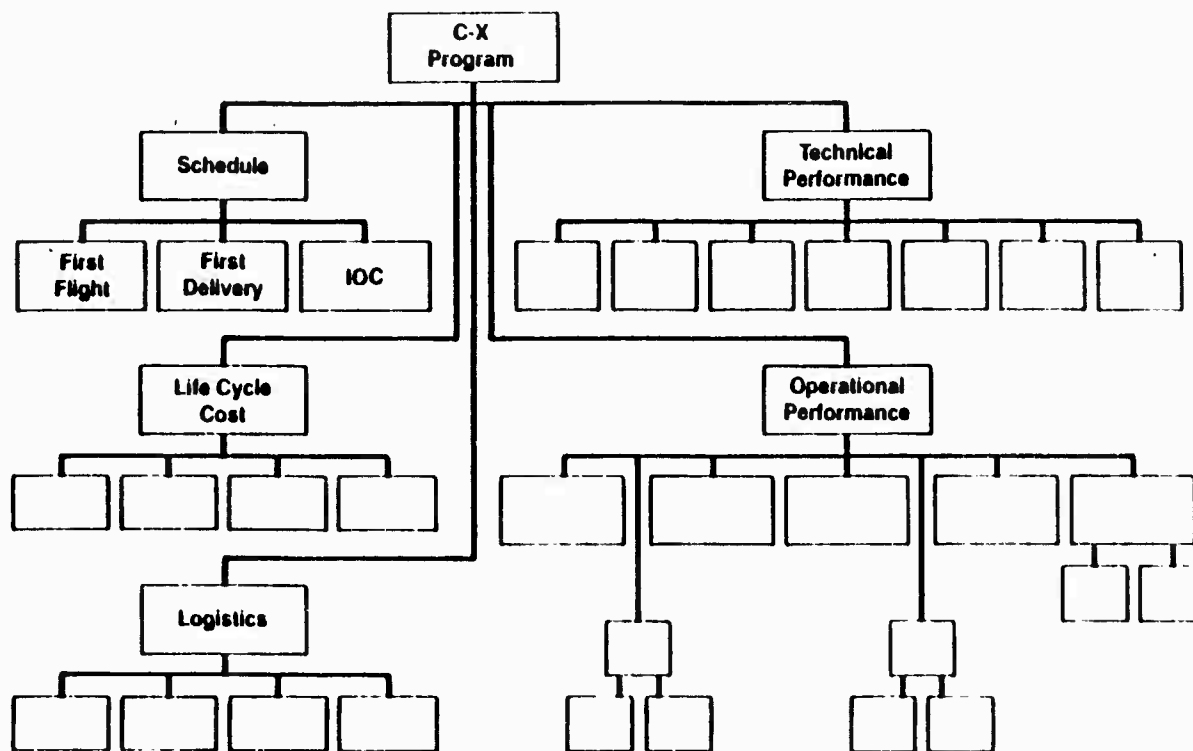


Figure 8. Typical Program Multiattribute Model

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

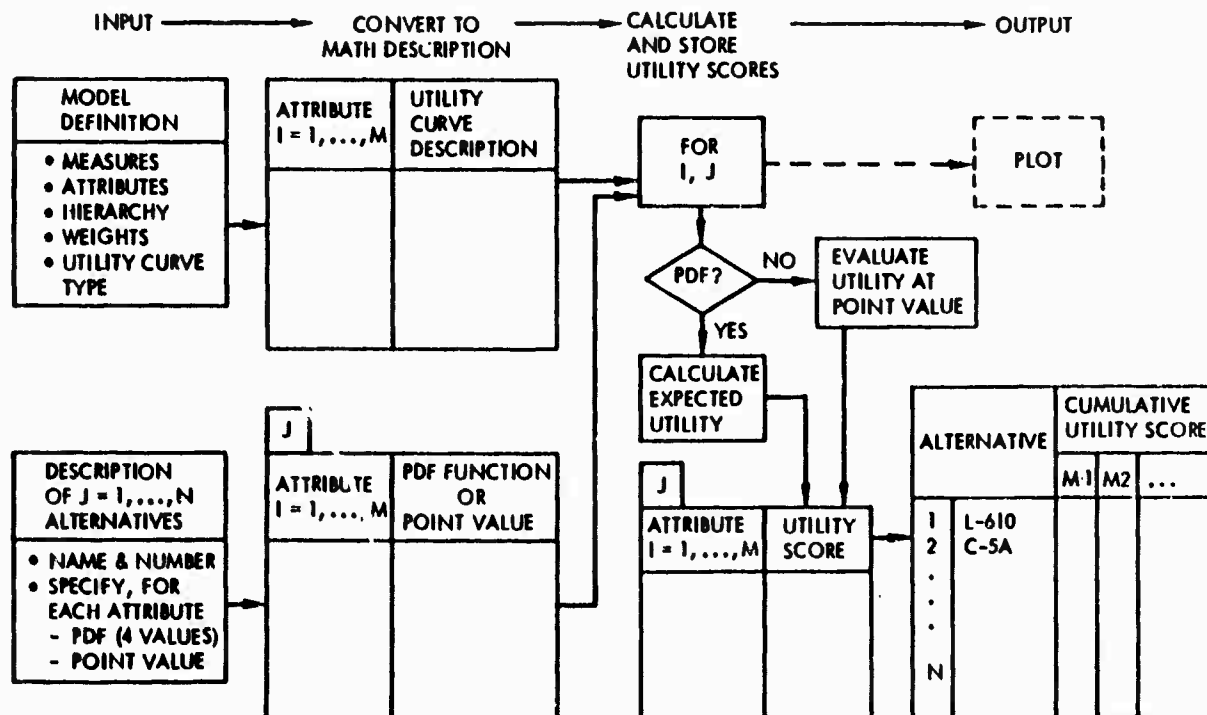


Figure 9. Flow Diagram for Multiattribute Decision Analysis

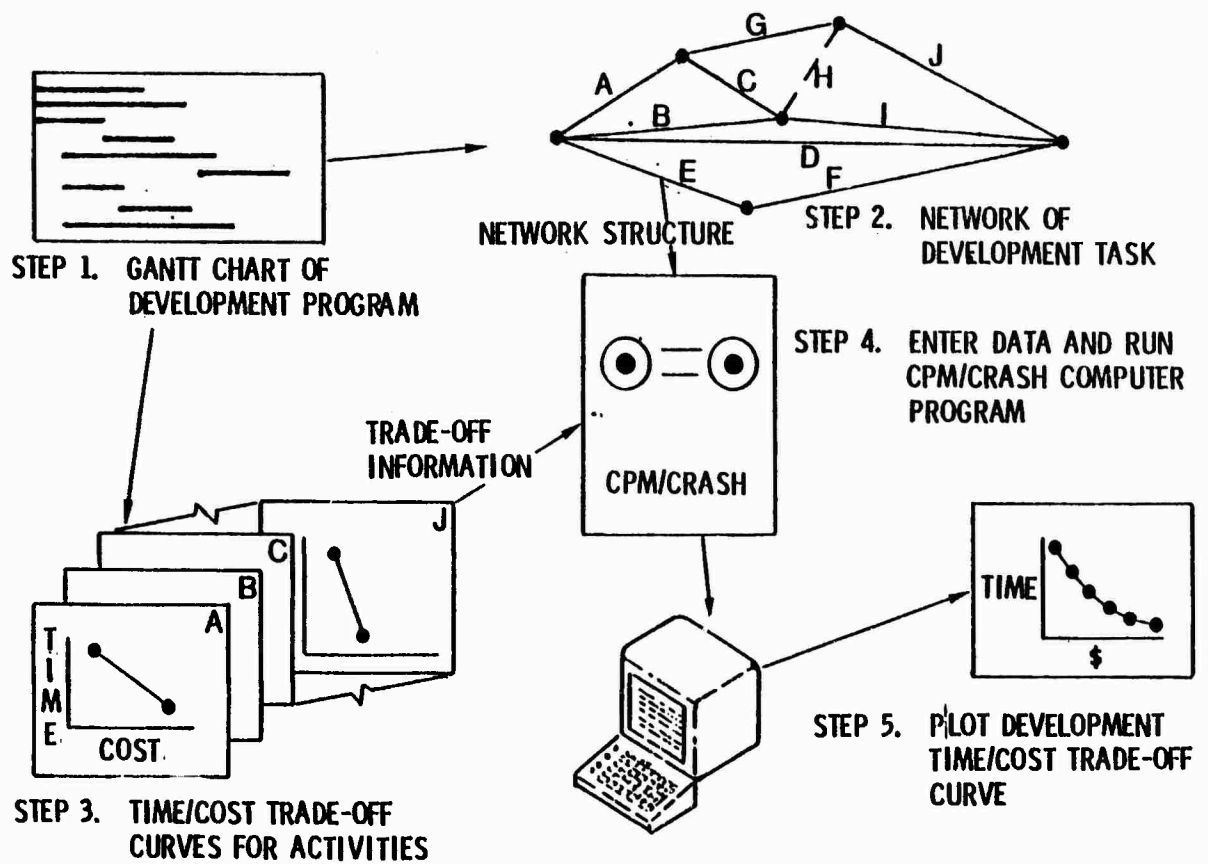


Figure 10. Process to Determine Project Time/Cost Tradeoff Curve

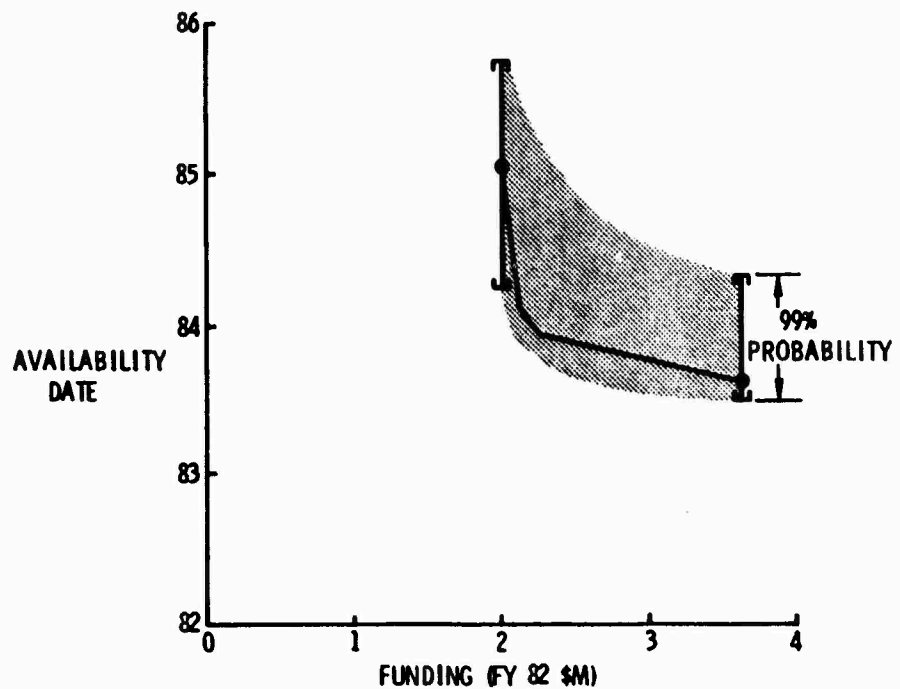


Figure 11. Confidence Band on CPM/CRASH Results

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.

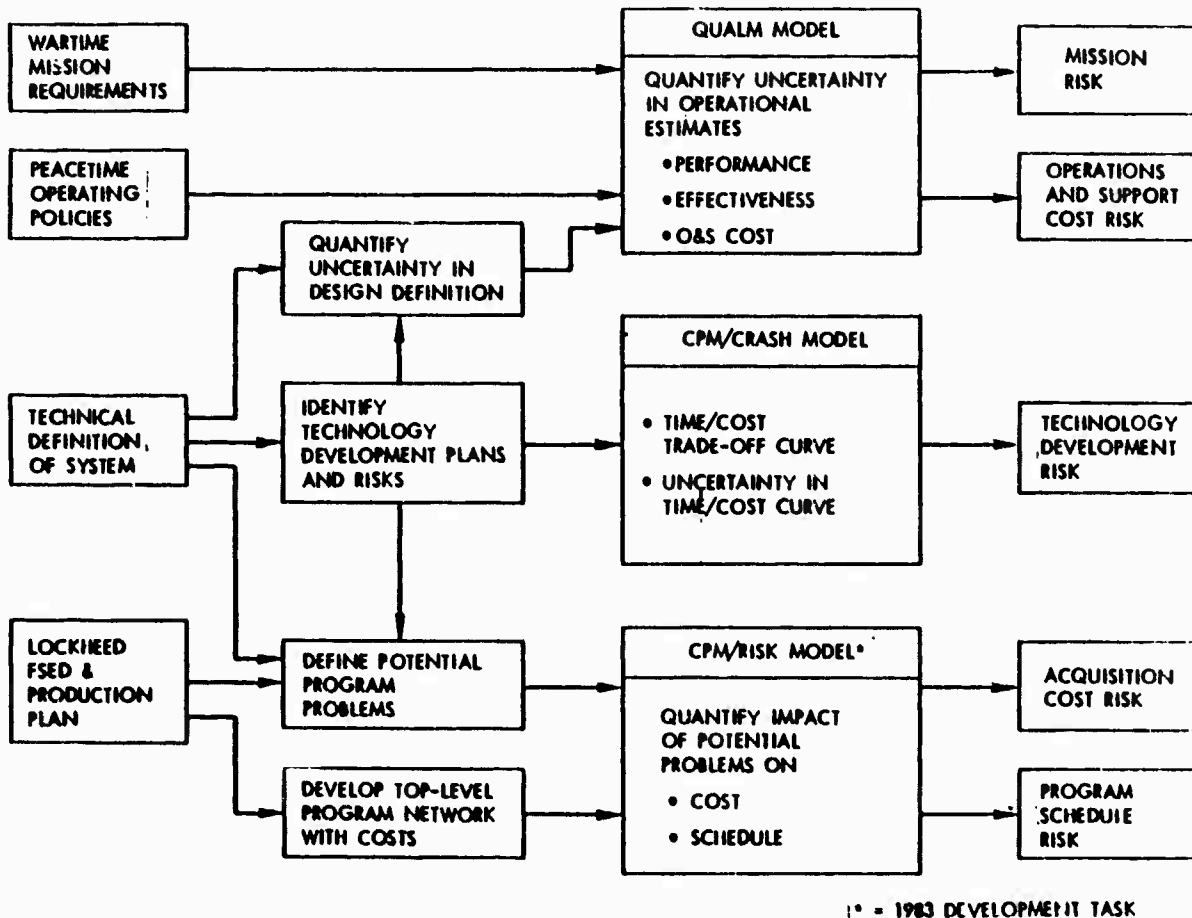


Figure 12. Unified Approach to Risk Analysis

Methods Currently Ready

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

Methods In Development or Ordered

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

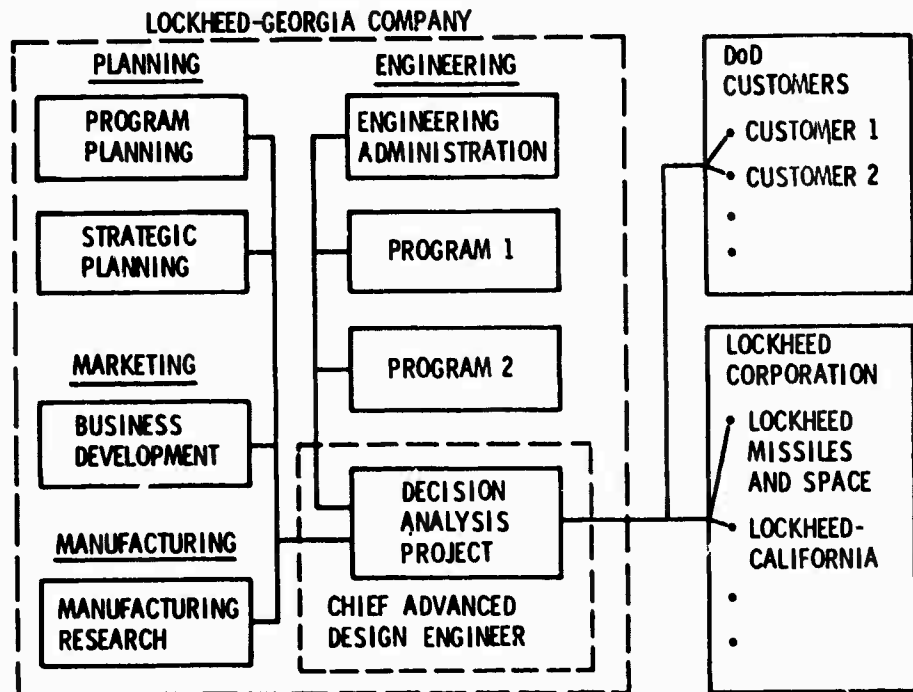


Figure 13. Extended Project Environment

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 where 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.

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