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Control Charts for First Order Autoregressive Analysis with An Exogenous Variable

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CONTROL CHARTS FOR FIRST ORDER AUTOREGRESSIVE ANALYSIS WITH AN EXOGENOUS VARIABLE

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by
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ABSTRACT

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There are many instances in industry, where the necessity of prediction models is extremely important. However, the difficulty of forecasting increases with the number of variables involved, and determining independent variables from dependent variables. Autocorrelation is one of the most common causes for many control charts and other quality measurement tools to falsely signal an error in the process. Time series models, such as autoregressive models, accommodate autocorrelated data to a certain extent. However, using a model that only analyzes historical data alone does not possess the accuracy necessary to be able to forecast data precisely. An addition of an independent variable into an AR(1) model will increase the accuracy by noting how correlated the two variables are and using that value in order to correct the previous errors. Likelihood functions will aid in the derivation of the model. The results will develop a new robust control chart.

DEDICATION

The completion of my master's studies would not have been possible without the love and support of my family. My mother, Maria E. Vela, my father, Eliazar Vela, and my brother, Isaac Vela, wholeheartedly inspired, motivated and supported me by all means to accomplish this degree. Thank you for your love and patience.

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INTRODUCTION

Statistical process control is a key element in any type of quality analysis of a process or system. To perform any type of statistical analysis on a sample data set, a group of assumptions must always be made about the data set under investigation. Typically, models assume the data to be normally distributed with a system of independent variables that are uncorrelated over time. However, many processes in reality do not display these inherent characteristics that are almost always assumed. Autocorrelated data displays the characteristics that a variable is correlated with itself over time. Once this occurs, the process is no longer independently distributed. Several studies have been conducted with methods of controlling this type of data.

Autocorrelated data should not be monitored with “traditional” SPC techniques, based upon the assumption of independent observations. Autocorrelated data can adversely affect the performance of traditional control charts, such as Shewhart control charts. A study has been conducted, Lu and Reynolds [12], that shows the adverse conditions autocorrelated data can place on a control chart, such as extremely tight control limits, which will cause several false alarms in the monitoring process. False alarms cause negative value for a company, consisting of wasted funds, materials, and labor. This type of data needs to be handled correctly before being placed in any type of control chart, and also before being implemented into any type of forecasting model as well.

Autoregressive models provide a remedy to the effects of autocorrelated data, with the ability to only examine the residuals of all the historical data being examined. This allows the raw data to be differenced into residuals, which eliminate the correlation effect. However, autoregressive models typically only use a single dependent variable in order to conduct its analysis. Only using the historical data for one single variable presents a problem when forecasting future data. Allowing for the addition of a second independent variable, which significantly influences the variable being investigated, will utilize the correlation between the two to better predict future points.

In this research, a new model will be developed that extends the first order autoregressive model. An independent variable will be added to the model, known as an exogenous variable. This exogenous variable should be correlated with the dependent variable under investigation. Once this model has been constructed, a demonstration will be applied to ERCOT load data as the dependent variable and Houston temperature as the exogenous variable. A new control chart will be applied to this case to demonstrate the amount of accuracy achieved in signal detection, with the aid of this added variable.

CHAPTER I

LITERARY REVIEW

AR and ARX Models

Data Correlation

Autocorrelation of data is one of the major causes of false alarms when using traditional control charts. Autocorrelation is defined as the correlation within a sequence of observations over a period of time from a specific process. However, the type of correlation seen in the weather data that will later be presented in this paper, that is known as cross correlation. Cross-correlation is defined as the correlation detected between two different variables. We present that there will be a cross-correlation between weather characteristics. It can be stated that there is a relationship between temperature and amount of energy used across the state to power air conditioners; the higher the temperature, the higher the power consumption. This relationship is easily detected intuitively, however when attempting to predict temperature changes and how much electricity will be consumed is a much more difficult task at hand [13]. Figure 1 shows a graphical demonstration of how data can be seen as autocorrelated.

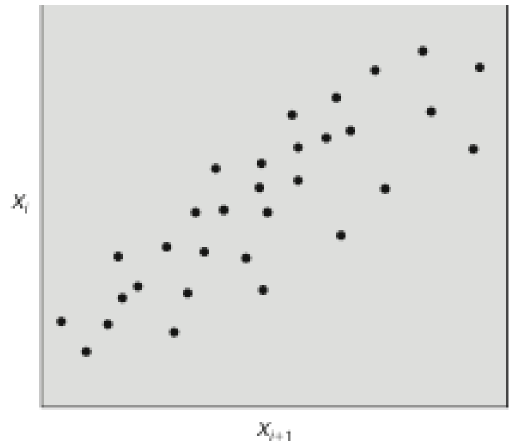


Figure 1 - Graph of Correlated Data [14]

Notice that there is a visual relationship between data points. Detection of a non-random process is crucial to determining if a process is autocorrelated. This can be indicated by the pattern in a basic graphical representation of the amount of observations being investigated; containing a mean value these observations should abide by. If there are consecutive points above the average followed by consecutive points below the average, and does not display an erratic motion between consecutive points, this shows that the process is non random [13]. This is the first step to proving that a data set has any type of correlation. Figure 1 illustrates positive correlation between data points. This is done through the continuous plotting of an observation at time (t) against an observation from the period before at time (t-1). If a slope line can be fitted to this data with few extreme outliers. This indicates that there is a strong positive relationship through the data, meaning a positive autocorrelation [13].

The amount of autocorrelation can also be calculated through an analysis based on the autocorrelation function:

$$\rho_k = \frac{Cov(x_t, x_{t-k})}{V(x_t)} \qquad k = 0,1,... \tag{1}$$

where $Cov(x_t, x_{t-k})$ is the covariance of observations that are k time periods apart. Also, the assumption that the observations have a constant variance, $V(x_t)$ [13]. This technique can be used when attempting to analyze time-oriented data sets that are deterministic based on the time this sample was taken. Another technique of measuring the amount of autocorrelation is to shorten the analysis by taking a sample of data:

$$r_k = \frac{\sum_{t=1}^{n-k}(x_t - \bar{x})(x_{t-k} - \bar{x})}{\sum_{t=1}^{n}(x_t - \bar{x})^2} \qquad k = 0, 1,... \tag{2}$$

Creating a sample autocorrelation analysis provides a simpler method, which only utilizes the mean and individual data points. However, statistical programs such as Minitab, or R can calculate these values and create a graphical analysis visually displaying the amount of autocorrelation.

Graphical representation can be read by the being able to notice the relationship between the value of sample autocorrelation and the lag value corresponding to the control limits generated by the model. Lag is defined at the amount of time between two consecutive data points. The control limits are determined by the standard deviation from the data, which are used to find any amount of autocorrelation in the data. If any value of the sample autocorrelation exceeds the upper or lower control limit, this indicates that there is a presence of correlation in the data. If the autocorrelation exceeds the upper limit, it is positive autocorrelation. Exceeding the lower limit indicates negative autocorrelation. Figure 2 shows an autocorrelation analysis graph with upper and lower control limits, depicts the type of correlations occurring in a data set. This graphical analysis also aids in determining the type of autoregressive technique should be used, i.e. AR(1), AR(2), etc [13].

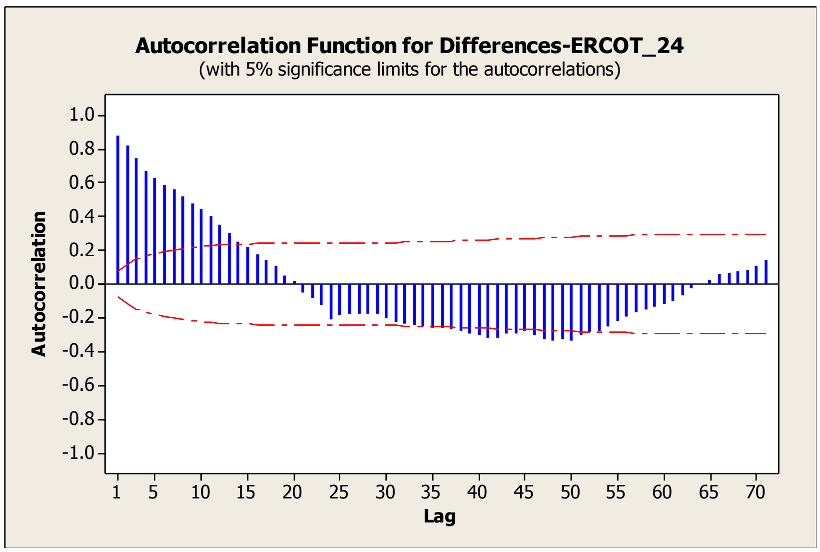


Figure 2 - Graph of Autocorrelated Data

This autocorrelation must be accommodated for from process data, because these relationships between data points could inherit a proper analysis of whether or not the process is in statistical control or not. Consequently, there are several techniques to the removal of this undesired characteristic. These techniques include, time series models such as first-order and second-order autoregressive models [13].

Time-Series Model

Time series modeling is one of many techniques used in order to eliminate the amount of autocorrelated data within a process. This approach generally consists of the procedure of assigning the correct time series model, removing the autocorrelated data, and applying a control chart to the resulting residuals generated by the time series model selected [13].

Residuals are referred to as "the difference between the actual data point and the value that would be generated from a least squares fit of the underlying analysis of variance model to the sample data." This type of residual analysis assumes that the model errors are normally and independently distributed with a mean of zero along with a standard deviation of σ. Also known as the "one-step-ahead prediction errors," residuals are heavily used in the field of statistical process control, in order to improve the results of control charts for autocorrelated processes [3]. The equation to calculate the residual is presented below [13].

$$e_{ij} = y_{ij} - \hat{y}_{ij} \tag{3}$$

There are several different types of time series models that can be utilized in multiple scenarios. The most common would be in the area of autoregressive analysis, which consists of an AR(1) model, along with the introduction of a modified autoregressive model with the addition of an exogenous variable to an AR(1) model. This newly developed model is referred to as an ARX model.

Autoregressive Model (AR(1))

An autoregressive model is also referred to as the Markov process. This model is used to create an autoregressive process of the *p*th order incorporating a random process [Z_1], with a mean of zero and variance of σ_Z^2 [5]. This term is purely random in regards that the correlation factor between any two points at any period in time will always be zero [2]. The equation for a standard autoregressive model of *p*th order is presented below.

$$X_t = \alpha_1 X_{t-1} + \cdots + \alpha_p X_{t-p} + Z_1 \qquad (4)$$

For this model, the process of X_t is not based on independent variables with in the analysis; however, this process is based on historical values of X_t. The term *auto*regressive indicates these characteristics of being dependent on past values [5]. Selecting coefficients for each of the variables included in an autoregressive model is determined by the selection of the order of the model. The order of an autoregressive model can range from $p\leq0$. If an autoregressive model has a *p* value of zero, then that simple means that the constant value in the model will be equal to zero. However, if the value of *p* increases for different models, that constant variable gains a coefficient.

A first order-order autoregressive model is typically utilized to examine the autocorrelated data in a time series process. A first-order autoregressive model will be denoted by the abbreviation of AR(1). An AR(1) model has an order of p=1. The equation that will be used throughout this analysis is shown below.

$$x_t = \delta + \phi x_{t-1} + \varepsilon_t \qquad (5)$$

The different parameters used in this model can be defined as the following. ε_t is a random variable that is independent and normally distributed random variable with a mean of 0 and variance of σ^2. The parameter δ represents the location of parameter of the autoregressive model. Lastly, the parameter ϕ serves that the autoregressive coefficient [18]. The autoregressive coefficient contains characteristics that indicate certain types of behavior. If $|\phi|<1$, this means that observations are actually fluctuating around the mean of the model [2]. As the order of the autoregressive model increases, the number of x_{t-1} variables starts to increase, which causes the need for further coefficient determination.

AR(1) model are used in several applications in prediction data, which the use of historical data as an input variable. Meteorological variables are heavily used with this type of model. Any kind of meteorological variable can be taken in terms of observation per hour, that will have a positively correlated relationship over a long period of time [4]. When analyzing a large sample size of meteorological data, it is crucial to fit the correct AR model to the behavior of the data. If the data only has one dependent variable and no other variable contributing to the behavior to the data, the selection begins with an AR(1), and will progress to a larger order with the addition of extra variables in the historical data.

Other characteristics of AR models are also taken into account for the examination of non-stationary data. Standard AR models are occasionally used to depict the "space-time evolution" of meteorological data. The meteorological data typically used in these types of models is wind speed data. Also, this type of model can be used to describe the "motions of objects that translate at a constant speed". However, when examining all types of meteorological data, several other independent factors come into model that must be handles carefully when generating the model [6].

Exogenous Variables (ARX Model)

Incorporating an external variable that directly influences and is correlated with the input variable is known as an exogenous variable. There are two different types of variables in an autoregressive model, exogenous and endogenous variables. Exogenous is described above, however, its behavior is best described as variables that affect a system but are not affected themselves [5]. This means that this variable is considered independent when it interacts with other possible variables. Also, an endogenous variable refers to variables that interact with each other and have the possibility of directly affecting each other [5]. This dictates that these are the dependent variables in the model.

For example, when handling meteorological data and trying to determine how much electricity is being consumed by an entire region, there are several parameters that influence the total amount of electricity. Factors such as temperature, barometric pressure, humidity, etc; these all affect the amount of electricity a region will consume. If the temperature is too high, more air conditioners are turned on. There is a direct effect on the electricity load [endogenous variable], while the temperature stays completely independent [exogenous variable].

When considering the addition of an exogenous variable in an autoregressive model, several aspects must be examined prior to the selection of an outside independent variable. Especially determining which factors can be directly related to the initial dependent variable data that's being analyzed. However, first a basic model of the formula must be generated prior to the selection of the actual data. The equation for an AR(1) process with the addition of an exogenous variable is presented below.

$$x_t = \delta + \phi x_{t-1} + \beta u_{t-1} + \varepsilon_t \tag{6}$$

This is the same model formula as the previous section, however an addition variable [u] with its coefficient [β] is necessary. Once again, the variable u_{t-1} is independent from the historical data that will be used for the input variable x_{t-1} [20]. Also, when determining the characteristics of the model, the coefficient β must be calculated as well. The same behavioral characteristics apply to the autoregressive coefficient of the endogenous variable.

The most suitable method of estimating model parameters for an ARX model is to use a maximum likelihood function. The purpose of the maximum likelihood function is to derive the model parameters that will "maximize the probability that the data came from this model" [19]. The probability density function is necessary for this process to proceed. The probability function describes the shape and behavior of the failure distribution involved with this data. Knowing the type of behavior, allows for a more accurate measurement of the parameters needed to fit the correct ARX model [7]. This experiment has a model that has a Gaussian white noise effect, which allows us to select the correct derivation for the probability density function. In the case of linear models, this derivation must be handled in a state-space form, which uses the Kalman predictor. This predictor will work independently from the white noise generated in the Gaussian distribution [19].

ARX models are considered to be deterministic in comparison to the standard AR(1) model. A model with deterministic features allows for it to counteract the "unpredictable" variations in the forecasting model [16]. There are also some very distinct advantages to using a ARX model. First, the extrapolation of the recursive process beyond any observation period can extend without an increase in random and systematic errors as the amount of time observed increases. Also, calibration of this prediction model can be performed very accurately not matter how long or short the observation period is [16]. The overall goal of the addition of the extra exogenous variable is to gain a more accurate prediction model for future data. If this model can precisely calculate the amount of correlation between the two variables, and determine the amount this exogenous variable actually affects the endogenous variable, each prediction will increase in accuracy each time.

Control Charts for AR and ARX Models

Control Charts for Autocorrelated Data

Autocorrelated data is heavily seen in data samples that have several variables controlling the output of a situation. However, when handling the results of a prediction model, the results must be evaluated over a new period of time. A Shewhart control chart is generated to evaluate the results. A control is defined as "a technique of statistical process control, which revolves around the plots of averages of measurements of a quality characteristic in samples from the process observed over time" [19]. Each control chart has features such as a centerline, upper control limit, and lower control limit [13]. These features are depicted below in Figure 3.

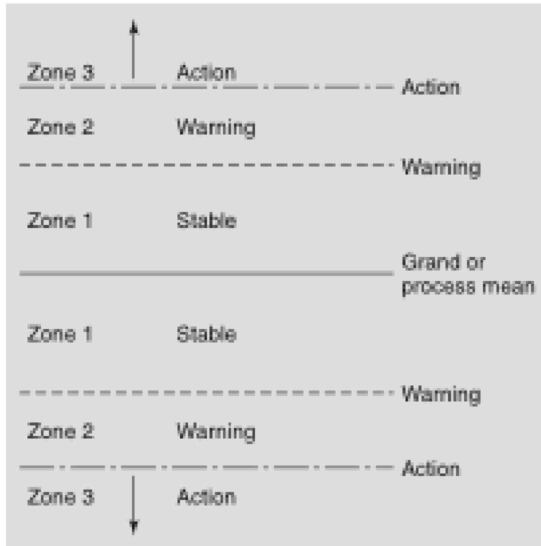


Figure 3 - Control Chart Features [14]

This tool allows for the monitoring of any process. This monitoring uses the control chart's upper and lower control limits as barriers by which each observation point must not exceed either limit. As long as the observation being examined at a specific period in time is within the limits, the process is considered to be "in statistical control" [14]. An analogy of a traffic light is often used in this situation. When observation values are between the control limits the process can proceed; the light is green. However, when observations start getting relatively close to the upper or lower control limit, the observer must direct their attention to the process carefully; the light is yellow. Lastly, if a point exceeds either control limit, the observation point is considered to be "out of statistical control." The observer must halt the process and carefully examine the cause of this observation and generate a solution; the light is red [14]. This is the general concept of the functionality of a Shewhart control chart; however, there are several types of control charts that are developed to observe different types of data, such as autocorrelated data.

These typical control charts were developed with the assumption that it is meant to examine observation points at varying times are independent random variables. Unfortunately, autocorrelated data does not display those types of characteristics; this type of data is very dependent on historical data points [12]. There are several types of effects that can occur by using traditional control charts with autocorrelated data. First, it can produce a negative bias in the use of traditional estimators of the process standard deviation. This causes the control limits of the chart to be must closer together than originally desired. Combining the two attributes, autocorrelated data along with tight control limits, this will cause several false readings of the control chart. False readings will cause the observer to assume that there is an error in the process causing this reading, however there is actually nothing wrong [12].

Several approaches have been attempted throughout literature in order to correct this error being generated by autocorrelated data. The optimal solution is to generate a control chart that is referred to as a CUSUM Chart. This control chart is solemnly based on the residuals calculated from a process along with the average run length [12]. These concepts will be examined further in the following sections.

Average Run Length

In order to gain a full understanding of the performance of a any control chart, an explanation of average run length must be completed. Average run length can be defined as the expected number of observations needed by a control chart in order to generate a signal that the process has become out of statistical control [12]. This technique is consistently used to measure the performance of a control chart. The relationship between the average run length and signal is optimal when the average run length is as short as possible. This means that the control chart used the least amount of time in order to detect an error in the process. However, when dealing with false alarms in a process while it is in statistical control, it is desirable to have a large average run length [12].

CUSUM Control Chart

A CUSUM control chart, or know as Cumulative Sum, is defined as a technique that utilizes all of the historical data when plotting residuals. This allows for closely examining small but persistent changes along with changes in trend [18]. The method used to generate a CUSUM control chart is by plotting the cumulative sums of the deviations of the sample values from a target value. This formula is divided into two CUSUMs, which are presented below.

$$\begin{aligned} C_i^+ &= \max\left[0,\ x_i - \left(\mu_0 + K\right) + C_{i-1}^+\right] \\ C_i^- &= \max\left[0,\ \left(\mu_0 - K\right) + C_{i-1}^-\right] \end{aligned} \qquad (7)$$

This pair of equations is referred to as “one-sided upper and lower cusums”. Each take the max value generated by accumulating the derivations from the target value, μ_0, that are either above, C^+, or below, C^-, this target value. Each equation contains a variable K, which is known as the reference value, or slack value. This value is chosen as the midpoint between the target value and what is considered to be out of control. Once these values are calculated, the CUSUM chart can be constructed. The result will appear relatively similar to the CUSUM chart below.

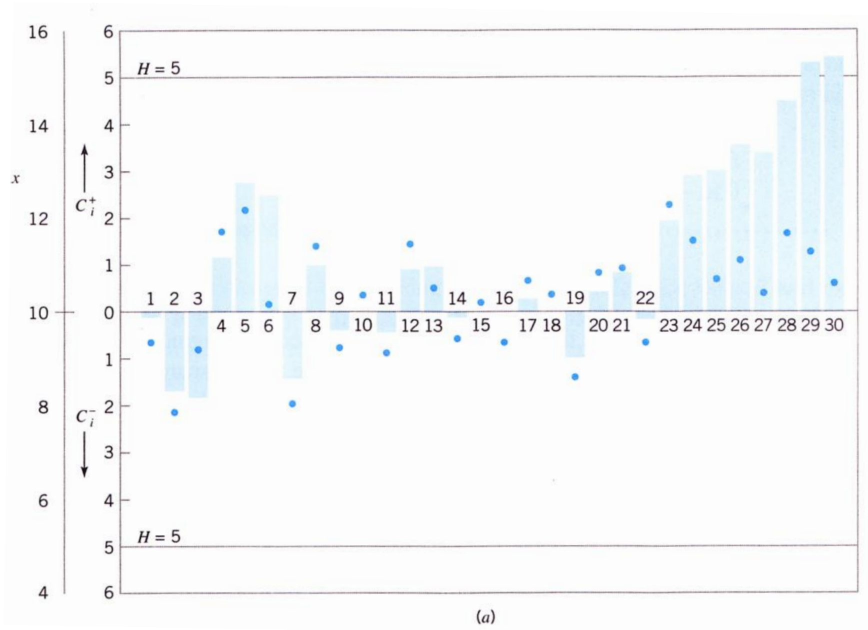


Figure 4 - CUSUM Control Chart [13]

Now, that the general concepts of a CUSUM control chart have been examined, this type of control chart can now be applied to an experiment that is centralized around an AR(1) process. As mentioned above, an AR(1) model handles processes that are heavily influenced by autocorrelated data. The parameter from the AR(1) under investigation is the location parameter, δ, as well as the change point, which will be denoted by ψ. The importance of the change point is this the point in time where the control chart has signaled an out of control observation [19].

The derivation of the change point method relying on a series of hypothesis tests that allow the determination whether there has been a change in the process or not. A study has been performed in the literature, *The development and evaluation of CUSUM-based control charts for an AR(1) process*, and the results will indicate that a CUSUM chart can be constructed from hypothesis testing, along with a development of likelihood functions [19]. Ultimately, the goal of deriving a CUSUM control chart specifically for an AR(1) process is to be able to generate a solution for the problem stemming from the change point occurring within the process [19].

CHAPTER II

DERIVATION

A robust control chart has been previously derived by Dr. Timmer in "A Magnitude-Robust Control Chart for the Level Parameter of an AR(1) Process" [17]. However, an extra variable is added to its original AR(1) model. In order to derive the control chart for determining if a process is in statistical control or not, the equation must be derived from an AR(1) process. The AR(1) process is defined below in equation (8).

$$x_t = \delta + \phi x_{t-1} + \beta u_{t-1} + \varepsilon \tag{8}$$

First, the expected value for each the mean and variance must be calculated. The expected value of the variance will determine the equation of the standard deviation used for the derivation of the control chart. The mean, Equation 9, and standard deviation, Equation 10, are shown below.

$$\mu = \frac{\delta + \beta u_{t-1}}{(1-\phi)} \tag{9}$$

$$\sigma_x^2 = \frac{\sigma_\varepsilon^2}{(1-\phi^2)} \tag{10}$$

Case 1: Monitoring δ

Initially In-Control State

The AR(1) process is assumed to start in statistical control, with $\delta=\delta_0$. Once T observations has been completed, the null hypothesis is defined as $\delta=\delta_0$ for $1 \leq t \leq T$. The alternative hypothesis will state that the process first started in statistical control but contains a change point [τ] and created an out of control process, where $\delta=\delta_a$ for $(\tau+1) \leq t \leq T$.

The likelihood functions for the null and alternative hypotheses are necessary to construct the likelihood ratio test. The null hypothesis likelihood function is below.

$$L_0(x) = (2\pi\sigma_\varepsilon^2)^{-\frac{T}{2}}(1-\phi^2)^{1/2} \times \tag{11}$$
$$exp\left[\frac{-1}{2\sigma_\varepsilon^2}(1-\phi^2)\left(x_1 - \frac{\delta_0 - \beta u_{i-1}}{1-\phi}\right)^2\right]\prod_{i=1}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta_0 - \phi x_{i-1} - \beta u_{i-1})^2\right]$$

The likelihood function for the alternative function is below.

$$L_a(\tau, \delta_1|x) = (2\pi\sigma_\varepsilon^2)^{-\frac{T}{2}}(1-\phi^2)^{1/2} \times exp\left[\frac{-1}{2\sigma_\varepsilon^2}(1-\phi^2)\left(x_1 - \frac{\delta_0 - \beta u_{i-1}}{1-\phi}\right)^2\right] \tag{12}$$
$$\prod_{i=2}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta_0 - \phi x_{i-1} - \beta u_{i-1})^2\right]\prod_{i=\tau+1}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta_a - \phi x_{i-1} - \beta u_{i-1})^2\right]$$

The likelihood ratio of L_0 and L_a is

$$R(\tau, \delta_a, x) = log_e\left[\frac{L_a((\tau, \delta_a|x))}{L_0(x)}\right] \tag{13}$$
$$= \frac{1}{2\sigma_\varepsilon^2}\left[\sum_{i=\tau+1}^{T}(x_i - \delta_0 - \phi x_{i-1} - \beta u_{i-1})^2 - \sum_{i=\tau+1}^{T}(x_i - \delta_a - \phi x_{i-1} - \beta u_{i-1})^2\right]$$

For a fixed value of τ, the result for δ_a that maximizes (13) is:

$$\hat{\delta}_a(\tau) = \bar{\delta}_{T,\tau} = \frac{1}{T-\tau}\sum_{i=\tau+1}^{T}\left(x_i - \phi x_{i-1} - \beta u_{i-1}\right) \quad for \quad \tau > 0 \tag{14}$$

Substituting (14) for δ_a in (13), the results for the likelihood ration are below.

$$R\left(\tau, \hat{\delta}_a(\tau)\middle|x\right) = \frac{1}{2\sigma_\varepsilon^2}(T-\tau)\left[\bar{\delta}_{T,\tau} - \delta_0\right]^2 \tag{15}$$

For each observation T, the maximum of the log likelihood ratio is:

$$R_T = R\left(\hat{\tau}, \hat{\delta}_a(\hat{\tau})\middle|x\right) = \max_{1\le\tau\le T} R\left(\tau, \hat{\delta}_a(\tau)\middle|x\right) \tag{16}$$

Initially Out-of-Control State

For the instance where a process begins out of statistical control, the null hypothesis likelihood function will remain the same equation. However, for the change point equation, the alternative hypothesis likelihood function must be modified.

$$L_a(\tau, \delta_a|x) = (2\pi\sigma_\varepsilon^2)^{-\frac{T}{2}}(1-\phi^2)^{1/2} \times exp\left[\frac{-1}{2\sigma_\varepsilon^2}(1-\phi^2)\left(x_1 - \frac{\delta_a - \beta u_{i-1}}{1-\phi}\right)^2\right] \times \tag{17}$$

$$\prod_{i=2}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta_a - \phi x_{i-1} - \beta u_{i-1})^2\right]$$

The likelihood ratio is:

$$R(\tau, \delta_a, x) = log_e\left[\frac{L_a((\tau, \delta_a|x))}{L_0(x)}\right] \tag{18}$$

$$= \frac{1}{2\sigma_\varepsilon^2}\left[\begin{array}{l}\left[(1-\phi^2)\left(x_1 - \dfrac{\delta_o - \beta u_{i-1}}{1-\phi}\right)^2 + \displaystyle\sum_{i=2}^{T}(x_i - \delta_0 - \phi x_{i-1} - \beta u_{i-1})^2\right] \\ -\left[(1-\phi^2)\left(x_1 - \dfrac{\delta_a - \beta u_{i-1}}{1-\phi}\right)^2 + \displaystyle\sum_{i=2}^{T}(x_i - \delta_a - \phi x_{i-1} - \beta u_{i-1})^2\right]\end{array}\right]$$

The same procedure used to find (14) is used to find the $\hat{\delta}_a$ for the case of τ=0.

$$\hat{\delta}_a(0) = \bar{\delta}_{T,0} = \frac{(1-\phi)}{T-\phi T+2\phi}\left[(\phi+1)\left(x_1 - \frac{\beta u_{i-1}}{1-\phi}\right) + \sum_{i=2}^{T}(x_i - \phi x_{i-1} - \beta u_{i-1})\right] \quad (19)$$

The maximum likelihood function estimator for $\hat{\delta}_a$ is:

$$\hat{\delta}_a(\tau) = \bar{\delta}_{T,t} = \begin{cases} \frac{(1-\phi)}{T-\phi T+2\phi}\left[(\phi+1)\left(x_1 - \frac{\beta u_1}{1-\phi}\right) + \sum_{i=2}^{T}(x_i - \phi x_{i-1} - \beta u_{i-1})\right] & \tau = 0 \\ \frac{1}{T-\tau}\sum_{i=\tau+1}^{T}(x_i - \phi x_{i-1} - \beta u_{i-1}) & 0 \le \tau \le T \end{cases} \quad (20)$$

A general formula for R(τ, δ_a|x) is constructed by substituting (19) into (18) and reducing the result. The formulas for R(τ, δ_a|x) for all values of τ are presented below.

$$R\left(\tau,\ \hat{\delta}_a(\tau) \mid x\right) = \begin{cases} \frac{T-\phi T+2\phi}{2(1-\phi)\sigma_\varepsilon^2}\left(\bar{\delta}_{T,0} - \delta_0\right)^2 & \tau = 0 \\ \frac{T-\tau}{2\sigma_\varepsilon^2}\left(\bar{\delta}_{T,\tau} - \delta_0\right)^2 & 0 < \tau < T \end{cases} \quad (21)$$

The maximum likelihood estimate of the change point is:

$$\hat{\tau} = arg \max_{0<t<T} R(t, \hat{\delta}(t)|x) \quad (22)$$

Case 2: Monitoring β

Initially In-Control State

This procedure is the same steps above, however, this time the solution will be in terms of beta, which is the exogenous term. The assumption taken is that the process will commence in statistical control until the change point occurs. The null hypothesis likelihood function is presented below.

$$L_0(x) = (2\pi\sigma_\varepsilon^2)^{-\frac{T}{2}}(1-\phi^2)^{1/2} \times \tag{23}$$

$$exp\left[\frac{-1}{2\sigma_\varepsilon^2}(1-\phi^2)\left(x_1 - \frac{\delta - \beta_0 u_{i-1}}{1-\phi}\right)^2\right]\prod_{i=1}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta - \phi x_{i-1} - \beta_0 u_{i-1})^2\right]$$

The alternative hypothesis likelihood function shows the occurrence of a change point where the process indicates it is out of statistical control. The alternative hypothesis likelihood function is shown below.

$$L_a(\tau, \beta_1|x) = (2\pi\sigma_\varepsilon^2)^{-\frac{T}{2}}(1-\phi^2)^{1/2} \times exp\left[\frac{-1}{2\sigma_\varepsilon^2}(1-\phi^2)\left(x_1 - \frac{\delta-\beta_0 u_{i-1}}{1-\phi}\right)^2\right] \tag{24}$$

$$\prod_{i=2}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta - \phi x_{i-1} - \beta_0 u_{i-1})^2\right]\prod_{i=\tau+1}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta - \phi x_{i-1} - \beta_a u_{i-1})^2\right]$$

The likelihood ratio of L_a to L_0 is:

$$R(\tau, \beta_a, x) = log_e\left[\frac{L_a((\tau,\beta_a|x))}{L_0(x)}\right] \tag{25}$$

$$= \frac{1}{2\sigma_\varepsilon^2}\left[\sum_{i=\tau+1}^{T}(x_i - \delta - \phi x_{i-1} - \beta_0 u_{i-1})^2 - \sum_{i=\tau+1}^{T}(x_i - \delta - \phi x_{i-1} - \beta_a u_{i-1})^2\right]$$

For a fixed value of τ, the result for β_a that maximizes (25) is:

$$\hat{\beta}_a = \bar{\beta}_{T,\tau} = \left(\frac{1}{u_{i-1}T - u_{i-1}\tau}\right)\sum_{i=\tau+1}^{T}(x_i - \delta - \phi x_{i-1}) \tag{26}$$

Substituting (26) for β_a in (25), the results for the likelihood ration are below.

$$R(\tau, \hat{\beta}_a(\tau)|x) = \frac{1}{2\sigma_\varepsilon^2}(T-\tau)\left[u_{i-1}\bar{\beta}_{T,\tau} - u_{i-1}\beta_0\right]^2 \tag{27}$$

For each observation T, the maximum of the log likelihood ratio is:

$$R_T = R\left(\hat{\tau}, \hat{\beta}_a(\hat{\tau})\middle|x\right) = \max_{1 \le \tau \le T} R\left(\tau, \hat{\beta}_a(\tau)\middle|x\right) \qquad (28)$$

Initially Out-of-Control State

For the instance where a process begins out of statistical control, the null hypothesis likelihood function will remain the same equation. However, for the change point equation, the alternative hypothesis likelihood function must be modified.

$$L_a(\tau, \beta_a|x) = (2\pi\sigma_\varepsilon^2)^{-\frac{T}{2}}(1-\phi^2)^{1/2} \times exp\left[\frac{-1}{2\sigma_\varepsilon^2}(1-\phi^2)\left(x_1 - \frac{\delta - \beta_a u_{i-1}}{1-\phi}\right)^2\right] \times \prod_{i=2}^{T} exp\left[\frac{-1}{2\sigma_\varepsilon^2}(x_i - \delta - \phi x_{i-1} - \beta_a u_{i-1})^2\right] \qquad (29)$$

The likelihood ratio is:

$$R(\tau, \beta_a, x) = log_e\left[\frac{L_a((\tau, \beta_a|x))}{L_0(x)}\right] \qquad (30)$$

$$= \frac{1}{2\sigma_\varepsilon^2}\left[\begin{array}{l}\left[(1-\phi^2)\left(x_1 - \frac{\delta - \beta_0 u_{i-1}}{1-\phi}\right)^2 + \sum_{i=2}^{T}(x_i - \delta - \phi x_{i-1} - \beta_0 u_{i-1})^2\right] \\ -\left[(1-\phi^2)\left(x_1 - \frac{\delta - \beta_a u_{i-1}}{1-\phi}\right)^2 + \sum_{i=2}^{T}(x_i - \delta - \phi x_{i-1} - \beta_a u_{i-1})^2\right]\end{array}\right]$$

The same procedure used to find (26) is used to find the β_a for the case of τ=0.

$$\hat{\beta}_a(0) = \bar{\beta}_{T,0} = \left[\frac{(1-\phi)}{u_{i-1}(T - \phi T + 2\phi)}\right]\left[(\phi+1)\left(\frac{\delta}{1-\phi} - x_1\right) - \sum_{i=2}^{T}(x_i - \delta - \phi x_{i-1})\right] \qquad (31)$$

The maximum likelihood function estimator for $\hat{\delta}_a$ is:

$$\hat{\beta}_a(\tau) = \bar{\beta}_{T,\tau} = \begin{cases} \left[\dfrac{(1-\phi)}{u_{i-1}(T-\phi T+2\phi)}\right]\left[(\phi+1)\left(\dfrac{\delta}{1-\phi}-x_1\right)-\sum_{i=2}^{T}\left(x_1-\delta-\phi x_{i-1}\right)\right] & \tau = 0 \\ \left(\dfrac{1}{u_{i-1}T-u_{i-1}\tau}\right)\sum_{i=\tau+1}^{T}\left(x_i-\delta-\phi x_{i-1}\right) & 0<\tau<T \end{cases} \quad (32)$$

A general formula for R(τ, β_a|x) is constructed by substituting (31) into (30) and reducing the result. The formulas for R(τ, β_a|x) for all values of τ are presented below.

$$R\left(\tau,\ \hat{\beta}_a(\tau)\mid x\right) = \begin{cases} \dfrac{(u_{i-1})^2(T-\phi T+2\phi)}{2(1-\phi)\sigma_\varepsilon^2}\left[\bar{\beta}_{T,0}-\beta_0\right]^2 & \tau = 0 \\ \dfrac{(T-\tau)}{2\sigma_\varepsilon^2}\left[u_{i-1}\bar{\beta}_{T,\tau}-u_{i-1}\beta_0\right]^2 & 0<\tau<T \end{cases} \quad (33)$$

The maximum likelihood estimate of the change point is:

$$\hat{\tau} = \arg\max_{0\le\tau<T} \frac{(T-\tau)}{2\sigma_\varepsilon^2}\left[u_{i-1}\bar{\beta}_{T,\tau}-u_{i-1}\beta_0\right]^2 \quad (34)$$

CHAPTER III

MODEL ANALYSIS

Sample Data

The sample data necessary for this experiment needed to possess the characteristics of correlation in order to be able to select an exogenous variable. Electrical load data is constantly exposed to multiple factors that change its outcome. It is intuitive that electrical load data increases or decreases when weather changes. Correlations such as electrical loads increase during summer because the temperature outside increases and many homes are forced to utilize their central air conditioning units more frequently. These types of correlations will be used in this experiment as we utilize the electronic load data from a region in Texas.

ERCOT is known as the Electrical Reliability Council of Texas, and this organization operates and regulates the electronic grid across the state of Texas. ERCOT regulates the flow of electricity to over 85% of the state [1]. With regulating these flows, this organization documents all electricity consumption of the state, divided into different regions. Shown below is the regional map that ERCOT divides its documentation [1].

Figure 5 - Texas ERCOT Electricity Market Zones

This map depicts four different regions that ERCOT regulates electric flow, and these regions are further dissected in their electricity consumption data, which was also found on their archives. The region of interest for this experiment is the Houston Region. This region was selected on the criteria that this is a small and condensed region that is not divided into multiple sub-regions in ERCOT's consumption data. This makes the consumption data manageable and allows for the research of historical weather data for the only major city in this region. The hourly electricity load data for 2011 is found at archive website [9]. This electricity load data can be found in Appendix I.

Since electric load data was given in hourly increments for the entire year of 2011, the data set must be trimmed in order to make it more manageable and eliminate the chance of false alarms in correlation. Since the correlation factor of weather was presented earlier, this is the relationship that will be used when attempting to generate an exogenous variable. Intuitively, one can note that during the summer time in the state

Texas, temperatures rise along with humidity, which causes residents to consume more electricity for their central air conditioning and other appliances needed during the summer since a larger portion of the household is home more often as well. This notable case allows us to select a month's worth of data during the summer time, since this direct correlation exists. The month of June 2011 was selected for this experiment.

Now that the raw data for electricity consumption has been found, the exogenous variable for our experiment must be found. Historical weather data for the city of Houston, TX was found in the archives of a weather documenting website for the year 2011[8]. This archive presents data for multiple aspects of what weather consists of, such as, temperature, humidity, pressure, wind speed, dew point, wind direction, etc. However, for this experiment the variables with the most consistent and steady data will be submitted for analysis. The selected variables will be temperature, humidity, pressure and dew point. All of these variables have been known to play a role in determining the forecast of electricity consumption. Each one of these variables will be submitted to a time series analysis to select which characteristic will serve as the optimal exogenous variable. The hourly historical weather data for the city of Houston, TX can be found in Appendix I.

Data Transformation

Prior to conducting any type of time series analysis on these data sets, the data must be a stationary process with no patterns. This step is necessary in order to further eliminate any false alarms in correlation. A differencing technique can be used with a lag of 24 hours. The equation developed for this data set is shown below.

$$\hat{x}_i = \sum_{n=25}^{696} x_i - x_{i-24} \quad (35)$$

This equation represents the differencing in data that allows the examination of differenced values as opposed to raw data values. Hour 1 of June 1, 2011 is subtracted from Hour 1 or June 2, 2011, and continuing the process until the full data has been differenced, which is why the summation is done until the 696th data point. This data set will be utilized for the remainder of the analysis.

Model Selection

The selection of a value for lag in a time series analysis is crucial, because this indicates instantaneous value that produces the best vector regression results. The control chart model derived in the Derivation portion is based on an AR(1) model with a lag of 1. Having this initial model, a lag must be selected for the raw historical electricity load data. For this experiment, the lag for the electricity load data will be identical to the lag in which the control model was created by.

However, a lag must be selected for the remaining variables in this model. These lags will not be identical to those of the control chart model. They will be selected by means of one of two techniques. The first method involves the use of the cross correlation values. The second method utilizes descriptive statistics to select the best fitting model.

Method I

In terms of selecting a specific lag for each variable in this vector regression analysis, the data must be examined and different correlations must be generated.

Generating a cross correlation creates a relationship between historical electricity load data and historical weather data. A cross correlation must be created for each pairing, which will be:

1. Load Data vs. Temperature
2. Load Data vs. Humidity
3. Load Data vs. Pressure
4. Load Data vs. Dew Point

These cross correlations were generated using Minitab, and generated correlation values for a series of 36 lags, both in the positive and negative direction. The purpose for examining the value for correlation is, because the lag with the highest correlation value will be selected as the specific lag that will be used in the proceeding autoregressive analysis. These correlations values indicate how closely related each weather characteristic is to the load data. Ultimately, the highest correlated weather characteristic will be used in the following analysis, as it will aid in generating better forecasting data.

After each cross correlation was conducted, the following results were recorded in Figure 6. The information presented below shows each weather characteristic with its corresponding lag selection and correlation value. The full cross correlation analysis is located in Appendix I.

		Largest Correlation	Lag	Abs. Largest Correlations	Order of Correlation
Δ Load	**Δ Temperature**	**0.36656**	**-4**	**0.36656**	**2**
Δ Load	Δ Humidity	-0.255973	-7	0.255973	4
Δ Load	Δ Dew Pt	0.354869	3	0.354869	3
Δ Load	**Δ Pressure**	**-0.369813**	**-7**	**0.369813**	**1**

Figure 6 - Cross Correlation Results

According the absolute value of each correlation value, the two most correlated weather characteristics are temperature and pressure. However, since the correlation value between the two characteristics is close, they are considered interchangeable. For this instance of weather analysis, the variable of temperature is more intuitively relatable to the increase and decrease in electricity consumption as opposed to pressure. Now that it is noted that temperature will be presented as the most correlated characteristic, this weather characteristic has proven to be the best fit for the exogenous variable in this analysis.

Method II

An alternate method to selecting a specific lag for this vector regression model, involves the generation of new descriptive statistics. The lag selection was generated in Gretl, shown in Figure 7 and 8, which uses three closely related criterions in order to select the best fitting model. The three criterions are:

1. Akaike criterion
2. Schwarz Bayesian criterion
3. Hannan-Quinn criterion

Each of these criterions contributes beneficial information for the selection of the correct model. This lag selection analysis will be performed for each variable in this experiment; load data, temperature, and pressure. These are the only variables being tested due to correlation values. Figure 7 shows the results from calculations performed in Gretl.

gretl: VAR lag selection

VAR system, maximum lag order 12

The asterisks below indicate the best (that is, minimized) values of the respective information criteria, AIC = Akaike criterion, BIC = Schwarz Bayesian criterion and HQC = Hannan-Quinn criterion.

lags	loglik	p(LR)	AIC	BIC	HQC
1	-1283.47005		3.758684*	3.771924*	3.763808*
2	-1283.10789	0.39474	3.760549	3.780409	3.768234
3	-1282.85404	0.47613	3.762731	3.789210	3.772978
4	-1281.83666	0.15374	3.762680	3.795779	3.775489
5	-1281.80315	0.79573	3.765506	3.805225	3.780876
6	-1279.04454	0.01883	3.760364	3.806703	3.778296
7	-1278.82306	0.50569	3.762641	3.815599	3.783134
8	-1278.26772	0.29193	3.763941	3.823519	3.786996
9	-1278.23670	0.80332	3.766774	3.832972	3.792391
10	-1277.87652	0.39602	3.768645	3.841463	3.796823
11	-1275.61803	0.03356	3.764965	3.844403	3.795705
12	-1274.86521	0.21980	3.765688	3.851745	3.798990

Figure 7 - Lag Selection Results for Temperature data

gretl: VAR lag selection

VAR system, maximum lag order 12

The asterisks below indicate the best (that is, minimized) values of the respective information criteria, AIC = Akaike criterion, BIC = Schwarz Bayesian criterion and HQC = Hannan-Quinn criterion.

lags	loglik	p(LR)	AIC	BIC	HQC
1	1916.73505		-5.598640	-5.585401*	-5.593517
2	1918.64300	0.05077	-5.601295*	-5.581436	-5.593610*
3	1918.64653	0.93300	-5.598382	-5.571902	-5.588135
4	1920.21531	0.07651	-5.600045	-5.566946	-5.587236
5	1920.23180	0.85587	-5.597169	-5.557450	-5.581799
6	1921.58076	0.10048	-5.598189	-5.551851	-5.580258
7	1921.58879	0.89911	-5.595289	-5.542330	-5.574795
8	1921.58903	0.98255	-5.592366	-5.532787	-5.569310
9	1923.13698	0.07849	-5.593968	-5.527770	-5.568351
10	1924.62628	0.08437	-5.595398	-5.522580	-5.567220
11	1925.28421	0.25133	-5.594398	-5.514960	-5.563658
12	1925.36596	0.68596	-5.591713	-5.505656	-5.558412

Figure 8 - Lag Selection Results for Pressure Data

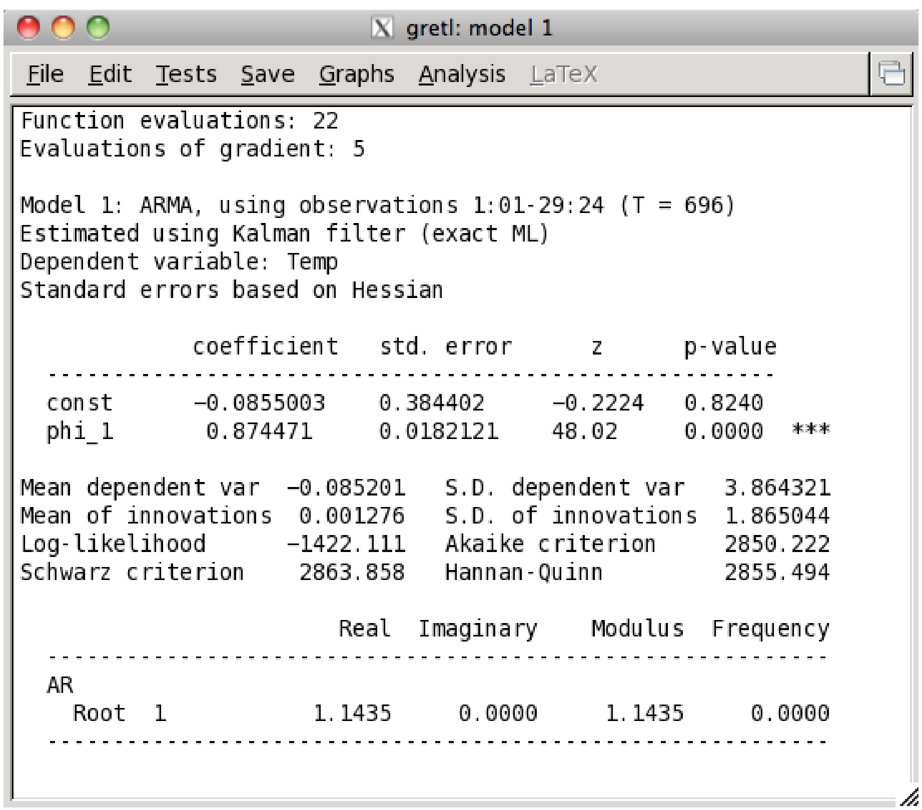
Figure 8 shows results from the Gretl analysis indicate that the lag selection for temperature should be lag 1 and the lag selection for pressure should be lag 2. These results do not exactly coincide with that of the cross correlation method; however, one method must be selected. Since method I executes its analysis utilizing the amount cross-correlation detected between the load data and each independent variable, this technique will be selected in determining the model.

Autoregressive Models

Once the lag selection is completed, a first order autoregressive model is generated with regards to the delta temperature data. The differenced data is used for this analysis, because to reduce the amount of autocorrelation in the results following the analysis. Two different autoregressive models are generated for this experiment, with and without the use of an exogenous variable. The first case presented is the typical first-order autoregressive analysis using only the temperature data as the dependent variable. The second case will have the addition of the exogenous variable, so the model will contain both the delta load data, as the dependent variable, along with the delta temperature data, as the independent variable.

Autoregressive Analysis without Exogenous Variable

The first analysis performed in Gretl is a standard first-order autoregressive analysis with the use of the delta temperature. The lag selected for this analysis is going to be 1, because this is an analysis to see this how this data behaves. Another outcome of this analysis is to obtain the optimal coefficients for this first-order autoregressive model. The analysis was performed in Gretl, and the results are presented below.


gretl: model 1

File Edit Tests Save Graphs Analysis LaTeX

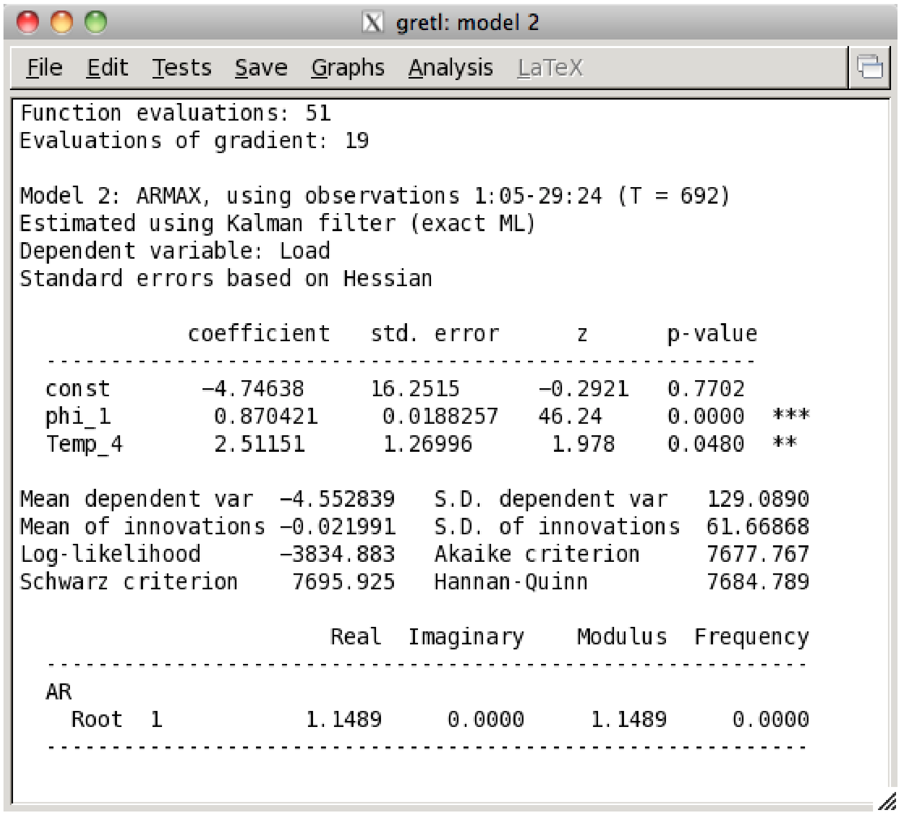
```
Function evaluations: 22
Evaluations of gradient: 5

Model 1: ARMA, using observations 1:01-29:24 (T = 696)
Estimated using Kalman filter (exact ML)
Dependent variable: Temp
Standard errors based on Hessian

             coefficient   std. error      z      p-value
  -------------------------------------------------------
  const      -0.0855003    0.384402     -0.2224   0.8240
  phi_1       0.874471     0.0182121    48.02     0.0000  ***

Mean dependent var  -0.085201   S.D. dependent var   3.864321
Mean of innovations  0.001276   S.D. of innovations  1.865044
Log-likelihood      -1422.111   Akaike criterion     2850.222
Schwarz criterion    2863.858   Hannan-Quinn         2855.494

                        Real  Imaginary    Modulus  Frequency
  -----------------------------------------------------------
  AR
    Root  1           1.1435     0.0000     1.1435     0.0000
  -----------------------------------------------------------
```

Figure 9 - Gretl Results of AR(1) Model without Exogenous Variable

The coefficients obtained from this model are presented in the coefficients column for both the constant and phi. These values will be compared to the coefficients generated in the second model, which includes the exogenous variable, and how the exogenous variable affects the values.

Autoregressive Analysis with Exogenous Variable

A second autoregressive model generated includes an exogenous variable (delta temperature) along with the delta load data. This exogenous variable is also the delta temperature data. Both of these data sets are inputted into the autoregressive model, only this model will include the lag values selected prior to the generation of the model. The load data lag will be 1 and the temperature data lag will be -4. These lags are chosen as the time period that these data sets have the largest correlation with each other. The analysis incorporates that specific time period when generating the new model coefficients. Gretl was used to perform this analysis and the results are presented below.



```
gretl: model 2
File  Edit  Tests  Save  Graphs  Analysis  LaTeX
Function evaluations: 51
Evaluations of gradient: 19

Model 2: ARMAX, using observations 1:05-29:24 (T = 692)
Estimated using Kalman filter (exact ML)
Dependent variable: Load
Standard errors based on Hessian

             coefficient   std. error      z      p-value
  --------------------------------------------------------
  const       -4.74638     16.2515      -0.2921   0.7702
  phi_1        0.870421     0.0188257   46.24     0.0000   ***
  Temp_4       2.51151      1.26996      1.978    0.0480   **

Mean dependent var   -4.552839   S.D. dependent var   129.0890
Mean of innovations -0.021991   S.D. of innovations  61.66868
Log-likelihood      -3834.883   Akaike criterion     7677.767
Schwarz criterion    7695.925   Hannan-Quinn         7684.789

                        Real  Imaginary    Modulus  Frequency
  -----------------------------------------------------------
  AR
    Root  1           1.1489     0.0000     1.1489     0.0000
  -----------------------------------------------------------
```

Figure 10 - Gretl Results for ARX Model

The results present a group of new coefficients that are different that those of the previous analysis, also with the addition of the coefficient for the exogenous variable of temperature. These coefficients will also be utilized in the ARX model developed for a simulation that will generate results using this model.

Analysis of Average Run Length Performance

In order to determine the performance of the new ARX model constructed in the previous section, a simulation must be performed. The simulation in this experiment is used to in order to analyze the performance of the average run length of the model. The average run length refers to the number of observations accumulated before an observation performs outside of the control limits, which causes a signal. However, several simulated observations must be generated in order to gain an understanding of how the control chart is behaving with the constructed ARX model. The method of generating a large amount of data is done through a parallel program developed through the use of software called JPPF.

JPPF is software that allows for a system of tasks to act in parallel through a number of computers. This allows for a number of applications to be running at the same time, which can ultimately save a sufficient amount of time needed to perform an analysis. The applications that are running in parallel are referred to as nodes. The JPPF software serves as a central hub where the information generated in each hub in organized and generates results in the manner of one single machine. The final output will be used in the final analysis of the control chart performance. Below is a pictorial that illustrates how the JPPF infrastructure is organized [10].

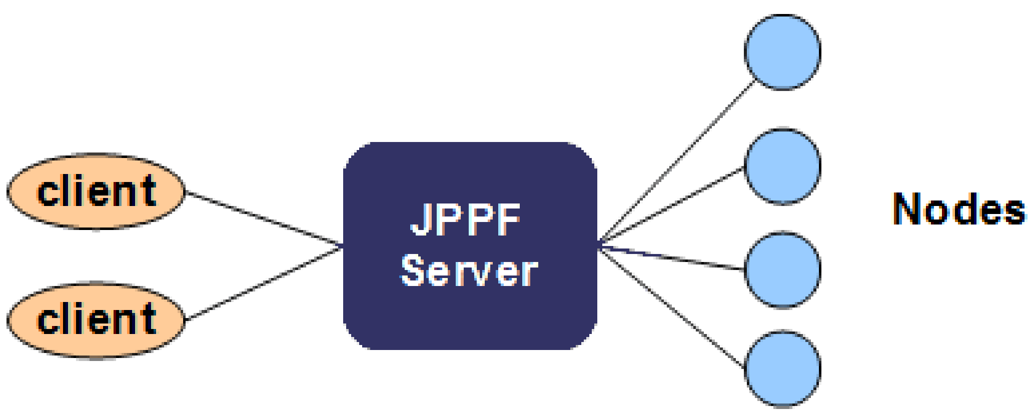


Figure 11 - JPPF Infrastructure [10]

With the addition of using parallel desktops, which allows to run several machines on one computer, allows JPPF to run simultaneously through those virtual machines. An analysis that could have taken a time period of weeks, only needed days per simulation. Each observation contains a specific amount of sub-observations that contribute to the total sample size for the entire simulation.

There are two different simulations that will be performed for this ARX model, on-target and off-target. Each simulation will contain its own parameters and value of n, which will accumulate to sum up the entire sample size, which will be different for each of the simulations. Information for each of these simulations can be found in Appendix I. In the next sections, descriptions of each simulation will be presented, along with the results.

On-Target Analysis

This analysis presents the scenario that the situation of the data set is that it is already assumed to be in control and the control chart will proceed from that starting point. Since the process is on-target, or in control, there will not be any simulated shifts within the control chart. The parameters used in this analysis will be phi (ϕ), which is the autoregressive coefficient and B, which is the size of the control chart. The values for phi are -0.9, -0.6, -0.3, 0, 0.3, 0.6, 0.9. The values for B are 30, 100, 300, 1000, 3000.03. The varying values of phi and B create a total of 35 different combinations of the two parameters. The total amount of observations is 700, however these observations are groups into increments of 10 observations in order to group together the generated data for each time phi changes value. Also the simulation was developed with 2 replicates, so each replicate has a total of 350 observations.

The analysis generates values of the run length and run length squared. Each observation has its own value of run length and run length squared. Grouping the output data into groups of 10 not only allows for each observation to have a sample size of 10,000 instead of 100, but it allows to create an average run length and variance for each grouped observation. The calculation of these values will aid in creating a control chart equation. The equations for the average run length and variance are presented below in Equation 36 and Equation 37.

$$ARL = \frac{\sum_{i=1}^{n} x_i}{n} \quad (36) \qquad S^2 = \frac{\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}}{n-1} \quad (37)$$

These calculations will be performed every 10 observations and each final value will be placed into a new excel spreadsheet that will have all the values for 70 observations. Along with those values a column containing the natural logarithm of the average run length will be added, which will be utilized in the next section. The calculated values are presented in Table 1.

Table 1 - Output Data from On-Target Analysis

n	B	arl	arl_var	ln(ARL)
10000	3	27.1254	678.7598748	3.300470558
10000	3	27.4231	723.6392864	3.311385724
10000	3	27.0778	693.7745472	3.298714204
10000	3	27.8549	743.716846	3.327008893

10000	3	27.6089	708.4223408	3.318138185
10000	3	27.0171	682.8326076	3.296469999
10000	3	27.6536	712.088607	3.319755918
10000	4	60.9886	3477.61247	4.110686961
10000	4	62.6533	3917.134299	4.137616354
10000	4	60.301	3322.946799	4.099348687
10000	4	61.9886	3629.43947	4.126950497
10000	4	62.8596	3903.681488	4.140903668
10000	4	60.606	3506.424364	4.104393898
10000	4	62.2427	3704.825397	4.131041259
10000	5	130.6961	16428.90114	4.872874781
10000	5	134.044	17026.15706	4.898168104
10000	5	133.1788	16620.25183	4.891692586
10000	5	134.0998	17692.12064	4.898584299
10000	5	132.9418	16897.09381	4.889911438
10000	5	131.0218	16160.58192	4.875363722
10000	5	133.4371	17228.54944	4.893630206
10000	6	284.925	76813.62758	5.652225988
10000	6	277.9273	73526.43281	5.627359569
10000	6	282.003	73562.02019	5.641917709
10000	6	282.8595	75661.33336	5.644950308
10000	6	289.5844	76865.51028	5.668446792
10000	6	277.7323	75970.44964	5.6266577
10000	6	280.1397	73856.27058	5.635288407
10000	7	575.0717	312019.1024	6.354494729
10000	7	592.2017	335455.6786	6.383847286
10000	7	585.2287	339793.0892	6.372002711
10000	7	586.4735	343469.1485	6.374127484
10000	7	586.2948	336019.2149	6.373822735
10000	7	578.1428	309917.067	6.359820897
10000	7	580.9452	335845.7562	6.364656432
10000	8	1174.8693	1297992.492	7.068912186
10000	8	1170.3284	1282313.143	7.065039672
10000	8	1158.9477	1241448.577	7.055267717
10000	8	1191.7748	1344205.808	7.083198904
10000	8	1172.7222	1291016.201	7.067082992
10000	8	1176.4654	1352188.068	7.070269798
10000	8	1167.0406	1269012.102	7.062226422
10000	9	2287.5587	4806487.745	7.735240458
10000	9	2257.5899	4707452.642	7.722053107
10000	9	2310.4754	4808405.604	7.745208583
10000	9	2309.7856	4852232.825	7.744909985
10000	9	2295.7127	4836020.203	7.738798619
10000	9	2321.652	5072252.706	7.75003428
10000	9	2316.1785	4982141.671	7.747673908
10000	3	27.2551	706.202624	3.30524066
10000	3	27.4887	726.7902723	3.313775011

10000	3	26.912	662.768856	3.292572284
10000	3	27.6407	708.5206035	3.319289324
10000	3	27.4189	681.1984228	3.311232557
10000	3	27.4703	719.3393179	3.313105421
10000	3	27.065	672.066575	3.29824138
10000	4	62.09	3611.0201	4.128584945
10000	4	61.7746	3598.221395	4.123492277
10000	4	61.5886	3650.42455	4.120476788
10000	4	62.3012	3647.430079	4.131980687
10000	4	62.7275	3763.836844	4.138799948
10000	4	61.3423	3494.346731	4.116469654
10000	4	62.6007	3831.21286	4.13677646
10000	5	133.6055	17635.19227	4.894891428
10000	5	133.4639	16956.2541	4.893831029
10000	5	132.3054	16860.83853	4.885112887
10000	5	132.2152	16746.91069	4.884430898
10000	5	135.2855	17712.84219	4.90738736
10000	5	134.4271	17301.67269	4.901022045
10000	5	130.829	16596.13516	4.873891127
10000	6	282.0947	76707.70793	5.64224283
10000	6	283.3606	75245.45397	5.646720291
10000	6	280.7787	77685.18953	5.637566815
10000	6	286.172	76531.31662	5.656593029
10000	6	287.0658	75658.06607	5.659711458
10000	6	278.8682	74926.04723	5.630739269
10000	6	279.0433	75126.89643	5.631366967
10000	7	581.6858	327303.4013	6.365930439
10000	7	571.1199	298147.6105	6.34759917
10000	7	580.5416	323801.1985	6.363961461
10000	7	585.525	327153.5418	6.372508881
10000	7	593.1216	336984.6978	6.385399437
10000	7	584.5171	316736.6479	6.370786036
10000	7	573.8093	315361.8829	6.352297111
10000	8	1178.0496	1344595.196	7.071615469
10000	8	1178.54	1273373.192	7.072031663
10000	8	1188.1511	1310289.85	7.08015368
10000	8	1174.9059	1330313.321	7.068943338
10000	8	1180.029	1337659.403	7.073294293
10000	8	1192.3236	1313049.726	7.083659287
10000	8	1162.091	1288410.021	7.057976248
10000	9	2286.5675	4939938.029	7.734807064
10000	9	2308.8257	4892911.11	7.744494319
10000	9	2281.2767	5016436.331	7.732490521
10000	9	2276.3234	4824691.027	7.730316877
10000	9	2327.8733	5002111.321	7.752710383
10000	9	2318.5892	4941403.095	7.748714176
10000	9	2310.2241	5009399.552	7.745099812

ANOVA – On-Target Analysis

An analysis of variance is performed on the output data of the simulation in order to see which parameters are statistically significant, and which parameters can be omitted entirely from the model. However, to abide by the characteristics of an ANOVA analysis, the natural logarithm of the average run length will be used as the response variable. The model will consist of the replicate, phi, B, and the interaction of phi*B. The replicate parameter will be considered a random variable in the ANOVA model as well. The ANOVA analysis was constructed in Minitab and the results are presented below.

General Linear Model: ln(ARL) versus Replicate, B, Phi

Factor	Type	Levels	Values
Replicate	random	2	0, 1
B	fixed	7	3, 4, 5, 6, 7, 8, 9
Phi	fixed	7	-0.9, -0.6, -0.3, 0.0, 0.3, 0.6, 0.9

Analysis of Variance for ln(ARL), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Replicate	1	0.0001	0.0001	0.0001	0.57	0.453
B	6	213.6879	213.6879	35.6146	381611.23	0.000
Phi	6	0.0025	0.0025	0.0004	4.52	0.001
B*Phi	36	0.0037	0.0037	0.0001	1.10	0.376
Error	48	0.0045	0.0045	0.0001		
Total	97	213.6986				

S = 0.00966059 R-Sq = 100.00% R-Sq(adj) = 100.00%

Figure 12 - ANOVA Results - On-Target Analysis

This analysis produces p-values for each parameter in the model and according to the values; B and ϕ are statistically significant parameters with a p-value of ≈ 0.000. These parameters are used when constructing a control chart equation based on the natural logarithm of the average run length. Table 2 shows the values for the average run length in correspondence to the different parameter combinations.

Table 2 - ARL Values for Statistically Significant Parameters

B	ϕ						
	-0.9	-0.6	-0.3	0	0.3	0.6	0.9
3	27.19025	27.4559	26.9949	27.7478	27.5139	27.2437	27.3593
4	61.5393	62.21395	60.9448	62.1449	62.79355	60.97415	62.4217
5	132.1508	133.754	132.7421	133.1575	134.1137	132.7245	132.1331
6	283.5099	280.644	281.3909	284.5158	288.3251	278.3003	279.5915
7	578.3788	581.6608	582.8852	585.9993	589.7082	581.33	577.3773
8	1176.459	1174.434	1173.549	1183.34	1176.376	1184.395	1164.566
9	2287.063	2283.208	2295.876	2293.055	2311.793	2320.121	2313.201

A linear regression analysis will be used to generate this equation. Linear regression will develop the necessary coefficients for the constant as well as B for the calculation of ln(ARL). This analysis is performed in Minitab, with ln(ARL) as the response variable with B as the predictor. The results are presented below.

Regression Analysis: ln(ARL) versus B, Phi

```
The regression equation is
ln(ARL) = 1.16 + 0.738 B + 0.00141 Phi


Predictor       Coef    SE Coef       T      P
Constant     1.16427    0.01509   77.18  0.000
B           0.737976   0.002385  309.40  0.000
Phi         0.001412   0.007951    0.18  0.859


S = 0.0472237   R-Sq = 99.9%   R-Sq(adj) = 99.9%


Analysis of Variance

Source          DF      SS      MS         F      P
Regression       2  213.49  106.74  47865.39  0.000
Residual Error  95    0.21    0.00
Total           97  213.70
```

Figure 13 - Linear Regression Results - On-Target Analysis

These results show that final equation for the relationship between ln(ARL) and *B* is ln(ARL) = 1.16 + 0.738B + 0.00141ϕ. This equation will be used to generate the final equation for the control chart, in term of *B*, which again dictates the size of the control chart. The equation will be solved for *B*, which will serve as an estimate of *B* for all input data of ln(ARL). The equation for *B* is presented below.

$$\hat{B} = \frac{\ln(ARL) - 0.00141\phi - 1.16}{0.738} \quad (38)$$

Off-Target Analysis

This simulation presents the scenario that the situation of the data set is that it is already assumed to be out of control and the control chart will proceed from that starting point. Since the process is off-target, or out of control, there will be simulated shifts within the control chart. The parameters used in this simulation will be phi (ϕ), which is the autoregressive coefficient and B, which is the size of the control chart, and d, which is the size of the shift occurring in the control chart. The values for phi are -0.9, -0.6, -0.3, 0, 0.3, 0.6, 0.9. The values for B are 30, 100, 300, 1000, 3000.03. The values for d are 6, 5, 4, 3, 2, and 1. The varying values of phi, B, and d create a total of 82 different combinations of the two parameters. The total amount of observations is 1,680, however these observations are groups into increments of 10 observations in order to group together the generated data for each time the size of the shift changes value. Also the simulation was developed with 2 replicates, so each replicate has a total of 840 observations.

The simulation generates values of the run length and run length squared. Each observation has its own value of run length and run length squared. Grouping the output data into groups of 10 not only allows for each observation to have a sample size of 1,000 instead of 10, but it allows to create an average run length and variance for each grouped observation. The calculation of these values will aid in creating a control chart equation. The equations for the average run length and variance are presented in Equation 36 and Equation 37.

These calculations will be performed every 10 observations and each final value will be placed into a new excel spreadsheet that will have all the values for 168 observations. Along with those values a column containing the natural logarithm of the average run length will be added, which will be utilized in the next section. The calculated values are presented in Table 3.

Table 3 - Output Data from Off-Target Analysis

B	Phi	Shift	n	ARL	ARL_VAR	LN(ARL)
3	-0.9	3	10000	1.2775	-0.74590625	0.244905043
3	-0.9	2	10000	2.0092	0.16531536	0.697736633
3	-0.9	1.5	10000	2.8992	2.20483936	1.064434837
3	-0.9	1	10000	5.0031	12.19609039	1.61005772
3	-0.9	0.5	10000	11.5264	97.14630304	2.444640057
3	-0.9	0.25	10000	19.9144	329.8328726	2.991443088
3	-0.6	3	10000	1.2806	-0.74093636	0.247328718
3	-0.6	2	10000	2.0113	0.18737231	0.698781279
3	-0.6	1.5	10000	2.912	2.208256	1.06884013
3	-0.6	1	10000	4.9978	11.59599516	1.608997816
3	-0.6	0.5	10000	11.6292	97.65050736	2.453519177
3	-0.6	0.25	10000	19.3503	316.7419899	2.962707923
3	-0.3	3	10000	1.2832	-0.74080224	0.249356958
3	-0.3	2	10000	2.0128	0.23423616	0.699526788
3	-0.3	1.5	10000	2.9353	2.27111391	1.076809663
3	-0.3	1	10000	4.9693	11.86815751	1.603278985
3	-0.3	0.5	10000	11.6358	97.53935836	2.454086552
3	-0.3	0.25	10000	19.5974	337.4965132	2.975396904

3	0	3	10000	1.1483	-0.74607001	0.138282588
3	0	2	10000	1.8058	0.13424671	0.591003707
3	0	1.5	10000	2.937	2.409231	1.077388652
3	0	1	10000	4.9676	11.54835024	1.602936826
3	0	0.5	10000	11.5269	97.28587639	2.444683434
3	0	0.25	10000	19.8587	339.5639343	2.988642198
3	0.3	3	10000	1.2693	-0.74782249	0.238465567
3	0.3	2	10000	2.0081	0.17203439	0.697189001
3	0.3	1.5	10000	2.8949	2.18465399	1.062950568
3	0.3	1	10000	4.9767	11.86815711	1.604767021
3	0.3	0.5	10000	11.4365	93.41096775	2.436809995
3	0.3	0.25	10000	19.4391	322.7842912	2.967286502
3	0.6	3	10000	1.2822	-0.73643684	0.248577353
3	0.6	2	10000	1.9876	0.13744624	0.686927881
3	0.6	1.5	10000	2.9077	2.24858071	1.067362391
3	0.6	1	10000	4.9911	12.07002079	1.607656326
3	0.6	0.5	10000	11.568	96.068376	2.448242665
3	0.6	0.25	10000	19.6428	331.2598082	2.977710859
3	0.9	3	10000	1.2792	-0.74035264	0.246234883
3	0.9	2	10000	2.0068	0.19995376	0.696541414
3	0.9	1.5	10000	2.9177	2.32732671	1.070795635
3	0.9	1	10000	5.0164	12.06693104	1.612712545
3	0.9	0.5	10000	11.5366	93.51626044	2.44552459
3	0.9	0.25	10000	19.6671	334.8840776	2.978947189
4	-0.9	3	10000	1.4552	-0.60680704	0.375143348
4	-0.9	2	10000	2.4126	0.62136124	0.880705004
4	-0.9	1.5	10000	3.6674	3.78417724	1.299482964
4	-0.9	1	10000	6.5197	18.37601191	1.874828363
4	-0.9	0.5	10000	17.2458	194.1807824	2.847568636
4	-0.9	0.25	10000	35.2998	1028.85972	3.563877298
4	-0.6	3	10000	1.4565	-0.59909225	0.376036297
4	-0.6	2	10000	2.447	0.663591	0.894862784
4	-0.6	1.5	10000	3.6788	3.79263056	1.302586612
4	-0.6	1	10000	6.6568	19.52261376	1.895638889
4	-0.6	0.5	10000	17.2145	196.4262898	2.845752052
4	-0.6	0.25	10000	34.8263	983.8743283	3.550372848
4	-0.3	3	10000	1.4494	-0.61636036	0.371149678
4	-0.3	2	10000	2.419	0.645839	0.883354232
4	-0.3	1.5	10000	3.6482	3.69363676	1.294233895
4	-0.3	1	10000	6.5882	19.12782076	1.88528017
4	-0.3	0.5	10000	17.3376	197.6572262	2.852877553
4	-0.3	0.25	10000	35.6804	1030.570856	3.574601518
4	0	3	10000	1.4452	-0.60960304	0.36824772
4	0	2	10000	2.4458	0.64166236	0.894372268
4	0	1.5	10000	3.647	3.642591	1.293904912
4	0	1	10000	6.6358	19.23755836	1.892479233
4	0	0.5	10000	17.4114	193.71635	2.857125164

4	0	0.25	10000	351828	1001.556984	12.7708977
4	0.3	3	10000	1.4544	-0.60827936	0.374593444
4	0.3	2	10000	2.4483	0.68872711	0.895393906
4	0.3	1.5	10000	3.645	3.563175	1.293356365
4	0.3	1	10000	6.6252	19.68752496	1.89088056
4	0.3	0.5	10000	16.9031	191.8825104	2.827497037
4	0.3	0.25	10000	35.1692	1002.113371	3.5601707
4	0.6	3	10000	1.4536	-0.62155296	0.374043238
4	0.6	2	10000	2.4301	0.66391399	0.887932409
4	0.6	1.5	10000	3.6702	3.86763196	1.300246156
4	0.6	1	10000	6.6578	20.07309916	1.8957891
4	0.6	0.5	10000	17.3822	202.0491232	2.855446694
4	0.6	0.25	10000	35.0881	992.9325384	3.557862042
4	0.9	3	10000	1.4495	-0.61795025	0.371218669
4	0.9	2	10000	2.4514	0.67883804	0.89665929
4	0.9	1.5	10000	3.6464	3.75276704	1.29374038
4	0.9	1	10000	6.68	19.5198	1.899117988
4	0.9	0.5	10000	17.2754	193.2927548	2.849283524
4	0.9	0.25	10000	35.0325	1019.489644	3.556276202
5	-0.9	3	10000	1.6528	-0.47894784	0.502470819
5	-0.9	2	10000	2.8846	1.10528284	1.059386242
5	-0.9	1.5	10000	4.4487	5.36016831	1.492611919
5	-0.9	1	10000	8.4187	29.22839031	2.130455422
5	-0.9	0.5	10000	23.9696	330.9076758	3.176786361
5	-0.9	0.25	10000	56.6666	2365.403844	4.037184972
5	-0.6	3	10000	1.6529	-0.48857841	0.502531321
5	-0.6	2	10000	2.8745	1.19614975	1.055878746
5	-0.6	1.5	10000	4.4305	5.38636975	1.488512445
5	-0.6	1	10000	8.2963	27.58850631	2.115809632
5	-0.6	0.5	10000	23.9562	341.5954816	3.176227163
5	-0.6	0.25	10000	56.8252	2355.716245	4.039979889
5	-0.3	3	10000	1.6527	-0.47871729	0.502410314
5	-0.3	2	10000	2.8871	1.24255359	1.060252538
5	-0.3	1.5	10000	4.4443	5.10349751	1.491622376
5	-0.3	1	10000	8.3652	27.17362896	2.124080243
5	-0.3	0.5	10000	24.0739	322.6214388	3.181128266
5	-0.3	0.25	10000	55.0993	2241.62444	4.009137012
5	0	3	10000	1.6503	-0.48259009	0.50095709
5	0	2	10000	2.917	1.237711	1.070555691
5	0	1.5	10000	4.4658	5.51543036	1.49644837
5	0	1	10000	8.327	27.546871	2.119503247
5	0	0.5	10000	23.967	340.508511	3.176677884
5	0	0.25	10000	56.0644	2358.390053	4.02650103
5	0.3	3	10000	1.65	-0.4893	0.500775288
5	0.3	2	10000	2.8989	1.20447879	1.064331355
5	0.3	1.5	10000	4.443	5.233551	1.491329824
5	0.3	1	10000	8.3857	28.31233551	2.126527874

5	0.3	0.5	10000	23.9775	323.0111938	3.177115891
5	0.3	0.25	10000	56.7691	2453.329185	4.038992164
5	0.6	3	10000	1.6528	-0.49154784	0.502470819
5	0.6	2	10000	2.9001	1.20851999	1.064745219
5	0.6	1.5	10000	4.4497	5.41186991	1.492836678
5	0.6	1	10000	8.2838	28.24005756	2.1143018
5	0.6	0.5	10000	23.8523	335.4468847	3.171880649
5	0.6	0.25	10000	56.6215	2327.194438	4.036388772
5	0.9	3	10000	1.6681	-0.47965761	0.511685254
5	0.9	2	10000	2.8725	1.08684375	1.055182731
5	0.9	1.5	10000	4.4605	5.39143975	1.495260867
5	0.9	1	10000	8.3857	27.39833551	2.126527874
5	0.9	0.5	10000	23.7379	326.3446036	3.167072927
5	0.9	0.25	10000	56.4872	2312.984236	4.034014064
6	-0.9	3	10000	1.8805	-0.35698025	0.631537699
6	-0.9	2	10000	3.345	1.637975	1.207466694
6	-0.9	1.5	10000	5.2445	6.85311975	1.657179908
6	-0.9	1	10000	10.1888	37.07575456	2.321289078
6	-0.9	0.5	10000	30.6889	484.0949168	3.423901026
6	-0.9	0.25	10000	82.5487	4389.828028	4.413388422
6	-0.6	3	10000	1.8578	-0.36082084	0.619392992
6	-0.6	2	10000	3.3425	1.66719375	1.20671903
6	-0.6	1.5	10000	5.2981	7.09863639	1.667348266
6	-0.6	1	10000	10.153	36.890391	2.317769228
6	-0.6	0.5	10000	31.3394	490.8394076	3.444876092
6	-0.6	0.25	10000	82.3734	4392.627972	4.411262569
6	-0.3	3	10000	1.8565	-0.36129225	0.618692995
6	-0.3	2	10000	3.3662	1.68209756	1.213784512
6	-0.3	1.5	10000	5.2573	7.13809671	1.659617587
6	-0.3	1	10000	10.1663	37.73544431	2.319078329
6	-0.3	0.5	10000	30.7061	474.2975228	3.424461332
6	-0.3	0.25	10000	81.7132	4328.154146	4.403215556
6	0	3	10000	1.844	-0.370536	0.611937125
6	0	2	10000	3.3643	1.76518551	1.213219918

The rest of the output data for the off-target analysis is located in Appendix I.

ANOVA – Off-Target Analysis

An analysis of variance is performed on the output data of the simulation in order to see which parameters are statistically significant, and which parameters can be omitted entirely from the model. However, to abide by the characteristics of an ANOVA analysis, the natural logarithm of the average run length will be used as the response variable. The model will consist of the replicate, phi, B, d, and the interaction of phi*B, B*Shift, Phi*Shift, B*Phi*Shift. The replicate parameter will be considered a random variable in the ANOVA model as well. The ANOVA analysis was constructed in Minitab and the results are presented below.

General Linear Model: LN(ARL) versus Replicate, B, Phi, Shift

```
Factor     Type    Levels  Values
Replicate  random       2  0, 1
B          fixed        7  3, 4, 5, 6, 7, 8, 9
Phi        fixed        7  -0.9, -0.6, -0.3, 0.0, 0.3, 0.6, 0.9
Shift      fixed        6  0.25, 0.50, 1.00, 1.50, 2.00, 3.00


Analysis of Variance for LN(ARL), using Adjusted SS for Tests

Source        DF    Seq SS    Adj SS   Adj MS       F      P
Replicate      1     0.000     0.000    0.000    0.00  0.993
B              6   107.173   107.173   17.862   30.86  0.000
Phi            6    13.209    13.209    2.201    3.80  0.001
Shift          5  1086.551  1086.551  217.310  375.45  0.000
B*Shift       30    29.174    29.174    0.972    1.68  0.017
B*Phi         36    10.413    10.413    0.289    0.50  0.993
Phi*Shift     30    69.964    69.964    2.332    4.03  0.000
B*Phi*Shift  180    51.790    51.790    0.288    0.50  1.000
Error        293   169.588   169.588    0.579
Total        587  1537.862


S = 0.760787   R-Sq = 88.97%   R-Sq(adj) = 77.91%
```

Figure 14 - ANOVA Analysis - Off-Target Analysis

This analysis produces p-values for each parameter in the model and according to the values; B, Shift, and ϕ are statistically significant parameters, along with the interaction of ϕ and Shift, with a p-value of ≈ 0.000. These will be the only parameters used when constructing a control chart equation based on the natural logarithm of the average run length. Table 4 shows the values for the average run length in correspondence to the different parameter combinations.

Table 4 - ARL Values for Statistically Significant Parameters

B	Shift	ϕ						
		-0.9	-0.6	-0.3	0	0.3	0.6	0.9
3	3.00	1.277	1.279	1.279	1.218	1.273	1.285	1.278
	2.00	2.010	2.012	2.006	1.905	2.005	1.996	2.008
	1.50	2.893	2.908	2.915	2.918	2.922	2.906	2.900
	1.00	4.963	4.968	4.963	4.987	4.964	4.985	4.980
	0.50	11.570	11.559	11.596	11.508	11.557	11.597	11.593
	0.25	19.746	19.434	19.558	19.737	19.490	19.633	19.626
4	3.00	1.454	1.458	1.449	1.374	1.457	1.456	1.453
	2.00	2.425	2.440	2.429	2.316	2.441	2.433	2.446
	1.50	3.660	3.643	3.650	3.638	3.659	3.663	3.666
	1.00	6.566	6.650	6.587	6.618	6.651	6.661	6.661
	0.50	17.339	17.384	17.307	17.451	17.235	17.282	17.428
	0.25	35.316	34.815	35.567	35.126	35.274	35.304	35.176
5	3.00	1.654	1.653	1.647	1.650	1.646	1.643	1.654
	2.00	2.892	2.880	2.883	2.898	2.906	2.885	2.880
	1.50	4.453	4.434	4.439	4.466	4.440	4.460	4.473
	1.00	8.382	8.320	8.348	8.282	8.408	8.350	8.381
	0.50	24.089	24.143	24.116	23.987	23.969	23.867	23.961
	0.25	56.725	56.807	55.666	55.975	56.758	56.090	56.302
6	3.00	1.875	1.863	1.861	1.854	1.856	1.853	1.853
	2.00	3.344	3.351	3.365	3.356	3.352	3.348	3.362
	1.50	5.267	5.310	5.246	5.274	5.254	5.264	5.267
	1.00	10.209	10.151	10.202	10.177	10.187	10.140	10.281
	0.50	30.990	31.217	30.837	30.867	31.015	30.705	30.841
	0.25	82.338	82.500	81.560	82.128	82.587	82.054	81.467
7	3.00	2.086	2.071	2.073	1.978	2.073	2.071	2.064
	2.00	3.828	3.858	3.846	3.656	3.846	3.847	3.839
	1.50	6.076	6.104	6.148	6.120	6.111	6.118	6.128
	1.00	12.043	12.035	12.107	12.011	12.011	12.075	11.961
	0.50	38.041	37.904	38.098	38.269	37.693	38.408	38.366
	0.25	111.168	109.550	111.093	110.412	110.201	109.089	109.335
8	3.00	2.300	2.291	2.295	2.185	2.303	2.291	2.309
	2.00	4.318	4.319	4.317	4.117	4.327	4.327	4.342
	1.50	6.945	7.000	6.926	6.968	6.972	6.992	6.943
	1.00	13.893	13.901	13.922	13.968	13.932	13.889	13.929
	0.50	45.334	45.300	45.777	45.353	45.385	45.487	45.412
	0.25	138.445	138.282	138.245	139.922	138.463	139.537	139.267
9	3.00	2.517	2.531	2.525	2.514	2.513	2.526	2.526
	2.00	4.813	4.849	4.819	4.810	4.833	4.821	4.844
	1.50	7.803	7.851	7.817	7.797	7.846	7.800	7.806
	1.00	15.856	15.805	15.843	15.804	15.842	15.768	15.911
	0.50	52.781	53.011	52.838	52.651	52.911	52.608	53.561
	0.25	167.995	168.381	167.334	166.583	168.290	164.841	166.676

CHAPTER IV

CASE STUDY

Introduction

This case study is being conducted to test the autoregressive model developed for the initially on-target analysis. Electronic load data provided by ERCOT, and temperature data, provided by Houston's historical weather data, will be utilized as the raw data for this analysis through the use of the generated control chart. Equations provided in the derivation chapter are utilized in a computer simulated program, similar to that of the on and off-target analysis sections. This computer program will provide estimations for the derived control chart parameters. For this case study, a common value for the ARL will be selected to be 370. Applying the equation found for B in equation 38, this control chart can be evaluated until an observation exceeds the size of the control chart limits.

Simulation Program

A program written in Java will be used as a tool for this simulation of the control chart. This program was created to simulate the derived parameters of the on-target control analysis, and create a robust control chart from the data. Nearly 700 observations are created in this program. Each observation provides an estimation for R_{MAX}, τ-hat, and δ-hat. A copy of the code used is presented in Appendix I.

Results

Estimation of Parameters

As mentioned, the Java program will provide estimations for the parameters for the construction of a control chart. First, a basic overview of the parameters and their role in the control chart. R_{MAX} represents the maximum value for the ratio of likelihood functions, for the null and alternative hypothesis, generated for this control. τ-hat represents the maximum likelihood estimation for the change-point value for the control chart, which is noted as when an observation appears to be out of the control limits. δ-hat represents the estimation of delta in order to create a maximum value for R.

The program produced nearly 700 observations, each generating a row containing the three control chart parameters. The first 100 observations are presented below.

Table 5 - Estimation of Control Chart Parameters

i	RMax	Tau Hat	Delta Hat
0	0.15864289	0	4.396596082
1	0.066747893	0	0.988848745
2	0.358562917	0	8.13560445
3	0.536080135	0	10.5464731
4	0.578454887	0	10.70251927
5	0.699532389	0	11.79972454
6	0.584660917	0	10.00554223
7	0.612999931	0	10.00226676
8	0.636124857	8	-74.3049802
9	0.251396038	8	-35.66669196
10	0.542716315	8	-41.84053326
11	0.544913797	8	-36.93583004
12	0.776936903	8	-39.12492746
13	0.494539148	8	-29.78465259
14	0.805169311	14	73.51063116
15	0.355655184	13	25.28211695
16	0.238651204	13	16.55616392
17	0.358552766	13	18.60815297
18	0.172654695	13	10.04787915

19	0.176371506	13	9.097086128
20	0.133944641	13	6.538509938
21	0.107748009	13	4.796138749
22	0.257832129	22	-49.03051519
23	0.114846397	23	24.80912184
24	0.08944105	23	13.69668503
25	0.105469198	23	11.60603293
26	0.086207444	23	8.056923436
27	0.139358491	23	9.813619687
28	0.230159674	23	12.3348304
29	0.128350758	23	7.063074823
30	0.089417295	29	-23.18699563
31	0.097637453	29	-20.47994879
32	0.468239754	32	54.93155568
33	1.063000186	32	58.83520102
34	0.719012343	32	37.94962062
35	0.25533359	32	17.28814182
36	0.207566044	32	13.02302156
37	0.227605814	32	12.23979917
38	0.206821718	23	5.169191036
39	0.229373673	23	5.384028876
40	0.295704455	32	11.06199863
41	0.185365771	13	2.226230771
42	0.260062466	23	5.19859031
43	0.200259148	13	2.263248237
44	0.18969871	43	-31.60581307
45	0.243502386	43	-29.59318968
46	0.883253021	46	77.21744475
47	0.362183845	46	32.36688734
48	0.261273268	46	20.991129
49	0.35596999	46	21.27056795
50	0.49182995	46	22.60644168
51	1.198772366	51	90.74144736
52	3.055556261	52	-157.1954547
53	2.23714126	53	125.6982948
54	1.102366086	53	60.00180136
55	2.442524146	53	73.9470465
56	0.978885757	56	-91.03343668
57	0.862503357	56	-62.01873608
58	1.750109252	58	110.6287573
59	3.368909972	58	108.4439576
60	2.813214289	58	79.70766014
61	1.912614887	0	9.140609949
62	1.056695037	0	5.508001872
63	1.048331533	0	5.401175754
64	0.955610921	0	4.88007445
65	0.999787119	0	5.037893032

66	1.039944375	0	5.170230444
67	0.882348521	46	12.71941631
68	1.123235571	46	14.52670144
69	1.125017707	46	14.13586849
70	0.889171324	46	11.70121373
71	0.833131267	46	10.86530188
72	0.893412395	46	11.11802379
73	0.718206093	46	9.221328967
74	0.621728853	46	8.023333771
75	0.504014202	73	-40.49344664
76	6.528250142	76	218.0858692
77	1.769513638	76	77.28718957
78	1.19867956	76	50.38140878
79	0.695494021	46	7.727078671
80	1.178722474	80	89.93954635
81	0.829092551	46	8.488801662
82	0.707093665	81	-56.602871
83	1.083264369	81	-57.15301229
84	0.696473919	81	-41.13805822
85	1.083942737	85	86.05298686
86	4.260818682	85	122.5485713
87	4.758022161	85	105.0864701
88	6.38961829	85	105.4803978
89	6.63516479	85	95.71994237
90	5.366702036	85	77.73535106
91	5.558773397	85	72.97135152
92	5.638985395	85	68.47453333
93	5.889639436	85	65.80455109
94	5.806515866	85	61.71011908
95	6.127831791	85	60.34698538
96	5.815469362	85	55.9665809
97	6.096047246	85	54.97531653
98	6.011683668	85	52.40328548
99	5.40883973	85	47.62404248
100	4.123765072	85	39.52944039

The remaining observation points can be found in Appendix I.

Evaluation of Control Chart

In the Model Selection chapter, a derivation for B was generated, which corresponds to the size of the control chart limits. This equation is presented as equation 38. This equation utilizes the natural log of a value for ARL. For this case study, a value will be selected for the average run length to be 370. Also, the value for ϕ is selected to be the value from the ARX results from Figure 10. Using this value for ARL, the value for be is solved below.

$$ARL(0) = 370$$

$$\hat{B} = \frac{\ln(370) - 0.00141(0.8704) - 1.16}{0.738}$$

$$\hat{B} = 6.439$$

This value for B-hat indicates that this is the control limit for the control chart generated from the historical data. This control limit is then applied to the values of R_{MAX}, and the control chart is evaluated. The first out of control point occurs with R_{MAX} of 6.528 for the 76th observation. This shows that the data remained within the limits until the change point value reached 76. A graph is shown below in Figure 15.

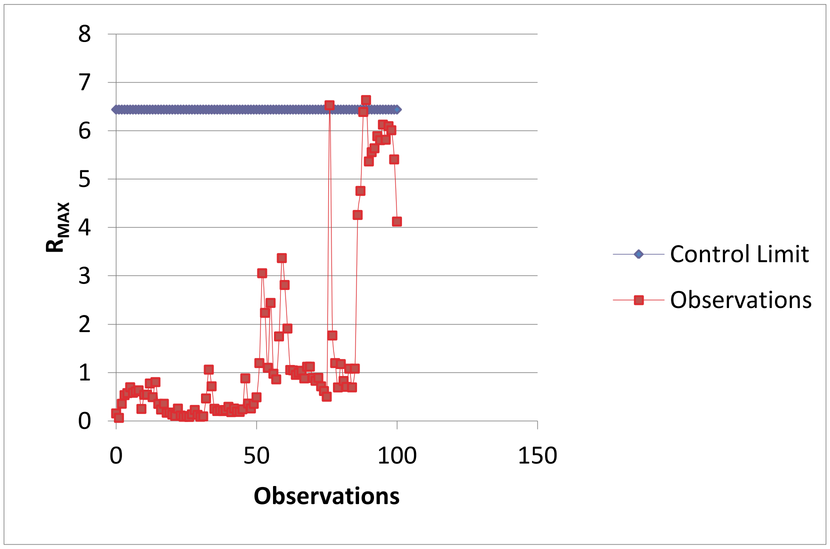


Figure 15 - Control Chart for On-Target Analysis

This appears to be a moderate length of time until a signal occurs, however further analysis can be conducted on the cause of this signal. Perhaps an assignable cause can be detected, or the chance of being a false alarm. Additional analysis can be conducted to further evaluate the performance of this control chart. There were a total of 19 statistically out of control points out of a total of 692 observations.

CHAPTER V

FUTURE RESEARCH

Case Study for Off-Target Analysis

A case study must be performed for the off-target analysis, in order to obtain any type of performance evaluation for the control for instances where the data starts performing outside of the control limits. However, since this analysis contains shifts within the control chart, this detail must be included into the Java program, which estimates the control chart parameters. The inclusion of this parameter will test the control chart with the ability of detecting shifts in the mean or variance.

A regression analysis must be conducted prior to creation of the Java program. The regression analysis utilizes the statistically significant parameters from the ANOVA analysis in Figure 14. The regression then generates a similar equation to that of equation 38, which indicates the size of the control chart limits. This estimation of B will aid in evaluation the performance of the control chart. The computer program generated for this case will also provide values for parameters R_{MAX}, τ-hat, and δ-hat.

Alternative Models

A specific procedure for model selection was presented in this research, involving the utilization of an AR(1) model along with two different types of lag selection. There are different approaches that could have been used in place of these. For example, the use of an AR(2) model could have been used in place of the AR(1) model. The accuracy of the control chart could change from the research if the foundation of the ARX model was based on an AR(2) model. This model would need the addition of another dependent variable, along with the electricity load data. However, other types of data sets can be explored for this certain application.

Also, with the notion of changing the foundation of the ARX model, an ARMA model would be used in the place of an AR(1) as well. The addition of a moving average parameter allows for the investigation of the behavior of the mean as the number of observations gets larger. The moving average portion of this model needs a recalculation of the mean every time an observation is retired and replace with a new observation. This constant change in mean may provide extra information that may alter the accuracy of the control chart for the better.

In addition to uses autoregressive models to perform a quality control analysis along with forecasting new observations, there are several other types of models that can be used. The introduction of intelligent machines has provided the necessary tools to perform large cumbersome tasks with ease and less time. Support Vector Machines and Neural Networks are the most common intelligent machines. These types of intelligent machines have the ability to process a large amount of input data that can be divided up into subsections. Once the data is process, specific tasks can be programmed to be performed into the machines. The machine then results in an output data. However, the key element makes these types of models different, is the ability to learn through repetition. Any type of input data that is ran through the system, the machine will recognize trends and statistical attributes. This may provide an advantage over the traditional statistical methods.

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APPENDICES

APPENDIX A

ERCOT ELECTRICITY LOAD DATA FOR EAST REGION FOR JUNE 2011

Hour_End	EAST	Differenced
6/01/2011 0:00	1547.739148	7.624539
6/01/2011 1:00	1415.441181	-9.516544
6/01/2011 2:00	1368.23789	23.946973
6/01/2011 3:00	1293.516907	12.609567
6/01/2011 4:00	1246.631389	9.14086
6/01/2011 5:00	1237.627847	22.982088
6/01/2011 6:00	1280.523677	25.518086
6/01/2011 7:00	1342.338884	38.659319
6/01/2011 8:00	1396.65805	46.321543
6/01/2011 9:00	1466.752872	21.664279
6/01/2011 10:00	1621.816576	60.773789
6/01/2011 11:00	1730.960133	-21.406198
6/01/2011 12:00	1908.619568	-15.660808
6/01/2011 13:00	1984.853809	-65.559353
6/01/2011 14:00	2029.699846	-79.285958
6/01/2011 15:00	2045.441725	-116.89348
6/01/2011 16:00	2083.847769	-87.592479
6/01/2011 17:00	2157.261018	-5.494363
6/01/2011 18:00	2160.775866	-27.149092
6/01/2011 19:00	2128.611999	-38.778157
6/01/2011 20:00	2046.341409	-16.983253
6/01/2011 21:00	1955.60813	-58.084412
6/01/2011 22:00	1869.332706	-59.723114
6/01/2011 23:00	1710.497272	-76.164477
6/02/2011 0:00	1540.114609	-83.223672
6/02/2011 1:00	1424.957725	-133.525395
6/02/2011 2:00	1344.290917	-103.469434
6/02/2011 3:00	1280.90734	-100.03527
6/02/2011 4:00	1237.490529	-92.456772
6/02/2011 5:00	1214.645759	-95.875422
6/02/2011 6:00	1255.005591	-77.159918
6/02/2011 7:00	1303.679565	-52.266769

6/02/2011 8:00	1350.336507	-77.847233
6/02/2011 9:00	1445.088593	-95.091721
6/02/2011 10:00	1561.042787	-105.119065
6/02/2011 11:00	1752.366331	-44.100816
6/02/2011 12:00	1924.280376	21.589909
6/02/2011 13:00	2050.413162	7.687391
6/02/2011 14:00	2108.985804	-40.516538
6/02/2011 15:00	2162.335205	-34.280885
6/02/2011 16:00	2171.440248	-10.966773
6/02/2011 17:00	2162.755381	-2.800544
6/02/2011 18:00	2187.924958	21.452842
6/02/2011 19:00	2167.390156	52.080338
6/02/2011 20:00	2063.324662	23.471584
6/02/2011 21:00	2013.692542	76.579597
6/02/2011 22:00	1929.05582	61.314235
6/02/2011 23:00	1786.661749	35.935137
6/03/2011 0:00	1623.338281	20.528664
6/03/2011 1:00	1558.48312	112.164293
6/03/2011 2:00	1447.760351	99.964395
6/03/2011 3:00	1380.94261	100.570932
6/03/2011 4:00	1329.947301	122.456637
6/03/2011 5:00	1310.521181	149.607825
6/03/2011 6:00	1332.165509	231.511582
6/03/2011 7:00	1355.946334	54.363128
6/03/2011 8:00	1428.18374	180.802784
6/03/2011 9:00	1540.180314	159.465529
6/03/2011 10:00	1666.161852	247.923061
6/03/2011 11:00	1796.467147	129.787022
6/03/2011 12:00	1902.690467	82.727975
6/03/2011 13:00	2042.725771	189.920303
6/03/2011 14:00	2149.502342	274.081288
6/03/2011 15:00	2196.61609	260.801174
6/03/2011 16:00	2182.407021	188.497636
6/03/2011 17:00	2165.555925	72.538191
6/03/2011 18:00	2166.472116	65.763282
6/03/2011 19:00	2115.309818	47.89966
6/03/2011 20:00	2039.853078	50.617929
6/03/2011 21:00	1937.112945	36.491285
6/03/2011 22:00	1867.741585	12.002557
6/03/2011 23:00	1750.726612	62.473893
6/04/2011 0:00	1602.809617	57.26494
6/04/2011 1:00	1446.318827	0.853747
6/04/2011 2:00	1347.795956	-12.052036
6/04/2011 3:00	1280.371678	4.435787

6/04/2011 4:00	1207.490664	-38.128429
6/04/2011 5:00	1160.913356	-60.968676
6/04/2011 6:00	1100.653927	-102.015773
6/04/2011 7:00	1301.583206	129.289198
6/04/2011 8:00	1247.380956	46.764184
6/04/2011 9:00	1380.714785	35.014016
6/04/2011 10:00	1418.238791	-38.913278
6/04/2011 11:00	1666.680125	56.068612
6/04/2011 12:00	1819.962492	-1.022725
6/04/2011 13:00	1852.805468	-76.827471
6/04/2011 14:00	1875.421054	-137.683089
6/04/2011 15:00	1935.814916	-128.004508
6/04/2011 16:00	1993.909385	-35.913167
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6/19/2011 17:00	2137.884075	-202.837868
6/19/2011 18:00	2127.464054	-171.980498
6/19/2011 19:00	2087.911858	-161.191127
6/19/2011 20:00	2050.307546	-139.483484
6/19/2011 21:00	2015.803672	-39.746755
6/19/2011 22:00	1945.301277	-31.305057
6/19/2011 23:00	1849.058553	-59.587702
6/20/2011 0:00	1730.49222	-30.823046
6/20/2011 1:00	1648.037342	6.945885
6/20/2011 2:00	1537.218555	-17.874502
6/20/2011 3:00	1491.612878	4.060524
6/20/2011 4:00	1455.457742	10.938268
6/20/2011 5:00	1437.812185	5.727713
6/20/2011 6:00	1455.260383	-7.262344
6/20/2011 7:00	1504.82684	10.164362
6/20/2011 8:00	1563.150795	35.126851
6/20/2011 9:00	1636.019847	65.043496
6/20/2011 10:00	1777.784218	91.685326
6/20/2011 11:00	1950.883784	155.163589
6/20/2011 12:00	2024.550146	75.601938
6/20/2011 13:00	2142.94814	114.682804
6/20/2011 14:00	2228.151429	96.076642
6/20/2011 15:00	2261.704966	107.81257

6/20/2011 16:00	2312.39836	160.447629
6/20/2011 17:00	2340.721943	210.805277
6/20/2011 18:00	2299.444552	217.833588
6/20/2011 19:00	2249.102985	239.289211
6/20/2011 20:00	2189.79103	261.525447
6/20/2011 21:00	2055.550427	212.30156
6/20/2011 22:00	1976.606334	204.288155
6/20/2011 23:00	1908.646255	228.994479
6/21/2011 0:00	1761.315266	214.193022
6/21/2011 1:00	1641.091457	151.603881
6/21/2011 2:00	1555.093057	136.755429
6/21/2011 3:00	1487.552354	155.250453
6/21/2011 4:00	1444.519474	143.369779
6/21/2011 5:00	1432.084472	182.348423
6/21/2011 6:00	1462.522727	239.224491
6/21/2011 7:00	1494.662478	220.940952
6/21/2011 8:00	1528.023944	220.346833
6/21/2011 9:00	1570.976351	235.231913
6/21/2011 10:00	1686.098892	308.295947
6/21/2011 11:00	1795.720195	371.758826
6/21/2011 12:00	1948.948208	470.332789
6/21/2011 13:00	2028.265336	526.576476
6/21/2011 14:00	2132.074787	581.130857
6/21/2011 15:00	2153.892396	563.231199
6/21/2011 16:00	2151.950731	521.491758
6/21/2011 17:00	2129.916666	460.112657
6/21/2011 18:00	2081.610964	415.611717
6/21/2011 19:00	2009.813774	329.087501
6/21/2011 20:00	1928.265583	287.827902
6/21/2011 21:00	1843.248867	253.849711
6/21/2011 22:00	1772.318179	226.002121
6/21/2011 23:00	1679.651776	246.023217
6/22/2011 0:00	1547.122244	235.215946
6/22/2011 1:00	1489.487576	272.857044
6/22/2011 2:00	1418.337628	263.689785
6/22/2011 3:00	1332.301901	223.936401
6/22/2011 4:00	1301.149695	223.355551
6/22/2011 5:00	1249.736049	163.800507
6/22/2011 6:00	1223.298236	100.039287
6/22/2011 7:00	1273.721526	86.206757
6/22/2011 8:00	1307.677111	59.060103
6/22/2011 9:00	1335.744438	-166.957686
6/22/2011 10:00	1377.802945	-130.208046
6/22/2011 11:00	1423.961369	-215.465543

6/22/2011 12:00	1478.615419	-208.459552
6/22/2011 13:00	1501.68886	-282.128564
6/22/2011 14:00	1550.94393	-365.842022
6/22/2011 15:00	1590.661197	-384.888934
6/22/2011 16:00	1630.458973	-396.373168
6/22/2011 17:00	1669.804009	-360.739407
6/22/2011 18:00	1665.999247	-398.967217
6/22/2011 19:00	1680.726273	-351.641811
6/22/2011 20:00	1640.437681	-359.294866
6/22/2011 21:00	1589.399156	-296.171203
6/22/2011 22:00	1546.316058	-284.907011
6/22/2011 23:00	1433.628559	-265.51382
6/23/2011 0:00	1311.906298	-262.066236
6/23/2011 1:00	1216.630532	-218.405163
6/23/2011 2:00	1154.647843	-208.093541
6/23/2011 3:00	1108.3655	-195.082039
6/23/2011 4:00	1077.794144	-169.041932
6/23/2011 5:00	1085.935542	-144.556895
6/23/2011 6:00	1123.258949	-156.231978
6/23/2011 7:00	1187.514769	-136.998677
6/23/2011 8:00	1248.617008	-135.199083
6/23/2011 9:00	1502.702124	13.149636
6/23/2011 10:00	1508.010991	-113.262873
6/23/2011 11:00	1639.426912	-84.998493
6/23/2011 12:00	1687.074971	-111.251691
6/23/2011 13:00	1783.817424	-115.921616
6/23/2011 14:00	1916.785952	-54.264462
6/23/2011 15:00	1975.550131	-58.567711
6/23/2011 16:00	2026.832141	-70.669132
6/23/2011 17:00	2030.543416	-121.759274
6/23/2011 18:00	2064.966464	-75.678778
6/23/2011 19:00	2032.368084	-74.575885
6/23/2011 20:00	1999.732547	-34.192946
6/23/2011 21:00	1885.570359	-65.459247
6/23/2011 22:00	1831.223069	-74.169278
6/23/2011 23:00	1699.142379	-108.745736
6/24/2011 0:00	1573.972534	-37.733484
6/24/2011 1:00	1435.035695	-74.22613
6/24/2011 2:00	1362.741384	-84.736148
6/24/2011 3:00	1303.447539	-81.494001
6/24/2011 4:00	1246.836076	-86.929907
6/24/2011 5:00	1230.492437	-71.381933
6/24/2011 6:00	1279.490927	-31.429483
6/24/2011 7:00	1324.513446	17.200321

6/24/2011 8:00	1383.816091	52.85661
6/24/2011 9:00	1489.552488	85.791518
6/24/2011 10:00	1621.273864	86.936123
6/24/2011 11:00	1724.425405	50.318543
6/24/2011 12:00	1798.326662	19.924188
6/24/2011 13:00	1899.73904	37.612515
6/24/2011 14:00	1971.050414	50.381963
6/24/2011 15:00	2034.117842	51.292492
6/24/2011 16:00	2097.501273	68.12957
6/24/2011 17:00	2152.30269	77.765056
6/24/2011 18:00	2140.645242	57.51147
6/24/2011 19:00	2106.943969	42.269138
6/24/2011 20:00	2033.925493	36.714441
6/24/2011 21:00	1951.029606	39.080577
6/24/2011 22:00	1905.392347	29.203407
6/24/2011 23:00	1807.888115	35.370237
6/25/2011 0:00	1611.706018	-5.167969
6/25/2011 1:00	1509.261825	28.285044
6/25/2011 2:00	1447.477532	28.581789
6/25/2011 3:00	1384.94154	22.625779
6/25/2011 4:00	1333.765983	25.998566
6/25/2011 5:00	1301.87437	10.911908
6/25/2011 6:00	1310.92041	28.044878
6/25/2011 7:00	1307.313125	106.526336
6/25/2011 8:00	1330.959481	104.105071
6/25/2011 9:00	1403.76097	26.212975
6/25/2011 10:00	1534.337741	27.556156
6/25/2011 11:00	1674.106862	20.537076
6/25/2011 12:00	1778.402474	11.982019
6/25/2011 13:00	1862.126525	-33.039368
6/25/2011 14:00	1920.668451	-46.150625
6/25/2011 15:00	1982.82535	-35.272498
6/25/2011 16:00	2029.371703	-48.067666
6/25/2011 17:00	2074.537634	-45.373877
6/25/2011 18:00	2083.133772	-41.894061
6/25/2011 19:00	2064.674831	-34.948312
6/25/2011 20:00	1997.211052	-2.216943
6/25/2011 21:00	1911.949029	-52.408885
6/25/2011 22:00	1876.18894	-70.76315
6/25/2011 23:00	1772.517878	-65.215833
6/26/2011 0:00	1616.873987	-106.726422
6/26/2011 1:00	1480.976781	-61.665387
6/26/2011 2:00	1418.895743	-61.820629
6/26/2011 3:00	1362.315761	-59.671142

6/26/2011 4:00	1307.767417	-86.27928
6/26/2011 5:00	1290.962462	-100.629953
6/26/2011 6:00	1282.875532	-136.807496
6/26/2011 7:00	1200.786789	-263.114562
6/26/2011 8:00	1226.85441	-279.220739
6/26/2011 9:00	1377.547995	-237.092019
6/26/2011 10:00	1506.781585	-235.862409
6/26/2011 11:00	1653.569786	-196.121435
6/26/2011 12:00	1766.420455	-219.059959
6/26/2011 13:00	1895.165893	-200.583606
6/26/2011 14:00	1966.819076	-178.89766
6/26/2011 15:00	2018.097848	-214.522437
6/26/2011 16:00	2077.439369	-145.566598
6/26/2011 17:00	2119.911511	-112.595756
6/26/2011 18:00	2125.027833	-115.343403
6/26/2011 19:00	2099.623143	-152.497238
6/26/2011 20:00	1999.427995	-191.525968
6/26/2011 21:00	1964.357914	-142.245148
6/26/2011 22:00	1946.95209	-101.879862
6/26/2011 23:00	1837.733711	-78.282665
6/27/2011 0:00	1723.600409	-30.443017
6/27/2011 1:00	1542.642168	-89.995797
6/27/2011 2:00	1480.716372	-50.666215
6/27/2011 3:00	1421.986903	-49.521404
6/27/2011 4:00	1394.046697	-25.116171
6/27/2011 5:00	1391.592415	-10.929509
6/27/2011 6:00	1419.683028	4.478261
6/27/2011 7:00	1463.901351	30.462477
6/27/2011 8:00	1506.075149	-28.435925
6/27/2011 9:00	1614.640014	-7.956074
6/27/2011 10:00	1742.643994	7.309704
6/27/2011 11:00	1849.691221	-4.71032
6/27/2011 12:00	1985.480414	-5.295869
6/27/2011 13:00	2095.749499	-17.117626
6/27/2011 14:00	2145.716736	-65.751932
6/27/2011 15:00	2232.620285	-56.982378
6/27/2011 16:00	2223.005967	-44.532689
6/27/2011 17:00	2232.507267	-19.588594
6/27/2011 18:00	2240.371236	-1.571973
6/27/2011 19:00	2252.120381	-5.409033
6/27/2011 20:00	2190.953963	3.938265
6/27/2011 21:00	2106.603062	-0.311922
6/27/2011 22:00	2048.831952	47.995453
6/27/2011 23:00	1916.016376	73.327363

6/28/2011 0:00	1754.043426	68.927257
6/28/2011 1:00	1632.637965	75.97399
6/28/2011 2:00	1531.382587	67.542071
6/28/2011 3:00	1471.508307	62.472771
6/28/2011 4:00	1419.162868	42.907361
6/28/2011 5:00	1402.521924	40.62616
6/28/2011 6:00	1415.204767	24.210677
6/28/2011 7:00	1433.438874	-1.639427
6/28/2011 8:00	1534.511074	63.333304
6/28/2011 9:00	1622.596088	36.209012
6/28/2011 10:00	1735.33429	51.644687
6/28/2011 11:00	1854.401541	82.541395
6/28/2011 12:00	1990.776283	73.826349
6/28/2011 13:00	2112.867125	79.801686
6/28/2011 14:00	2211.468668	77.602802
6/28/2011 15:00	2289.602663	92.0013
6/28/2011 16:00	2267.538656	31.211945
6/28/2011 17:00	2252.095861	-21.572926
6/28/2011 18:00	2241.943209	-12.249773
6/28/2011 19:00	2257.529414	42.462009
6/28/2011 20:00	2187.015698	57.322008
6/28/2011 21:00	2106.914984	51.93804
6/28/2011 22:00	2000.836499	24.816957
6/28/2011 23:00	1842.689013	34.673103
6/29/2011 0:00	1685.116169	34.833187
6/29/2011 1:00	1556.663975	28.687212
6/29/2011 2:00	1463.840516	30.159526
6/29/2011 3:00	1409.035536	50.616827
6/29/2011 4:00	1376.255507	50.143717
6/29/2011 5:00	1361.895764	-1.971239
6/29/2011 6:00	1390.99409	-2.350417
6/29/2011 7:00	1435.078301	2.5395
6/29/2011 8:00	1471.17777	-20.191487
6/29/2011 9:00	1586.387076	-3.631834
6/29/2011 10:00	1683.689603	-29.493732
6/29/2011 11:00	1771.860146	-189.838351
6/29/2011 12:00	1916.949934	-165.052927
6/29/2011 13:00	2033.065439	-92.722825
6/29/2011 14:00	2133.865866	1.793626
6/29/2011 15:00	2197.601363	-20.471251
6/29/2011 16:00	2236.326711	-45.385561
6/29/2011 17:00	2273.668787	-29.435926
6/29/2011 18:00	2254.192982	-45.012798
6/29/2011 19:00	2215.067405	-60.905308

6/29/2011 20:00	2129.69369	-63.867914
6/29/2011 21:00	2054.976944	-48.8475
6/29/2011 22:00	1976.019542	-37.318918
6/29/2011 23:00	1808.01591	-65.8726
6/30/2011 0:00	1650.282982	
6/30/2011 1:00	1527.976763	
6/30/2011 2:00	1433.68099	
6/30/2011 3:00	1358.418709	
6/30/2011 4:00	1326.11179	
6/30/2011 5:00	1363.867003	
6/30/2011 6:00	1393.344507	
6/30/2011 7:00	1432.538801	
6/30/2011 8:00	1491.369257	
6/30/2011 9:00	1590.01891	
6/30/2011 10:00	1713.183335	
6/30/2011 11:00	1961.698497	
6/30/2011 12:00	2082.002861	
6/30/2011 13:00	2125.788264	
6/30/2011 14:00	2132.07224	
6/30/2011 15:00	2218.072614	
6/30/2011 16:00	2281.712272	
6/30/2011 17:00	2303.104713	
6/30/2011 18:00	2299.20578	
6/30/2011 19:00	2275.972713	
6/30/2011 20:00	2193.561604	
6/30/2011 21:00	2103.824444	
6/30/2011 22:00	2013.33846	
6/30/2011 23:00	1873.88851	

APPENDIX B

HISTORICAL METEOROLOGICAL DATA FOR HOUSTON, TX FOR JUNE 2011

Date	Time (CDT)	Temp. (°F)	Res. Temp	Pressure (in)	Res. Press.
6/1/11	12:53 AM	75.9	-1.1	30.18	0.100
6/1/11	1:53 AM	75.9	0.0	30.17	0.090
6/1/11	2:53 AM	73.9	-2.0	30.18	0.100
6/1/11	3:53 AM	73.0	-2.9	30.19	0.120
6/1/11	4:53 AM	73.0	-2.0	30.2	0.140
6/1/11	5:53 AM	73.0	-2.0	30.2	0.140
6/1/11	6:53 AM	73.0	-2.9	30.21	0.140
6/1/11	7:53 AM	78.1	0.0	30.21	0.110
6/1/11	8:53 AM	81.0	0.0	30.21	0.110
6/1/11	9:53 AM	84.9	0.0	30.22	0.130
6/1/11	10:53 AM	88.0	0.9	30.21	0.140
6/1/11	11:53 AM	90.0	0.0	30.2	0.140
6/1/11	12:53 PM	93.0	0.0	30.18	0.140
6/1/11	1:53 PM	95.0	-1.1	30.16	0.150
6/1/11	2:53 PM	93.9	-1.1	30.14	0.150
6/1/11	3:53 PM	93.9	-3.1	30.12	0.140
6/1/11	4:53 PM	93.9	-2.2	30.1	0.140
6/1/11	5:53 PM	93.0	-4.0	30.09	0.150
6/1/11	6:53 PM	91.9	-4.2	30.07	0.140
6/1/11	7:53 PM	88.0	-5.0	30.08	0.150
6/1/11	8:53 PM	84.0	-5.1	30.07	0.140
6/1/11	9:53 PM	82.9	-3.1	30.08	0.140
6/1/11	10:53 PM	80.1	-4.8	30.08	0.120
6/1/11	11:53 PM	78.1	-4.8	30.08	0.110
6/2/11	12:53 AM	77.0	-5.0	30.08	0.110
6/2/11	1:53 AM	75.9	-5.1	30.08	0.100
6/2/11	2:53 AM	75.9	-5.1	30.08	0.110
6/2/11	3:53 AM	75.9	-4.2	30.07	0.090
6/2/11	4:53 AM	75.0	-4.0	30.06	0.070
6/2/11	5:53 AM	75.0	-3.1	30.06	0.050
6/2/11	6:53 AM	75.9	-2.2	30.07	0.040
6/2/11	7:53 AM	78.1	-2.9	30.1	0.070

6/2/11	8:53 AM	81.0	-3.0	30.1	0.060
6/2/11	9:53 AM	84.9	-1.1	30.09	0.050
6/2/11	10:53 AM	87.1	-2.9	30.07	0.030
6/2/11	11:53 AM	90.0	-1.0	30.06	0.020
6/2/11	12:53 PM	93.0	2.0	30.04	0.020
6/2/11	1:53 PM	96.1	4.2	30.01	0.000
6/2/11	2:53 PM	95.0	4.0	29.99	-0.020
6/2/11	3:53 PM	97.0	6.0	29.98	-0.020
6/2/11	4:53 PM	96.1	5.1	29.96	-0.040
6/2/11	5:53 PM	97.0	7.9	29.94	-0.060
6/2/11	6:53 PM	96.1	9.0	29.93	-0.070
6/2/11	7:53 PM	93.0	9.0	29.93	-0.090
6/2/11	8:53 PM	89.1	7.1	29.93	-0.100
6/2/11	9:53 PM	86.0	5.9	29.94	-0.100
6/2/11	10:53 PM	84.9	6.8	29.96	-0.100
6/2/11	11:53 PM	82.9	5.9	29.97	-0.100
6/3/11	12:53 AM	82.0	6.1	29.97	-0.100
6/3/11	1:53 AM	81.0	5.1	29.98	-0.070
6/3/11	2:53 AM	81.0	6.0	29.97	-0.070
6/3/11	3:53 AM	80.1	4.2	29.98	-0.090
6/3/11	4:53 AM	79.0	4.0	29.99	-0.100
6/3/11	5:53 AM	78.1	3.1	30.01	-0.090
6/3/11	6:53 AM	78.1	3.1	30.03	-0.090
6/3/11	7:53 AM	81.0	2.9	30.03	-0.100
6/3/11	8:53 AM	84.0	2.0	30.04	-0.100
6/3/11	9:53 AM	86.0	1.1	30.04	-0.100
6/3/11	10:53 AM	90.0	2.9	30.04	-0.090
6/3/11	11:53 AM	91.0	1.0	30.04	-0.080
6/3/11	12:53 PM	91.0	0.0	30.02	-0.100
6/3/11	1:53 PM	91.9	-2.0	30.01	-0.100
6/3/11	2:53 PM	91.0	-2.9	30.01	-0.090
6/3/11	3:53 PM	91.0	-2.9	30	-0.090
6/3/11	4:53 PM	91.0	-2.9	30	-0.080
6/3/11	5:53 PM	89.1	-2.8	30	-0.070
6/3/11	6:53 PM	87.1	-3.9	30	-0.060
6/3/11	7:53 PM	84.0	-3.1	30.02	-0.050
6/3/11	8:53 PM	82.0	-0.9	30.03	-0.050
6/3/11	9:53 PM	80.1	-0.9	30.04	-0.060
6/3/11	10:53 PM	78.1	-0.9	30.06	-0.050
6/3/11	11:53 PM	77.0	-1.1	30.07	-0.030
6/4/11	12:53 AM	75.9	-1.1	30.07	-0.030
6/4/11	1:53 AM	75.9	0.0	30.05	-0.040
6/4/11	2:53 AM	75.0	-0.9	30.04	-0.030
6/4/11	3:53 AM	75.9	2.0	30.07	-0.020

6/4/11	4:53 AM	75.0	0.0	30.09	0.000
6/4/11	5:53 AM	75.0	-0.9	30.1	0.000
6/4/11	6:53 AM	75.0	-0.9	30.12	0.020
6/4/11	7:53 AM	78.1	-0.9	30.13	0.010
6/4/11	8:53 AM	82.0	0.0	30.14	0.030
6/4/11	9:53 AM	84.9	-1.1	30.14	0.040
6/4/11	10:53 AM	87.1	-3.9	30.13	0.030
6/4/11	11:53 AM	90.0	-5.0	30.12	0.030
6/4/11	12:53 PM	91.0	-6.0	30.12	0.050
6/4/11	1:53 PM	93.9	-4.2	30.11	0.070
6/4/11	2:53 PM	93.9	-6.1	30.1	0.090
6/4/11	3:53 PM	93.9	-7.0	30.09	0.100
6/4/11	4:53 PM	93.9	-6.1	30.08	0.120
6/4/11	5:53 PM	91.9	-5.1	30.07	0.130
6/4/11	6:53 PM	91.0	-0.9	30.06	0.090
6/4/11	7:53 PM	87.1	-4.8	30.07	0.090
6/4/11	8:53 PM	82.9	-7.1	30.08	0.090
6/4/11	9:53 PM	81.0	-8.1	30.1	0.090
6/4/11	10:53 PM	79.0	-9.0	30.11	0.100
6/4/11	11:53 PM	78.1	-9.0	30.1	0.100
6/5/11	12:53 AM	77.0	-7.0	30.1	0.120
6/5/11	1:53 AM	75.9	-7.0	30.09	0.120
6/5/11	2:53 AM	75.9	-4.2	30.07	0.110
6/5/11	3:53 AM	73.9	-6.2	30.09	0.130
6/5/11	4:53 AM	75.0	-3.1	30.09	0.120
6/5/11	5:53 AM	75.9	-2.2	30.1	0.130
6/5/11	6:53 AM	75.9	-3.1	30.1	0.120
6/5/11	7:53 AM	79.0	-5.0	30.12	0.140
6/5/11	8:53 AM	82.0	-4.0	30.11	0.120
6/5/11	9:53 AM	86.0	-4.0	30.1	0.120
6/5/11	10:53 AM	91.0	-2.9	30.1	0.130
6/5/11	11:53 AM	95.0	-1.1	30.09	0.130
6/5/11	12:53 PM	97.0	-3.0	30.07	0.130
6/5/11	1:53 PM	98.1	-1.9	30.04	0.120
6/5/11	2:53 PM	100.0	-0.4	30.01	0.130
6/5/11	3:53 PM	100.9	12.9	29.99	0.130
6/5/11	4:53 PM	100.0	12.9	29.96	0.060
6/5/11	5:53 PM	97.0	15.0	29.94	0.000
6/5/11	6:53 PM	91.9	9.0	29.97	0.050
6/5/11	7:53 PM	91.9	7.9	29.98	0.070
6/5/11	8:53 PM	90.0	7.1	29.99	0.080
6/5/11	9:53 PM	89.1	8.1	30.01	0.100
6/5/11	10:53 PM	88.0	7.9	30.01	0.090
6/5/11	11:53 PM	87.1	9.0	30	0.090

6/6/11	12:53 AM	84.0	7.0	29.98	0.080
6/6/11	1:53 AM	82.9	4.8	29.97	0.080
6/6/11	2:53 AM	80.1	3.1	29.96	0.060
6/6/11	3:53 AM	80.1	4.2	29.96	0.060
6/6/11	4:53 AM	78.1	2.2	29.97	0.070
6/6/11	5:53 AM	78.1	3.1	29.97	0.060
6/6/11	6:53 AM	79.0	4.0	29.98	0.050
6/6/11	7:53 AM	84.0	5.9	29.98	0.040
6/6/11	8:53 AM	86.0	3.1	29.99	0.050
6/6/11	9:53 AM	90.0	4.0	29.98	0.040
6/6/11	10:53 AM	93.9	5.9	29.97	0.030
6/6/11	11:53 AM	96.1	6.1	29.96	0.030
6/6/11	12:53 PM	100.0	19.0	29.94	0.010
6/6/11	1:53 PM	100.0	17.1	29.92	0.010
6/6/11	2:53 PM	100.4	12.4	29.88	-0.010
6/6/11	3:53 PM	88.0	-3.0	29.86	-0.020
6/6/11	4:53 PM	87.1	-3.9	29.9	0.030
6/6/11	5:53 PM	82.0	-8.0	29.94	0.080
6/6/11	6:53 PM	82.9	-3.1	29.92	0.050
6/6/11	7:53 PM	84.0	-0.9	29.91	0.010
6/6/11	8:53 PM	82.9	0.0	29.91	0.010
6/6/11	9:53 PM	81.0	0.0	29.91	-0.010
6/6/11	10:53 PM	80.1	1.1	29.92	-0.020
6/6/11	11:53 PM	78.1	0.0	29.91	-0.030
6/7/11	12:53 AM	77.0	0.0	29.9	-0.050
6/7/11	1:53 AM	78.1	2.2	29.89	-0.040
6/7/11	2:53 AM	77.0	1.1	29.9	-0.010
6/7/11	3:53 AM	75.9	0.9	29.9	-0.010
6/7/11	4:53 AM	75.9	2.0	29.9	-0.010
6/7/11	5:53 AM	75.0	1.1	29.91	-0.020
6/7/11	6:53 AM	75.0	0.0	29.93	-0.010
6/7/11	7:53 AM	78.1	0.0	29.94	-0.020
6/7/11	8:53 AM	82.9	0.0	29.94	-0.030
6/7/11	9:53 AM	86.0	0.0	29.94	-0.040
6/7/11	10:53 AM	88.0	0.0	29.94	-0.030
6/7/11	11:53 AM	90.0	0.7	29.93	-0.030
6/7/11	12:53 PM	81.0	-10.9	29.93	-0.020
6/7/11	1:53 PM	82.9	-8.1	29.91	-0.030
6/7/11	2:53 PM	88.0	-5.0	29.89	-0.040
6/7/11	3:53 PM	91.0	-0.9	29.88	-0.030
6/7/11	4:53 PM	91.0	0.0	29.87	-0.040
6/7/11	5:53 PM	90.0	0.0	29.86	-0.050
6/7/11	6:53 PM	86.0	-2.0	29.87	-0.040
6/7/11	7:53 PM	84.9	0.9	29.9	-0.040

6/7/11	8:53 PM	82.9	0.9	29.9	-0.050
6/7/11	9:53 PM	81.0	0.9	29.92	-0.040
6/7/11	10:53 PM	79.0	0.0	29.94	-0.020
6/7/11	11:53 PM	78.1	0.0	29.94	-0.030
6/8/11	12:53 AM	77.0	0.0	29.95	0.000
6/8/11	1:53 AM	75.9	-1.1	29.93	-0.010
6/8/11	2:53 AM	75.9	0.0	29.91	-0.030
6/8/11	3:53 AM	75.0	-0.9	29.91	-0.030
6/8/11	4:53 AM	73.9	-1.1	29.91	-0.030
6/8/11	5:53 AM	73.9	0.0	29.93	-0.020
6/8/11	6:53 AM	75.0	-0.9	29.94	-0.020
6/8/11	7:53 AM	78.1	-2.0	29.96	-0.020
6/8/11	8:53 AM	82.9	-1.1	29.97	0.000
6/8/11	9:53 AM	86.0	1.1	29.98	0.000
6/8/11	10:53 AM	88.0	-1.1	29.97	0.000
6/8/11	11:53 AM	89.3	0.2	29.96	-0.010
6/8/11	12:53 PM	91.9	-1.1	29.95	0.000
6/8/11	1:53 PM	91.0	-0.9	29.94	0.010
6/8/11	2:53 PM	93.0	-2.0	29.93	0.020
6/8/11	3:53 PM	91.9	-1.1	29.91	0.010
6/8/11	4:53 PM	91.0	-0.9	29.91	0.020
6/8/11	5:53 PM	90.0	0.0	29.91	0.020
6/8/11	6:53 PM	88.0	0.0	29.91	0.010
6/8/11	7:53 PM	84.0	0.0	29.94	0.030
6/8/11	8:53 PM	82.0	0.0	29.95	0.040
6/8/11	9:53 PM	80.1	0.0	29.96	0.040
6/8/11	10:53 PM	79.0	0.0	29.96	0.030
6/8/11	11:53 PM	78.1	0.0	29.97	0.030
6/9/11	12:53 AM	77.0	0.0	29.95	0.020
6/9/11	1:53 AM	77.0	0.0	29.94	0.030
6/9/11	2:53 AM	75.9	0.0	29.94	0.030
6/9/11	3:53 AM	75.9	0.0	29.94	0.030
6/9/11	4:53 AM	75.0	0.0	29.94	0.030
6/9/11	5:53 AM	73.9	-1.1	29.95	0.040
6/9/11	6:53 AM	75.9	2.0	29.96	0.030
6/9/11	7:53 AM	80.1	1.1	29.98	0.040
6/9/11	8:53 AM	84.0	0.0	29.97	0.020
6/9/11	9:53 AM	84.9	-1.1	29.98	0.020
6/9/11	10:53 AM	89.1	1.1	29.97	0.020
6/9/11	11:53 AM	89.1	-2.8	29.97	0.030
6/9/11	12:53 PM	93.0	-0.9	29.95	0.030
6/9/11	1:53 PM	91.9	-2.0	29.93	0.020
6/9/11	2:53 PM	95.0	4.0	29.91	0.020
6/9/11	3:53 PM	93.0	1.1	29.9	0.020

6/9/11	4:53 PM	91.9	0.0	29.89	0.010
6/9/11	5:53 PM	90.0	-1.0	29.89	0.010
6/9/11	6:53 PM	88.0	0.0	29.9	0.030
6/9/11	7:53 PM	84.0	-0.9	29.91	0.020
6/9/11	8:53 PM	82.0	-0.9	29.91	0.020
6/9/11	9:53 PM	80.1	-0.9	29.92	0.010
6/9/11	10:53 PM	79.0	-1.1	29.93	0.020
6/9/11	11:53 PM	78.1	-0.9	29.94	0.030
6/10/11	12:53 AM	77.0	-1.1	29.93	0.020
6/10/11	1:53 AM	77.0	0.0	29.91	0.000
6/10/11	2:53 AM	75.9	-1.1	29.91	0.010
6/10/11	3:53 AM	75.9	0.0	29.91	0.010
6/10/11	4:53 AM	75.0	-0.9	29.91	0.000
6/10/11	5:53 AM	75.0	-0.9	29.91	-0.020
6/10/11	6:53 AM	73.9	0.0	29.93	-0.010
6/10/11	7:53 AM	79.0	-1.1	29.94	-0.010
6/10/11	8:53 AM	84.0	0.0	29.95	-0.010
6/10/11	9:53 AM	86.0	0.0	29.96	-0.010
6/10/11	10:53 AM	88.0	-1.1	29.95	-0.010
6/10/11	11:53 AM	91.9	3.9	29.94	-0.020
6/10/11	12:53 PM	93.9	2.0	29.92	-0.030
6/10/11	1:53 PM	93.9	0.9	29.91	-0.020
6/10/11	2:53 PM	91.0	0.0	29.89	-0.020
6/10/11	3:53 PM	91.9	-1.1	29.88	-0.020
6/10/11	4:53 PM	91.9	0.0	29.88	-0.010
6/10/11	5:53 PM	91.0	0.0	29.88	0.000
6/10/11	6:53 PM	88.0	0.0	29.87	-0.010
6/10/11	7:53 PM	84.9	0.0	29.89	0.000
6/10/11	8:53 PM	82.9	2.8	29.89	-0.010
6/10/11	9:53 PM	81.0	0.9	29.91	0.000
6/10/11	10:53 PM	80.1	2.0	29.91	-0.020
6/10/11	11:53 PM	79.0	2.0	29.91	-0.010
6/11/11	12:53 AM	78.1	1.1	29.91	-0.020
6/11/11	1:53 AM	77.0	2.0	29.91	-0.010
6/11/11	2:53 AM	77.0	2.0	29.9	-0.020
6/11/11	3:53 AM	75.9	0.9	29.9	-0.010
6/11/11	4:53 AM	75.9	2.0	29.91	-0.010
6/11/11	5:53 AM	75.9	3.9	29.93	0.010
6/11/11	6:53 AM	73.9	0.9	29.94	0.010
6/11/11	7:53 AM	80.1	3.1	29.95	0.000
6/11/11	8:53 AM	84.0	2.0	29.96	-0.010
6/11/11	9:53 AM	86.0	1.1	29.97	0.010
6/11/11	10:53 AM	89.1	2.0	29.96	0.000
6/11/11	11:53 AM	88.0	-3.0	29.96	0.000

6/11/11	12:53 PM	91.9	-1.1	29.95	0.000
6/11/11	1:53 PM	93.0	-0.9	29.93	-0.010
6/11/11	2:53 PM	91.0	-4.0	29.91	-0.020
6/11/11	3:53 PM	93.0	-3.1	29.9	-0.010
6/11/11	4:53 PM	91.9	-2.0	29.89	-0.020
6/11/11	5:53 PM	91.0	-2.0	29.88	-0.020
6/11/11	6:53 PM	88.0	-1.1	29.88	-0.030
6/11/11	7:53 PM	84.9	0.0	29.89	-0.030
6/11/11	8:53 PM	80.1	-2.8	29.9	-0.030
6/11/11	9:53 PM	80.1	-0.9	29.91	-0.040
6/11/11	10:53 PM	78.1	-2.0	29.93	-0.040
6/11/11	11:53 PM	77.0	-2.0	29.92	-0.060
6/12/11	12:53 AM	77.0	0.0	29.93	-0.040
6/12/11	1:53 AM	75.0	-2.0	29.92	-0.050
6/12/11	2:53 AM	75.0	-2.0	29.92	-0.050
6/12/11	3:53 AM	75.0	0.0	29.91	-0.060
6/12/11	4:53 AM	73.9	-1.1	29.92	-0.040
6/12/11	5:53 AM	72.0	-3.0	29.92	-0.040
6/12/11	6:53 AM	73.0	-2.0	29.93	-0.060
6/12/11	7:53 AM	77.0	-3.1	29.95	-0.050
6/12/11	8:53 AM	82.0	-2.0	29.97	-0.050
6/12/11	9:53 AM	84.9	-2.2	29.96	-0.060
6/12/11	10:53 AM	87.1	-2.0	29.96	-0.060
6/12/11	11:53 AM	91.0	1.0	29.96	-0.060
6/12/11	12:53 PM	93.0	-0.9	29.95	-0.050
6/12/11	1:53 PM	93.9	0.0	29.94	-0.040
6/12/11	2:53 PM	95.0	0.0	29.93	-0.020
6/12/11	3:53 PM	96.1	1.1	29.91	-0.030
6/12/11	4:53 PM	93.9	-1.1	29.91	-0.020
6/12/11	5:53 PM	93.0	1.1	29.9	-0.030
6/12/11	6:53 PM	89.1	0.0	29.91	-0.020
6/12/11	7:53 PM	84.9	-2.2	29.92	-0.020
6/12/11	8:53 PM	82.9	0.0	29.93	-0.020
6/12/11	9:53 PM	81.0	-1.0	29.95	-0.030
6/12/11	10:53 PM	80.1	0.0	29.97	-0.040
6/12/11	11:53 PM	79.0	0.0	29.98	-0.030
6/13/11	12:53 AM	77.0	-1.1	29.97	-0.030
6/13/11	1:53 AM	77.0	0.0	29.97	-0.020
6/13/11	2:53 AM	77.0	0.0	29.97	-0.010
6/13/11	3:53 AM	75.0	-0.9	29.97	-0.010
6/13/11	4:53 AM	75.0	-0.9	29.96	-0.020
6/13/11	5:53 AM	75.0	0.0	29.96	-0.010
6/13/11	6:53 AM	75.0	0.0	29.99	0.030
6/13/11	7:53 AM	80.1	1.1	30	0.030

6/13/11	8:53 AM	84.0	0.0	30.02	0.030
6/13/11	9:53 AM	87.1	0.0	30.02	0.040
6/13/11	10:53 AM	89.1	-0.9	30.02	0.060
6/13/11	11:53 AM	90.0	-3.0	30.02	0.070
6/13/11	12:53 PM	93.9	-1.1	30	0.070
6/13/11	1:53 PM	93.9	-1.1	29.98	0.080
6/13/11	2:53 PM	95.0	-1.1	29.95	0.070
6/13/11	3:53 PM	95.0	0.0	29.94	0.080
6/13/11	4:53 PM	95.0	-1.1	29.93	0.090
6/13/11	5:53 PM	91.9	-2.0	29.93	0.090
6/13/11	6:53 PM	89.1	-1.9	29.93	0.090
6/13/11	7:53 PM	87.1	0.0	29.94	0.080
6/13/11	8:53 PM	82.9	-1.1	29.95	0.080
6/13/11	9:53 PM	82.0	0.0	29.98	0.110
6/13/11	10:53 PM	80.1	-0.9	30.01	0.130
6/13/11	11:53 PM	79.0	-1.1	30.01	0.140
6/14/11	12:53 AM	78.1	-2.0	30	0.130
6/14/11	1:53 AM	77.0	-3.1	29.99	0.120
6/14/11	2:53 AM	77.0	-2.0	29.98	0.110
6/14/11	3:53 AM	75.9	-2.2	29.98	0.120
6/14/11	4:53 AM	75.9	-1.1	29.98	0.120
6/14/11	5:53 AM	75.0	-2.0	29.97	0.090
6/14/11	6:53 AM	75.0	-3.1	29.96	0.060
6/14/11	7:53 AM	79.0	-2.0	29.97	0.040
6/14/11	8:53 AM	84.0	-0.9	29.99	0.070
6/14/11	9:53 AM	87.1	-0.7	29.98	0.080
6/14/11	10:53 AM	90.0	-1.4	29.96	0.080
6/14/11	11:53 AM	93.0	1.1	29.95	0.070
6/14/11	12:53 PM	95.0	1.8	29.93	0.080
6/14/11	1:53 PM	95.0	-2.0	29.9	0.060
6/14/11	2:53 PM	96.1	0.0	29.88	0.050
6/14/11	3:53 PM	95.0	-2.0	29.86	0.030
6/14/11	4:53 PM	96.1	0.0	29.84	0.030
6/14/11	5:53 PM	93.9	0.9	29.84	0.030
6/14/11	6:53 PM	91.0	1.0	29.84	0.030
6/14/11	7:53 PM	87.1	1.1	29.86	0.040
6/14/11	8:53 PM	84.0	2.0	29.87	0.040
6/14/11	9:53 PM	82.0	0.0	29.87	0.010
6/14/11	10:53 PM	81.0	0.0	29.88	0.020
6/14/11	11:53 PM	80.1	0.0	29.87	0.010
6/15/11	12:53 AM	80.1	0.0	29.87	0.010
6/15/11	1:53 AM	80.1	1.1	29.87	0.010
6/15/11	2:53 AM	79.0	0.0	29.87	0.010
6/15/11	3:53 AM	78.1	0.0	29.86	0.000

6/15/11	4:53 AM	77.0	0.0	29.86	0.000
6/15/11	5:53 AM	77.0	0.0	29.88	0.010
6/15/11	6:53 AM	78.1	1.1	29.9	0.020
6/15/11	7:53 AM	81.0	0.0	29.93	0.040
6/15/11	8:53 AM	84.9	0.0	29.92	0.020
6/15/11	9:53 AM	87.8	-1.8	29.9	0.010
6/15/11	10:53 AM	91.4	-1.6	29.88	-0.010
6/15/11	11:53 AM	91.9	-1.1	29.88	-0.010
6/15/11	12:53 PM	93.2	-1.8	29.85	-0.030
6/15/11	1:53 PM	97.0	0.2	29.84	-0.020
6/15/11	2:53 PM	96.1	-0.9	29.83	-0.020
6/15/11	3:53 PM	97.0	0.9	29.83	-0.010
6/15/11	4:53 PM	96.1	2.2	29.81	-0.010
6/15/11	5:53 PM	93.0	0.0	29.81	0.000
6/15/11	6:53 PM	90.0	0.9	29.81	0.000
6/15/11	7:53 PM	86.0	-1.1	29.82	0.000
6/15/11	8:53 PM	82.0	-2.0	29.83	0.010
6/15/11	9:53 PM	82.0	-0.9	29.86	0.030
6/15/11	10:53 PM	81.0	-1.9	29.86	0.010
6/15/11	11:53 PM	80.1	-1.9	29.86	0.000
6/16/11	12:53 AM	80.1	-1.9	29.86	0.000
6/16/11	1:53 AM	79.0	-2.0	29.86	0.000
6/16/11	2:53 AM	79.0	-2.0	29.86	0.010
6/16/11	3:53 AM	78.1	-3.9	29.86	0.000
6/16/11	4:53 AM	77.0	-5.0	29.86	0.000
6/16/11	5:53 AM	77.0	-4.0	29.87	0.010
6/16/11	6:53 AM	77.0	-4.0	29.88	0.010
6/16/11	7:53 AM	81.0	-1.9	29.89	0.010
6/16/11	8:53 AM	84.9	-1.1	29.9	0.010
6/16/11	9:53 AM	89.6	0.5	29.89	-0.010
6/16/11	10:53 AM	93.0	0.0	29.89	-0.020
6/16/11	11:53 AM	93.0	-0.9	29.89	-0.020
6/16/11	12:53 PM	95.0	1.1	29.88	-0.020
6/16/11	1:53 PM	96.8	-0.2	29.86	-0.030
6/16/11	2:53 PM	97.0	0.9	29.85	-0.030
6/16/11	3:53 PM	96.1	0.0	29.84	-0.030
6/16/11	4:53 PM	93.9	0.0	29.82	-0.040
6/16/11	5:53 PM	93.0	0.0	29.81	-0.050
6/16/11	6:53 PM	89.1	-0.9	29.81	-0.050
6/16/11	7:53 PM	87.1	0.0	29.82	-0.050
6/16/11	8:53 PM	84.0	-0.9	29.82	-0.060
6/16/11	9:53 PM	82.9	0.0	29.83	-0.060
6/16/11	10:53 PM	82.9	0.0	29.85	-0.060
6/16/11	11:53 PM	82.0	0.0	29.86	-0.050

6/17/11	12:53 AM	82.0	0.0	29.86	-0.060
6/17/11	1:53 AM	81.0	-1.0	29.86	-0.050
6/17/11	2:53 AM	81.0	0.0	29.85	-0.050
6/17/11	3:53 AM	82.0	0.0	29.86	-0.050
6/17/11	4:53 AM	82.0	1.0	29.86	-0.060
6/17/11	5:53 AM	81.0	0.0	29.86	-0.070
6/17/11	6:53 AM	81.0	0.9	29.87	-0.080
6/17/11	7:53 AM	82.9	0.0	29.88	-0.080
6/17/11	8:53 AM	86.0	0.0	29.89	-0.080
6/17/11	9:53 AM	89.1	-0.9	29.9	-0.070
6/17/11	10:53 AM	93.0	2.0	29.91	-0.050
6/17/11	11:53 AM	93.9	-1.1	29.91	-0.040
6/17/11	12:53 PM	93.9	-2.2	29.9	-0.040
6/17/11	1:53 PM	97.0	0.0	29.89	-0.030
6/17/11	2:53 PM	96.1	0.0	29.88	-0.030
6/17/11	3:53 PM	96.1	-0.9	29.87	-0.020
6/17/11	4:53 PM	93.9	-1.1	29.86	-0.020
6/17/11	5:53 PM	93.0	-2.0	29.86	-0.020
6/17/11	6:53 PM	90.0	-1.4	29.86	-0.010
6/17/11	7:53 PM	87.1	-2.0	29.87	-0.010
6/17/11	8:53 PM	84.9	0.9	29.88	-0.020
6/17/11	9:53 PM	82.9	0.0	29.89	-0.020
6/17/11	10:53 PM	82.9	0.0	29.91	-0.030
6/17/11	11:53 PM	82.0	0.0	29.91	-0.030
6/18/11	12:53 AM	82.0	0.0	29.92	-0.020
6/18/11	1:53 AM	82.0	0.0	29.91	-0.020
6/18/11	2:53 AM	81.0	-1.0	29.9	-0.020
6/18/11	3:53 AM	82.0	0.0	29.91	-0.010
6/18/11	4:53 AM	81.0	0.0	29.92	0.010
6/18/11	5:53 AM	81.0	0.9	29.93	0.030
6/18/11	6:53 AM	80.1	0.0	29.95	0.040
6/18/11	7:53 AM	82.9	0.0	29.96	0.050
6/18/11	8:53 AM	86.0	1.1	29.97	0.040
6/18/11	9:53 AM	90.0	0.9	29.97	0.050
6/18/11	10:53 AM	91.0	-2.0	29.96	0.050
6/18/11	11:53 AM	95.0	3.1	29.95	0.040
6/18/11	12:53 PM	96.1	1.1	29.94	0.040
6/18/11	1:53 PM	97.0	0.9	29.92	0.040
6/18/11	2:53 PM	96.1	-0.9	29.91	0.060
6/18/11	3:53 PM	97.0	0.9	29.89	0.050
6/18/11	4:53 PM	95.0	3.1	29.88	0.050
6/18/11	5:53 PM	95.0	4.0	29.88	0.060
6/18/11	6:53 PM	91.4	3.4	29.87	0.040
6/18/11	7:53 PM	89.1	3.1	29.88	0.050

6/18/11	8:53 PM	84.0	0.0	29.9	0.060
6/18/11	9:53 PM	82.9	-1.3	29.91	0.070
6/18/11	10:53 PM	82.9	0.0	29.94	0.070
6/18/11	11:53 PM	82.0	0.0	29.94	0.070
6/19/11	12:53 AM	82.0	0.0	29.94	0.080
6/19/11	1:53 AM	82.0	1.0	29.93	0.080
6/19/11	2:53 AM	82.0	1.0	29.92	0.080
6/19/11	3:53 AM	82.0	1.0	29.92	0.090
6/19/11	4:53 AM	81.0	0.9	29.91	0.090
6/19/11	5:53 AM	80.1	0.0	29.9	0.090
6/19/11	6:53 AM	80.1	-0.9	29.91	0.100
6/19/11	7:53 AM	82.9	0.0	29.91	0.100
6/19/11	8:53 AM	84.9	0.0	29.93	0.120
6/19/11	9:53 AM	89.1	1.3	29.92	0.120
6/19/11	10:53 AM	93.0	3.0	29.91	0.110
6/19/11	11:53 AM	91.9	0.9	29.91	0.110
6/19/11	12:53 PM	95.0	4.0	29.9	0.110
6/19/11	1:53 PM	96.1	2.2	29.88	0.100
6/19/11	2:53 PM	97.0	4.0	29.85	0.090
6/19/11	3:53 PM	96.1	1.1	29.84	0.090
6/19/11	4:53 PM	91.9	0.0	29.83	0.080
6/19/11	5:53 PM	91.0	0.0	29.82	0.070
6/19/11	6:53 PM	88.0	-1.1	29.83	0.090
6/19/11	7:53 PM	86.0	0.0	29.83	0.080
6/19/11	8:53 PM	84.0	0.0	29.84	0.100
6/19/11	9:53 PM	84.2	1.3	29.84	0.090
6/19/11	10:53 PM	82.9	0.0	29.87	0.100
6/19/11	11:53 PM	82.0	-0.4	29.87	0.110
6/20/11	12:53 AM	82.0	-0.9	29.86	0.090
6/20/11	1:53 AM	81.0	-1.0	29.85	0.080
6/20/11	2:53 AM	81.0	-1.0	29.84	0.080
6/20/11	3:53 AM	81.0	-1.0	29.83	0.070
6/20/11	4:53 AM	80.1	-1.9	29.82	0.040
6/20/11	5:53 AM	80.1	-1.9	29.81	0.020
6/20/11	6:53 AM	81.0	0.0	29.81	0.010
6/20/11	7:53 AM	82.9	0.0	29.81	0.000
6/20/11	8:53 AM	84.9	-2.2	29.81	0.000
6/20/11	9:53 AM	87.8	-1.3	29.8	-0.030
6/20/11	10:53 AM	90.0	2.9	29.8	-0.030
6/20/11	11:53 AM	91.0	1.4	29.8	-0.020
6/20/11	12:53 PM	91.0	-0.9	29.79	-0.040
6/20/11	1:53 PM	93.9	2.0	29.78	-0.040
6/20/11	2:53 PM	93.0	-3.1	29.76	-0.050
6/20/11	3:53 PM	95.0	0.0	29.75	-0.060

6/20/11	4:53 PM	91.9	-2.0	29.75	-0.030
6/20/11	5:53 PM	91.0	-0.9	29.75	-0.030
6/20/11	6:53 PM	89.1	-0.9	29.74	-0.050
6/20/11	7:53 PM	86.0	0.0	29.75	-0.040
6/20/11	8:53 PM	84.0	0.0	29.74	-0.070
6/20/11	9:53 PM	82.9	0.0	29.75	-0.110
6/20/11	10:53 PM	82.9	0.0	29.77	-0.130
6/20/11	11:53 PM	82.4	-0.5	29.76	-0.120
6/21/11	12:53 AM	82.9	0.0	29.77	-0.110
6/21/11	1:53 AM	82.0	0.0	29.77	-0.120
6/21/11	2:53 AM	82.0	0.0	29.76	-0.120
6/21/11	3:53 AM	82.0	0.0	29.76	-0.110
6/21/11	4:53 AM	82.0	0.0	29.78	-0.110
6/21/11	5:53 AM	82.0	0.0	29.79	-0.090
6/21/11	6:53 AM	81.0	-1.0	29.8	-0.110
6/21/11	7:53 AM	82.9	9.9	29.81	-0.130
6/21/11	8:53 AM	87.1	17.1	29.81	-0.150
6/21/11	9:53 AM	89.1	19.1	29.83	-0.160
6/21/11	10:53 AM	87.1	15.5	29.83	-0.130
6/21/11	11:53 AM	89.6	17.6	29.82	-0.190
6/21/11	12:53 PM	91.9	19.9	29.83	-0.110
6/21/11	1:53 PM	91.9	20.3	29.82	-0.030
6/21/11	2:53 PM	96.1	19.1	29.81	-0.050
6/21/11	3:53 PM	95.0	14.0	29.81	-0.070
6/21/11	4:53 PM	93.9	11.9	29.78	-0.110
6/21/11	5:53 PM	91.9	9.9	29.78	-0.090
6/21/11	6:53 PM	90.0	8.0	29.79	-0.080
6/21/11	7:53 PM	86.0	5.4	29.79	-0.080
6/21/11	8:53 PM	84.0	5.0	29.81	-0.090
6/21/11	9:53 PM	82.9	3.9	29.86	-0.050
6/21/11	10:53 PM	82.9	4.8	29.9	-0.030
6/21/11	11:53 PM	82.9	4.8	29.88	-0.050
6/22/11	12:53 AM	82.9	4.8	29.88	-0.030
6/22/11	1:53 AM	82.0	5.0	29.89	-0.020
6/22/11	2:53 AM	82.0	5.0	29.88	-0.010
6/22/11	3:53 AM	82.0	6.1	29.87	-0.030
6/22/11	4:53 AM	82.0	5.0	29.89	-0.020
6/22/11	5:53 AM	82.0	6.1	29.88	-0.030
6/22/11	6:53 AM	82.0	6.1	29.91	-0.020
6/22/11	7:53 AM	73.0	-4.0	29.94	0.020
6/22/11	8:53 AM	70.0	-9.0	29.96	0.010
6/22/11	9:53 AM	70.0	-12.0	29.99	0.050
6/22/11	10:53 AM	71.6	-10.4	29.96	0.020
6/22/11	11:53 AM	72.0	-15.1	30.01	0.080

6/22/11	12:53 PM	72.0	-15.1	29.94	0.020
6/22/11	1:53 PM	71.6	-19.4	29.85	-0.060
6/22/11	2:53 PM	77.0	-14.4	29.86	-0.030
6/22/11	3:53 PM	81.0	-12.0	29.88	-0.010
6/22/11	4:53 PM	82.0	-9.9	29.89	0.020
6/22/11	5:53 PM	82.0	-9.4	29.87	0.030
6/22/11	6:53 PM	82.0	-6.0	29.87	0.000
6/22/11	7:53 PM	80.6	-5.4	29.87	-0.010
6/22/11	8:53 PM	79.0	-3.9	29.9	0.020
6/22/11	9:53 PM	79.0	-2.0	29.91	0.030
6/22/11	10:53 PM	78.1	-2.9	29.93	0.030
6/22/11	11:53 PM	78.1	-2.0	29.93	0.040
6/23/11	12:53 AM	78.1	-0.9	29.91	0.020
6/23/11	1:53 AM	77.0	-1.1	29.91	0.030
6/23/11	2:53 AM	77.0	0.0	29.89	0.010
6/23/11	3:53 AM	75.9	-1.1	29.9	0.050
6/23/11	4:53 AM	77.0	0.0	29.91	0.060
6/23/11	5:53 AM	75.9	-1.1	29.91	0.080
6/23/11	6:53 AM	75.9	-1.1	29.93	0.070
6/23/11	7:53 AM	77.0	-3.1	29.92	0.040
6/23/11	8:53 AM	79.0	-1.1	29.95	0.050
6/23/11	9:53 AM	82.0	-2.9	29.94	0.060
6/23/11	10:53 AM	82.0	-2.0	29.94	0.050
6/23/11	11:53 AM	87.1	2.2	29.93	0.040
6/23/11	12:53 PM	87.1	-2.9	29.92	0.040
6/23/11	1:53 PM	91.0	1.0	29.91	0.040
6/23/11	2:53 PM	91.4	1.4	29.89	0.040
6/23/11	3:53 PM	93.0	3.0	29.89	0.060
6/23/11	4:53 PM	91.9	2.8	29.87	0.040
6/23/11	5:53 PM	91.4	3.6	29.84	0.020
6/23/11	6:53 PM	88.0	2.0	29.87	0.040
6/23/11	7:53 PM	86.0	3.1	29.88	0.030
6/23/11	8:53 PM	82.9	0.5	29.88	0.040
6/23/11	9:53 PM	81.0	0.0	29.88	0.010
6/23/11	10:53 PM	81.0	0.0	29.9	0.030
6/23/11	11:53 PM	80.1	0.0	29.89	0.020
6/24/11	12:53 AM	79.0	-1.1	29.89	0.040
6/24/11	1:53 AM	78.1	-0.9	29.88	0.030
6/24/11	2:53 AM	77.0	-1.8	29.88	0.060
6/24/11	3:53 AM	77.0	-1.1	29.85	0.010
6/24/11	4:53 AM	77.0	-1.8	29.85	0.010
6/24/11	5:53 AM	77.0	-1.1	29.83	-0.030
6/24/11	6:53 AM	77.0	-1.1	29.86	-0.020
6/24/11	7:53 AM	80.1	-0.9	29.88	-0.010

6/24/11	8:53 AM	80.1	-2.8	29.9	0.000
6/24/11	9:53 AM	84.9	-2.2	29.88	-0.010
6/24/11	10:53 AM	84.0	-5.1	29.89	0.000
6/24/11	11:53 AM	84.9	-5.1	29.89	-0.010
6/24/11	12:53 PM	90.0	-1.9	29.88	-0.020
6/24/11	1:53 PM	90.0	-1.0	29.87	-0.010
6/24/11	2:53 PM	90.0	-3.0	29.85	-0.030
6/24/11	3:53 PM	90.0	-1.9	29.83	-0.040
6/24/11	4:53 PM	89.1	-2.8	29.83	-0.030
6/24/11	5:53 PM	87.8	-2.2	29.82	-0.040
6/24/11	6:53 PM	86.0	-2.0	29.83	-0.050
6/24/11	7:53 PM	82.9	-3.1	29.85	-0.040
6/24/11	8:53 PM	82.4	-0.5	29.84	-0.060
6/24/11	9:53 PM	81.0	-1.0	29.87	-0.040
6/24/11	10:53 PM	81.0	0.0	29.87	-0.050
6/24/11	11:53 PM	80.1	0.0	29.87	-0.050
6/25/11	12:53 AM	80.1	1.1	29.85	-0.060
6/25/11	1:53 AM	79.0	0.0	29.85	-0.050
6/25/11	2:53 AM	78.8	-0.2	29.82	-0.070
6/25/11	3:53 AM	78.1	-0.9	29.84	-0.050
6/25/11	4:53 AM	78.8	0.7	29.84	-0.050
6/25/11	5:53 AM	78.1	0.0	29.86	-0.040
6/25/11	6:53 AM	78.1	0.0	29.88	-0.030
6/25/11	7:53 AM	81.0	0.0	29.89	-0.040
6/25/11	8:53 AM	82.9	-2.0	29.9	-0.040
6/25/11	9:53 AM	87.1	-0.9	29.89	-0.060
6/25/11	10:53 AM	89.1	0.0	29.89	-0.060
6/25/11	11:53 AM	90.0	-1.0	29.9	-0.050
6/25/11	12:53 PM	91.9	0.0	29.9	-0.040
6/25/11	1:53 PM	91.0	0.0	29.88	-0.050
6/25/11	2:53 PM	93.0	1.1	29.88	-0.030
6/25/11	3:53 PM	91.9	-2.0	29.87	-0.030
6/25/11	4:53 PM	91.9	0.5	29.86	-0.020
6/25/11	5:53 PM	90.0	-1.0	29.86	-0.020
6/25/11	6:53 PM	88.0	-1.1	29.88	0.000
6/25/11	7:53 PM	86.0	0.0	29.89	0.000
6/25/11	8:53 PM	82.9	0.0	29.9	-0.010
6/25/11	9:53 PM	82.0	0.0	29.91	-0.010
6/25/11	10:53 PM	81.0	0.0	29.92	-0.020
6/25/11	11:53 PM	80.1	0.0	29.92	-0.030
6/26/11	12:53 AM	79.0	-1.1	29.91	-0.030
6/26/11	1:53 AM	79.0	0.0	29.9	-0.040
6/26/11	2:53 AM	79.0	0.0	29.89	-0.030
6/26/11	3:53 AM	79.0	0.0	29.89	-0.030

6/26/11	4:53 AM	78.1	0.0	29.89	-0.030
6/26/11	5:53 AM	78.1	1.1	29.9	-0.030
6/26/11	6:53 AM	78.1	0.0	29.91	-0.010
6/26/11	7:53 AM	81.0	0.0	29.93	-0.020
6/26/11	8:53 AM	84.9	0.0	29.94	-0.020
6/26/11	9:53 AM	88.0	0.9	29.95	-0.020
6/26/11	10:53 AM	89.1	-0.9	29.95	-0.020
6/26/11	11:53 AM	91.0	-0.9	29.95	-0.010
6/26/11	12:53 PM	91.9	-1.1	29.94	-0.010
6/26/11	1:53 PM	91.0	-2.9	29.93	-0.020
6/26/11	2:53 PM	91.9	-2.0	29.91	-0.030
6/26/11	3:53 PM	93.9	0.0	29.9	-0.030
6/26/11	4:53 PM	91.4	-1.6	29.88	-0.050
6/26/11	5:53 PM	91.0	-0.9	29.88	-0.050
6/26/11	6:53 PM	89.1	-0.9	29.88	-0.060
6/26/11	7:53 PM	86.0	0.0	29.89	-0.070
6/26/11	8:53 PM	82.9	-1.1	29.91	-0.080
6/26/11	9:53 PM	82.0	-0.9	29.92	-0.090
6/26/11	10:53 PM	81.0	-1.0	29.94	-0.090
6/26/11	11:53 PM	80.1	-0.9	29.95	-0.080
6/27/11	12:53 AM	80.1	0.0	29.94	-0.080
6/27/11	1:53 AM	79.0	-1.1	29.94	-0.070
6/27/11	2:53 AM	79.0	0.0	29.92	-0.080
6/27/11	3:53 AM	79.0	0.0	29.92	-0.070
6/27/11	4:53 AM	78.1	0.0	29.92	-0.070
6/27/11	5:53 AM	77.0	-1.1	29.93	-0.080
6/27/11	6:53 AM	78.1	0.0	29.92	-0.090
6/27/11	7:53 AM	81.0	0.9	29.95	-0.070
6/27/11	8:53 AM	84.9	0.9	29.96	-0.080
6/27/11	9:53 AM	87.1	0.0	29.97	-0.070
6/27/11	10:53 AM	90.0	0.9	29.97	-0.070
6/27/11	11:53 AM	91.9	-1.1	29.96	-0.080
6/27/11	12:53 PM	93.0	1.1	29.95	-0.080
6/27/11	1:53 PM	93.9	0.0	29.95	-0.060
6/27/11	2:53 PM	93.9	-1.1	29.94	-0.060
6/27/11	3:53 PM	93.9	0.7	29.93	-0.060
6/27/11	4:53 PM	93.0	-0.9	29.93	-0.060
6/27/11	5:53 PM	91.9	0.0	29.93	-0.060
6/27/11	6:53 PM	90.0	-1.0	29.94	-0.040
6/27/11	7:53 PM	86.0	-1.1	29.96	-0.010
6/27/11	8:53 PM	84.0	-0.2	29.99	0.020
6/27/11	9:53 PM	82.9	0.5	30.01	0.030
6/27/11	10:53 PM	82.0	0.0	30.03	0.000
6/27/11	11:53 PM	81.0	-1.0	30.03	-0.020

6/28/11	12:53 AM	80.1	-0.9	30.02	-0.020
6/28/11	1:53 AM	80.1	1.1	30.01	0.010
6/28/11	2:53 AM	79.0	0.0	30	0.010
6/28/11	3:53 AM	79.0	0.2	29.99	0.040
6/28/11	4:53 AM	78.1	1.1	29.99	0.020
6/28/11	5:53 AM	78.1	0.0	30.01	0.020
6/28/11	6:53 AM	78.1	-0.9	30.01	-0.010
6/28/11	7:53 AM	80.1	-1.9	30.02	-0.020
6/28/11	8:53 AM	84.0	-0.9	30.04	-0.020
6/28/11	9:53 AM	87.1	0.0	30.04	-0.020
6/28/11	10:53 AM	89.1	0.0	30.04	-0.010
6/28/11	11:53 AM	93.0	0.0	30.04	0.000
6/28/11	12:53 PM	91.9	0.0	30.03	0.000
6/28/11	1:53 PM	93.9	-1.1	30.01	0.000
6/28/11	2:53 PM	95.0	0.0	30	0.010
6/28/11	3:53 PM	93.2	-1.8	29.99	0.030
6/28/11	4:53 PM	93.9	-2.2	29.99	0.040
6/28/11	5:53 PM	91.9	-2.0	29.99	0.050
6/28/11	6:53 PM	91.0	-0.9	29.98	0.040
6/28/11	7:53 PM	87.1	-2.0	29.97	0.020
6/28/11	8:53 PM	84.2	-1.8	29.97	0.020
6/28/11	9:53 PM	82.4	-1.6	29.98	0.020
6/28/11	10:53 PM	82.0	0.0	30.03	0.050
6/28/11	11:53 PM	82.0	1.0	30.05	0.090
6/29/11	12:53 AM	81.0	0.9	30.04	0.080
6/29/11	1:53 AM	79.0	0.0	30	0.050
6/29/11	2:53 AM	79.0	0.9	29.99	0.050
6/29/11	3:53 AM	78.8	0.7	29.95	0.000
6/29/11	4:53 AM	77.0	0.0	29.97	0.020
6/29/11	5:53 AM	78.1	1.1	29.99	0.020
6/29/11	6:53 AM	79.0	0.9	30.02	0.030
6/29/11	7:53 AM	82.0	0.0	30.04	0.030
6/29/11	8:53 AM	84.9	0.7	30.06	0.040
6/29/11	9:53 AM	87.1	0.0	30.06	0.030
6/29/11	10:53 AM	89.1	-0.9	30.05	0.040
6/29/11	11:53 AM	93.0	0.0	30.04	0.030
6/29/11	12:53 PM	91.9	0.0	30.03	0.020
6/29/11	1:53 PM	95.0	0.0	30.01	0.020
6/29/11	2:53 PM	95.0	-3.1	29.99	0.020
6/29/11	3:53 PM	95.0	-1.1	29.96	0.010
6/29/11	4:53 PM	96.1	-0.9	29.95	0.020
6/29/11	5:53 PM	93.9	-1.1	29.94	0.020
6/29/11	6:53 PM	91.9	0.0	29.94	0.020
6/29/11	7:53 PM	89.1	0.0	29.95	0.010

6/29/11	8:53 PM	86.0	1.1	29.95	0.000
6/29/11	9:53 PM	84.0	1.1	29.96	0.000
6/29/11	10:53 PM	82.0	1.0	29.98	0.000
6/29/11	11:53 PM	81.0	0.9	29.96	-0.020
6/30/11	12:53 AM	80.1		29.96	
6/30/11	1:53 AM	79.0		29.95	
6/30/11	2:53 AM	78.1		29.94	
6/30/11	3:53 AM	78.1		29.95	
6/30/11	4:53 AM	77.0		29.95	
6/30/11	5:53 AM	77.0		29.97	
6/30/11	6:53 AM	78.1		29.99	
6/30/11	7:53 AM	82.0		30.01	
6/30/11	8:53 AM	84.2		30.02	
6/30/11	9:53 AM	87.1		30.03	
6/30/11	10:53 AM	90.0		30.01	
6/30/11	11:53 AM	93.0		30.01	
6/30/11	12:53 PM	91.9		30.01	
6/30/11	1:53 PM	95.0		29.99	
6/30/11	2:53 PM	98.1		29.97	
6/30/11	3:53 PM	96.1		29.95	
6/30/11	4:53 PM	97.0		29.93	
6/30/11	5:53 PM	95.0		29.92	
6/30/11	6:53 PM	91.9		29.92	
6/30/11	7:53 PM	89.1		29.94	
6/30/11	8:53 PM	84.9		29.95	
6/30/11	9:53 PM	82.9		29.96	
6/30/11	10:53 PM	81.0		29.98	
6/30/11	11:53 PM	80.1		29.98	

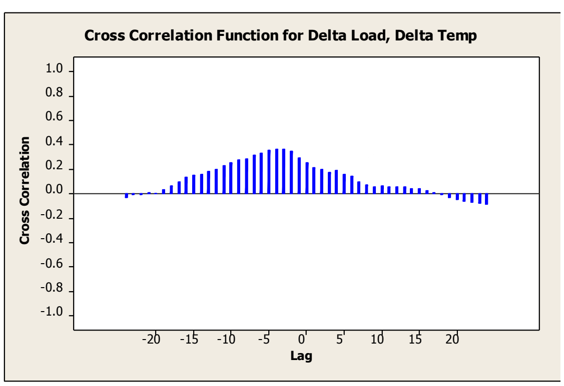
APPENDIX C

CROSS-CORRELATION RESULTS FROM MINITAB

Cross Correlation Function: Delta Load, Delta Temp

CCF - correlates Delta Load(t) and Delta Temp(t+k)

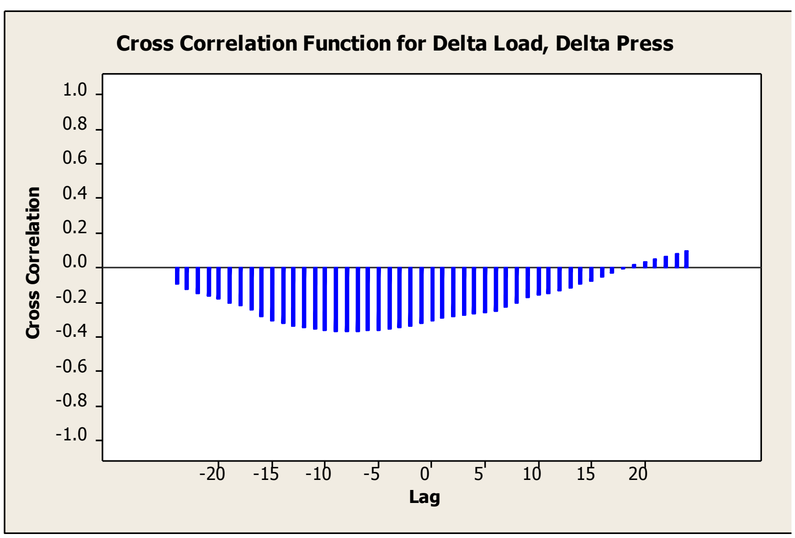
Lag	CCF	Lag	CCF
-24	-0.027898	0	0.255355
-23	-0.005035	1	0.210231
-22	-0.010837	2	0.198278
-21	0.004901	3	0.174270
-20	-0.000430	4	0.186878
-19	0.029439	5	0.157737
-18	0.059225	6	0.138963
-17	0.098450	7	0.095967
-16	0.136095	8	0.068936
-15	0.152391	9	0.058711
-14	0.158362	10	0.060547
-13	0.179699	11	0.056546
-12	0.200736	12	0.051366
-11	0.224806	13	0.052937
-10	0.253539	14	0.037517
-9	0.272814	15	0.036367
-8	0.284112	16	0.025884
-7	0.317066	17	0.005189
-6	0.330869	18	-0.011833
-5	0.355404	19	-0.031030
-4	0.366560	20	-0.049789
-3	0.364377	21	-0.063620
-2	0.349238	22	-0.069751
-1	0.294018	23	-0.079166
		24	-0.083770



Cross Correlation Function: Delta Load, Delta Press

CCF - correlates Delta Load(t) and Delta Press(t+k)

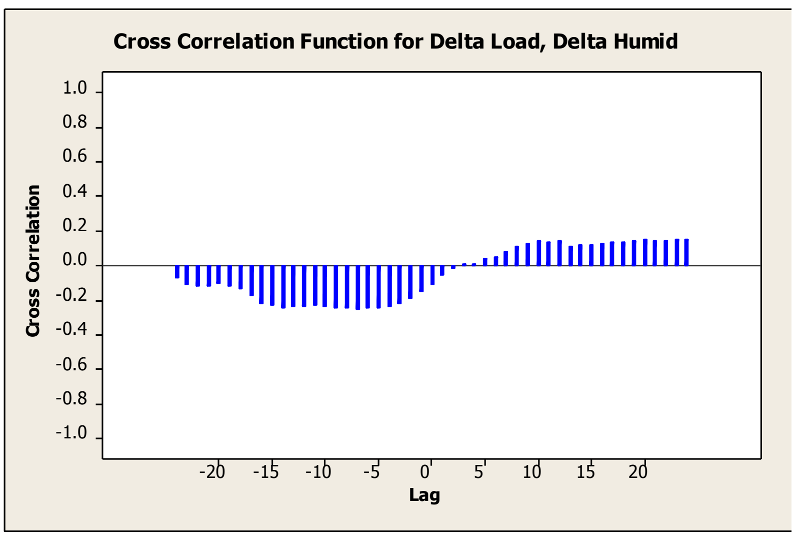
Lag	CCF	Lag	CCF
-24	-0.095833	0	-0.307932
-23	-0.125724	1	-0.293606
-22	-0.147357	2	-0.282074
-21	-0.164682	3	-0.274616
-20	-0.184004	4	-0.267393
-19	-0.203451	5	-0.261280
-18	-0.220479	6	-0.251901
-17	-0.248419	7	-0.231399
-16	-0.285192	8	-0.201136
-15	-0.309625	9	-0.175994
-14	-0.326933	10	-0.160690
-13	-0.340491	11	-0.146313
-12	-0.350139	12	-0.132481
-11	-0.356274	13	-0.114465
-10	-0.364598	14	-0.093375
-9	-0.367970	15	-0.077100
-8	-0.369039	16	-0.056386
-7	-0.369813	17	-0.031663
-6	-0.363955	18	-0.010270
-5	-0.361065	19	0.015153
-4	-0.352740	20	0.033737
-3	-0.343683	21	0.049296
-2	-0.335719	22	0.065914
-1	-0.322006	23	0.082312
		24	0.096579



Cross Correlation Function: Delta Load, Delta Humid

CCF - correlates Delta Load(t) and Delta Humid(t+k)

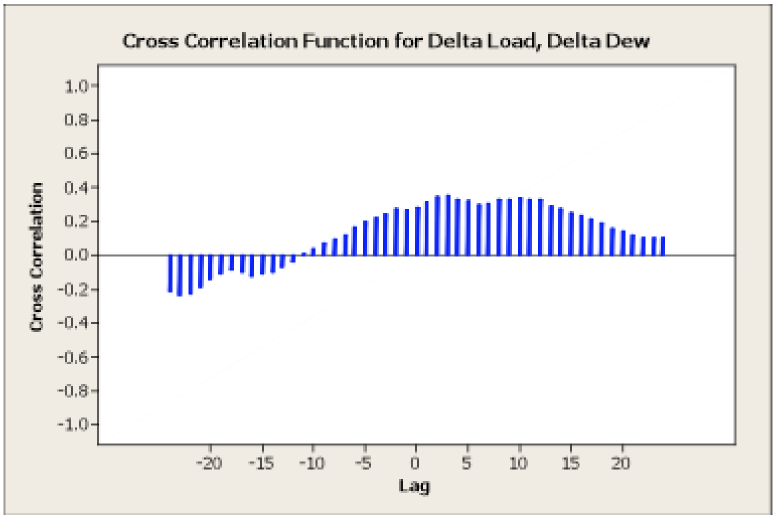
Lag	CCF	Lag	CCF
-24	-0.074573	0	-0.109962
-23	-0.111638	1	-0.051444
-22	-0.114514	2	-0.017585
-21	-0.115924	3	0.010810
-20	-0.100869	4	0.007404
-19	-0.120611	5	0.039866
-18	-0.134435	6	0.046596
-17	-0.171377	7	0.080884
-16	-0.220976	8	0.114213
-15	-0.232476	9	0.129453
-14	-0.240592	10	0.138240
-13	-0.239042	11	0.137900
-12	-0.237037	12	0.139865
-11	-0.227989	13	0.112801
-10	-0.239839	14	0.118167
-9	-0.247141	15	0.116352
-8	-0.245165	16	0.123099
-7	-0.255973	17	0.132021
-6	-0.240790	18	0.136537
-5	-0.241751	19	0.138224
-4	-0.238825	20	0.151519
-3	-0.218618	21	0.143529
-2	-0.187137	22	0.138486
-1	-0.152631	23	0.149896
		24	0.148024



Cross Correlation Function: Delta Load, Delta Dew

CCF - correlates Delta Load(t) and Delta Dew(t+k)

Lag	CCF	Lag	CCF
-24	-0.212437	0	0.287531
-23	-0.232716	1	0.316022
-22	-0.225335	2	0.349319
-21	-0.190419	3	0.354869
-20	-0.142213	4	0.335002
-19	-0.111746	5	0.327013
-18	-0.090280	6	0.303043
-17	-0.099741	7	0.310319
-16	-0.122349	8	0.329185
-15	-0.107575	9	0.331015
-14	-0.104818	10	0.338921
-13	-0.072202	11	0.329463
-12	-0.039581	12	0.328986
-11	0.010423	13	0.291781
-10	0.040625	14	0.272470
-9	0.067053	15	0.254239
-8	0.091033	16	0.237109
-7	0.119916	17	0.213218
-6	0.162756	18	0.187288
-5	0.195378	19	0.159509
-4	0.217260	20	0.143982
-3	0.245652	21	0.117743
-2	0.275964	22	0.099161
-1	0.270894	23	0.101221
		24	0.101928



APPENDIX D

REMAINING CASE STUDY RESULTS FOR CONTROL CHART PARAMETERS

i	RMax	Tau Hat	Delta Hat
101	4.299819374	100	-132.6225907
102	3.220393822	85	32.14270561
103	3.436339994	85	32.34311442
104	3.32451251	85	30.81090874
105	3.354203539	85	30.10858969
106	2.546178453	85	24.92329092
107	2.210428329	85	22.29033676
108	1.980826923	46	10.71800455
109	2.071347895	85	20.35722945
110	1.758974302	46	9.600343206
111	1.583189823	46	8.761095154
112	2.479984781	110	-84.04096507
113	2.511392375	110	-73.85097728
114	1.828410751	106	-44.05567716
115	2.223216887	106	-45.86803325
116	2.676057271	106	-47.76247768
117	2.671268389	106	-45.89429081
118	2.429772862	106	-42.45067397
119	2.515153191	106	-41.71198798
120	2.490896599	106	-40.2859256
121	2.499683615	106	-39.21803867
122	2.64608055	106	-39.15416533
123	2.586950855	106	-37.80901685
124	2.358596045	106	-35.4740502
125	2.367669356	125	129.4498073
126	1.74324416	106	-29.87387021
127	6.723865884	127	-230.8925159
128	15.62345569	127	-248.5011946
129	6.587402733	129	219.0931361
130	16.5122154	130	-359.1370854
131	23.22310011	131	415.534611
132	14.98544024	131	233.9794465
133	6.284306237	131	121.4792925
134	3.51945411	131	77.06002504
135	2.969457428	106	-32.18470366

136	2.924529076	106	-31.53354638
137	2.840946804	106	-30.73218721
138	2.918700843	106	-30.68324444
139	2.332882494	106	-27.59114127
140	2.240131412	106	-26.81028486
141	2.295998373	106	-26.77129231
142	2.132231994	106	-25.68249119
143	2.034362998	99	-23.28970532
144	2.035133462	99	-23.09051265
145	1.998139957	99	-22.7286152
146	1.903727726	99	-22.11484545
147	1.862942401	99	-21.75156356
148	1.854455241	99	-21.54226244
149	1.80946213	99	-21.17379813
150	1.826447551	99	-21.09125416
151	5.386299666	151	197.6603302
152	5.819581689	151	144.0219668
153	5.592283015	153	-210.9870075
154	45.60011343	154	584.1821746
155	15.3588377	155	-346.5359659
156	12.04907908	155	-218.8093664
157	8.475881319	155	-151.3387805
158	5.664339105	155	-108.5289157
159	4.449693425	155	-87.01982699
160	5.033017446	155	-84.62273585
161	2.8121129	155	-60.02370352
162	2.050722767	131	17.3315391
163	1.963170765	155	-45.47853941
164	1.843615127	131	15.56200198
165	1.924909847	131	15.70632834
166	1.825582775	131	14.89306292
167	1.789319244	131	14.43247628
168	1.805546215	131	14.26405947
169	1.844524633	131	14.220224
170	1.850617685	131	14.01254767
171	1.854295856	131	13.8007722
172	1.844086744	131	13.52812736
173	1.393098277	131	10.95132994
174	1.780762553	131	12.79873905
175	1.38282301	131	10.54183185
176	4.543839005	176	181.1586404
177	5.675537406	176	142.1692994
178	4.496849627	178	-189.6876489
179	4.05303368	178	-128.898677
180	1.714401132	178	-70.6751913
181	1.638724445	131	10.8868072
182	1.610782336	131	10.60319686
183	1.626311721	131	10.53081463

184	2.032957911	131	12.17543584
185	1.61212724	131	10.18493177
186	1.436195185	131	9.220273864
187	1.413012447	131	8.985032578
188	1.394109934	131	8.774786621
189	1.195098636	131	7.666013062
190	1.174877444	131	7.457566871
191	1.075734186	131	6.835184177
192	1.041535265	131	6.55732449
193	0.954171225	131	5.986654697
194	0.940410808	131	5.825408581
195	0.928530171	131	5.677297882
196	0.93598335	131	5.639462785
197	1.992497675	197	118.3594334
198	1.784843993	198	-121.2608278
199	1.208256645	199	91.11843677
200	1.295770483	131	7.119355732
201	1.036561111	201	-93.53904807
202	1.071415355	131	5.892412423
203	1.134903214	131	6.127827934
204	1.127247638	131	6.017614259
205	1.12478834	131	5.933943848
206	1.163397267	131	6.044003345
207	1.124105998	131	5.791128076
208	1.231814971	131	6.213482056
209	1.218851464	131	6.08643924
210	1.271697587	131	6.249413635
211	1.170017379	131	5.735357938
212	1.122212057	131	5.456204245
213	1.182164849	131	5.661915772
214	1.121667506	131	5.331567157
215	1.193762237	131	5.58906323
216	1.195831357	131	5.537698746
217	1.306674501	131	5.941799338
218	1.351300018	131	6.060845305
219	1.430944028	131	6.312113583
220	1.592644071	131	6.855216595
221	1.721680339	131	7.24958567
222	1.456999494	131	6.228895665
223	1.468987272	131	6.214544657
224	4.870500119	224	-197.2178794
225	1.502466507	222	-58.19691475
226	2.782179396	224	-88.73328707
227	1.484069989	222	-48.12055392
228	2.548739277	227	93.70625823
229	2.733359496	227	78.50039164
230	1.981288248	227	56.63313982
231	1.603989928	227	44.65003909

232	1.308620856	131	5.132017166
233	1.290972605	131	5.017435209
234	1.311161765	131	5.046064501
235	1.319317854	131	5.029586861
236	1.302097944	131	4.919659029
237	1.288720603	131	4.824836664
238	1.288890931	131	4.781051975
239	1.283115164	131	4.715974624
240	1.291726104	131	4.704418982
241	1.259311476	131	4.542957493
242	1.299393197	131	4.647411864
243	1.265850646	131	4.484256789
244	1.285615933	131	4.515152346
245	1.217282344	131	4.226387028
246	2.695218761	246	138.4317418
247	1.834844675	246	78.78781764
248	4.38912036	246	100.742764
249	3.588567573	246	77.85935865
250	3.471248534	250	-167.2348334
251	1.995342126	250	-91.85744801
252	4.299756366	250	-109.1561039
253	5.162781965	250	-103.8276459
254	4.198122967	254	173.9464916
255	2.016751996	254	82.83078863
256	1.347693302	131	4.273274724
257	1.614793427	254	50.66617065
258	1.348063869	131	4.203761469
259	1.391867576	131	4.312692895
260	1.381740722	131	4.24489442
261	1.387381736	131	4.228775651
262	1.423723724	131	4.311061668
263	1.416280029	131	4.253327518
264	1.396219203	131	4.155957493
265	1.543369571	131	4.578596218
266	1.319442317	131	3.843862036
267	1.282205859	131	3.690818084
268	1.18588165	266	-59.57908836
269	1.287490658	266	-54.22546935
270	1.574674019	266	-53.68931159
271	2.097833438	266	-56.31547702
272	1.379819559	266	-43.46695329
273	1.533766566	266	-42.93327
274	9.543933875	274	264.6820133
275	2.38677541	274	90.52674928
276	1.259605906	274	51.76505912
277	1.749262644	274	52.92723389
278	3.126802595	278	-158.962539
279	2.374534766	278	-99.7748898

280	2.460945413	278	-83.73599796
281	2.674847512	278	-76.06438223
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290	0.93102744	275	-25.78420797
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293	0.857564927	275	-23.27471333
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353	0.735994269	131	0.263928127
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358	0.694766264	131	0.067902688
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399	1.235200314	131	1.163412154
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692	1.932577555	131	0.3678465

APPENDIX E

PROGRAMS FOR SIMULATION

A request for the Java programs can be made by emailing *bvela55@gmail.com*

BIOGRAPHICAL SKETCH

Becky M. Vela graduated December 2012 with a Master of Science with a major of Manufacturing Engineering from the University of Texas Pan -American. Becky pursued many opportunities to further her knowledge in the field of manufacturing by becoming a Graduate Research Assistant at the University of Texas Pan American. Also, she had the opportunity to gain experience by becoming an adjunct professor with the Precision Manufacturing Technology department at South Texas College. Both of these opportunities aided in enhancing her knowledge and skills necessary to be successful in this field. On the subject of future employment, her work comprises of optimizing manufacturing plants with the use of quality control tools, along with all other knowledge gained throughout her education as a manufacturing engineer.