Technical Review of DS-RADS Model

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Briefing Report, November 2001

EPRI Project Manager

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ABSTRACT

This document provides a review of the reliability planning model, DS-RADS, developed by Snohomish Public Utility District and The University of Washington. The objectives of this review were to determine (1) the problems addressed by the model, (2) the validity of the approach in terms of providing a practical tool for utility planning and (3) the potential for use in EPRI distribution reliability research. The results are presented as a Power Point briefing with notes. The report has four sections: (1) Introduction and objectives, (2) Reliability planning problems addressed and not addressed by DS-RADS, (3) Model evaluation and (4) Recommendations for a new strategic, risk-based approach that would extend the scope and usability of DS-RADS.

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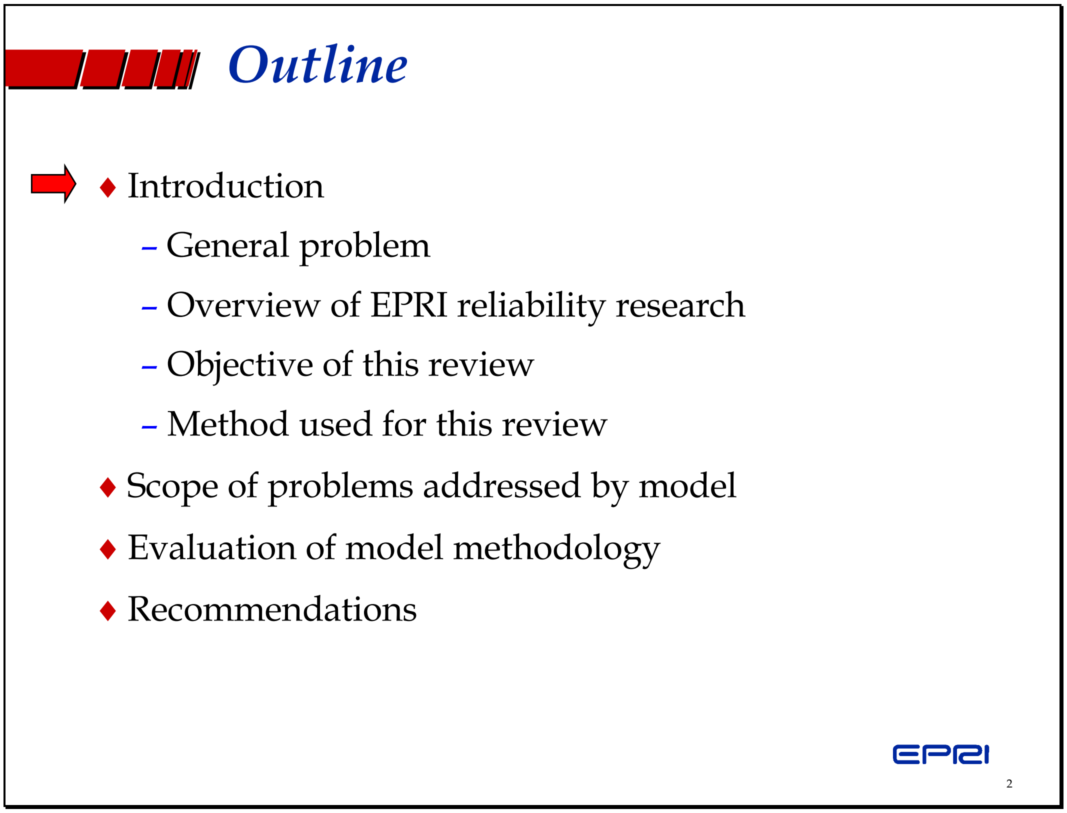
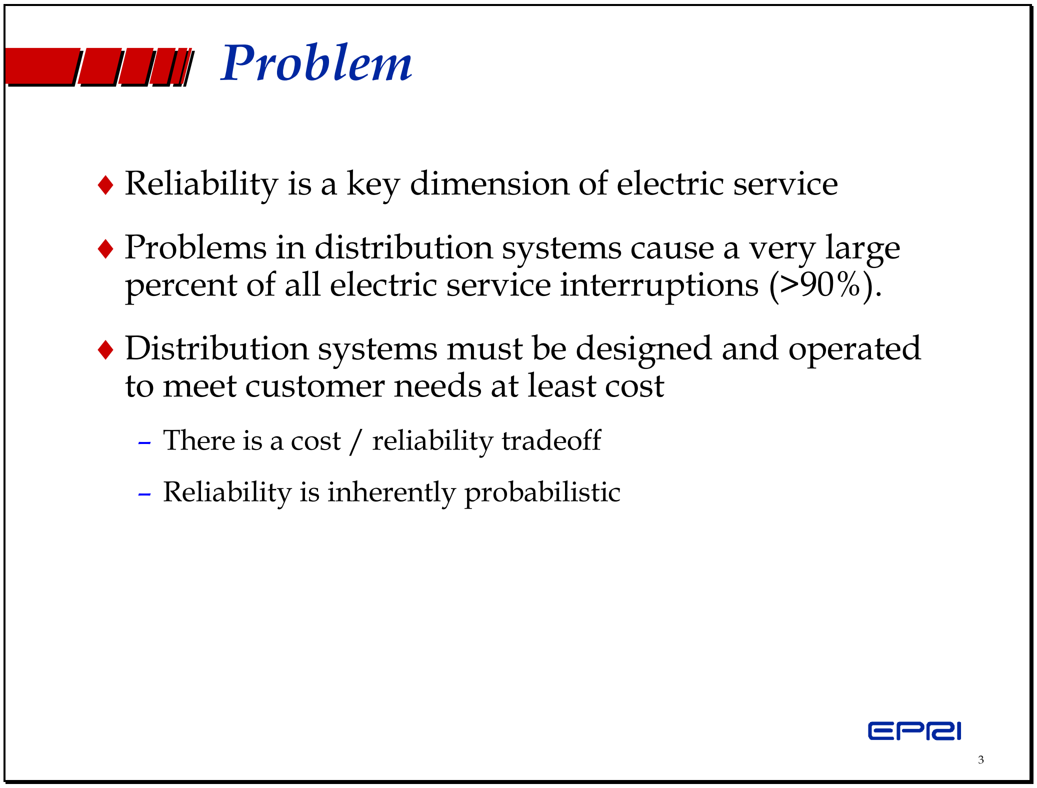
INTRODUCTION



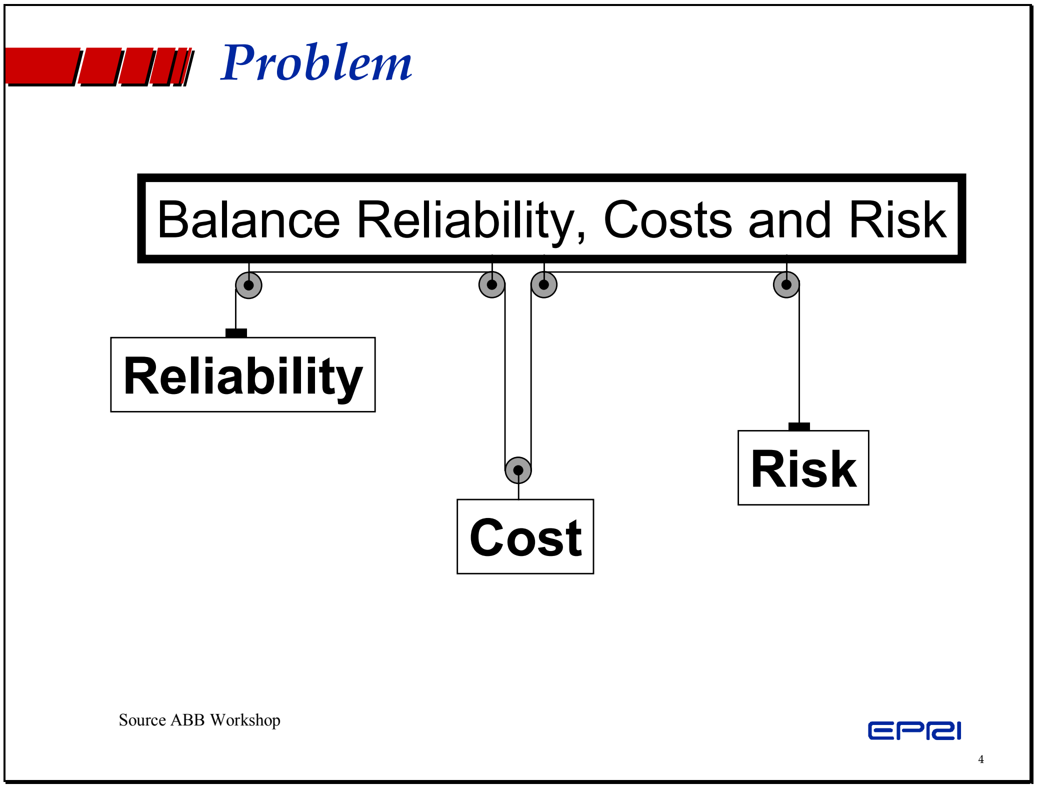
This briefing paper has four sections. The first section sets the context for the review of DS-RADS by (1) describing the general distribution reliability planning problem, (2) giving an overview of the EPRI research project Measuring and Valuing Distribution Reliability, (3) stating the objectives of the review, and (4) outlining the method used in the model review.

The second section discusses the scope of the planning problems that DS-RADS is designed to address and the problems that it does not address. Section 3 summarizes the results of the model evaluation, and Section 4 contains the recommendations.

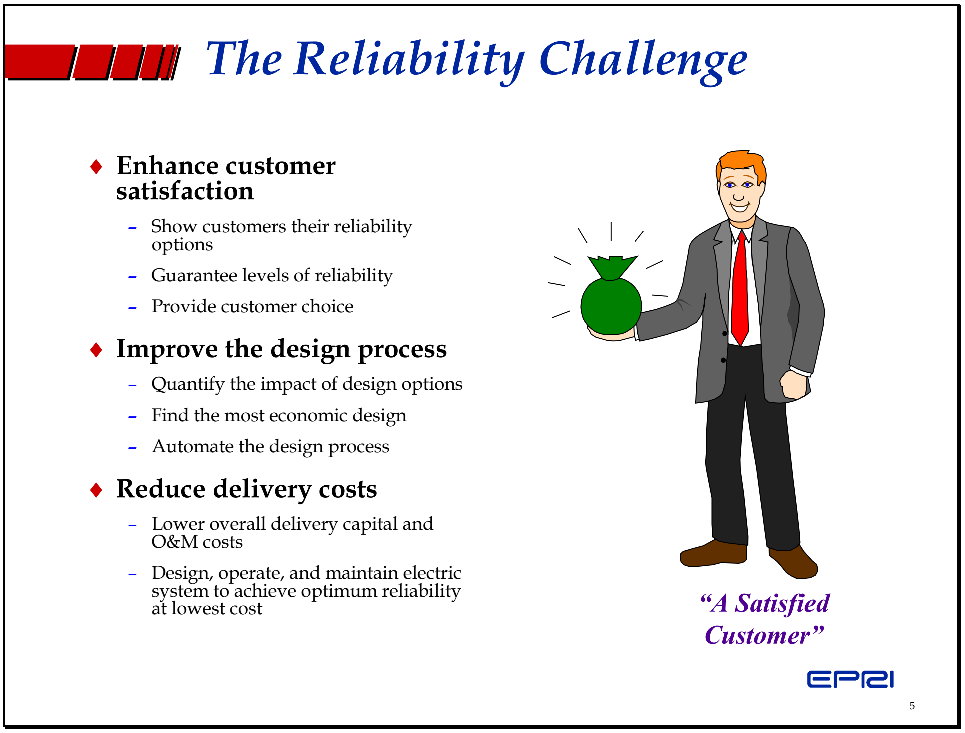


The reliability planning problem that electric distribution companies face is derived from four facts:

- Reliability, measured by the frequency and duration of outages, is a fundamental dimension of electric service.
- A very large percentage of electric service interruptions, perhaps greater than 90 percent, are due to problems in the distribution system.
- There is a tradeoff between reliability and costs – reliability costs money.
- Reliability is probabilistic – given specific design and maintenance practices, the electrical system's reliability varies from year to year. It also varies with design and maintenance. This variation creates risk – forecasts of expected or average reliability are not representative of the full range of reliability outcomes. For example, in networked systems, average frequency, duration and the number of customers impacted by service outages may be very low. However occasionally events occur that impact large numbers of customers and have long durations. Average statistics provide no measure of the risk of the significant events.

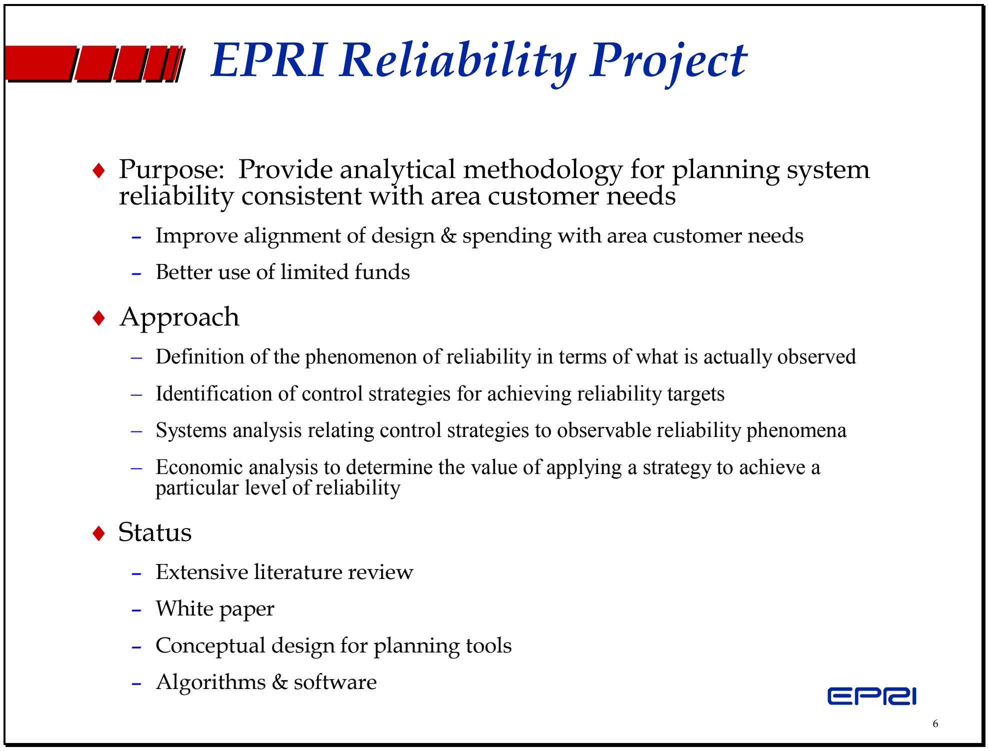


The challenge that utility planners face is to balance utility cost of service, customer costs of outages and the risk of events that impose high costs on both customers and the electric utility.



Utilities face a number of reliability challenges and opportunities.

- Utilities can enhance customer satisfaction by illuminating customers' service options and providing them with clear service choices.
- Companies can improve their design processes to better match specific customer needs by focusing on customers' diverse needs for reliability,.
- Utilities can better focus on customer needs and improve the design process for meeting those needs.   By so doing, utilities can achieve the goal of meeting customer needs at least cost.



The purpose of the EPRI project, Measuring and Valuing Reliability, is to provide tools to help companies improve the alignment of their investment and O&M spending with the needs of area customers for electric service. These tools will be designed to balance the three critical dimensions of the reliability problem: (1) the cost of different levels of electric service reliability, (2) the cost of customer outages, and (3) the risk of events that have high costs to both customers and the electric utility.

Motivation for Review: why is DS-RADS interesting?

- It implements fundamentally sound concepts developed by Billinton and others (see EPRI white paper)
- The DS-RADS implementation is a good choice for modeling and forecasting at least some aspects of reliability
- DS-RADS developers have done a lot of work to set up the software so that the inputs and outputs meet the needs of distribution planners

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This review was motivated by several considerations:

- First, EPRI has an opportunity to purchase DS-RADS for the benefit of EPRI funders. However, before making the purchase we have been asked to review the model and report back to our funders.
- Second, the model implements some concepts developed by Roy Billinton and others that have promise for improving utility investment and O&M decisions.
- Third, the algorithm used in DS-RADS allows for modeling and forecasting some common reliability statistics (average outage rates, duration, etc.).
- Fourth, DS-RADS may provide a good foundation for advancing the state-of-practice of reliability modeling. EPRI may be able to build productively on what has already been done at the University of Washington and Snohomish PUD.

Review Objective

- To extent feasible, determine:
  - problems addressed by the model
  - validity of approach and software implementation
- Determine potential for application in EPRI reliability R&D

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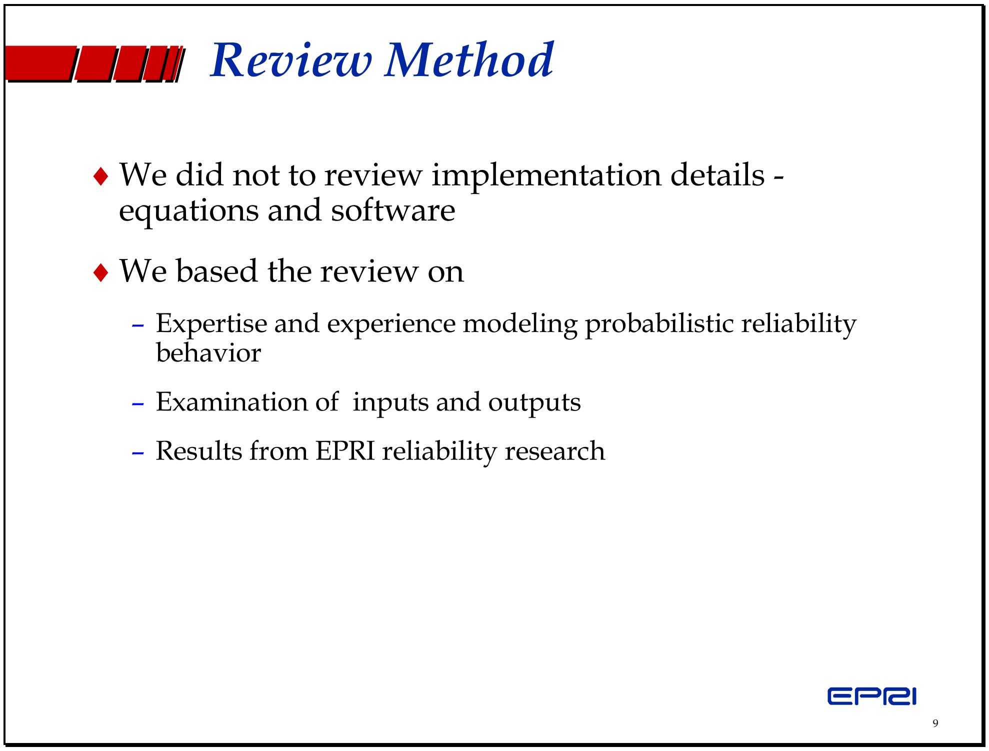
The objectives of this review were to determine (1) the problems addressed by the model, (2) the validity of the approach in terms of providing a practical tool for utility planning, (3) the potential for use in EPRI distribution reliability research.

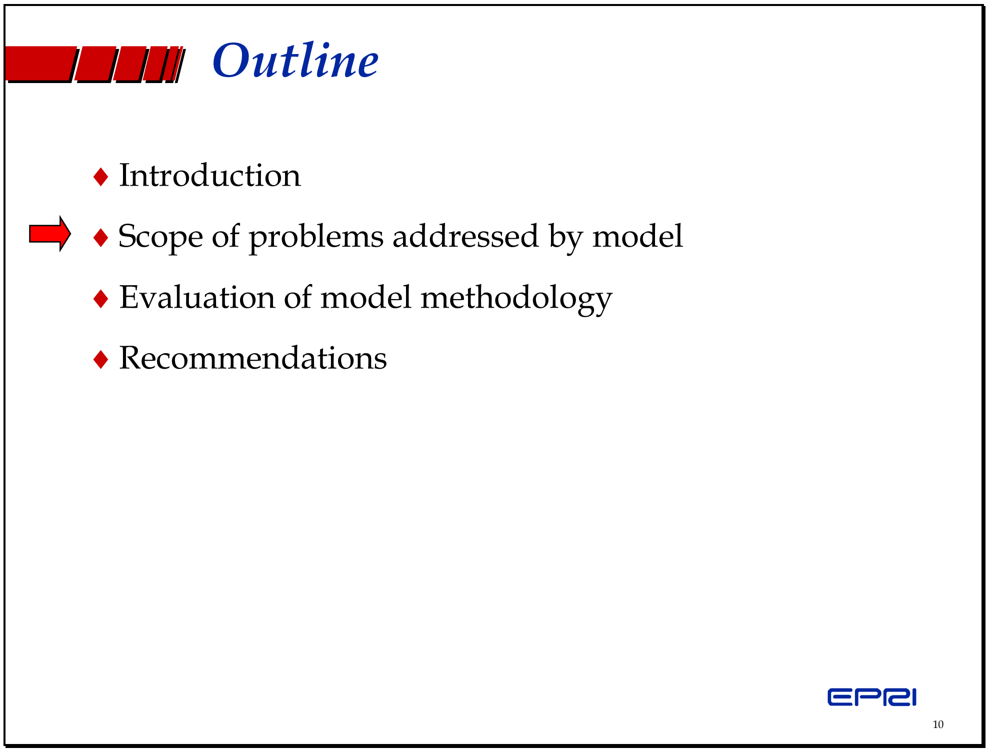


In this review we have had extensive conversations with Robert Fletcher, the DS-RADS project manager at Snohomish PUD. We have also attended a seminar on Reliability modeling sponsored by ABB. A presenter at the seminar was Richard Brown. Richard was one of the key developers of DS-RADS while at the University of Washington.

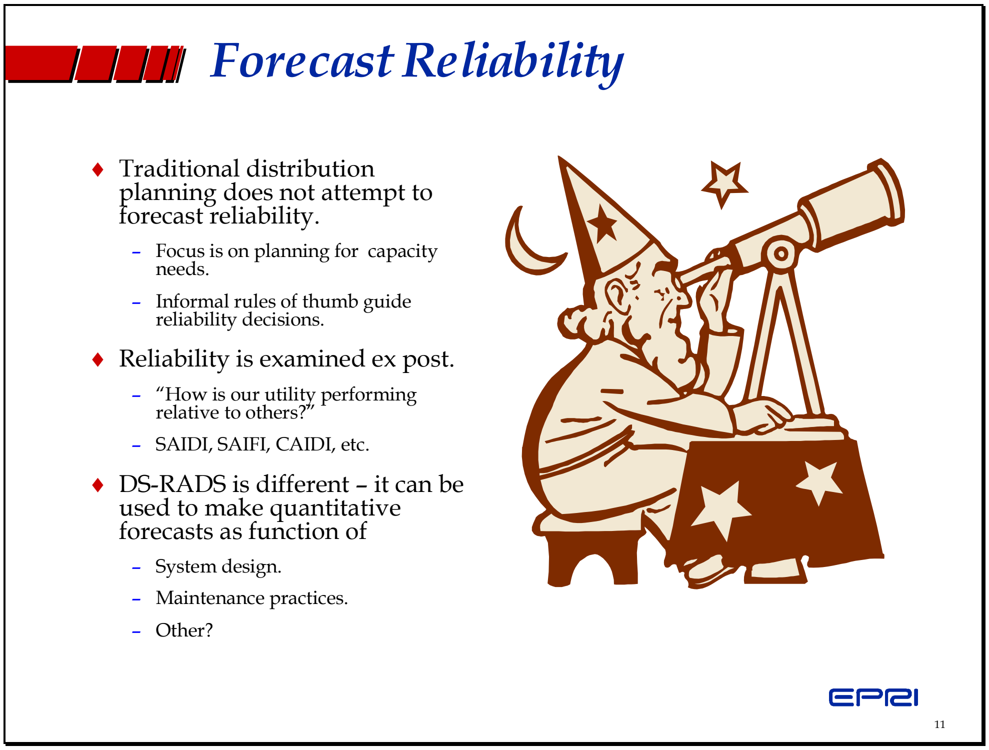
The EPRI reliability modeling team has experts in engineering-economic systems with specialization in optimization and Markov modeling. In addition the team has performed an extensive review of the reliability literature. This is documented in *Reliability of Electric Distribution Systems: EPRI White Paper*, TR-1000424, EPRI, October 2000, and in *Customer Need for Electric Power Reliability and Power Quality: EPRI White Paper*, TR-1000428, EPRI, October 2000.

We did not examine the source code or equations that were used in the implementation. These were not available to us.

SCOPE OF PROBLEMS ADDRESSED BY MODEL



In the next section we summarize the problems addressed by the model. This summary is based on materials provided to EPRI by Snohomish PUD. We also outline the reliability planning problems that appear not to be addressed by the model.



Traditional distribution planning is characterized both by its focus on meeting needs for capacity and its lack of focus on reliability. This does not mean that reliability is ignored. Historically, rules of thumb have guided system design for reliability. However there has been little quantitative analysis of the design practices.

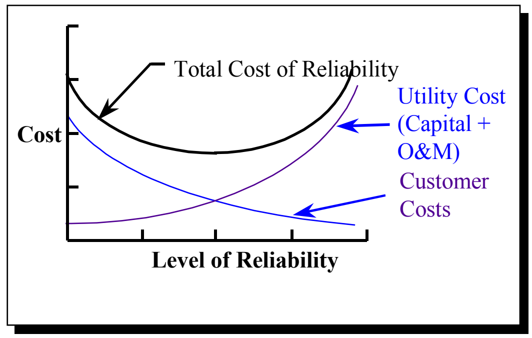
This approach has served customers well in the past – distribution systems have tended to be reliable especially for urban and residential customers. However with increasingly constrained budgets, the rules of thumb that have guided design and maintenance practices are, in many companies, not being applied.

Quantitative treatment of reliability has been ex post. Companies examine reliability outcomes using system average indices such as SAIDI. They use these indices to benchmark themselves against other utilities. This practice does not provide insight into how to change reliability or even if it makes economic sense to do so.

In contrast, DS-RADS is designed explicitly to provide quantitative forecasts of reliability.

Economics of Cost / Reliability Tradeoff

- Same story as forecasting – traditional focus is on capacity not cost versus reliability
- DS-RADS is different – it can be used to address the tradeoff



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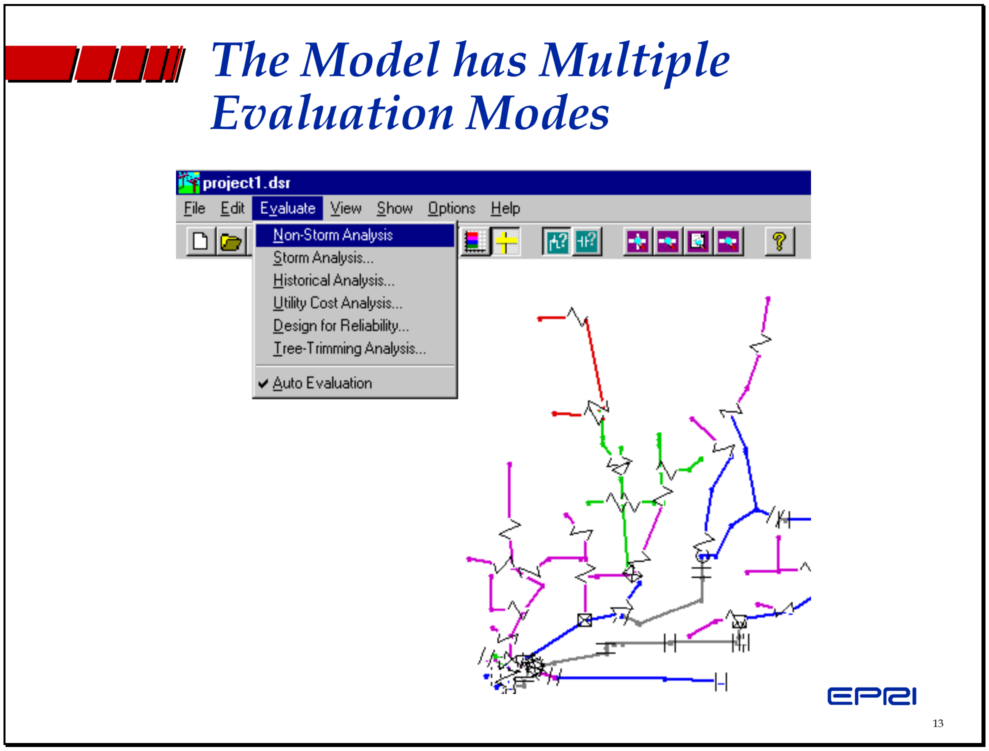
Because companies have not attempted to quantify the reliability effects of the design and maintenance practices, they obviously have not attempted to optimize the level of reliability – to sum up all costs, customer and utility, and minimize the total. Rule-of-thumb decision making has a tendency to be conservative. This is especially true where the some of the decision choices have uncertain and potentially bad outcomes. The electric power industry experience with fuel inventory planning is a case in point – see *Utility Fuel Inventory Model: Basic Concepts,* EA-4766-CCML, Revision 1, EPRI, March 1990.

Utility distribution planners understand firsthand that reliability is stochastic and traditional design practices reflect this fact. They understand the benefits of redundancy and overcapacity. The problem is they have never had the tools to address the reliability / cost tradeoff.

DS-RADS and models like DS-RADS may be used to address the tradeoff and have the potential to play and important role in improving design and maintenance decisions.



The figure shows one of the screens from the DS-RADS model. It illustrates that the model can be used in a number of evaluation modes. For example, the model can:

- Analyze storm and non-storm situations.
- Evaluate system design changes,
- Help develop tree trimming strategy,
- Forecast reliability for the system and for planning areas in the system.

The Model Addresses Reliability Economics

- Identify reliability improvement options (capital + O&M)
  - Improved equipment maintenance (RCM)
  - Improved system operations
  - Portable generation (i.e. >$1000/kW)
  - Loop primary - auto-transfer systems
  - UG systems - Reconductoring - new circuits - new substations
  - Improved distribution protection and sectionalizing
  - Improved vegetation management
- Determine the minimum cost to achieve SAIDI target limits

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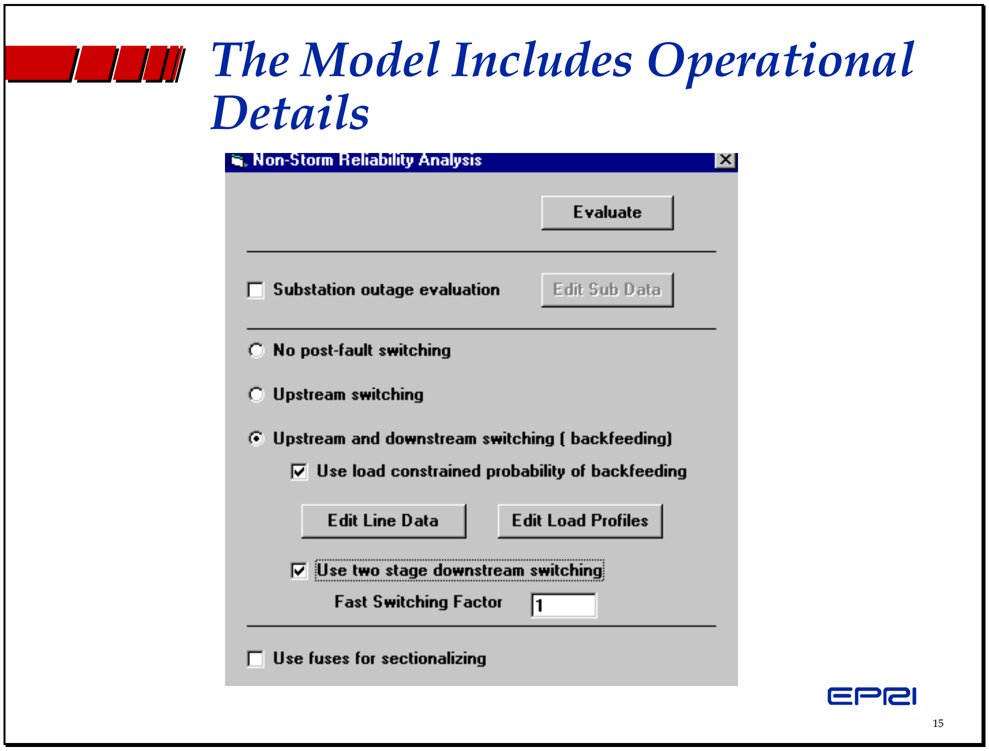
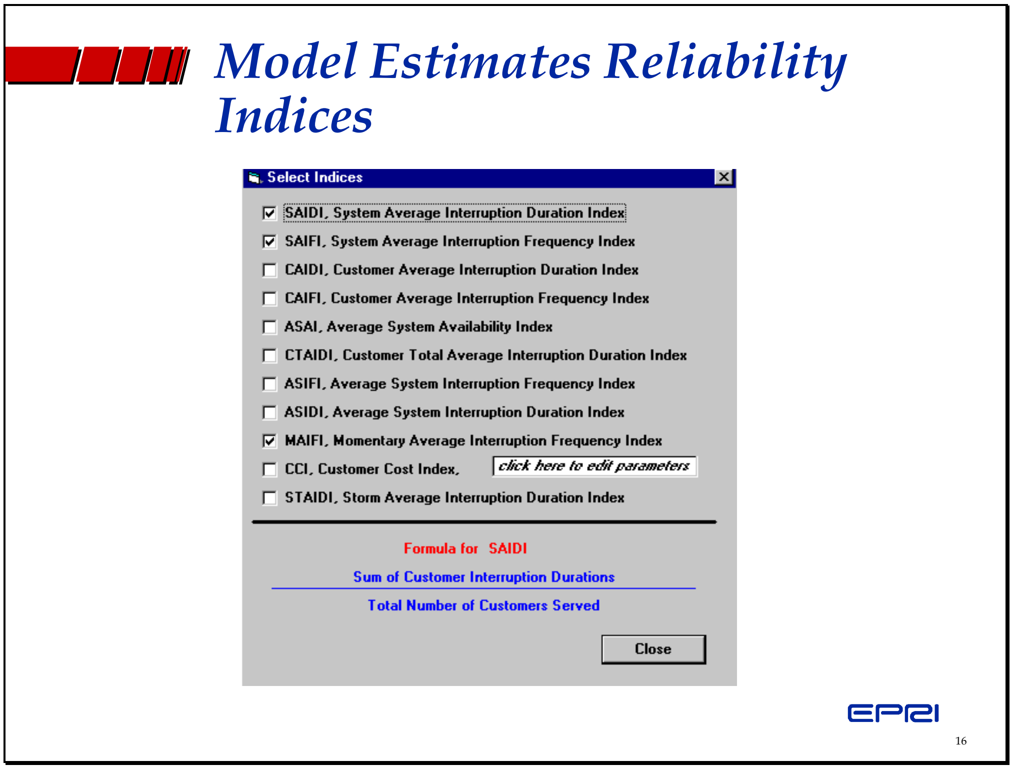
The main purpose of DS-RADS and models like DS-RADS should be to address reliability economics – to improve investment and O&M decision making.

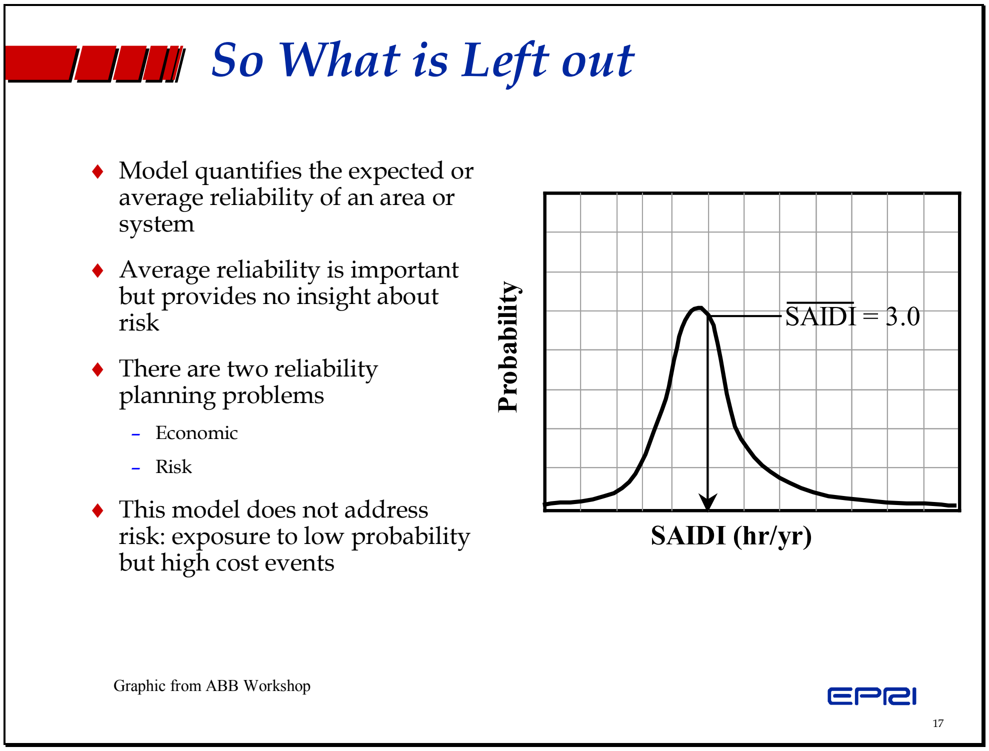
As indicated earlier, with increasingly constrained budgets, utilities face the challenge of being forced to meet customer needs with less money. Planning rules of thumb are inadequate for this new challenge.



This figure illustrates some of the operational aspects of the model.



In our opinion the key contribution of DS-RADS is its ability to quantify reliability indices. The figure shows the list of indices that the model is designed to produce.

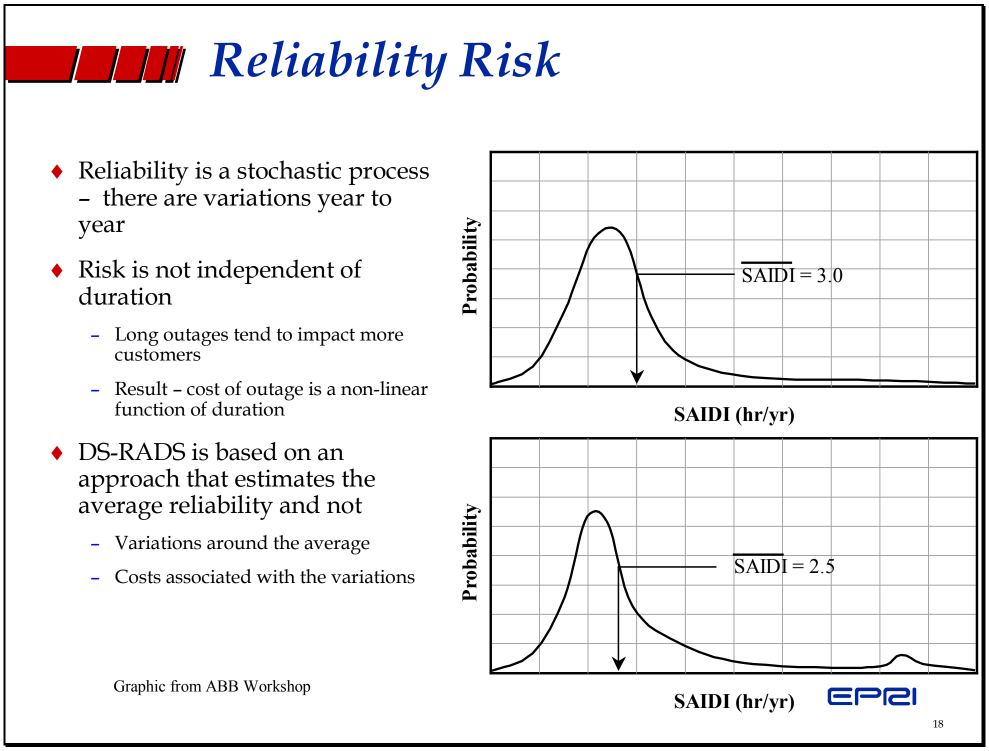


We have stated what the model does. The remaining question is what does it not do?

In our opinion, there are two reliability planning questions: (1) identifying investment and maintenance decisions that minimize total costs including customer and utility costs, and (2) understanding and managing the risks that may be associated with these decisions.

Typically when dealing with processes that have uncertain future cost implications, for example stochastic reliability, expected values are used in the analysis, both as inputs and as outputs. DS-RADS falls in this category. For example, SAIDI, CAIDI, SAIFI, etc., are all measures of system averages.

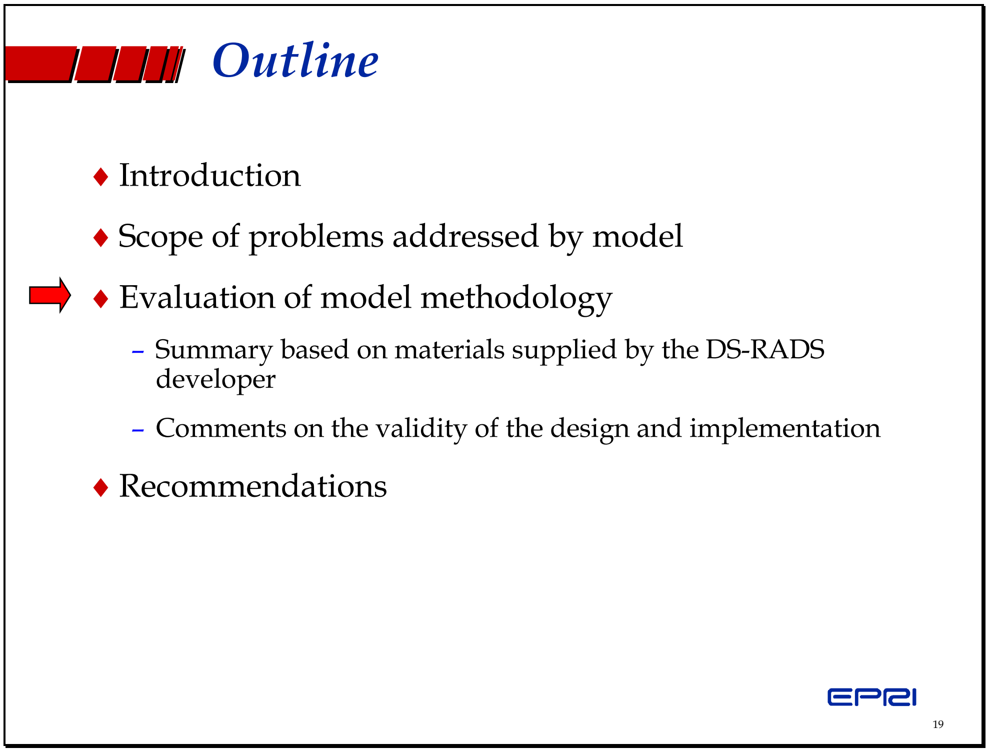
However in some problems, the "least cost" solutions derived from expected cost analysis can have the potential for unexpected "bad outcomes." It is important to know when such situations exist and how frequently they might occur. Models based primarily on providing expected values provide limited information about possible bad outcomes, especially if the outcomes have low probability of occurrence.



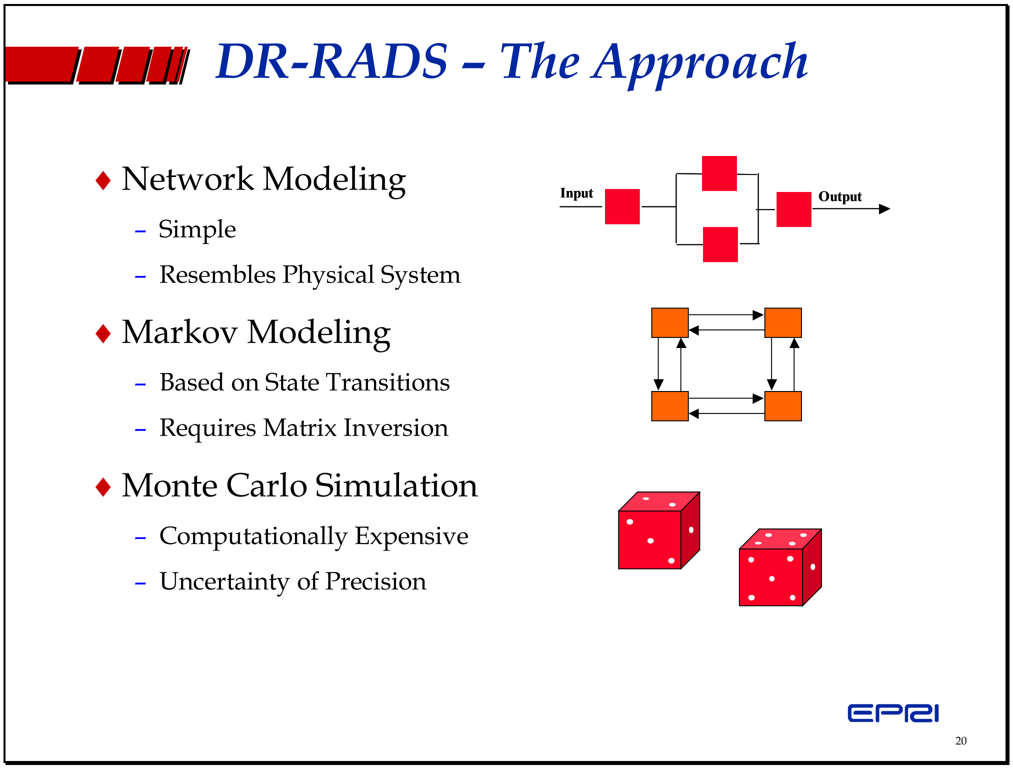
Reliability is stochastic in that it varies from year to year. This is illustrated in the graphs here. For some distribution designs and areas, the variation might be quite small – an hour or less. In others they may be a chance that an event will occur that will be ten or twenty times greater than the average.

One of the problems with the rare events is that, not only are they of long duration but they tend to impact a large numbers of customers. This makes disruption costs highly non-linear. An event may be ten times the duration of the average but the cost might be 100 or 1000 times greater than the average. Rare events can be very risky. The problems in Chicago and New York City in 1999 illustrate the importance of planning for risky events

EVALUATION OF MODEL METHODOLOGY



In this section we make some brief comments about the technical validity of DS-RADS.



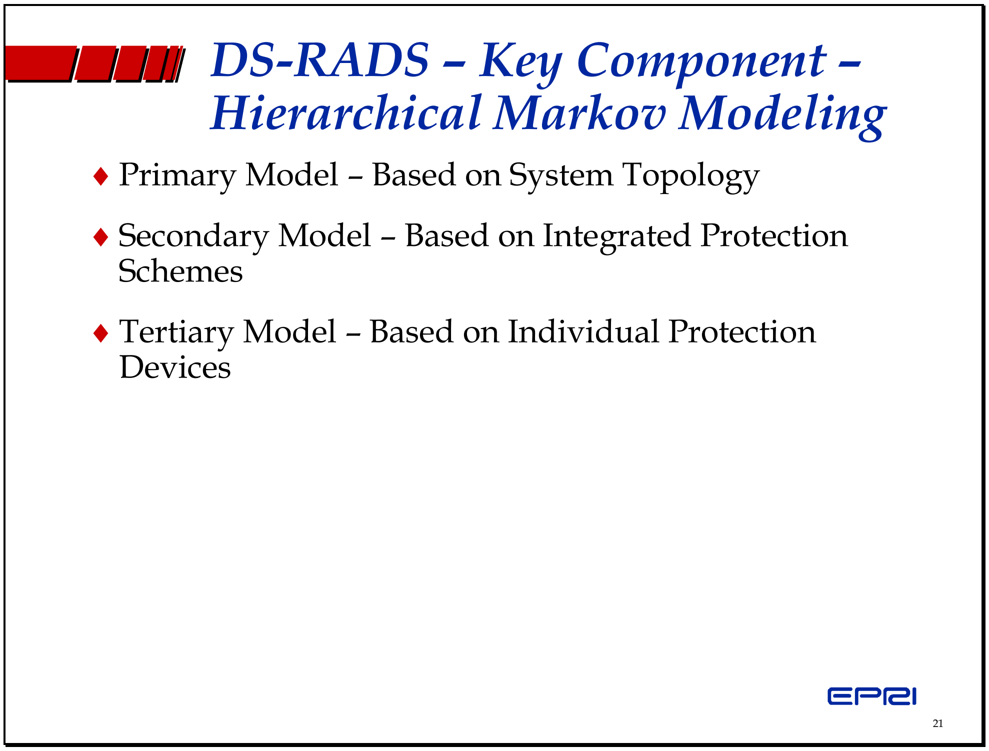
For electric systems, there are three approaches for modeling reliability. The simplest approach is to calculate the probability of failure based on the network representation of the components in the system and their likelihood of failure and average time to repair.

The second approach is to describe the system using state transitions and to derive analytically the likelihood of being in any given state assuming that the state has reached steady state.

The third approach is simulation. The problem with simulation is that it is computationally expensive and typically data intensive, especially for modeling systems with large numbers of components. For example, sensitivity analyses are very difficult with simulation. Moreover, simulation requires special statistical expertise to apply correctly and is often very hard to understand.

The probabilistic calculations in DS-RADS are based on the second approach – Markov Modeling.

Slide 21



DS-RADS applies the Markov method at three levels – (1) system topology, (2) integrated protection schemes, and (3) individual protection schemes.

While we have not had access to the source code, our speculation is that the primary model is used to derive the likelihood of an event that could cause a failure and the other two levels are used to estimate the average incidence rate and average duration of an outage given different combinations of topology conditions under which an outage could occur.

Slide 22

Algorithm Development

- Basic Analytical Method (Hierarchical Markov Model)
- Incorporate Fault Isolation and Restoration
- Incorporate Backup Protection
- Incorporate False Tripping and Stuck Breakers
- Compute All IEEE Std. 1366 Reliability Indices
- Probability of Load Constrained Successful Switching
- Upstream/ Downstream Second stage switching
- Substation Contingency Probability
- Compute and Evaluate Momentary interruptions
- Compute Reliability during storms (Monte Carlo)

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This is the list of algorithm development was provided by Snohomish PUD.

Algorithm Development

- Automated Design-for-Reliability (Genetic Algorithm, Integer Programming, fuzzy set algorithm)
- Optimal Tree Trimming Scheduling (Genetic Algorithm & Neural Network failure rate model)
- Objective Function used
  - Minimize Total Cost of Reliability (TCR)
  - Minimize Utility Cost for given Reliability
  - Maximize Reliability for a given utility Cost

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This is additional information giving high-level details of the algorithm development. It was provided by Snohomish PUD.

Is Markov Modeling Appropriate for Characterizing the Reliability of Distribution Systems?

- The answer is Yes!
- A Markov Model is a system of differential equations which , when solved, reveals the dynamics of a system .
- A Markov Model is typically used to find the probability of being in any given state after the system has reached steady state.
- A Markov Model can be used to characterize the behavior of a system that has not reached steady state

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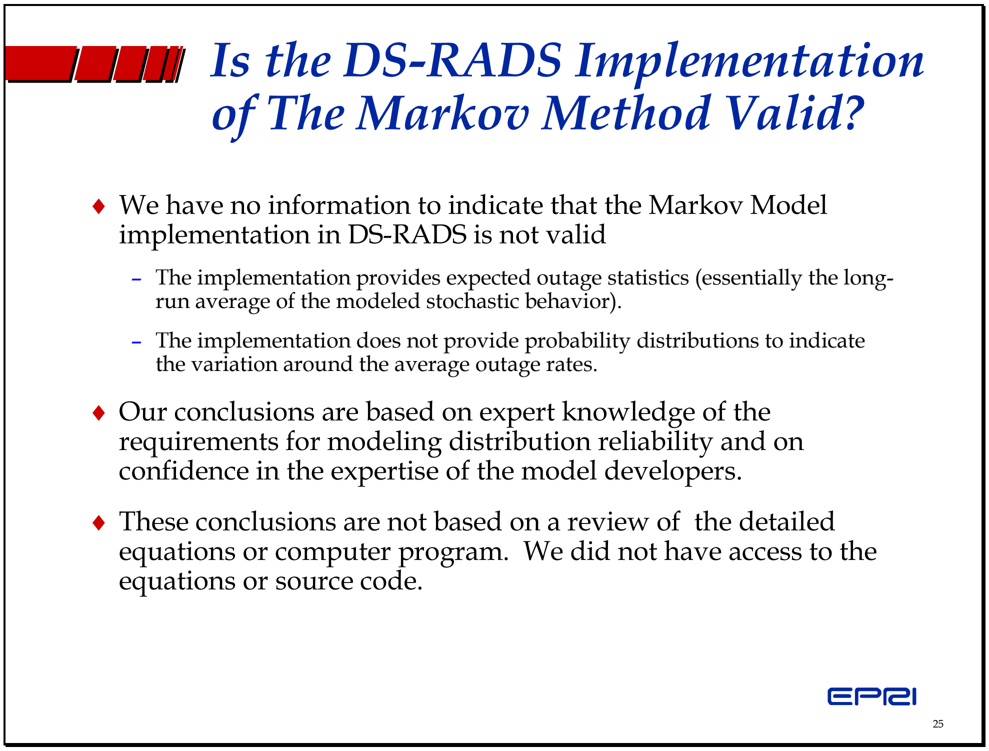
One fundamental question that we set out to answer is the one stated here: is Markov Modeling appropriate for characterizing the reliability of distribution systems?

The answer is "yes." We understood the answer to this question before we started the review. Our early discussions with Snohomish PUD also revealed that the DS-RADS implementation estimates the likelihood of being in any state after the system has reached steady state. This is the basic reliability calculation of the model.

We also know from other projects such as EPRI's Fuel Inventory Model and EPRI's Load Forecasting Model thatit is possible using the Markov approach to go beyond describing the expected values (probability of states given that the system has reached the steady state). Using advanced probabilistic modeling techniques, the approach can also be extended to address the question of risk or deviation from expected values. DS-RADS does not address this type of risk.



The other question that we were asked to address concerns the implementation. Our conclusion is that we have incomplete information to answer this question. We have seen no evidence either that the implementation is flawed or that it is not. We do believe, based on our review of the technical literature and attending the ABB workshop, that the developers are well qualified both in terms of (1) their understanding electric systems and (2) their understanding of the applied mathematics necessary to implement the Markov approach. Nevertheless, it is important to note that our conclusions are not based on a review of the detailed equations or source code as we did not have access to either. In addition, while we made a limited number of model runs, we have no way to verify if the calculations are exactly correct.

Is the DS-RADS Implementation of The Markov Method Valid?

- This review addresses the capability of the model to predict reliability statistics
- This review does cover other parts of the model including
  - economic analysis
  - storm analysis,
  - tree trimming
  - automated system design for reliability.
- We have three areas of reservation.
  - The ability of the model to capture common-mode failure phenomena
  - The model as implemented requires a lot of data.
  - The model is complex.

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This review is focused strictly on the capability of the model to predict reliability statistics. We did not review and cannot comment on other parts of the model that are designed to perform economic analysis and to identify optimal design and operating procedures. Other areas of the model include: storm analysis, the tree trimming algorithm, and automated system design for reliability.

We have three areas of reservation about the implementation.

It appears that the probabilities of failures of distribution components are treated as independent events in the model. To the extent that this is true, and to the extent that there is a potential for common-mode failure, the model could substantially understate failure rates, especially those of rare but devastating joint events .

The model as implemented requires a large amount of data. This includes detailed data that characterizes the many components of the physical system. These data are typically contained in load flow models and exported to DS-RADS. The model also requires failure statistics for distribution components – mean time-to-failure and mean time-to-repair.

The model is complex, at least when viewed from the strategic planning perspective. Our experience with stochastic problems outside of the electric distribution arena indicates that a model like DS-RADS can be greatly simplified and in the process made more useful for strategic planning. The right balance for strategic analysis would likely be less detail about averages and more information about risks.

DS-RADS – The Pros and Cons

- Method for forecasting annual average reliability statistics
- Forward looking to support system design, aging asset strategy and maintenance practices
- Can be used to do reliability /cost tradeoff analysis
- Includes operational details

- Does not address risk
- Data requirements are extensive
- Too detailed for strategic planning – level of detail obfuscates what is important
- May not capture the important impact of common-mode failures

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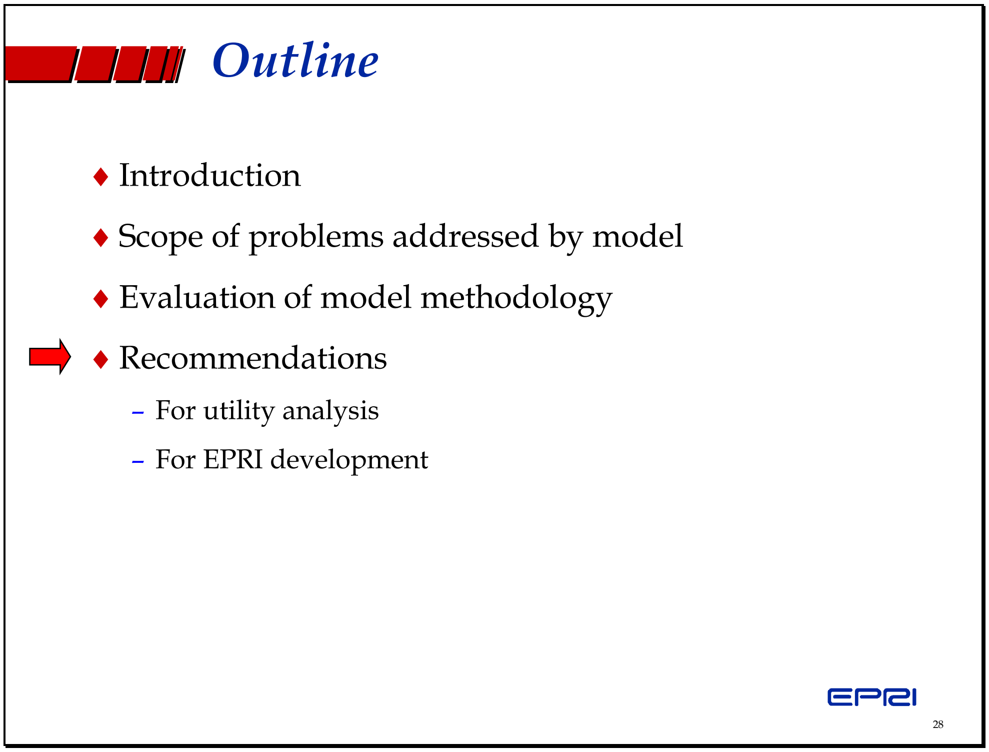
To summarize, DS-RADS has several useful features:

- It provides a method for forecasting reliability statistics.
- It should prove useful when planning system design, developing aging asset management strategies, and developing maintenance practices.
- It can be used in support of investment planning studies that include all costs, both customer and utility.

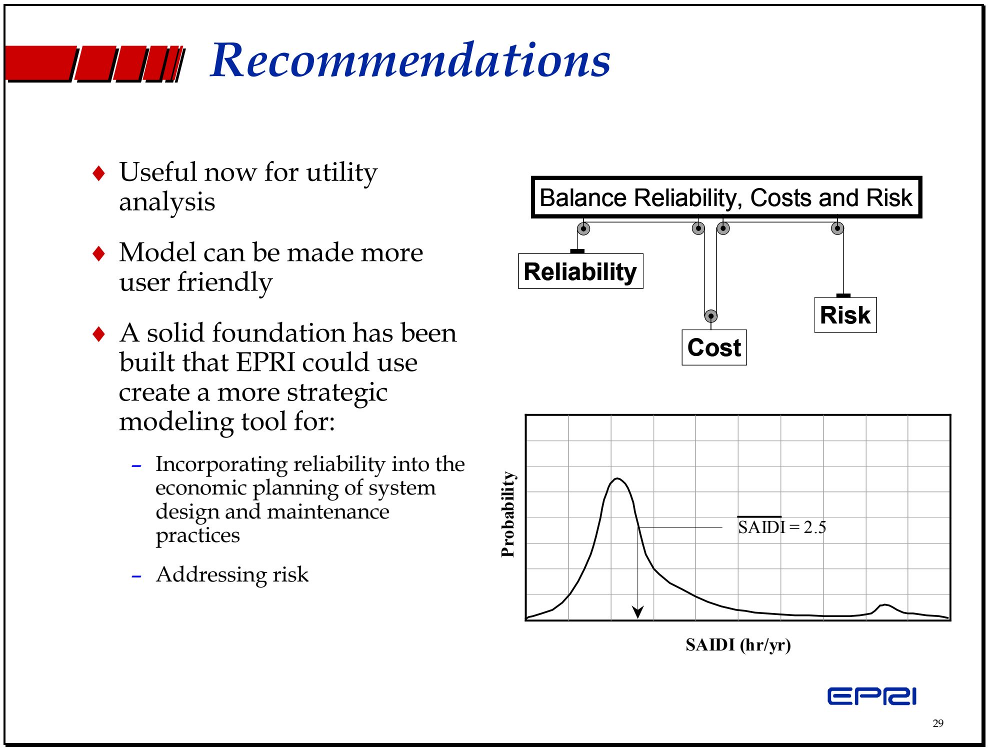
It appears that there are a number of useful tools that would complement or supplement DS-RADS:

- Tools focused on measuring and controlling risk – understanding the implications of small probability, high consequence events.
- Tools with less data burdensome requirements.
- Tools oriented at a more strategic analysis of system design alternatives.
- Tools that explicitly address the impact of common-mode failure phenomena.

RECOMMENDATIONS



This last section contains our recommendations.



DS-RADS should be considered by a utility that is looking for a tool to incorporate reliability explicitly into their analysis of investment and O&M planning decisions. Adopting the model will require significant effort to (1) assemble the necessary data and (2) train engineers to apply the model. The utility should keep in mind that the key reason for adopting DS-RADS should be to perform analysis that (1) includes both utility and customer costs, and (2) identifies better investment and operating strategies.

With significant effort, but with likely very high benefits, EPRI could make the model much easier to use. EPRI could reduce the model data requirements. In addition we are confident that we could improve the economic modeling and optimization.

The focus of the EPRI development would be on creating a higher level, more strategic tool to aid system design. That tool would address both of the reliability planning problems: (1) identifying solutions that minimize total costs, and (2) incorporating risk information into the decision process.

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