Customer Needs for Electric Power Reliability and Power Quality: EPRI White Paper

Technical Report

Customer Needs For Electric Power Reliability And Power Quality:
EPRI White Paper

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REPORT SUMMARY

There has been much research on the subject of customer needs for electric power, but the current state of knowledge is fragmented and incomplete. This report attempts to create some order out of the vast array of conflicting and confusing data and studies. It provides a systematic structure for characterizing and eventually updating our current state of knowledge.

Background

This report's original intent was to provide an exposition of what is known and not known about customer needs for electricity. However, without an integrating structure—especially in the reliability arena—this would only reshuffle the same information that has been available for years. Despite the paucity of data on customer needs, utilities have to make decisions that affect power reliability to customers. To make these decisions, utilities need tools for valuing reliability. Thus, this project attempted the somewhat ambitious task of “pulling it all together” in a quantitative *Reliability Valuation Framework*. The framework is a starting point for helping electric utilities integrate customer values into investment decisions that affect reliability.

Objectives

To answer the questions, “What do electricity customers value?” and “How do customers think about reliability and power quality?” and to provide guidance on the *process* of how a valuation can be performed—how to use customer survey data to put an economic value on reliability.

Approach

The project team conducted a thorough review of the literature and, based on the results, developed an analytical approach to quantifying customer outage costs.

Results

The literature review identified the following nine key factors for valuing reliability: (1) interruption duration, (2) time of day, (3) time of week of interruption, (4) time of year of interruption, (5) advance warning of interruption, (6) advance notice of duration of interruption, (7) type of customers interrupted, (8) frequency of interruptions, and (9) number of customers interrupted. The *Reliability Valuation Framework* provides a simple method for quantifying the impact of each factor on the value of reliability. It provides a starting place for quantifying all the aspects of electric power faced by customers.

The report is divided into six main sections and two appendices. The "Literature Review and Library" section summarizes the literature review and the contents of the physical and electronic versions of the Customer Needs Library. The "Methodologies for Assessing Outage Costs" section summarizes the many diverse survey methods and analytical approaches to quantifying customer outage costs. The "Quantitative Results—How Customers Value Electric Power

Reliability" section presents quantitative results of specific outage cost studies. The section also presents results of customer satisfaction surveys, studies of switching behavior, and results from priority service programs. The "Qualitative Results – How Customers Value Electric Power Quality" section presents the attributes of power quality and the other non-reliability aspects of electric power that customers value most highly. The "Reliability Valuation Framework" section presents a valuation framework and a placeholder analysis to demonstrate (1) how customers weigh different aspects of electric power reliability and (2) how a utility can use the framework to assess customer reliability needs. Finally, the "Conclusions: Moving beyond Traditional Reliability Analysis" section lays out some of the implications of the research.

EPRI Perspective

Electric power restructuring is changing the nature of electric distribution planning, engineering, and operations. Corporate management and regulators are increasing their scrutiny and control of distribution investment and maintenance decisions while requiring distribution system managers and engineers to plan, design, construct, and maintain electric distribution infrastructure that satisfies customer needs for reliability and power quality. The need both to reduce costs and to satisfy specific customer needs is creating an important distribution-planning problem. Investment and O&M decisions must be supported by explicit analysis of this tradeoff.

One perspective on distribution planning is that there are two problems—planning for capacity and planning for reliability. EPRI has worked on the capacity problem since 1992. EPRI’s *Dynamics Load Model* and *Area Investment Strategy Model* are state-of-the-art tools for forecasting load and developing least-cost investment strategies under uncertainty. However, the treatment of reliability by these tools is unsophisticated. Moreover, the capacity problem and the reliability problem have become more closely linked as restructuring proceeds.

In 1999, EPRI initiated two projects to help quantify the reliability cost tradeoff: “Assessing Customer Needs” and “Measuring and Valuing Reliability.” This report is the first result from the Customer Needs project. The research summarized here addresses two questions: (1) What do we know about customer needs and (2) what methodologies are available for assessing these needs?

Keywords

Customer needs, preferences, attitudes
Value of reliability
Customer surveys
Customer outage costs
Willingness-to-pay for electricity
Value-based reliability planning

ABSTRACT

The current state of knowledge on the subject of customer needs for electric power is fragmented and incomplete. This report attempts to create some order out of the vast array of conflicting and confusing data and studies. We provide a systematic structure for characterizing and quantifying the impact of each important aspect of electricity service on the value of reliability. The quantitative customer-focused approach allows us to measure customer needs directly rather than reflecting them indirectly with a set of ad hoc reliability measures more oriented towards system performance than towards customers. The new approach ties together traditional cost-benefit economic analysis and the modeling tools of engineering system analysis.

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INTRODUCTION

1.1 Overview

What do electricity customers value? How do customers think about reliability and power quality? There has been much research on the subject of customer needs for electric power, but the current state of knowledge is fragmented and incomplete. This report attempts to create some order out of the vast array of conflicting and confusing data and studies. We provide a systematic structure for characterizing and eventually updating our current state of knowledge.

This report documents a literature review and literature synthesis of customer needs for electricity. We report on methods for gathering and analyzing data about customer needs, and also summarize the data itself. We classify different types of customer needs and preferences, and lay out the various approaches that have been taken for segmenting the electricity customer population.

The original intent of the report was to provide an exposition of what is known and what is not known about customer needs for electricity. However, we soon realized that without an integrating structure -- especially in the reliability arena -- this would only reshuffle the same information that has been available for years. In spite of the paucity of data on customer needs, utilities have to make decisions that affect power reliability to customers. To make these decisions, utilities need tools for valuing reliability. Thus, we attempted the somewhat ambitious task of "pulling it all together" in a quantitative *Reliability Valuation Framework*. The framework is a starting point for helping electric utilities integrate customer values into investment decisions that affect reliability.

The objective of the Reliability Valuation Framework is not a "best and final" numerical valuation of reliability, applicable to all utilities, although we do provide some placeholder numbers. Rather, the objective is to provide guidance on the *process* of how a valuation can be performed -- how to use customer survey data to put an economic value on reliability. We also direct the reader to data sources that can provide preliminary numbers to support such a valuation in specific cases.

1.2 Summary of Literature Review

From the literature, we can make several observations with confidence. First, current studies consistently suggest that customers are more concerned about reliability than about any other attributes 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.

Thus, not surprisingly, the bulk of the literature on the subject of customer needs focuses on placing a value on reliable power. Typically, studies estimate the outage cost, which is the cost incurred, or equivalently, the loss of value due to a power interruption. We summarize the diverse methodologies that have been developed for assessing outage costs and the many outage-cost studies that have been performed.

Moreover, there is increasing knowledge about which aspects of an outage really matter. For example, outages that differ in characteristics like frequency, duration and warning can have very different impacts on customers. We summarize how different electricity customer segments weigh these cost.

There is some literature on waveform quality, but the results tend not to be quantitative. The focus is on defining power quality and describing the power conditioning equipment currently in use by commercial and industrial customers. The value to customers of utilities taking a more active part in providing better quality power in the future is examined only qualitatively for the most part.

Several detailed surveys have been performed to quantify the value of “environmentally friendly” power, in an effort to assess customers’ willingness-to-pay for such power. Other subsets of customers have preferences for environmentally friendly power, or for particular aspects of the whole electricity service package, such as the rate plan, the quality of customer service, the contract length, etc. But, in general, aspects of the electric service package not directly related to reliability have not been the subjects of much quantitative analysis.

1.3 Reliability Valuation Framework

The first five chapters of this report may be thought of as identifying and characterizing the important pieces of the customer needs puzzle. The Reliability Value Framework presented in Chapter 6 provides a structure for piecing together the most important pieces of the puzzle.

In particular, the literature review identified the following nine key factors for valuing reliability. The framework provides a simple method for quantifying the impact of each of these factors on the value of reliability.

- interruption duration
- time of day
- time of week of interruption
- time of year of interruption
- advance warning of interruption
- advance notice of duration of interruption
- type of customers interrupted

- frequency of interruptions
- number of customers interrupted

The Reliability Valuation Framework provides a starting place for individual utility analyses by providing a logical structure for quantifying all the aspects of the electric power faced by customers. It reflects our best estimate of the relative weights customers place on different attributes of electric power, given our current state of information.

But the framework is very much a “placeholder” analysis. It attempts to quantify the value of reliability *at an aggregate level* given the current state of the art. As new information is obtained, the framework can be easily updated. Most importantly, individual utility companies will want to replace part if not all of the numbers in this aggregate analysis with data specific to their customers.

In some cases, the best we could accomplish was to use the quantitative results from a single industry study, and sometimes we borrowed data from one of a series of ongoing EPRI case studies. When no study was available, we did not shy away from making judgments based on anecdotal evidence – in these cases, we indicate clearly when judgment was applied. In the many areas in which there is uncertainty about the value of reliability, we attempted to characterize the range of uncertainty.

We hope that the framework will be useful both for guiding future data collection and for helping electric power planners devise investment strategies that more accurately and efficiently match what their customers really want.

1.4 Overview of Report

The remainder of the report is divided into six sections and two Appendices. The main sections are:

Literature Review and Library

This section summarizes the literature review and the contents of the physical and electronic versions of the Customer Needs Library. Detailed listings of the reports as well as an annotated bibliography and a summary of Customer Needs Library references are provided in the Appendices.

Methodologies for Assessing Outage Costs

This section summarizes the many diverse survey methods and analytical approaches to quantifying customer outage costs.

Quantitative Results – How Customers Value Electric Power Reliability

This section presents quantitative results of specific outage cost studies. It shows how customers trade-off the different attributes of outages and how different customer segmentations affect the results. The section also presents the results of customer satisfaction surveys, studies of switching behavior and results from priority service programs.

Qualitative Results – How Customers Value Electric Power Quality

This section presents the attributes of power quality and the other non-reliability aspects of electric power that customers value most highly.

Reliability Valuation Framework

This section presents a reliability valuation framework and a placeholder analysis to demonstrate (1) how customers weigh different aspects of electric power reliability, and (2) how a utility can use the framework to assess customer reliability needs.

Conclusions: Moving Beyond Traditional Analysis

This section summarizes how the new reliability valuation framework can be used to support a much more customer-focused approach to reliability planning.

2
LITERATURE REVIEW AND LIBRARY

2.1 Objectives

The first task in the Customer Needs project was a Literature Search and Analysis. The task had four objectives:

1. Compile a library of reports and other documents that have been identified and reviewed and found to be useful for the study of customer needs. This is a physical library, located at EPRI, and available to EPRI members and staff for future reference.
2. Summarize the large body of data that is relevant to the customer needs analysis. Such data includes market size, customer segments, willingness-to-pay values, results from customer surveys and different types of analysis methods.
3. Write an annotated bibliography that describes the articles and reports that were reviewed.
4. Document in a “State of the Practice” report (this report) what is known and what is not known about customer needs. This description is intended to be dynamic in the sense that it can be updated over time as more is learned and as the state of the practice advances.

The literature search began with the identification of an initial set of keywords or ideas that defined the scope of the research:

- Customer needs, preferences, attitudes: data and speculations
- Existing models--what is already represented in mathematical form
- Willingness-to-pay data and analysis
- Revealed preference data and analysis
- Existing surveys, including the design of the survey instrument
- Differentiated pricing, service, or quality
- Customer cost of outages
- Dimensions of quality perceived by customers
- Customer segmentation and the consequences of selecting any segmentation scheme
- Market size ($, MW, MWh)
- Price sensitivity or elasticity of demand for electricity

- Consequences of deregulation with respect to customer choice-- effects this has had on consumer choice--measurements and speculations

These key words led to a set of references, which in turn led to others. The Customer Needs Library was built by selecting the references that were meaningful to the study of electricity customer needs.

2.2 Customer Needs Library

The Customer Needs Library consists of reports and journal articles, and one book. Some reports and journal articles were reviewed and deemed irrelevant. All of the documents in the library have also been summarized. The Appendices contain a listing of the documents as well as a compilation of the summaries. At the time of this writing, here is the current inventory of the books, reports and journal articles that have been reviewed, summarized and placed in the library:

Table 2-1
Customer Needs Library contents

	Reviewed	In Library	Summarized
Reports	46	31	31
Journal Articles	29	24	24
Books	1	1	1

3

METHODOLOGIES FOR ASSESSING OUTAGE COSTS

3.1 Range of Methodologies

Various methodologies exist for gathering data on customer outage costs. Most methods do not apply equally well to residential and commercial/industrial customers, so a study that samples all of these customers often utilizes multiple methods. The most common combination of methods is to use a direct cost survey for commercial and industrial customers, and a contingent-valuation or contingent-ranking survey for residential customers. Each of these methods is described in some detail in this section.

Some studies simply obtain a single aggregate outage cost, and ignore many of the factors such as duration and timing that affect outage costs. Others attempt to construct a table of or formula for outage costs that explains the influences of various factors. The larger studies tend to use the same methodology, with more questions, to obtain the necessary data points. Other studies assess the cost of say, a one hour outage at 10:00 am on a summer Friday morning, and then use aggregate customer load data to scale costs to other scenarios. Table 3-1 summarizes the scope of some key studies.

We classify outage cost methodologies into two types: survey-based methods and analytical methods. The specific types of surveys and analytical methods used often depend on whether the customer is residential or commercial/industrial. Residential surveys tend to be based on preference questions aimed at determining which aspects of outages people dislike the most, while commercial and industrial surveys tend to rely on a direct economic calculation of outage costs.

Table 3-1
Scope of Key Customer Outage Cost Studies

			Customers			Outage Parameters						
Identifiers	**Year**	**Method**	**Res**	**Ind**	**Com**	**dur**	**freq**	**time**	**day**	**mo.**	**notice**	**segm**
IEEE	1972	survey		X	X	X						X
Jackson, Salvage	1974	survey		X		X	X					
Telson	1975	proxy		X								
Krohm: NTIS	1978	blackout			X							
Munasinghe	1980	proxy	X	X	X	X						
Ontaraio Hydro	1980	survey	X	X	X		X					X
Yabroff	1981	proxy	X	X	X							
Bental, Ravid	1982	proxy		X								
Billinton, Wacker, Wojczynski	1982	survey	X	X	X	X	X	X	X	X	X	X
Bental, Ravid	1982	proxy		X								
Gilmer, Mack	1983	proxy	X									
Sanghvi	1983	proxy	X						X	X		
Meta Systems, et. al.	1986	proxy	X									
Meta Systems, et. Al.	1986	survey	X					X		X		
Keane, McDonald, Woo	1989	behavior	X									
Doane, Hartman, Woo	1989	survey	X	X		X		X		X		
Goett, McFadden, Woo	1989	survey	X					X		X		
Woo, Train	1989	survey			X							
Bonneville, Hagler Bailly	1990	survey	X	X	X	X		X				X
Southeast, Hagler Bailly	1990	survey	X	X	X	X						X
NSERC	1991	survey	X									
Hamm, Wood; Union Elec.	1992	survey		X	X	X	X				X	X
Hamm, Wood; Com. Edison	1992	survey		X	X	X	X				X	X
Duke, EPRI	1996	survey	X	X	X	X		X		X	X	

Below are the most common types of methods for each class of customer. Each method is than discussed.

Survey Methods

- Residential Customers
- Contingent valuation methods
- Contingent ranking methods
- Indirect cost approaches
- Commercial and Industrial Customers
- Direct cost approaches

Analytic Methods

- Residential Customers
- Wage rate proxy
- Value of service in the home
- Commercial and Industrial Customers
- Case studies of blackouts
- Backup generator proxy
- Output to electricity consumption ratio
- GNP relation to energy use

3.2 Survey Methods

Surveys encode customers' preferences for different levels of reliability and other aspects of electric power. The main drawback to survey methods is that, without careful survey design and implementation, actual behavior in the marketplace is often inconsistent with stated intentions. Also, answers to survey questions tend to be quite sensitive to the specific wording, which does not inspire confidence in the results and is surely one of the reasons that results can be substantially different across surveys.

Willingness to Pay vs. Willingness to Accept

Surveys of residential customers often use either Willingness to pay (WTP) or Willingness to accept (WTA) as their definition of outage cost. It is important to understand that these can have quite different implications.

Willingness to pay is defined as the maximum amount of money a customer is willing to pay to avoid an interruption. Willingness to pay can be sub-categorized as:

- Willingness to pay for backup service on an optional, case-by-case basis
- Willingness to pay for backup service on an unconditional basis
- Willingness to pay for improved reliability

Willingness to accept is defined as the minimum amount of money a customer is willing to accept as compensation for an interruption.

Survey-based willingness-to-pay and willingness-to-accept values tend to differ by nearly a factor of two. Neither measure is very well regarded as an accurate way to obtain direct assessments from customers. In fact, survey designers in composing survey questions and interpreting responses apply a substantial amount of judgment. For example, in two surveys

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1 Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs; EPRI EL-6791

performed by the same researchers, WTP values of $0 were given by 25% to 40% of the respondents. The analysts assumed that some of these were valid and some were due to the respondent being unwilling to come up with a realistic estimate. Since the portion of valid responses was unknown, the analysts calculated all aggregate results once with all of the data and once with the $0 respondents removed from the sample. This provided upper and lower bounds for the actual average outage costs.

Alternative types of surveys

There are a number of different survey approaches in the literature. Below we summarize the most prominent survey types. The pros and cons of each method are included in each table.

Table 3-2
Summary of Alternative Types of Surveys

Contingent valuation methods[2] [3]	
Description	Survey-based assessment of WTP to avoid an interruption or WTA compensation for an interruption
Customers	Residential
Pros	Allows assessment of residential customers
Cons	General survey weaknesses, plus customers are notoriously poor at providing numerical estimates of their actual willingness to pay when faced with real choices
Contingent ranking methods[4]	
Description	Customer value functions are inferred from customer's choice or ranking of a series of outage options, each accompanied by a rate increase or decrease. WTP and WTA can be inferred from a technique called conjoint analysis applied to these rankings.
Customers	Residential
Pros	Very accurate results due to close duplication of actual customer choice procedure
Cons	Can involve large amounts of data if many attributes are considered

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[2] *Assessment of Electric Service Reliability Worth*; Billinton, Tollefson, Wacker

[3] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

[4] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

Direct cost approaches[5]	
Description	Respondent evaluates costs associated with particular outage scenarios
Customers	Commercial/Industrial (sometimes used with residential, but with limited success)
Pros	Provides consistent results where outage costs are quantifiable
Cons	Does not apply well to residential sector, where impacts are less tangible, or to any situation in which monetary losses are not directly identifiable
Indirect cost approaches[6]	
Description	Evaluation of costs by identifying adequate substitutes for reliable power, such as insurance policies to compensate for interruption effects
Customers	Mostly residential
Pros	Addresses preferences rather than straight monetary effects – better than direct cost approach when intangible values are present
Cons	Can be very unreliable. Error is introduced by non-monetary features of the substitutes – for example, payment terms and conditions of insurance policies. Typically, a large number of aggregate assumptions need to be made.

Contingent ranking methods are generally regarded as the state-of-the-art approach because they present the customer with the same types of choices as in real life. Additionally, the customer does not have to provide numerical judgments – the approach only requires the customer to indicate simple preferences between two alternatives at a time. A technique called conjoint analysis converts these rankings into a quantitative customer value function.

Note that in most direct cost approaches, particular attention is paid to what constitutes an outage-related cost and what does not. The following categories of costs are generally covered:

- lost product due to spoilage
- damaged equipment
- lost services
- wages paid to employees unable to work, or overtime paid to make up for lost services

After all of these quantities have been assessed, an effort is made to determine which losses could be made up at another time, and subtracting the appropriate dollar amount from the outage cost.

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[5] *Assessment of Electric Service Reliability Worth*; Billinton, Tollefson, Wacker

[6] *Assessment of Electric Service Reliability Worth*; Billinton, Tollefson, Wacker

3.3 Analytical Methods

In the context of outage cost estimation, analytical methods are those that rely on theoretical models fit to aggregate data rather than direct customer assessment. Here are some of the most common analytical methods.

Table 3-3
Summary of Analytical Methods

Wage rate proxy[7] [8]	
Description	Equates lost leisure time due to outages with wages earned
Customers	Residential
Pros	Simple, eliminates problems inherent in survey methods, some research suggests wage rate is a valid proxy
Cons	Does not address time-of-day differences, likely to overestimate outage costs, does not reflect actual customers' needs
Case studies of blackouts[9] [10]	
Description	Measure the direct and indirect economic costs of a large-scale blackout, including costs related to looting, rioting, and arson
Customers	All
Pros	Provides a concrete basis for assessment
Cons	Information is only relevant to the incident, and not easily generalized
Backup generator proxy[11]	
Description	Assumes customers will purchase backup generators until the cost meets the marginal cost of unsupplied power
Customers	Commercial/Industrial
Pros	
Cons	Provide only an upper bound on outage costs for customers who do not purchase backup generation, relies on many assumptions: average generator cost, depreciation rates, generator lifetime, fuel costs, interruption hours per year

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[7] *Assessment of Electric Service Reliability Worth*; Billinton, Tollefson, Wacker
[8] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510
[9] *Assessment of Electric Service Reliability Worth*; Billinton, Tollefson, Wacker
[10] Costs of Interruptions of Electrical Service in the Commercial Sector; Krohm; NTIS.
[11] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

Output to Electricity Consumption proxy[12]	
Description	Output per kWh of electricity consumed provides an upper bound on outage costs
Customers	Commercial/Industrial
Pros	
Cons	Assumes no substitution for electricity with other factors of production, ignores damaged equipment costs, assumes production cannot be made up after power resumes
The Value of Production in the Home[13]	
Description	Values residential outage costs by the market value of services lost in the event of a power outage
Customers	Residential
Pros	
Cons	Assessing market value of home services requires many assumptions, assumes services lost due to outage cannot easily be made up at another time
GNP relation to electricity use[14]	
Description	Relate use of electricity to Gross National Product (GNP)
Customers	Commercial/Industrial
Pros	Data is publicly available
Cons	Assessments are only available on a large geo-political scale

3.4 Comparison of Methods

Analytical methods typically require many assumptions and are highly aggregate in nature. Thus, they are best used for general insight, not to provide inputs for making specific investment decisions.

For survey methods, the state-of-the-art method is contingent valuation. Contingent valuation has been used successfully in many private industries for years and is the “gold standard” of customer preference analysis techniques. However, contingent valuation is generally much more expensive and requires more sophisticated analysis than the other methods. Of the other methods, WTP/WTA is probably the next most reliable approach, but is best used to get relative estimates rather than highly accurate reliability values.

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[12] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

[13] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

[14] *Assessment of Electric Service Reliability Worth*; Billinton, Tollefson, Wacker

4

QUANTITATIVE RESULTS – HOW CUSTOMERS VALUE RELIABILITY

4.1 Ranges of Results

Although many outage cost studies have been performed, it is often difficult to determine whether the results are consistent, or to draw conclusions about customers' willingness to pay to avoid power outages. Some of the reasons for these difficulties are the wide range of results, the different forms of the results and the different underlying assumptions about outage parameters used in each study.

The range of results from a single study often span 2-3 orders of magnitude, and aggregate results among studies come in wide ranges as well. Consider the following compilation of twelve outage cost studies:

Table 4-1
Residential Outage Costs for a One Hour Interruption: Aggregate results from different studies[15]

Study	Method	Outage Costs ($/kWh unserved)	Special Conditions
Gilmer and Mack (1983)	Proxy – market value	.66 to 2.25	upper bound
Meta Systems et.al. (1986)	Proxy – backup power	15.00	upper bound
Sanghvi (1983a)	Proxy – backup power	1.81	upper bound
Meta Systems et.al. (1986)	Consumer Surplus	.22	
Sanghvi (1983a)	Consumer Surplus	.02 to .28	summer weekday
Billinton, Wacker, Wojczynski (1982)	Direct Cost	.47 to 1.54	
Doane, Hartman, and Woo (1989a)	Direct Cost	14.61 4.84	winter 5 PM summer 2 PM
Doane, Hartman, and Woo (1989b)	Direct Cost	12.23 4.01	winter 5 PM summer 2 PM

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[15] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

Doane, Hartman, and Woo (1989b)	Contingent Ranking Method	8.24	
Goett, McFadden, and Woo (1989)	Contingent Ranking Method	1.91	winter 10 AM
Meta Systems et. al. (1986)	Contingent Valuation Method	3.93 2.19	winter 5 PM summer 2 PM
Ontario Hydro	Contingent Valuation Method	.09 to .18	daily interruptions

Some conversions were made using average load assumptions in order to get results from different studies into the same form ($/kWh unserved). See reference for details.

Note in particular the difference between the highest direct estimate of $14.61/kWh and the lowest of $0.09/kWh.

Different definitions

Outage costs come in myriad forms. On the surface, outage cost units may seem to have fairly simple conversions to one another, but often some assumptions need to be made to make a conversion. This makes it difficult to compare outage cost results from different studies. For example, consider the following very different common forms of outage costs:

- $/kWh unserved
- $/peak kW
- $ for interruption of specified duration and time of occurrence
- $/kW for interruption of specified duration and time of occurrence
- Formula for outage costs with coefficients aggregated by industry
- Fixed component + variable component, variable component depends on outage parameters

Outage Cost Distribution

An interesting empirical result is that distributions of non-zero outage costs tend to be log-normal, and anywhere from 5% to 30% of customers state an outage cost of $0. This holds for the three major customer segments -- commercial, industrial, and residential customers – as shown in the two charts below.[16] [17] Here is the outage cost distribution for commercial/industrial customers:

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[16] *Interruption Cost Methodology and Results – A Canadian Commercial and Small Industry Survey*; Billinton, Wacker, Wojczynski

[17] *Interruption Costs, Customer Satisfaction, and Expectations for Service Reliability*; Sullivan, Suddeth, Vardell, Vojdani

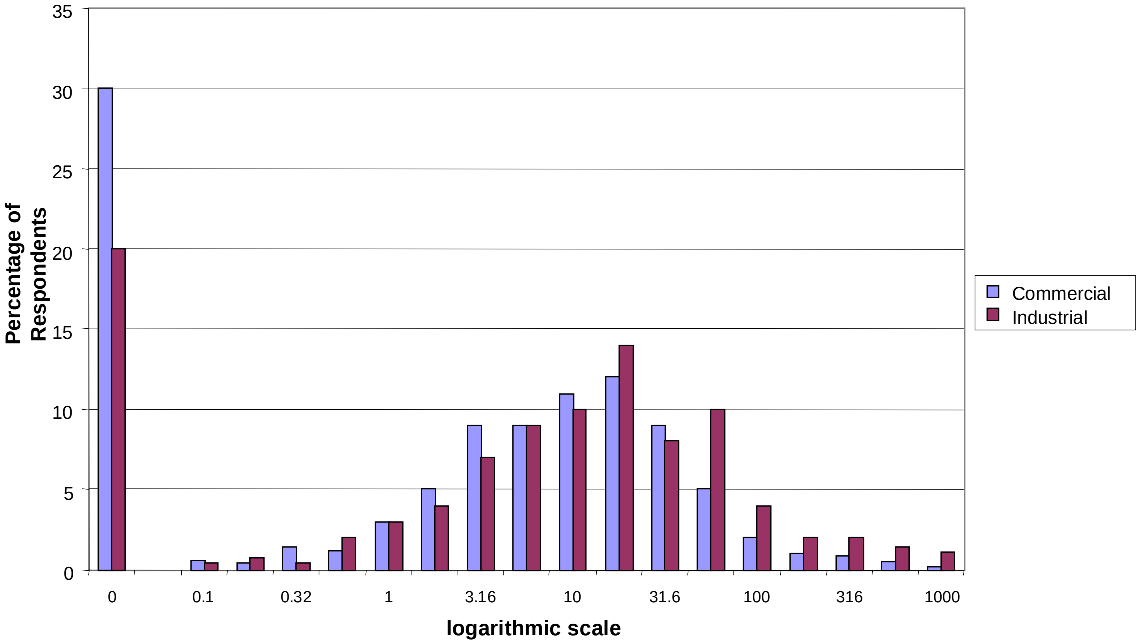

Figure 4-1
Distribution of One Hour Interruption Costs

Here is the outage cost distribution for residential customers.

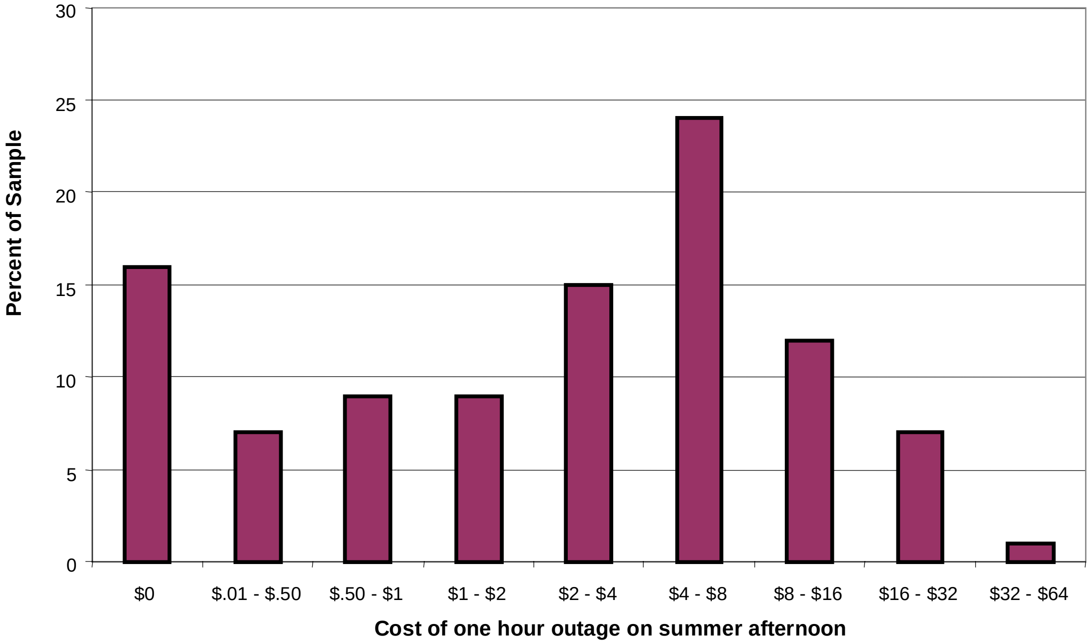

Figure 4-2
Residential Customer Outage Costs

4.2 Effects of Different Outage Characteristics

Outage costs can vary dramatically, depending on the characteristics of the outage being measured. For example, outage costs tend to vary with time of occurrence and duration of the outage.

Some outage cost studies just measure the effect of a single outage, either ignoring each parameter of the outage or choosing an arbitrary value for some of the parameters. Other outage cost studies explicitly address different outage cost characteristics and measure their individual effects. The interruption parameters most often analyzed by various studies are:

- interruption duration
- time of day/week/year of interruption
- amount of advance notice before interruption
- notice of duration after interruption starts
- frequency of interruptions

Unfortunately, few studies address all parameters in the same way so that the results may represent the costs associated with quite different outage scenarios. Nevertheless, we were able to separate out the differing effects of some of these parameters. Below, we summarize some of the impacts of advance notice, duration and timing because these are the outage characteristics on which most empirical data exists. In Section 6, we quantify the impacts of other less well-studied parameters as well.

Sensitivity to Advance Notice

Most studies indicate that advance notice of an interruption allows commercial and industrial customers to make arrangements that substantially reduce outage costs. The amount of notice required varies by firm, with most customers requiring between 30 minutes and 8 hours.

The average reduction in interruption costs from a one-hour advance notice, according to one survey[18], is

- 35% for large commercial customers
- 43% for large industrial customers

A different survey shows consistent findings, with 60% of commercial and 75% of industrial customers stating that advance warning would allow cost saving arrangements. Moreover, most customers require 1 to 4 hours to reap any warning benefit, but 3% of the customers require more than 48 hours[19] to reap any benefit.

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[18] *Interruption Costs, Customer Satisfaction, and Expectations for Service Reliability*; Sullivan, Suddeth, Vardell, Vojdani

[19] *Interruption Cost Methodology and Results – A Canadian Commercial and Small Industry Survey*; Billinton, Wacker, Wojczynski

Sensitivity to Duration of Outage

Since different firms have a wide range of critical outage durations, the effect of duration on outage cost is difficult to measure in the aggregate. Clearly a longer duration outage is more disruptive than a shorter duration outage for all customers, but there is quite a bit of variation when the figures are viewed as a cost per hour of interruption, rather than as a cost per interruption.

- Industrial customer outage costs per hour tend to decrease with duration up to 8 hours (from a comparison of 3 different surveys)[20]
- Outage costs per hour for commercial customers may increase or decrease with duration over an eight hour period[21] [22]
- Industrial customers prefer less frequent, longer duration outages
- Commercial and residential customers, on average, slightly prefer more frequent, shorter duration outages, on average
- Critical outage duration for commercial buildings ranges from a single cycle to 12 hours (see the figure below).

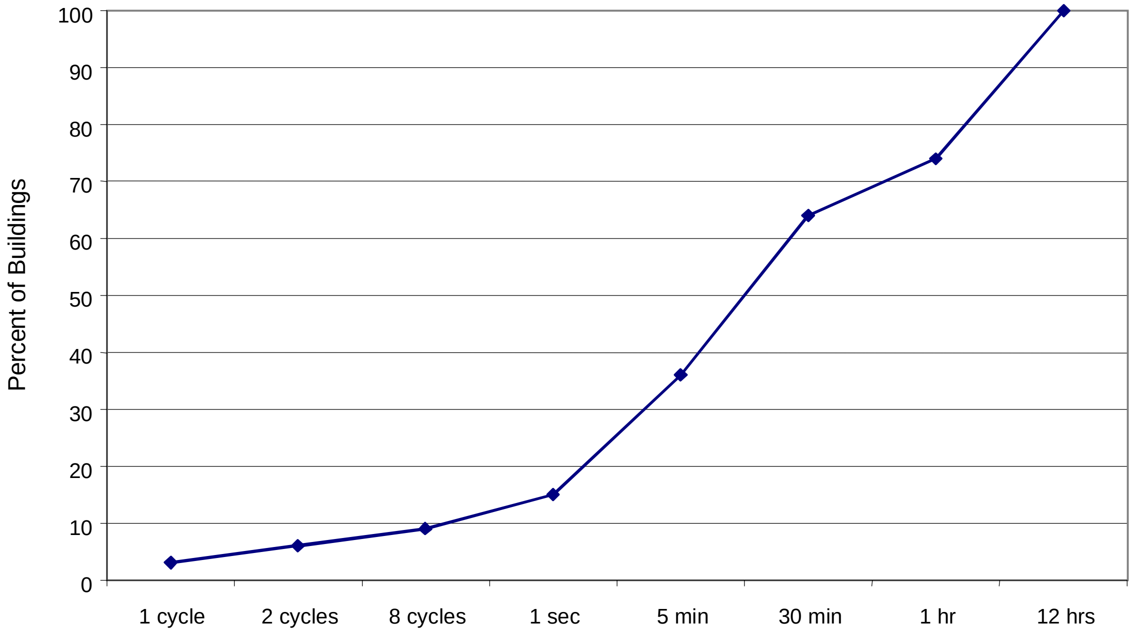

Figure 4-3
Critical Outage Duration (cumulative distribution)

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[20] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

[21] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

[22] Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs; EPRI EL-6791

Sensitivity to Timing of Outage

Not enough studies take a detailed look at the timing of an outage, i.e., when it occurs. Therefore, it is difficult to draw many conclusions about the impacts of timing on outage costs. Timing differences within normal business hours tend not to have a large impact on outage costs for residential, commercial, or industrial customers. Time of year can make a big difference for residential customers, depending on the region.

Sensitivity to timing for retail, industrial, and large commercial customers are measured in one survey:[23]

- Large commercial customers' outage costs are not very sensitive to season, day of week, or time of day
- Industrial outage costs are significantly higher in the winter months than in summer
- Retail outage costs increase throughout the year, and then drop significantly in January
- Retail and industrial outage costs are fairly constant on weekdays; industrial outage costs drop for both Saturday and Sunday, whereas retail outage costs only drop on Sunday

Here is a graph of how outage costs vary by day of the week:

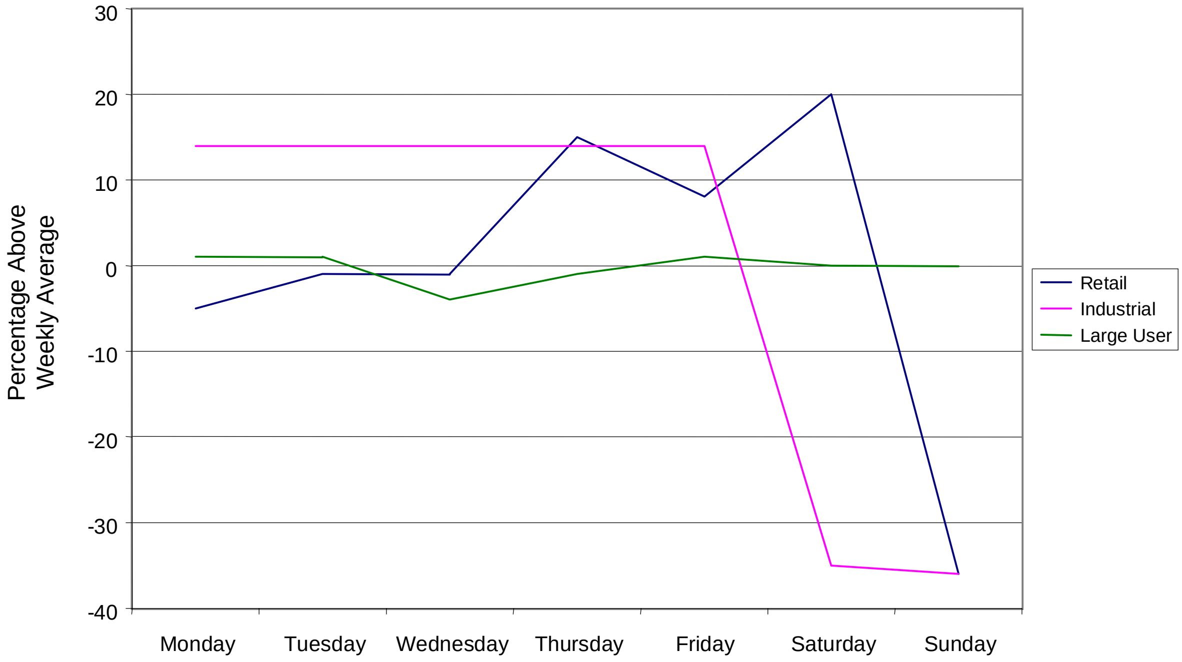

Figure 4-4
Variation in Outage Costs by Day of Week

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[23] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

Here is a graph of how outage costs vary by time of day:

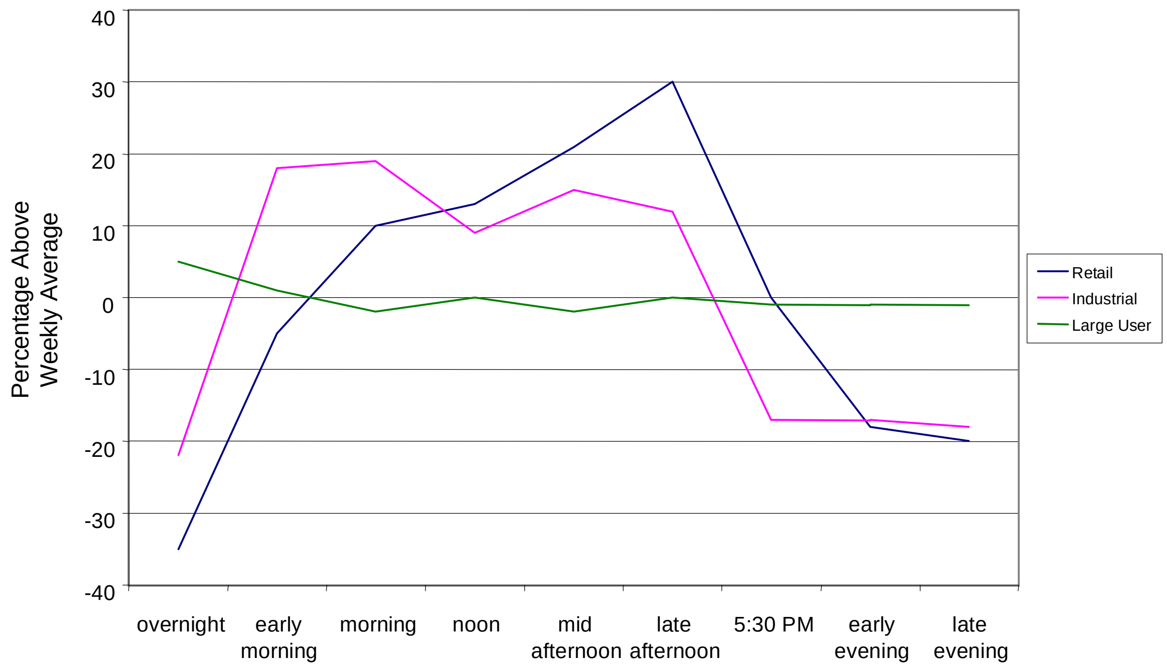

Figure 4-5
Variation in Outage Costs by Time of Day

4.3 Customer Satisfaction with Power Reliability

Satisfaction ratings from different studies consistently show that a vast majority of customers are satisfied with their electric power service. In one survey, 77% of households feel that the number of interruptions they experience is “low” or “very low.”[24]

Results from one study indicates a negative relation between reliability and customer satisfaction. Customers with less reliable power by the MAIFI reliability index are more satisfied on average. This suggests that a customer’s perception of reliability is not just a function of the power itself, but of expectations as well. SAIFI and CAIDI reliability indices showed no statistically significant relation to satisfaction.[25]

Note that customer satisfaction ratings in the residential, commercial, and industrial sectors are all weighted towards “Very Satisfied.”[26]

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[24] Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs; EPRI EL-6791

[25] *SRP Service Quality Power Outage Analysis Research Notes*, WestGroup Research, Feb 1998.

[26] Predicting Customer Choices Among Electricity Pricing Options, Volume 2: Retail Markets, EPRI TR-1088644-V2

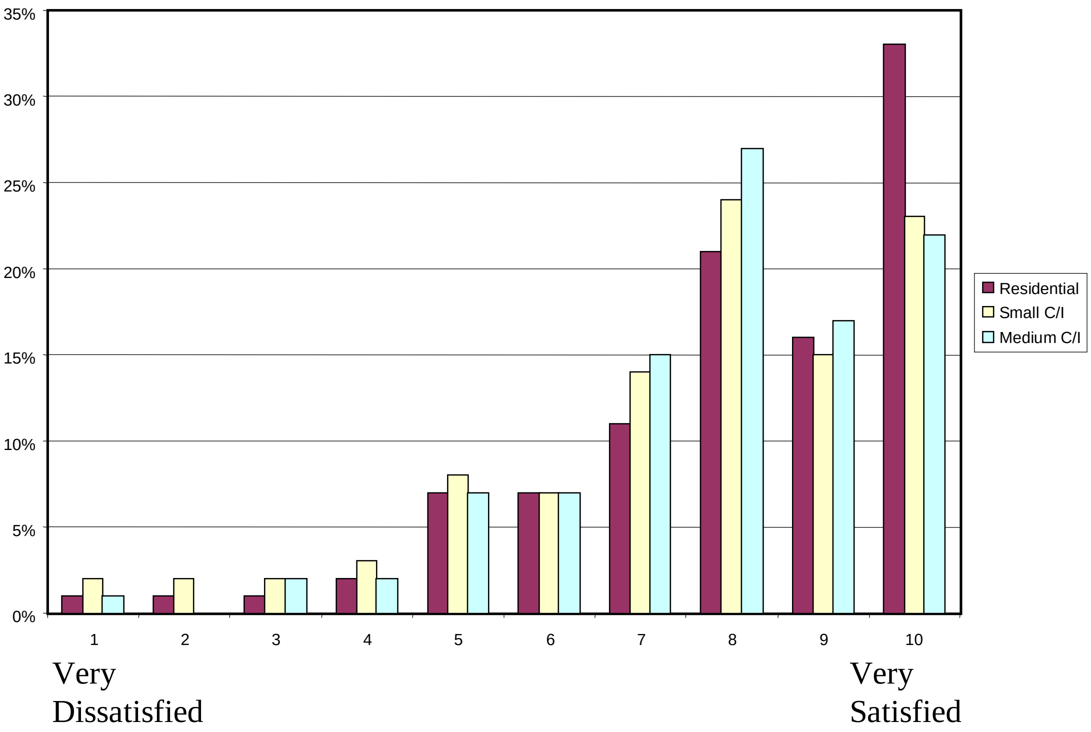

Figure 4-6
Customer Satisfaction with Local Utility

4.4 Customer Segmentation

Some survey-based studies have been performed to define customer segmentations for electric service preferences. A needs-based segmentation defines customer segments by their specific electric power needs, rather than by demographic characteristics. Needs-based segmentations are generally accompanied by a demographic profile of each segment.

An alternative to a formal segmentation is simply to define a few demographic variables within a study and analyze the variables later to see which had an impact on the results.

Needs based residential customer segmentation

Needs based customer segmentation[27]

Residential customers rated each of the following needs in a survey of 1,200 respondents, and customer segments were defined based on these ratings.

Customer needs rated:

- Low energy bills

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[27] CLASSIFY-Profiles Volume 1: Residential Customer Needs and Energy Decision Making; EPRI TR-104567-V1

- Increased comfort
- Surge protection
- Time-saving appliances
- Resource conservation
- Enhanced security
- Safe appliances
- Personal control
- Attractive appliances
- Hassle-free purchases
- High-tech appliances

A brief demographic profile of each segment is given below.

Table 4-2
Definition of Customer Segments
(Listed in increasing order of electricity needs):

Segment Name	Fraction of Sample	Demographics	Description
Lifestyle Simplifiers	12%	Middle-aged, average education, slightly lower income, renters	Low needs for appliances and energy, interested in protecting environment
Technology Focused	9%	Young, well educated, average income	Low needs for everything except high tech features and attractive appliances
Value Seekers	15%	Young, well educated, high income, large household	Want to find best value, price is important as well as performance
Hassle Avoiders	13%	Slightly older, own home, average income, household size	Do not want to put effort into finding a programs or products
Middle Roaders	14%	Average age, income, size of household, home ownership	Average energy use and appliance needs, low need for enhanced security and attractive appliances
Resource Conservers	12%	Older, not well educated, low income, own home	Environmentally motivated, concerned about safety and protecting appliances
Enthusiasts	12%	Older, not well educated, low income, small household, own home	Strong interest in energy for convenience and comfort , strong interest in conserving natural resources
Energy Reliants	13%	High income, own home	Strong dependence on electricity for convenience, comfort, entertainment, security, technology

Here is a list of respondent characteristics that were studied to determine whether they were important predictors of outage costs.

Table 4-3
Outage costs respondent variables[28] [29]

Respondent Variable	Sensitive?
Served by investor-owned utility	very
Power-sensitive health problem	very
Often not at home during the day	not especially
Computer present	not especially
Age	yes
Size of household	yes
Income of household	very
Perception of number of power problems	not especially
Use surge protector	not especially
Backup generator present	not especially
Sex of respondent	not especially
Education of respondent	yes
Type of dwelling – apartment, bungalow	not especially
Location of dwelling – urban, rural	not especially
Electric heat usage	yes
Attitude towards utilities	not especially
Energy consumption	not especially
Monthly electrical bill	not especially
Income earning business at home	yes
User experience with interruptions	not especially

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[28] Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs; EPRI EL-6791

[29] *Interruption Cost Methodology and Results – A Canadian Residential Survey*; Billinton, Wacker, Wojczynski

Commercial/Industrial

Most studies aggregate results by SIC. There is such a tremendous range of outage costs in the commercial and industrial sectors that this categorization is often insufficient for narrowing down outage cost ranges. Even within an industry, there tends to be a wide range of outage costs from one plant or company to another.

A few other parameters that may vary from one plant to another within an industry are commonly used to aggregate results:

- Plant restart time – the amount of time necessary to resume production after an electric service interruption
- Critical duration – the minimum outage duration necessary to incur losses
- Peak demand level

The cost structure of a firm is also an important determinant of interruption costs. At a high level, cost structure can be characterized by[30]:

- Capital intensity (sum of overhead rate and profit rate)
- Overhead rate = fixed overhead and depreciation percentage of expenses
- Profit rate = (value of output – operating costs)/value of output
- Labor intensity (wages paid / kWh consumed)
- Electricity intensity (value of output / kWh consumed)

Industry is generally not found to be a good indicator of outage costs. Labor-intensive firms have higher lost product costs. Willingness-to-pay was found to be higher in energy-intensive firms.

Needs based commercial and industrial customer segmentation[31]

Commercial and industrial customers rated each of the following needs in qualitative discussions, surveys and in-depth interviews.

- Provide superior service
- Improved business operations
- Departmental cost control
- Compete on price
- Long range management

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[30] Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs; EPRI EL-6791

[31] CLASSIFY-Profiles Volume 2: Commercial and Industrial Customer Needs and Energy Decision Making; EPRI TR-104567-V2

- Market new products/services
- Clean power
- Continuous power
- Centralized decisions
- Improved equipment efficiency
- Supportive utility relationship
- Lead through technical innovation
- Take risks to grow business
- Deliver high quality products/services
- Lower rates
- Efficient technologies and controls
- Backup generation
- Customize services
- Managed energy use
- Flexible billing
- Leased equipment
- Improved cash flow

Based on the above ratings, customer segments were defined as shown in the table below. A brief demographic profile of each segment is included.

Table 4-4
Definition of Customer Segments:

Segment	**Fraction of Sample**		**Description**
	Com	**Ind**	
Leading Edge Customers			
Proactives	13%	29%	All needs much stronger than average
Innovators	8%	19%	Strongest needs are related to innovators position as market leader
Solid Implementor Customers			
Conservatives	9%	5%	Strongest needs relate to provision of superior service, risk averse, not adaptive to new technology
Self-Reliants	13%	5%	Strongest needs relate to provision of superior service, low energy expenditure
Slow Changing Customers			
Dependents	13%	5%	Strong energy needs, but not strongly differentiated business needs
Status Quos	14%	3%	Average on most needs
Utilitarians	11%	12%	Strongest needs relate to survival, low energy expenditures, interested in service and price
Troubled Customers			
Survivors	10%	11%	Strongest need is to improve performance, focus is on short term
Besieged	10%	3%	Focus on very near term, poor financial performance

4.5 Switching Behavior

In addition to knowing which attributes customers are willing to pay most for, it is worthwhile to predict what will make a customer switch electric service providers. Most switching studies use surveys about switching intentions to try to predict customer-switching behavior. The surveys usually include questions about the respondent’s history with switching long distance telephone carriers as well.

Trading off Attributes Against Price Discounts

- Likelihood of switching for a given price discount and no other change increases considerably from 0% discount to 10% discount, but much less from 10% discount to 20% discount
- The more efficient an electric utility is perceived to be, the less likely a customer is to switch. However, this effect can be almost entirely offset by a 10% discount.
- Reliability serves as a disincentive to switch, but at a 20% reduction this disincentive has been removed.
- Deceptive advertising is an incentive to switch which is not entirely offset by a 10% or 20% discount[32]

Segmentation of Customer Switching Behavior[33]

The following customer segmentation for likelihood of switching electric service providers was defined based on a survey of over 30,000 households.

Table 4-5
Definition of Customer Segments and Switching Probability

10 Cents A Dance	29%	Of the pop, low income, widowed, separated or divorced. Likely to be comprised of minorities. Mid Atlantic states
Distance Runners	21%	Married, large families, large income. Tend to be college graduates, Disproportional professionals, executives, etc. Tend to live in West North Central Census region
Got my MTV	12%	National norms for household size and income. Generally, young, never been married, rent. Work in Precision Production and Farming, Forestry, and Fisheries
Home Grown	17%	Likely to be in the nest building phase. Likely to be divorced, homeowners with 4 people, moderate incomes
Give me my MTV	14%	Immediately preceding life stage Status Quo. Married homeowners, 2 person household, 45 to 64 yrs, peak wage earning
Status Quo	7%	Retired

Significant variation in switching intentions was found between these segments. For example, 14.5% in the Status Quo segment stated that they were likely to switch for a 10% price discount. In contrast, 97.4% in the 10 cents a Dance segment stated that they were likely to switch for the same discount.

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[32] Residential Customers: Perceptions About Utility Providers and Electric Switching Intentions; EPRI TR-108465

[33] Residential Customers: Perceptions About Utility Providers and Electric Switching Intentions; EPRI TR-108465

4.6 Priority Service Programs

Some studies focus directly on predicting customer participation in priority service programs. Although the results from such studies may be less general than outage cost data, the surveys tend to more closely represent the kind of choices a customer would actually be making in the marketplace.

Two kinds of priority service studies exist: those that are based on data from actual participation in existing programs, and those that are based on surveys where customers are asked to trade off various priority service products. Since there are few priority service programs in existence, most emphasis is put on the survey methods.

Two similar studies use conjoint analysis (an application of the contingent ranking method) to predict customer enrollment in priority service programs for commercial and industrial customers.[34] [35] The attributes of each program, while not identical, are represented by the following list:

Sensitive attributes

- Expected gross dollars saved
- Notice period
- Expected kilowatt hours of control
- Time between interruptions

Less sensitive attributes

- Form of incentive
  - Fixed savings (Savings based on power use)
  - Flexible savings (Savings based on actual interruptions)
- Length of contract and monetary penalty
- Method of control
  - Direct control period (automatically curtail power down to FPL)
  - Indirect control period (increase price with advance notice)
- Maximum duration of interruption

Insensitive attributes

- Rebate amount
- Expected duration of control periods

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[34] Priority Services Design and Forecasting Project: Priority Service Methods at Union Electric Co; EPRI TR-101431

[35] Priority Services Design and Forecasting Project: Priority Service Methods at Commonwealth Edison; EPRI TR-101430

5

QUALITATIVE RESULTS – HOW CUSTOMERS VALUE ELECTRIC POWER

5.1 Waveform Quality

In addition to outages, the quality of electricity waveform is important to some customers with sensitive electronic equipment. Most of these customers purchase power conditioning equipment, but there is some speculation that utilities may play a greater role in the area of power quality in the future.

Unfortunately, there is little quantitative data on customers' willingness to pay for waveform quality. However, there is a fairly large body of qualitative information about which elements of power quality are important to customers. For illustrative purposes, we describe some examples below.

Here is a breakdown of types of waveform disturbances that impose costs on customers[36]:

- Fast voltage fluctuations (transients, impulses, spikes, noise, notches, glitches)
- Short duration voltage variations (sags, surges)
- Long duration voltage variations (overvoltages, undervoltages, brownouts)
- Power interruptions (momentary, temporary, permanent)
- Harmonic distortion

The amount of impact depends on the specific industry. For example, the top three power quality related problems in the semiconductor industry, according to one representative, are[37]

- Successful grounding applications
- Cost-effective power conditioning for sensitive computer-based equipment
- Momentary power outages

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[36] *Power Quality: End User Impacts*; Smith

[37] *The Electric Utility – Industrial User Partnership in Solving Power Quality Problems*; Emmett, etc.

Uninterruptible Power Supply (UPS) customers want to protect sensitive electronic equipment, especially in the following areas[38]:

- data centers
- telecommunications
- individual computers
- process controls
- medical equipment

A representative from a chemical manufacturing company lists the following sensitive electronic equipment as defining a need for quality power[39]:

- process controllers
- adjustable speed drives
- static inverters
- distributed control systems
- automatic data processing equipment

5.2 Green Power

Environmentally Friendly Power Sources

Green power comes in two basic forms, and customers' willingness to pay for green power is sensitive to the details of these forms:

- Renewable sources
- Non-polluting sources

In general, renewable sources are more valuable than simply non-polluting sources. Sources that are simply more efficient than standard sources also tap into the green power market.

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[38] The Status of Static UPS Applications in the United States; EPRI CU-6498

[39] *The Electric Utility – Industrial User Partnership in Solving Power Quality Problems*; Potts, etc.

Rating of environmental friendliness of sources by residential customers[40]:

Table 5-1
Environmental Friendliness Ratings

Wind	9.18
Solar	9.12
Hydro	8.59
Natural gas	6.96
Waste to energy	6.44
Nuclear	4.32
Oil/petroleum	3.78
Coal	3.33

Green power market segmentation[41]

A customer segmentation for green power preferences was defined based on the results of a nation-wide survey of 27,500 residential customers. Most residential customers stated some willingness to pay for green power. Preferences for particular sources vary by customer segment, and the willingness to pay in the Core Green Market is stronger than for the market as a whole.

Table 5-2
Definition of Customer Segments

Segment	Fraction of Sample	Description
Core Green Market		
Radical Greens	4%	Very serious about environmental issues
Alarmists	11%	Very concerned about safety, prefer green products if they are also safer than alternatives
Any Greens	11%	Positive attitudes about environmental issues, but not extreme
Other		
Parochials	10%	More concerned about local community issues than global, environmental issues
Bottom Liners	27%	Most concerned about costs
Don't Cares	36%	View generation method as utility's choice

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[40] Green Power Guidelines Volume 1: Assessing Residential Market Segments; EPRI TR-109192-V1

[41] Green Power Guidelines Volume 1: Assessing Residential Market Segments; EPRI TR-109192-V1

There is a potentially large market for green products, strongest in the residential sector.

- Over 75% of the residential market as a whole state a willingness to choose green power over a 5% discount on electricity service, and over 90% in the core green market group
- Commercial and industrial customers are less interested in green power than residential customers, but 41% state willingness to pay 5% more for greener power; only 6% state willingness to pay 10% more[42]

Willingness-to-pay is very sensitive to the details of the service package.

- The preferred source varies by customer segment
- Only about 10-15% of customers report actual behavior that is consistent with stated willingness-to-pay beliefs
- Skepticism about marketing claims is believed responsible for much of the difference between actual participation rates in green programs and stated willingness-to-pay
- Residential customers are more willing to pay an up-front cost for renewable energy than see an increase in their monthly bill
- Commercial, industrial, and residential customers all have a strong preference (74% of residential, 80% of C/I) for spreading the cost of renewables across the entire customer base, rather than paying for it by voluntary participation

Rooftop photovoltaic (PV) systems

Residential customers have high willingness to pay for PV systems, with 82% of customers willing to pay at least $3/month more, and 13% willing to pay $25/month more. Current green pricing program participants have higher than average figures for rooftop PV. Consumers are more willing to pay for wind and solar power when they are more informed.

5.3 Rate Plans

Residential customers have different preferences for different rate plans, beyond just seeking the lowest price. The plans looked at by one study, in order of general preference, are:

- fixed rate $/kWh
- seasonal rate
- time-of-day rate[43]

In addition, some studies compare preferences of commercial and industrial customers for spot pricing, guaranteed rate, variable rate with advance notice, and some other variations on this theme.

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[42] Willingness to Pay for Electricity from Renewable Resources: A Review of Utility Market Research; Farhar (NREL)
[43] Estimating Customer Preferences for New Pricing Products; EPRI TR-111483

5.4 Infrastructure and Details

Customers also have preferences for the details of the electric service package, such as customer service. These attributes are more likely to give a utility a competitive edge than to yield any willingness to pay. Some of the attributes customers care about are:

- Who is the electric service provider (local, well-known, unknown)
- Who provides customer service (utility, outsourced)
- Contract length, or no contract[44]
- Energy-saving information/seminars provided by utility
- Bundling of electricity with other products and services[45]

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[44] Estimating Customer Preferences for New Pricing Products; EPRI TR-111483

[45] Bundling of Products and Services in the Energy Services Industry; EPRI TR-108985

6

A STRATEGIC RELIABILITY VALUATION FRAMEWORK

6.1 Objective of the Framework

An obvious question arising from the first five sections is: "Is there a way to pull this myriad of incomplete and sometimes conflicting data together to determine the value of reliability?" This section presents an initial attempt to do just that. We develop a quantitative framework that shows how to put all of the information together to determine the value of reliability. The framework allows us to compare the impacts of an initiative that affects the reliability of one customer segment to an initiative that affects another customer segment.

Most importantly, the framework is a first step in developing a fundamental link between two classical types of reliability analysis – contingency planning, which has typically been the approach of utility engineers and value-based planning (e.g., cost/benefit analysis), which has typically been the approach of utility economists. Thus, the framework provides a common structure for dealing simultaneously and consistently with reliability issues and customer needs issues.

In this report our objective is to give an overview of the framework, but not a detailed "how to" manual. We are applying the framework in several EPRI case studies and will describe it in more detail with examples when the case studies are completed.

The model discussed here could conceptually be extended beyond reliability to some other aspects of power, such as power quality and green power, but since quantitative data is so scarce in these areas, we deferred that for a future project.

There are many ways to address the question posed above. A useful approach follows from focusing on the information necessary to make decisions. In particular, we ask, "What information about reliability does a company need in order to make rational investment decisions that affect reliability?" As we shall see, this way to frame the problem provides clarity. However, the question is not so easy to answer as it might at first appear.

Consider the challenge of building a quantitative reliability value model. From the previous sections, we can make some statements about what the inputs for such a model need to be.

6.2 Inputs to the Framework

The literature review revealed a set of factors important in determining the value of reliability:

- interruption duration
- time of day
- time of week of interruption
- time of year of interruption
- advance warning of interruption
- advance notice of duration of interruption
- type of customers interrupted
- frequency of interruptions
- number of customers interrupted

It is useful to think of customers as having value (or utility) functions that depend on a set of key attributes. The first seven factors can be thought of as the attributes key in determining the value of a single outage to a single customer. The eighth factor, “frequency of interruptions,” is necessary to determine the cost of multiple interruptions. The ninth factor, “number of customers affected,” is necessary to determine the value of reliability to the entire customer populations.

The challenge is to construct a value model that estimates the value of reliability as a function of these nine factors.

6.3 Placeholder Approach

The reader may ask, given the low data quality in many areas, isn’t this objective overly ambitious? That is perhaps true, but we believe that the best way to make progress is to construct a “placeholder model.” A placeholder model represents the best we can do given our current state of information.

In this short report, we use existing data when available to estimate value tradeoffs directly; when data is inconsistent or incomplete, we augment the data with judgment. The placeholder model provides a framework for updating our state of information as we acquire new data. It also provides a way to gauge the value of collecting new data.

6.4 Map of Framework

Objective

The objective of the framework is to estimate an "equivalent outage cost" that includes not only the traditional simplistic per-customer, per-incident estimate, but also the impact of all the factors listed above. It is useful to think about the value of reliability in three stages and add in realism and complexity in layers. We start by examining the impact of a single, fixed-duration outage, and then factor in the impacts of multiple outages and then multiple customers. To help as a guide through the details, here is an overview of the three-stage approach.

Stage 1 -- Value of Reliability for a Single Customer and a Single Outage

Avoided outage cost is the classic way in which analysts have thought about the value of reliability. Traditionally, avoided cost is measured by a single number, the "customer outage cost," which is defined as the cost to a single "typical" customer of a single "typical" outage.

Then, within this single-incident, single-customer category, we ask how the outage cost depends on the type of outage and the type of customer.

Stage 2 -- Value of Reliability for a Single Customer and Multiple Outages

For making investment decisions, understanding the impacts of only one outage is not enough. Different investment plans lead to different numbers of outages. The utility needs to think about, not just one "typical" outage, but about the number and type of service interruptions that may occur under a given investment program. Thus, any realistic reliability-valuation approach must quantify the value of reliability as a function of customer outage cost for multiple incidents

Stage 3 -- Value of Reliability for Multiple Customers and Multiple Outages

Finally, we must ask how many customers each type of outage affects? And which types of customers? It is clear that we need to divide customers into market segments. For example, the value of reliability is quite different for a residential household than it is for a large computer manufacturer.

Next we describe the three stages in detail. For each stage, we summarize the state of the literature, a formula for quantifying the various factors relevant to that stage, and a set of placeholder numbers one can use in applying the formula.

6.5 Value of Reliability for a Single Customer and a Single Outage

We begin by establishing the simple classic model which estimates outage cost as a function of duration. Then, we expand the model the issues of timing and warning:

- Step 1.1 Estimate outage cost as a function of duration

- Step 1.2 Add the issue of timing
- Step 1.3 Add the issue of advance warning

Step 1.1. Outage cost as a Function of Duration

The basic Customer Outage Cost function as developed in the majority of studies is different for residential and commercial/industrial customers. For residential customers, outage costs is calculated as a base value times a duration factor that indicates how the cost of an outage grows as it persists over time. For commercial/industrial customers, outage cost is calculated as a base value times the annual kWh used by the firm times a duration factor.

For both types of customers, the attribute of duration is well studied. Here is the state of information in the literature about the Duration attribute:

Table 6-1
State of Information for the Duration Attribute

Attribute	Description	Coverage in Literature
Duration	Effects of outage duration on outage cost are studied heavily and consistently show a large impact	Strong

Following are formulas for computing outage cost as a function of duration. In this initial step, the base value is predicated on a scenario that specifies when the outage occurs and how long it lasts. The impacts of changing these assumptions are addressed later.

Residential

Valuation Formula

Outage Cost = Base Value * Duration Factor

Numerical Parameters

For residential, we choose a base value that lies within the ranges of results of many different survey-based studies. Non-survey-based approaches sometimes yield results nearly an order of magnitude greater. The base value is not a strict average of results from various studies, but rather is a ballpark figure in an area with tremendous variation.

<u>Residential Base Value</u>

Assumed Scenario: 1 hour outage on a winter weekday afternoon

Base Value: $2.00 (US dollars, year 2000)

Residential Duration Factor

The entries in the table below[46] are per hour factors. That is, they need to be scaled by the duration of the outage.

Table 6-2
Residential Per Hour Factors

Duration	20 minutes	1 hour	4 hours	8 hours	24 hours	48 hours
Factor	0.52	1.00	2.76	2.94	4.45	5.48

Figure 6-1 shows that the per hour duration factor is increasing, indicating that a 4 hour outage is generally more than 4 times as costly as a 1 hour outage.

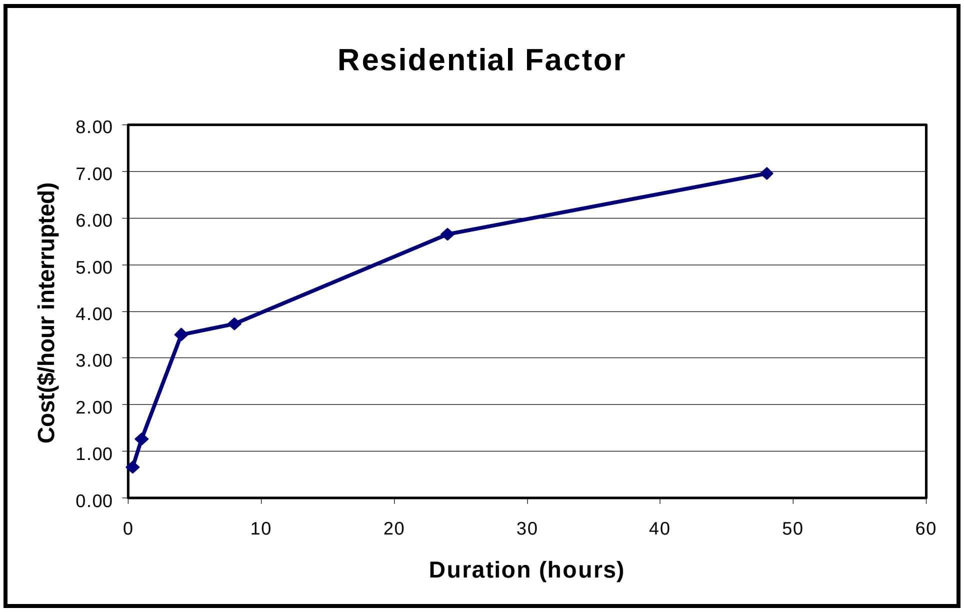

Figure 6-1
Marginal Outage Cost Increases as Duration Increases

Next we present a formula for the Commercial/Industrial customer class.

Commercial/Industrial

Valuation Formula

Outage Cost = Base Value * Annual kWh used by firm * Duration Factor

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[46] *Application of Customer-Interruption Costs for Optimum Distribution Planning*; Mok, Chung; Energy Vol. 21, No. 3 1996.

Numerical Parameters

For commercial/industrial customers, the numbers below are to be used with caution, since many reports have made the point that there are other features of a firm that tell a lot more about its outage costs than simply industry. For instance, the cost structure of a firm (labor intensity, electricity intensity, etc.) is believed to have a large impact and can be inconsistent from one firm to another, even within a given industry. However, it is much easier to obtain and use data on an industry basis. We also provide one rule-of-thumb number averaged over industries.

Commercial/Industrial Base Value

Assumed Scenario: 1 hour outage on a winter weekday afternoon

Base Value (Industry Average): $0.005/annual kWh

Table 6-3
aBase Value by Industry[47]

Industry	Base Value (1990 US $/annual kWh)
Warehouse	0.00972
Office	0.00232
School	0.00142
Restaurant	0.000654
Lumber	0.0308
Paper	0.000389
Food	0.0273
Retail	0.00129
Chemicals	0.0000297
Metals	0.00000
Health	0.000346
Hotel	0.00100
Misc. Services	0.000814
Nonferrous metals	0.000481

Note the sensitivity of the base value to the industry. The numbers vary by over two orders of magnitude. This highlights the importance of customizing individual utility reliability analyses to the specific mix of industries in their service territories

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[47] Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs, Volume 2; EPRI EL-6791

Commercial/Industrial Duration Factor[48]

Commercial/Industrial duration factors were derived from the results of Billinton, Wacker and Wojczynski, who assessed direct costs for 1 minute, 20 minute, 1 hour, 4 hour, and 8 hour outages.

Table 6-4
Commercial/Industrial Duration Factors

Duration	Factor	
	Industrial	Commercial
1 minute	0.12	0.05
20 minutes	0.47	0.35
1 hour	1.00	1.00
4 hours	2.83	3.68
8 hours	5.44	9.54

Alternatively, the following normalized factors can be used, and multiplied by the duration of the outage. These are simply the above figures divided by the durations to give a per-hour interruption value. The trends are easier to see in these numbers.

Table 6-5
Commercial/Industrial Per Hour Interruption Values

Duration	Normalized Factor	
	Industrial	Commercial
1 minute	7.049	3.109
20 minutes	1.427	1.047
1 hour	1.000	1.000
4 hours	0.708	0.920
8 hours	0.680	1.193

The shapes of the normalized interruption costs ($/hour interrupted) by duration for industrial and commercial customers are below. Notice that for industrial customers, the cost is decreasing, indicating that an 8-hour outage costs less than twice as much as a 4-hour outage. In the commercial sector, there is not such a clear trend. The shape of this curve in the industrial sector is much more consistent across studies than that of the commercial sector. The curve for the commercial factor is near the middle of the range of analogous curves from other studies. In

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[48] *Interruption Cost Methodology and Results – A Canadian Commercial and Small Industry Survey*; Billinton, Wacker, Wojczynski ,IEEE Transactions on Power Apparatus and Systems, Feb. 1984

fact, when the commercial curve is broken down by industry, on observes that some cost vs. duration curves are decreasing and some increasing with duration, with substantial variation from one industry to the next. The trend tends to be stated in the aggregate, across many industries. Only a few illustrative examples of the effects of duration on different industries were found, involving no more than 5 or 6 different industries.

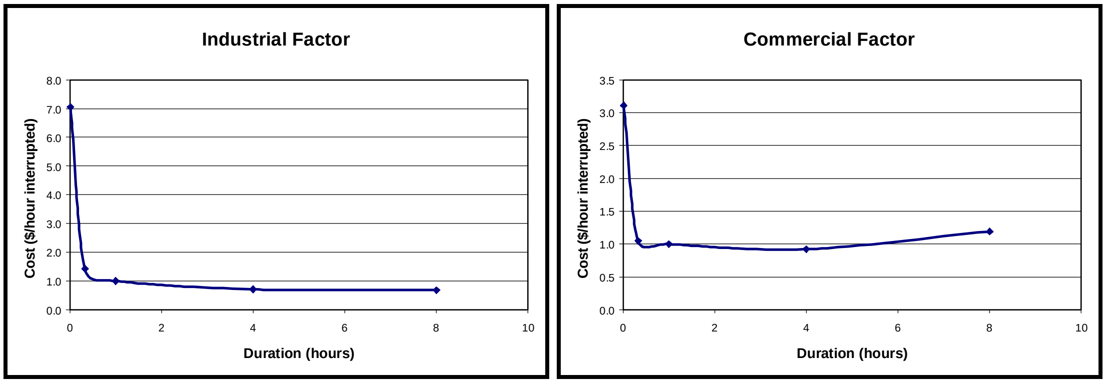

Figure 6-2
Normalized Interruption Costs ($/hour interrupted) by duration

It is important to note that these figures show the marginal costs of interruptions, i.e., the incremental cost per hour as a function of duration.

Step 1.2. Add Timing Factor:

The importance of when an interruption occurs is also a well-studied phenomenon. Here is the state of information in the literature about the Timing attribute:

Table 6-6
State of Information for the Timing Attribute

Attribute	Description	Coverage in Literature
Timing	time of day/day of week/month or season of year effects are covered in less detail than duration but quantitative results do exist. Results tend to be sensitive to timing.	Strong

Again, the formulas for estimating the impact of timing depend on the type of customer.

Residential

Valuation Formula

Outage Cost = Base Value * Duration Factor * Timing Factor

where

Timing Factor = Time of Day & Week Factor * Month Factor

Residential Time of Day & Week Factor

On a weekday, afternoon outages are less bothersome to residential customers than morning and evening outages. Weekend outages are slightly less bothersome than weekday outages, and little information is available for variations during the day on a weekend. The weekend evening factor is simply the average of the weekend morning and afternoon factors. The following factors are based on "bothersomeness ratings" of outages at various times of day in the Bonneville study[49].

Table 6-7
Residential Time of Day & Week Factor

	Morning	Afternoon	Evening
weekday	1.36	1.00	1.45
weekend	0.85	0.96	0.90

Residential Month Factor

In most studies, winter outages are more costly to residential customers than summer outages. However, some results show summer outages being more costly. This is most likely due to climate in different regions. Studies with winter outages more costly than summer typically have a factor between 2 and 3 for winter over summer. More detailed information is not available.

The following factors are based on a factor of 2 and a sine curve shape:

Table 6-8
Residential Month Factor

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.00	0.97	0.88	0.75	0.63	0.53	0.50	0.53	0.63	0.75	0.88	0.97

Commercial/Industrial

Valuation Formula

Outage Cost = Base Value * Annual kWh used by Firm * Duration Factor * Timing Factor

The definition of the timing factor depends on the size of the company:

If Small Commercial/Industrial

Timing Factor = Time of Day Factor * Day of Week Factor * Month Factor

If Large Commercial/Industrial

Timing Factor = 1.00 (large customers not sensitive to timing)

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[49] Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs, Volume 2; EPRI EL-6791

Numerical Parameters

All commercial/industrial timing factors shown here are derived from the same source.

Table 6-9
Small Commercial/Industrial Time of Day Factor[50]

	over-night	early morning	morning	noon	mid afternoon	late afternoon	5:30 PM	early evening	late evening
Small Commercial	0.54	0.79	0.91	0.93	1.00	1.07	0.83	0.68	0.66
Small Industrial	0.68	1.03	1.03	0.95	1.00	0.97	0.72	0.72	0.71

Table 6-10
Small Commercial/Industrial Day of Week Factor

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Small Commercial	1.00	1.04	1.04	1.21	1.14	1.26	0.67
Small Industrial	1.00	1.00	1.00	1.00	1.00	0.57	0.56

Table 6-11
Small Commercial/Industrial Month Factor

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Small Commercial	1.00	1.00	1.02	1.03	1.09	1.09	1.08	1.11	1.14	1.13	1.24	1.25
Small Industrial	1.00	1.02	0.98	0.91	0.84	0.83	0.80	0.82	0.84	0.89	0.98	1.01

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[50] Customer Demand for Service Reliability: A Synthesis of the Outage Cost Literature; EPRI P-6510

Step 1.3. Add Advance Warning Factor

We separate advance warning into two types: 1. Advance notice that an outage is going to occur (advance warning) and 2. Advance notice about the duration of an outage once it begins (duration notice). The impact of each type of warning is different for residential and commercial/industrial customers.

The attribute of advance warning is not as well-studied as those of duration and timing. Here is the state of information in the literature about the Advance Warning attribute:

Table 6-12
State of Information for Advance Warning Attribute

Attribute	**Description**	**Coverage in Literature**
Advance Warning	Advance notice has been shown to reduce outage costs a fair amount but the results tend not to be very detailed. The amount of advance notice necessary to make cost saving arrangements varies from firm to firm.	Moderate
Duration Notice	Notice of the expected duration of an outage after the outage starts has been examined in very few studies. The amount of coverage is weak, but there is some quantitative data for the magnitude of the savings from notice of duration.	Weak

Residential

Valuation Formula

Outage Cost = Base Value * Duration Factor * Advance Warning Factor

Numerical Parameters

Residential customers are relatively insensitive to warning. As a first order approximation:

Residential Advance Warning Factor = 1.00

Commercial/Industrial

Valuation Formula

Outage Cost = Base Value * Annual kWh used by firm * Duration Factor * Timing Factor *Advance Warning Factor* Duration Notice Factor

Numerical Parameters

Advance Notice Factor

The following advance notice factors were taken from aggregate expected savings from a specified advance notice:

For 1 hour advance notice[51]:

0.65 for commercial (35% savings)

0.57 for industrial (43% savings)

For 3 days advance notice[52]:

0.40 for commercial (60% savings)

0.32 for industrial (68% savings)

The following table contains the values obtained by interpolating the cost savings by fitting exponentially decaying functions (for the record, the fitting equations were: –exp [-.431*notice0.176] for commercial and –exp[-.562*notice0.165265] for industrial):

Table 6-13
Commercial/Industrial Advance Warning Factor

	Amount of advance notice (hours)					
	0	1	4	8	24	72
Commercial	0.0	0.65	0.58	0.54	0.47	0.40
Industrial	0.0	0.57	0.49	0.45	0.39a	0.32

Duration Notice Factor

The duration notice factor measures the value of receiving information about the duration of an outage at the start of the outage. This factor is slightly different on average for commercial and industrial customers:

Commercial Duration Notice Factor = 0.79 (represents 21% savings)

Industrial Duration Notice Factor = 0.73 (represents 27% savings)

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[51] *Interruption Costs, Customer Satisfaction, and Expectations for Service Reliability*; Sullivan, Suddeth, Vardell, Vojdani, IEEE Transactions on Power Systems, May 1996.

[52] *Interruption Cost Methodology and Results – A Canadian Commercial and Small Industry Survey*; Billinton, Wacker, Wojczynski, IEEE Transactions on Power Apparatus and Systems, Feb. 1984

6.6 Value of Reliability for a Single Customer and Multiple Outages

The simplistic way to deal with multiple outages, and the most common traditional way, is to simply multiply the per-outage cost by the number of outages/year to determine the outage cost/year. However, this approach does not address what common sense and reliability planners often assert – outage costs may go up (and sometimes down) dramatically as the number of outages go up. Residential customers are willing to put up with a certain incidence of outages, especially in hot summers and cold winters, but beyond a given number the perceived cost becomes much higher. A well-known phenomenon is "anchoring." Customers tend to anchor on historical frequencies in the sense that they react poorly when the frequency rises above past levels. Similarly, businesses adapt their work processes around a relatively stable frequency of outages; when this frequency rises over historical levels, costs and complaints can increase sharply.

Unfortunately, while most reliability planners indicate that the frequency of outages has an important and non-linear impact on value, quantitative research is scarce in the literature. Here is the state of information in the literature about the Frequency attribute:

Table 6-14
State of Information for Frequency Attribute

Attribute	**Description**	**Coverage in Literature**
Frequency	Scant quantitative information is available on the effects of outage frequency on outage costs. Some studies suggest that higher frequency leads to lower outage costs, but the info is neither complete enough nor reliable enough to use in formulas	Weak

Valuation Formula

Value of Reliability = Avoided Outage Cost * Frequency Factor

One can think of the Frequency Factor as determining an equivalent number of interruptions. For example, avoiding residential outages after the first set of 10 outages in a year might have a marginal value of twice the marginal value of avoiding an outage for each of the first 10 residential customer outages. In this case, the Frequency Factor for the eleventh and subsequent incidents would be 2 – the eleventh interruption imposes twice the cost of each of the first ten. For this example, the Frequency Factor would be as follows:

Table 6-15
Example Frequency Factor for Momentary Outages

Momentary Outages		Frequency Factor (Equivalent Incidents)
First Group of Interruptions	0-10	1.0
Second Group of Interruptions	> 10	2.0

The Frequency Factor can be different for momentary and sustained outages as illustrated in the example table below.

Table 6-16
Example Frequency Factor for Sustained Outages

Sustained Outages		Frequency Factor (Equivalent Incidents)
First Group Interrupted	0.00-1.53	1.00
Second Group Interrupted	1.53-1.67	.86
Third Group Interrupted	1.67-4.00	.31
Fourth Group Interrupted	4.00-10.00	.28

In this example, reducing sustained outages for the first set of customers has a higher value than reducing sustained outages for subsequent customers. In practice, we have observed Frequency Factors both above and below unity – indicating increasing and decreasing marginal values. As a placeholder, given the lack of data, we would specify Frequency Factors equal to 1.0 for both types of outages, implying equal marginal value for all customers.

Numerical Parameters

Frequency Factor for Momentary Outages = 1.0

Frequency Factor for Sustained Outages = 1.0

6.7 Value of Reliability for Multiple Customers and Multiple Outages

There are a number of reasons that outage cost per customer may not be constant as a function of the number of customers affected. For individual utilities, rate penalties may be imposed above a certain number of customers affected.

Here is the state of information in the literature about the Number of Customers attribute:

Table 6-17
State of Information for Number of Customers Attribute

Attribute	Description	Coverage in Literature
Number of Customers	No quantitative information on the effects of multiple customers on outage costs was found.	None

Valuation Formula

Value of Reliability = Avoided Outage Cost * Frequency Factor * Customer Factor

In ongoing EPRI case studies, we have found that the marginal cost per customer goes down as the number of customers goes up, as indicated in the tables below. However, the literature search did not uncover a study of this multiple-customer effect. As with the Frequency Factor, one can think of the Customer Factor as an equivalent number of customers. For example, avoiding an outage for each of the first set of 2,000 residential customers has a marginal value of twice the marginal value of avoiding an outage for additional residential customers. Equivalently, avoiding an outage for each of the first 2,000 customers is equivalent to avoiding an outage for two of the second group of customers.

Numerical Parameters

Table 6-18
Numerical Parameters for Number of Customers Factor

Residential Customers		Customer Factor (Equivalent Customers)
First Group Interrupted	0-2,000	2
Second Group Interrupted	2,001-40,000	1
Business Customers		Customer Factor (Equivalent Customers)
First Group Interrupted	0-1	6
Second Group Interrupted	2-3	2
Third Group Interrupted	4-50	1
Critical Customers		Customer Factor (Equivalent Customers)
First Group Interrupted	0-1	2
Second Group Interrupted	2-3	1

7

CONCLUSIONS: MOVING BEYOND TRADITIONAL RELIABILITY ANALYSIS

In this report we studied how customers value reliability. In a companion report, *Reliability of Electric Utility Distribution Systems,* we characterized the state of the art of the analysis of reliability in distribution systems. Together, the two studies give some clear directions for an improved approach for controlling and optimizing reliability with respect to customer needs and values.

The customer-focused approach described in the sections above measures customer values directly rather than reducing them to a set of ad hoc reliability measures more oriented towards system performance than towards customer needs. This final section considers briefly the potential consequences of the new approach.

In the Reliability study we found that there are a large number of indices for measuring reliability as well as a collection of methods for measuring these indices. Some of the common reliability measures are SAIFI, SAIDI, CAIDI, CAIFI, ASAI, CTAIDI, ASUI, ENS, AENS, MAIFI, MICIF, ALII, ASCI and ACCI, just to name a few. Even though each of these measures taken alone has some intrinsic logic to it, the sheer number of different indices brings confusion rather than clarity to reliability planning. In a seminar, Ronald A. Howard of Stanford University once compared a situation like this to Sir Isaac Newton trying to deduce the law of gravity by throwing up feathers from a pillow into the wind. Utility planners need a way to balance the issues that drive the different indices. The customer-focused approach provides a natural integrating framework.

In the Customer Needs study, we characterized the most fundamental customer needs in terms of key attributes of electric service, such as number of outages per year and duration per outage. We developed a customer value function with respect to these attributes. The customer value function measures the importance of each attribute for customers and, most importantly, permits attributes to be compared directly. A fundamental implication of the value function is that the attributes and the indices measure different things. The service attributes that customers value are *not* the same as the system indices. In other words, the system indices are not what customers value.

The two reports suggest that a better reliability planning method would begin with customer needs and use those needs to define the important aspects of system performance. With this view, we should create tools to measure system performance in terms of customer value attributes, determine how to control these measures of system performance and then build economic analysis tools that trade off the cost of control with customer values.

Utility planners need a way to balance the issues that drive the different indices and the customer-focused approach provides a natural integrating framework. Here in summary form are some of the implications of the customer-focused approach.

7.1 The new approach ties together traditional cost-benefit economic analysis with engineering system analysis

Traditional reliability analysis is engineering oriented. There is a clear and intentional equipment and electrical system focus to the reliability-index definitions.

Figure 7-1 shows the traditional reliability planning approach. Control strategies, such as repair/replace and installation of new equipment and circuits, are chosen that affect system performance and customer values, but the choice is made based on system indices that are only indirectly correlated with customer values. While there is no question that an improved system improves the way in which customer needs and values are satisfied, there is no direct link between system indices and customer values.

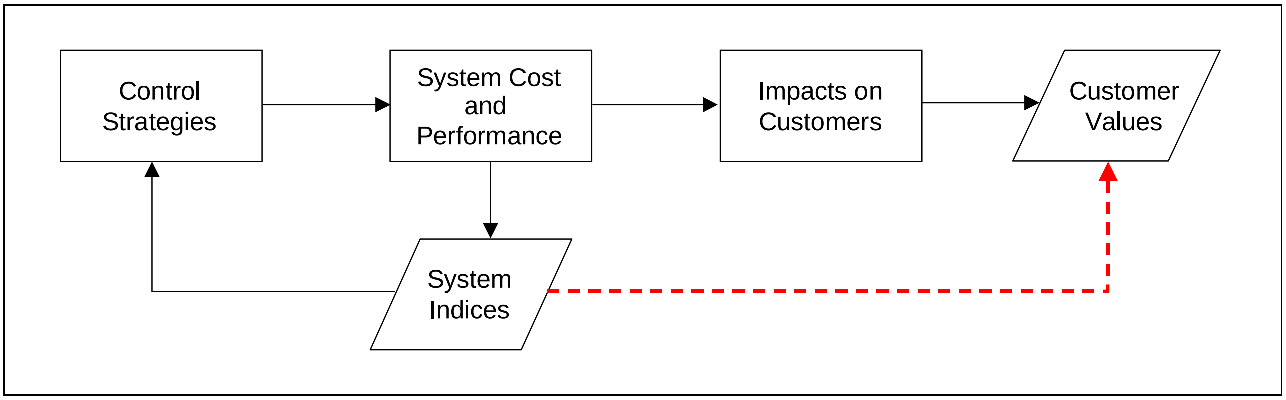

Figure 7-1
Traditional Approach to Reliability Planning

The issue is not whether the system is improved, but whether a utility can do even better with the same resources. The answer is almost certainly “yes,” because the customer value function defines an explicit target or performance measure that can be maximized. Figure 7-2 shows a new approach, based on an explicit measurement of customer needs. In this approach, customer values, including the trade-off between cost and reliability, are used directly to drive the control strategy. System indices are still important for intuition and understanding, but only as intermediate measures that help to summarize the behavior of the complicated distribution system.

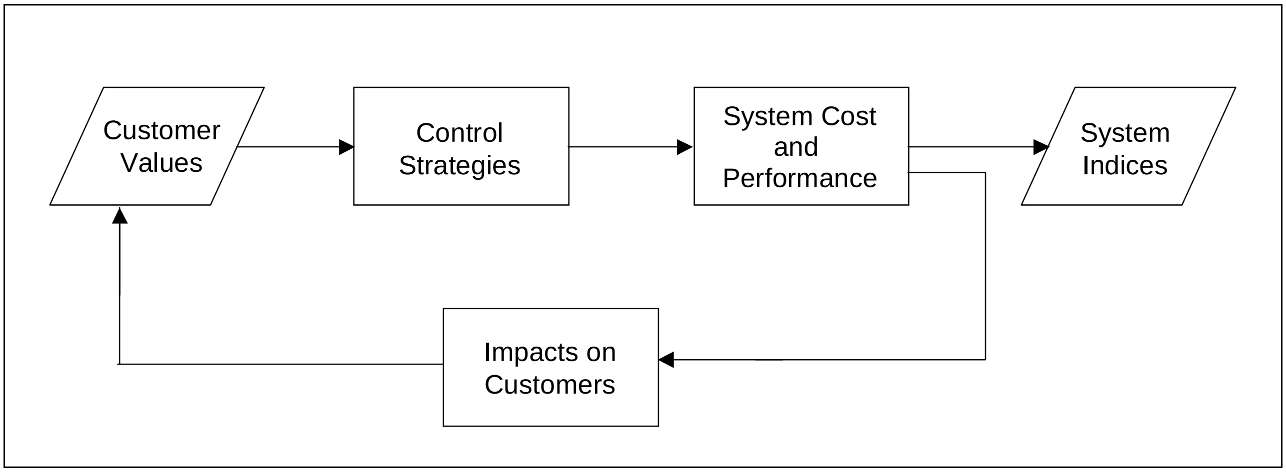

Figure 7-2
New Approach to Reliability Planning

7.2 The new approach allows comparison across customer segments

The Customer Needs study found that segmentation of the customer population is important. It is clear that different customer groups have very different values for electricity. Moreover, their needs are multi-dimensional.

System average indices do not reflect the diversity of the customer population and offer no way to balance the needs of the different customer segments. However, the customer-focused approach allows a direct comparison of the different dimensions of reliability and their differing impacts on different customer segments.

7.3 Reliability indices are ad hoc and do not directly address customer needs

As argued above, current reliability planning practice uses indices that are measures of system performance, not customer values or needs. While we would expect these indices to be correlated with customer value, they do not measure it. Consider, for example, the CAIDI index (Customer Average Interruption Duration Index). Two vastly different systems can have the same CAIDI, but the actual cost to customers can be arbitrarily distributed.

The distinction we are drawing is between means and ends. System performance, measured by the various indices, is a “means objective” in contradistinction to meeting customer needs, which is an “ends objective.” In other words, system performance is only a means to a more fundamental end, which is to provide customers with reliable, high quality electricity. System indices are intermediate measures, not ultimate impacts.

7.4 Planning based on averages ignores risk and extreme events

Planning using only averages does not allow one to evaluate risk and the possibility of deviations from normal operations. In a very fundamental sense, reliability planning using averages makes no sense. Risk, or deviation from average, is the essence of reliability. If the electrical system always operated under “average” conditions, reliability planning would be easy. For example, there would be no need for reserve margins, no need for multiple-contingency planning and no need for backup generation or distribution.

Yet, while multiple-contingency policies and other risk averse strategies seem to make intuitive sense, current methods based on averages only cannot evaluate such policies. We need a way of predicting the range of outcomes and their probabilities based on all realistic contingencies.

Technically, approaches based on averages require a large number of limiting and possibly unrealistic assumptions (for example, exponential failure and restoration time distributions). One always needs to question whether there is there sufficient data to justify the assumptions empirically.

7.5 Planning based on averages ignores some key customer needs

Even if averages are calculated correctly, they are inadequate for representing stakeholder values. Our work in customer needs tells us that customers have non-linear value functions for both arrivals of outages and duration of outages. Non-linear value functions mean that excursions from average conditions can be very important.

This is not just a minor technical point; it is a practically important issue. Customers and utility planners get upset when unusual events occur. Reserve margins and safety levels are based on unusual events and regulators often penalize companies in nonlinear fashion – for example, penalizing a company only after the number of outages exceeds some threshold level. It is often the unusual “non-average” event that drives utility planning at the highest level of the company. Consider the recent front-page newspaper headlines in California when parts of the state approached a Level 3 condition under which brownouts would occur. California utilities were subjected to conflicting pressures as voters questioned the lack of capacity while at the same time ratepayer groups were demanding lower rates.

To go beyond planning based on averages, we need new tools to evaluate the full consequences over the range of events that could occur (which, in mathematical parlance is to say that we require the complete probability distribution over outcomes). It is fortunate that the theory necessary to guide the development of such tools appears to exist at present.

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5) "Costs of Electricity-supply Interruptions to Industrial Consumers"; A.F. Jackson, B. Salvage, Proc. IEEE, Vol 121, No. 12, December 1974.

6) "Costs of Inadequate Capacity in the Electric Utility Industry", William B. Shew, Energy Systems and Policy Volume 2, Number 1, 1977.

7) "Customer Retention in a Competitive Power Market: Analysis of a 'Double-Bounded Plus Follow-ups' Questionnaire", Yongxin Cai, Iraj Deilami, Kenneth Train.
Energy Journal, Vol. 19, No. 2. 1998

8) "The Demand for Electricity Services and the Quality of Supply", Romesh Dias-Bandaranaike, Mohan Munasinghe; The Energy Journal, Vol. 4, No. 2 1983.

9) "Economic Criteria for Opitmizing Power System Reliability Levels", M. Munasinghe, M. Gellerson (1979), The Bell Journal of Economics, Vol. 10, No. 1, pp 353-365

10) "The Electric Utility-Industrial User Partnership in Solving Power Quality Problems"; John E. Flory, Thomas S. Key, William M. Smith; IEEE Transactions on Power Systems, August 1990

11) "Factors Affecting the Development of a Commercial Customer Damage Function"; R. Billinton, G. Wacker, R.K. Subramanian, IEEE Transactions on Power Systems, Vol. PWRS-1, No. 4, November 1986.

12) "Green Pricing: The Bigger Picture"; Bryan Byrnes, Maribeth Rahimzadeh, Renee de Alba, Keith Baugh; Public Utilities Fortnightly, August 1996.

13) "Interruption Cost Methodology and Results – A Canadian Commercial and Small Industry Survey", E Wojczynski, R. Billinton, G. Wacker; IEEE Transactions on Power Apparatus and Systems, Vol PAS-103, No. 2, February 1984.

14) "Interruption Cost Methodology and Results - A Canadian Residential Survey", G. Wacker, E. Wojcsynski, R. Billinton, IEEE Transactions on Power Apparatus and Systems, October 1983, Vol. PAS-102, No. 10

15) "Interruption Costs, Customer Satisfaction and Expectations for Service Reliability", Michael J. Sullivan, B. Noland Suddeth, Terry Vardell, Ali Vojdani; IEEE Transactions on Power Systems, Vol. 11, No. 2, May 1996.

16) "A Major UK Distribution Power Quality Survey" Eamon J. Delaney, David R. Mueller, Nigel G. Foster, Proceedings of the 29th Universities Power Engineering Conference, 1994

17) "Optimal Dispatch of Interruptible and Curtailable Options"; Douglas W. Caves, Joseph A. Herriges, Operations Research Vol. 40, No. 1, Jan-Feb 1992.

18) "Power quality: End user impacts"; J.C. Smith; Energy Engineering, 1991 p 35-54

19) "Reliability Pricing of Electric Power Service: A Probabilistic Production Cost Modeling Approach"; Youssef Hegazy, Jean-Michel Guildman, Energy Vol. 21, No. 2, pp 87-97, 1996.

20) "Report on Reliability Survey of Industrial Plants, Part II: Cost of Power Outages, Plant Restart Time, Critical Service Loss Duration Time, and Type of Loads Lost Versus Time of Power Outages"; IEEE Transactions on Industry Applications, Vol 1A-10, No. 2, March/April 1974

21) "Shock the Electricity Market", International Journal of Retail & Distribution Management, pg. 59. Jan 1, 1998, MCB University Press Ltd.

22) "A Simple Method for Evaluating the Marginal Cost of Unsupplied Electricity", Benjamin Bental, S. Abraham Ravid, The Bell Journal of Economics

23) "Utilities Today Must Provide 'Clean' Power"; Wayne Beaty, Electric Light and Power, March 1993

24) "Why Your Customers Switch", Kerry Diehl, Rich Gillman, Public Utilities Fortnightly, Apr 15, 1997

A.3 Books

1) Customer Choice: Finding Value in Retail Electricity Markets, Ahmad Faruqui, J. Robert Malko; Public Utilities Reports, Inc. 1999

B
SUMMARY OF REPORTS, JOURNAL ARTICLES AND BOOKS IN THE CUSTOMER NEEDS LIBRARY

B.1 Reports

EPRI Reports

1) Outage Cost Estimation Guidebook; Final Report December 1995 TR-106082
Contains a methodology for measuring customers' perceptions of outage costs, including a copy of the outage cost assessment survey used by Duke power. Outages are broken down by duration and by time of day, and the major inconveniences caused by each kind of outage are estimated and also used to measure annoyance (e.g. how annoyed would you, a residential customer, be if all the food in your fridge spoiled, as opposed to just having to set all the clocks again). Willingness to pay is addressed explicitly. Surveys for residential and commercial customers are included, with standard demographic profiles. Contains a list of other utilities that have performed customer needs surveys:
    - *Bonneville Power Administration*
    - *Florida Power Corp*
    - *Niagara Mohawk*
    - *Ontario Hydro*
    - *PG&E*
    - *Southern CA Edison*
    - *Southern Companies*

2) Guide to Value-Based Distribution Reliability Planning; Volume I, chapter 4:
"Customer Outage Costs", Report for the Canadian Electricity Association CEA 273 D 887
Description of methodologies for estimating customer outage costs. Includes results from a survey sponsored by CEA and the Natural Sciences Research Council (NSERC) in 1991. Estimates damage functions by duration of outage for the following sectors:
    - Residential
    - Large Users
    - Small Industry
    - Government & Institutions
    - Commercial
    - Office Building
    - Farm

3) Estimated Customer Preferences for New Pricing Products;
Final Report October 1998 TR-111483
A study of customer preferences for pricing plans. Does not include any other attributes of electricity service. Contains a customer preference study including much of the data obtained, and applies a logit choice model. Chapter 7 contains recommendations for conducting a more complete customer needs survey, outlining the necessary steps.

4) Bundling of Products and Services in the Energy Services Industry;
Final Report Nov 1997 TR-108985
Contains no data. A qualitative approach to the art/science of bundling of products. Attempts to summarize lessons from successful and unsuccessful bundling in other industries and apply them to electric power. Will not directly supply any customer needs data, but is a customer choice-based approach to viewing the electric utility industry.

5) Predicting Customer Choices Among Electricity Pricing Options;
Volume 1: Wholesale Markets, Final Report Nov 1998 TR-108864-V1
Study of wholesale customers' (municipal utilities) preferences for alternative pricing plans. Consists of a survey of 30 customers. Not very relevant to willingness-to-pay. Wholesale customers are segmented by (1-10):
    - Wholesale price environment (high/low)
    - Size (MWh sales)
    - Ownership of generation
    - Type of sales (resale vs. ultimate consumers)

Wholesale customer attitudes identified as drivers of preference (4-1):
    - Concerns about the future of wholesale and retail power markets (loss of large retail customers to other suppliers, changes in rate structures)
    - Perceptions of Needs for New Wholesale Power Supply Options
    - Dimensions of Power Supply Risk (risk tolerance of utility)

6) Predicting Customer Choices Among Electricity Pricing Options; Volume 2: Retail Markets, Final Report November 1998 TR-108864-V2
Study of retail customers' preferences for alternative pricing plans. Consists of a conjoint analysis survey of residential and small, medium, and large commercial/industrial customers. Residential customer characteristics measured include demographics, home ownership, and main type of heating fuel (4-2). For small and medium C/I customers, building type, business type, main type of heating fuel, and number of employees are considered. Power generation was added to these for large C/I customers. Services other than electricity desired from utilities are listed for Residential and small and medium C/I customers (4-11), and for large C/I customers(4-16).
Estimated utility functions (5-2 to 5-6) for the following features:
    - Rate Plan (fixed or seasonal, $/kWh)
    - Contract (none, 1 year, 5 years)
    - Electricity Supplier and Customer Service Provider
      (local or central, well known or unfamiliar)

Large C/I customers measured each of above features for both base and -incremental load, plus base and incremental load coverages (fixed no limit, subject to maximum)
Willingness-to-pay estimates for above features:
    - residential (5-11)
    - small C/I (5-20)
    - medium C/I (5-25)
    - large C/I (5-32)

Switching behavior (6-4)

7) <u>Priority Service: Unbundling the Quality Attributes of Electric Power</u>;
Interim Report Nov 1986 EA-4851
Provides a theoretic framework for assessing customer outage costs and creating products that maximize the amount customers choose to pay. Does not contain data. Introduces the idea of priority insurance, a plan that reimburses consumers for outages. This could provide a measure of willingness to pay. Classifies outages only by MWH lost by consumer, not by time of day, amount of advance notice, or other factors useful in measuring the severity of an outage.

8) <u>Analysis of Residential Response to Time-of-Day Prices</u>; Final Report May 1982 EA-2380
A framework for a demand model by time-of-day. Includes data from one experiment (Arizona – chapter 7). Demographics only relate to variables that directly affect electricity consumption (family size, appliance stock index, air conditioning variable). An analysis of customer choice by cost avoidance, but provides insight on willingness-to-pay by time of day.

9) <u>Impact Evaluation of Demand-Side Management Programs</u>; Volume 2: Case Studies and Applications, Final Report September 1991 CU7179, V2
Summarizes methodology and effects on consumer behavior of several residential, commercial, and mixed sector DSM programs. The different programs use different data collection methods: customer surveys and controlled program experimentation. Results focus mainly on savings in DSM group over control group. Includes a theoretic framework for analyzing impact.

10) <u>The Value of Service Reliability to Consumers</u>; Proceedings, May 1986 EA-4494
Collection of articles on electricity service reliability

11) <u>Priority Services Design and Forecasting Project: Priority service methods at Commonwealth Edison</u>;, Hamm, G.L.; Wood, R.O.; Buchanan, J.B. Applied Decision Analysis;
Quinn, J.A.; Caves, D.W. Christensen Associates, Dec 1992 TR-101431
A study performed by ADA for Commonwealth Edison to evaluate interest in controlled energy service. A combination of logit choice model and C-VALU model are used to generate results. Characteristics of control periods examined are advance notice, duration, frequency, and price. Demographics include small and large, industrial and commercial customers. A distinction is made between current participants and non-participants in a controlled energy program. Contingent ranking method is used, requesting that participants select the most attractive energy package from a list of alternatives. The attributes measured in the survey are listed below.

12) <u>Priority Services Design and Forecasting Project: Priority service methods at Union Electric Co.</u>; Hamm, G.L.; Wood, R.O.; Buchanan, J.B. Applied Decision Analysis; Quinn, J.A.; Caves, D.W. Christensen Associates, Dec 1992 EPRI-TR-101430
A study performed by ADA for Union Electric Co. to evaluate interest in controlled energy service. A combination of logit choice model and RECURSIVE model are used to generate results. Characteristics of control periods examined are advance notice, duration, frequency, and price. A distinction is made between current participants and non-participants in a controlled energy program. Contingent ranking method is used, requesting that participants select the most attractive energy package from a list of alternatives.

13) <u>CLASSIFY-Profiles Volume 1: Residential Customer Needs and Energy Decision Making</u>;
National Analysts, Inc.; D. Lineweber, C. Finkbeiner
EPRI Final Report December 1994, TR-104567-V1
A segmentation of residential customers and description of their needs relating to electricity

14) CLASSIFY-Profiles Volume 2: Commercial and Industrial Customer Needs and Energy Decision Making; National Analysts, Inc.; J. Berigan, D. Lineweber, C. Finkbeiner Final Report April 1995, TR-104567-V2
A segmentation of customers based on needs, along with a table of measurable characteristics of each segment for commercial (Appendix A) and industrial (Appendix B).

15) Green Power Guidelines, Volume 1: Assessing Residential Market Segments; TR-109192-V1, December 1997
A literature review, focus group, and survey analysis of the market for green power. Includes a needs-based segmentation of residential customers and some demographic characteristics, as well as a willingness-to-pay analysis for green power. Addresses issues of different definitions of green power and how each is perceived by the different segments.

16) Designing New Utility Programs and Services: Case Studies on the Use of Conjoint Analysis; 1996, TR-105778
A conjoint analysis survey by Niagara Mohawk Power Corporation, EPRI, and Research Triangle Institute (RTI) to assess customer willingness to pay for attributes of heat pump DSM, green power, and other DSM programs.

17) Customer Demand for Service Reliability: A Synthesis of the Outage Costs Literature; Caves, D.W.; Herriges, J.A.; Windle R.J.; Laurits R. Christensen Associates, INC. , Sept. 1989 EPRI-P-6510
Prepared by EPRI to evaluate the worth of Priority Service Programs. It has a comprehensive listing of studies and methodologies which can be used to price Outage Costs.

18) Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs, Volume 1: Measurement Methods and Potential Applications in Reliability Cost-Benefit Analysis; RCG/Hagler, Baillly, April 1990 EPRI EL-6791
Evaluation and discussion of outage cost measurement methodologies, referring to results of Bonneville and Major Southeast Utility studies (volumes 2 and 3 of Cost-Benefit series)

19) Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs, Volume 2: Measurement of Interruption Costs for the Bonneville Power Administration; RCG/Hagler, Baily, Inc., April 1990 EPRI EL-6791 Vol. 2
Results of a study performed by PERI on BPA. Analysis of residential done with CVM. Analysis of C&I done with direct cost assessment.

20) Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs, Volume 3: Measurement of Interruption Costs for a Major Southeast Utility; RCG/Hagler, Baily, Inc., Principal Investigator A. P. Sanghvi., May 1990 EPRI EL-6791 Vol. 3
Results of a study performed by PERI on a major Southeast Utility. Analysis of residential done with CVM. Analysis of C&I done with direct cost assessment.

21) Status of Static UPS Applications in the United States; Chester & Schmidt Consultants., Principal Investigators T. L. Chester and R.V. Schmidt, November 1989 EPRI CU-9498
How uninterruptible power supply products are viewed by users, manufacturers, and utilities, what the future may bring with regards to the market and applications, and general information regarding sales and EPRI’s influence.

22) Residential Customers: Perceptions About Utility Providers and Electric Switching Intentions; PNR & Associates, Principal W. Serad, July 1997 TR-108465
A survey of 30,000 consumers was made to determine the electric utility attributes and consumer demographic which create switching situations. The survey was done for several types of utilities but this report focuses mainly on the electric utilities industry.

23) Designing an Integrated Menu of Electric Service Options: Modelling Customer Demand for Priority Service Using C-VALU—the Niagara Mohawk Application;
Laurits R. Christensen Associates, Inc., Principal Investigators: D. W. Caves and J. D. Glyer, October 1992 TR-100523
C-VALU is a computer simulator that was used by EPRI to study the affects of Priority Service on customer behaviours. Here is a summary of the findings from a several simulation runs as well as a description of how to design and run simulations for yourself.

24) Residential Customer Preference and Behaviour: effective Residential Program Design With PULSE; National Analysts, Synergic Resources Corporation and QEI, Inc.,
March 1990 EM-5909
PULSE is a system, created by EPRI by which electric utilities can perform their own market and product analysis to discover customer preferences and optimal product offerings. This describes how PULSE works, how to perform a PULSE study, and what information it can give you.

25) Environmental and Socio-economic Consequences of a Shortage in Installed Generating Capacity; Mathtech, Inc. and ICF, Inc., June 1982 EPRI EA-2462
A review of several methodologies for studying outage costs in both the residential and industrial sectors. Complete with sample case studies and many mathematical formulas.

Non-EPRI Reports

1) Customer Demand for Service Reliability: Existing and Potential Sources of Information;
Douglas W. Caves, Joseph A. Herridges, Robert J. Windle. Christensen Associates April 1989
Two Main Sections: Customer Outage Costs and Priority Service Programs.
I. Outage Costs. Summarizes methodologies and results from several different studies on outage costs for residential, commercial, and industrial customers
II. Priority Service Programs
Analyzes customers' value for Interruptible/Curtailable power, demand subscription (subscription to maximum demand level for rebate), and direct load control.

2) Guide to Value-Based Distribution Reliability Planning, Volume II: Appendices; Canadian Electricity Association, January 1996
A summary of outage cost estimation methodologies, problems inherent in existing studies, and key findings from various surveys. Includes a substantial collection of tables of outage cost data from several surveys. Addresses residential, industrial, commercial, and agricultural customers.

3) Costs of Interruptions of Electrical Service in the Commercial Sector; U.S. Dept. of Commerce, National Technical Information Service. Sep 1978, Gregory Krohm.
A survey to assess outage costs for commercial and industrial customers based on losses in a severe power outage following an Illinois ice storm in 1978. Contains survey methodology, formulas, and some results.

4) A Survey of Attitudes and Experience Relating to Electric Power Interruptions; The National Electric Reliability Study: Technical Study Reports,
D.D. Harver, A.S Forrest, G.J. Langley, United States Department of Energy April 1981.

5) The Short-Term Cost of Electricity Supply Interruptions; Irving Yabroff, National Electric Reliability Study Volume II: Technical Study Reports, Oct. 1980
SRI outage cost study of 21 industrial, 7 commercial, and 1 residential categories. Includes brief summary of previous outage cost work. Describes survey methodology and results, aggregates results by region, and displays sensitivity analysis of day of week and by firm-specific parameters (critical duration, recovery time, cleanup cost, standby power)

6) SRP Service Quality Power Outage Analysis Research Notes; West Group Research, Feb 1998.
Reports aggregate results of customer satisfaction survey, and relation between reliability indices and satisfaction level. In many cases, there is no statistically significant relationship. Most interesting outcome is that the MAIFI and Worst 30 indices work in reverse of expected ratings. That is, customers that report being more satisfied tend to have higher values for each index.

B.2 Journal Articles

1) **"Assessment of Electric Service Reliability Worth"**, R. Billinton, G. Tollefson, G. Wacker; Electrical Power and Energy Systems, Vol 15 No. 2 1993.
An overview of methodologies for assessing customer outage costs, and a brief review of the studies conducted by the University of Saskatchewan. Methodologies examined include
    - Analytical methods (estimates based on wage rates or other measures)
    - Case studies of blackouts
    - Customer surveys
    - Contingent valuation methods
    - Direct costing methods
    - Indirect costing methods

University of Saskatchewan surveys include residential, commercial, industrial, and agricultural customers.

2) **"Comprehensive Bibliography on Reliability Worth and Electrical Serice Interruption Costs: 1980 – 1990"**; G. Tollefson, R. Billinton, G. Wacker, Transactions on Power Systems, Nov. 1991

3) **"Cost of Electrical Interruptions in Commercial Buildings"**, Power Systems Reliability Subcommittee Report, Philip E Gannon, IEEE Conference Record of 1975 Industrial and Commercial Power Systems Technical Conference, May 5-8, 1975.
Outage cost survey of 48 companies, representing a total of 55 buildings. The following quantities are assessed:
    – Cost of power outages to commercial buildings ($/kWh undelivered, $/square foot-hr, $/employee-hr)
    – Critical service loss duration time

Data was collected for the buildings as well, regarding auxiliary generators, type of electrical service, and physical characteristics. Outage cost information is aggregated by:
    – Office Building vs. all commercial buildings
    – Office building: with or without computers

4) **"Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs",** Ontario Hydro Surveys. Outage Costs (E-42). Reliability report.

5) **“Costs of Electricity-supply Interruptions to Industrial Consumers”**; A.F. Jackson, B. Salvage, Proc. IEEE, Vol 121, No. 12, December 1974.
23 manufacturing companies were visited in an effort to assess the effects and costs of interruptions from under a minute to 8 hours. Firms were grouped according to plant startup time and risk of plant/material damage for the analysis. Costs are supposed to represent physical damage and lost production that cannot be made up. Costs can be estimated as the sum of two components, one varying with interruption frequency and the other with duration. Graphs of interruption costs are included.

6) **“Costs of Inadequate Capacity in the Electric Utility Industry”**, William B. Shew, Energy Systems and Policy Volume 2, Number 1, 1977.
Focus is on loss of GNP due to power outages. Individual outage costs are alluded to, but not studied explicitly. The only relevant outage cost information is a table on page 94: Values of Parameters Used to Estimate Shortage Costs.

7) **“Customer Retention in a Competitive Power Market: Analysis of a ‘Double-Bounded Plus Follow-ups’ Questionnaire”**, Yongxin Cai, Iraj Deilami, Kenneth Train. Energy Journal, Vol. 19, No. 2. 1998
Uses survey and mathematical model to predict customer switching behavior. Survey consists of trade-off style questions (worded as “would you switch if…” rather than “would you prefer…”), varying price only or price and one other attribute at a time. Attributes of power quality considered are reliability, renewable power, energy conservation assistance, and customer service. ‘Double-Bounded’ means that the survey is interactive, raising or lowering price discounts until and upper and lower bound are attained on the attribute value that would cause a customer to switch providers, all else held constant. Presents mathematical framework for analyzing the data, and a summary of switching probabilities. No demographic information is assessed from respondents.

8) **“The Demand for Electricity Services and the Quality of Supply”,** Romesh Dias-Bandaranaike, Mohan Munasinghe; The Energy Journal, Vol. 4, No. 2 1983.
Theoretic framework for constructing double-log demand functions for varying levels of electricity quality. Quality is defined as a combination of voltage variations and outages, which tend to be highly correlated. The formulas derived are combined with empirical data from Costa Rican commercial customers, and used to estimate the coefficients of an electricity quality value formula.

9) **“Economic Criteria for Opitmizing Power System Reliability Levels”**, M. Munasinghe, M. Gellerson (1979), The Bell Journal of Economics, Vol. 10, No. 1, pp 353-365
A methodology and results for approximating outage costs for residential, commercial, and industrial energy consumers. Residential outage costs are based on a loss of leisure estimated by wage rate. No surveys are involved. Demand and income data from Cascavel, Brazil are used in the estimates.

10) **“The Electric Utility-Industrial User Partnership in Solving Power Quality Problems”**; John E. Flory, Thomas S. Key, William M. Smith; IEEE Transactions on Power Systems, August 1990
Summary of views on power quality from various industrial users and utility personnel. Informal interviews with representatives from various industries (including automotive manufacturing, chemical manufacturing, semi-conductor manufacturing), to establish the most salient power quality problems and their causes.

11) **“Factors Affecting the Development of a Commercial Customer Damage Function”**; R. Billinton, G. Wacker, R.K. Subramanian, IEEE Transactions on Power Systems, Vol. PWRS-1, No. 4, November 1986.

A study of the effects of standby power on outage costs in the commercial sector. Based on same survey as Billinton, Wacker, Wojczynski study. Addresses no standby system, engine-driven system, and battery system. Outage costs are found to be highly sensitive to the existence of a standby system. Outage parameters include duration, season, time of day, and day of week.

12) **"Green Pricing: The Bigger Picture"**; Bryan Byrnes, Maribeth Rahimzadeh, Renee de Alba, Keith Baugh; Public Utilities Fortnightly, August 1996.
Green power has so far only been marketed to residential customers, but there is evidence that commercial customers have as much interest and a 300% - 700% higher willingness to pay.
Crafting a program: a list of attributes that a successful green power program should possess.

13) **"Interruption Cost Methodology and Results – A Canadian Commercial and Small Industry Survey"**, E Wojczynski, R. Billinton, G. Wacker; IEEE Transactions on Power Apparatus and Systems, Vol PAS-103, No. 2, February 1984.
A commercial and industrial mail survey to assess outage costs. Base case is defined as an interruption on Friday at 10:00 AM near the end of January. Day of week, time of day, and month variations are assessed relative to the base case.
Table 1 – Useable Survey Responses (439) – Number of responses by SIC
Damages included in costs are: lost business, wages paid to staff unable to work, equipment or goods damaged, but not sales that can be made up after business resumes
Table 2 – Interruption Cost Estimates (440) – Cost estimates (total, $/KWH, $/KW) by commercial and industrial, by duration.
Table 4 - Possible cost saving arrangements (441) – Respondents were asked whether they could make cost saving arrangements given duration information or advance warning.
Respondents traded off frequent, short outages with infrequent, long outages.
Existence of standby equipment, industrial restart times, and commercial energy consumption and peak demand were also assessed.
Results were compared with Ontario Hydrostudy results, and differences were found to be reasonable.

14) **"Interruption Cost Methodology and Results - A Canadian Residential Survey",** G. Wacker, E. Wojcsynski, R. Billinton, IEEE Transactions on Power Apparatus and Systems, October 1983, Vol. PAS-102, No. 10
Canadian mailed survey of residential outage costs, with 100 respondents. Direct cost assessment questions were asked, in addition to questions regarding preparatory actions consumers might take to avoid the inconvenience caused by a power outage. Factors investigated include interruption characteristics – duration and frequency of occurrence, season, day of week, time of day; user characteristics – number and age of household members, sex and education of respondent, type of dwelling, location of dwelling, electric heat usage, attitude towards utilities, energy consumption, monthly electrical bill, income earning business at home, user experience with interruptions.

15) **"Interruption Costs, Customer Satisfaction and Expectations for Service Reliability"**, Michael J. Sullivan, B. Noland Suddeth, Terry Vardell, Ali Vojdani; IEEE Transactions on Power Systems, Vol. 11, No. 2, May 1996.
Summary of Value Based Reliability Planning (VBRP) survey performed by Duke Power on residential, commercial, and industrial customers. Residential survey was by mail, addressing WTP, with 1584 respondents. Small and Medium Commercial/Industrial survey was phone/mail combo, with 1080 respondents. Large C/I was in person, with 210 respondents. Outage parameters include advance notice and duration. Voltage sags are also addressed. Segmentation is alluded to. Orders of magnitude difference appear in ranges of results.

16) **"A Major UK Distribution Power Quality Survey"** Eamon J. Delaney, David R. Mueller, Nigel G. Foster, Proceedings of the 29th Universities Power Engineering Conference, 1994
An increasing emphasis is being placed on the quality of electricity supply, due to automated operations that have strong needs for high quality power. Monitoring equipment can be placed into three broad categories:
    - Low Frequency Power Monitors (RMS data only)
    - Fault Recorders (only record info during fault conditions)
    - Full Feature Power Quality Monitors (many types of power quality parameters, both steady state and transient)

    Steady state disturbances: high or low RMS voltage, voltage imbalance, harmonic distortion, current distortion.
    Transient disturbances: records "events", or instances of the voltage exceeding specified parameters for voltage waveshape.
    Analysis is very data intensive (~ 1 GB of data for East Midlands Electricity project discussed).

17) **"Optimal Dispatch of Interruptible and Curtailable Options";** Douglas W. Caves, Joseph A. Herriges, Operations Research Vol. 40, No. 1, Jan-Feb 1992.
Describes a dynamic programming algorithm to maximize the net benefit of calling an interruption at any given time t. focuses on mathematical statement and proof of the optimality of the algorithm, and uses Niagara Mohawk Power Corporation data in an example application.

18) **"Power quality: End user impacts"**; J.C. Smith; Energy Engineering, 1991 p 35-54
Discusses problems and solutions of power quality from perspectives of the utility, the customer, and the equipment supplier. Looks at transient and steady state waveshape distortion, and the sources of these problems. Customer site corrections: Equipment Power Supplies, Voltage Regulators, Line Conditioners, Motor-Generator Sets, UPS.

19) **"Reliability Pricing of Electric Power Service: A Probabilistic Production Cost Modeling Approach";** Youssef Hegazy, Jean-Michel Guildman,
Energy Vol. 21, No. 2, pp 87-97, 1996.
Methodology for pricing of electricity with varying levels of reliability. Uses outage cost data from EPRI EA-2642 to create a table of outage costs by time of day for 4 customer classes: large industrial, small industrial, residential, commercial. Investigates three different pricing schemes (SPOT, RAMSEY, RELIAB), and calculates the total economic welfare for each scheme. Total economic welfare is a function of a customer choice model and a supply-cost model.

20) **"Report on Reliability Survey of Industrial Plants, Part II: Cost of Power Outages, Plant Restart Time, Critical Service Loss Duration Time, and Type of Loads Lost Versus Time of Power Outages"**; IEEE Transactions on Industry Applications,
Vol 1A-10, No. 2, March/April 1974
Reports results of survey performed by IEEE Industrial and commercial Power Systems Committee on outage costs of industrial plants. Costs were measured by:
    Extra expense incurred because of a failure only
    Value of lost production during downtime
    Maximum demand when plant is operating at capacity
    Results include:
    Cost of power outages to industrial plants in US and Canada ($/kW interrupted + $/kW undelivered)
    Plant restart time after complete shutdown
    Critical service loss duration time (maximum power failure that will not stop production)
    Type of loads lost vs. time of outage

21) **"Shock the Electricity Market"**, International Journal of Retail & Distribution Management, pg. 59. Jan 1, 1998, MCB University Press Ltd.
A brief article revealing some statistics on predicted customer switching behavior:
29% will definitely remain loyal, 55% are willing to change suppliers
Most important factor in purchase decision:
- supplier identity (25%)
- price (18%)
- product (18%)

Alliances between utilities and bundling of energy with other home services are preferred qualities
60% are highly satisfied with current service, 39% feel some loyalty.

22) **"A Simple Method for Evaluating the Marginal Cost of Unsupplied Electricity"**, Benjamin Bental, S. Abraham Ravid, The Bell Journal of Economics
Uses backup power generation costs to estimate marginal costs of outages. Assumes that businesses will use backup power only when the expected benefits balance the costs, and sets up a simple formula.

23) **"Utilities Today Must Provide 'Clean' Power"**; Wayne Beaty, Electric Light and Power, March 1993
Customer needs for power quality are growing as equipment is becoming more sensitive and customers are better informed. Electricity waveform is important, as well as costly outages. Sources of power quality problems are listed and described, as well as some of the existing solutions (including UPSs, power conditioners, etc.). In the near future, power quality is likely to become the utility's concern rather than the customers'.

24) **"Why Your Customers Switch"**, Kerry Diehl, Rich Gillman.
Public Utilities Fortnightly, Apr 15, 1997
A segmentation of customers and analysis on how likely they are to switch energy service providers. Study is based on consumer behavior in deregulated telecom. Most influential factor in switching behavior found in this study is age of consumer.

B.3 Books

Customer Choice: Finding Value in Retail Electricity Markets
Ahmad Faruqui, J. Robert Malko
Public Utilities Reports, Inc. 1999

Introduction

Chapter 1: The Brave New World of Customer Choice

Energy Service Providers (ESPs) are preparing for a competitive market. This book surveys a range of strategies to help ESPs create lasting value for shareholders and customers.

Figure 1-1: Restructuring of the U.S. Electricity Industry – a summary of the status of deregulation throughout the U.S.
Studies reveal that the key driver for switching ESPs is to save money.
Customers are reluctant to switch without a price incentive
Customers will switch if they perceive they can save money
Other drivers include: green power, customer service, reliability, value-added services.
Switchers may be switching to unregulated affiliates of UDCs

Section I: What is Customer Choice?

Chapter 2: The Open Market Customer

Periods of growth and evolution – discussion of the history of the electric energy business

How big is the marketplace? – Open Market Customer served by broad industry:

- providers of energy to residential, commercial, and industrial users
- providers of equipment and technology to convert energy to meet customers' needs
- providers of design, construction, operation, maintenance, and finance of equipment
- those who provide knowledge and information to the energy marketplace
- federal, state, and local level regulators of marketplace

Table 2-1: Functions the Open Market Customer Must Perform

Table 2-2: Business Functions in the Open Market Customer Energy Industry

To compete or not to compete – in response, utilities are embracing one of two business areas:

- regulated wires business
- adding energy or energy service components

What are the real costs? – EPRI commissioned studies of 4 large C/I sites

Table 2-3: Annual Expenditures for Energy/Services

Table 2-4: Total Investment for Energy/Services

List of issues facing open market customer (pg 18)

Is there one open market customer? – open market customers are diverse

More choices – Open market customer will see in the future:

- more technologies that convey energy to services
- new energy-efficient lighting, heating, etc.
- more variety of service reliability products at different prices
- more marketing and billing options
- innovative marketing strategies
- energy service outsourcing
- financial offerings
- methods to control energy consumption

Chapter 3: Determining What Customers Really Want

Gleaning information from customers – Utilities are having to collect data on what consumers value for the first time.

Table 3-1: Characteristics of organization-Centered and Customer-Centered Mindsets

Standards-based approach:

- determining what customers want
- codifying preferences
- enforcement

this suffers from client-agent problem (engineers don't know what customers want)

Market-test approach: assess customer needs based on what market players are successful. This is difficult since open competition is new.

Asking the consumer directly: (discussion of pros and cons of surveying customers)

Sending messages to consumers – forms:

- complaint handling
- provision of information
- consumer education
- public relations

Messages address a variety of attributes:

- knowledge
- skills
- beliefs

- attitudes
- values

Chapter 4: Using Choice Modeling to Understand Customer Preferences: A Tale of Four Studies

Four case studies on modeling customer choice:

Revealed preference

- same offers to many customers
- customer-specific offers

Stated preference

- switch from current supplier
- choose among new suppliers

Residential customers in Pennsylvania pilot: Revealed preference data when offers are common to large groups of customers –

Pilot background: generation was deregulated

Residential customers were provided with:

- $0.03/kWh credit to shop for new generation and capacity
- 13% credit in the non-generation portion of electric bill

Customer data

Model specification: multinomial logit model

Lessons learned

Commercial customers in Pennsylvania pilot: customer-specific offers – commercial customers' choice of supplier

Customer data: interviewed 436 commercial customers

Model specification: multinomial logit model

Lessons learned

Application of double-bounded with follow-up stated preference method to California commercial customers – estimates commercial customers' likelihood of switching electric suppliers

Double-bounded plus follow-up survey approach: phone survey to 600 small-medium commercial customers

Model approach and generic results: maximum likelihood estimates obtained by:

- estimate overall price discount level from 50% of customers to switch
- use results to estimate value of non-price attributes

Predicted switching rates drop considerably when customers consider non-price attributes.

Application of conjoint stated preference method to California commercial customers – mail survey using conjoint analysis

Survey data

<u>Table 4-4 Attributes Utilized in Creating Conjoint Packages</u>

Modeling approach and comparison of findings with double-bounded plus follow-up method

Summary

Chapter 5: How to Hear the Voice of the Customer

Listening to the voice of the customer

Voice of the Customer (VOC) is a qualitative technique involving one-on-one interviews with customers.

Hierarchy of customer needs:
Tertiary: What was said?
Secondary: What does that mean?
Primary: What is the overall need?

Determining customer preferences

Choice-based conjoint analysis is a tool for determining customer preferences once needs have been established.

Preference vs. actual choice

Asking some behavioral questions as well (loyalty, inertia, switching) helps to predict actual choice, as opposed to just preferences
Conclusion

Section II: What is Driving Customer Choice?

Chapter 6: Convergence of Utility Services: Technological Challenges and Opportunities

Utility deregulation: Technology push/market pull
Deregulation: the current situation
Convergence, step 1: intra-industry mergers
Convergence, step 2: gas & electric utility mergers
Convergence, step 3: communications and other services
International aspect of convergence
Technology for strategic advance – cost reduction, increased customer satisfaction, asset utilization, participation in more complex markets
Utility of the future –

- patchwork of service arrangements will emerge
- convergence across industries (communications, electricity, gas, etc.)

Chapter 7: Preparing for Gas/Electric Convergence: Mergers or Alliances?

Diversification or specialization?
The decline of scale and scope
Competing in convergent markets
The demand side
The strategic alliance alternative
Conclusions

Chapter 8: Lights Out for Regulated Monopolies

Section III: What Opportunities are Created by Customer Choice?

Chapter 9: Electric Restructuring and Consumer Interests: Lessons from Other Industries

Examining analogous industries – gas, long-distance telecom, airlines, trucking, railroads
Significant customer benefits – in all 5 industries, customer benefits grew over time.
Widespread customer benefits
Low-cost customers still saved money
What's seen and what's not seen –

- savings at the corporate level still trickle down to the consumer
- ingenuity in deregulated industries improves

Chapter 10: Lessons from the Natural Gas Business

It won't work in our industry
We don't want choice
Customers love choice
The paper world

Section IV: What Strategies Should Energy Service Providers Pursue?

Chapter 11: Creating Competitive Advantage by Strategic Listening

What is strategic listening? – a management process that involves listening to all players in the value chain – from customers to competitors to suppliers

Why strategic listening? – planning paradigm has shifted from regulated business planning to competitive market planning

Competitive strategies

- become low cost provider
- become niche provider
- expand product horizons

What is not strategic listening?

- Anemic listening – information through assumptions, rather than active listening
- Unfocused listening – listening w/o strategic process

Pursuing strategic listening

Utility examples

Other industry examples

Compaq Computer Corporation

Ford Motor Company

VF Corporation

Nintendo Company Ltd.

R.S. Means Company

What is worth listening to?

Methods of strategic listening

Conclusions

Chapter 12: Is Anyone Listening?

Meeting the needs of the customer

Listening to what customers want

The customer-supplier relationship

Chapter 13: Creating Economic Value through Risk-Based Pricing

Risk-based pricing (RBP) addresses different preferences for price volatility

- spot pricing
- forward pricing
- combination of spot and forward
- guaranteed pricing
- guaranteed bill

Market strategies

Customer-merchant preferences

Types of risk-based pricing

Economics of RBP

Benefits of risk-based pricing for the retail electricity merchant

Market simulation: "Product Mix" – a simulation model from EPRI – a tool to help utilities assess consequences of offering retail products with a variety of risk profiles

Pricing tactics

Conclusions

Chapter 14: A Market-Oriented Approach to Electric Utility Strategy

The satisfied customer and company profitability

Market research and segmentation analysis

Marketing mix elements

Distribution considerations

Conclusions

Chapter 15: Managing Customer Choice: Implications from Market Segmentation Research, Theory, and Practice

Customer loyalty and customer choice – loyalty is difficult to measure

Everyone makes choices – insights:

- products developed for a broad class may be sub-optimal for almost everyone
- customer may buy sub-optimal products but not build customer loyalty
- over time, capturing large market share may be impossible with “mass” products
- the number of segments that might be served is unknown at this point
- not all providers will want to serve all segments

Developing a branding strategy

Developing a customer retention strategy

Practical implications for ESPs

Customer assessment of green power products

How can market segmentation be applied in the case of green power?

marketing portions of process:

step 1: feasibility screens

step 2: feasibility analysis

step 3: concept testing

step 4: targeting analysis

step 5&6: pilot offer and rollout

Conclusions

Chapter 16: Implications of Retail Customer Choice for Generation Companies

Electricity value chain:

- creation of electricity through generation (GENCO)
- transmission (TRANSCO)
- distribution (DISCO)

GENCOs – the historical perspective

GENCOs – the competitive challenge

- generation is no longer a monopoly activity
- industry must be restructured by breaking the existing utility into independent units

Future of the GENCO industry – business processes

Business strategies for selected companies

- PECO energy – growth through nuclear
- GPU Inc. – Counting of transmission and distribution with a little generation of the side
- United Illuminating – Exiting the generation business

GENCO keys to success

Conclusions

Chapter 17: Customer-Connected Strategies

Value Compass framework addresses 4 dimensions of customer and shareholder value creation:

- selecting the right customers to serve
- determining the right value proposition to offer those customers
- identifying the industry value-added role that best leverages the firm’s capabilities
- creating appropriate reward and risk sharing mechanisms with customers, suppliers, and employees

The strategic landscape of the utility industry today

Five main strategic directions being taken:

- consolidation
- conglomeration
- convergence
- concentration

- confusion
  Customer emancipation: freeing of customers to choose is what causes change
  Customer-based versus product-driven strategies
  The connection between customer and shareholder value
  Searching for untapped customer and shareholder value
  Mapping strategies with the Value Compass
  The grand ESCO experiments
  Effective customer portfolio management
  The distribution of customer relationship value: All customers are not created equal
  Economic segmentation: The Willie Sutton principle
  The customer relationship supply curve
  Optimizing a company's value proposition
  Avoiding the total solution virus
  Determining the right role on the industry value-added chain
  Establishing effective risk and reward sharing arrangements
  Conclusion

Section V: What Enabling Technologies and Infrastructure are Needed?

(Does not address customer values)

Section VI: What Are the Key Market Structure Issues?

(Does not address customer values)

Target:
Distribution Systems

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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