Impact, Process, and Technology Assessment
for Smart Meter-Enabled Demand Response

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ABSTRACT

NSTAR Electric Company, serving the Boston, Massachusetts region, has deployed the first phase of a smart grid pilot program to demonstrate the viability of using home-area networks and customers' broadband internet connections to enable dynamic pricing, two-way direct load control, and the provision of near real-time customer information. Through the unique experimental design, the pilot will allow for a better understanding of how a variety of rates and technologies interact to generate changes in customer electricity consumption and to influence customer acceptance. The evaluation approach is designed to accurately estimate the reductions in peak load and overall energy consumption, assess customer acceptance, and establish minimum functional requirements for the Smart Grid technologies. The initial feedback from customers participating in the pilot has been positive and an ongoing technical review is assessing whether the pilot system architecture can provide a viable solution to achieve the pilot's interval metering and customer information objectives without a full investment in smart meter infrastructure and capability.

Introduction

Residential Smart Grid efforts typically require a massive investment in metering and communications infrastructure that can result in stranded assets through the premature replacement of fully functioning and non-depreciated equipment. However, utilities may be able to leverage existing automated meter reading (AMR) deployments common throughout the U.S. to mimic many advanced metering infrastructure (AMI) capabilities at significantly lower cost.[1]

NSTAR Electric Company has deployed the first phase of a pilot program, supported by a matching grant from the U.S. Department of Energy's Smart Grid Demonstration program, to demonstrate the viability of using home-area networks (HAN) and customers' broadband internet connections to enable dynamic pricing (time-of-use and critical peak rates/rebates), two-way direct load control, and the provision of near real-time customer information. More than 2,000 customers in the Boston, Massachusetts area have been participating since the beginning of 2012, and nearly 3,000 participants are expected by mid-year.

Smart Meter Pilot Program

The pilot program offerings to customers consist of 1) a rate design and 2) a set of one or more technologies to enable interval metering, provision of enhanced customer information about pricing and electricity consumption, and (for some participants) automated load response (NSTAR, 2009). Each of four customer test groups in the pilot, as described below, receive a unique combination of rates and

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[1] Cost savings may be particularly significant for utilities serving the 25% of customers nationwide and the 80% of customers in the Northeast who currently have AMR meters (Scott 2009).

technologies in order to test hypotheses regarding the impact of technology on load reduction and the interaction of various technologies and rate structures.

In place of the standard electricity rate, most participants in the pilot receive service under one of the following two new rate designs:

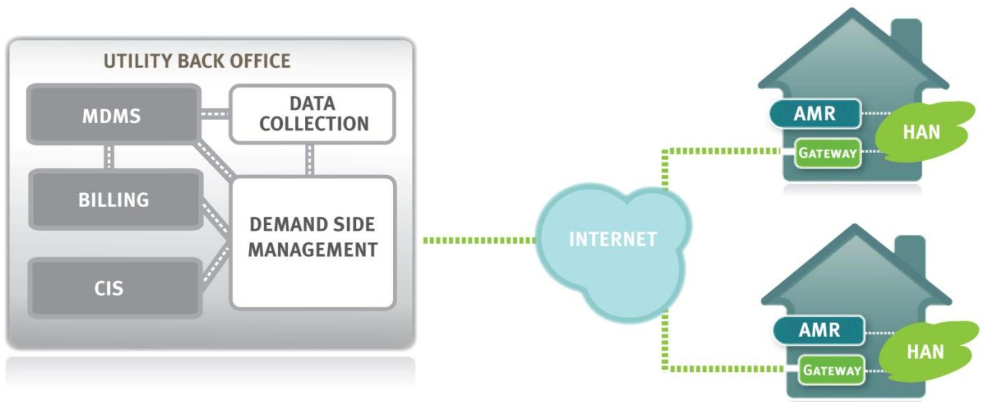
1. A new time-of-use (TOU) rate with critical peak pricing (CPP) for events called by NSTAR.
2. A critical peak rebate (CPR) overlaid on the standard applicable rate, with a pre-established rebate amount awarded to customers who utilize automated thermostat controls or an automated AC load control switch to reduce load during critical peak events.

There is also one customer segment that receives a base suite of in-home technology but stays on their otherwise applicable standard rate, which will allow NSTAR to assess the achievable load reductions from a technology-only option that does not require customers to change rates.

Smart Grid Technology

The underlying technology architecture consists of existing AMR meters and customer broadband connections linked to each other and to NSTAR through in-home and back office equipment and software provided by Tendril, a provider of home energy management systems. This technology infrastructure is intended to establish a reliable communications pathway from the meter to NSTAR's internal systems that allows meter reading resolution suitable for TOU and CPP rate plans. The deployed equipment also enables automated load control of central air conditioning and provides customer information via in-home displays or the internet.

The Tendril platform offers the capability of utilizing the customer's existing Internet connection as the communications backhaul. This is accomplished by an Internet gateway device that enables wireless communications to and from the home-area communications network. The AMR meter transmits wirelessly the consumption information on regular intervals and the ERT Bridge captures it. Time-stamped data is then transmitted wirelessly via the Internet Gateway to NSTAR utilizing the customer's broadband connection, as illustrated in Figure 1.



Source: Tendril

Figure 1. Communications Pathway to and from the Customer Home

These technologies constitute the Smart Grid from the customer perspective. They provide feedback on energy consumption (via an in-home display or a web portal) and offer participants the convenience of remotely controlling household temperature in the event that typical schedules change. The automated response to critical events may allow for greater load reductions and bill savings.

Experimental Design

Customer segmentation for the pilot is based on a combination of the applicable rate (standard, TOU with CPP, or critical peak rebate) and the technologies provided. All participants outside the control group will receive at least two types of technology: 1) an in-home energy display, and 2) Smart Grid communications infrastructure including an internet gateway, ERT bridge, and access to the web portal. In addition, roughly half of the CPP participants and all participants eligible for the critical peak rebate will receive a programmable smart thermostat that can automate load curtailment of air conditioners according to customer preferences in response to an event called by NSTAR.

Based on the proposed rate structures and technology options, the pilot participants have been categorized into one of four unique test groups (Table 1) (Horton, 2010).

Table 1. Smart Grid Pilot Customer Segments

	Time Variable Rate	**AC Load Control**	**Sample Size**
1	TOU Rate plus Critical Peak Pricing (CPP)		700
2		✓	700
3	Critical peak rebate	✓	700
4	Technology-only segment		770
	Total		**2,870**
Note: All groups except the control group will receive an Internet gateway and an in-home energy display.			

This combination of time-variable rates and enabling technologies allows for testing of various hypotheses regarding the impact of individual rate structures and technologies. For example, Customer Segments 1 and 2 can be compared to the control group to assess the impact of a TOU rate on peak period consumption as well as the impact of the high-priced critical peak event relative to normal peak hours. Comparing Customer Segment 2 with Segment 3 then allows for measurement of how a critical peak *price* influences consumption relative to a critical peak *rebate*.

Control groups will serve as benchmarks for purposes of estimating load impacts. The evaluation will employ the following control groups (Table 2), each selected to best serve the intended purpose:

Table 2. Control Group Specification

Control Group	Purpose in Evaluation	Rationale
Existing interval-metered load research sample*	Peak load and time-of-day impacts	Evaluation requires interval data from prior years in order to assess time-varying impacts adjusted for weather, economic, and other macro factors.
Monthly bill customers*	Annual, seasonal, and monthly impacts	Monthly billing data is readily available and allows for a large control group; interval data is not needed for impacts at monthly or lower granularity.
Participants' own interval data	Impacts of load control and CPP events	Customers are their own best-matched control group. Since events occur a finite number of times for relatively short durations, participants' own interval data from non-event days and hours constitute a strong basis for comparison.

* The evaluation is using a subsample of each control group population to serve as the comparison group, based on matching of energy consumption patterns with the participant group.

Approach to Evaluation of Smart Meter System

The Pilot is intended to assess energy and load reduction impacts and confirm the functionality of smart meter technologies utilizing two-way communications for load control, dynamic pricing, and customer information. Meeting these objectives requires an *evaluation approach* that can achieve the following objectives:

1. Accurately estimate the reductions in peak load and overall energy consumption
2. Assess customer acceptance, and
3. Establish minimum functional requirements for the Smart Grid technologies.

A major outcome of the evaluation will be to provide sound technical, economic, and marketing information that can be used to inform both near-term strategies and the Company's future Smart Grid investment decisions.

Energy and Load Impact Analysis

The estimation of the consumption impacts of all four participant groups requires at least hourly meter data collected for each participant as well for an appropriately sized control group.[2] The evaluation team is consolidating all of the individual time-series into a single panel (or longitudinal) data-set; that is, a data-set that is both cross-sectional (including many different individuals) and time-series (repeated observations for each individual). Once the team cleans the consumption data of obvious outliers, erroneous readings, and missing values, the consumption impacts of all four groups are

[2] Navigant typically uses hourly data for its analysis of DR, pricing, and customer information programs and has found this level of resolution to be sufficient for estimating impacts of all program types. Although it is not necessary, 15-minute data can be useful for more precise assessment of snap-back effects immediately after an event and can add accuracy if the start/end of load control events do not line up with the beginning and end of the interval metering period.

estimated using *fixed effects regression analysis*:

- Fixed effects regression analysis is a panel-data technique which extends the standard Ordinary Least Squares (OLS) regression by assigning every household in the sample a unique constant (a dummy variable) to be estimated.
- The household specific dummy variable (or individual-level fixed effect) allows the analyst to control for time-invariant differences between individuals who are not already controlled for by other explanatory variables.
- Put another way, the fixed effect allows the analyst to control for a variety of unchanging household characteristics (e.g., building size, orientation, etc.) that differ between individuals (but not over time) without needing to explicitly control for each of these characteristics individually.

Baseline estimation. An advantage of regression analysis relative to straight comparison of a participant group and a control is that it implicitly establishes a baseline from which deviations, such as customer response to a CPP event, may be estimated through the inclusion of dummy indicator variables. As noted above, *interval data is being collected for a control group of customers not participating in the pilot*; this data will allow for estimation of a baseline consumption level for each hourly interval (i.e., what consumption would be if the customer were *not* a participant in the pilot) against which the participant's true consumption can be compared. The model architecture does this analysis inherently for each hour and each participant, but the analysis can utilize the model to explicitly calculate a baseline consumption level.

Weather normalization. Additional time-series variables have been included in each regression to control for variations in ambient temperature, weather, and whether a day is a weekend, holiday or weekday. The inclusion of weather and temperature variables implicitly performs weather normalization and obviates the need for explicit adjustments to the data to account for weather impacts. Essentially, the regression controls for weather effects and allows the analyst to forecast the effect that weather changes will have on the variable of interest (i.e., electricity consumption).

Impact of differing participant rate schedules. Customers on any of several different rate schedules are eligible to participate. The diversity of rate schedules suggests that consumption impacts may differ depending on the customers' rate structures. Initially, the evaluation approach is to integrate participants across all rate schedules within a single Group-specific model specification, controlling for the effects of different rate structures with additional explanatory variables. Additional exploratory analysis will be conducted to specifically identify the impacts of the various technology/rate groups on demand and consumption by running *separate regressions for customers on each rate schedule* within each participant Group. In either case, through the proposed modeling approach, the evaluation will be able to present an estimate both of the *average overall impact of each Group* given the mix of rates, as well as an estimate of the *rate-specific impact of each Group*.

Process Evaluation

The process evaluation is the primary research tool used to assess achievement of evaluation objectives, which include the following:

» Identification of the level of customer acceptance and satisfaction with each of the Pilot Groups overall and the devices, technologies, and provided information in particular;

» Assessment of barriers to participation (including for the low-income population) and possible changes in marketing strategies and program structure that can help customers to overcome these barriers; and

» Recommended improvements to each Pilot Group offering going forward.

Process evaluation encompasses a review of how well the Company is administering each individual Pilot sub-program, how Pilot customers perceive the program, how customers react to the information provided, and how the technologies are working from the customer’s perspective. Program delivery assessment includes interviews with Company staff, vendors, and participants to identify each of the four Pilot Groups’ strengths, areas for improvement, and features that are preferred or disliked by customers. Selected customers declining to participate are also being interviewed to understand their concerns and potential barriers to participation.

Customer Surveys. Customer feedback is the primary input to the process evaluation and is being obtained primarily through surveys of a sample of participants at various stages of Pilot program implementation. For each Pilot Group, depending on its applicability, the following customer surveys are being administered (Schare 2011):

1. **Recruitment surveys** administered at the time of enrollment to determine motivations, expectations, concerns, and customer characteristics.
2. **Decline-to-Participate surveys** administered immediately after a customer declines to participate during telephone recruitment to help identify barriers to participation and means to overcome those barriers.
3. **Post-installation surveys** to evaluate the equipment installation and education process, customer rationale for selecting their chosen automated response strategy.
4. **Participant drop-out surveys** to assess the reasons for customers dropping out of the program and opportunities to enhance long-term participation rates.
5. **Critical event surveys** to assess awareness of the events, impacts on customer comfort, and any manual load curtailment response
6. **End of summer participant satisfaction and feedback surveys**.
7. **End-of-pilot participant satisfaction and feedback surveys.**

Surveys are being administered via the internet using email invitation wherever feasible. In this way, all participants have an opportunity to respond to relevant surveys. Telephone surveys are used where needed, such as to reach participants immediately after critical events and to reach customers who declined to participate. Sample sizes vary by survey type and are based on customer response to survey invitations. More than half of all customers have responded to the recruitment and installation surveys, and the evaluation team expects more than 1000 responses for the end-of-summer and end-of-pilot surveys.

Survey Topics. A unique set of survey questions were developed for each participant Group, but where possible similar questions are being posed to enable comparison between program offerings with similar characteristics and objectives. Table 3 presents a summary of major survey topics, covering customer perceptions, preferences, and willingness to participate in a full scale program.

Table 3. Major Customer Survey Topics

• Perceived program value and benefits throughout the pilot	• Perceived usefulness of information provided
• Perceived ease of device use and technology/frequency	• Immediate and longer term behavior changes
• Perceived usefulness of information and feedback	• Satisfaction with involvement, technology, media
• Comfort impact from critical events	• Expected savings, awareness of and satisfaction with actual
• Frequencies of and reasons for overrides during events	• Willingness to continue participation
• Reaction to voluntary events (if applicable)	• Impact on customer satisfaction with NSTAR
• Preferences regarding information format or content	• Suggestions for improvement – technology, information, processes

Technology Assessment

The technology assessment addresses the reliability and customer acceptance of the various technologies associated with the Pilot architecture. These technologies include the customer-facing equipment such as in-home displays, load switches, smart thermostats, and web portals, as well as communication gateways, the HAN platform and back-end systems. The evaluation is specifically addressing system communication success and failure rates, AMR/ERT meter data collection completeness, processing of meter reads, and incorporation of participant billing data into the billing system.

The assessment is also examining the process and initial success of the installation and operation of thermostats, load switches and communications devices, and will track equipment failure rates and other issues throughout the Pilot. The knowledge gained from this information will help ensure successful installation and operation of equipment and systems as the Pilot scales.

These objectives will be met through review of meter data, thermostat settings, and other available device information, as well as actual data obtained from continuous operation of the system. Navigant is obtaining the information from various sources, including the technology vendor's system, log files, etc. as available. This includes information from load control events to assess the efficacy of the systems under real conditions.

The analysis will characterize the operation of the overall system, including any issues or trends with equipment and communications that could be indicators of concern for scaling up the technology or approach in question to a full load curtailment program. Specifically, the assessment will measure the percentage of thermostats and other equipment operated correctly or that had to be replaced, and how much of the meter data and other information was successfully communicated either to or from the devices and the home.

The assessment will cover, at a minimum:

- HAN message success and failure rates
- Percentage of end-to-end communications signals sent and received

- Impact on signal success of building size, building materials, floor plans, and distance between devices
- Need for HAN signal repeaters and resulting success rates
- Issues with broadband configuration or reliability
- The need for equipment replacement during installation and operations

The system level data is typically collected by the equipment vendor and/or implementation vendor, to track the success and failure rates of messages sent to and from the customer equipment, such as thermostats, in-home displays, and web-portals. Key determinants of the technologies' ability to transmit data are the characteristics of the home (for example, stucco construction typically uses a wire mesh underlayment which can significantly attenuate radio signals used for some HAN communications, such as Zigbee radios), the location of equipment, and (in the case of the broadband communications pathway), the internet service provider.

Data collected onsite by the installation contractor includes:

- Home characteristics (age, size, construction type, number of stories)
- Equipment locations
- Broadband service provider
- Air conditioner characteristics (make/model, size in tons)

It is anticipated that the pilot Smart Meter architecture based on existing AMR meters and installed HANs will provide many of the features and capabilities of a full AMI deployment such as remote upgrades, net metering, and meter diagnostics. Table 4 presents a comparison of the features and capabilities of the two deployment scenarios. Evaluation of the pilot will provide test data to assess the performance of the pilot architecture with respect to the first four system features and capabilities.

Table 4. Comparison of Features: AMI vs. Pilot Architecture

System Feature Comparison		
Description	**AMI with HAN**	**Pilot Architecture with HAN**
Interval Data	☑	☑
Customer Information	☑	☑
Direct Load Control	☑	☑
Temperature Setbacks	☑	☑
Remote Upgrades	☑	☑
Revenue Protection	☑	☑†
Net Metering	☑	☑
Meter Diagnostics	☑	☑
Remote Disconnect	☑	
Automated Outage Reporting	☑	☑*

†Interval data can be used to determine some level of revenue protection.
*Future enhancement proposed.

Source: Based on assessments by NSTAR Engineering, Tendril product information and expected enhancements prior to deployment, and Navigant analyses.

Early Findings

The first phase of the pilot was a Soft Launch in 2010, enrolling approximately 200 participants and installing in-home displays and the equipment to enable interval meter reading and two-way communications. The Soft Launch participants remained on the standard rate but were able to view consumption data on the in-home displays and via the web portal. Initial findings from the recruitment, installation, and operation phases suggest the following:

1. **Interest** in the Smart Grid is high, with nearly 10% of customers who received invitations requesting enrollment in the Pilot.
2. **Equipment installations**. Conversion from enrollment requests to equipment installation must overcome both customers' second thoughts upon receiving the enrollment agreement and the fact that some homes' air conditioning systems are incompatible with the current version of the thermostats.
3. **Value of information.** After several months, a majority of participants reported checking their devices daily, and more than 40% reported the information to be "very valuable" or "valuable".

Conclusions

The initial feedback from customers participating in NSTAR's smart grid pilot indicates the possibility of customer acceptance and significant perceived value from access to information and technology that assists customers in controlling their electricity usage and bills. A preliminary technical assessment of the pilot system architecture is still underway and will determine whether the technology provides a viable solution to achieve the pilot's interval metering and customer information objectives.

Through the unique experimental design, the pilot will allow for a better understanding of how a variety of rates and technologies interact to generate changes in customer electricity consumption and to influence customer acceptance. The pilot leverages NSTAR's recently installed and non-depreciated metering infrastructure, and the Company intends to use the technical, economic, and marketing information obtained from the pilot to better serve its customers by informing the company's future Smart Grid investment decisions. Furthermore, a successful pilot has implications for how utilities across the country may enable time-differentiated rates and provide customers with near real-time usage information without the costly investment in AMI.

The NSTAR pilot is one of several in the United States testing the efficacy of using customers' existing broadband to enable the two-way communications needed to provide customer information, verifiable demand response, and dynamic rates. Perhaps the greatest uncertainty is the level of customer interest once the equipment and the pilot are no longer a novelty, and the largest technical hurdle is the reliability and of revenue-grade interval meter data. By the end of 2012, the pilot will have a year's worth of data for most of the roughly 3,000 participants, and NSTAR can begin to share findings with its regulators, other utilities, and the energy efficiency community.

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