Engineering 90 Proposal

Adaptive Electricity Use Model

Swarthmore College, Department of Engineering

Advisor: Carr Everbach, Ph.D

Omer M. Corluhan

November 15, 2007

Abstract

An energy model is proposed to predict the electricity consumption at Swarthmore College. Factors such as historical weather data and the College's class schedule are considered as major decision variables for the model. The model will be implemented through a Windows-based computer program. The College's Facilities Department plans to use the model to estimate the College's future electricity demand. The model will help Facilities managers to avoid potentially high electricity costs as a result of the coming deregulation of electricity prices in Pennsylvania in 2010. The model's feedback system will improve its results based on the deviations between predicted and actual data collected over time.

1. Introduction

The Swarthmore College Energy Analysis Project, "the Project", at Swarthmore College, "the Client" or "the College", was created in response to the energy challenge the College faces in future. The three major objectives of the Project are minimizing the College's energy cost, reducing greenhouse gas emissions and heightening students' awareness of wasteful practices. The Project analyzes quantitatively the College's increasing electricity consumption. Last year, the College was charged for its electricity demand by local contractors PECO/Exelon at $0.08 per kWh, which cost in total $1,387,010.56 from August 2005 to July 2006. An additional demand charge for exceeding the allowable peak limit was $25 per kW. The College paid approximately $52,000 for the excess demand.

2. Technical Discussion

Electricity forecast models become increasingly common as electricity becomes a traded commodity such as oil or natural gas. Various hedge funds develop models to predict future electricity demand to take advantage of any arbitrage opportunities in the market. PJM Interconnection[1] is a regional transmission organization (RTO) that coordinates the continuous buying, selling and delivery of wholesale electricity through the Energy Market. PJM uses locational marginal pricing that reflects the value of the energy at the specific location and time it is delivered.

In the Swarthmore College Energy Analysis Project, a model will be developed to estimate the electricity demand in future based on selected decision variables. The decision variables are factors ranging from class schedule to historical and forecasted future weather data. Extensive data will be acquired from the Swarthmore College Facilities Management Department (FMD) through its established data-gathering system. The FMD will send the raw data to an intermediate server. A Windows-based program will read the data from the server. An interface portion of the program will analyze the data and present it based on statistical concepts. After the data gathering and analysis phase is completed, the electricity model will digest this data to output tomorrow's predicted electricity demand in terms of kW and kWh. A user interface will help the user to choose among the program options. The result will be displayed in a graphical

[1] PJM Interconnection coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.

representation and in numerical form. During the next day, the predicted result of the model will be compared to actual data. A separate performance program will measure any deviations. Through a feedback loop mechanism, the deviations will be minimized and the model will optimize over time.

The selection of decision variables for the electricity model is essential. Various factors will be investigated and a simple linear regression analysis will be run for each factor. Factors with high correlation coefficient based on historical electricity demand data become the main decision variables of the model.

Theory for correlation coefficient and simple linear regression analysis

A relationship between the electricity demand and various other factors will be investigated by simple linear regression analysis method for number of classes and electricity demand. Linear Regression Analysis (LRA) is a fundamental statistical method used throughout the Project's data analysis.

As a first approach to data analysis in many engineering problems, data is often investigated by graphing the dependent and independent variables against each other. This procedure helps to visualize the correlation variable to find the type of the relationship between the independent and dependent variables. "The correlation coefficient (ρ) of two random variables X_1 and X_2 is computed by dividing the covariance of X_1 and X_2 by their respective standard deviations."[2] We can write:

$$\rho = \frac{\mathrm{Cov}(X_1, X_2)}{\sigma_1 * \sigma_2} = \frac{\mathrm{E}(X_1, X_2) - \mu_1 * \mu_2}{\sigma_1 * \sigma_2}$$ **, Equation 1**

where σ_1 and σ_2 are the standard deviations of X_1 and X_2, respectively. A positive or negative correlation will indicate whether there is a relationship between dependent and independent variables, while a correlation value of zero will indicate no relationship. A correlation number of -1 is a perfect negative linear correlation, whereas a value of 1 indicates a perfect positive linear correlation.

However, in most engineering problems the data is further investigated by regression analysis. Simple regression analysis has a dependent variable and an independent variable. We

---

[2] Khisty, C. J. and J. Mohammadi. Fundamentals of Systems Engineering with Economics, Probability and Statistics. Prentice Hall, September 2000.

are interested in finding a relationship between these two variables to find the expected value of the dependent variable for any given value of independent variable. We can write:

E(Electricity Demand | Number of Classes) = a + b*X , **Equation 2**

in which a and b are constants. To find the estimates for constants, a and b, the method of least-square analysis is used. The deviation of each estimated dependent value from the actual dependent value or, in other words, the difference between the estimated value and the experimental value, $\Delta_i = y^*_i - y_i$, is called the residue. In the least square method, the sum of the square values of residues is minimized to find the best fit line for the given data[3]. The sum of squares of residues can be denoted as SS_E. Minimizing the sum of squared of residues can be described as:

$$SS_E = \sum_{i=1}^{n}\left(y_i^* - y_i\right)^2 = \sum_{i=1}^{n}(a + bx_i - y_i)^2$$, **Equation 3**

Two equations below estimate the coefficients a and b.

$$\frac{\partial SS_E}{\partial a} = 0$$, **Equation 4**

$$\frac{\partial SS_E}{\partial b} = 0$$, **Equation 5**

The R^2 value, which is defined as one minus sum square of residues, will present the success of the linear regression analysis. A high R^2 value indicates a strong relation between the dependent and independent variable. Based on the linear regression analysis, the electricity model's decision variables are determined and weights are assigned.

The model will improve itself in a continuous manner as it is implemented.
A separate performance program will use a feedback loop system to improve the model based on the deviations between the actual and predicted electricity demands. These results will be recorded and presented to the user.

[3] In the data-gathering process, data is collected in Y and X pairs.

As an extension to the project, the model's result might be presented on a public server so that the College students can see the amount of electricity the College will demand at a given time in future. Upcoming peaks might be avoided by informing the college community through this website. This extension aims to increase a student's awareness as a global citizen to protect the environment and remember his/her ethical responsibility of using only the necessary amount of electricity.

3. Project Plan

The three major objectives of the Project are minimizing the College's energy cost, reducing green house gas emission and increasing environmental consciousness among students. These three objectives can be listed in more detail as:

1. to minimize College's future electricity demand in terms of kW and kWh and to avoid any potentially high electricity costs after full electrical deregulation in 2010.
2. to make the College more environmentally friendly in terms of reducing its carbon foot print.
3. to raise awareness among Swarthmore students. The project might be a major first step to create responsible and environmentally-aware global citizens that will use resources more carefully. Various student organizations at the campus such as Earthlust may be involved[4].

The current price for electricity is, in constant dollars, similar to 1991's electricity prices[5]. The current rate cap resulted from an agreement related to the deregulation of the energy industry starting in 1996. However, electricity prices are subject to change in 2010, when electricity prices will adjust every fifteen minutes based on the market price determined by supply and demand. The Client is concerned that the College's electricity bill may triple as a result of free-market electricity prices. The Client's endowment has returned outstanding results while beating the market in past years. However, tripling the current electricity bill of approximately $1.4 million will squeeze the College budget in a significant way leading to cuts in other spending. The Project will establish an electricity model that will forecast the Client's future

---

[4] Eathlust's Mission Statement: "Our goal is to foster an awareness of the environment as an integrated community of humans, other living things, and natural landscapes and resources. We work to increase each person's awareness of the effects that his or her decisions have on our environment. We also educate the college community about local and global environmental issues." For more information please visit: http://www.swarthmore.edu/students/organizations/council/Group/Charter/Earthlust.pdf

[5] A detailed explanation will be provided upon request.

electricity consumption so that the Client will have the means to take any necessary precautions.

Besides financial concerns, the Client is responsible for understanding its electricity demand in order to excel as the best undergraduate institution in the country. To minimize its effect on global climate change, the College should reduce its carbon footprint and maintain leadership in higher education. The Project will reduce the College's carbon footprint by correcting inefficiencies and minimizing electricity consumption. At the same time, the Project aims to educate environmentally responsible Swarthmore students by showing our responsibility to consume only that which is necessary. Collaboration with the College's student environmental organizations and presentation of the Project's results on a public server are the first steps to the third objective of the Project.

A black-box model that runs on a Windows-based computer will be developed to implement the electricity model. A user-friendly Windows-based interface will help the user to upload the data from the server. The result will be presented in terms of statistical measures and simple output. The performance of the model will be continuously monitored and a feedback loop will work on improving model's results.

4. Project Qualifications

I am a senior, double-majoring in (ABET Accredited) Engineering and Economics at Swarthmore College. I am qualified to conduct the research and development necessary for the successful completion of this project. I have worked with Professor Everbach and Professor McGarity in systems engineering, energy modeling and optimization projects at Swarthmore College. I acknowledge that a major difficulty in this project is acquiring the necessary data. Swarthmore College Facilities management Department has been collecting data in the last several years. The long collaboration of the Engineering Department with the FMD assures a solid data stream. In the previous projects, Tom Cochrane from FMD was extremely helpful for my projects.

5. Project Cost

Since the project heavily relies on modeling and optimization, the project is estimated to cost less than the budget. However, any possible extension and field experiment such as putting motion sensors in selected test areas might increase the cost of the project. A 2, 5 and 10 meter range motion sensors from Digi-Key cost approximately $38. Considering five motion sensors are needed to do such an extension, the cost of the project is still estimated to be about $250[6].

6. Project Reporting

A brief bi-weekly report will be submitted to my advisor. The paper will discuss recent developments and challenges in the process. Weekly meetings with my advisor will be scheduled to obtain guidance and help along the Project.

7. Project Plan Overview

The Critical Path Method (CPM) is explained in detail in Table 1 below. A Gantt diagram for the CPM is shown in Figure below. Further changes to the CPM will be reported in bi-weekly reports.

Table 1: Swarthmore College Electricity Analysis Project Coordinated Development Plan

Swarthmore College Electricity Analysis		
Phase	Task	
I	Data Analysis Concept Development	A - Study the College's energy system and focus on its electricity consumption, determine possible inefficiencies at Swarthmore College
		B - Research the existing literature about the electricity modeling and forecast
		C - Collect data through the College's Facilities Department data gathering system
		D - Establish potential decision variables
		E - Evaluate concepts for potential electricity models
		F - Finalize concepts for the electricity analysis model
II	Model Development and Evaluation	G - Build a windows based program to analyze and output the real-time collected data
		H - Finish the objective function and constraints of the electricity model
		I - Test the model with real data
		J - Improve the model based on deviations between predicted and actual results
III	Testing and Model Feedback	K - Establish a program to evaluate the model based on its results and present the performance of the results with statistical methods
		L - Create a feedback loop to improve model's performance
		M - Evaluate and test further data with model's feedback

[6] An additional $60 is put aside for general cost of the Project.

		loop
IV	Implementation and Experiment	N - Field experiment and recommendation based on model's results
		O - Work with facilities on site to implement the model
V	Campus Awareness and Field Test	P - Present the model result on a public website to raise awareness among students for becoming a more responsible resource consumer
		Q - Present the results to campus
V	Building user interface	R - Package the model in an user-friendly interface
		S - Refine the model and design it as a black box model so that the user can upload data and get output
VI	Writing the report	T - Assembling and gathering previous documents and reports
		U – Writing the final report

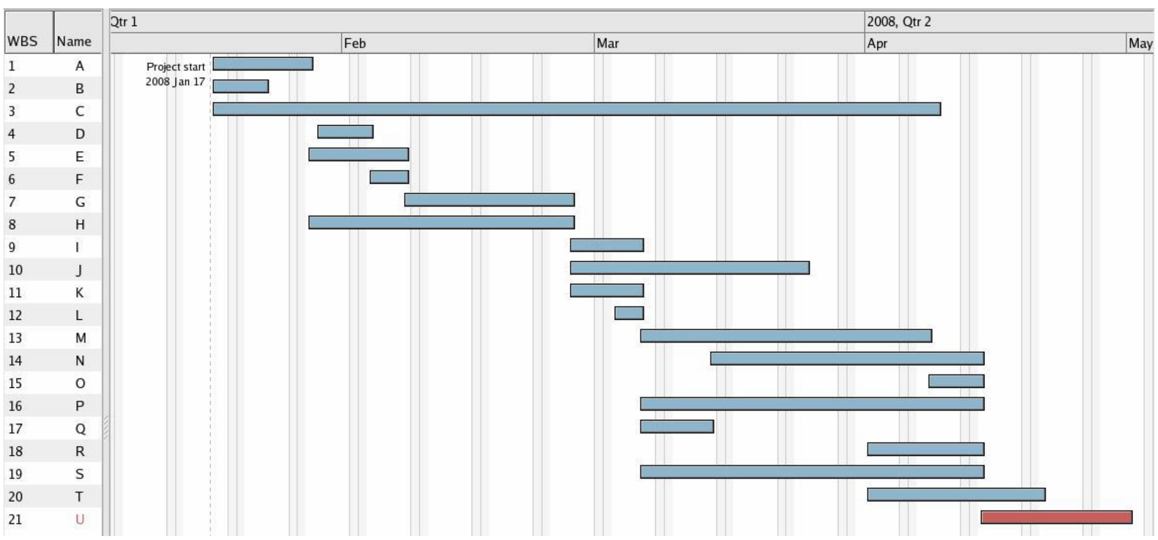

Figure 1

8. References

- Khisty, C. J. and J. Mohammadi. Fundamentals of Systems Engineering with Economics, Probability and Statistics. Prentice Hall, September 2000.
- Swarthmore College Facilities Management Department, Swarthmore, PA