Distribution System Reliability Modeling: Research Status Report

1001882

Interim Report, December 2001

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This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Distribution System Reliability Modeling: Research Status Report, EPRI, Palo Alto, CA: 2001. 1001882.

REPORT SUMMARY

Most measures of reliability are used for describing system reliability indices, rather than planning for the appropriate level of reliability to meet customer demands for reliability and power quality. This report describes new methods for reliability analysis in distribution systems planning. It also addresses the problem of strategic analysis of distribution system alternatives. Both areas of research will enhance existing EPRI products or result in new ones that help utilities better meet specific customer needs.

Background
EPRI sponsored this research to develop methods for incorporating reliability into distribution business decisions. Two existing EPRI tools—the Area Investment Strategy Model and the Project Prioritization methodology—will be modified to include these new methods. In addition, based on previous EPRI work (white papers on reliability and customer needs, reports 1000424 and 1000428, respectively), EPRI has developed a new approach to include low-probability, high-consequence events in distribution reliability planning. The motivation for this approach is that existing methods do not address reliability in terms of the strategic risks associated with distribution planning alternatives.

Objectives
- To develop appropriate methods for incorporating reliability considerations into distribution systems planning and apply the new methods to EPRI's existing planning methodologies.
- To create a strategic approach to reliability analysis in distribution systems that specifically addresses low-probability, high-consequence events.

Approach
The project team studied the existing approaches to reliability analysis as part of the research on area investment planning and project prioritization. Based on that study, new methods were designed that both capture the important aspects of distribution system reliability and simplify the data input task. The team also formulated the problem of distribution system strategic risk and designed an approach to developing risk mitigation strategies.

Results
New methods have been designed for distribution system reliability analysis in area investment planning and project prioritization. The basis of the method for area investment planning is a logical model of the incremental effect of capacity additions on important indices such as the System Average Interruption Duration Index (SAIDI), where "system" applies to the local planning area only. That logical model has not yet been implemented. The basis of the method

for project prioritization is an assessment of the parameter changes associated with distribution projects—such as failure rates, repair rates, customers affected, and failure modes (including common-mode failures). These parameter changes serve as inputs to a dynamic model of reliability behavior, as measured by a selected set of descriptors. The descriptor most commonly used currently is SAIDI, but the new methods are not restricted to one single index. That dynamic model has not yet been implemented.

The problem of strategic analysis of distribution system alternatives has been formulated. The new formulation recognizes the difference between steady-state reliability analysis and control on the one hand and catastrophic event analysis and risk mitigation on the other. The formulation also recognizes that the cost, time to recover, effort required to recover, and the associated social, political, and psychological costs are found in the latter problem rather than the former. Although it is surely valuable to provide superior steady-state performance, the marginal returns given the current system reliability are almost certainly less than the value of mitigating the risk of catastrophic events. The new strategic analysis formulation will guide EPRI's Scenario/Risk Mitigation Strategy (S/RMS) methodology development in 2002.

EPRI Perspective

Electric power restructuring is changing the nature of electric distribution planning, engineering, and operations. The dual need to reduce costs and maintain customer satisfaction is creating an important distribution-planning problem—namely, investment and O&M decisions must be supported by explicit analysis of these objectives. In 1999, EPRI initiated two projects to address this problem—Assessing Customer Needs and Measuring and Valuing Reliability. This report is the second result from the reliability project. During the past year, the EPRI technical team has developed a deeper understanding of the reliability planning problem, analytical requirements for solving the problem, and specific tools for addressing the problem. Clearly, the reliability planning problem must address the questions of economics and risk. Of these two, risk is the most difficult to answer and the one for which there are currently no satisfactory solutions. Fortunately, EPRI's reliability research during the past year has produced a promising approach for risk identification, analysis, and mitigation. This approach will be implemented as a new planning method in 2002.

Keywords

Reliability
Risk mitigation
Distribution system capacity planning
Distribution system project prioritization
Value-based reliability planning
Value of reliability

ABSTRACT

This report describes new methods for reliability analysis in distribution systems planning. Two existing models, the Area Investment Strategy Model (AISM) and the Project Prioritization (P^2) methodology, will be modified to include these new methods. In addition, the problem of strategic analysis of distribution system alternatives has been formulated. A new strategic formulation is described in the report. The formulation permits the analysis of low-probability, high-consequence events that can adversely impact the distribution system. We will implement the problem formulation in the new Scenario/Risk Mitigation Strategy (S/RMS) model in 2002.

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1 INTRODUCTION

Studies have confirmed that customers are more concerned about reliability than about any other attribute of electric power. Other attributes of electric power, such as waveform quality, are important to a selected set of customers, such as those with particularly sensitive electronic equipment. However, reliability is important to all customers. (*Customer Needs for Electric Power Reliability and Power Quality: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000428. 1-1).

Our concern in this report is to create methodology that supports distribution system planning decisions. Since reliability is a critical attribute of electric power delivery, the distribution system must be designed to meet customer needs for reliability at least cost. Indeed, this is the essential problem of distribution system strategic planning. Two aspects of this problem are of particular interest: (1) there is a cost/reliability tradeoff and (2) reliability is inherently probabilistic.

The cost/reliability tradeoff is not currently performed in an optimal manner. Traditional planning does not focus on reliability economics. Instead, the focus is on planning for capacity needs and informal engineering rules rather than formal economic analysis guide reliability decisions. Indeed, reliability is examined *ex post*, and the examination emphasizes the relative performance of a particular utility, compared with a comparable industry subset, measured by such indices as SAIDI, SAIFI, and CAIDI, all measures of the average duration or frequency of customer interruptions. An optimal approach to reliability economics addresses the tradeoff explicitly, representing both the utility cost of achieving various levels of reliability and the customer cost of experiencing various levels of reliability. Clearly, as reliability improves, the cost to the utility increases but the cost to the customer decreases. The optimal reliability level minimizes the total cost. See figure 1-1. This optimal level almost surely will not be found by application of informal engineering rules.

The inherent probabilistic nature of reliability suggests that, at least, the following three factors are essential aspects of correct analysis. First, there are variations from year to year in distribution system reliability. Second, the costs associated with reliability are dependent on the uncertainties in the duration and the frequency of outages. Typically, the costs are nonlinear functions of both duration and frequency. Third, it therefore follows that in order to incorporate risk into distribution system investment decisions, methodologies must address both the uncertainties of outage frequencies and durations as well as the costs associated with those uncertainties. Our research has indicated that there is no methodology that is designed to address these factors in distribution system planning (*Reliability of Electric Utility Distribution Systems: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000424).

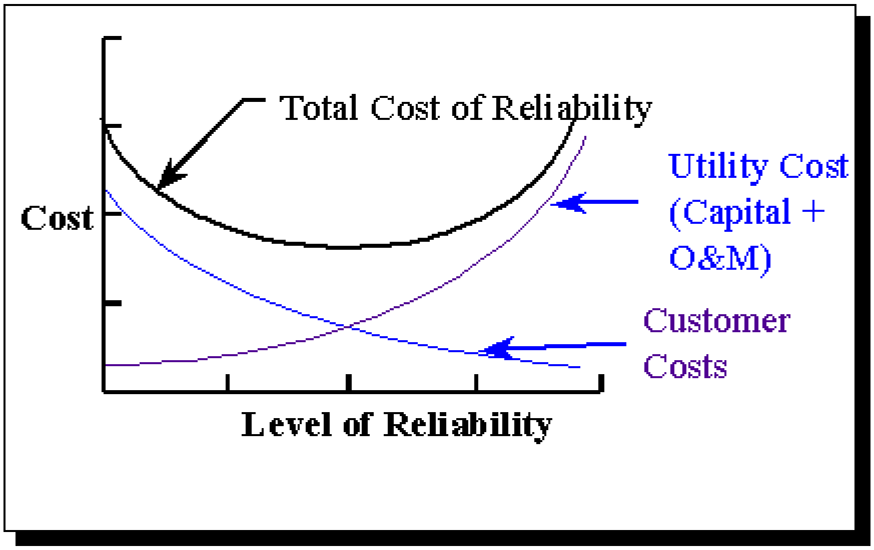


Figure 1-1
The Cost/Reliability Tradeoff

We have addressed the problem of reliability planning for distribution systems in two existing methodologies, the Area Investment Strategy Model (AISM) (*Area Investment Strategy Model User's Manual.* EPRI, Palo Alto, CA: 1999) and the Project Prioritization (P^2) methodology . (*Project Prioritization System: Methodology Summary*, EPRI, Palo Alto, CA: 2001. 1001877.)

One of the objectives of the present research is to improve the reliability analysis in each of these methodologies. These improvements are discussed in Chapters 2 and 3, below. The basis of these improvements is to align more precisely distribution system investments and project selection with specific area customer needs. We accomplish this alignment by treating reliability as a decision variable in each of the methodologies, as is suggested in figure 1-1, above. In particular, we formally determine the following aspects of reliability analysis.

- *Define* what we mean by reliability. We consider such aspects as outage rate, outage duration, signal quality and noise, voltage consistency, harmonics, sags and spikes, etc.
- Specify how to *measure* reliability. This includes describing what is observed and what data must be kept to specify the reliability provided. A particularly interesting question for project prioritization is how to specify reliability improvements given the data that utilities currently keep.
- Determine how to *value* reliability. Here we determine as precisely as possible the value of reliability to the customer and to the utility. The result of this analysis is a set of functions similar to those shown in figure 1-1.
- Identify control strategies that *change* reliability. Here we specify the decisions that can be made that will alter reliability and quantify the effects of such changes.

Another objective of the current research is to apply what has been learned about customer needs and preferences so that the current practice can evolve to an appropriate form of strategic planning. This is the subject of Chapters 4 and 5 of this report, but we introduce some ideas here.

There are two distinct problems in reliability-based planning and operations: (1) steady-state reliability analysis and control and (2) catastrophic events and risk mitigation. EPRI and others have written a great deal about the steady-state problem. Methods that purport to solve the steady-state problem are beginning to appear (see *Reliability of Electric Utility Distribution Systems: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000424). These approaches and considerations are typically concerned with measuring and changing the values of indices such as SAIDI and SAIFI. Certainly, the steady-state problem is of interest and it may indeed be essential that some utilities improve the system averages in order to provide satisfactory customer service. However, it is also clear that most distribution systems perform very well on average and that the relative cost of improvement of a system average can be very large. Further, it is also clear that customers strongly wish to avoid the extreme consequences of catastrophic events, which usually result in either a large number of customers taken out of service or long outage durations or both.

The risk posed by catastrophic events, events that we refer to as low probability—high consequence events, is not addressed by existing methodologies. This is unsatisfactory, because it is the occurrence of just this kind of event that requires a great deal of effort, money, and time to overcome. The low probability—high consequence events are the ones that get people's attention. This kind of attention is unwanted by utilities and it is reasonable to suppose that they would be willing to adopt strategies to mitigate this risk.

Mitigating the risk posed by low probability—high consequence events is a very different problem compared with moving a system average. Therefore, we developed a different approach to solve it. Our approach is based on four components combined into a system. Risk Mitigation Strategies (RMS) are based on (a) likelihood estimation, (b) consequences description and (c) strategies to alter either likelihood or consequences or both. We have developed methods for treating each of these three components. But what makes this problem challenging is that it is not clear how to identify the catastrophic events. We claim that risk mitigation generally fails because of a failure of imagination, the inability to anticipate what could possibly occur. The events of September 11, 2001 are consistent with this claim. Therefore, at the heart of our approach is a special methodology that identifies risky scenarios. EPRI is uniquely prepared to develop this approach. The complete system is called S/RMS (or scenario generation / risk mitigation strategies) and is discussed in Chapters 4 and 5.

We intend to complete all model designs and implementations in 2002.

2
RELIABILITY ANALYSIS IN THE AREA INVESTMENT STRATEGY MODEL

The Area Investment Strategy Model

The Area Investment Strategy Model identifies least-cost dynamic capacity expansion plans in a local planning area subject to uncertain load growth (*Area Investment Strategy Model User's Manual.* EPRI, Palo Alto, CA: 1999). The purpose of the model is to address the issue of minimizing the cost of providing *reliable* distribution system capacity in the face of uncertain load growth. The model is not aimed at changing the basic distribution planning process, but rather augments that process by allowing further insights to be gained into the robustness of the expansion plan. The planner determines current area capacity, forecasts demand, and identifies capacity-related issues, including thermal loading, voltage, and reliability, and then constructs capacity expansion plans that meet the forecasted needs and respond to the identified issues. The model aids in construction of the least-cost expansion plans.

The emphasis on reliable distribution capacity expansion plans motivated explicit modeling of the costs associated with varying degrees of reliability associated with capacity alternatives and alternative expansion plans.

Current Approach

The current approach to modeling reliability in the Area Investment Strategy Model is based on models of losses and unserved energy costs. We attempted to represent reliability costs by these two surrogate variables. The model logic is as follows.

As load increases in a distribution planning area, additional capacity investment is required in order for demand to be satisfied. Nevertheless, even if there is sufficient capacity to meet the demand, events may occur that prevent the system as it is configured from satisfying all customers. *Unserved energy* is the term used to describe that demand that is not met for any reason at any time. It is natural to consider unserved energy as an annual value. Further, the physical nature of the apparatus in the distribution system entails *losses*, which are expressible as an annual cost. These losses are a function of the impedance of circuit elements and the load on the system. The Area Investment Strategy Model includes a procedure for measuring the costs associated with unserved energy and losses.

The basis of the procedure is a collection of data the user supplies. The data exhibit the losses and unserved energy that are associated with each investment alternative as load on the system grows. Once these data are provided, the Area Investment Strategy Model can compute losses and unserved energy costs for any capacity expansion plan.

The user provides a set of curves that describe Losses and Unserved Energy costs as a function of load for each of the main capacity alternatives, what the model refers to as *strategic alternatives*. (Examples are substations, feeders, distributed generation, etc.) That is, if the only capacity expansion decisions made were a single strategic alternative, repeated sufficiently to respond to load growth, then the losses and unserved energy costs as a function of load are specified. These functions characterize the pure strategies only. We suppose that these curves or tables can be gotten by users in a straightforward manner, perhaps by using their favorite load flow software or similar analysis tools. It is also possible to consider the strategy of doing nothing. This pure strategy also entails unserved energy and losses. The user is also asked to provide a set of curves for this "strategy." (The complete set of curves is used to describe the effects of installing (so-called) bandaids as well. The Area Investment Strategy Model considers certain capacity expansion alternatives, such as capacitors, non-strategic, that can be used for a certain time to delay larger, more costly investments. These alternatives are collectively referred to as *bandaids*. Some bandaids can be removed from the system, or salvaged, and some cannot. It is not important to elaborate on these details here except to note that the effects of bandaids are dependent upon what else is installed. The interested reader may consult the manual cited above.)

Trajectories need not be restricted to pure strategies, and it is necessary to characterize the joint effect of several strategic alternatives. The Strategy Model computes the interaction effects using some simplifying assumptions. We assume that losses are determined by both the total load and the assets installed. We assume that the actual amount of losses can be best approximated by the minimum value of the losses given by the curves provided by the user, where the minimum is taken over the strategic expansion alternatives actually installed. We assume that the incremental load on the assets installed determines the unserved energy. We also assume that the total load can be allocated to the strategic expansion alternatives actually installed based on the capacity of those alternatives. Total unserved energy is additive and the total cost is found by superposition.

Critique

We have found that the required losses and unserved energy curves can be difficult for users to assess. Moreover, as designed, these variables are clearly a proxy for important failure characteristics. When the Area Investment Strategy Model was developed, the main emphasis was on modeling the interaction of the uncertain load, the capacity expansion alternatives, and the dispatching (operating) economics. We knew we would return to reliability analysis at some time in the future and replace these proxies with more direct models.

Proposed Approach

The proposed approach has four specific aspects. First, we require a direct assessment of the current values of the important reliability indices such as SAIFI, CAIDI, SAIDI, etc., that the user might wish to use to characterize reliability. More than one index could be used to characterize reliability, but at least one measurement of performance must be selected. We anticipate a pull-down list of possible indices.

Second, for the indices selected, an assessment of value is required. This could be as simple as a specification of the marginal value of a unit change in each index, or as complex as a multi-dimensional value function. We require a specification of the value, measured in current dollars, of changing all indices selected. One simple, and satisfactory, approach would be to specify the value of customer hours lost. This is consistent with selecting SAIDI as the reliability index to describe performance. Also, our customer needs study (*Customer Needs for Electric Power Reliability and Power Quality: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000428) provides default economic information in the form of an easy-to-use model about the value of reliability for those users reluctant to assess the value of changing indices directly.

Third, the reliability characteristics of each capacity expansion alternative will be specified. We anticipate that it will be sufficient to describe failure rates and repair rates for each alternative.

Fourth, we will build a set of simple logical models that will specify the consequences, measured by changes in the assessed, selected indices, of additional capacity installations as load grows. These models, described to some degree in our reliability report (*Reliability of Electric Utility Distribution Systems: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000424), will capture the effects of equipment failure and repair, redundancy, system topology, switching capabilities, and customer subsets served under various failure conditions. These models will determine the dynamic behavior of the indices over the planning period as a function of capacity expansion plan and load growth.

The economic data provided by the user (or the customer needs model, as noted above) will translate this behavior into a statement of value. Thus, the value of reliability can be determined directly and the proxies can be eliminated. We expect to complete the models required and specify the new input data structures in 2002.

3 RELIABILITY ANALYSIS IN THE PROJECT PRIORITIZATION METHODOLOGY

The Project Prioritization Methodology

The Project Prioritization methodology (*Project Prioritization System: Methodology Summary* Final Report. EPRI: Palo Alto, CA: November 2001. 1001877) is designed to prioritize and select a dynamic portfolio of distribution system projects over a fixed planning period, subject to budget constraints (capital, operating, labor, etc.), such that a multi-attribute objective is maximized. The project attributes that determine the value of a project and its contribution to the overall performance of the portfolio of projects are selected and ranked by individual users. This selection and ranking determines the multi-attribute objective. Almost surely, users will include such attributes as power quality, safety, change in net revenue, and reliability. Since, in this methodology, a project is valuable because it provides levels of valued attributes, the methodology includes procedures that convert the fundamental descriptors of distribution projects into specifications of levels of the attributes. Therefore, in particular, the methodology requires an approach to measuring reliability.

Current Approach

The methodology allows utilities to measure and value reliability in any manner they choose. A common approach is related to SAIDI. Users must describe the number of customers affected by a project, the interruption frequency (i.e., number of interruptions per year) experienced by these customers, and the interruption duration (per interruption) experienced by these customers. These attributes must also be specified if nothing is done in the area.

These attributes are not directly valued, however. Instead, the current approach requires the user to value SAIFI (the customer-interruptions per year) and CAIDI (the customer-hours lost per interruption), along with the number of customers served. Clearly, SAIFI and CAIDI can be computed given the data provided by the user. (Note that in the in the context of the Project Prioritization methodology, "valuing" means assigning a (possibly nonlinear) scale value to each observed value of each of the three attributes, viz., number of customers, CAIDI, and SAIFI. The assigned scale value measures the relative importance, from best possible to worst possible, of each computed level of each of these three attributes.) Then, since SAIDI=SAIFI x CAIDI, the reliability attribute is the product of the scaled value of the customers served multiplied by the product of the scaled values of SAIFI and CAIDI. Thus, the attribute is, in effect, the scaled value of the total customer-hours lost.

Critique

We have not had enough experience with this attribute to judge whether users find it appropriate or reasonable to assess. We anticipate, however, that the attribute may be difficult to assess. We also recognize that this attribute is not based on simple observables and must instead be computed outside the methodology by some means we have not specified. Furthermore, our modeling philosophy enjoins us to replace complex data sets and requirements with logical relationships and fundamental data. Therefore, we would prefer to base the reliability attribute on simple observables that project managers and engineers can easily provide.

Proposed Approach

The fundamental idea in the proposed approach is to replace assessments with simple models. We anticipate that the user will select appropriate reliability descriptors such as SAIDI, SAIFI, CAIDI, etc. For each of these indices, we will require the user to specify conditions in the area addressed by the proposed project that will allow us to compute the dynamic behavior of each index if nothing is done in the area. We can present the results predicted by the models to the users. At this time, the user may want to revise the assumptions used to characterize the consequences of doing nothing in the area. In any case, the model will provide a base case for reliability measurement in the area. Alternatively the user may wish to rely on the customer value models developed in a prior EPRI study (Customer Needs for Electric Power Reliability and Power Quality: EPRI Whitepaper, EPRI, Palo Alto, CA: 2000. 1000428). These models will permit the user to describe the consequences of doing nothing in an area in terms that customers find important. Qualitatively, the kind of conditions that must be specified by the user will vary depending on the indices selected. We can imagine something simple, like the annual expected failure rate if nothing is done, which is sufficient to describe SAIFI. Alternatively, we can imagine something complex, such as specifying the local area topology, with appropriate switching capabilities, accompanied by failure rates, repair rates, and customers served. The models will be designed to handle a range of inputs.

After the base case is computed, the models will respond to the changes in parameters provided by the project under consideration. Clearly, the models will have to be sufficiently flexible and robust in order to handle the modifications to the area provided by the project. We anticipate that a collection of straightforward logical models will be sufficient to capture the effects on the indices of any set of changes provided by a project. The result will be a complete dynamic forecast of the behavior of the chosen indices.

We believe that we can complete the models required and specify any new input data structures in 2002. However, that completion date depends on whether we have sufficient experience with users of the project prioritization system. If the current formulation of the reliability variable is satisfactory, our efforts might be better directed in other ways.

4
RISK MITIGATION STRATEGIES: THE S/RMS MODEL

Introduction

The reliability research described in this and our other reports is charged with answering the following question (as specified in the problem statement for this research): What are the important measures of reliability (i.e., what matters to customers and does this vary by type of customer)? Previous efforts were described in the customer needs report (*Customer Needs for Electric Power Reliability and Power Quality: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000428) and in the reliability report (*Reliability of Electric Utility Distribution Systems: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000424).

What is clear from these two reports is that the solution of the reliability problem has implications for operating and maintenance policies as well as investment policies. What is also clear is that the current approach to reliability analysis is essentially reactive and based on considerations of the average behavior of the system.

We believe that this reactive, essentially tactical, approach to reliability analysis and planning should be replaced, or at least complemented, by a more strategic approach. There are several reasons for our belief. First, budgets are being cut, customers are demanding service quality, and there is a persistent, but unverified, claim that the system is overly reliable. In this environment, reactive strategies will almost certainly lead to noticeable deterioration of service over time through the combined effects of decreased availability of resources and the unjustified but perceived need to permit the system to run at greater risk of failure. Second, relying on averages to describe the behavior of the system is fundamentally flawed. The main reason that this description is flawed is that averages greatly understate the risk to any individual customer. This is discussed further in Chapter 5. Third, the methods currently used to analyze reliability do not treat uncertainty in an appropriate manner. This is a criticism of the models and methods themselves. Since the essential question associated with reliability is the uncertainty of future system performance, failure to treat uncertainty appropriately seems particularly misguided. Fourth, the strategic implications of what is lost in performance when budgets are cut must be quantified to understand the consequences of adopting various strategies. Fifth, the entire notion of developing a long-term strategy as compared with a short-term tactical response must be directly addressed in any successful methodology. The current situation requires a strategic response, not a tactical one.

Some of these considerations can be placed in an important context by recognizing that there are two distinct problems associated with reliability analysis. The first problem is one of steady-state reliability analysis and control. Existing methods are aimed at solving this steady-state problem, as documented in our reliability report (*Reliability of Electric Utility Distribution Systems: EPRI White Paper,* EPRI, Palo Alto, CA: 2000. 1000424). The second problem is concerned with catastrophic event analysis and risk mitigation. No method exists to solve this second problem. We note that catastrophic events are typically those that occur relatively rarely but have important consequences when they do occur. We refer to such events as low probability—high consequence events.

The main reason it is important to consider these two problems separately is that the essential risk to the distribution system is present in the consequences of catastrophic events, not the steady-state behavior of the system. Surely, the money, time, and effort required to recover from a failure to anticipate or adopt a strategy to prevent a catastrophic event—as well as the unfortunate visibility that follows—is far greater than any failure to maintain the current very high level of steady-state performance. The point is that the current steady-state performance is excellent and further efforts to improve steady-state performance are almost surely far less important than efforts to mitigate the risk of low probability—high consequence events.

In terms of methodology, it is important to recognize that these two problems are different, and therefore must be solved by different methods. Methods designed to measure and control system average indices are wholly inappropriate for risk analysis to distribution systems. Therefore, we are developing new methodology.

Proposed Approach: S/RMS Model

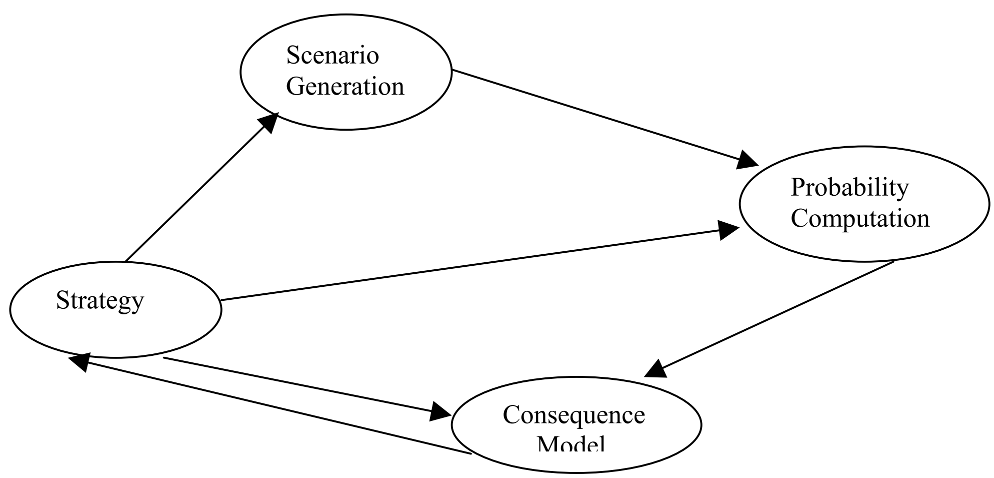
Our approach consists of four components. Three components of the model are concerned with Risk Mitigation Strategies (RMS). These three components are (1) likelihood estimation, (2) consequence description, and (3) strategy to alter either likelihood or consequences (or both).

The risk posed by a catastrophic event is based on both the probability of its occurrence and its consequences. We would not care much about an event that is unlikely to occur unless its consequences were extreme; and we would not care much about an event that is likely to occur if its consequences were benign. The most troublesome case, of course, is an event that is not likely to occur but has extremely direful consequences. The joint purpose of the three components is to determine the likelihood of an event, to determine the consequences of the event in question should it occur, and to determine strategies that either reduce the likelihood of occurrence of the event or mitigate the consequences, should the event occur. This seems straightforward, and we and others have built many models that accomplish all three of these tasks.

The challenge is to identify the catastrophic events. By nature, these events are not just extreme departures from steady-state conditions. Instead, they are qualitatively different occurrences. We argue that the most critical aspect of identifying catastrophic events is to think beyond the ordinary. In fact, we claim that risk mitigation fails in general because of a failure of imagination.* This suggests the need for the fourth component of the model structure, scenario generation (S/, in the acronym).

EPRI, and this research group, are uniquely prepared to integrate scenario generation methods and risk mitigation methods. The scenario generation process combines expert judgments about uncertainties, current system structure, and importance of uncertainties into a collection of scenarios that could have catastrophic consequences. The CATALYST process, an EPRI methodology developed for strategic planning, can be a basis for further work in scenario generation. This methodology is discussed further in Chapter 5.

The S/RMS model can be described in the figure below. It is our intention to create the four separate components that will (1) generate scenarios, (2) specify likelihoods using probability computations based on the scenario characteristics, (3) determine consequences of scenarios, and (4) develop strategies that can modify either the nature of the scenarios, the likelihood of their occurrence, and the consequences experienced should the events occur. We expect to be developing the methodology during 2002. Completion time for the methodology is uncertain at present.



* A poignant example of the failure of imagination is provided by the reaction of an unnamed New York Times reporter who attended the press conference for the release of the Hart-Rudman report on National Security (*Road Map for National Security: Imperative for Change).* One of the claims made in the report is: "A direct attack on American citizens on American soil is likely over the next quarter-century….In the face of this threat, our nation has no coherent or integrated governmental structure." During the final press conference, the NY Times reporter walked out in the middle. Later, Hart asked the correspondent why he did that. "He told me," said Hart, "and these are the exact words: 'This isn't important. None of this is ever going to happen.'" (Reported by Richard Reeves.)

Figure 4-1
S/RMS Model Structure

5
TOOLS FOR RISK MITIGATION

This chapter has two objectives. The first objective is to discuss current approaches for modeling distribution system reliability and to show why these approaches neither result in an accurate measure of risk nor lead to a "safe" risk mitigation strategy. The second objective is to present elements of a framework for risk mitigation that involves integration of new and existing tools and processes.

Current reliability models do not estimate the full range of outcomes faced by the utility customer. Traditional analytic models are based on classic reliability theory. These traditional models calculate reliability indices that measure system averages. The "A" in SAIDI, SAIFI, CAIDI and CAIFI, and indeed in most system reliability indices, stands for "Average."

Using averages as measures of system risk is a dangerous practice for two reasons. First, the indices themselves provide no measure of the range of customer outcomes. To overcome this deficiency, more advanced practitioners are building models that characterize risk by estimating the variability of system reliability indices, e.g., estimating how SAIFI might vary from year to year. Unfortunately, as we shall show, the variability of system indices seriously understates the variability in customer outcomes.

We shall argue that to develop robust risk mitigation strategies, we need to understand not just expected values or distributions on expected values, but the full range of risks facing a distribution system. Further, it is clear that one cannot avoid or mitigate risks if one does not understand how catastrophic events can affect individual customers. We begin by reviewing the approach of simulating uncertainty in system indices and then show why this is inadequate for risk mitigation, even if done perfectly.

Simulation

Attempts to extend the classic models fall short of estimating the true risk due to distribution system unreliability. Typically, such attempts are based on the use of simulation models to forecast variations in system averages. Simulation has some classic problems including computational inefficiency and inaccuracy. Moreover, simulation models are often black boxes – it is difficult if not impossible to understand the underlying reasons for a result. In the risk mitigation arena, simulation has a specific weakness: The very nature of simulation creates a very real possibility of overlooking rare but important events.

Most importantly, for developing risk mitigation strategy to protect customers, simulation typically simulates the wrong events! Customers are not interested in system indices; they are interested in what happens to them.

Capturing the Full Range of Risk

Consider a simulation of SAIDI (System Average Interruption Duration Index). Even if the simulation is based on a huge number of samples so that we have no doubts that the resulting distribution is accurate, the result can be very misleading. Even perfect simulations of average measures like SAIDI can greatly underestimate the range of outcomes for customers.

Consider the following example. The wider distribution is a given distribution of outage durations across a set of 100 customers in a given year. The mean of this distribution is 4 hours – more precisely, 4 hours is the average total outage duration a customer experiences in a year. This distribution has a great deal of information beyond the mean. For example, it implies that a substantial number of customers experience less than 1 hour of interruption; 25% of the customers experience over 5 ½ hours of interruption; and, worse yet, about 5% of the customers experience over 12 hours of interruption.

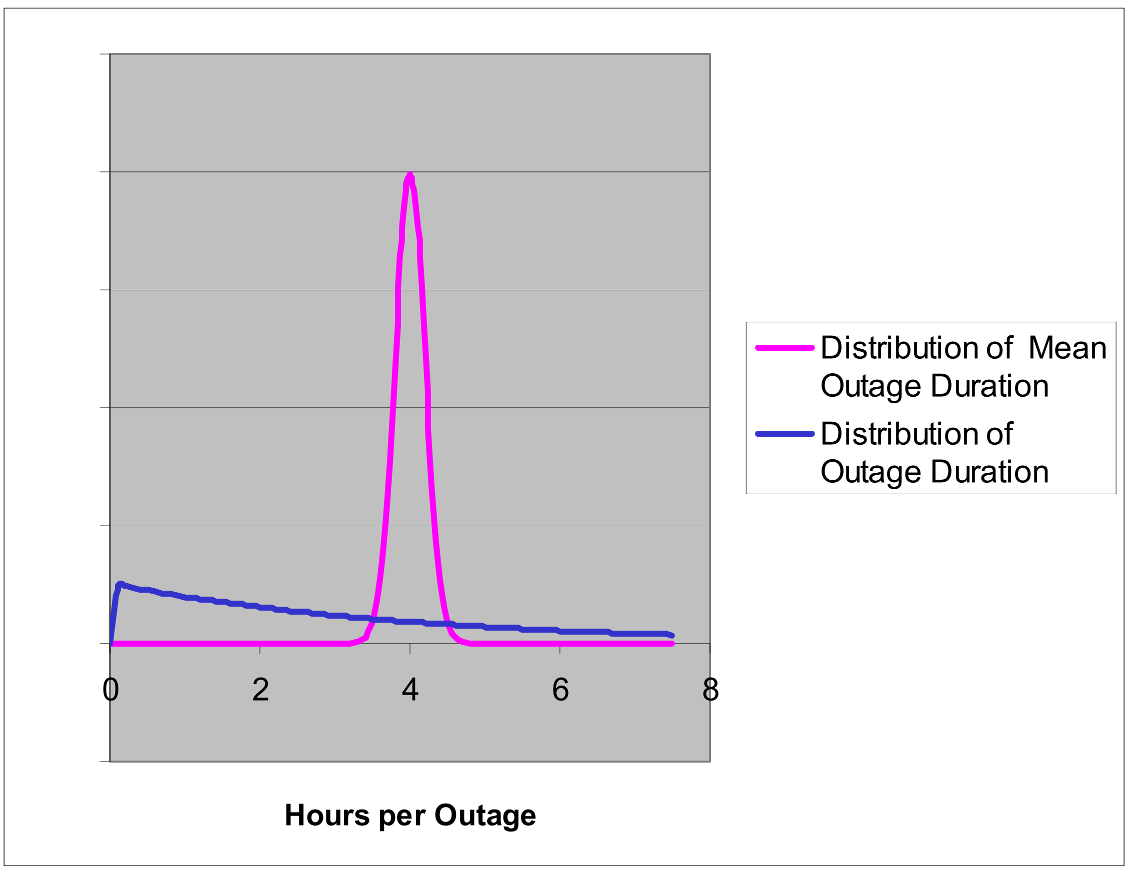


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Figure 5-1
Capturing the Full Range of Risk

Based on the duration distribution, it is possible to calculate mathematically the implied distribution of yearly variations in mean outage durations. More precisely, the narrow distribution measures the year-to-year variation in SAIDI (System Average Interruption Duration Index) that would result from the distribution of customer outages. Thus, the range of the distribution on SAIDI, a measure which is widely used by system planners, is a gross underestimate of the range of reliability impacts experienced by customers.

Strategic versus Operations Focus

Another aspect of reliability models that bears close examination in relation to risk mitigation strategy is the focus of such models. Typically, reliability models focus on operations issues rather than strategic issues. As an example of the level of detail necessary for modeling operations issues, consider the following excerpt from one of the primary developers of DS-RADS, a leading operational reliability model [Richard Browne, "*Probabilistic reliability and Risk Assessment of Electric Power Distribution Systems*," ABB Power Distribution Solutions report]. He describes the logic of an ABB simulation model:

> *The key to an analytical simulation is to accurately model the sequence of events after a contingency to capture the different consequences for different customers. A generalized sequence of events is:*
>
> *1. Contingency: A fault occurs on the system*
>
> *2. Reclosing: A reclosing device opens in an attempt to allow the fault to clear. If the fault clears, the reclosing device closes and the system is restored to normal.*
>
> *3. Automatic Sectionalizing: Automatic sectionalizers that see fault current attempt to isolate the fault by opening when the system is de-energized by a reclosing device.*
>
> *4. Lockout: If the fault persists, time overcurrent protection clears the fault. Lockout could be the same device that performed the reclosing function, or could be a different device that is closer to the fault.*
>
> *5. Automated Switching: Automated switches are used to quickly isolate the fault and restore power to as many customers as possible. This includes both upstream restoration and downstream restoration. In upstream restoration, a sectionalizing point upstream from the fault is opened. This allows the protection device to reset and restoration of all customers upstream of the sectionalizing point. In downstream restoration, other sections that remain de-energized are isolated from the fault by opening switches. Customers downstream from these points are restored through alternate paths by closing normally-open tie switches.*

6. Manual Switching: Manual switching restores power to customers that were not able to be restored by automated switching (certain customers will not be able to be restored by either automated or manual switching). As in automated switching, manual switching has both an upstream restoration component and a downstream restoration component.

7. Repair: The fault is repaired and the system is returned to its pre-fault state.

This type of operational reliability model is quite useful for detailed system design; however, it does not focus on the rare but catastrophic events often of most concern to utilities and the public. As we shall see, in gauging the risk of a catastrophic outcome, even a small probability of a common-cause event can overwhelm the impacts of the individual component failure rates. A strategic focus requires a higher vantage point than detailed switching operations and individual component failures. And a more strategic focus is needed to represent the true range of uncertainty and risk exposure, and to analyze properly risk mitigation strategy.

Approaches to Strategic Analysis

A set of advanced operations research and modeling techniques exist that may be used to address rare events and evaluate high-level risk mitigation strategies explicitly.

One type of model useful for strategic analysis is a Markov Decision Process. An optimization technique known as Policy Iteration identifies strategic outcomes with rare but far reaching consequences. An example of strategic Markov Decision modeling is EPRI's Electric Utility Fuel Inventory model (UFIM) (*Utility Fuel Inventory Model.* EPRI, Palo Alto, CA: 1990. EA-4766-CCML.)

The principal goal of inventory management is to balance the cost of building and maintaining fuel reserves against the risk of running out of fuel. The most important risks that drive inventory policy are rare but extreme-cost disruptions. UFIM uses Policy Iteration to provide utilities with strategies and insights about how to strike this balance. UFIM has been used to help many power companies develop strategic, low-cost fuel inventory policies.

The same underlying Markov model that is used to calculate system averages in operational models can also often be used to calculate the probabilities of rare events necessary for strategic models. Calculating full probability distributions often requires careful modeling effort to capture problem regularities, but our experience indicates that the full probabilistic analysis can likely be accomplished in the strategic reliability application.

Examples of dynamic probabilistic models that represent the full probability distribution of outcomes are EPRI's Load Dynamics Model (*LoadDynamics User's Manual.* EPRI, Palo A lot CA: 2000) and EPRI's Area Investment Strategy Model *(Area Investment Strategy Model User's Manual*. EPRI, Palo Alto, CA: 1999). The Load Dynamics Model provides probabilistic information about future load growth that feeds the Strategic Area Investment Model. Together they aid the development of local area investment strategies for the electric power industry. In selecting strategy under uncertainty, the decision process must be dynamic and responsive to change. Good decision makers understand this well. They know that they must decide what to do today, and as the future evolves, they will have to react to the changing situation and make further decisions and commitments. The Area Investment Strategy Model not only identifies what action to take today, but also how to respond as key uncertainties evolve. It is likely that modeling both dynamics and uncertainty explicitly will also be critical in developing risk mitigation strategy for distribution systems.

Preliminary System Risk Model

We have constructed a preliminary system risk model. The model is programmed in Excel and Visual Basic and is best described as research software. It does not yet explicitly address strategy. Here we describe how the model works for a simple example involving the system risk consequences of two fairly reliable circuits. It is important to state that the topic need not be circuits. The example could as well describe two components of any kind, or more generally, two events of any type. Although the example is simple, in concept it can be generalized to more complex situations.

The example illustrates two key concepts. First, it demonstrates the difference between a full probabilistic analysis and an analysis based only on expected values. Second, it demonstrates the overriding importance of understanding and modeling probabilistic dependency by modeling one very important type of dependency – that which stems from common-cause events. Common-cause events are events that cause more than one device, component or circuit to fail simultaneously. When such an event is possible, even with small probability, it can have a profound impact on system risk and risk mitigation strategy.

Consider two circuits whose reliability is described by the matrices shown in the screen shot below. Each circuit has its own failure mode. If Circuit A is in the “Up” or non-failure state, there is a 0.990 probability that it will stay “Up” in the next period and a 0.010 probability it will go into the “Down” or failure state. Similarly, if Circuit B is in the “Up” or non-failure state, there is a 0.980 probability that it will stay “Up” in the next period and a 0.020 probability it will go into the “Down” or failure state.

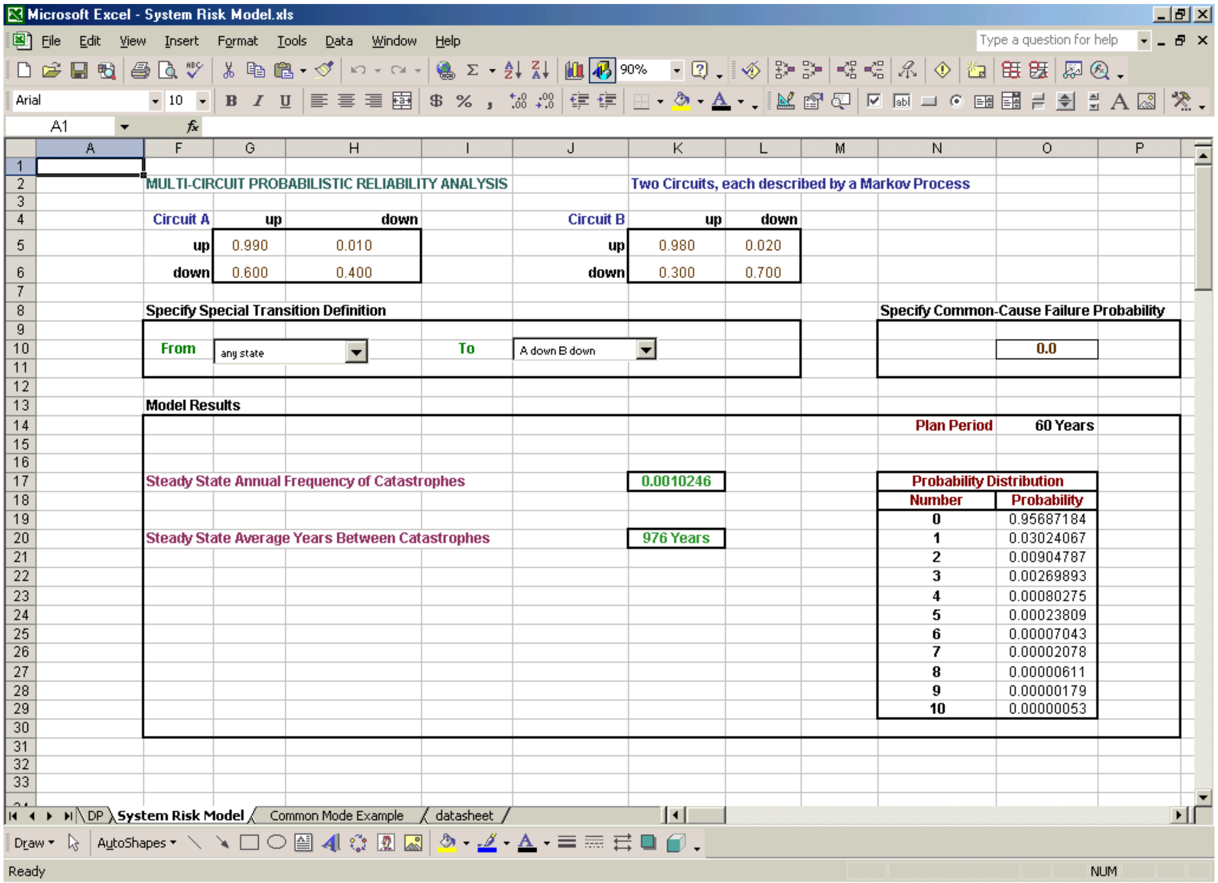

Figure 5-2:
Risk Example One

These probabilities imply that the average time between failures in Circuit A is 100 years and the average time between failures in Circuit B is 50 years. Thus, each circuit might be considered to be reasonably reliable.

Now, consider the possibility of joint failures. The overall system state is function of each circuit's failure state. In this case, there are four possible system states:

- **A Up B Up**
- **A Up B Down**
- **A Down B Up**
- **A Down B Down**

Suppose that in examining the possible system states, we determine that "Down, Down" is a catastrophic case of strategic importance. This might occur if either circuit acts as the only backup for the other circuit in the event that one of them fails. In this case, if both circuits go down simultaneously there is no backup and customers are without electricity for a very long time. The figure shows that the model user invoked this definition of Catastrophe by defining a Special Transition to be a transition from "Any State" to "A Down and B Down." The model allows the user to define a Special Transition flexibly to be a transition from any system state or set of states to any other system state or set of states.

The model solves a set of discrete differential equations (the calculation is not shown) to provide several interesting outputs. The fundamental output is the full probability distribution on the number of Special Transitions or Catastrophes for any specified planning period. In the example, we see that for a planning period of 60 years, there is over a 95% probability that no Catastrophes will occur; 3% probability that exactly one Catastrophe will occur; and 1% probability of more than one Catastrophe. The same types of probabilities can be calculated for planning periods of any length.

The model may be used to calculate averages as well. For the case shown, the company should expect an annual catastrophe frequency of slightly more than one in a thousand, or, equivalently, an average time between catastrophes of slightly less than a thousand years.

The power of such an analytic model is in its ability to run different cases. For example, suppose someone argues that the only true catastrophe would be a system transition from both circuits up to both circuits down. Perhaps this is because emergency measures are taken when one circuit goes down, such that the impact of the other going down later is mitigated. However, both circuits going down simultaneously with no warning would be disastrous. We reflect this state of knowledge in the figure below by redefining the meaning of a special transition to be "*From* A up and B up *To* A down and B down." Note that the average time between catastrophes is now 5422 years, over 5 times as long as in the previous case. This emphasizes the critical importance of addressing the question, "What is a catastrophic event?" Answering this question is both a modeling issue and a process issue.

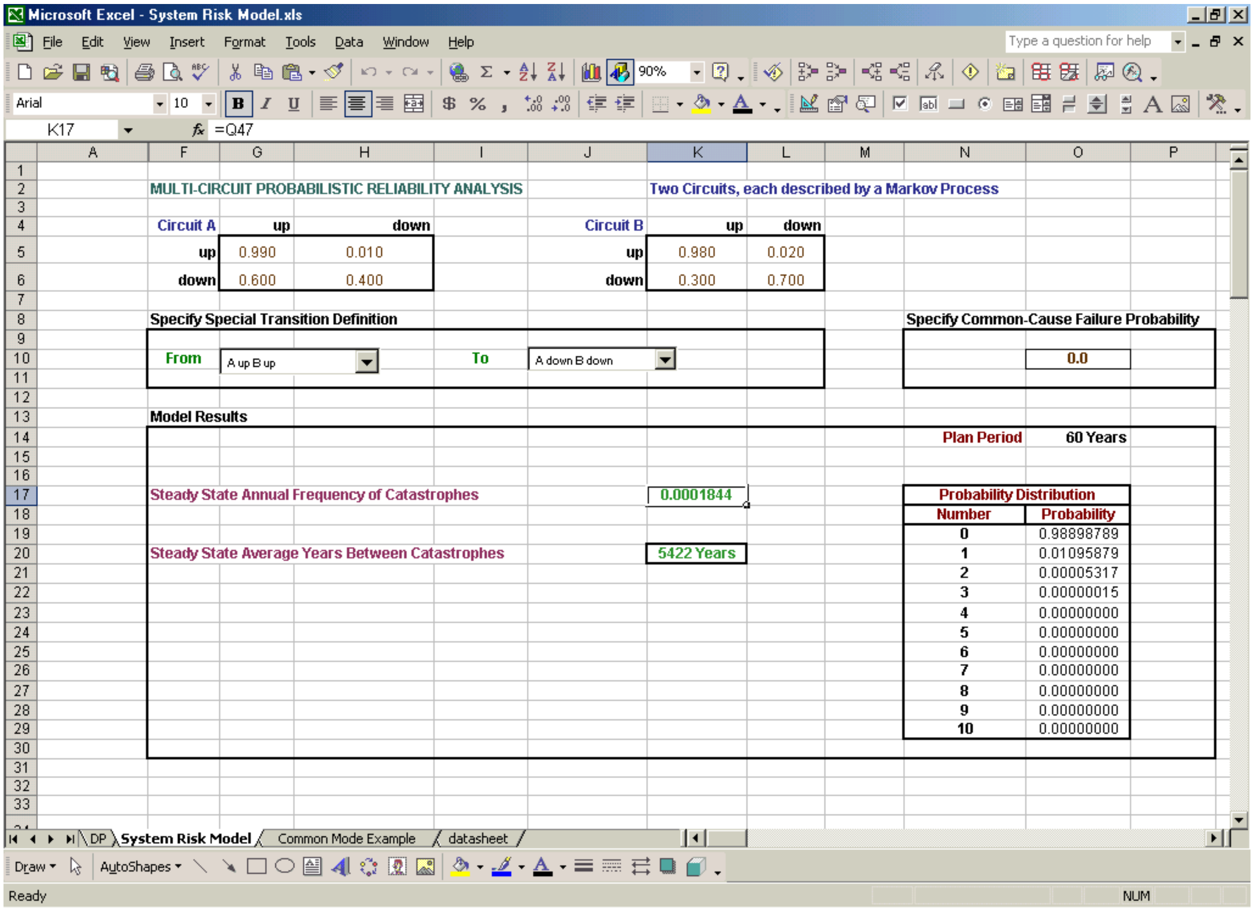

Figure 5-3
Risk Example Two

In the cases above we made an implicit but critical assumption: the circuits were assumed to fail independently. But what if the same factors that tend to cause one circuit to fail also tend to cause the other to fail? If failures of two circuits or components have some common causes or even potential common causes, the probability of system failures or catastrophes dramatically increases.

Suppose, for example, that we take the original definition of Special Transition and assume a 10% chance of a "Common Mode Failure" -- that is, a 10% chance that if one of the circuits fails, the underlying event that caused the failure will also cause the other circuit to fail. The figure below shows the dramatic effects of a small common-mode failure probability:

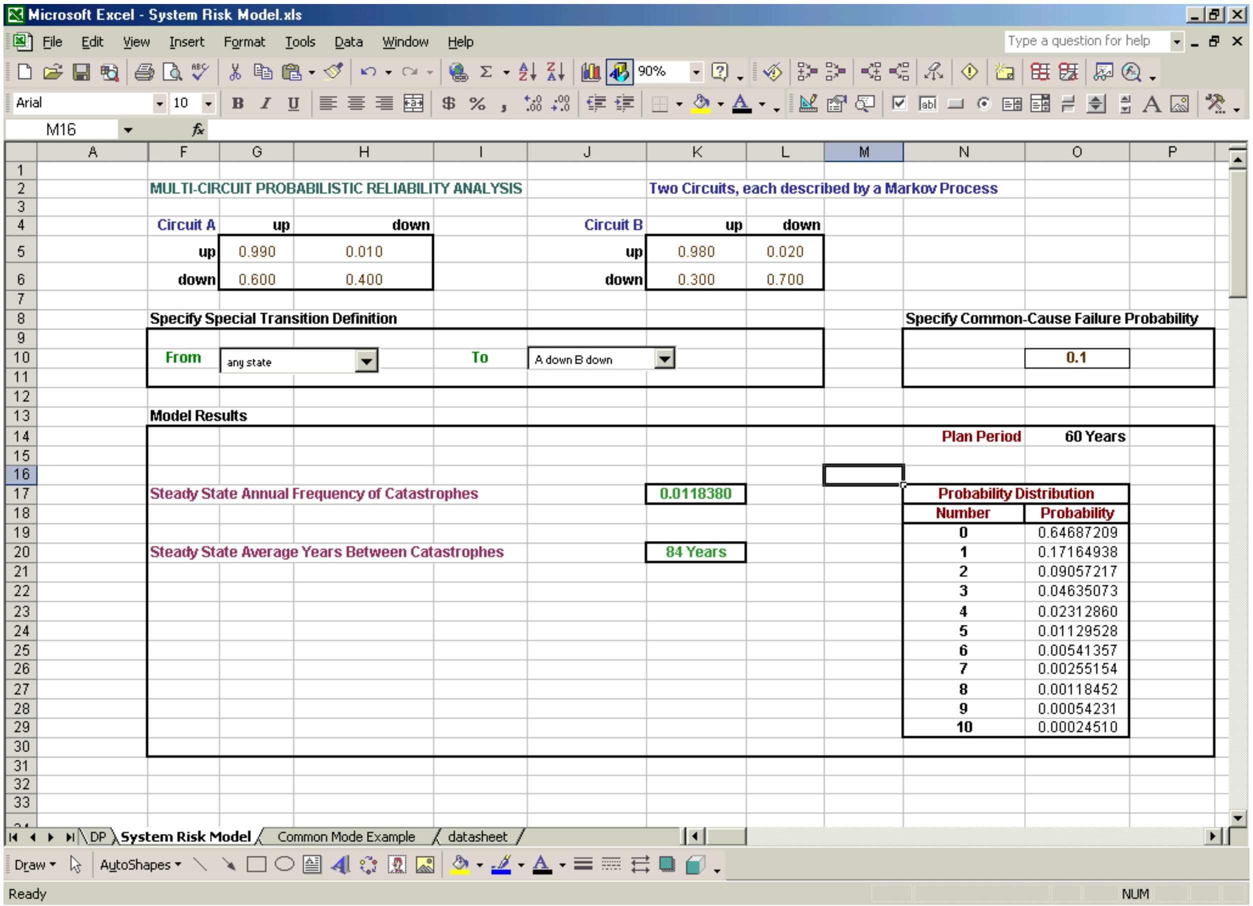

Figure 5-4
Risk Example Three

For a common-cause probability of 10%, the average years between catastrophes shrinks from over 900 years to 84 years. Moreover, the probability of at least one catastrophe in the planning period is 35%. If such a catastrophe is very costly, the use of such a probabilistic model that explicitly calculates the risk can be extremely useful.

Finally, we used the model to create the following chart that shows how the average years-between-catastrophes depends heavily on the common mode failure probability.

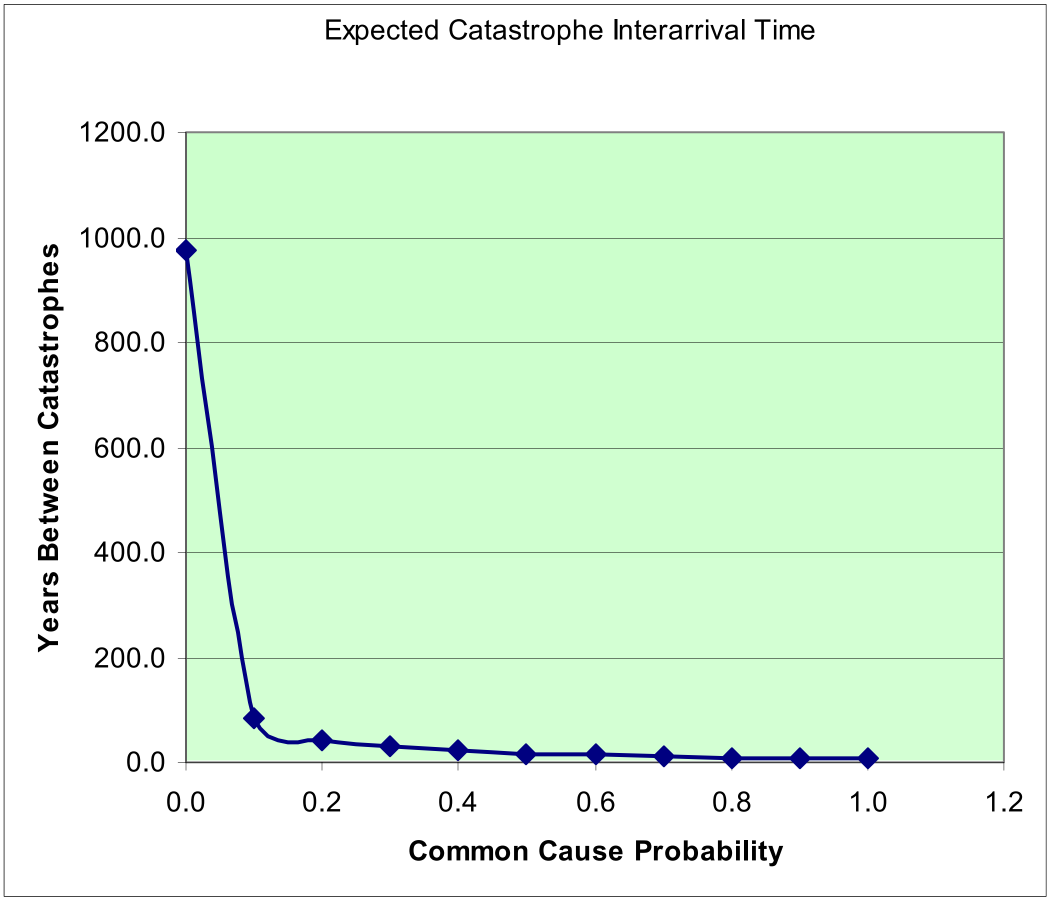

Figure 5-5
Average years-between-catastrophes versus common mode failure probability

In summary, system risk models such as the one described above appear to be quite promising; however, the present model needs substantial work to generalize it to multiple circuits, components or events.

The example also emphasizes the clear need to augment analytical models with structured procedures for generating worst-case scenarios. Building such procedures may be even more important than building analytical tools. In the example case, there were only four possible system states. In general, if there are N key events (or components, or circuits), there will be 2 raised to the Nth power possible system states. For example, 10 events imply 1024 system states.

With a large number of system states, a key question becomes, "Which system states are important enough to worry about and analyze?" Each future system state may be considered to be a potential future risk "scenario." The next section discusses processes and procedures for identifying critical future risk scenarios.

Pitfalls of Historical Analysis

Statistical analysis alone is inappropriate for predicting rare, one-of-a-kind events. It has long been know that in the practice of risk assessment, even the best analytical models must be augmented with expert judgment. Consider the following chart of U.S. casualties from terrorist attacks. Before September 11, 2001, a statistical extrapolation would have indicated a future like the lower line. Clearly, a statistical analysis based on past data was not a good predictor of the future.

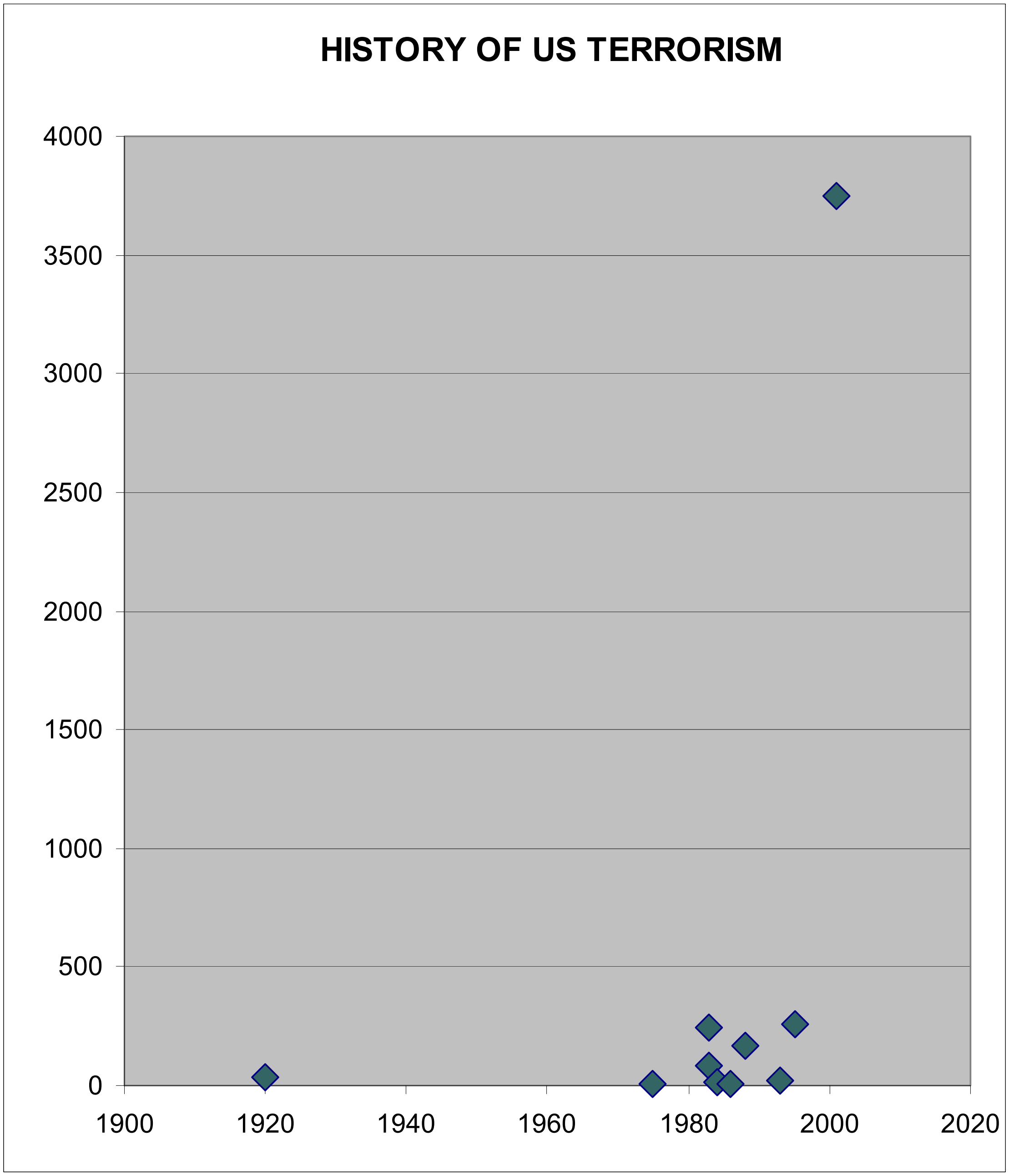

Figure 5-6:
U.S. casualties from terrorist attacks

Could anyone have foreseen this horrible occurrence? Certainly one could not have foreseen the precise sequence of events that took place, although the author Tom Clancy came close. Nevertheless, a structured process for thinking about potential extreme events would likely have included this type of outcome and perhaps spurred policy makers to take appropriate risk mitigation actions.

The figure below shows a well-known probability assessment exercise in which participants estimate the percentiles of three unknown quantities and then the group results are scored. The results are powerful. Over and over again, across thousands of samples, people say that they know little about these uncertain quantities, but when asked to quantify their knowledge, invariably overstate its precision. Typically, at least 50% of the actual values fall outside the 1 to 99 percentile range. In other words, events that people say are only 2% likely to happen occur over 50% of the time!

Probability bias demonstration

Probability Assessment Demonstration

PROBABILITY

	0.01	0.50	0.99	True Value
1. U.S Consumption of beef in 1991				
2. Number of Auto Thefts in the U.S. in 1991				
3. Height of Mt Everest as measured by the Surveyor General of India in 1954 (feet)				
4. Year in which Attila the Hun died				
5. The equatorial diameter of Jupiter (miles)				
6. Date of birth of Genghis Khan (year)				

Source ADA

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A set of tools has been developed to help experts more accurately communicate their knowledge and stretch the tails of their probability distributions appropriately. In so doing, scenarios that might at first seem out of the range of plausibility become explicitly considered. Any risk mitigation strategy must be careful not to ignore risks that only appear inconsequential because they have not been sufficiently examined.

Decision analysis and other disciplines have developed structured tools that ought to be considered for distribution system risk mitigation. Among them are:

- Tools for integrating expert judgments
- Probability elicitation for encoding expert judgment
- Multi-expert processes for combining information from a group of diverse experts

Structured processes have successfully generated important scenarios and insights in many other applications, including:

- Strategic planning (CATALYST cases described below)
- Fuel inventory
- Load forecasting
- Nuclear power plant protection
- Test ban treaties

Structured Scenario Generation

Statistical analysis is not only insufficient to estimate the chance of rare, one-of-a-kind events, but it can be argued that it is even worse than nothing. It has often been said that "The problem with statistical analysis is that it's like driving by looking through a rear view mirror … it's okay as long as the road remains straight, but disastrous when you hit a curve." Consider the following historical predictions [***"They Believed It," Source: C. Cerf and V. Navasky, The Experts Speak]***

- **"Heavier than air flying machines are impossible."**
    - Lord Kelvin, president of the British Royal Society 1895
- **"With over 50 foreign cars already on sale here, the Japanese auto industry isn't likely to carve out a big slice of the U.S. market for itself."**
    - Business Week, August 2, 1968
- **"A severe depression like that of 1920-1921 is outside the range of probability."**
    - The Harvard Economic Society, November 16, 1929
- **"I think there is a world market for about five computers."**
    - Thomas J. Watson, chairman of IBM, 1943
- **"There is no reason for any individual to have a computer in their home."**

   - Ken Olson, president, Digital Equipment Corporation, 1977

- **"We don't like their sound. Groups of guitars are on the way out."**

   - Decca Recording Co. executive, turning down the Beatles, 1962

- **"The phonograph …. is not of any commercial value."**

   - Thomas Edison, inventor of the phonograph, 1890

- **"No matter what happens, The U.S. Navy is not going to be caught napping."**

   - Frank Know, Secretary of the Navy, December 4, 1941

- **"They couldn't hit an elephant at this dist…"**

   - General John Sedgwick, last words, Battle of Spotsylvania, 1854

No one can predict the future, but there are a set of useful methods for making sure that we mitigate risks by considering an appropriately wide range of future possibilities. We believe that these methods can be customized for dealing with reliability issues. As one example, consider the method called "Backcasting" Backcasting, sometimes called "Headlining" helps identify contingent strategies and options by focusing on the future rather than today's decisions.

The process of Backcasting involves thinking about future possible newspaper headlines:
"Imaging yourself 5 years from today reading the newspaper and there is a headline about a distribution system catastrophe. It reads …"

Among the questions addressed by a Backcasting exercise would be [excerpts from an Applied Decision Analysis, Inc. presentation]:

- What does the headline say (future state/uncertainty)?
- What are people going to do about it (response)?
- What actions did the "players" take in to anticipate this occurring (strategies)?

More generally, the most directly relevant process for developing distribution system risk mitigation scenarios may be CATALYST, a strategic process developed by EPRI. Although developed as a general strategic planning tool, many of the elements of CATALYST could be tailored to the distribution system risk mitigation problem.

CATALYST: Towards a Process for Generating Risk Mitigation Scenarios

Here we provide a brief summary of CATALYST. The purpose is not to suggest that CATALYST can or should be used with no modification. However, we do suggest that

CATALYST has many of the basic features necessary to generate appropriate scenarios for constructing and evaluating risk mitigation strategies. Most of the text below is copied from CATALYST documentation. The reader interested in finding out more about CATALSYT should contact Steve Chapel at EPRI (650-855-2608).

CATALYST was developed as a process by which utilities could make strategic decisions, such as deciding which new technologies to develop, choosing which capital investments to make, or selecting which resources to acquire. CATALYST is a six-stage process based on the principles of decision analysis and group problem-solving techniques. The process is typically implemented as a two- or three-day off-site meeting of key decision makers and analysts.

The origins of CATALYST were similar in spirit to the origins of the EPRI reliability risk mitigation project. CATALYST was begun several years ago when EPRI and the industry were involved in the development of many planning tools that were excellent computer models, but did not address some of the complex, non-mathematical business issues. At that time, the utility industry and its world were changing and many utilities were finding themselves in "Scenario B" worlds when they had thought they would be in "Scenario A" worlds. It was a time when documentation of decision processes was becoming ever more important to utilities.

The unusual feature of CATALYST is that it explicitly considers the uncertain environment surrounding the problem and it quickly brings to bear the knowledge and brain power of many different experts. It does this by combining the principles of decision analysis and structured group problem solving. The process was designed to assure that low probability events are explicitly considered and to assure that decision making is structured to be robust.

CATALYST gives the group step-by-step directions on how to

- Define the problem
- Identify the candidate strategies
- Identify the key uncertainties that affect the success or failure of the strategies
- Construct a set of representative, weighted scenarios out of combinations of the key uncertainties
- Develop contingency plans for how each strategy would respond to each scenario and assess the desirability of the resulting outcomes
- Use this information to choose between strategies
- Determine the appropriate next steps

The main benefits Of CATALYST are that it develops

- The logic and structure of the problem
- Common understanding and consensus among key decision makers and analysts
- A rigorous framework for detailed evaluation of strategies
- A framework and common vocabulary for communication of results

Many of the most important strategic decisions facing utilities are also the most complex. They are often surrounded by a host of uncertainties. Any action may have a bewildering array of side effects. And the expertise needed to solve the problem may be spread out all over the organization. CATALYST shows how to consider explicitly the uncertain environment surrounding the problem and it quickly brings to bear the knowledge and brain power of a company's many different experts

The benefits Of CATALYST can best be illustrated by describing how it addresses three common obstacles to decision making:

- Uncertainty about the future
- The complexity of contingency planning
- The broad range of expertise needed to analyze a complex issue

Why Uncertain Futures Are an Obstacle to Planning

The outcomes of most plans of action depend on how something else turns out in the future. Such unknown factors can be external (such as the future load, customer behavior, or actions by competitors) or internal (such as the results of an R&D program). Thus, one would have to know the future in order to pick a guaranteed best plan of action.

One traditional solution to this problem is to make a long-range forecast of these factors. The alternative candidate plans of action are then evaluated assuming that this forecast comes true.

But such forecasts are always off - at least a little. And even small errors might dramatically change the desirability of the outcome yielded by a plan. Thus, it is very risky to plan for the "nominal" forecast. It is vital to consider the likelihood of deviations from the forecasts and their significance to the outcomes of the plans.

CATALYST addresses this problem by adapting tools from the science of decision analysis to plan explicitly for uncertainty. CATALYST assumes that a range of futures may occur. It then helps decision makers identify the scenarios and strategies that represent the opportunities and risks posed by this uncertainty.

Why Contingency Planning Is an Obstacle to Planning

In planning one tries to pick the course of action that will yield the greatest value. But once this course is chosen, it is still not carved in stone. Over time one will make adjustments, take strategic "off ramps," or otherwise respond to contingencies that arise. This is done to avoid risks or take advantage of opportunities. Thus, the contingent actions taken will affect the value achieved by the strategy.

However, the set of contingent actions available differs for each candidate strategy. So to assess the true value of a strategy, one must consider the particular set of flexible strategies it allows, how these responses would affect the value yielded by the strategy, and how likely it is that one would use each response.

CATALYST considers all three of these factors. It includes procedures to plan how each strategy would respond to each major contingency. It then includes the benefits of these contingency plans when evaluating the candidate strategies. This approach allows accurate comparison of the competing strategies and provides a head start on responding to any contingencies (“forewarned is forearmed”).

Why Dispersed Expertise Is an Obstacle to Planning

Because of the complexity of many modern problems, the people best equipped to solve them often

- Are very busy
- Work in different buildings, divisions, departments, or operating companies
- Have different opinions and perspectives on the problem
- Have different "languages" for talking about the problem

CATALYST overcomes these problems because it is a group problem-solving process (as opposed to, for example, a computer model). Several aspects of the process's design have special benefits:

- The face-to-face meeting format quickly airs the different perspectives on the problem and builds consensus among them.
- The off-site location focuses the participants' attention on the problem by removing them from the day-to-day distractions of the office.
- The two or three days of the workshop is enough time for a complete first pass analysis of the problem, but does not exceed participants' endurance.
- The outside facilitator aids maximum participation and consensus-building by all the different stakeholders.
- The structured process maintains the participants' enthusiasm in the analysis by giving them a steady stream of small, achievable goals that add up to a comprehensive analysis.
- Group problem-solving techniques maintain the group's progress (prevent getting "bogged down'), elicit participation from all group members, resolve disagreements, etc.

Additional Benefits Of CATALYST

CATALYST'S solutions to these four common obstacles to planning combine to provide additional benefits:

- They increase the company's understanding of the problem by creating a logical structure for thinking about it.

- They forge consensus among the key decision makers and analysts.
- They ease communication of results (both within the group and to other members of management) by providing a common vocabulary and logical structure.
- They accelerate decision making.

Overview of the CATALYST Process

The benefits of CATALYST outlined above are achieved with an explicit sequence of precisely-defined steps. The steps actually begin with preparations long before the session. These steps ensure that CATALYST is really the most appropriate tool for the job and that the most appropriate people attend the session. They also make sure that the participants have accurate expectations about what they will do during the CATALYST session and what they will get out of it.

The Six Stages Of CATALYST

Each pass through the CATALYST process consists of six stages. The results of each pass are summarized in a "Strategy-Scenario Matrix" (see the figure below). The stages of a CATALYST pass can be illustrated by examining sections of the Strategy-Scenario Matrix.

Stage 1: Problem Definition. This stage begins the pass by probing the root causes of the problem and identifying the alternative strategies that might be used to solve the problem. This stage fills in the strategy titles and descriptions at the top of the Strategy-Scenario Matrix columns.

	Strategy A	Strategy B	Strategy C	Likelihood
Scenario 1	impact & response value	impact & response value	impact & response value	x%
Scenario 2	impact & response value	impact & response value	impact & response value	y%
Scenario 3	impact & response value	impact & response value	impact & response value	z%

Average	value	value	value	100%
Std. Dev.	value	value	value	

Figure 5-7
CATALYST Strategy-Scenario Matrix

Stage 2: Uncertainty Identification & Stage 3: Scenario Development. The first of these two stages identifies the key uncertainties that affect the outcomes of the alternative strategies. The second of these two stages takes the key uncertainties and constructs a set of scenarios of future states of the world (see the row titles of the Strategy-Scenario Matrix). CATALYST's step-by-step procedure for constructing scenarios ensures that the final set is representative (i.e., it spans the range of possible future states of the world) and that each scenario is internally consistent (i.e., does not contain implausible combinations of events, such as an economic boom at the same time as an oil price shock).

The procedure also estimates the relative likelihoods of the scenarios. These likelihoods are crucial because they enable you to consider not only the desirability of each outcome, but its likelihood as well. Few other scenario planning processes include this feature. These likelihoods are recorded in an extra column to the right of the Strategy-Scenario Matrix

Stage 4: Strategy Development & Stage 5: Strategy-Specific Risk Analysis. These stages are in many ways the heart and soul of CATALYST because they are where the participants recognize and enhance the flexibility of the candidate strategies. For each cell in the matrix the group tells a story about the impact that the scenario would have on the company and the contingent actions the company would take in response. Participants often find that these stages create the most insights and thus the most enjoyment.

Stage 6: Evaluation. This is the stage in which the participants gain closure on the pass. First they quantify the value of the decision criteria achieved by each strategy under each scenario. Then they take a step back and review these values along with their likelihoods (from Stage 3). This produces many insights about the "upsides" and "downsides" of each strategy, and their likelihoods. It can even inspire the invention of entirely new strategies.

Next CATALYST leads the group through a systematic examination of where further analysis would be most valuable. The group completes the pass by deciding what specific action items need to be accomplished and distributing responsibility for them to its members. In this way the CATALYST pass leads to action rather than to a report that sits on a shelf.

CATALYST’s six stages produce several concrete end products in addition to insights about the problem:

- Broad set of alternative strategies
- Representative set of future scenarios
- Contingency plans for how each strategy would respond to each scenario
- Comparison of strategy outcomes across the range of possible futures
- List of next steps: actions and analyses
- Structure for further analyses
- Structure for communicating results

6
CONCLUSIONS

This report presented some new results and new directions in our reliability research. We described methods we intend to apply to improve the reliability analysis capabilities of our Area Investment Strategy Model and our Project Prioritization methodology. These methods replace data requirements with models and simplify the data-gathering burden on users.

We identified an important new area of research and development. We intend to create a methodology for risk mitigation strategies that can respond to the risks associated with low probability—high consequence events. This new S/RMS model integrates existing EPRI capabilities (the CATALYST methodology) and existing research models and expertise.

We intend to develop all the models discussed in this report in 2002. As we achieve further progress, we shall update this report.