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METHODS TO QUANTIFY ENERGY SAVINGS FROM DEMAND-SIDE MANAGEMENT PROGRAMS: A TECHNICAL REVIEW

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EXECUTIVE SUMMARY

In recent years, energy savings from demand-side management (DSM) initiatives have caught the attention of utilities, regulators, and legislators. The high cost of new power plants and the public's popular support of energy efficiency have provided much of the stimulus for utility DSM activities. Kilowatt and kilowatthour savings resulting from DSM initiatives ultimately translate into dollar savings and avoided construction of new generating facilities. This report focuses on methods for measuring or monitoring kilowatt and kilowatthour savings from DSM activities. Evaluating the amounts of dollar savings and other economic benefits is outside the scope of this report.

As defined by the Electric Power Research Institute (EPRI), DSM initiatives fall into six major types: strategic conservation, peak clipping, valley filling, load shifting, strategic load growth, and flexible load shape. For some initiatives, total energy use falls, as in the conservation initiative. For other initiatives, such as process reorientation, energy consumption may not change; rather, peak load is reduced (kilowatt) and load factors are increased. All these initiatives share the feature of potentially generating dollar savings and, ultimately, reducing the average cost of electricity.

Evaluating energy and peak savings serves several functions. In the preprogram-developmental phase of a DSM initiative, savings are evaluated to reach a decision on whether or not to fund full-scale programs. Even when such programs are run, commissions may still want to evaluate their savings over several years in determining financial incentives. In some instances, a utility might initiate a pilot project before undertaking a full-scale program, particularly when net benefits are in doubt.

For some programs in the preprogram-developmental stage, evaluating the energy savings at a high degree of accuracy may not be necessary. A more accurate quantification of potential benefits would be required, however, for initiatives where DSM bids are evaluated and where regulators offer utilities incentives for promoting energy savings. With electric

utilities now making large investments in DSM programs, state commissions rightly are beginning to ask more frequently how much electricity is actually being saved.

Methods for quantifying energy savings can be grouped into two broad categories: engineering models and econometric models. Engineering models simulate the characteristics of end-use equipment and predict the savings assuming the operation of the equipment was controlled in a predetermined fashion. Econometric models are better suited for estimating the number of customers that would participate in a large-scale program and for dealing with the self-selection problem that arise when estimating the energy savings from a voluntary conservation program.

Engineering methods and econometric methods in many instances complement each other in quantifying energy savings. Engineering methods are better suited for modeling the <u>technical</u> characteristics, while econometric methods can model the <u>behavior</u> of consumers in responding to a DSM initiative.

General statements rarely can be made that one method of evaluation is always better than another. Selecting the best method should be guided by the type of initiative, the underlying objective, and the characteristics of the electric power system. Sometimes, different methods can be complementary, for example, in verifying the energy savings estimates for a particular DSM program.

No matter which method is applied, energy savings cannot be calculated with precision, but can only be estimated using as the base an energy use prediction of the energy that would have been consumed by participants absent a DSM program. Estimating savings more precisely will become particularly important when commissions offer utilities the opportunity to receive financial incentives for achieving energy savings. In protecting ratepayers, commissions may choose a conservative or a lower-than-the-mean estimate of energy savings in determining what incentive a utility should receive.

An important question for state commissions centers on who should verify the energy savings. It would be imprudent for commissions to accept the utility's estimates without reviewing them, particularly when energy savings are tied to pecuniary incentives funded by general ratepayers. In addition, even when receiving incentives, utilities would have an incentive to misreport the actual energy savings to their regulators. That is, utilities would like to receive financial rewards for perceptibly good DSM programs while, in actuality, encountering small losses in their sales and revenues. Some state commissions, however, may not have the resources to conduct a detailed independent review process. Such commissions might, instead, choose to review and question the evaluation methods proposed or used by the utilities. At the other end of the spectrum, other state commissions might prefer to take a more active role in the details of the evaluation process including producing independent estimates of energy savings.

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FOREWORD

Having a good understanding of the methods available and employed to quantify energy savings from DSM programs is important for several reasons. One is so that regulators and others are comfortable in encouraging or requiring DSM programs for their jurisdictional utilities. A second is that, once implemented, regulators need assurance that payouts and paybacks where incentive returns are involved with DSM are actually realized in the amounts and ways claimed.

This report is intended to contribute to both ends.

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CHAPTER 1

INTRODUCTION

Accurately estimating the savings from conservation programs is becoming an increasingly critical issue as public utility commissions adopt policies designed to encourage utilities to invest in conservation programs when they are cost effective. Typically, when such policies are adopted the firm's earnings are tied to the expected savings from conservation investment. The reason for this is to remove the firm's disincentive to invest in conservation measures that otherwise would decrease their sales and profit. This can be accomplished by splitting the value of the expected energy savings (resource or billing) between the utility and its ratepayers, making adjustments to the firm's rate of return, or allowing a lump-sum or "bounty" payment for meeting prespecified conservation goals.[1]

In addition, other programs increasingly are related to the estimated energy savings from demand-side programs. Examples include the 1990 Clean Air Act Amendments' provision that allows electric utilities to earn additional allowances for adopting a "qualified" conservation program and recently proposed federal legislation designed to, among other things, encourage conservation. Public utility commissions must be particularly vigilant when estimating conservation savings or reviewing a utility's estimate since these incentives could give the utility a motivation to overstate expected program savings. As expressed by Eric Hirst, "serious" evaluation of demand-side programs has only recently occurred, especially for determining incentive payments to utilities conducting large-scale conservation programs.[2]

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1. For a detailed discussion of these methods see David Moskovitz, *Profits and Progress Through Least-Cost Planning* (Washington, D.C.: National Association of Regulatory Utility Commissioners, November 1989).
2. Eric Hirst, "Analytical Foundations of Successful Utility DSM Programs," *Proceedings of the National Conference on Integrated Resource Planning* (Santa Fe, NM: The National Association of Regulatory Utility Commissioners, April 8, 1991), 100.

Unlike supply options, however, where the output of a plant is measurable when being proposed, DSM options must be estimated. This can occur either through engineering models, using experimental data on a group of volunteer households or firms, or estimating the savings retrospectively after a program has been adopted.

Prior to the 1970s, electric utilities planned under the assumption that electric energy demand was an exogenous, uncontrollable quantity.[3] They saw their responsibility in terms of predicting the demand and then planning the power supply to meet it.

Load management and load control activities by electric utilities were initiated in the 1960s and 1970s.[4] The early load control activities took place in Europe and New Zealand. In the United States, they did not begin to grow in popularity until the late 1970s. The object of these activities was to achieve load-shape changes in two ways: to build off-peak and off-season load by storage space heating and to clip load peaks by controlling electric water heating. These load management strategies are known as "valley filling" or "load shifting," and "peak clipping," respectively. The terms "load control" or "direct load control" refer to the process of a utility's load dispatcher controlling the operation of technologies such as electric water heaters or air conditioners.

Today, the term "demand-side management" (DSM) embraces a wide range of activities by the utility and its customers including load management or load control. It primarily refers, however, to conservation through use of more energy efficient technologies. Most DSM initiatives generally have an effective benefit horizon extending over a period of ten to thirty years while load management generally has a shorter time horizon.

Gellings and Talukdar point out that DSM actions are taken to:[5]

> . . .control load growth, alter the shape of the load curve, or increase the supply through nonutility or [independent] sources. The actions may be initiated to reduce capital expenditures, improve capacity limitations, provide economic dispatch, reduce the

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3. Sarosh Talukdar and Clark W. Gellings, eds., *Load Management*, (New York: IEEE Press, 1987).
4. Ibid.
5. Ibid.

cost-of-service, improve load factors, improve system efficiency, or improve system reliability. The actions may be normal procedures or emergency procedures.

"Normal procedures" refer to indirect actions of control such as conservation and incentives while "emergency procedures" include voluntary or mandatory energy curtailments and voltage reductions.

Categories of DSM Programs

The Electric Power Research Institute (EPRI) categorizes DSM programs into six basic types: strategic conservation, peak clipping, valley filling, load shifting, strategic load growth, and flexible load shape. Table 1-1 describe this categorization. These categories are well elucidated in several publications and by Talukdar and Gellings.[6]

Load Shape Activities

Utilities can directly control load shape in two ways. The first involves direct load control achieved by switching end-use equipment on and off. This is the most active area of technology development. Most of this development is directed at households, since residential loads generally have uneven load shapes. Controlling customer air conditioning and water heating equipment has been the most popular application of load control.

Load cycling represents the second method of direct load control. Instead of timing a specific group of end-use equipment for a certain duration as in the direct load control scheme, end-use equipment is switched off and on according to a predesigned pattern under a cycling strategy. For example, assume that turning 100 air conditioners off for thirty minutes would be required to reduce the system peak demand under direct load control. Under the cycling strategy, 500 air conditioners might be turned off and on in accordance with a selected pattern during the same thirty-minute period. As a matter of practice, not all the air conditioners would be turned off at the same time.

6. Ibid.

TABLE 1-1

LOAD-SHAPE AND DEMAND-SIDE ALTERNATIVES

Utility Load-Shape Objectives	Example of Customer Options: Residential	Commercial	Industrial
Peak clipping, or reduction of load during interruptible peak periods, is generally achieved by directly controlling customers' appliances. This direct control can be used to reduce capacity requirements, operating costs, and dependence on critical fuels.	* Accept direct control of air conditioners	* Accept direct control of water heaters	* Subscribe to interruptible rates
Valley filling, or building load during off-peak periods, is particularly desirable when the long-run incremental cost is less than the average price of electricity. Adding properly priced off-peak load under those circumstances can decrease the average price.	* Uses off-peak water heating	* Store hot water to augment space heating	* Add nighttime operations
Load shifting, which accomplishes many of the goals of both peak clipping and valley filing, involves shifting load from on-peak to off-peak periods, allowoing the most efficient use of capacity.	* Subscribe to time-of-use rate	* Install cool-storage equipment	* Shift operations from daytime to nighttime
Strategic conservation involves a reduction in sales, often including a change in the pattern of use. The utility planner must consider what conservation actions would occur naturally and then evaluate the cost-effectiveness of utility programs intended to accelerate or stimulate conservation actions.	* Supplement home insulation	* Reduce lighting use	* Install more efficient processes
Strategic load growth, a targeted increase in sales, may involve increased market share of loads that are or can be served by competing fuels, as well as development of new markets. Un the future, load growth will include greater electrification--electric vehicles, automation, and industrial process heating.	* Switch from gas to electric water heating	* Install heat pumps	* Convert from gas to electric process heating
Flexible load shape involves allowing customers to purchase some power at lower than normal reliability. The customer's load-shape will be flexible, depending on the real-time reliability conditions.	* Demand subscription service	* Group load cooperatives	* Interruptible rates

Source: Clark W. Gellings and Sarosh Talukdar, "Load Management Concepts," Load Management, Sarosh Talukdar and Clark W. Gellings, eds., (New York: IEEE Press, 1987), 7, © 1987 IEEE.

Utilities have used cycling strategies to control residential and commercial-package air conditioning units. A 25 percent cycling strategy, for instance, would turn off the compressor and cooling fans as follows: 7 1/2 minutes off and 22 1/2 minutes on. The reductions in peak demand and energy depend on the cycling strategy. The switching on or off is conducted either remotely or at the site of the end-use equipment.

In addition to direct load control, unlimited possibilities exist for indirect load control. Strategic conservation, time-of-day pricing, improvement of end-use equipment efficiency, and a host of other activities fall under the option of indirect load control.

Benefits of DSM Programs

Two distinguishable kinds of benefits arise from DSM programs. Programs such as home weatherization and the use of more efficient end-use equipment can be classified under strategic conservation. Similarly, peak clipping and strategic load growth measures usually display a clear difference in the energy consumed before and after the program.

Valley filling and load shifting may not necessarily change the user's total energy consumption. While the temporal pattern of energy use would change, the total energy consumed over a period might remain unchanged. Nevertheless, benefits might accrue because of the change in load shape from altered patterns of consumption. Shifting consumption from peak periods (when more expensive generating units are used on the margin) to lower demand periods produces dollar savings to the utility by increasing the use of lower-cost generating units. As an additional benefit, the reduced peak load would lower the requirement for reserve generating equipment.

In sum, dollar savings arise for one of two reasons: a reduction in energy consumption (or increase in conservation) or an improvement in load shape that results in smaller capital investments for energy supply facilities, net of any investment required for load shaping, storage, or conservation equipment.

Goals of the Report

This report examines and evaluates methods that quantify the energy and peak demand benefits of DSM initiatives. The term "benefits" is used to describe several different outcomes from DSM programs. In their fundamental form, benefits imply kilowatthour and kilowatt savings. Taken one step further, benefits equal the dollar values associated with the savings, including those arising from the reduction in reserve equipment. Further, a reduction in kilowatt demand arising from changes in load shape produces lower production costs, since increased energy generation occurs during the off-peak period from units with lower incremental cost of generation. All these effects translate into dollar savings. Consequently, the kilowatt and kilowatthour savings-shifting results in monetary, environmental, and other benefits as the timing and amount of electricity produced change.

Some literature on methods of calculating kilowatt-kilowatthour savings exists. Methods for evaluating kilowatt or load-shape savings often include engineering models that simulate the technical characteristics of end-use equipment. The forecast of participation rates and estimating energy savings from conservation programs are often done by econometric methods.

Several journal articles examine the finer details of cost-benefit analysis. The literature addresses methods for comparing monetary expenditures with monetary benefits. This analysis is carried to a higher plane by the application of econometric-statistical principles. "Self-selection," "all ratepayers," "no-losers test," the "snap-back effect," and many other tests and concepts needed to evaluate overall societal benefits illustrate the application of econometric principles. In view of the interests of state commissions on least-cost planning where supply side and demand-side options are considered jointly, the calculation of societal benefits and the debate over their values in rate case hearings have become more frequent. The NARUC manual on least-cost planning substantiates and exemplifies this discussion of "benefits."[7] Therefore, it is evident that if the term benefit evaluation were to include all of the above, it would be impossible to examine all types of benefits within the scope of one report.

The motivation for this report stems from the recent move by many state commissions to offer utilities pecuniary incentives for promoting DSM programs. With such incentives funded by general ratepayers, commissions would want to confirm whether a certain targeted quantity of kilowatt and kilowatthour savings was in fact achieved.[8] Similarly, under all-source bidding for capacity and energy, commissions may want to confirm on a continuing basis that contracted quantities of kilowatts and kilowatt-hours are being saved by utility-purchased DSM measures.

As part of the NRRI project on DSM, a questionnaire was sent to state commissions asking the staff to outline the methods used by them or utilities in their state to calculate kilowatt and kilowatthour benefits. (Appendix A contains a summary of responses.) One finding was that in the course of least-cost planning or conservation efforts, most states include, in one form or another, the cost-benefit analysis of DSM and conservation activities. Some states adopted the principle of cost-benefit analysis and applied the tests outlined in the NARUC least-cost utility planning handbook and the California manual of standard practice.[9] Some commission staff applied econometric, statistical, and time series methods to quantify energy savings. Such models are particularly suited to account for nonparticipants in a DSM program, as well as those that would have undertaken DSM measures without the presence of a program. Another

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7. National Association of Regulatory Utility Commissioners, *Least-Cost Utility Planning, A Handbook for Public Utility Commissioners* (Washington, D.C.: National Association of Regulatory Utility Commissioners, 1988).
8. In a recent paper, The Electricity Consumers Resource Council (ELCON) argues that measuring the performance of DSM programs should depend on "actual savings and costs and not solely on theoretical or potential engineering estimates of savings or cost." See ELCON, "Profiles in Electricity Issues: Demand Side Management (DSM)," *Profile Number 14* (Washington, D.C.: ELCON, December 1990), 11.
9. California Public Utilities Commission and California Energy Commission, "Economic Analysis of Demand-Side Management Programs," *Standard Practice Manual* (San Francisco: California Public Utilities Commission and California Energy Commission, 1987), 400-87-006.

category of methods termed "engineering models" addresses the technical characteristics of end-use equipment such as air conditioners, water heaters, high-efficiency motors and lighting, and heat-loss models for space heating. Such models simulate the operation of end-use equipment at a predetermined or fixed level to evaluate the effect on load shape and kilowatthour savings. Commissions generally have relied on utilities to generate impact estimates from engineering models.

The word "impacts" has been used to designate the economic, technical, and social outcomes of DSM programs. In a similar vein, monitoring a DSM program involves the prediction as well as the constant surveillance of benefits.[10] Consequently, as they are used in this report, these terms overlap. When they do not, the distinction is pointed out or it should be clear in the context of the reasoning. In terms of benefits or impacts, however, this report addresses only the reduction in kilowatts or kilowatthours and not any other economic or cost benefit aspects.

The remaining chapters of this report examine methods to quantify the physical benefits of DSM programs. They include engineering models that assess load shape changes and econometric models that measure changes in energy consumption. Not surprisingly, strengths and weaknesses associated with each method were found.

Summary

This report provides the reader with a broad overview of different methods for quantifying the energy and peak savings from DSM initiatives. While the report focuses on the technical side of methods, it touches on how the information generated by these methods can be interpreted by commissions for decisionmaking. Finally, the report addresses different

10. One energy expert proposes using seven performance indices to assist utilities and regulators in obtaining a quick "snapshot" of how DSM programs have performed. See Steven Nadel, "Use of Simple Performance Indices to Help Guide Review of DSM Program Performance," *Proceedings of the National Conference on Integrated Resource Planning* (Santa Fe, NM: The National Association of Regulatory Utility Commissioners, April 8, 1991), 116-30.

roles that commissions can play in working with utilities to select methods and to verify estimates of energy savings.

This report makes several observations. The major ones include:

1. As a general matter, commissions should not expect to find an ideal method for quantifying energy savings except for situations that are utility, program, and program-stage specific.
2. Commissions have to live with the reality that any method applied to quantify energy and peak savings will produce estimates containing some degree of error. In accounting for uncertainty, commissions may want utilities to develop a confidence interval of energy-peak savings for individual DSM programs
3. Engineering methods are preferable to econometric methods for measuring kilowatt (kW) savings and changes in load shape. Engineering methods rely on empirical observations and engineering relationships to allocate energy use by hour of the year. Some engineering methods simulate the technical characteristics of end-use equipment. Econometric methods are better suited for measuring kilowatthour (kWh) savings.
4. Econometric methods account for the effect of consumer behavior on energy savings induced by DSM initiatives. For example, evaluating the energy savings from a rebate pilot program for air conditioners may require the use of econometric methods to estimate the number of participants for a full-scale program and the actual energy savings from the pilot program.
5. Selecting the best method for quantifying energy savings depends importantly on the stage of implementation of a DSM initiative. The stage dictates the purpose of quantifying energy savings. The report identifies four stages: preprogram, developmental, full-scale, and mature full-scale. As an example, a major task of pilot programs involves acquiring data on actual impact to assist utilities in deciding whether to expand programs on a large scale. As another example, monitoring a full-scale program will have the objective of assessing whether the program has achieved its anticipated performance.
6. The effort and money that should be expended on developing and applying methods hinges directly on the risk of inaccurate or

poor energy savings estimates. Poor estimates leading to incorrect regulatory and utility management decisions may carry a high cost, particularly when the decisions involve large expenditures financed by ratepayers' monies. One example involves commissions offering utilities an incentive for a DSM program with actual energy savings much lower than what was estimated. Consequently, ratepayers may end up paying the utility for a subpar program. As another example, distorted estimates from pilot programs may lead to a utility adopting full-scale programs that are not cost effective.

7. As a policy matter, because of the uncertainty surrounding estimates of energy savings regulators need to exercise caution in sanctioning DSM bidding, ratebasing of DSM expenditures, and other explicit incentives for inducing DSM activities. In placing DSM activities on an equal footing with supply side resources, commissions may want to use lower-bound estimates of energy savings. Commissions, in protecting consumers from the risk of overestimating energy savings, also may want to use "low" estimates as the basis for incentive payments to utilities for conducting DSM activities as well as to determine maximum payments made by utilities to outside providers of DSM resources.

8. Engineering methods and econometric methods, in some situations, take on a complementary relationship in producing more accurate energy savings. For example, the preferable approach for evaluating all DSM initiatives may involve combining an engineering-based approach with an empirically based statistical approach.

9. Verifying utilities' estimates, or assuming an active role in evaluating DSM initiatives, may require staff resources and expertise that only a few commissions can afford or want to acquire. With the rapid growth of DSM initiatives, however, commissions may want to step up their activities in verifying and evaluating the impacts of these initiatives. Especially in states where utilities are recalcitrant toward DSM initiatives, commissions may want to assume an active role.

10. Tradeoffs exist in selecting methods that satisfy primary objectives (for example, theoretical realism of methods, nonprohibitive data requirements, manageable commission-utility evaluation expenditures, and adequate treatment of uncertainty). To illustrate, producing more accurate energy savings estimates may require expensive statistical and end-use metering approaches.
11. Commissions should seriously consider assuming a collaborative role with utilities in selecting methods and in verifying estimates of energy savings. Although it can be argued that utilities have superior technical expertise, commission oversight may be needed to assume that energy savings estimates are based on acceptable methods applied appropriately by utilities. Collaboration currently is being carried in a few states including California, Illinois, Texas, and Wisconsin.
12. Different methods can be applied to help verify estimates of energy savings for individual DSM initiatives. The fact that all methods produce estimates suggests that different methods be used where applicable to compare estimates. Work has begun in some parts of the country to compare energy savings estimates from different methods.
13. Since most utility-funded strategic conservation programs are voluntary, participants are considered to be "self-selected." Unless corrected, self-selection leads to biased estimates of energy savings.
14. A two-equation, three-step econometric model can be applied at reasonable cost to correct self-selection bias. This method has the advantage of requiring only single-period, cross-sectional data, can be estimated by currently available econometric computer programs, and yields reliable estimates.

Audience

The report outlines and examines the different methods for calculating the kilowatt and kilowatthours saved. The staffs of state commissions embarking on DSM programs consult many documents while evaluating programs in their states. This report, by serving as a complement to these documents, should assist state commissions in their efforts to evaluate DSM programs.

The report highlights the major features of engineering models. The description of the econometric method is unavoidably mathematical. These methods, outlined in chapter 4, presume the reader has a basic knowledge of mathematics, econometrics, and statistics.

CHAPTER 2

MONITORING DSM BENEFITS

This chapter examines benefit evaluation for the life cycle of a DSM program, delineating the stages of the program in which the benefits can be evaluated or monitored, and examining conceptually the type of impacts that might be observed. A later chapter examines the benefit calculation methods themselves.

Phases of Monitoring

DSM initiatives can be grouped into four major phases: preprogram stage, developmental stage, full-scale program stage, and mature full-scale program stage (see Table 2-1).[1] Figure 2-1 depicts the linkages among the different stages.

The preprogram stage involves undertaking a trial process to obtain some parameters in designing a development program. The preprogram stage may include small-scale field testing of different technologies-concepts and the building of mathematical models-computer programs or both. In this phase it is possible to meter or wire typical end-use equipment to determine their characteristics and responses under load control conditions.

In the developmental stage more extensive trials are undertaken to assess the behavior of a large group of customers subject to the program. Monitoring might include statistical, technical, and subjective techniques. For instance, all end-use consumption might be monitored on an hour-to-hour

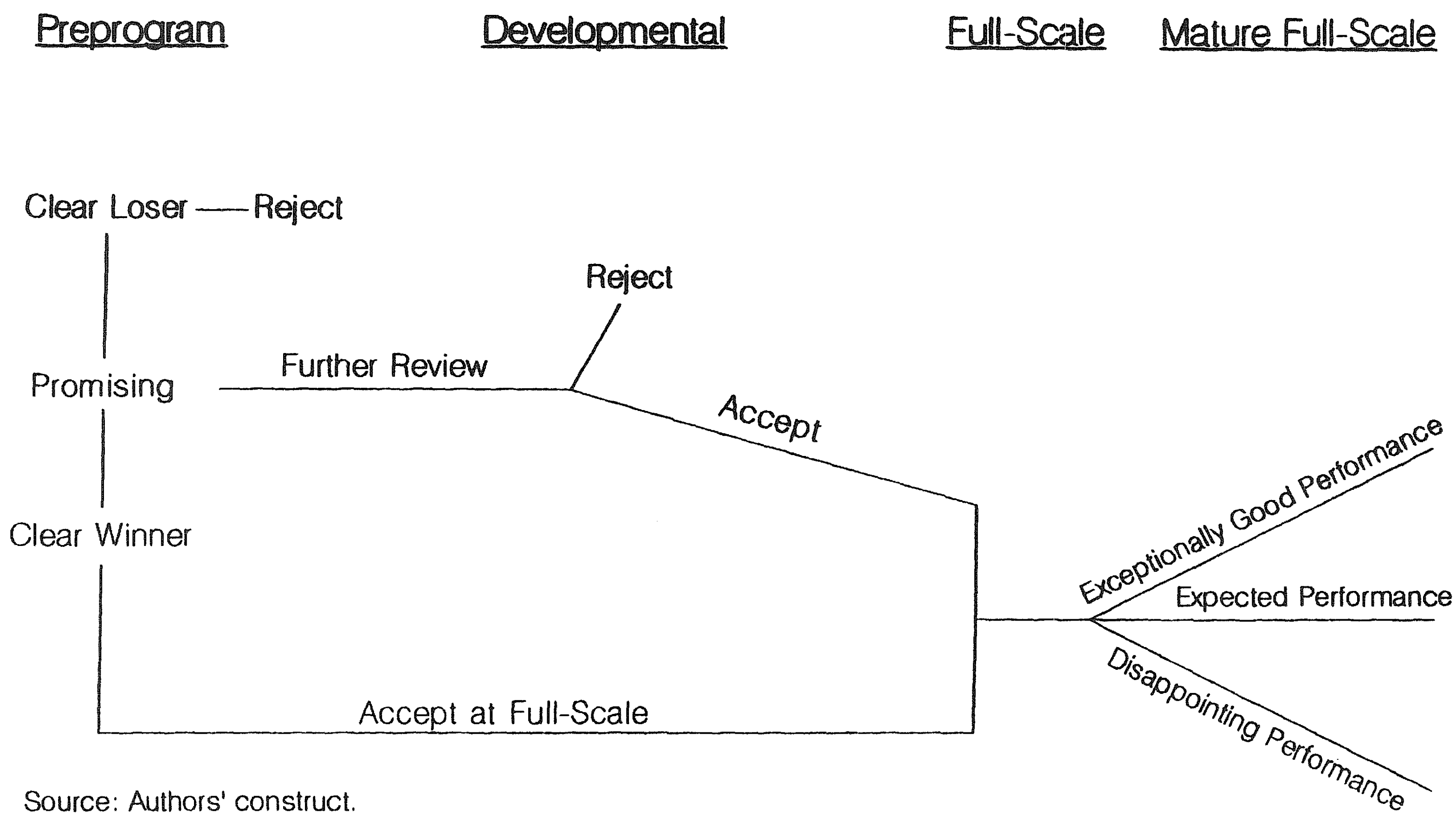
1. Electric Power Research Institute, *DSM Program Monitoring*, prepared by Applied Management Sciences, Inc. and Battelle-Columbus Division (Palo Alto, CA: Electric Power Research Institute, March 1988).

TABLE 2-1

ACTIVITIES/OBJECTIVES OF DIFFERENT STAGES FOR DSM INITIATIVES

Stage	Activity	Objective
Preprogram	• field testing • simulation modeling	• Identify most promising initiatives for further review
Developmental	• pilot project • feasibility analysis • hour-to-hour monitoring of sample	• Evaluate performance of initiatives for full-scale operation
Full-Scale	• utility-wide programs • large expenditures	• Select initiatives compatible with least-cost planning goals
Mature Full-Scale	• opinion polling • billing analysis • cost sampling	• Evaluate performance of on-going programs relative to expectations

Source: Authors' construct.



Source: Authors' construct.

Fig. 2-1. Sequential steps in program evaluation.

basis to assess the diversity of use, the effect of participation rates on load shape, and so on.[2]

During this phase a feasibility analysis as well as preliminary costs and load-energy analyses are conducted. Based on the results, the *expected* benefits of a full-scale program are extrapolated. Assumptions include variables such as participation rates, diversity of consumption of the larger samples, as well as financial and economic parameters. The developmental stage results in a "go-or-no-go" decision on whether the utility should proceed to the next stage. A decision to embark on a full-scale program requires favorable results from a cost-benefit analysis.

During the developmental stage, it is common to undertake pilot programs. A pilot program, or any DSM program for that matter, has two objectives: 1) accurately measure the effect of a DSM program on the participant group itself, and 2) generalize the pilot, or small-scale, results to a wider--or the entire--population. The success of a pilot program depends on applying the measured effects of the program to customers outside its scope. A poorly designed pilot program that yields bad information has little value either for a utility or a commission. A pilot program's chief purpose lies in minimizing the risk of a utility running a "bad" program or rejecting a "good" program, both on a large scale. Since a large-scale program can cost a utility and its ratepayers millions of dollars, obtaining valid and meaningful data for the outcomes of a pilot program reduces the chances of a utility and its commission adopting a "bad" program. Similarly, by rejecting a "good" program because of faulty data, a utility may expend large sums of money unnecessarily for power plant construction and operation.

2. Under normal use (without DSM measures) there is a certain diversity in the demands of the connected equipment. Diversity is defined as the connected total of nameplate loads to the actual load presented to the system. For instance, consider 100 air conditioners with 2 kW nameplate ratings connected to the system. At any given time,only thirty thermostats may cut in presenting a load of 60 kW to the system. As the set temperature in the controlled room is reached, the thermostats turn off but the thermostats of other air conditioners turn on. The diversity of this group of air conditioners is then 200/60 = 3.33. Of course, the diversity reduces at higher ambient temperatures.

Two primary objectives exist for examining and interpreting the data collected from a pilot program: 1) estimating the change in electricity consumption by participants that is directly attributable to the program, and 2) projecting the change in electricity consumption by participants outside the test area that would result from adopting a permanent program. The biggest obstacle lies in the fact that the true response to a program both by participants and nonparticipating customers is unobservable. For example, how participants would have behaved in the absence of a program cannot be observed. Nor can the response of customers outside the test site if the program were offered to them.

To illustrate this point, suppose a utility operates a pilot program that offers a $100 rebate to residential customers in the town of Hotspot who replace their air conditioners with units that have high energy efficiency. In ascribing an increase in the number of energy efficient air conditioners to the rebate program, the major factors affecting purchases should be controlled. Measuring the effects of the rebate program focuses on the problem of separating the influences of the rebate from other factors that are likely to affect customer purchases. The causal model applicable to this example can be expressed in general terms as:

$$\Delta AC = f(R,Z),$$

where the increase in the number of energy efficient air conditioners in Hotspot (ΔAC) is related to the amount of the rebate (R) and a vector of the other factors (for example, socioeconomic characteristics, air conditioning saturation level) for Hotspot (Z) affecting purchases of energy efficient air conditioners. The equation correlates the response rate of a sample of customers with several factors representing, say, socioeconomic, housing, and appliance holding characteristics. The advantage of a causal model is that it simultaneously measures the effect of several factors on a household's response rate.

In the developmental stage of some DSM programs, the actual load shape (kilowatts saved) and the energy consumption (kilowatthours saved) in test groups actually can be metered. In such cases, no ambiguity exists in the results of the test group. The focus, however, may be on projecting the savings by analytical means to the full-scale stage.

The full-scale stage of the program is characterized by a commitment to a substantial expenditure of money and a large-scale eligibility of participants. That the program *will* be cost effective is assumed based on the results of the previous stages. This is not certain, however. It is critical to monitor the impact at the full-scale stage to yield ultimate conclusions. The details of the methods to monitor the impacts are discussed in the next section.

The mature full-scale-program stage is embarked upon when the cumulative experience with the program is ample. During this stage, the program's operations are optimized by proper monitoring techniques, which include cost sampling, load sampling, opinion polling, and so forth.

In subsequent sections of this report, the preprogram and developmental stages of DSM activity will be referred to as a program's "preimplementation" period. Similarly, the mature full-scale-program stage will be referred to as its "postimplementation" period. The benefits (kilowatts and kilowatthour savings) evaluated in the preimplementation period are termed the "forecast benefits."[3]

Anatomy of Monitoring

Figure 2-2 illustrates an experimental research design for monitoring. Measurements (of load shape or energy) of a control group and a treatment group are made in the pretreatment, program treatment, and posttreatment stages. (The actual methods of analysis including that of properly accounting for the control or comparison group are examined in Chapter 4.) In the experimental research design, a comparison group (control group) serves to provide a prediction of the expected behavior of the treated

3. A distinction has to be drawn between forecasting benefits and monitoring benefits. Forecasting benefits implies their estimation (kilowatt and kilowatthour savings) in the preprogram stage. Monitoring benefits necessarily implies that a program or a pilot program has been installed and the benefits (kilowatt and kilowatthour savings) are quantified. Note that quantification need not necessarily mean measurement. It might include simulation techniques, and some techniques used in the preprogram state. Similarly, the preprogram evaluation might include techniques simulating the behavior of end-use equipment in a computer-based model.

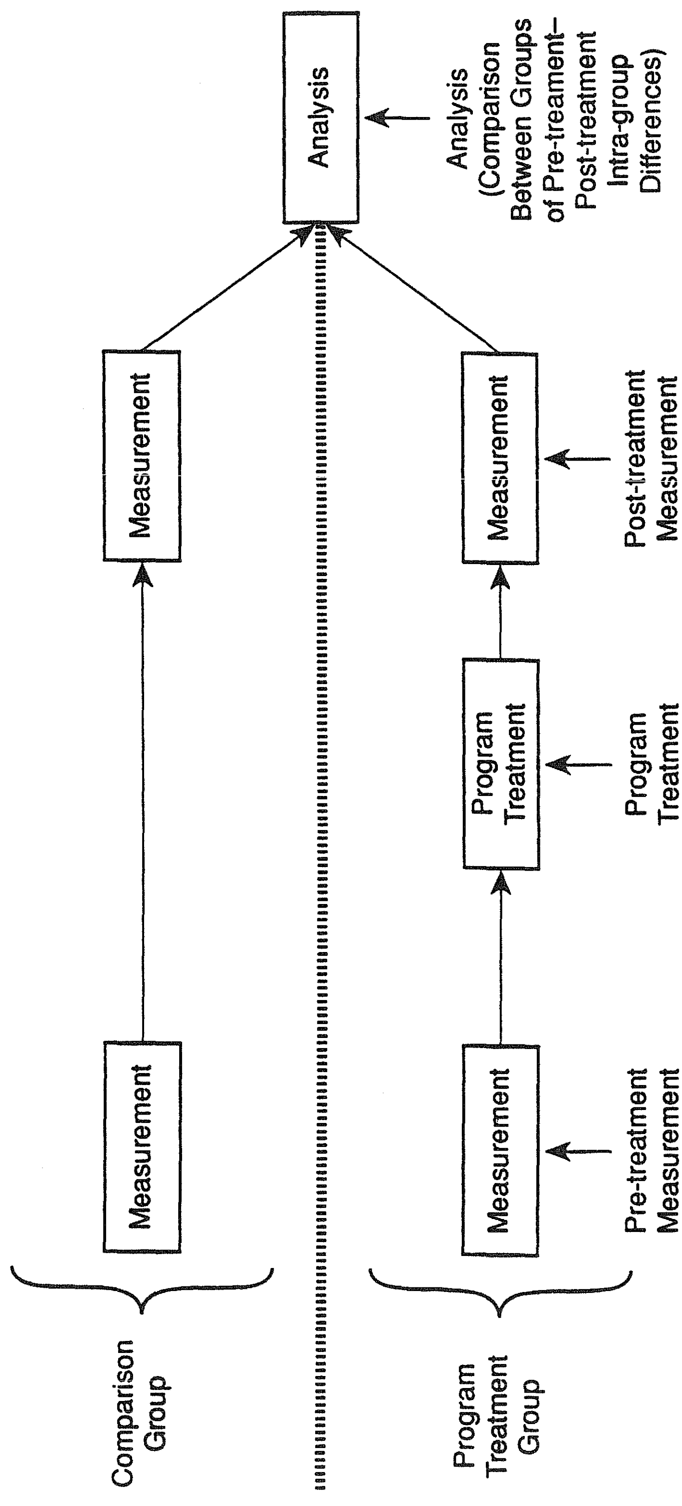


Fig. 2-2. Research design for monitoring DSM programs (Source: Electric Power Research Institute, *DSM Program Monitoring*, EPRI EM-5706). © 1988, Electric Power Research Institute. Reprinted with permission.

group in the absence of the DSM program. As noted, measurements at different stages would also be required.

Measuring the amount of energy consumed by the end-user on a continual basis is facilitated by electronic metering and carrier telemetering techniques. Telemetering the energy consumption of every end-user represents a major task that may entail substantial costs but can, nevertheless, be undertaken. Measuring load shape, which requires keeping records of hourly use of every end-user, also is a major task that may require substantial costs in spite of modern metering and telemetering techniques. Therefore, from a practical standpoint load-shape monitoring is undertaken only in the experimental stages, typically in the first two stages (preprogram and developmental) of the program described earlier.

Monitoring energy use may suffice for evaluating programs where a change in total energy consumption occurs. Under these circumstances, the attention focuses on quantifying kilowatthours saved from a program. Consequently, strategic conservation programs are ideal candidates for the above type of monitoring. For the other categories of DSM initiatives (see Figure 2-2), particularly those where no change in energy consumption patterns occurs, monitoring based only on energy measurements may not apply. The actual kilowatt savings, however, can be measured in the experimental stages. The experimental results then can be extrapolated using statistical techniques to quantify the impact of such DSM initiatives in the postimplementation period.

One concern revolves around quantifying changes in load shape caused by other factors. These changes are not observable. Therefore, in quantifying changes in load shape, mathematical simulation models based on experiments and the characteristics of end-use equipment are commonly used. Corrections for changes that would have occurred in the absence of the DSM initiative are made through statistical techniques that make use of a control group. Statistical techniques generally are well suited to energy measurements rather than to load shape changes or kilowatt measurements, which (as mentioned earlier) are better handled by engineering models. It should be noted that the objective of the statistical techniques centers on projecting the savings at a future stage of the program. Statistical techniques also are used to correct for self-selection effects, "snap-back" effects, and to estimate participation rates.

The results of a recent Electric Power Research Institute study reported that most DSM program monitoring has focused on strategic conservation programs for residential customer classes, mostly based on retrospective evaluation.[4] The study further found that monitoring of commercial and industrial DSM programs has occurred much less often; only recently have load-shape impacts been monitored.

The objectives of a monitoring effort typically are threefold: to measure the specific results of the program, to compare the results to the objectives, and to assess the program's operational efficiency.[5] As mentioned earlier, this report focuses on the first objective, namely that of examining methods to measure the kilowatt and kilowatthour savings.

The necessity of substantiating these savings has taken an important turn in view of some states offering the utilities financial incentives or credits for certain DSM measures. Assessing DSM bids in all-sources bidding is important as well. Such an assessment in the preimplementation phase requires forecasting the benefits in addition to actually monitoring benefits in the postimplementation stage. Under such circumstances, the regulator would like reliable estimates of the actual savings as well as verification of the savings.

All loads are metered. All residential and industrial customers are measured for their energy consumption (kilowatthour meters). The kilowatt consumption of only the major loads is metered.

To establish the actual impact in the full and mature stage of a DSM program, the analyst generally resorts to a before-and-after analysis of billing data. This technique is suitable, at least in theory, for analyzing both the kilowatt and kilowatthour savings. This technique, however, is more suited to kilowatthour savings, as in conservation programs. The difficulty in using this technique to examine kilowatt or load-shape impacts arises mainly from two factors. First, data has to be carried out for each hour (or for several hours) to examine the impact on hourly kilowatt loads. The second is that the kilowatt consumption of all loads is not metered. Therefore, the analyst normally resorts to some form

4. Electric Power Research Institute, *DSM Program Monitoring*.
5. Ibid.

of engineering simulation method to quantify the actual kilowatt savings or the load shape impact. In some cases statistical techniques also are used to examine kilowatt savings, particularly when examining the consumer response to different pricing procedures.[6] Further, corrections to account for customers who would have undertaken certain DSM measures without a particular program can be handled formally by statistical techniques.

Subsequent chapters of this report examine the methods in common use for kilowatt- and kilowatthour-savings quantification. In doing so and in view of the recent attention given to pecuniary incentives offered to utilities for promoting cost-effective DSM programs, the focus of this report lies with methods for quantifying the "actual" savings in the full-mature stage of DSM programs. Some of the methods are valid in the preimplementation stage as well. The preimplementation stage addresses the concerns of commissions over estimated energy savings from pilot programs that are designed to identify initiatives for which a utility should spend large sums of money. Examples include large-scale pilot projects in the developmental stage where the analyses are equally applicable. Therefore, frequent references to the preimplementation stage are unavoidable.

6. Douglas Caves, Joseph Herriges, and Kathleen Kyesta, "Load Shifting Under Voluntary Residential Time-of-Use Rates," *The Energy Journal* 10 no. 4 (1989): 83-99.

CHAPTER 3

METHODS OF MONITORING LOAD-SHAPES

This chapter addresses the techniques, both econometrically and engineering-based, used in the modeling of load-shape impact. Chapter 4 focuses on econometric methods used to project kilowatthour savings. The two chapters attempt to provide the reader with available techniques for quantifying the kilowatt-kilowatthour savings from DSM initiatives. Such techniques or their combinations can be used to evaluate the impact of any type of DSM initiative.

The objectives of the monitoring effort focus on the following problems:[1]

- Measuring or simulating specific results,
- Comparing results to the objectives of the program.

Classification of Monitoring Techniques

The EPRI report classifies twenty-eight monitoring techniques into seven categories: subjective, market survey, market data analysis, management information, load energy simulation, load-energy measurement and analysis, and economic benefit analysis.[2]

These techniques allow the analyst to assess the various results of DSM programs, including customer participation and acceptance rates, load-energy impact, operational efficiency, and cost effectiveness.

Some of the techniques are more appropriate for examining certain types of outcomes at different stages of a program. For instance, in the preprogram stage subjective techniques to estimate participation rates or kilowatts or kilowatthours saved are more appropriate. Market survey, market data, and management information techniques are equally well suited

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1. Electric Power Research Institute, *DSM Program Monitoring*, prepared by Applied Management Sciences, Inc. and Battelle-Columbus Division (Palo Alto, CA: Electric Power Research Institute, March 1988).
2. Ibid.

to predicting participation rates. Such methods, however, may be less defensible for assessing kilowatt or kilowatthour savings than load energy simulation or measurement and analysis techniques. In short, the first three techniques are more appropriate for estimating participation rates while the others are more appropriate for quantifying kilowatthour-kilowatt savings.

Preimplementation Monitoring

Engineering models simulate the performance of end-use equipment such as water heaters, air conditioners, and other processes. Having established the savings from a particular type of end-use equipment, the question in the preimplementation stage as to the impact of such devices in the postimplementation period still remains. Projecting savings to the future can be done either through econometric models or engineering models depending on the type of DSM program.

There are several methods commonly used in the preimplementation stage (excluding econometric and engineering models, which are found in later sections).

Some Evaluation Methods

The Delphi Method

The Delphi method is the most common qualitative method. A panel of technical experts in the field answers questions (sometimes in response to a survey) such as when a new process will gain widespread acceptance or what new developments will take place in a field of study.[3]

The general limitation of the Delphi method is that it is insufficiently reliable, its results are oversensitive to ambiguous questions, the degree of expertise of the panel members may be uneven and difficult to assess, and unexpected factors are impossible to account for.[4]

3. Ibid.
4. Ibid.

Cross-Impact Matrices

A cross-impact matrix portrays two types of data for a set of possible future developments. The first type of data is an estimation of the probability each development will occur within some specified future time period. The second type is an estimation of the probability that a possible development would affect the likelihood of the occurrence of alternative developments. The matrix is developed from data obtained by using a subjective assessment procedure or a method such as the Delphi approach.

Cross-impact analysis refines the probability of individual future developments and their interaction with other developments so these probabilities become a basis for planning or forecasting. This method can be used to examine a series of possible DSM options which might affect a specific sector, in view of certain overlapping and influencing impacts.[5]

The Juster Survey

A Juster survey obtains probabilistic information from respondents rather than mere yes-no responses. As a measuring device, this approach asks each respondent to choose one set of descriptive words. The probabilities associated with the descriptive words vary as follows:

Descriptive Word	Probability
Certain, practically certain	.99
Almost sure	.90
Very probable	.80
Probable	.70
Good possibility	.60
Fairly good possibility	.50
Fair possibility	.40
Some possibility	.30
Slight possibility	.20
Very slight possibility	.10
No chance, almost no chance	.01

5. Ibid.

The results of such surveys are ideally suited to determining customer acceptance of various DSM options. The Juster survey also has been used to assess time-of-use electricity pricing experiments.[6]

Cubic Spline Method

This technique has recently been applied to time-of-day electricity pricing experiments.[7] The model provides the consumption for each hour of the day for the entire period for which temperature forecasts are available.[8]

Although the cubic spline is strictly a time-series technique (that is, the load shape is modeled as a function of time alone), the model is often given a structure. This is made possible by the fact that a cubic spline is solely formed by values at what are called "knots" (the preselected points at which the third derivative is discontinuous). The function represents a linear combination of values at these knots. When these knot values of the function can be forecast as functions of structural variables (for example, income, prices), changes in the shape and level of the load curve can also be forecast.

S-Curve Method

The S-curve model is frequently used to forecast the penetration of new technologies. The curve assumes that new technology penetration will start slowly then grow fast and finally stabilize. This characterizes many technological developments such as the sales of several products and the expenditure of money in construction programs.

A good application of growth curves involves tracing emerging DSM technologies (for example, photovoltaic units) and their penetration or

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6. Ibid.
7. Ibid.
8. Electric Power Research Institute, *Regional Load Curve Models: Specification and Estimation of DRI Model: Volume 1* (Palo Alto, CA: Electric Power Research Institute, 1981).

predicting the participation rate for a program, each as a function of time.

Spectral Analysis[9]

While not a forecasting tool per se, spectral analysis facilitates the search for inherent cyclical patterns and the determination of their significance. Once a forecasting model accounts for the patterns in a time series (of consumption, say) what is left should be patternless "noise." Spectral analysis is used to test whether or not this is true. Thus, it must be combined with other time-series methods in building a forecasting model of electricity consumption.

Box & Jenkins Model

Box-Jenkins represents another time-series model designed for forecasting purposes. It has been used by utilities for short-term load forecasting (that is, day-to-day load use forecasts). The method combines autoregressive and moving-average processes in accounting for cyclical and seasonal movements in the historical series. The objective is to obtain a trend or future forecast.

As mentioned by Comerford and Gellings, the need for large amounts of monthly or quarterly data generally has precluded its application for DSM programs.[10] As DSM data expands to provide monthly data, however, the role of this method in forecasting DSM parameters could increase.

"A priori" Models

These models are essentially elasticity models, which sometimes assume that the factors affecting a certain DSM technology are known. These models are based on a tested hypothesis which in turn depends on past performance or experimental records. A typical example[11] might be

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9. Electric Power Research Institute, *DSM Program Monitoring*.
10. R. B. Comerford and C. W. Gellings, "The Application of Classical Forecasting Techniques to Load Management," *Load Management*, S. Talukdar and C. W. Gellings, eds., (New York: IEEE Press, 1987).
11. Ibid.

$$\frac{QAC_{t+n}}{QAC_t} = (1.03^n) \left[\frac{PE_{t+n}}{PE_t} \right]^{+0.4} \left[\frac{COST_{t+n}}{COST_t} \right]^{-0.2} .$$

The model states that the ratio of change in efficient air conditioners at time t+n to those at time t is a function of economic growth, electricity price (PE), and air-conditioner costs (COST). In the above illustration, it is assumed that the economy grows at 3 percent a year, that a 1 percent increase in the electricity price will cause a 0.4 percent increase in the saturation of efficient air conditioners, and that a 1 percent decrease in the cost of efficient air conditioners will increase the saturation by 0.2 percent. Other a priori relationships also can be assumed.

Other Methods

Other methods include market share methods, the Fourt-Woodlock method, as well as variations of the methods discussed above. The reader is referred to other sources for details of these methods.[12]

Postimplementation Monitoring

DSM program monitoring has played an increasing role in recent years because of the regulatory incentives that utilities can earn for achieving energy savings and the need to assess the cost-effectiveness of large-scale programs. Furthermore, regulators would like to confirm that the savings anticipated for DSM bids are actually being realized.

The required measurements or simulation for monitoring a program depend on the type of DSM activity. For example, the measurements required for a thermal heat storage program could be different from those required from an off-peak sales promotion. The results of all measurements or simulations, however, consist of kilowatt or kilowatthour quantifications of the program's productive effects. Examples include annual kilowatt-

12. Ibid. and Electric Power Research Institute, *DSM Program Monitoring*.

hours, summer-winter kilowatthours, peak-period kilowatthours, kilowatts at system annual peak hour, kilowatts at system seasonal or monthly peak hour, and kilowatts at class peak hour.[13]

Econometric forecasting models have been used to predict the kilowatt and kilowatthour savings. The Pacific Gas and Electric Company (PG&E) case study of an industrial time-of-use rate program discussed later illustrates the estimation of kilowatt savings from econometric methods. Some of these methods may be applicable during pilot studies or other experiments as well.

End-Use Techniques

The starting point for some engineering models involves simulating the technical characteristics of end-use equipment or the process. Such models give a more dependable basis for estimating the load shapes than econometric methods. As explained in the National Association of Regulatory Utility Commissioners (NARUC) least-cost utility planning manual, end-use models are needed for estimating load shape and energy:[14]

> Consistent and comprehensive treatment of demand-side options in a least-cost planning analysis requires the use of end-use energy and load-shape forecasting models. End-use detail is required to identify the effects of specific demand-side activities. Load shapes are required to provide a consistent basis for comparison with supply-side activities.
>
> Although econometric forecasting models are an improvement over simple extrapolations of historic demand growth rates into the future, they cannot capture changes in the structure of demand. Without details of this structure, we cannot use these models to forecast the effects of individual demand-side measures, as is required by LCUP. Indeed, econometric models are of limited value for long-run forecasting precisely because of their inability to reflect structural changes in the composition of demand; the

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13. Ibid., Electric Power Research Institute.
14. National Association of Regulatory Utility Commissioners, *Least-Cost Utility Planning Handbook for Public Utility Commissioners* (Washington, D.C.: National Association of Regulatory Utility Commissioners, 1988).

possibility for such large changes is essential for a rigorous evaluation of LCUP options.

End-use models simulate the relationship between energy usage and the technical characteristics of a piece of end-use equipment.[15] The total energy consumed for a given end use equals the product of the number of forecasting units (for example, households, floor area, number of efficient lamps, and so on) and the average energy consumed by each unit. Econometric methods play a role in the total energy forecast by estimating the number of participants consuming a particular end use (for example, cooling and space heating). An econometric study might involve collecting and analyzing data to estimate the number of participants as a function of their incomes, geographic location, and other variables. Consequently, engineering and econometric models complement each other in estimating the energy savings. Some end-use models incorporate engineering simulations as well as econometric methods. Consequently, it may not be possible to place models strictly in either the engineering or econometric category.

Current models examining changes in load shape caused by DSM activities that do not necessarily change total energy consumption (valley fillings, for example) are engineering in nature. They tend to rely on contributions of empirical observations and engineering relationships to allocate energy use to the different hours of the year.

Certain end-use models currently in use are complex. Consumption is disaggregated by sector, end-use energy source, vintage of equipment, and technology and is based on residential, commercial, industrial, and other uses. In each sector, particularly residential and commercial, the use is broken down to heating, cooking, cooling, lighting, and so on. Some models not only include all major fuels (electricity, natural gas, oil, biomass, and so on) but also algorithms to model fuel switching. The complexity of these models in addition to their demanding data requirements is evidenced

15. It is important not to confuse end-use models with those that model end-use equipment. An end-use model could incorporate a simulation of end-use equipment behavior as well as statistical and econometric methods to account for the degree of participation, free riders, and the like. Models of end-use equipment are sometimes called engineering models that simulate the behavior of equipment like air conditioners, water heaters, and so on.

by the following excerpt from the NARUC least-cost utility planning manual:[16]

> The available models are distinguished by the mechanisms used to predict future demand. The simplest models only multiply exogenously specified growth rates by an exogenously specified EUI [energy utilization index]. The most advanced models use inputs from econometric forecasts to relate exogenously specified macroeconomic changes (such as population growth, fuel prices, income, economic activity) to microeconomic, behavioral and structural consumption decisions at the end-use level, based on a model of consumer behavior and the options available to consumers to modify consumption. Because of the nature of current specification of the models, most end-use models tend to be more responsive to long-run trends than short-term fluctuations in underlying economic influences.

The data requirements for end-use models can be staggering. The weakest link in an LCUP evaluation often is the unavailability of relevant and reliable data. Data are more readily available for the residential sector than for the commercial sector. Not surprisingly, residential models are most highly developed while commercial models are still relatively primitive. Load shape models are constrained solely by the current lack of measured data.[17]

Research is underway in some parts of the country to compare the results from statistical or econometric models with those obtained by hybrid statistical and engineering models.[18] For example, New England Electric System has asked two consultants to examine the combination of engineering and thermodynamic principles with the statistical approach for analyzing heating, cooling, ventilation, interior lighting, exterior lighting, domestic hot water heater, refrigeration, cooking, and miscellaneous (office equipment, cash registers, and so on) DSM measures. The results were expected sometime in 1991.

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16. National Association of Regulatory Utility Commissioners, *Least-Cost Utility Planning Handbook*.
17. The subject of data requirements is elaborated on in Chapter 6 of this report.
18. "1990 Conservation and Load Management Plan," New England Electric System (June 8, 1990).

Simulations

The utility industry has faced the question of how to forecast reliably the impact of a certain DSM program on the load shape. One of the early attempts to answer this question was the computer model Electric Load Curve Synthesis (ELCS) developed by Public Service Electric and Gas Company (PSE&G).[19] In addition, other computer models have since been developed. (Some of these models are discussed briefly later in this chapter.) This section discusses the characteristics of end-use equipment as they are simulated in models that attempt to replicate the load shape.

Adequate literature exists on models that simulate the energy usage of air conditioning and hot water heating equipment. The reason for this is the interest in the late 1970s and early 1980s in controlling such equipment. In recent years, interest surged into other areas of DSM such as thermal heat, cold storage, and conservation measures that use more efficient end-use equipment. In terms of modeling, the processes for most conservation measures are simple and require no elaborate engineering models. For instance, the savings in terms of kilowatts or kilowatthours can be specified by the characteristics of the equipment for high efficiency lighting equipment or motors. Therefore, the resulting savings when used for a certain period of time or in a certain processes can be obtained easily. The only uncertainty in the planning or the preprogram stage for such DSM measures involves the predicted number of participants in programs that offer incentives to consumers (subsidy, rebates, and so on). In a well established DSM program, however, these data (number of participants) are obtained easily by a well designed survey, by bill examination, or by participants' actual records. In all cases, the kilowatts and kilowatthours saved by such conservation programs can be calculated with reasonable accuracy. To complete the analysis, statistical techniques would be required to assess the effect of those who would have installed such efficiency measures on their own without a particular DSM program.

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19. Clark W. Gellings and R. W. Taylor, "Electric Load Curve Synthesis--A Computer Simulation of an Electric Utility Load Shape," *Load Management*, S. Talukdar and C. W. Gellings, eds. (New York: IEEE Press, 1987).

Some other forms of conservation programs, however, are not well suited to such simple calculations. Home weatherization and heat and cold storage programs exemplify situations where kilowatt and kilowatthour savings depend on ambient weather conditions. Methods outlined in the literature to quantify savings from such DSM measures invariably show a robust relationship (based on field experiments) between kilowatthour-kilowatt consumption per customer and temperature. Heat-cold storage is somewhat complex to examine because the ambient temperature at the time of heat-cold recovery is crucial in determining the load shape. For weatherization where kilowatthours are always saved at any ambient temperature, statistical techniques are used to compare nonparticipants' consumption with that of participants. Chapter 4 examines and critiques such methods.

An Illustration: Water Heaters and Air Conditioners

Many technical articles contain simulations of the operation of air conditioners and water heaters. Air conditioners are turned off for a certain duration and are "cycled," a term which refers to the control of a number of air conditioner groups where, at any instant, a certain number are turned off. Each group in turn suffers an interruption for a given duration. Water heaters also are controlled in a similar fashion to air conditioners. A large body of literature exists on these two DSM activities, reflecting the high interest in them dating back to the mid-1970s.

Simulation models can be used to quantify what is called the "payback effect." When a water heater or an air conditioner is turned off for a certain amount of time, thermostats "cut-in."[20] As soon as the power is turned back on, the loads of this equipment are reconnected to the network.

Because load diversity is decreased, it is critical to form a proper cycling strategy with a determined number of loads to be turned off for a specified period. Consequently, when control is removed the group of

20. The thermostats of air conditioners cut in after a certain off period depending on the ambient temperature. The thermostats of water heaters cut in if there is water usage during the period under consideration.

devices presents a demand to the system which can be significantly larger than normal. This outcome is sometimes called the "payback" or "rebound effect."

Methods of Estimating Payback

Constantopoulos and Talukdar,[21] have shown that simple models are sufficient to capture the essence of the payback or rebound effect. These models have the form:

$$D_{k+1} = d_{k+1} + \sum_{m=0}^{N} \beta_m (D_{k-m} - P_{k-m}) ,$$

where d_k is the original power demand in interval k, D_k is the inflated demand resulting from curtailments in prior intervals, $P_k \leq D_k$ is the power actually supplied in interval k, the βs are constants depending on the load's characteristics and the lengths of the intervals, and N is the number of intervals over which the load's "memory" extends. The βs are commonly called rebound factors. They can be calculated from field tests. β, the rebound factor, is assumed to be independent of ambient temperature. A more sophisticated method is under development by the IEEE load management subgroup.[22]

Figure 3-1 shows the experience of Detroit Edison Company for water heater utility payback characteristics.[23] Note that the time delay of utility payback is also shown. For example, if water heaters are turned off for three hours, the payback is 100 percent the instant they are turned back on; that is, the load on the system is the sum of the rated demands of

21. Sarosh N. Talukdar, V. Kalyan, and M. McNitt, "Models for Assessing Energy Management Options," *Load Management*, S. Talukdar and C. W. Gellings, eds. (New York: IEEE Press, 1987), 122.
22. Sarosh Talukdar and Clark W. Gellings, eds., *Load Management* (New York: IEEE Press, 1987).
23. B. F. Hastings and J. H Byron, "A Method for Calculating Direct Operating Load Management Benefits from Thermal Storage Devices," 1980 IEEE-PES Winter Power Meeting, New York City, New York, February 3-8, 1980.

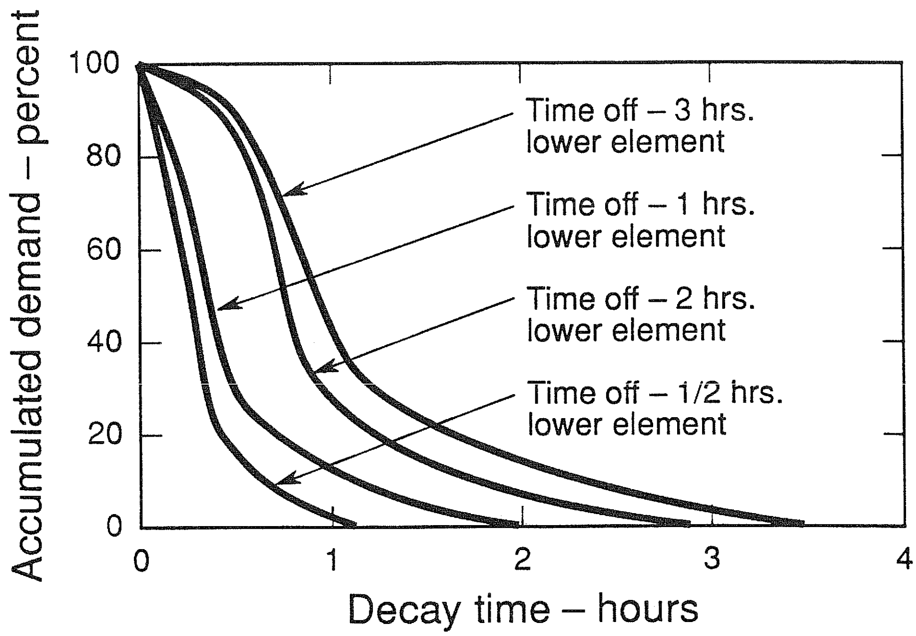

Fig. 3-1. Water heater characteristics (Source: Hastings and Byron, "A Method for Calculating Direct Operating Load Management Benefits," 150). © 1987 IEEE. Reprinted from IEEE Power Engineering Society Winter Meetings, 1980.

each piece of equipment. After about three-and-one-half hours the diversity falls to the "normal" level that existed before turning them off (that is, the accumulated demand is 0 percent).

Data obtained by American Electric Power Company for air conditioning load is shown in Figure 3-2. As shown, a field test was conducted to establish the kilowatt demand per customer. A least-square error function of the ambient temperature versus kilowatt load of customers was obtained from the field data. Subsequent analysis using data from a combination of tests and simulations gives the kilowatts saved when a certain percentage of customers are cycled, as shown in Figure 3-3.

There is no end to the sophistication and embellishment of models--one can examine different cycling strategies and the time duration of

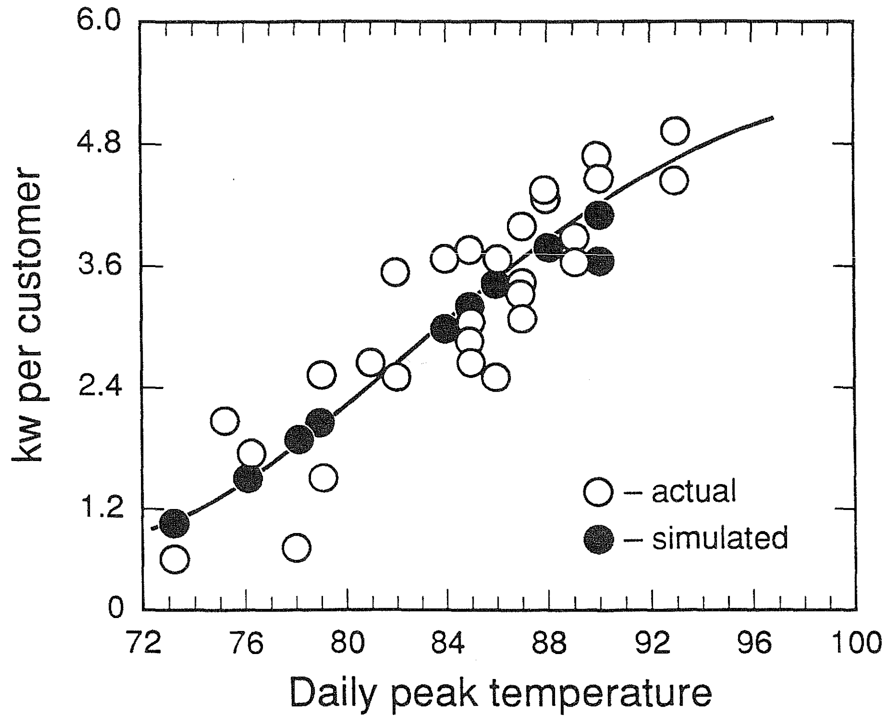

Fig. 3-2. Air conditioning demand as a function of temperature (Source: IEEE Evaluation Subgroup, "Impacts of Several Major Load Management Projects," *Load Management*, S. Talukdar and C. W. Gellings, eds. (New York: IEEE Press, 1987), 163). © 1987 IEEE. Reprinted from *IEEE Transactions on Power Apparatus and Systems* (October 1982): 3885-3891.

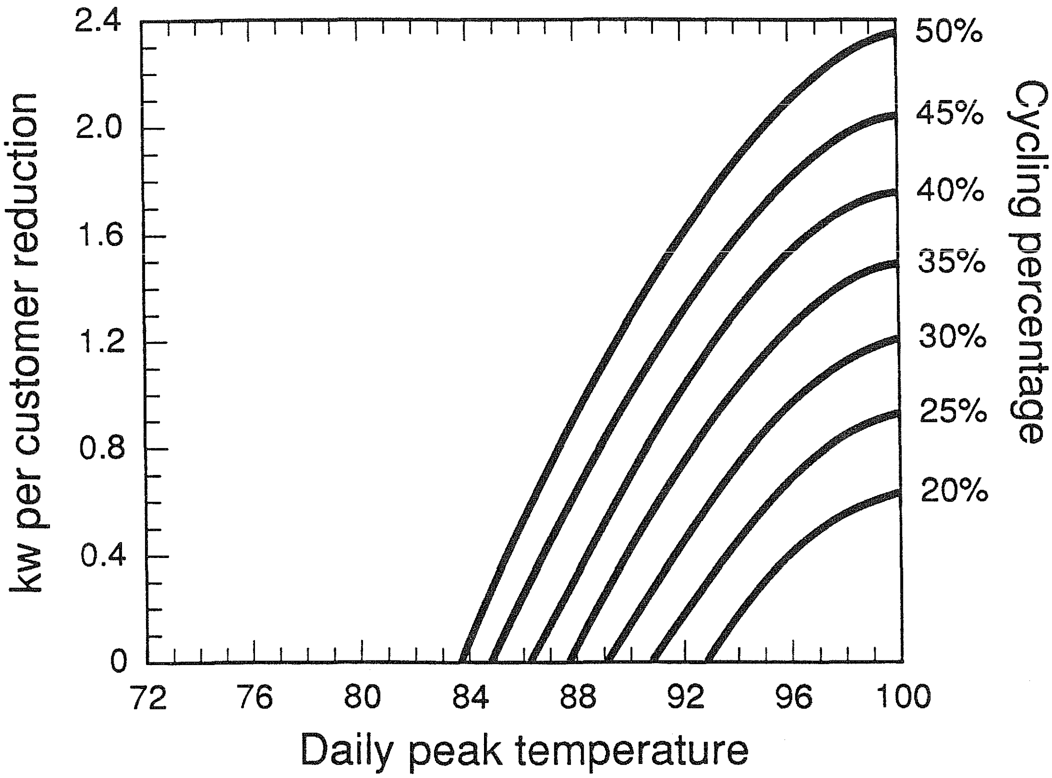

Fig. 3-3. Reduction in air conditioning demand from cycling strategy (Source: IEEE Evaluation Subgroup, "Impacts of Several Major Load Management Projects," 166). © 1987 IEEE. Reprinted from *IEEE Transactions on Power Apparatus and Systems* (October 1982): 3885-1891.

interruption or control. It is not the intent of this report nor is it possible to explore all the models in use; the purpose here is to point out the general nature of models and the nature of uncertainty that might surround them. A field test (which may or may not be possible) is the only way to confirm actual savings. In some instances and for some programs, the kilowatt savings are directly observable. For instance, the reduction in actual kilowatt demand when air conditioners or water heaters are switched off is directly and immediately observable in the control room. When there is a continuous cycling of end-use equipment control, however, the kilowatt change may not be directly observable.

Another Illustration: Duty Cycling

The advantages of the cycling approach already discussed is that the payback, when appliances are allowed to come on, is compensated for by switching off the next batch of air conditioners. Actual cycling schemes allow for the payback of returning load as well as additional load reduction when required to meet the objectives.

The duty-cycle approach to forecasting energy savings combines an engineering-based approach (which accounts for the way appliances operate under natural and utility-controlled conditions) with an empirically based statistical approach (which accounts for the effects of consumer behavior). The definition and benefits of duty cycle are well laid out in a recent EPRI article:[24]

> Duty cycle is a convenient means of representing energy use based on the standard kilowatthour measure. The average duty cycle of an appliance is the percentage of time that the appliance is used during a measurement period. An air conditioner with an estimated connected load of 4 kW and measured energy use over a particular half-hour period of 1 kWh, for example, has an average duty cycle of 50 percent for that half-hour period (2 kWh/0.5 hour/4 kW).
>
> The duty-cycle representation of energy use is well suited to DLC [direct load control] program analysis

24. Steven Braithwait, "Measuring Direct-Load-Control Impacts," *EPRI Journal* 14 (December 1989): 44-47.

because DLC programs achieve load and energy reductions by altering the natural, or uncontrolled, duty cycles of appliances. Implementation of a cycling, or shedding, strategy affects an appliance's duty cycle by limiting its operation and scheduling it during the control period.

A given cycling strategy, however--such as one that cycles air conditioners off for fifteen minutes every half hour--will reduce energy use only for those appliances whose natural duty cycles exceed the upper limit imposed by the strategy--in this case, 50 percent (fifteen minutes/thirty minutes). In addition, the impact on appliances with natural duty cycles that do exceed the limit varies with the difference between the natural duty cycle and the upper limit.

To forecast the effect of a cycling strategy, the probability distribution of duty cycles across the population of appliances needs to be considered. Figure 3-4 represents the actual uncontrolled duty-cycle distribution for Athens, Tennessee on a particular half-hour.[25] The figure also portrays the distribution of duty cycle that would be expected to occur if 50 percent cycling were to be imposed. This means turning off air conditioners fifteen minutes every half-hour.

With such a cycling strategy all the air conditioners that would normally have duty cycles larger than 50 percent would be constrained to duty cycles of 50 percent. It is evident, however, that air conditioners with natural duty cycles below 50 percent would be unaffected by the cycling strategy. The duty cycles of such air conditioners would, therefore, be the same for control and noncontrol days and are unaffected by cycling.

Estimating Load Impact

Estimating load impact of direct load control (DLC) is made difficult in some cases because of the fact that the actual load that would have occurred in the absence of load control may not be observable. In a situation where a batch of water heaters, air conditioners, or other

25. Ibid.

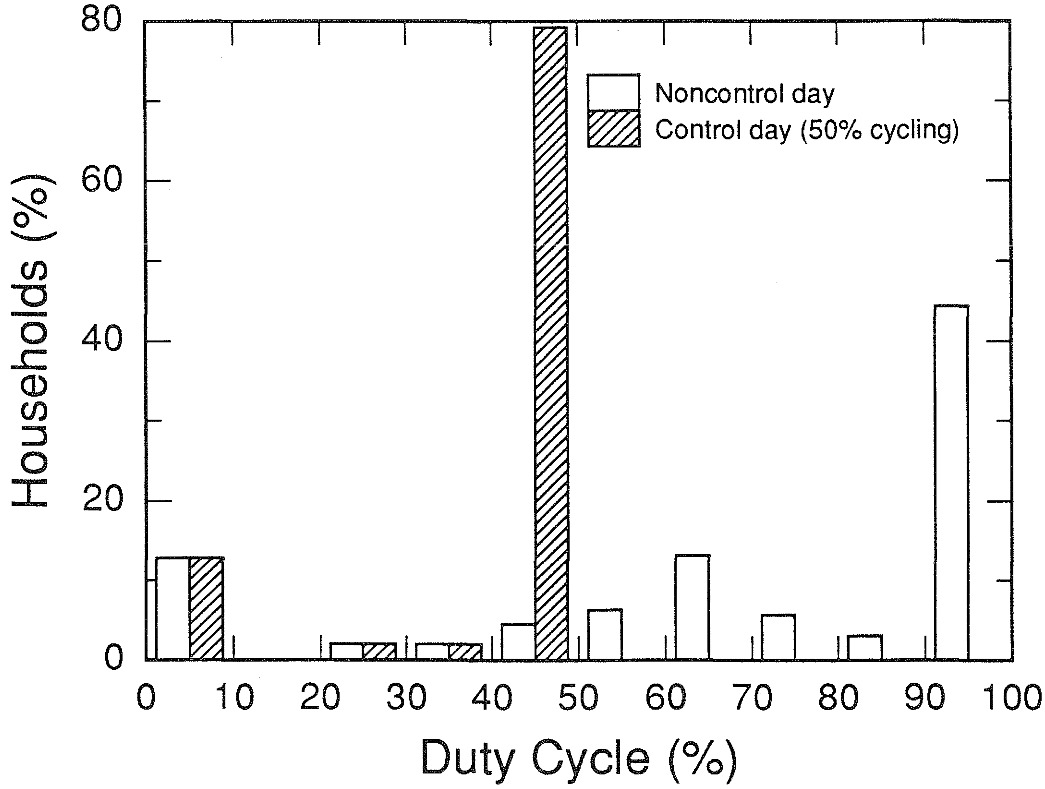

Fig. 3-4. Distributions of duty cycle (Source: Braithwait, "Measuring Direct-Load-Control Impacts," *EPRI Journal*, 45). © 1989 Electric Power Research Institute. Reprinted with permission.

equipment is turned off or on, the change in load is observable at the metering points (at the substation, for example) as a sudden jump in load. If a cycling strategy is adopted, however, where some appliances are turned off while others are turned on, the actual change in load would be unobservable. Similarly, the change in load resulting from improved weatherization programs is also unobservable.

One standard approach to estimating the load impact of a DLC strategy is to calculate the difference between the curtailed load on the day of control and the uncontrolled load on a comparison day. Such a comparison applies aggregated load data at the system (or perhaps substation) level since load data at the appliance level are not usually available.[26] Finding days with truly comparable weather conditions is difficult; and besides, such comparisons do not provide the capability to estimate the load impact under different conditions than those actually observed.

The EPRI article illustrates the use of the duty-cycle approach to evaluate load impact.[27] The article shows the load reduction using the data of the Athens (Tennessee) Utilities Board, Atlantic Electric Company (AE), and Florida Power Corporation (FPC). Figure 3-5 shows the results, which were obtained by accounting for different relative frequencies associated with each duty-cycle range on a control day and a noncontrol day as in Figure 3-4. The results of Figure 3-5 have been obtained by combining the implied duty-cycle reduction derived by the cycling strategy across all relative frequency distribution ranges of Figure 3-4.[28]

It is clear from the above that the duty cycle approach is one useful method for evaluating kilowatts and kilowatthours saved.

Other Categories of DSM Initiatives

The most popular DSM initiatives are heat and cold storage and strategic conservation. For other DSM initiatives there exists scant

26. Ibid.
27. Ibid.
28. The reader is referred to the source document for the definition of hot days, very hot days, and other details.

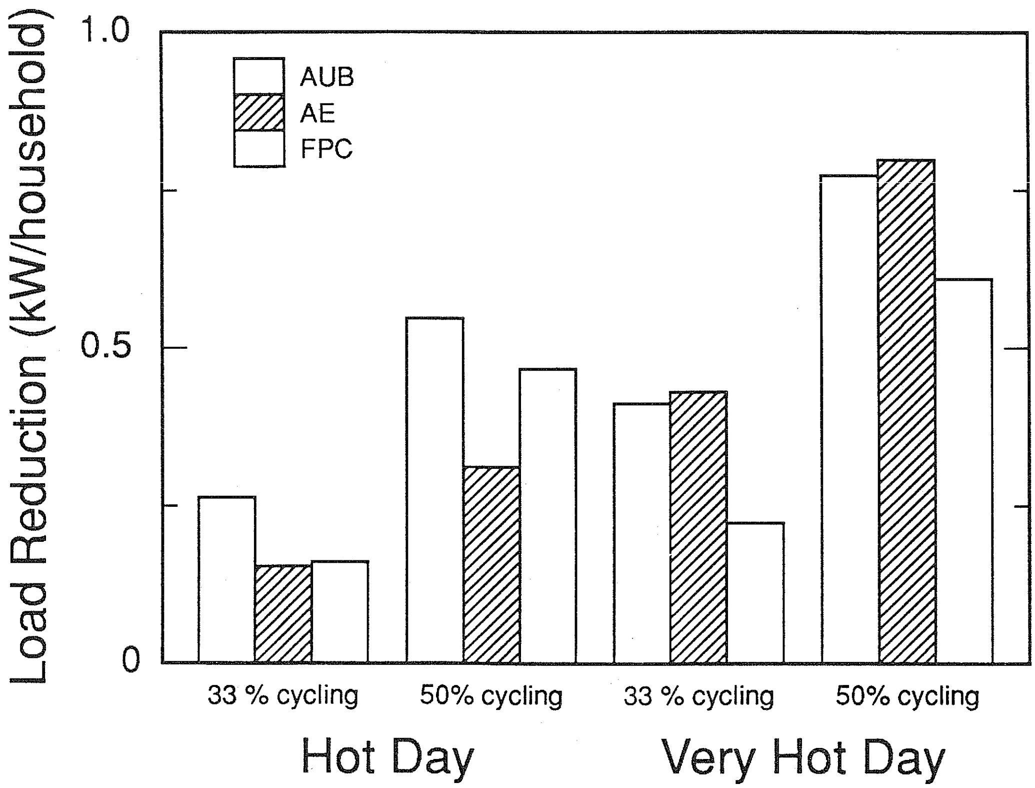

Fig. 3-5. Effect of cycling on load reduction (Source: Braithwait, "Measuring Direct-Load-Control Impacts," *EPRI Journal*, 46). © 1989 Electric Power Research Institute. Reprinted with permission.

literature outlining methods to quantify kilowatt and kilowatthour savings. (Several computer models used to examine the popular programs are briefly explained later in this chapter.)

The economics of many DSM initiatives are system- and process-specific. For instance, in the Pacific Northwest particular attention is given to reducing energy consumption rather than reducing peak demand. Such a position stems from the fact that the electric system in that part of the country is predominantly hydroelectric, which signifies a system that is more energy constrained than capacity constrained.

Based on the above discussion, it is difficult to suggest particular methods or models or to definitely critique the methods of evaluation. The users of different methods tie their models to engineering and economic assumptions that are pertinent to regional circumstances.

Monitoring and Financial Incentives

Monitoring DSM activities is a complex but important task. Although some initiatives may not produce a net change in energy consumption, they are generally analyzed by engineering models that simulate end-use equipment and processes. The data input to such models is based largely on judgment and experience. The savings indicated by the models depend crucially on the input data.

The use of engineering models in the preimplementation stage of a particular DSM program influences the "go-no-go" decision. Incorrect data may, therefore, impinge on electricity system efficiency since economic opportunities for good DSM initiatives may be lost while bad initiatives may be undertaken. These possible outcomes are of concern to regulators.

What may worry regulators more is the situation where some financial incentives are offered to utilities in the postimplementation stage. To illustrate, consider the situation where two Wisconsin electric utilities are allowed the opportunity to earn certain financial rewards, depending on the actual kilowatts or kilowatthours saved:[29]

29. Wisconsin Public Service Commission, *Advance Plans for Construction of Facilities as filed with the Commission for Review and Approval Pursuant to section 196.491, Wisconsin Statutes: Findings of Fact, Conclusion of Law and Order*, Exhibit EPP-3, Docket 05-EP-5, Schedule 1 (April 6, 1989), 1.

Wisconsin Electric Power Company-WEPCO will receive [a 1 percentage point additional] return on its investment in conservation for every 125 MW of demand savings it achieves. The return is calculated on the basis of the unamortized conservation investment. Generally, WEPCO was supposed to achieve these savings at a cost of $200 per kilowatt and $0.02 per kilowatthour.

Wisconsin Power and Light Company-WP&L's Bright Ideas for Business Program is a shared-savings program in which the participating customer pays the utility's cost of capital on what is essentially a loan. The loan is repaid by the savings achieved, so that the customer's out-of-pocket expenses are always less than if he/she had not participated in the program. While the utility's investment is essentially "rate-based"and the utility receives its current return on the investment, there is not a substantial ratepayer impact on the program, as the participating customer pays for most of the costs. WP&L's performance incentive is that it can write a contract with a participating customer for more than its authorized return provided it saves the customer at least 10 percent [of energy]. Its additional return (in terms of percentage points) is calculated as follows:

Customer Saves:	WP&L can earn an additional:
10%	1.0%
15%	1.5%
20%	2.0%
25%	2.5%
30%	3.0%
etc.	etc.

In offering explicit incentives to utilities, state commissions obviously would like to ensure that the actual savings can be measured or metered. As already noted, the kilowatt and kilowatthour savings of most conservation-type techniques are measurable or can be estimated with reasonable accuracy. If a customer uses more efficient end-use equipment, the savings in demand (kilowatts) and energy consumption (kilowatthours) can be derived with reasonable accuracy from knowing the characteristics of the equipment and its diversity of use.[30] If the conservation program involves improving building weatherization or air conditioner control by knowing the actual ambient temperature profile or degree days, the actual savings can be determined with reasonable accuracy. Some of the engineering methods for quantifying the energy savings were discussed earlier.

Monitoring and Third-Party Bidding

In discussing bidding here, the attention will be on whether the bid kilowatts or kilowatthours is an observable and measurable quantity. An example of bids for DSM initiatives is the solicitation by the Orange and Rockland Utilities.[31] The following enumerates eligible measures and their ceiling prices allowed for the bids.

DSM Measure	Ceiling Price $/Peak kW)
Efficient Heat Pump	$400
Efficient Air Conditioning	350
Cool Storage	300
Nonelectric Air Conditioning	300
Efficient Lighting-Ballasts and Fixtures	250
Efficient Motors	150
Efficient Fluorescent Replacements	150

All measures--with the exception of cool storage--are measures that are designed to stimulate energy conservation. For conservation measures, the kilowatthour savings can be determined with reasonable confidence by knowing the characteristics of the newer and the older equipment, the actual number of such installations, and the demand diversity of the load determined by experiments.

30. The actual diversity of use can be established by periodical tests and measurements.
31. William LeBlanc, "Bidding Methods, Evaluation, and Tactics," *Demand-Side Management Strategies for the 90s, Proceedings: Fourth National Conference on Utility DSM Programs, Volume 2* (Palo Alto, CA: Electric Power Research Institute, April 1989), 70-71.

It is unclear how the ceiling prices were set by Orange and Rockland Utilities. The avoided cost savings for other DSM initiatives cannot be determined easily. Invariably, such a determination requires the modeling of end-use equipment. In some cases the savings may be unobservable. The following example illustrates the difficulty in monitoring the kilowatts delivered by specific DSM bids.

Monitoring of Kilowatts Saved in DSM Bids for Programs other than Conservation

Consider, for instance, that an industrial customer proposes to save 5 percent of kilowatt demand in 1995. Assume for simplicity that the industrial process has no growth and, therefore, there exists no change in demand between now and 1995. The proposed 5 percent reduction can be achieved by different measures undertaken by the consumer. For instance, the consumer may propose installing a peaking unit to supply 5 percent of the load at peak hours. The peak time of operation of such a unit could be defined as the hours when the load is above 95 percent of the present peak load. Consequently, the proposed installation would supply demand over and above 95 percent of the present peak load. In this instance, since kilowatts supplied by the peaking unit are measurable, the savings in demand would be observable.

An alternative proposal involves reorienting the process itself. Processes can be modeled in complex mathematical ways.[32] For simplicity, consider an ore processing industry. Normal activity entails crushing the ore between 9:00 a.m. and 2:00 p.m. with chemical processes starting after 2:00 p.m. The peak load of this process is, say, between 10:00 a.m. and 1:00 p.m. The process may change by crushing the ore during the night shift hours, reducing demand during the peak hours of the day.[33] Such a

32. For an example of such modeling see A. K. David and Y. C. Lee, "Dynamic Tariffs: Theory of Utility Consumer Interaction," *IEEE Transactions in Power Systems*, 4 (August 1989): 904-11.
33. The expenses involved in paying premiums for night shift work and other process reorientation will have to be taken into consideration by the industrial electricity consumer.

process reorientation might reflect a response to a request for bids for capacity in which customers are allowed to bid on DSM measures.[34] Such a process reorientation may be classified under any DSM category such as time-of-day pricing, valley filling, peak clipping, or load shifting measures.

The actual kilowatts saved in this alternative reoriented process will always defy precise measurement. Certainly, an analyst can resort to modeling the process to estimate the kilowatt savings (and the attendant savings in production cost from an improved load shape). If incentive payments to the utility are available, however, the regulator may want to ensure that such simulations err on the safe side and, if anything, underestimate the savings. Underestimations protect against the uncertainties associated with the model, the input data, or both. On the other hand, the bidder of the DSM initiative may contend that he or she has been inadequately compensated.

As mentioned earlier, engineering models and econometric-statistical models sometimes complement each other. At other times, however, their relationship changes, as in the above examples. For instance, the load at any hour may be modeled as a function of the size of ore, the tonnage crushed, the number of employees, and other variables. Data collection along with regression analysis can estimate the coefficients that quantify the relationship. Disagreement can exist over whether modeling the process would yield more reliable results than the statistical method. Reconciling this may require verification tests and comparing estimates from each method. New England Electric's initiative exemplifies such an effort.[35]

Estimating kilowatts saved by using engineering models, however, is not free from error. An additional complication stems from the customer's own dynamic behavior, particularly for industrial and commercial loads. Demand over the relevant period (1990-1995) could increase (or decrease) because of variations in process activity. If so, notwithstanding process reorientation, the actual peak demand in 1995 might exceed the demand in

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34. Discussions regarding who should pay for such DSM measures or how such bids should be evaluated falls outside the scope of this report.
35. New England Electric System, "1990 Conservation and Load Management Plan."

1990. The task facing the analyst is to determine the component of load reductions resulting from DSM measures and the component of load increases (decreases) resulting from increased (decreased) production. Under such circumstances, it would be extremely difficult to know the exact kilowatts and kilowatthours saved directly as a result of the DSM initiative in order to determine the incentive payment. The use of statistical techniques to determine what the load would have been without the DSM bid would be required. One alternative for confirmation might be to monitor the number of tons of ore crushed in each hour to ensure the delivery of DSM measures.

A further complication in soliciting DSM bids centers around the method of determining future capacity and energy needs. These needs are based on a comparison between forecast demands and existing resources. The forecasting methodology may require many technical, economic, and demographic variables. For shorter-term industrial demand forecasts, methods based on a survey of energy requirements of industrial customers generally are the most reliable. The need for additional capacity and energy is, therefore, influenced by the input data provided collectively by the industrial consumers. Since the very customers who provide the data for the forecasts can be DSM program bidders, a conflict of interest would arise. It would be difficult or perhaps impossible to ensure that a particular industrial customer had not overestimated its future requirement of capacity and energy so that a larger amount might be available for DSM (and generating capacity) bids. If this were the case, it would be equally hard to ascertain if the bid amount of kilowatt and kilowatthour savings from the DSM measures did materialize.

Until now, a majority of the DSM bids received and awarded come under the category of strategic conservation. For future bids that involve, say, process reorientation, a careful procedure to determine the actual savings (kilowatts-kilowatthours) in the postimplementation stage should be followed. Analysis of such bids would include the use of engineering models. Regulators then would have to ensure that the models were working properly and that their data are acceptable.

Case Study: DSM Bids for Chiller Modification

An example of a DSM program affecting process reorientation recently was approved by the New Jersey Board of Public Utilities.[36] Under the program, the bidder undertook installation of storage medium of eutectic salts in five treatment groups using chillers.[37] During off-peak periods, the host's existing chiller equipment will be used to charge the storage tank. During on-peak time periods, the stored cooling capacity will be discharged and used to cool the facility. The bidders anticipated a reduction of 12,285 kilowatts in 1992.

Payments

The program includes no payment to the bidder for energy savings. For each kilowatt saved, however, the bidder is paid $101.50 per kilowatt per year, the rate charged by the Pennsylvania-New Jersey-Maryland Power Pool (PJM) for capacity purchases. The bidder is obligated to deliver at least 90 percent of the contracted capacity; failing to do so will result in the bidder being charged a penalty equal to the difference between 90 percent of the bid value and the actual delivery multiplied by the capacity deficiency rate for the PJM pool. Other guarantees require forfeiture of some deposit sum if certain milestones are not reached.

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36. In the *Matter of the Application for Approval of the Power Savings Agreement Between Transphase Systems, Inc. and Jersey Central Power & Light Co.*, Order of Approval, Docket No. 8010-687B, New Jersey Board of Public Utilities (September 1988).

37. The technology of storage heat in salts is also used in residential heat and cold storage programs. Monitoring such programs, due to a larger number of installations, is not generally based on actual measurement in each installation as in the case of the industrial example under discussion.

Monitoring

Several details in the contract outline the calibration of measuring equipment and other procedures. A summary of the main monitoring features is presented below.

The installer must keep detailed hourly logs of fluid flows and temperatures. Such records and the operation of the plant are open to inspection by the utility or its representatives. By knowing flows and temperature, the heat removed from the storage medium can be calculated. From the engineering performance characteristics of the compressor equipment and its thermodynamic properties (in the form of performance curves specified in the contract) the load in kilowatts that would be required to generate the heat content taken out of storage (had the storage not been in place) is calculated as the kilowatt savings. The capacity savings calculated for payment to the bidder is based on the utilities' obligation to PJM interconnection as follows:

Capacity savings = [0.38 x (average peak reduction)] +
[0.75 x (summer peak reduction)] +
[0.08 x (winter peak eduction)],

where the months and hours of peak and off-peak usage are defined in the contract.

Some of the conflicts alluded to earlier do not exist in this case. The proxy to actual kilowatt savings is continuously measured as the heat content, and the price is based on the spot-market price in the power pool.

While the savings in this example are quantifiable, the delivered kilowatthour and kilowatt benefits from all types of DSM bids generally are not observable or measurable; at best they can reasonably be estimated. This relates to the view that DSM bids are not fully comparable to supply side bids where output is known with greater certainty. Establishing a common scoring system for DSM and supply bids would be a complex task due to these difficulties in measuring some DSM benefits.[38]

38. LeBlanc, *Bidding Methods*.

The concerns here with DSM bidding mirror those of others, including William LeBlanc, Project Manager of Bidding, Cogeneration, and Pricing at the Electric Power Research Institute:

> Whether a DSM program is developed through a bidding solicitation or form within a utility, the problem of proper measurement remains one of the more significant barriers to acceptance of this resource. EPRI and several utilities have developed sophisticated methods to solve such problems, and many tools exist to monitor, measure, and predict load shape impacts from DSM programs. Some types of DSM program impacts are inherently easier to quantify than others; interruptible rates, for example, are relatively easy to measure, while many energy efficiency enhancements may be difficult to quantify due to variable human and external factors.
>
> Two basic methods of DSM bidding solicitations have evolved: 1) prescriptive equipment installations, and 2) equivalent supply displacement. Although the prescriptive method allows easier quantification (e.g., number of water heater blankets, capacity of thermal energy storage systems), questions still remain as to which investments would have been made without DSM programs, and whether each installation provides the necessary offsetting benefits.[39]

Illustration of Two Widely Used Models

The following discussion highlights two models commonly used in evaluating DSM benefits. The models are presented here to expose the reader to methods that have been tested and used by various electric utilities throughout the country.

The Princeton Scoring Method (PRISM)

The Princeton Scoring Method (PRISM) estimates the energy savings actually achieved from conservation initiatives and other types of DSM initiatives targeted at certain segments of the residential sector. These

39. Ibid., 71-3.

segments are primarily single-family homes without electric air conditioning. The PRISM algorithm calculates a weather corrected index of energy consumption. The model may be applied to measure the effects of a particular conservation project (for example, heating system replacement) or program (for example, residential conservation retrofit) for a particular home, or it may be used to calculate a "control-group-adjusted" savings for a group of treated homes.

PRISM requires both pretreatment and posttreatment data: the average daily consumption during the time interval (twelve months), and heating degree days per day computed to the reference temperature, t, in the time interval. The method regresses energy consumption as a function of temperature, for a "guessed" value of the reference temperature. An iterative "Newton's method" technique was developed for the model to find the optimal reference temperature value that makes the regression line more linear. The method is applied to the above-mentioned data sets to derive normalized annual consumption (NAC) for every house in the group. From the individual home values, average values (means or medians) for the NAC measures may be calculated.

The major limitation of PRISM lies with its application for evaluating only conservation programs targeted at certain parts of the residential sector. It is not yet applicable to conservation programs targeted at the commercial-industrial sector.

Electric Load Curve Synthesis (ELCS)

The ELCS model evaluates load management, conservation, and other impacts on the electric system load curve and any major component of the total load curve. ELCS was initially developed for Public Service Electric & Gas Company (PSE&G) of New Jersey. ELCS allowed PSE&G to examine its present electric load shape, apply appropriate forecasted nonload management and then load management impacts, and examine the resulting revised load shape. The model has some significant advantages over other methods. These include the ability to: (1) investigate the diversified load curves of various end-use appliances; (2) separate the system load curve by rate, revenue component, and/or class of business; and (3) determine the impact on any of the major components of the system load curve on an hourly basis resulting from a change in any major end-use component.

ELCS operates under three principles. First, it synthesizes the total system load curve from end-use components. The loads produced by any component are either "base" or "weather-sensitive" loads. Weather-sensitive loads generically are any loads that vary in magnitude in relation to some weather parameter. These include loads such as those produced by a residential air conditioner. Base loads are independent of any weather parameter variations. An example would be the load produced by a domestic water heater.

Second, ELCS considers three general types of customers: residential, industrial-commercial, and miscellaneous. For residential customers, thirty-five major components represent the actual end-use appliances. For industrial and commercial customers, a systemized breakdown by user type is developed. Each rate schedule serving these customer types are subdivided into as many as nine categories, each representing a type of user having similar load characteristics. The miscellaneous customer category includes sales for resale, street lighting, and intracompany use.

Third, ELCS models each type of weather sensitive load by using up to two second-order polynomials each with specified boundary conditions, overall seasonal response factors, a time-of-week response factor, with the hourly varying weather data as the driving force. The article by Gellings et al., presents a detailed discussion and derivation of these models.[40]

40.Talukdar and Gellings, eds., *Load Management*.

CHAPTER 4

ECONOMETRIC ESTIMATION OF CONSERVATION PROGRAM SAVINGS

This chapter examines the use of econometric methods for estimating the energy savings from a conservation program. The chapter is divided into two sections. The first section discusses issues concerning data collection. The second section presents methods for estimating energy savings from a conservation program using data from a cross-section of households or firms. A two-equation, continuous-discrete econometric model is specified for this purpose (with three alternative means of specifying the discrete equation). In general, the techniques used in this chapter can be applied both to electric and natural gas conservation programs.

Econometric analysis represents use (kilowatt or kilowatthour) as a mathematical statistical function of several variables such as price, household income, and ambient temperature. The objective is to collect adequate data for estimating the coefficients in a mathematical relationship. The discussion here includes techniques to account for participation biases and other econometric problems. Although econometric methods may be used in the preimplementation stage to predict savings in a future conservation program, they can also be used in the post-implementation analysis of a program.

The econometric approaches presented here were chosen primarily because they are well suited to estimate energy savings from a particular conservation program. Longitudinal data and analysis (collecting data on the same households and/or firms over time[1]) could also be used for this purpose; however, the approach presented here does not require the data or

1. For a discussion of longitudinal analysis and problems encountered see, J. J. Heckman and B. Singer, *Longitudinal Analysis of Labor Market Data*, Cambridge, England: Cambridge University Press, 1985. In particular, chapter 4 by J. J. Heckman and R. Robb, "Alternative Methods for Evaluating the Impact of Interventions," deals with the problem of sample selection bias discussed below with longitudinal data.

the cost and time needed to collect multiyear data for a longitudinal study. As more conservation programs are implemented and more data collected for evaluations, longitudinal data and/or repeated cross-sections of different households and firms will most likely be used for post-implementation evaluations. Since data of this type are not yet generally available, these methods are not discussed here. Single-period cross-sectional data and the type of analysis presented here provide an empirically tractable means of reliably estimating energy savings. Also, it can yield information about households' and firms' energy use that can be useful when designing future conservation programs.

Time-series data (such as billing data) on total energy use also could be used in a Box-Jenkins approach, such as intervention analysis.[2] However, while data for this type of analysis is more readily available, it cannot distinguish between particular program savings or assist in accounting for unanticipated changes in energy use that cross-sectional data can provide. For these reasons time-series approaches also are not discussed here.

Data Collection

A cross-sectional analysis of the type presented here involves collecting data from utility customers through mailed questionnaires, telephone interviews, personal interviews at the customer's residence or business, or a combination of these approaches. In addition, general data must be collected, such as prices and energy use. This extensive process of collecting cross-sectional data can make it an expensive means of analysis. However, it also yields direct insights into households' and firms' motivations for taking a specific action, which can be used not only to evaluate the program being analyzed, but can aid in designing future programs as well. The cost of data collection is commonly balanced against

2. G.E.P. Box and G.C. Tao, "Intervention Analysis with Application to Economic and Environmental Problems," *Journal of the American Statistical Association* 70 (1975): 70-79.

the expected benefit from the information obtained from the analysis when considering what level and detail of analysis to conduct.

It also is important for this type of analysis that data be collected both on program participants and nonparticipants. This is especially critical for statistical identification of the econometric model presented below, but is also important for comparing the two groups in a descriptive manner. Data of this type can be collected in two ways. First a group of households or firms could initially be *randomly* selected from within a given area (for example, the utility's service territory). The conservation program offer would be made to this group and extensive data would then be collected both for those who accepted and rejected the offer. A second means of data collection would be to offer the program to all households or firms in a service territory or state. Once the participants have been identified, a control group is selected from the nonparticipants.

An advantage to the first technique is that the analyst has more control of the total number of households or firms analyzed. A disadvantage is that the group selected could be nonrepresentative of the entire population (from a statistical standpoint, have a different mean and variance). This could especially be a problem if only a small number in the group chose to participate (which would be a limiting factor for the econometric analysis). Of course, this disadvantage can be alleviated by increasing the sample size (discussed below). The second technique would likely not have the problem of a small number of participants if the program were to be offered to a sufficiently large number of households or firms. The analyst may not be able to control or predict program evaluation costs, however, since the total number of households or firms is not known until after the program has been offered.

Central to the discussion below are methods to account for an inherent feature of most conservation programs that affects the evaluation data. Most states and utilities have conducted programs that are voluntary, and are unlikely to make participation in a conservation program mandatory in the future. A household's or firm's decision to participate is related to the expected energy savings from the program. Thus, in most programs participants are "self-selected" (that is, not randomly selected). The econometric implication of this is discussed in more detail below.

Sample Size

Unfortunately, there is no straightforward way to determine the "optimal" sample size for model estimation. Basic statistics suggests that as the sample size increases, the more likely it is that the sample parameters (mean and variance) will approximate the actual population's parameters. Statistical methods exist that allow an analyst to determine how large to make the sample so that the actual population mean will fall within a specified confidence interval of the sample mean.[3] These methods, however, require specific knowledge of the actual population parameters, such as the standard deviation and distribution. Moreover, these methods cannot be applied to models of the type presented below. As a result, analysts are required to consider the sample size used in comparable studies and apply their own judgment when deciding about their particular study.[4]

Collecting a sample that is too large can be a problem because, as noted above, collecting detailed cross-sectional data for this type of analysis can be costly. Cost is likely to be the most serious drawback to collecting too much data, assuming the households or firms are selected randomly. From an evaluation standpoint it is more critical that the sample not be too small. For this reason it may be best to determine a minimum sample size or range based on other studies.

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3. See for example, chapter 7 of Paul G. Hoel and Raymond J. Jessen, *Basic Statistics for Business and Economics* (New York: John Wiley and Sons, 1982). Other basic statistics texts also usually include discussions on this topic.

4. These basic methods as well as a more advanced method, Bayesian sampling, are discussed in Electric Power Research Institute, *Impact Evaluation of Demand-Side Management Programs, Volume 1: A Guide to Current Practice*, prepared by RCG/Hagler, Bailly, Inc., February 1991, EPRI CU-7179. This study also discusses several other data collection issues including control group specification and survey techniques.

An EPRI study cites a 1974 book that reviewed sample sizes of several hundred regional and national studies.[5] They found that regional studies with no or few subgroups of households ranged from 200 to 500, regional studies of institutions (again with no or few subgroups) ranged from 50 to 200. With many subgroups, regional studies of household were over 1,000 while there were over 500 in regional studies of institutions. The EPRI study also examined several residential and commercial conservation program impact evaluations. While it is difficult to make comparisons across these studies, they ranged from just under 200 households or firms (total sample size) for programs that were one of several programs to over 2,000 for two statewide programs (in New Jersey); most programs were in the 500 to 1,200 household or firm range.

While it is important to consider other comparable programs when choosing the sample size, it is also important that the analyst consider the particular factors of the program being analyzed. These factors include the type of program offered, the number of likely participants, how wide a geographic area the program is being offered in, the length of time over which the study will be conducted, how long the program offer will be made, and the funding available to conduct the analysis. All these factors can be judged only on an individual program basis.

Variable Selection

Data for cross-sectional analysis is often collected by a survey instrument developed by the analyst. As noted, the survey may be conducted through a mailed questionnaire, telephone interview, an interview at the house or firm, or a combination such as an interview at the home with a telephone follow-up. Of course, each survey method has its advantages and disadvantages: a mailed questionnaire is relatively inexpensive and allows for some detailed questions, but usually has a low response rate (particularly without a follow-up); telephone interviews, in general, have

5. Ibid., 3-11. The book they cite is S. Sudman and N. M. Bradburn, *Response Effects in Surveys: A Review and Synthesis* (Chicago: Aldine Press, 1974).

a higher response, but usually cannot collect as much detailed information; an interview at the house or firm can collect the most detailed and accurate information of the survey methods, but is the most expensive; and combining methods allows some flexibility to take advantage of the strengths of the various methods, but again is relatively expensive.

These surveys usually seek considerable detail on the households or firms that are being analyzed. When designing the survey instrument and selecting questions, the analyst should consider the program or programs being analyzed, the time period of the analysis (that is, one year or a multiyear panel or longitudinal study), the geographic area and eligible households or firms offered the program, the method of analysis (for example, descriptive, econometric, and so on), and possible future uses, such as a comparative analysis of program effectiveness or for developing future programs.

Tables 4-1 and 4-2 contain some suggested survey items for a residential and commercial or industrial energy conservation program evaluation. These data items can be used for both a descriptive and/or econometric analysis. Not all items would be used as variables in the final econometric analysis of the type presented below, since many would be correlated to each other (causing collinearity problems in the model) or would not be used in the model specification. Several items would become dummy variables (having a value of either 0 or 1, such as program participation and the presence of a central air conditioner) and interactive dummy variables can be specified. Again, the variables selected will depend on the nature of the program being analyzed. The model is presented in a general form, with the analyst then selecting the variables for estimating the probability of participation and energy savings.

Table 4-3 provides an example of variables used in the type of econometric analysis presented below from a study of an energy conservation program.[6]

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6. Kenneth E. Train, "Incentives for Energy Conservation in the Commercial and Industrial Sectors," *The Energy Journal* 9 no. 3 (July 1988).

TABLE 4-1

SURVEY DATA NEEDED FOR A CROSS-SECTIONAL DESCRIPTIVE AND ECONOMETRIC ANALYSIS OF A RESIDENTIAL ENERGY CONSERVATION PROGRAM

Household Energy Use

kWh/ccf--total, per month

Prices--electricity, natural gas, oil, etc.

Heating--primary, secondary, and supplemental fuels, equipment age

Cooling--primary fuel used, central, number of room ac units, swamp cooler, equipment age

Heat pump--primary fuel, age

Water heating--primary fuel, heated swimming pool, equipment age

Large appliances--electric/gas range, freezer, dishwasher, electric/gas clothes dryer, water pump, ownership, and age of equipment

Residential Structure

Single family--own/rent, square feet

Townhouse--own/rent, square feet, shared walls, floor, or ceiling

Condominium--own/rent, square feet, shared walls, floor, or ceiling

Apartment--square feet, pays heating/cooling costs

Mobile home--own/rent, square feet

Type of construction--single story frame, two story brick, etc.

Age of structure

Insulation levels

Glass type--single or double pane, storm windows

Occupancy Characteristics

Full-time

Seasonal or part-time

TABLE 4-1--Continued

Household Demographic Characteristics

Number of household members

Age of household members

Income

Education levels

Number of people at home during day/evenings

Urban/suburban/rural

Number of children--under 6 years of age, school age

Conservation Action

Nonprogram conservation adopted--weatherization, insulation, etc.

Program participant (Yes/No)

Attitudes and Opinions Toward:

Energy conservation

Energy efficient equipment

Future energy prices

Expected energy savings from program

Other Data

Weather data for study period--heating and cooling degree days

Billing cycle

Source: EPRI, *Impact Evaluation of Demand-Side Management Programs*; Pacific Gas and Electric Company, Phase II Load Impact Analysis of the Pacific Gas and Electric Company's Residential Time-of-Use Pricing Experiment (Berkeley, CA: Cambridge Systematics, Inc., May 1988); and authors.

TABLE 4-2

SURVEY DATA FOR A CROSS-SECTIONAL DESCRIPTIVE AND ECONOMETRIC ANALYSIS OF A COMMERCIAL AND/OR INDUSTRIAL ENERGY CONSERVATION PROGRAM

Commercial or Industrial Energy Use

Energy consumption--kWh/ccf total, per month prices--electric, natural gas, oil, etc.

Space heating--primary, secondary, supplemental fuels, equipment age

Air conditioning--primary, secondary, supplemental fuels, equipment age

Process heating/refrigeration--primary, secondary, supplemental fuels, equipment age, steam temperature

Self- or cogeneration of electricity, waste heat recovery system

Water heating--primary fuel, equipment age

Cooking--fuel

Lighting systems and usage

Industrial process equipment--number, type, fuel, hours of operation, and utilization rates

Other equipment--computers, backup systems

Commercial or Industrial Structures

Main activity of firm (SIC classification)

Number of buildings

Building functions--office, retail, warehouse, school, etc.

Number of employees--number of shifts, employees per shift

Hours occupied

Square footage

Production level--units

Age of building

Ownership

Window area

Insulation levels

Construction--wood frame, steel frame, masonry

Glass type--single or double pane, store windows

TABLE 4-2--Continued

Conservation Actions

Nonprogram conservation adopted--weatherization, insulation, efficient lighting

Program participant (Yes/No)

Other Data

Weather data for study period--heating and cooling degree days

Billing cycle

Source: EPRI, *Impact Evaluation of Demand-Side Management Programs*; and authors.

TABLE 4-3

VARIABLES USED IN AN ECONOMETRIC EVALUATION OF AN ENERGY CONSERVATION PROGRAM

Probability of Participation Equation*

Offered rebate in 1983 (Yes = 1, No = 0)**

At least one auditor visit in 1983, for:

peak demand < 200 kW+

peak demand ≥ 200 kW

Number of auditor visits in 1983

Number of auditor visits in 1982

Number of people in building**

Operating hours per month+

Square footage, in thousands+

Cooling degree days**

Heating degree days**

Commercial customer

TABLE 4-3--Continued

Rates: GS-1 (kWh charge only) taken as base+
GS-2: kW charge in addition to kWh charge
Location: Central region taken as base
Southern region
Northwestern region
Eastern region**
Southwestern region+
Energy Savings Equation
Operating hours per month**
Square footage**
Commercial customer**
Peak demand 20-199 kW
200-499 kW
500-999 kW
1,000 + kW
Location: Central region taken as base
Southern region
Northwestern region
Eastern region
Southwestern region

Source: Train, "Incentives for Energy Conservation."

* Total number of observations was 1,316; 885 took action, 431 did not take action.

**Variable was significant at the 95 percent level.

+ Variable was significant at the 90 percent level.

Econometric Methods to Estimate Energy Savings from a Conservation Program

The material presented in this section assumes familiarity with advanced statistics and econometrics. Nontechnical readers, however, are encouraged to continue through this section to assist their understanding of econometric methods applied to conservation program evaluation. Citations in this section include more basic references as well as more technical sources containing proofs and expanded explanations. Skipping the remainder of this section will not result in a loss of continuity needed to understand the conclusions of the entire report.

General Model Specification

The methods presented in this section are drawn from the current econometric literature developed to analyze problems that are in the category of continuous-discrete models.[7] These models have been used to study problems similar to the one of estimating the savings from a conservation program. The particular methods presented below were selected because of their suitability to this problem and because they are relatively more tractable than others examined; particularly since the calculations are readily available in most econometric computer programs. Since the analyst will face a wide variety of data, conservation program types, and problems that are particular to a program, a general framework is provided that can be adapted to suit as many situations as possible.

7. Technically, as will be shown later, the "continuous" dependent variable is actually a censored variable since the analyst only observes the dependent variable for those who invest in the utility's conservation program. A solution to this problem is presented below.

It is assumed below that the conservation program has the following features:[8]

1) participants are volunteers,
2) the program is utility sponsored (electric or natural gas),
3) the program is designed to promote energy conservation (although many features can be used with a time-of-use pricing load management program as well),
4) the analyst is interested in estimating the energy savings *that result from* the conservation program (different from total conservation in a service area),
5) the program was either a limited and controlled experiment to estimate the savings of a program that may be applied system wide later or a program that was initially offered system wide--in either case the intention of the analyst is to determine the energy savings, or potential savings, due to the utility sponsored program system wide,
6) the data is collected from a cross-section of households or firms for a specified time (for example, one or two years),[9] and
7) extensive data has been collected on the characteristics of both the participating and nonparticipating households or firms.

Self-Selection Bias

As mentioned earlier, since most conservation programs are voluntary, the data collected on households and firms that take action is nonrandomly

8. All of the assumptions except the last are common features in the programs that were examined for this analysis. As will be seen, the last assumption is required to identify the first equation in the two equation model presented below. For a method of working with volunteer-only data (where the customer's participation motives are modeled for five time-of-use experiments and compared to the results where self-selection is not corrected for), see Dennis J. Aigner and Khalifa Ghali, "Self-Selection in the Residential Electricity Time-of-Use Pricing Experiments," *Journal of Applied Econometrics* 4 (1989): S131-S144.
9. Pooled cross-section, time-series data (or panel or longitudinal data) may also be used with the type of analysis presented here; however, it is not addressed specifically.

selected. Any estimation that does not correct for this "self-selection" bias is likely to overestimate the actual energy saved *due to the program.*[10]

To illustrate the problem of self-selection econometrically, consider the following simple model formulated to estimate the savings due to a utility's conservation program:

$$S_i = \beta \mathbf{X}_i + \gamma d_i + u_i \tag{1}$$

where

S_i = energy saved from a conservation action (kWh or ccf per year) for firm or household i,

$\mathbf{X}_i$ = vector of observed firm or household attributes (for example, number of employees, square feet, etc. for an industrial program and income, number of people in household, etc. for a residential program. See previous section of this chapter for a discussion of variable choice),

β and γ = parameters to be estimated,

u_i = disturbance term or unobserved factors, and

d_i = a dummy variable that equals 1 if the firm or household participates in the utility's program and 0 otherwise.

The coefficient of d_i (γ) would be intended in this model to estimate the effect of the utility's program. This would depend, however, on the assumption that d_i is *exogenously* determined. Since the decision to participate in the utility's conservation program is in part determined by the expected energy savings, then d_i is in fact *endogenous*. The structure of this model implies that the amount of energy saved is dependent on the

10. These include firms and households that planned to invest in the conservation measure without the utility's program. This subset of self-selected participants are often referred to as "free riders." Techniques designed to separate the free riders from the set of self-selected participants are discussed in EPRI, *Impact Evaluation of Demand-Side Management Programs, Volume 1: A Guide to Current Practice*, 6-17 to 6-20. From a policy perspective, however, the concern is estimating the energy savings due to the particular program, that is, corrected for self-selection bias as discussed here.

participation in the utility's program; expected savings, however, affects the decision to participate. Therefore, estimating the energy savings of a utility's conservation program, given the above assumptions, requires that the dummy variable d_i be treated endogenously. A model that does not take this into account will result in biased and inconsistent estimators of the coefficients.

A Continuous/Discrete Two-Equation Model to Correct Self-Selection Bias

Fortunately, the econometric literature is well developed to solve the problems related to self-selection. These methods have been used to study, among other things, housing choice, college choice, transportation choice, union membership, and labor force participation.[11] The model presented below uses two equations to estimate participation and energy savings; this formulation is based largely on the work of Heckman,[12] McFadden,[13] Dubin and McFadden,[14] and Train.[15]

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11. For a good, albeit dated, survey of these types of models see T. Amemiya, "Qualitative Response Models: A Survey," *Journal of Economic Literature* 19 no. 4 (December 1981): 1483-1536.

12. J. J. Heckman, "The Common Structure of Statistical Models of Truncation, Sample Selection and Limited Dependent Variables and a Simple Estimator for Such Models," *Annals of Economic and Social Measurement* 5 no. 4 (1976); J. J. Heckman, "Dummy Endogenous Variables in a Simultaneous Equation System," *Econometrica* 46 no. 6 (July 1978); and J. J. Heckman, "Sample Selection Bias as a Specification Error," *Econometrica* 47 no. 1 (January 1979).

13. McFadden assumes that a consumer's utility is a random function. This is based on the hedonic-price problem in econometrics and the psychology literature of probabilistic choice. These underlying assumptions and the utility model are not discussed here, see D. McFadden, "Conditional Logit Analysis of Qualitative Choice Behavior," *Frontiers in Econometrics*, ed. by P. Zarembka (New York: Academic Press, 1973), 105-42; D. McFadden, "Modelling the Choice of Residential Location," in *Studies in Regional Science and Urban Economics*, ed., A. Andersson and W. Isard, *Volume 3: Spatial Interaction Theory and Planning Models*, ed., A. Karlqvist, et al. (Amsterdam: North Holland Publishing Company, 1978); D. McFadden, "Econometric Models of Probabilistic Choice," in *Structural Analysis of Discrete Data*, ed. by C. Manski and D. McFadden (Cambridge, MA: MIT Press, 1981).

14. J. Dubin and D. L. McFadden, "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption," *Econometrica* 52 no. 2 (March 1984).

15. Kenneth E. Train, *Qualitative Choice Analysis*, (Cambridge, MA: MIT Press, 1986); idem, "Incentives for Energy Conservation."

Equation 1: Estimation of the Probability of Participation Using a Binary Logit Model

A preferred method to that presented above is to use a three-step process developed to analyze problems of this type. The first step is to estimate the probability of participation. Since this probability is not directly observable, a qualitative choice model is used. We begin by assuming that an underlying and unobserved response variable y_i^* is defined by the regression relationship

$$y_i^* = \beta \mathbf{X}_i + u_i \ . \tag{2}$$

The actual y_i^* is an index of the "strength of feeling" that firm or household i has for participation and is a linear function of $\mathbf{X}_i$. Its actual value is unknown, but a dummy variable y_i is observed where ($\mathbf{X}_i$ and u_i are as defined in equation 1) and

$$y_i = 1 \text{ if } y_i^* > 0 \text{ or firm or household i participate,}$$

$$y_i = 0 \text{ otherwise.} \tag{3}$$

If it is assumed that u_i has a cumulative logistic distribution, then (see Appendix B for how this is derived) the probability of participation can be estimated by

$$P_i = \frac{e^{(\beta \mathbf{X}_i)}}{1 + e^{(\beta \mathbf{X}_i)}} \tag{4}$$

where

P_i = the probability of firm or household i taking conservation action given knowledge of $\mathbf{X}_i$ ($y_i = 1$) and

e = the base of the natural logarithms (~2.718),

which is the form of the logit model.[16]

Equation 2: Estimation of Energy Savings

If it is assumed that when the firm or household participates in a conservation program there is a reduction in energy usage, the energy savings can be represented as

$$S_i = \beta \mathbf{X}_i + \epsilon_i \tag{5}$$

where S_i and $\mathbf{X}_i$ are the same as defined in equation 1 above and ϵ_i is the disturbance term.

Estimating equation five is complicated since S_i (energy savings) is not observed (that is, equals zero) for the entire population of firms or households, but only for those that participate in the utility's conservation program. (There may be some savings realized from other conservation measures adopted by the firm or household, but at this stage

16. This is usually estimated with a maximum-likelihood (ML) estimation procedure. A detailed discussion of ML procedures used for logit models can be found in R. S. Pindyck and D. L. Rubinfeld, *Econometric Models and Economic Forecasts* (New York: McGraw-Hill Book Company, 1981) or G. S. Maddala, *Limited-Dependent and Qualitative Variables in Econometrics* (Cambridge, England: Cambridge University Press, 1983). Many computer programs are available (for most systems) that include a logit estimation routine.

the concern is the savings from the utility's program.) Unobserved factors that affect the probability of participation, P_i, or more specifically, u_i in equation two, is related to the savings that result from participation. Therefore, u_i and ϵ_i are correlated and the mean of ϵ_i (conditional on S_i being observed) is not zero. This means that ordinary least squares (OLS) estimation, without correction, would lead to sample selection or self-selection bias discussed above.[17]

Dubin and McFadden found that if[18]

(a) u_i has a cumulative logistic distribution (which is assumed),

(b) ϵ_i is normally distributed in the population of all firms or households with zero mean and variance σ_ϵ^2, and

(c) the correlation between u_i and ϵ_i in the population is $\rho_{u\epsilon}$, then

$$E(\epsilon_i) = - \frac{\sqrt{6\sigma_\epsilon^2}}{\pi} \rho_{u\epsilon} \cdot \left[\frac{(1-P_i) \ln (1-P_i)}{P_i} + \ln P_i \right] = \lambda C_i \quad (6)$$

17. Heckman, "The Common Structure of Statistical Models of Truncation," "Dummy Endogenous Variables," and "Sample Selection Bias." In general, self-selection bias causes the regression line to be flatter (that is, less slope) than the unknown "true" regression line. For example, if there is a positive relationship between an explanitory variable, such as what may be expected with household income, then self-selection bias will overestimate the energy savings for low levels of household income and underestimate for high levels of income.

For an example of the use of a self-selection bias correction for time-of-use pricing experiments with voluntary participation see Aigner and Ghali, "Self-Selection in the Residential Electricity Time-of-Use Pricing Experiments." In general, they find that the bias causes the estimates of the elasticity of substitution between peak and off-peak electricity consumption to be biased upwards by as much as 24 percent; substantially overstating the expected response of customers in a mandatory time-of-use program. For a discussion of the effect that self-selection bias has see Train, "Qualitative Choice Analysis."

18. Dubin and McFadden, "An Econometric Analysis." The following formulation of Dubin and McFadden's correction is based on Train and Strebel, "Energy Conservation and Rebates in Commercial Food Enterprises," *American Journal of Agricultural Economics* 69 no. 1 (February 1987).

where

$$\lambda = - \frac{\sqrt{6\sigma_\epsilon^2}}{\pi} \cdot \rho_{u\epsilon} \quad \text{and}$$

$$C_i = \frac{(1 - P_i) \ln (1 - P_i)}{P_i} + \ln P_i \ . \tag{7}$$

σ_ϵ and $\rho_{u\epsilon}$ are not known, however C_i can be found by using the estimated P_i and λ can then be estimated as a regression coefficient. This is the second step of the process described here. The third step is the estimation of the energy savings equation, which is now rewritten as

$$S_i = \beta \mathbf{X}_i + \lambda C_i + \tilde{\epsilon}_i \ . \tag{8}$$

Since the disturbance term $\tilde{\epsilon}_i$ now has, by construction, a zero conditional mean, energy savings can now be estimated using OLS on the subsample of firms or households that participated in the utility's conservation program. The C_i term allows unbiased estimation of the parameters and unbiased prediction of energy savings conditional on participation. Using this approach, Train[19] found that the estimated annual energy (kilowatthours) savings attributable to a particular utility's rebate program was 30 percent of the total savings obtained by firms that were offered a rebate.

Multinomial Logit Model

Thus far it has been assumed that the firm's or household's decision to participate can be modeled in the first equation (step 1) as a binary

19. Train, "Incentives for Energy Conservation."

choice model (either participate or not participate). However, it may be appropriate in some cases to specify the first equation as a multinomial logit model. The utility, for example, may offer several conservation options, or the researcher may choose to model the firm's or household's decision as one of three mutually exclusive choices: (1) participating in the utility's program, (2) not participating, or (3) investing in some other conservation measure other than the utility's.

In the first example, the utility may offer "j" through "m" choices to customers. Assuming the choices are mutually exclusive and the options are not ranked or ordered in any way, the problem can be written as a generalized form of the binary logit model[20] (equation four)

$$P_{ij} = \frac{e^{(\beta \mathbf{X}_{ij})}}{1 + \sum_{j=1}^{m-1} e^{(\beta \mathbf{X}_{ij})}} \qquad (j = 1, 2, \ldots, m - 1) \quad , \tag{9}$$

and

$$P_{im} = \frac{1}{1 + \sum_{j=1}^{m-1} e^{(\beta \mathbf{X}_{ij})}} \quad . \tag{10}$$

Using equation seven, a C_i (step 2) can be calculated for each j alternative and equation eight can then be used to estimate the energy savings (step 3), also for each j.

20. As with the binomial logit model, there are several commercially available computer programs that will estimate multinomial logit models.

Nested Multinomial Logit Model

A more complete model of a household's or firm's conservation actions can be represented as a nested multinomial logit model (NMNL). McFadden[21] has shown that an NMNL model avoids some of the limitations of the binomial or multinomial logit models.[22] In general, estimating an NMNL model involves the sequential use of multinomial logit models.

A tree structure of conservation action can be developed to represent the sequence of decisions the household or firm makes that suits the particular conservation program being studied. Figure 4-1 provides an example of an NMNL model used to estimate energy savings.

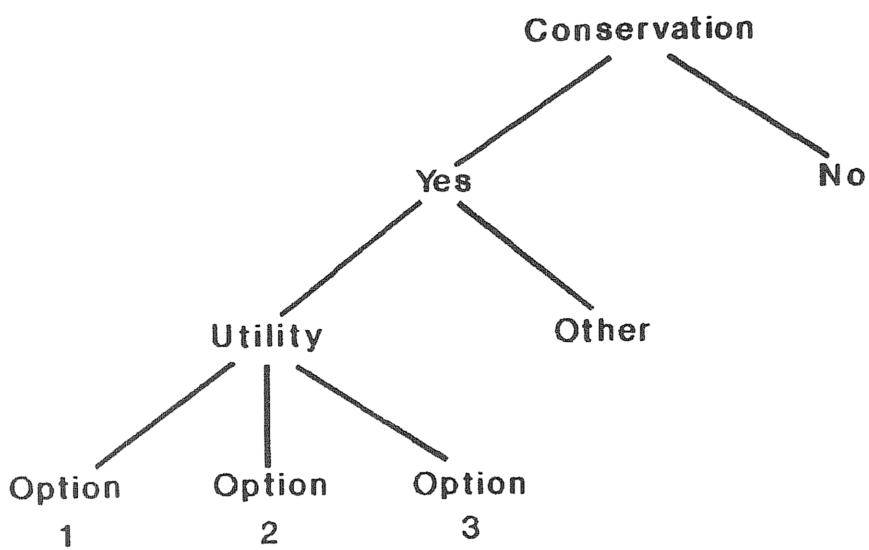
In this example, the index a (a = 0,1) refers to the different attributes of conservation (all nonprogram and program), b (b = 0,1) refers to the different attributes of the utility's program, and j (j = 1,2,3) refers to the attributes of the different options the utility offers. Then

$$P_{abj} = P_{j|a,b} \cdot P_{b|a} \cdot P_a \quad .$$

Maddala suggests an estimating procedure[23] for the conditional probabilities, $P_{j|a,b}$ and $P_{b|a}$ and for P_a.

Energy savings for each j alternative can be estimated using this tree structure where: (1) the household or firm invested in energy conservation, (2) the household or firm chose one of the utility's programs (given that they chose some conservation), and (3) the household or firm chose a particular utility option given that a utility program was selected. All

21. McFadden, "Modeling the Choice of Residential Location."
22. Primarily the requirement of independence of irrelevant alternatives ("red-bus/blue-bus problem") since NMNL allows a general pattern of dependence among the choices.
23. See section 3.6 of Maddala, *Limited-Dependent and Qualitative Variables*, for estimation procedure. Again, there are econometric programs available that can estimate an NMNL model.



Level

1) firm or household decide whether to invest in conservation

$$a = \begin{cases} 1 \text{ if yes} \\ 0 \text{ otherwise} \end{cases}$$

2) firm or household choose utility's program or other conservation:

$$b = \begin{cases} 1 \text{ if utility's} \\ 0 \text{ otherwise} \end{cases}$$

3) firm or household choose from several utility options:

$$j = \begin{cases} 1 \text{ for option } 1 \\ 2 \text{ for option } 2 \\ 3 \text{ for option } 3 \end{cases}$$

Fig. 4-1. Tree structure of conservation action by firms or households.

three of these decisions are discrete with the energy savings a continuous variable represented by the relation in equation (eight) and estimated with the correction factor C_i. A structure like the one presented here can be constructed to suit a particular conservation program analysis.[24]

All three cases of the discrete variable models, binomial, multinomial, and NMNL can be used in the three-step process described in this section. The analyst first would select the suitable discrete model to estimate the probability of participation, second, calculate the correction factor, and finally estimate the savings equation with the correction factor.

24. See Train, "Incentives for Energy Conservation," for another example.

CHAPTER 5

IMPLICATIONS FOR REGULATORY COMMISSIONS

This report outlined different methods for quantifying kilowatt and kilowatthour savings from DSM initiatives. Whether any particular method is preferable to another at a certain stage of an initiative remains an open question. Another issue involves the role of commissions in evaluating DSM programs and in prescribing methods to be used for estimating energy savings.

Methods of Evaluation at Different Stages

While some DSM initiatives appear clearly economical for full-scale operation, others may require careful review; for example, by way of a pilot or demonstration project. For such programs as weatherization and efficient lighting, energy savings are highly likely even though the economics of similar programs and the cost-benefit analysis would vary from utility to utility. For instance, if the incremental cost of energy is low, as from nuclear or hydro generation, the dollar savings of weatherization in temperate climates also would be low. Therefore, a particular initiative, which might be viewed a clear winner in some states, may require a careful appraisal--for example, through a pilot study--in other states to decide if it should be conducted on a larger scale. Therefore, the preferred method can vary from state to state even for identical programs.

Another important question relates to the increasingly common practice of commissions offering utilities pecuniary incentives on the basis of kilowatts and kilowatthours actually saved.[1] Equally important is the

1. For a case study of a utility receiving explicit incentives and, at the same time, achieving greater-than-expected savings from a DSM program, see Alan F. Destribats et al., "Demand-Side Management at New England Electric," *Proceedings of the National Conference on Integrated Resource Planning* (Santa Fe, NM: The National Association of Regulatory Utility Commissioners, April 8, 1991), 108-15.

question of whether winning DSM bidders do in fact deliver the kilowatts and kilowatthours that were bid and solicited. The state commissions' interest in methods to quantify kilowatts and kilowatthours saved arises from these more recent activities involving potentially significant ratepayer funding.

The report concludes that several approaches can be applied in a complementary way at each stage of a DSM program. Certain exceptions do exist, however. In the preprogram-pilot stage, for example, an engineering model can be used to estimate the kilowatt or kilowatthour savings from direct load control of a particular piece of energy-using equipment by modeling its technical characteristics. In certain situations, the behavior of users of this type of equipment could be modeled by statistical methods using sampling techniques and frequency distributions. The projection of benefits at the full-scale stage would also require the application of statistical forecasting techniques. Concerns over modeling errors may not be serious if benefits (ex ante) are judged clearly to overwhelm costs and if the study is undertaken to reach a "go-no-go" decision on whether to conduct a pilot project.

Another example of model complementarity occurs at the developmental stage, when more extensive trials or pilot projects are undertaken. The actual metering and assessment of changes in consumption in the test groups can be conducted by engineering or simulation methods. The method of accounting for control groups and the projection of benefits to a larger population, however, require statistical methods. As in the previous example, selecting the most appropriate method may not be crucial if the goal is to decide on whether a utility should conduct a pilot project. If, however, the question involves deciding on the level of incentives to be received by utilities undertaking DSM initiatives or prices to be paid to third-party suppliers of DSM resources, selecting the right method becomes more important from the perspective of ratepayers and achieving least-cost planning objectives.

In the full-scale stage of conservation programs, the kilowatthour savings from conservation-type programs are more readily quantifiable than from other types of DSM programs. Savings in kilowatthours from improved weatherization or cycling air conditioners can be estimated by the methods identified earlier in this report. Even for these DSM activities, comparing the estimated savings at different levels of weather conditions for example, heating degree days, remains a required task.

Commission Assessment of Methods

Notwithstanding these findings, there might exist circumstances under which a commission would choose a particular method over others. Such a preference is less likely in an ex ante prediction of savings than in an ex post situation. In the ex ante situation, the analyst attempts to predict or forecast benefits during an early stage of a DSM activity. In the ex post situation, either because of pecuniary incentives or the assurance that the bid DSM kilowatts have been delivered, commissions are likely to, and indeed should, examine estimated benefits in greater detail.

All methods share the feature that they estimate actual energy savings. Some methods may have advantages over others for a particular utility or a region. In sum, the preferred method depends on both the stage of the DSM program and the characteristics of the utility implementing it. Commissions may choose a particular method or combination of methods (recognizing that any method produces only estimates that contain a margin of error) that quantifies energy savings in an acceptable band or below a conservative upper bound.

As mentioned earlier, for many DSM technologies engineering models, with reasonable accuracy, can measure potential kilowatthour savings; estimating expected savings for some DSM programs and technologies, however, may require the use of statistical methods. For instance, when predicting the number of participants for large-scale programs from the output of pilot studies or the number of customers that would have undertaken a particular DSM measure even without an initiative in place, engineering methods should not be employed. Such information is needed to estimate (ex ante forecast) the kilowatt and kilowatthour savings for a full-scale program initiative. This information may come from various sources:

- an extrapolation of the participation rate in the pilot stage to the full-scale stage by proper statistical techniques;

- the conduct of a well designed survey at appropriate intervals in the full-scale stage; or

- the conduct of an experiment with proper measuring and control techniques at periodic intervals during the full-scale stage of the program.

These alternative methods may produce different dollar-saving estimates. Commissions may want to choose the lowest savings value for making incentive payments to the utilities.[2] The cost associated with estimating savings from different methods should be considered by commissions before choosing a method or methods. In addition, a commission may want either to choose the method that is likely to give the lowest estimate of savings, or require that all methods be used at periodic intervals and the method giving the lowest estimate of savings be selected. Furthermore, a commission might question the theoretical construct of each method or the data input, in either case a formidable task.

This report does not suggest a preferred method or even rank the methods based on a set of criteria. It supports the position that no cookbook rule can be devised for identifying the ideal method except for situations that are utility, program, and stage specific.

The Role of Commissions

While some commissions may want to assume an active role by requiring utilities to use a particular method or methods, others may choose simply to review and question the evaluation methods supported by the utilities. The second procedure may be more practicable for commissions with small staffs and where DSM initiatives are minimal.

Some of the commissions (for example, Wisconsin and California) have chosen the path of joint evaluation of mandated plans and cooperative approaches to program evaluation and demand-side research. More state commissions in the future may adopt this approach, since it has the

2. The dollar figures used by Wisconsin mentioned earlier are a safe upper bound established by a process similar to the one discussed here.

attractive feature of exploiting the expertise of both utilities and commissions.

Current Commission Approaches to Monitoring

This report underlines the benefits of a cooperative relationship between the utility and its regulator to monitor properly DSM programs. Following are examples of states in which this collaboration is being carried out.

Wisconsin

Information from Wisconsin shows that engineering-based evaluation is being carried out by the utilities. Commission staff has questioned utility simulations and their data requirements. In a 1986 ruling, the Commission articulated its support for collaboration:

> The Commission views the utility conservation programs as a joint effort between the utilities and the Commission. Wisconsin Statutes S. 196.491, mandates such cooperation and joint planning. The Commission does not intend to be overly specific with the details of conservation and other demand-side programs, preferring instead to leave utilities with sufficient flexibility to carry out what they believe to be cost-effective programs. However, because of the Commission's continued interest in achieving cost-effective conservation, it is necessary at times, as evidenced in this order, to become more specific about details of such programs.[3]

In Wisconsin the energy savings estimates assume a value that is unlikely to exceed actual savings. In situations where some uncertainty surrounds the savings estimates (whether kilowatt, kilowatthour, or dollar savings), the Commission would tend to specify an upper bound benefit based either on a Delphian approach, judgment, or consensus. As an example mentioned earlier, the incentives to WP&L in earning a higher rate of

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3. Wisconsin Public Service Commission, *Application of Wisconsin Electric Power Company for Authority to Increase Retail Electric and Steam Rates With Respect to 1987 Test Year; Findings of Fact and Order*, 6630-UR-100 (December 1986).

return are determined by perceived customer savings. Details of the calculations used to establish the incentives were not available in the documents provided for this report. The following excerpt from a commission order, however, illustrates the Wisconsin approach:

> It is appropriate to use the staff's proposed figures of $200 per kW of peak demand and 2 cents per kWh energy savings for estimating the maximum amount which can be spent on achieving electric energy conservation at this time. The Commission wishes to note that this benchmark is an initial estimate to set forth those conservation investments which are clearly cost-effective under any conceivable least-cost plan. The staff's conservative number is even below the estimated cost of the most inexpensive combustion turbine (approximately $290/kW).[4] (Emphasis added.)

The Public Service Commission of Wisconsin has also stipulated certain standard data reporting systems.[5] Several other states either have just instituted or are in the process of putting in place data reporting systems to monitor DSM programs.

California

Starting in the spring of 1990, California's four private utilities began submitting plans for program measurement along with their application for DSM incentives. This measurement plan is an implicit contract between the utilities, the commission, and other stakeholders to assure that new utility profits are linked to DSM program effectiveness. Although the measurement guidelines represent only a first step in developing these plans, they have helped provide the basis for a new level of evaluation activity now and for future negotiations over DSM incentives.[6]

4. Ibid.
5. Wisconsin Public Service Commission, *Advance Plans for Construction of Facilities as filed with the Commission for Review and Approval Pursuant to Section 196.491, Wisconsin Statutes: Findings of Fact, Conclusion of Law and Order*, Exhibit EPP-3, Docket 05-EP-5, Schedule 1, April 6, 1989.
6. Association of Demand-Side Management Professionals, *Strategies* 1 no. 1 (Spring 1990).

The data collection and analysis program outlined all the stipulated data to be collected annually by the utilities, including: hourly system-load information; sectoral peak-load estimates; sectoral monthly load profiles; and annual peak-day and typical monthly weekday and weekend day hourly load profiles of residential and commercial building air conditioning loads.[7]

Texas

Pursuant to Commission Rule 23.22, utilities must submit energy efficiency plans to the Commission every two years. The submission must conform to a standard format which requires detailed information on supply side efficiency, rate design, customer service activities, and measurable demand-side management programs.[8]

No specific directions exist for assessing the impacts of DSM programs. The utilities must provide narrative information, descriptions of technologies, costs, assumptions used in the economic and technical models, billing data, and the details of evaluation methods.

The Commission expects to examine the impact analysis on a case-by-case basis.

Illinois

The Illinois Commerce Commission requires utilities to report test results of DSM activities periodically. The information and the standard format for reporting are outlined in a staff document.[9] The methods for quantifying energy savings that the staff discusses include a data survey method and a control group approach. All the methods will apply only to energy kilowatthour savings for conservation programs.

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7. Ibid.
8. Public Utility Commission of Texas, Electric Division, "Format for Energy Efficiency Plans Filed Pursuant to Substantive Rule 23.22, December 31, 1989" (August 1989).
9. Illinois Commerce Commission, *Procedures for Evaluating Pilot Energy Conservation Measures: Implementation of Commissions' April 15, 1987 Order in Consolidated Dockets 83-0034/43* (October, 1987).

Florida

The Public Service Commission in a 1986 document sets out the details of the required data and calculations to be supplied by the utilities.[10] The document outlines procedures for calculating economic benefits and lists some computer programs. Utilities select the data to be used in the evaluation models.

Alternative Approaches

Ralph Prahl of the Wisconsin Public Service Commission outlines four approaches that commissions can apply to evaluate DSM programs:[11]

1. Conduct independent evaluations using data submitted by regulated utilities.

2. Require utilities to submit plans to evaluate specific programs, and review these plans for their research objectives, timing, and underlying method.

3. Require utilities to conduct joint evaluations of mandated programs, and participate in the interutility technical committees charged with this responsibility.

4. Encourage the development of new, cooperative approaches to program evaluation and other kinds of demand-side research.

Prahl particularly emphasizes the problems of state commissions evaluating DSM programs because of such factors as resource restrictions, the adversarial environment, the traditional authority of commissions, and

10. Florida Public Service Commission, "Cost Effectiveness Manual for DSM Programs," Staff Report Draft, Revision 5 (May 15, 1990).
11. Ralph Prahl, "Evaluations for PUCs," *Proceedings of the American Council for an Energy Efficient Economy, Summer Study in Energy Efficiency in Buildings* (Madison, WI: Public Service Commission of Wisconsin, 1988).

administrative restrictions on designing and implementing DSM programs. Prahl points out, however, that commissions have advantages over other parties including the primary one of having the authority to affect the allocation of utility resources. Another advantage held by commissions is that they may be the best repositories of data needed for evaluating DSM programs.

APPENDIX A

SUMMARY OF DSM ACTIVITIES IN THE STATES

The following is a summary of DSM activities in the states. This material was excerpted from information supplied by the state commissions in response to a February 1990 letter.

Alaska

The Commission has no formal statutes on demand-side planning in place and has only adopted broad regulations on demand-side measures. The Commission General Order 13 (U-83-47) describes the original process conceived by the Commission to establish measures.

California

The Public Utilities Commission reported that the estimate of the electrical load and energy reductions attributable to DSM programs is made in the utilities' measurement and evaluation programs.

The methods used in those programs were developed by the California Energy Commission (CEC). The programs (methods) involve conducting electrical energy and load impact studies, customer satisfaction surveys, and customer participation estimates.

The California Public Utilities Commission has developed a standard practice manual called "Economic Analysis of Demand-Side Management Programs," which all utilities use to translate their data from the above programs into a program cost-effectiveness value.

Colorado

The Colorado Public Utilities Commission is only beginning to establish demand-side management programs. It has six pilot projects and a proposal from Public Service Company of Colorado for 100 MW of demand-side programs to be instituted through a bidding process.

Evaluation of demand-side programs is currently under consideration, and together with the proper degree of monitoring, is a subject of discussion with Public Service Company of Colorado. Evaluation procedures for pilot programs and the proposed 100 MW bidding programs have not been decided.

Connecticut

The Connecticut Department of Public Utility Control (DPUC), in order to determine the effectiveness of the utility evaluation plan, intends to engage a management consultant to review the plan. A report provided by the Commission stated that the DPUC invites proposals from consulting firms to conduct an audit of 1990 conservation and load management evaluation plans of the Connecticut Light and Power Company (C&LM).[1] The audit, according to the report, will not entail engineering or technical analysis of actual C&LM programs, but will require an initial comprehensive analysis of the evaluation plan, extended monitoring of implementation over a time period to be determined, and periodic reporting including a final report.

Delaware

The Public Service Commission provided a Hearing Examiner's report and orders that pertain to Delmarva Power & Light Company's "Challenge 2000" plan. We found no evidence in these reports that the Commission applied or adopted any method to evaluate kilowatt and kilowatthour savings of DSM programs.

District of Columbia

Most of the demand-side projects were implemented within the last year and only at a pilot level. Therefore, few evaluations of the energy savings of these projects are available and have yet to be analyzed by the Commission. However, both the gas and electric utility companies have been required to file status reports to provide some insight into the evaluation plans.

The Commission has adopted and developed a series of evaluation techniques. These techniques are the Princeton Scorekeeping Method (PRISM), the conditional demand models, and an internally developed analysis method designed to measure the impacts of free riders on energy savings programs. Descriptions of these models are as follows.

1. PRISM

The value of PRISM for Washington Gas Company is that it provides a uniform means of comparing results across programs offered to one particular sector ensuring a consistency of comparisons. It is

1. State of Connecticut, Department of Public Utility Control, "A Request for Proposal: DPUC Investigation into the Conservation and Load Management Evaluation Plan for the Connecticut Light and Power Company," (New Britain, CT: Connecticut Department of Public Utility Control, April 18, 1990).

suggested that PRISM be used as a first step in analyzing any conservation program in the sector(s) to which it is applicable. The Commission staff is well aware that more detailed analysis will be necessary to evaluate any particular program and suggests that this further analysis will have to be specific to the program being evaluated.

2. Conditional Demand Models

These models measure a customer's energy usage conditional upon the mix and characteristics of its gas-using durables. They produce energy usage coefficients by appliance type as well as price and income elasticities. Washington Gas Company is currently implementing conditional demand models to provide the end-use model with the resulting energy use coefficients and to use it in conjunction with other DSM models.

The technique in conditional demand study relates a customer's monthly consumption to its known stock of gas-using durables to estimate the average monthly usage by appliance. The estimates can account for differences due to household size, temperature, price, income, and age of the house or appliance.

Regression analysis is the primary tool used to develop the conditional demand model.

3. District of Columbia Public Utility Commission Scoring Method

The Commission staff observed that PRISM's shortcomings include its inaccuracy in measuring savings from programs targeted to air conditioning loads, its narrow range of applicability outside of the residential sector, and its inability to account for consumption changes across appliances within the same household. Commission staff proposed a method to address these deficiencies. The following is the description of the Washington Gas Company method as stated in the document sent in response to our questionnaire.[2]

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2. District of Columbia Public Service Commission, *Status Report* (Washington, D.C.: District of Columbia Public Service Commission, June 1990).

A simple statement of the problem is as follows: What is the difference between the consumption of the household-business in the period following the implementation of conservation measures and the consumption that the household-business would have had absent the implementation of the conservation measures? Of course, answering this problem precisely is impossible because only one of the two events is observable.

For this reason, a control group must be selected. The control group is selected so that it is comparable to the participant group in all important respects except that the control group is not participating in the program. Alternatively, the control group may exhibit different consumption patterns, but the differences must be explainable by observable phenomenon. For example, consumption may be larger in the control group than the participant group, but if consumption differences can be traced to differences in family size, then the control group may be reasonably compared to the participant group.

To test for this condition, consumption in the control group is compared to the consumption of the population and consumption of the participant group for some period prior to the start of the pilot program implementation. This should indicate that consumption of the population, the control group of nonparticipants, and the participant group is equal or explainable.

As suggested by the Commission staff, a number of statistical test will be used to test for consumption differences. These include:

- Tests for mean consumption differences (t-test for two group differences, F test for more than two group differences)

- Tests for consumption variations (F test)

- Test for representativeness of the control group (correlation coefficient).

Florida

A report "staff draft" by Florida Public Service Commission (FPSC), issued May 15, 1990, reveals that FPSC is required to review and approve cost-effective utility conservation programs.[3] In addition, the report describes the cost-effectiveness tests used by the Florida Public Service Commission to evaluate utility-proposed conservation programs and direct load control programs.

The tests set forth in the manual are not intended to be used individually or in isolation. However, the total resource cost test is considered to be the primary test. The precise weighting of each test relative to the other tests is not specified in the manual. It is emphasized that the tests simply provide a uniform format for reporting cost-effectiveness data whenever an evaluation of an existing, new, or modified conservation program is required by the FPSC. The kilowatthour and kilowatt savings, however, are an input data provided by the utilities.

Georgia

The Georgia Public Service Commission as of this date has not developed any special treatment for, or evaluation of, demand-side management programs. The DSM program's development and evaluation process will be a part of the least-cost planning program, which is just being started in Georgia.

Hawaii

Development of demand-side management programs has not been a high priority of the energy utilities in Hawaii. For example, the state's major electric utility has not engaged in significant DSM activities other than developing rate initiatives and considering specific technologies such as heat-pump water heaters. Consequently, the Commission has yet to conduct any meaningful examination or evaluation of DSM programs.

Recently, however, the Commission has issued an order requiring energy utilities to implement integrated resource planning. The order also specifies that DSM options be identified and considered in the development of any integrated resource plan.

3. Florida Public Service Commission, "Cost Effectiveness Manual for DSM Programs," Staff Report Draft, Revision 5 (May 15, 1990).

Idaho

The Commission staff makes decisions on DSM programs based on expected savings from proposed programs. If proposed programs meet the cost-effectiveness test, staff approves them. As expenditures for such programs increase, staff pays increasing attention to the actual savings which result to see if the programs are as cost-effective as proposed, and to judge whether changes in incentives or other program delivery mechanisms are required.

Commission treatment of these savings measures is evolving. The staff has not specified a methodology which utilities must use, but it does expect utilities to provide some sort of worksheets detailing the evaluation of cost-effectiveness.

Illinois

The Illinois Commerce Commission initiated an investigation in 1983 concerning the propriety and appropriateness of developing and implementing energy conservation programs by directing the state's ten major electric and natural gas utilities to propose and implement such programs on a pilot basis. The Commission also indicated that it would adopt, on a consolidated basis, the methodology for evaluating the pilot programs. Due to the highly contested nature of the consolidated proceeding, the Commission did not enter an order adopting the methodologies for evaluating utility-sponsored pilot energy conservation programs until April 15, 1987.[4] In that order, the Commission adopted a cost-effectiveness model as the primary test for assessing the economic benefits and costs of such programs. The Commission further adopted the distributional test and a model proposed by Central Illinois Light Company (the CILCO test) to provide additional information on individual pilot programs for the Commission to consider in its deliberations. Moreover, the Commission directed the utilities to apply the CILCO test (which is based on economic

4. Illinois Commerce Commission, "An Investigation Concerning the Propriety and Appropriateness of the Development and Implementation of Energy Conservation Programs," Order ICC, 1987, Docket 83-0034-43 (April 1987).

welfare theory) to evaluate their respective pilot programs and to submit the results of the evaluation for review by Commission staff and other interested parties in public hearings in the individual dockets.

Since Commission staff has responsibility to assess the utilities' evaluation studies when they are submitted in the individual dockets, staff is concerned about the consistency in utilities' implementation of the Commission order. Therefore, it initiated efforts to provide common guidelines to operationalize the common order.

The staff report *Procedures for Evaluating Pilot Energy Conservation Programs* discusses some of the above issues in detail.[5] The methods for quantifying energy savings that the staff discusses include a data survey method and the control group approach as well as others. All the methods address the energy kilowatthour savings only in conservation programs.

Louisiana

The Commission has issued no document, order, or sample calculation outlining the treatment and evaluation of DSM programs. The staff also has not indicated any studies on demand-side management programs which they have undertaken.

Maine

Utilities must provide a quarterly report of their demand-side energy management programs in accordance with requirements and definitions of chapter 380, section 4(c) of the Maine Public Utilities Commission's rules and regulations.

The Maine Public Utilities Commission (MPUC) has reported no evaluation method for estimating energy and capacity savings. However, utilities such as Central Maine Power (CMP) currently is using PRISM and conditional demand methodologies for such estimations.[6]

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5. Illinois Commerce Commission, *Procedures for Evaluating Pilot Energy Conservation Measures: Implementation of Commissions' April 15, 1987 Order in Consolidated Dockets 83-0034/43*, October 1987.
6. Linda Ecker, Michael Parti, and Monica Dion, "A Comparison Study of Energy Savings Methodologies," *Demand-Side Management Strategies for the 90s, Proceedings: Fourth National Conference on Utility DSM Programs, Volume 2* (Palo Alto: CA: Electric Power Research Institute, April 1989).

The MPUC rulemaking, chapter 380, sets forth the "all-ratepayers' test" as the primary basis of cost effectiveness. The all-ratepayers test is an analysis of the overall economic efficiency of the use of ratepayer resources to produce electricity-related end-uses.

Maryland

The Public Service Commission of Maryland issues annually a ten-year-plan report, a compilation of information pertaining to the long-range plans of Maryland's electric utilities regarding generating needs and means for meeting those needs.

The Commission's immediate goal is to influence the planning process at an early stage to encourage use of demand-side management and other least-cost options.

The last report issued by PUC of Maryland is entitled, "Ten-Year Plan, 1989-1998" issued in September 1989. Section IV evaluates the long-range plans of Baltimore Gas and Electric Company and Potomac Edison Company. The key issues analyzed in reviewing the long-range demand-side plans include:

- the screening process,
- the cost-effectiveness criteria employed,
- the selection of key inputs to the cost-benefit methodology,
- an analysis of the sensitivity of the program impacts estimates to probable ranges of key input estimates, and
- the consistency of the evaluation with supply-side option evaluation.

The report defined screening as the process through which a utility identifies potential demand-side programs, performs detailed evaluations of those programs which may be cost beneficial, and selects programs for system-level analysis.

The key questions analyzed by the Commission staff include:

- Are adequate procedures and sources being used by the utility to identify potentially feasible measures to reduce or moderate electricity demand?

- Are appropriate criteria being used by the utility to screen potentially feasible demand-side measures for further study?

Massachusetts

The Department of Public Utilities (DPU) required each electric utility (Docket D.P.U. 89-260 and D.P.U. 86-36-F) to include in its cost-effectiveness test the following elements: (1) the full incremental cost of the conservation and load management measure regardless of who pays that cost, (2) all administrative costs incurred by a utility that can be attributed to a given program, (3) any quantifiable and significant end-user benefits, and (4) environmental externalities.

The Department clarified its conservation and load management (C&LM) cost-effectiveness test regarding free riders and "snap-back effects."

Western Massachusetts Electric Company filed for the approval of conservation and load management programs and cost recovery. Docket D.P.U. 89-260, issued on June 29, 1990 by the DPU, describes the Department's position on all aspects of load management programs, cost-effectiveness, and savings evaluations. The quantitative techniques proposed by the Company to conduct its impact evaluation include billing analysis, engineering estimates, and direct metering. The Department report stated that "[t]he determination of net savings is both the most difficult factor to measure and the most critical in determining the ultimate cost-effectiveness of a program and the Company's incentive payment." The Department acknowledges that this is not a simple task, because for various reasons a kilowatt and kilowatthour conserved are not as easily measured as a kilowatt and kilowatthour produced: conservation and load management occurs at thousands of homes and business dispersed throughout a service territory making measurement complex. Moreover, attributing specific savings levels to particular measures in a multimeasure installation in a setting with multiple end-uses of electricity cannot generally be determined from a before-and-after analysis of utility bills without submetering.

To calculate net savings, Western Massachusetts Electric has proposed primarily an engineering calibration approach, which first involves examining the relationship between the directly observed measurement of impacts in end-use metered samples with engineering estimates of impacts.

The approach then extrapolates that relationship between engineering estimates and measured savings from a smaller sample of participants to all participants.

The Department supports the Company's efforts and suggests that the Company consider free riders and "snap-back effects" in the savings estimation.

Nevada

In response to Sierra Pacific Power Company's proposed 1989-2008 Electric Resource Plan, the Commission staff suggested that the generally accepted set of cost-effectiveness tests contained in the joint publication of the California Energy Commission and California Public Utilities Commission, entitled "Standard Practice Manual: Economic Analysis of Demand-Side Management Programs" (December 1987), be used to standardize the evaluation of Sierra's programs.

However, in that response, the Commission has not specified any methodology to evaluate the energy and capacity savings of a DSM program.[7]

New Jersey

A collaborative working group, called The New Jersey Conservation Analysis Team (NJCAT), composed of the seven investor-owned utilities in the state and several public agencies, was created by the New Jersey Board of Public Utilities. The overall purpose of NJCAT is to:

1. Quantify the savings, in terms of both energy and peak, produced by nine categories of conservation programs across seven utilities;

2. Determine the value of these electricity, gas, and oil savings; and

3. Compare the value of the conserved electricity, gas, and oil with the costs of the programs in overall benefit-cost tests.

7. Before the Public Utilities Commission of Nevada In the *Matter of Sierra Pacific Power Company's Proposed 1989-2008 Electric Resource Plan*, Docket No. 89-676 (October 6, 1989).

The objective of the project was to provide these quantitative results; it was decided that a "process" evaluation was not within the scope of the effort.

The underlying philosophy embodied in selecting the methods used to estimate program impacts is contained in the contractor's report to the NJCAT:

> The approach taken in this project involved the use of both engineering methods and statistical-econometric methods. Both sets of methods were believed to be required if adequate results were to be obtained. This is due to the different strengths and weaknesses of the two approaches and the data available for use in this project. There was not enough load research on program participants to allow for statistical inferences around peak savings, or savings in different time-differentiated periods. These peak and time-differentiated savings estimates can be important for the benefit-cost analyses. Statistical-econometric approaches can be applied to billing data, but these data are available only on a monthly basis and, for practical reasons, estimates for time periods shorter than a full heating season or cooling season tend to be unreliable. In addition, statistical models of energy savings may not always provide reliable estimates of energy savings, due to problems with the underlying data. These problems can be measurement-accounting errors or simply the fact that the savings that the researcher is trying to isolate in the model are confounded by the magnitude of other factors for which adequate controls are not available.
>
> Another potential problem with statistical-econometric approaches is that they may give reliable estimates of savings but only for a subcomponent of the participant group, leaving out some participants for which no estimate is available. For example, by using residential data for customers that have clean billing data, 12-month occupancy, and no anomalous energy use, an econometric model can be specified that give reasonable results. However, this model may not provide information on vacation or part-time residences that participate in the program. The same is true for the commercial sector, where a statistical model on small commercial customers may work well, but may not adequately accommodate certain customer groups, such as schools or churches.
>
> For these reasons, a key component of the evaluation was to use sophisticated engineering methods to estimate program impacts as well as statistical-econometric methods. The engineering methods serve to provide comparison estimates when the data do not allow for reliable statistical-

econometric estimates and, since they utilize hourly load data, engineering estimates provide information on how savings are disaggregated into peak and time-differentiated periods.[8]

New York

The Commission directed each utility in September 1987 to prepare and submit long-range plans annually. The Commission directed that these plans:

- Provide estimates of DSM potential within each customer class;
- Identify and describe specific DSM approaches that may be applicable to this potential within each customer class;
- Assess the lifetime costs and benefits of prospective DSM programs;
- Identify and describe DSM programs being considered as utility resource options, and provide a schedule for moving cost-effective programs to full-scale implementation;
- Provide a detailed summary of necessary DSM planning and research activities;
- Provide a review of the achievements of DSM projects conducted over the past four years; and
- Identify specific DSM energy and capacity objectives for each year of this century.

The Commission, in Opinion No. 88-20, decided that the basic elements and concepts of an effective integrated planning methodology should be incorporated into the utilities' planning processes, but that uncertainty and changing circumstances justify allowing the utilities flexibility to develop their individual processes.[9] However, the Commission believes that a uniform reporting format for presenting input assumptions and the DSM plans resulting from these planning processes would greatly assist reviewers of these plans. The Commission intends to work with the

8. Daniel M. Violette, *New Jersey Conservation Analysis Project: Contractor's Report to the NJCAT, Executive Summary* (Boulder, CO: RCG/Hagler, Bailly, Inc., August, 1990).
9. James T. Gallagher, Peter Seidman, and Sam M. Swanson, "Demand-Side Planning at New York's Electric Utilities: An Assessment of Initial Efforts," *Demand-Side Management Strategies for the 90s, Proceedings: Fourth National Conference on Utility DSM Programs, Volume 1* (Palo Alto, CA: Electric Power Research Institute, 1989), 13-1.

utilities to develop standard reporting requirements and formats for subsequent long-range DSM plans.

North Carolina

The North Carolina Utilities Commission issued an order on least-cost integrated resource planning (LCIRP) in December 1988. The order required utilities to submit initial plans in April 1989. Each plan was to contain energy and peak-load forecasts for at least fifteen years; an integrated resource plan considering a variety of existing and new generating facilities, alternative energy resources, conservation and load management programs, purchased power, and transmission and distribution facilities; and a short-term action plan describing the specific steps the utilities will take to implement their integrated resource plan during the next three years.

A report by a private consultant (ERC Environmental and Energy Service Company) prepared for the Commission suggested a review of the resource planning processes within the utilities and recommend to the Commission the necessary evaluation process and techniques to evaluate demand-side programs.[10] The report did not recommend any specific method to be used to estimate energy and capacity savings of DSM programs.

Oregon

The Public Utilities Commission of Oregon reported no technical evaluation method for DSM programs. However, it uses the following approach in assessing the utilities' conservation activities. First, it identifies resource development standards to apply to conservation. Second, it determines which sectors have the greatest potential for conservation savings. Third, it reviews existing and planned programs to determine whether they are consistent with the development standards and cover all sectors with large potential savings. Finally, it develops

10. Benson H. Bronfman, W. Michael Warwick, and Eric Hirst, "Least Cost Integrated Resource Planning in North Carolina: Review of Utility Plans and Planning Process," prepared for North Carolina Utilities Commission (October 1989).

recommendations for program changes and new programs to fill the gaps identified in current conservation activities.

The following standards are what the PUC believes should guide utility conservation activities:

1. Conservation strategies should be utility-specific;

2. All cost-effective lost conservation opportunities should be acquired;

3. Discretionary measures that cost less than current avoided cost should be acquired;

4. Other discretionary measures should be acquired so that the savings will be available when needed to defer more expensive sources;

5. Utilities should develop the ability to obtain savings from discretionary conservation;

6. Rates should be minimized, as long as there is no substantial failure to acquire least-cost measures;

7. Utilities should attempt to weatherize the same fraction of all low-income homes, rental units, and other housing.

Pennsylvania

The Commission established a rule (L-840098) which works as a common methodology to evaluate the costs and benefits of conservation and load-management programs.

The regulation revises existing requirements for filing information on conservation activities of electric and gas utilities. It is believed by the Commission that these regulations are necessary to assess adequately the impact of conservation activities upon the utilities' descriptions of existing and proposed programs and their results.

1. Annual Conservation Report:

   a. Each electric and gas public utility shall submit an annual conservation report on or before May 1 of each year. The report shall contain a description of conservation and load-management programs implemented or operational during the past calendar year and all programs which are proposed to be implemented within one year following the filing of the report.

b. The description shall conform to the form ACR-1 and shall contain:

   i. A descriptive title of the program.
   ii. The purpose or objective.
   iii. The details of program activity and implementation schedule.
   iv. An accounting of the monetary and personnel resources actually or proposed to be expended or devoted to the program.
   v. The actual or anticipated results of the program in terms of energy savings, reduction of utility on peak demand, or any other appropriate measure of the program's objective.

c. The report shall also contain, for each class or type of energy user, the number of customers in each class as of the end of the previous year, the total energy consumed by each class, and the individual target consumption reductions for each class. Examples are as follows:

   i. Residential: all-electric
   ii. Residential: water-heating only
   iii. Commercial, industrial, and street-lighting.

d. The report shall include a summary of all programs.

e. For each program with an annual utility expenditure of more than 0.1 percent of total annual revenue excepting informational, educational, and research and development programs, the utility shall submit a cost-benefit analysis using the common evaluation methodology which will be described later.

f. The Commission may issue a list of specific conservation and load-management programs which shall be considered for implementation by each designated utility. The utility shall provide information documenting the consideration of these and other conservation and load-management options and supporting the utility's decision whether or not to implement the options.

g. Utilities shall maintain copies of the annual conservation reports open to public inspection during normal business hours. Customers shall be notified, in writing, of the availability of the reports for public inspection.

h. The following methodology, suggested by PUC shall be utilized by electric and gas utilities to evaluate the cost and benefits of conservation and load management programs.

   i. Participant test
   ii. Nonparticipant test

iii. Utility revenue requirement test
iv. All-ratepayers' test

The four test are similar to the California PUC's standard tests.

South Carolina

The Commission reported that it is in the early stages of developing its treatment of DSM.

Texas

The Public Utilities Commission requires utilities to provide the information necessary for cost-benefit analysis of conservation programs. Commission staff prepares a filing format for the preparation of energy efficiency plans. The issues that staff considers in its review of demand-side programs include:

1. Energy efficiency goals and program selection;
2. Program achievements;
3. Program design; and
4. Other policy issues.

Commission staff first examines the system energy efficiency goals of the utility to insure that they are compatible with the utility's resource requirements and commission policy. Staff has been critical of utilities which rely exclusively on load-factor-improvement goals because it believes energy-efficient end-use devices and summer peak-demand reduction should be emphasized in Texas. It then assesses whether the programs selected by utilities are compatible with the system energy efficiency goals.

The staff analysis of program achievements focuses on participation or penetration and program impacts. Program participation for an individual utility is compared with comparable programs of other Texas utilities. Energy and demand impacts are assessed by examining the assumptions used by the utilities in developing impact estimates, which are usually based on engineering methods.

The review of program design includes an analysis of costs and efficiency standards. Incentive, marketing, and administrative costs are critically examined to assess whether the incentive levels are too high or low, whether a program has adequate administrative support, and whether the program is supported with a sufficient marketing effort. The promoted technologies are examined to determine whether a program is truly enhancing energy efficiency, or whether it is encouraging the use of average efficiency devices. The program design review is integrally related to the goals, program participation, and program impacts.

The Commission staff has employed spreadsheet models since 1985 to perform cost-benefit analysis of the reported programs. The models are based on California standard practice.

Vermont

The Vermont Public Service Board has settled on no single methodology for evaluating DSM programs. The Board is currently preparing an order in its Docket 5270, an investigation into least-cost integrated planning. In this order, general guidelines for the development and analysis of DSM resources will be set out.

West Virginia

The Public Service Commission reported that it had limited exposure to utility demand-side programs, therefore, it does not have a particular method for evaluating these programs.

The only time in which DSM programs have been addressed is in a case involving a utility's ten-year supply and demand projections. The utility projected that its DSM programs would reduce its load at time of peak by approximately 300 MWs over the next ten years. An intervener, who desired to build PURPA projects, challenged the projection as being too optimistic. The Commission staff questioned the Company on how it evaluated and selected its DSM programs. The utility responded that it used four tests: the participant test, the nonparticipant test, the all-ratepayer test, and the utility test. The failure of a particular program in any test does not necessarily eliminate it from further consideration.

Wisconsin

The Public Utility Commission of Wisconsin has extensive activities and experiences in promoting and evaluating demand-side management programs. The Commission has experimented with four different approaches to program evaluation:

1. Conducting evaluations more or less independently, using data submitted by regulated utilities;

2. Requiring utilities to submit plans for evaluating specific programs, and reviewing these plans for their research objectives, timing, and methodology;

3. Requiring utilities to conduct joint evaluations of mandated programs, and participating in the interutility technical committees charged with this responsibility; and

4. Encouraging the development of new, cooperative approaches to program evaluation and other kinds of demand-side research.

Each of these approaches has advantages and disadvantages, and appear to be most appropriate to certain types of evaluation projects.[11] Under the first approach, Commission staff either conduct by themselves or contract the detailed technical work of an evaluation project. The Commission has yet to complete an entire evaluation project in this manner[12] although this approach has been used to complete parts of several projects. For example, since 1985, two evaluations have been conducted of the Wisconsin Utility Weatherization Assistance Program, a statewide program providing weatherization grants to state residents with incomes below 150 percent of the poverty level. Both evaluations examined overall savings and cost-effectiveness of individual weatherization measures, and the relative performance of each of the state's ten individual utility programs. Methodologically, both studies employed a pre-post, quasiexperimental design with a control group to adjust for extraneous factors. In addition, both used the popular Princeton Scorekeeping Method (PRISM) to normalize fuel consumption for variations in weather.

In the article by Ralph Prahl, a good discussion on the pros and cons of the Wisconsin four approaches can be found.[13]

11. Ralph Prahl, "Evaluation for PUCs," *Proceedings of the American Council for an Energy Efficient Economy, Summary Study on Energy Efficiency in Buildings* (Madison, WI: Public Service Commission of Wisconsin, 1988).
12. Ibid.
13. Ibid.

APPENDIX B

DERIVATION OF THE PROBABILITY OF PARTICIPATION

From equations two and three in chapter 4

$$P_i = \text{Prob } (u_i > -\beta \mathbf{X}_i) \quad \text{(B-1)}$$

where

P_i = the probability that $y_i = 1$,

then

$$P_i = 1 - F(-\beta \mathbf{X}_i) \quad \text{(B-2)}$$

where

F is the cumulative distribution function for u_i.

If it is assumed that u_i has a cumulative logistic distribution, then B-2 takes the form of the logit model,[1] where

1. If the distribution of u_i is assumed to have a cumulative normal distribution, then B-2 will take the form of the probit model. Except for very large samples, however, the logit and probit models are unlikely to lead to very different results. Logit is used here because its closed-form expression (i.e., it does not involve integrals explicitly as the cumulative normal distribution does) allows more straight forward estimation of the model developed here. For a comparison of logit and probit models and their estimates see Amemiya, "Qualitative Response Models;" S. Pindyck and D. L. Rubinfeld, *Econometric Models and Economic Forecasts* (New York: McGraw-Hill Book Company, 1981; or G. S. Maddala, *Limited-Dependent and Qualitative Variables in Econometrics* (Cambridge, England, Cambridge University Press, 1986).

$$F(-\beta \mathbf{X}_i) = \frac{e^{(-\beta \mathbf{X}_i)}}{1 + e^{(-\beta \mathbf{X}_i)}} = \frac{1}{1 + e^{(\beta \mathbf{X}_i)}} \tag{B-3}$$

which leads to equation four (in Chapter 4), the probability of participation, since

$$1 - F(-\beta \mathbf{X}_i) = \frac{e^{(\beta \mathbf{X}_i)}}{1 + e^{(\beta \mathbf{X}_i)}} = P_i$$

from B-2 and B-3.

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