An Approach to the Establishment of Load Research Metering to Support the Design and Evaluation of Natural Gas DSM Programs

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Minnegasco, a Midwestern natural gas utility, has initiated a load research project specifically designed to meter and analyze natural gas end-use and class load data for large samples of residential and nonresidential customers. The data gathered from this project will be used to determine the impact of its DSM programs. The load research project is designed to meet three goals: collect baseline information to define the demand patterns of major classes; to determine demand patterns or significant end-users of natural gas; and, to detect the change in demand patterns of DSM participants. The study will provide information for DSM impact and evaluation planning. As a result of being one of the first load research projects designed specifically to determine the impact of DSM programs, Minnegasco faced several challenges. As a result of these challenges the installation of equipment was delayed until after 1993-94 heating season. The focus of this paper will be on the challenges encountered in implementing a natural gas load research project. This discussion will include a description of the sample design and the approaches to develop the load research baseline analysis. The paper will conclude with the approach that will be taken to evaluate Minnegasco's residential natural gas DSM programs.

Introduction

Background

Minnegasco serves the greater Minneapolis area and has approximately 500,000 residential customers and nearly 600 million ccf of annual consumption. A vast majority of these customers heat their homes with natural gas space conditioning equipment. Figure 1 presents a bar chart of the average monthly energy use for this class. Reflecting space heating requirements, the class displays dramatic seasonal variations with the winter monthly energy use approximately nine times the summer monthly use.

Currently Minnegasco offers several DSM residential and commercial programs as part of its Conservation Improvement Program ("CIP"). As expected, the key focus of the Minnegasco residential DSM programs is to improve the efficiency of the customer's space heating equipment.

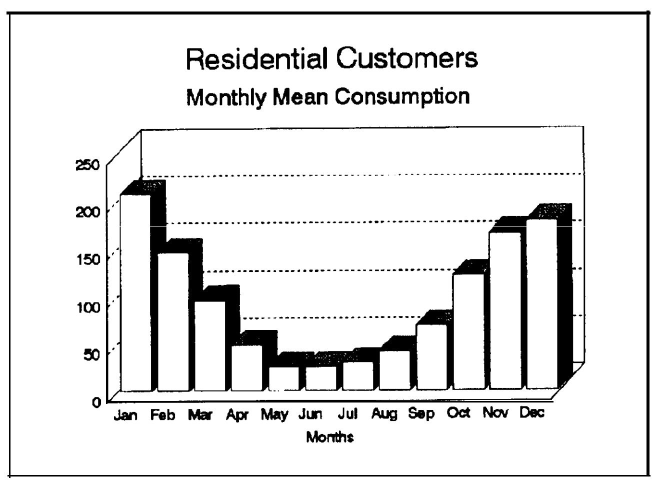

Figure 1. Distribution of Annual Use By Month

Scope

In 1993, Minnegasco adopted a comprehensive approach to evaluate the impact of its DSM programs. Specifically, the evaluation approach was designed to address two needs. First, Minnegasco wanted to determine the economic benefits of implementing DSM programs. To effectively accomplish this, Minnegasco recognized the need to develop long run avoided costs and tie that information to the time differentiated demand[1] of its customers. As gas service becomes "unbundled", and the supply pricing structure becomes disaggregated into demand and commodity charges, the value of time-differentiated usage information increases. Therefore, when Minnegasco evaluated its informational needs it recognized the results would need to be applicable to the design of future programs. Furthermore, the information had to be gathered so that it would be applicable in determining the effects on DSM programs, given the various supply pricing scenarios that may evolve. Second, Minnegasco recognizes that the benefits of DSM include system distribution benefits. Specifically, Minnegasco wanted to quantify the impact of set back thermostats on the *ripple effects,* and the *bend over effects*[2] associated with the extreme temperatures. In addition, the Company was interested in how the promotion of high efficiency appliances and conservation impact such effects. To address this need, Minnegasco chose to develop time-differentiated results based on an ambitious load research program. The evaluation was designed so that the data gathered through the baseline and program specific studies will be robust enough to be applicable to specific customer groups, and produce end-use load shapes for specific end-uses of interest.

To evaluate its current programs, Minnegasco chose to end-use meter a sample of the *High Efficiency Heating System Rebate Program* participant furnaces. Additionally, Minnegasco wished to monitor the heating systems of customers with set back thermostats[3]. To establish baseline information to disaggregate its load curve, the Minnegasco baseline sample included metering of specific end-use equipment such as water heaters, cooking equipment (i.e., ovens, ranges, and grills), water heating equipment (i.e., domestic hot water, pool heaters, and hot tub heaters), and, fireplaces.

The implementation of a natural gas load research project did not come without its challenges. The Load Research Plan called for the installation of the metering equipment in the fall of 1993. However, when Mimegasco submitted its Load Research Plan its Plan for approval, the Minnesota Department of Public Service Staff (the "Staff") questioned certain aspects of the plan. Specifically, the Staff wanted Minnegasco to more fully explain how the implementation of the baseline and end-use load research study would result in cost-effective savings for the CIP and to justify the load research evaluation approach for natural gas. After Minnegasco submitted additional supporting documentation, the Commission ultimately found that Minnegasco's load research approach was appropriate. Unfortunately, the regulatory process delayed the initiation of the project until midwinter. The late delayed produced a domino effect, beginning with the late initiation of the acquisition of equipment, the premature recruiting of participants, and the ultimate delay in the installation of the metering equipment. These confounding effects resulted in the project missing the 1993-94 winter period. The winter of 1993-94 was so severe it neared *design day*[4] conditions. These delays were an unfortunate turn of events. This paper will describe the Load Research Plan, including the sampling strategy, its application to the residential natural gas space heating baseline and end-use samples, and chronicle the challenges faced in initiating this project.

The Natural Gas Load Research Plan

The Baseline Sample Design

To implement the Load Research Plan two samples were designed. The first sample was a "Total Load Sample" to estimate load shapes on a total customer basis. The second sample was an "End-Use Sample," to estimate the load shapes of specific end uses. The samples were designed using *model based statistical sampling* (Wright, 1983) or "MBSS" techniques.

MBSS takes advantage of other available data to leverage expensive sample data. Load research sample designs usually use monthly consumption available in the target population as a proxy for variables of interest (i.e., daily or hourly demand). When there is a strong association between the billing data *(y)* and the demand variables *(x)* to be measured in the sample the billing data will contribute to the population demand estimates. With this approach, the statistical precision usually can be improved or the size of the load research sample can be reduced.

The strength of MBSS comes from fitting a heteroscedastic ratio model (See Figure 2) to the relationship between *y* and *x*. The model has two equations:

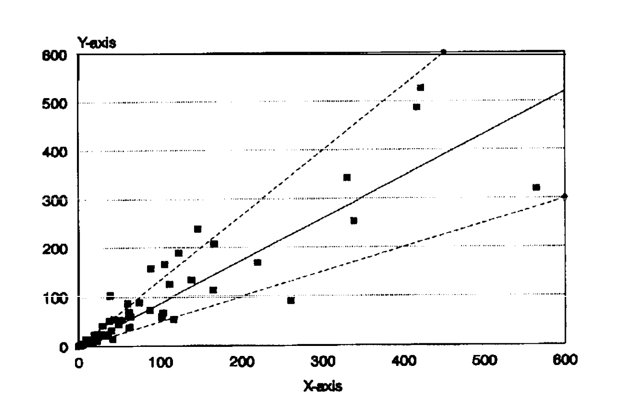

Figure 2. An Example of a Heteroscedastic Ratio Model Between Demand and Energy

1. A primary equation for the expected value of customer i's demand, denoted E(yi). Mathematically the primary equation can be expressed as:

$$E(yi) = \beta x_i$$

2. A secondary equation for the standard deviation of customer i's demand, denoted $o(y_i)$. The model contains only three parameters, β, σ_O and γ regardless of the number of strata[5] Mathematically the primary equation can be expressed as:

$$\sigma(yi) = \sigma_0(x_i)^\gamma$$

These three parameters determine the effectiveness of any sampling plan. In particular, σ_0 and β determine the required sample size, while γ determines the optimal stratification and allocation. Fortunately, past experiences with other natural gas projects have shown γ is usually stable between classes and is well approximated by $\gamma = 0.8$ for most classes. However, σ_0, (and, therefore, the required sample size), is very sensitive to the characteristics of the class and the target demands.

The MBSS methods of sample design are very effective when adequate prior sample data are available. With software the analysis is easy and the results are excellent, but the calculations are complex and difficult to explain. Moreover, the approach provides little help in choosing the sample size for applications that lack prior sample data. However, a simplified MBSS ratio model–called the error-ratio model—promotes meaningful discussion of the required sample size.

The error-ratio approach builds on the MBSS ratio model. In model based designs, the strength of relationships between two variables is measured using a parameter called the *error ratio* (Wright, 1992). (See Table 1). An error ratio is analogous to a coefficient of variation. If the error ratio is small, then there is a strong association between demand and use so that a small sample will yield good precision. Accordingly, when the error ratio is larger, a much larger sample will be required for the same precision. For example, if the error ratio is equal to 25%, then a sample of only 17 customers will generally yield +/-10% precision at 90% confidence for the peak hour. Alternatively, when the error ratio is 100% then a sample of over 270 may be required for the same precision.

Under optimal circumstances a utility's prior load research data would be used to construct the error ratio and to estimate gamma. However, since this was Minnegasco's first load research project, Company specific data was unavailable. Fortunately a regional natural gas utility, with similar characteristics, had just completed a gas load study[6] and was willing to share its data with Minnegasco. These parameters are expected to be similar to the values that will be found for Mimegasco's customers.

The Residential Space Heating Sample

To design the residential space heating sample, population information was obtained to construct a bill frequency distribution of customer bills for December 1992 and January 1993. To avoid the necessity of manipulating the full set of residential bills, the bill frequency information was used to construct a very large random sample of residential space heating customers. This large sample was then used to serve as a proxy for the entire population file. The proxy population was allocated into five strata based on their January consumption patterns. MBSS was then used to design a sample for this class.

Because of the limited number of household appliances that use natural gas (i.e., space heating, water heating, clothes drying, cooking), natural gas demand is more homogeneous than electric demand. Furthermore, because of the preponderance of natural gas demand during peak times being a result of space heating, samples designed on these variables are relatively small (as compared to electric samples). As expected, the analysis of hourly load data[7] showed the lack of diversity of energy consumption patterns among residential customers during extreme cold winter weather. This lack of diversity resulted allowed the application of a small error ratio (31%). Based on these parameters the sample size for space heating customers' total load characteristics could be adequately represented with a sample of 25 customers. This means that for samples designed to determine aggregate total loads, a small sample of residential space heating customers would provide sufficient information to characterize the hourly winter load on peak days.

However, an important objective of the load research project was to develop hourly load information for use in developing comparison groups for current and future DSM offerings. Therefore, Minnegasco designed its residential sample so that information based on a disaggregation of results would be statistically significant. For example, to evaluate the *High Efficiency Heat System Rebate Program*, the residential baseline needed to be designed to yield information regarding energy use of customers with low efficiency and standard efficiency furnaces. In addition, the load research project needed to be designed so that it could examine the effect of various housing stock information (e. g., age, location, insulation level) on energy use. Ultimately, the load research information from this project will be used to calibrate a simulation model for use in predicting the energy and demand impacts of current and future DSM programs.

Table 1. The Error Ratio Model

Objective. A simplified approach to estimating required samples for ratio estimation with strong model-based stratification

Assumptions. The ratio model with $\gamma = 1$, strong stratification, model-based allocation, negligible finite population correction, ratio estimation

Notation:

E = Expected Relative Precision, e.g., $\pm 10\%$.
z = Normal coefficient, e.g., z @90% confidence = 1.645
R = Error Ratio = σ (yi)/E(yi) = $\sigma_0/$, e.g., 30%.
n = Required Sample Size.

Results:

$E = (z \times R) / n^{1/2}$
$n = ((z \times R) / E)^2$

Typically, demand or usage is the primary stratification variable. However, to test the hypotheses such as the ripple effect, stratification based on demographic variables of interest was desired. This requirement resulted in the design of a two dimensional sample design. The first dimension was defined by significant demographic variables, and the second by demand characteristics of the population.

Unfortunately, Minnegasco did not have demographic information associated with its billing file. Therefore, secondary sources of data were used to target the project. One target stratification variable was housing stock. To incorporate this information into the sample design, housing stock derived from census data was used to characterize the Minnegasco service territory into four mutually exclusive zones.

The first zone was the *Minneapolis Core.* The Minneapolis core zone is located in and around Minneapolis proper. Census data shows that the Minneapolis Core housing stock consists of the homes dating from the turn of the century and encompasses many low income neighborhoods. The second zone defined was the *Inner Loop.* The Inner Loop is adjacent to the core and goes to the Minnesota river to the south, I-494 to the west, and 133 Avenue to the North. Census data suggested that the housing stock in this area was constructed during the 1950's, '60's and '70's. The third zone was the *Outer Loop.* The Outer Loop encompasses the outer suburbs of the area around Minneapolis. Examples include Eden Prairie to the west, Anoka to the north, and Burnsville to the south. These areas were more recently developed with home construction occurring over the past two decades. The fourth and last zone was *Out State.* The remaining service territory was grouped together. The housing stock for this area was not easily classifiable.

While the development of the four zones provided a primary stratification for the sample design, to reduce the sample size and to make the results applicable within usage categories, a second stratification variable was needed. For the residential space heating sample the second stratification variable was based on annual natural gas consumption. Annual consumption served a proxy for the size of the home and the number of natural gas use appliances in the house.

To determine the optimal boundaries for the usage strata, *conditional* and *marginal* strata boundaries were examined. For *conditional* boundaries, optimal strata boundaries are developed within each geographic zone. Alternatively, *marginal* boundaries are optimally set based on all customers annual usage. In other words, the stratum cut points within each geographic zone are the same. After determining that there was not an appreciable difference between the marginal and conditional strata boundaries, for ease of application marginal strata boundaries were adopted. As a result of the limited amount of variation between customers, a three usage strata design was selected.

The final sample design is a two dimensional (geographic and usage) design, featuring 12 strata. The stratification, estimated number of customers in the population and the recommended sample sizes are presented in Table 2.

Using a two-way stratification with a sufficiently large total load sample allows the data to be obtained on a diverse housing stock. As a result the sample will produce results for a wide range of residential customers. The preliminary recommended sample size for total load metering was 240 customers. This large residential sample was expected to provide statistically reliable information (±10% precision, at 90% confidence level) for the peak hour for each stratum. On a total class basis, the sample will yield approximately ±3% precision at 90% confidence for the peak hour.

After the determination of the sample design, Minnegasco faced an unanticipated, substantial increase in metering costs. To address this practical constraint, the sample size had to be reduced by approximately one-half (128 total points). While the uncertainty associated with the results increases because of the decrease in the sample size, Minnegasco feels that the sample size is still robust enough to yield significant results. (The overall precision for the entire class became ±4.4%.)

End-Use Metering Sample Design

At the time of formation Load Research Plan, Minnegasco recognized the opportunity to develop end-use information for the residential market segment. To satisfy this need for detailed hourly end-use data, it was determined an end-use metering would be performed on a sample of nonparticipants. The end-use metered sample was imbedded into the total load sample providing a *double sampling*[9] (Townsley and Wright, 1990)[9] strategy that will be extremely effective during the analysis of the end-use metered and total load data.

Using approximate cost information from the monitoring contractor and anticipated error ratios, an optimal allocation between end-use metered data and total load data was estimated. The price of a total load metering point was initially estimated at $500 and the incremental cost of a multiple end-use metered point was estimated at $1,500 additional. An error ratio of 40% between the total load and billing information was estimated. An error ratio of 20% between the end-use metered data and the best simulation developed from the total load was estimated. Combining these parameters estimates yield a 4 to 1 relationship between end-use metered information and total load information. The end-use metered sample was targeted based on the load research participant's response to a mini survey conducted at the time of the initial recruitment.

Once again, upon implementation of the end-use metering design the project encountered an increase in metering costs associated with the total load sample. This increase made the collection of end-use information more economical. The final design included multiple end-uses for

Table 2. The Residential Space Heating Two-Way Residential Stratification

Zone	Description	<1,028 ccf	1,028-1,346 (ccf)	1,346-19,444 (ccf)	Total
1	Population Size	33,446	30,428	40,756	104,630
	Sample Size	10	15	29	54
2	Population Size	61,083	55,091	35,582	151,756
	Sample Size	20	26	23	69
3	Population Size	51,276	37,329	28,517	117,122
	Sample Size	16	18	20	54
4	Population Size	62,905	43,855	34,138	140,898
	Sample Size	19	21	23	63
	Population Size	208,710	166,703	138,993	514,406
	Sample Size	65	80	95	240

56 sample points, single end-uses for an additional 66 sample points, and total load points for the remaining 36 sample points.

Lessons Learned and Future Work

The Minnegasco experience has initiated an important step in the application of load research in the evaluation of natural gas DSM programs. The project is unique because it was able to incorporate some of the newest concepts in load research (i.e. the borrowing of data to develop samples, two-way stratification, and double sampling), while demonstrating to natural gas utilities the immense challenges of initiating a comprehensive load research program.

Minnegasco had initiated the project with sufficient time to have the samples installed for the winter of 1993-94. However, verifying the old adage "nothing is as easy as it seems", this project demonstrates nearly all of the challenges that a natural gas utility could be faced with when initiating such a program. Notwithstanding the fact that this project built upon the electric load research experience, regulatory oversight and equipment delay resulted in over a six month delay.

As a result, the Minnegasco evaluation of its CIP programs, and baseline information is very much a work in progress. The quantification of the current DSM programs will be performed after a full season of heating information is obtained during the winter of 1994-95. This section presents the approach that the Company will take to perform those evaluations.

DSM Program Evaluation Design

The evaluation of the Minnegasco's *High Efficienqy Furnace Rebate* Program, and its *Set Back Thermostat* Program features the "Cross Sectional Comparison Group" research design. This research design monitors participants and a control group on a post-installation basis. As compared to some other research designs, this design was chosen because it reduces threats to internal validity. The participant post-installation load shapes will be compared to results of baseline customers. In the population and baseline load research samples, households with both low and standard efficiency heating systems will be both total load and end-use metered.

A total of 30 High Efficiency Heating System Rebate participants and 20 set back thermostat participants will have their heating systems monitored, in addition to their total load. This information will be compared to end-use information gathered from the baseline sample. Of the 128 sites, a sub-sample of 60 of these sites are being end-use metered. The end-use metered channels will monitor a variety of standard efficiency and low efficiency heating systems, water heat, miscellaneous gas end-use (e. g., ranges, dryers). Outdoor temperature will be obtained on a regional basis.

The load research information, in conjunction with the survey results, will be used to estimate the net impacts of the program. Additionally, the results of the cross sectional comparison, adjusted for other control variables, can be used to determine the extent of interactive effects, if any, with other utility sponsored programs. The applicable aggregated data can be used in planning or economic evaluation of the existing program or future programs assuming alternative implementation and participation scenarios.

Endnotes

1. The definition of "demand" is slightly different among electric utilities as compared to natural gas utilities. Generally, both are defined by the utilities marginal cost of demand. For an electric utility "demand" is usually used to refer to the highest instantaneous demand on the generating system. Natural gas supply contacts have been defined by the highest natural gas "demand" during a given 24 hour period.

2. The *ripple effect* describes a phenomenon that suggests a customers instantaneous gas usage peaks demand is a function of time related to the distance from the business core. In effect, the ripple effect produces time differentiated peak demand on local distribution networks that move towards a city in throughout the morning, and away from the city as the evening progresses. The *bend over effect* describes the point when a customers demand reach a maximum, and does not change regardless of a decrease in temperature.

3. Minnegasco has the potential to develop a program to promote set back thermostats. While the installation of this type of equipment has shown to decrease natural gas consumption, Minnegasco wanted to test the hypothesis that set back thermostats lead to a degradation of daily load factor, and increase instantaneous peak demands.

4. When planning a natural gas distribution system, and for supply, natural gas planners use a *design day* which is colder than the most severest historical weather.

5. The three parameters are pronounced "beta," "sigma-naught," and "gamma."

6. This load study that this refers to was designed for rate making purposes, rather than for DSM purposes, as Minnegasco's.

7. To test the "ripple effect" and system distribution constraints, hourly demand was adopted as the design variable.

8. In double sampling, the relatively inexpensive total load monitoring will be combined with energy simulations to help leverage the more expensive end-use metered data. The success of this approach depends on the strength of the association between the energy simulations developed in conjunction with the total facility load and the end-use metering data. If the association is strong, then the energy simulations can be developed in a relatively large sample and combined with end-use metering in a small sample. Even though the end-use metering is small, this approach may give the same precision as a much larger end-use metered sample used without the supporting simulations. Having developed a calibrated simulation model for estimating the energy consumption based on various parameters, the Company will be in the position to answer a multitude of DSM related issues regarding the anticipated impacts of various combinations of measures.

9. For an in depth discussion, please see Pacific Gas and Electric. Double Ratio Analysis Final Report, Xenergy Inc, and RLW Analytics, Inc.

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