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RISK ANALYSIS METHODOLOGY SURVEY

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ABSTRACT

Several NASA regulations specify that formal risk analysis be performed on a program at each of several milestones as it moves toward full-scale development. Program risk analysis is discussed as a systems analysis approach to risk, an iterative process (identification, assessment, management), and a collection of techniques. These techniques, which range from extremely simple to complex, network-based simulation, were surveyed. A Program Risk Analysis Handbook was prepared in order to provide both analyst and manager with a guide for selection of the most appropriate technique.

Various researchers have verified that 85-90% of the risk in complex, technological systems development originates in the technical definition of the system. Risk may be assessed on cost, schedule, or performance individually; the preferred approach is to treat these as dependent random variables and perform an integrated risk assessment. All program risk assessment techniques were shown to be based on elicitation and encoding of subjective probability estimates from the various area experts on a program. Techniques to encode the five most common distribution-types were given. Then, a total of twelve distinct approaches to risk assessment were given. For each approach we identified the steps involved, good and bad points, time involved, and degree of computer support needed.

We discuss why risk analysis should be used by all NASA program managers. How to establish a risk analysis capability and some of the special difficulties in performing a risk analysis were related. Tools available at NASA/MSFC were identified, along with commercially available software. Both an extensive bibliography (150 entries) and a program risk analysis check-list were provided.

Recommendations are to:

1. Perform integrated cost/risk assessment on each program, prior to each RFP release.

2. Require contractors to perform quantitative risk assessments during proposal preparation and after contract award.

3. Select (or hire) a full-time risk analyst in Program Planning, with responsibilities for applications, methods development, interface with other centers, and consulting to program and engineering managers.

TABLE OF CONTENTS

INTRODUCTION

The article "GRO Project Beset by Complications" appeared in the 6/14/87 Huntsville Times. The NASA/GSFC Project Manager, Jeremiah Madden, stated "the sheer magnitude and complexity of the GRO program overwhelmed managers and engineers and obscured some of the program's finer details." These complications occur on all space and defense projects, especially those that use unproven technology, attempt a new mission, and/or scale up (or down) the size of the craft used -- for example, the C5A, the Trident Submarine, Space Telescope, and the Stealth Bomber. The specific problems encountered on the GRO project are typical:

- manufacturing processes not well-understood
- manufacturing problems due to materials faults/availability
- lack of trained manufacturing work force
- unexpected electromechanical interference between instruments, once integrated
- redesign of components and tooling

These problems led to a modest cost growth of \$380 million to \$500 million, and a schedule slip from May '88 to early 1990. Space Telescope cost growth is \$500 million to \$1.4 billion. The average cost growth observed in both NASA and DoD projects, from the start of Full-Scale Development (FSD) to the completion of prototype production, has been in the range 30-40%.

This type of track-record for Federal acquisition of large-scale systems has led to Congressional skepticism, public outrage, and occasionally loss of support for the continuation of the project. Since the '60s, DoD and NASA project managers have sought management techniques that will help them control cost growth and schedule slippages. Major General John R. Guthrie, USA, stated at the 1970 DoD Project Managers Conference that:

> "the most rudimentary sort of good risk analysis might have enabled us to avoid most of the pitfalls we have encountered. By rudimentary I mean -- did we identify those items which were new and identify the impact on overall system performance if that particular component or subsystem were to experience difficulty?"

Program risk analysis is an iterative <u>process</u> (Figure 1) for identifying, quantifying, and managing the uncertainties associated with complex design and development programs typical to NASA. Others have defined risk analysis as a systems analysis <u>approach</u> to risk, or as a <u>collection of techniques</u> to identify, quantify, and manage risk. In contrast to techniques for quantifying operational risk (e.g., failure modes and effects analysis, fault tree analysis, reliability analysis),

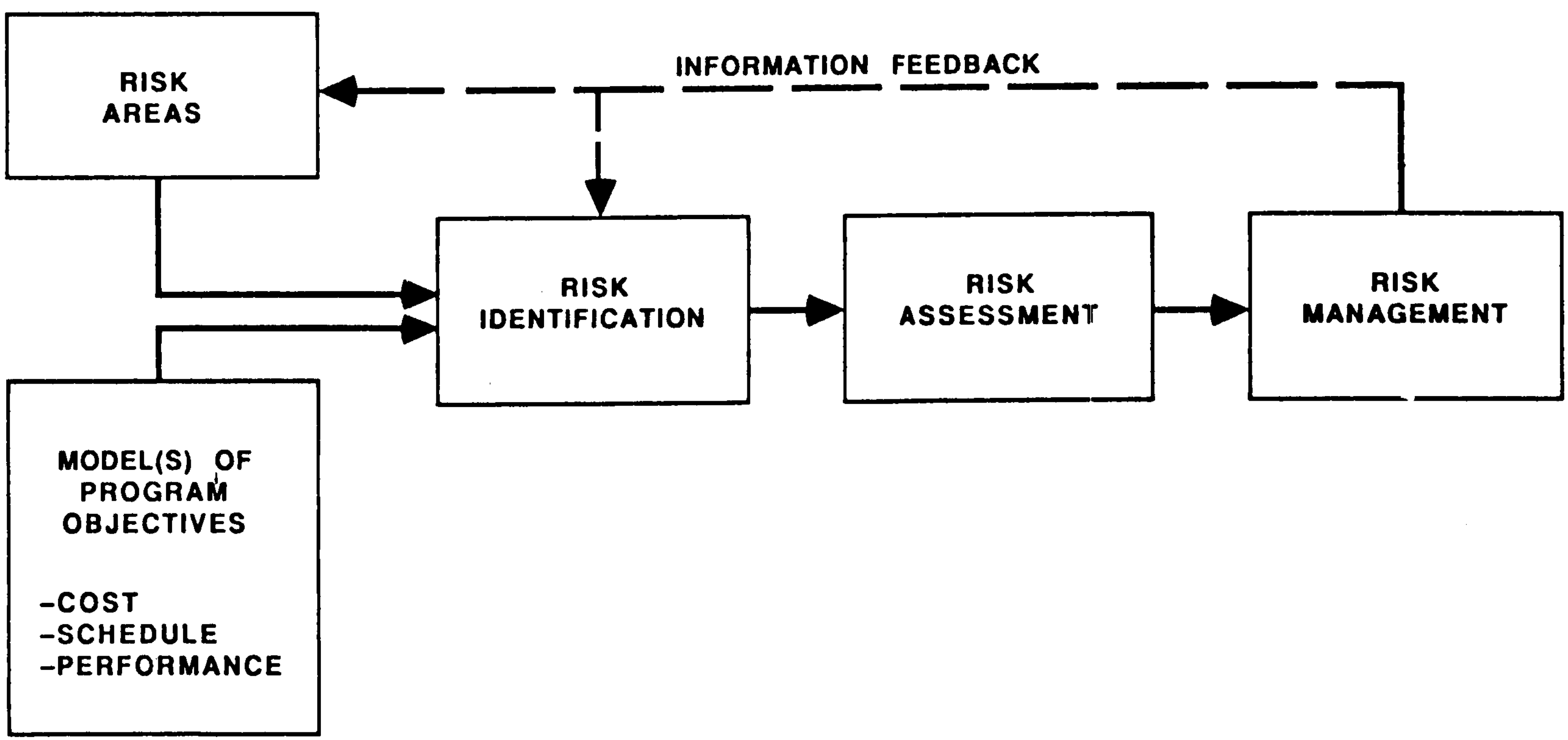

Figure 1 Risk Analysis Iterative Process

program risk analysis deals with program cost, schedule, and technical performance estimates. The key question to be answered by risk analysis is what are the distributions of probability on the mature (achieved) values of each of these three random variables. In some risk analyses, two of these variables (say, performance and schedule) are thought of as fixed. Then the probability distribution on the mature value of the other (cost) is derived. However, in a comprehensive risk analysis, the dependence among these variables is assessed and uncertainty in one affects the assessment of risk in the other two.

NASA NMI 7100.14A (Major System Acquisition) calls out risk evaluation as a criteria <u>second only to performance</u> for initiating FSD. MMI 7110.1 requires risk analysis and cost risk assessment for both formal project pre-development reviews. Program risk analysis is useful to program managers as both a source of information on the program and as a decision-aiding tool. The reason is that it is a formal, systematic, and documented approach to dealing with uncertainty, versus "seat-of-the pants" dealing with problems as they arise. It can be used in both Phases A and B, as requirements and design configurations evolve, for the purpose of early identification and resolution of technical uncertainties. Classic risk resolution strategies are parallel development, design/operations trade-offs, and development of back-up solutions. It is probably of most use for assessing the potential for cost and schedule slippages in programs moving into Phase C/D, because this is the point at which significant resource commitments will be made. Risk analysis can be applied to subsystems or instruments, individual technologies, manufacturing processes, and other elements that make up a program; however, its true value is in synthesizing these multiple uncertainties.

OBJECTIVES

Each task team leader and project manager (PM) at NASA/MSFC should become aware of the valuable information available from a program risk analysis. The risk analysis process is iterative and risk analysis should not be viewed as a one-time, check-the-box type activity. This handbook is written with the view of the PM as the consumer for risk analysis, and a range of options is provided so that the appropriate type of analysis, at the right level of detail, may be requested.

This handbook is prepared as a guide and reference source for any NASA employee who is requested to perform a risk analysis in support of the PM. This individual will be referred to as "the risk analyst," although he/she may be a cost analyst, schedule analyst, program analyst, engineer, or scientist. An entire range of risk analysis tools will be provided, along with some guidance for selecting the appropriate technique for a given situation. However, it is always necessary that the risk analyst apply his judgment when initiating a risk analysis at the request of a PM. For example, he must decide what technique is appropriate, given the time available and the software tools he has at his disposal. Another key question is how much access to and cooperation from program personnel the analyst can expect; no meaningful risk analysis can be generating without repeated, probing discussions with practically all program personnel in order to identify technical uncertainties and their potential cost and schedule impacts. Good relations between risk analyst and technical team members is essential if a valid, useful risk analysis is to be conducted. The only alternative, and one that works well, is for the risk analyst to be part of an ad-hoc team of experts, independent of the project, whose job it is to review the project and report to higher authority on its findings.

The selection and support of a risk analyst (or risk analysis group) is an important step for large industry/government design organizations and laboratories. The risk analyst is the alter-ego of top management in his evaluation of a project, much as the quality assurance analyst is for a production facility. He is often feared, avoided, circumvented, and detoured. Other engineers generally view the risk analyst as a nuisance who will take their valuable time, produce nothing new, and perhaps misrepresent their professional judgment. Although it is desirable for the risk analyst to be involved early in programs, and have an established relationship with both PM and project personnel, the fact is that risk analysis is usually a last-minute effort, performed on an ad-hoc basis, prior to some major decision/presentation. The risk analyst is often not at all familiar with the technology or program being analyzed. He must therefore:

1. Educate himself quickly.

2. Acquire the data.

3. Use the data in some pre-developed model.

4. Present recommendations based on model output.

The above discussion clearly reveals that conducting a risk analysis is not an easy job. The risk analyst must be an individual of highest quality in education, technical/program experience, human relations, and recognition of management needs. Many of these positions are filled by individuals with graduate-level training in statistics, operations research, or systems analysis. An undergraduate degree in engineering or hard sciences helps, but is not necessary. Individuals who are enthralled with math models and/or computer techniques generally aren't good risk analysts. The interaction with project personnel, the collection and verification of data, and preparation of finding into a format useful for management are the key activities of the risk analyst.

TERMINOLOGY

Several general references on program risk analysis are given in the Bibliography. The definitions presented below are stated in broad terms and would be accepted by anyone working in the program risk analysis area. Of course, certain organizations and programs within organizations adopt more specific definitions for terms such as "risk area" -- in fact one of the first jobs for a risk analyst newly assigned to a program is to work with the PM on an agreeable set of definitions and working groundrules. Note also that more specialized terminology is used in health and environmental risk analysis, and these terms are not appropriate for program risk analysis.

Definitions

Risk -- the probability of undesirable future consequences of actions (inaction) taken today. Thus risk has a temporal element, and is a function of both probability and consequence.

Program risk -- the probability that the actual cost, time, or performance of a system will fail to match predictions. Also, the degree by which such predictions are missed and the associated consequences.

Potential problem -- an identified, but not yet occurring problem that if actualized, will impose unplanned resource demands, rescheduling, and/or degraded performance, quality, or safety margins.

Risk area -- a collection of related potential problems. Also a common source of several potential problems.

Potential problem analysis (risk identification) -- identification of risk areas and the sequence of interrelated potential problems that stem from them. Also can include identification of immediate cost, schedule, and performance impacts of potential problems, recognizing that potential problems may actualize at one of several levels of severity and that there is a probability associated with each level.

Risk assessment -- using the information from risk identification, and one or more quantitative techniques to synthesize the information, to create an overall assessment of program cost, schedule, or technical risk and also an assessment of the risk contributed by each risk area. May include ranking risk areas by severity or timing in order to identify a course of action.

Risk management -- identifying alternatives, selecting an approach, and taking action in order to reduce risk to levels deemed acceptable by the organization. Action may be directed at risk reduction or in trading one type of risk for another. In some instances, work around plans and/or contingency budgets are defined as back-up solutions to the selected risk reduction approach.

Probability -- the relative frequency of an outcome of a repeatable, observable experiment. Also, a measure between 0 and 1 assigned to each outcome of an experiment based on its relative frequency.

Subjective probability -- a measure of the lack of information an organization or an individual has about the actual outcome of some future experiment. Essentially, it is a "degree of belief" measure based on human experience and reasoning, as opposed to a "frequency of occurrence" measure.

Probability encoding -- a process whereby the lack of information of an expert is quantified as a subjective probability distribution on a state variable, developed under specific assumptions, in a scientifically correct way, with as much accuracy as is justifiable. Accuracy can be increased by spending more time per encoded variable, or by combining the opinions of several experts.

RISK ANALYSIS METHODOLOGY

A 95-page Program Risk Analysis Handbook was prepared as the primary product of this fellowship. This handbook will be published as a NASA/MSFC Technical Memorandum (TM). The contents will be summarized here.

All risk assessment techniques use subjective probability distributions as input. The process of interviewing a technical expert and determining the nature of the uncertainty in a variable of interest is referred to as "probability encoding." We discuss this process and give algorithms to encode the density function of five distribution types: uniform, triangular, beta, Weibull, and normal.

Twelve distinct techniques for risk assessment were identified and discussed. We grouped these techniques into three classes:

- Quick Risk Assessment Techniques, which require 1-2 days to implement and use point probability estimates (risk factors) as inputs. These methods require only a hand-held calculator, and include:

  - Equi-risk contours method
  - Risk factor method (RFM)
  - Probabilistic event analysis (PEA)
  - Probabilistic Evaluation and Review Technique (PERT)
  - Analytic Cost Risk Method
  - Method of Moments

- Standard Risk Assessment Techniques, which require 1-2 weeks to implement and are based on Monte Carlo simulation. These techniques require at least a microcomputer, and include:

  - Simulation of the Critical path
  - Simulation of the Project Network
  - Simulation of the Cost Model
  - Simulation of a Performance Model

- Integrated Risk Assessment Techniques, which require 1-2 months to implement and are performed using a network-based, simulation package such as GERT, VERT, or RISNET. The techniques are:

  - Integrated Cost/Schedule Risk Assessment, based on direct evaluation of cost and time uncertainty on each activity.

- Integrated Technical/Cost/Schedule Risk Assessment, based on simulation of the occurrence of technical problems and their time/cost penalties.

Note that only in the integrated techniques are time and cost treated dependently. A full discussion of each of these techniques and related reference material may be found in the Program Risk Analysis Handbook. The techniques currently used at NASA/MSFC are indicated by an asterisk in Figure 2 below.

	BASIS OF TECHNIQUES			
TIME TO IMPLEMENT	SUBJECTIVE FACTORS AND/OR POINT PROBABILITIES	SUBJECTIVE PROBABILITY & ANALYTICAL METHODS	SUBJECTIVE PROBABILITY & MONTE CARLO SIMULATION	
1 - 2 DAYS	● EQUI-RISK CONTOURS ● RISK FACTOR METHOD ● PROBABILISTIC EVENT ANALYSIS	● PERT ● ANALYTIC COST RISK ● METHOD OF MOMENTS	CRITICAL PATH SIMULATION*	
1 - 2 WEEKS			SIMULATION OF COST MODEL* SIMULATION OF SCHEDULE NETWORK SIMULATION OF PERFORMANCE MODEL	INDUSTRY/ GOVERNMT. STANDARD
1 - 2 MONTHS			INTEGRATED COST/SCHEDULE NETWORK SIMULATION INTEGRATED TECHNICAL/COST/ SCHED. NETWORK SIMULATION	NETWORK-BASED STATE-OF-THE-ART

* = IN USE AT NASA/MSFC

Figure 2 Summary of Risk Assessment Methodology Alternatives

CONCLUSIONS AND RECOMMENDATIONS

Based on a thorough literature search, the range of quantitative methods for program risk assessment have been presented. As shown in Figure 2 twelve distinct alternatives were identified. These are discussed in detail in the Program Risk Analysis Handbook, prepared as the major product of this fellowship. All methods are based on the Bayesian view of probability; they differ in how subjective probability is collected (level of detail, assumptions, distribution types, etc.) and how these probabilities are combined into an overall assessment of uncertainty. Although "a risk assessment" can be done in a matter of several days, the truly comprehensive risk methods treat technical, cost, and schedule risks in an integrated (network-based) fashion and require at least one month of up-front development. The management benefits of integrated, network-based methods are worth the expense and waiting-time for the initial model output.

The recommendations for NASA/MSFC based on discussions with Program Planning Office personnel and the contents of the handbook are:

1. Commit to performing integrated cost/schedule risk assessment on each program prior to releasing RFPs for the phase in question. Quick risk assessments are, of course, appropriate in certain circumstances.

2. Require contractors to perform quantitative risk assessments as part of their proposal preparation effort. Require that these assessments be submitted as part of the technical volume or as a separate volume, or back-up document. Be explicit that meaningless LOW-MEDIUM-HIGH risk ratings are not acceptable, and that integrated methods are preferred. Require risk analysis be part of the systems analysis/management process after contract award.

3. Select (or hire) a full-time risk analyst to be stationed in Program Planning with the following responsibilities:

   o Perform risk analyses on all PD studies, with early involvement with PM and study team.

   o Write risk analysis requirements for all RFPs.

   o Develop and document databases, questionnaires, and methods.

   o Plan evolution of tools, either in-house development or outside acquisition.

   o Train project control personnel to perform risk analyses.

- o Interface with other centers.

- o Consult with PMs, chief engineers on use of risk analysis on their project.

4. Commit to investing the time and money to build a state-of-the-art capability in program risk analysis at NASA/MSFC.

   - o Give selected analyst one year to build background, learn to use tools you have (ARTEMIS, SLAM, and SAM), and to review available methods and computer packages.

   - o Consider purchase of network simulation package designed for risk analysis.

     - RISNET
     - MICRO-VERT

5. Inform technical personnel in PD, and lab personnel supporting PD, about what risk analysis is and how they may be involved. Perhaps include some training in basic statistical concepts (classical and Bayesian) and generally encourage team-work, cooperation in generation of risk information.

6. As experience is gained, consider expanding this handbook to include:

   - risk identification methods
   - risk management methods
   - lessons learned
   - case histories

7. Consider expanding from one risk analyst to a risk and decision analysis group.

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