February 26, 1973

To the Graduate Council:

I am submitting herewith a thesis written by Satish Kumar Ailawadhi entitled "Daily Load Forecasting Using Weather Information." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Electrical Engineering.

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DAILY LOAD FORECASTING USING WEATHER INFORMATION

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Satish Kumar Ailawadhi

March 1973

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ABSTRACT

The purpose of the study was to develop a forecasting model which utilizes the historical load data and latest weather information in making the load forecast of a particular hour for a day of the week. The technique then could be extended for developing such different models for all hours of the day and thereby leading to the ultimate objective of daily load forecasting. The studies have been carried out on treatment of actual data obtained from Knoxville Utilities Board and Weather Bureau. The load demand at any hour has been first separated into two components, the base load and weather sensitive component. These two components are forecasted separately and then combined to get total forecast. In developing the weather load model efforts have been made to identify the variables to which weather dependent part of the load is sensitive. A multiple linear regression program was employed for calculating the independent variable coefficients of the model. The model-developed has been tested for its performance with the data collected from the two sources mentioned above. The model calculated demand as compared with the actual demand recorded shows that the method of load forecasting is quite accurate and so the value of the technique is established.

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CHAPTER I

INTRODUCTION

Since the earliest days of the electric utility industry, system load has been responsive to changes in weather conditions. Therefore, in order to obtain high accuracy a forecaster must be concerned with weather variations and the consequent load swings. This is because of the fact that the weather sensitive component of the load demand is a rapidly changing component and contains fast hour-to-hour variations in the load. Today's need for better forecasting accuracy, therefore, has brought the weather effects into sharp focus as an important component for daily forecasting of load demand. Taking this aspect into consideration efforts have been made, in the course of this study, to identify the different variables to which the weather dependent part of the load is sensitive. The problem of short term load forecasting (up to 24 hours) has been the subject of several recent publications (1, 2, 3)*, but the different weather variables have not been considered which are responsible for the load variations.

The studies have been carried out on treatment of actual load data and the weather variables. The load is

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*Numbers in parentheses refer to similarly numbered items in the Bibliography.

first separated into two components, the base load and the weather-sensitive component. Each component is then forecasted separately and then combined to get the total forecast. Since the two components grow at different rates such procedure had to be adopted to get better accuracy.

Three weather variables, temperature, wind speed and cloud cover, are considered for obtaining weather load model. An available multiple linear regression program was adapted to the problem, which by the method of least squares calculated the coefficients of various weather variables in the model. In addition, the relative importance of each independent variable was also calculated.

The model developed by this technique has been tested for its performance with the actual data. It is observed that the difference between recorded demand and the model-calculated demand is very small and the percentage error is within that required by the industry.

CHAPTER II

LOAD FORECASTING

Large capital investment is characteristic of the electric power industry. This results in capital charges being a large component of the total power cost. Therefore, to the extent feasible, systems strive to build only those facilities needed to serve load requirements fully and reliably. However, unrestricted use of power is taken for granted in our society, and accordingly it is essential that sufficient facilities be ready when needed. In meeting these dual objectives lies the importance of accurate load forecasting.

The need for comprehensive study of the methodology of electric utility load forecasting has been increasingly recognized primarily due to two factors: greater volatility of load because of larger components of weather-sensitive load and lengthening lead times for planning and installing bulk supply facilities. These studies have been limited to short term forecasts which are effected largely by the weather variations.

I. NEED FOR LOAD FORECASTING

Estimate of both demand and energy requirements in the future constitute the foundation for planning in the

electric utility industry. Every distributor of electric power, large or small, should have demand and energy forecasts available upon which to base its physical and financial planning. Others associated with the industry, such as suppliers, regulatory agencies and heavy equipment manufacturers, also need such forecasts to carry out their functions.

Electric Systems

Electric utilities plan the capacity of their physical system to meet expected peak demand requirements. Demand forecasts are the basis for planning additions to generating capacity as well as to transmission and distribution plant. In addition to maximum demand forecasts, the load shape (hour-by-hour demand estimates for the period) may influence the choice of kind of generating capacity. For example, peaking units as opposed to base load capacity, might be used when maximum demands are of short duration. Such forecasts can also be useful for evaluating interchange capabilities and joint planning with other systems.

Regulatory Agencies

Regulatory agencies need demand and energy forecasts and an understanding of the basis on which these forecasts are made in the performance of their regulatory functions

of rate review, facilities evaluation, interchange evaluation and merger review.

Suppliers

Manufacturers and other suppliers to the electric utility industry rely on demand and energy forecasts in order to plan the manufacturing capabilities required for the production of generators, turbines, transformers, line materials and other utility plant components.

Continued growth in the use of electric power has demanded and produced new technological developments in all components of electric utility plant. It is through the use of forecasts that the industry can anticipate the limitations of equipment currently in use and engage in the necessary research and development to make equipment available to meet future requirements.

II. TIME SPANS

The purpose of a forecast usually determines the time period to be covered and accuracy needed. The forecasts are usually divided into four time categories:

1. The immediate future (day or week).
2. The near future or short-term (12 to 24 months).
3. The intermediate-term (4 to 6 years and now frequently to 8 years).
4. The long term (10 to 30 years).

Figure 1 shows the forecasting and planning boundaries.

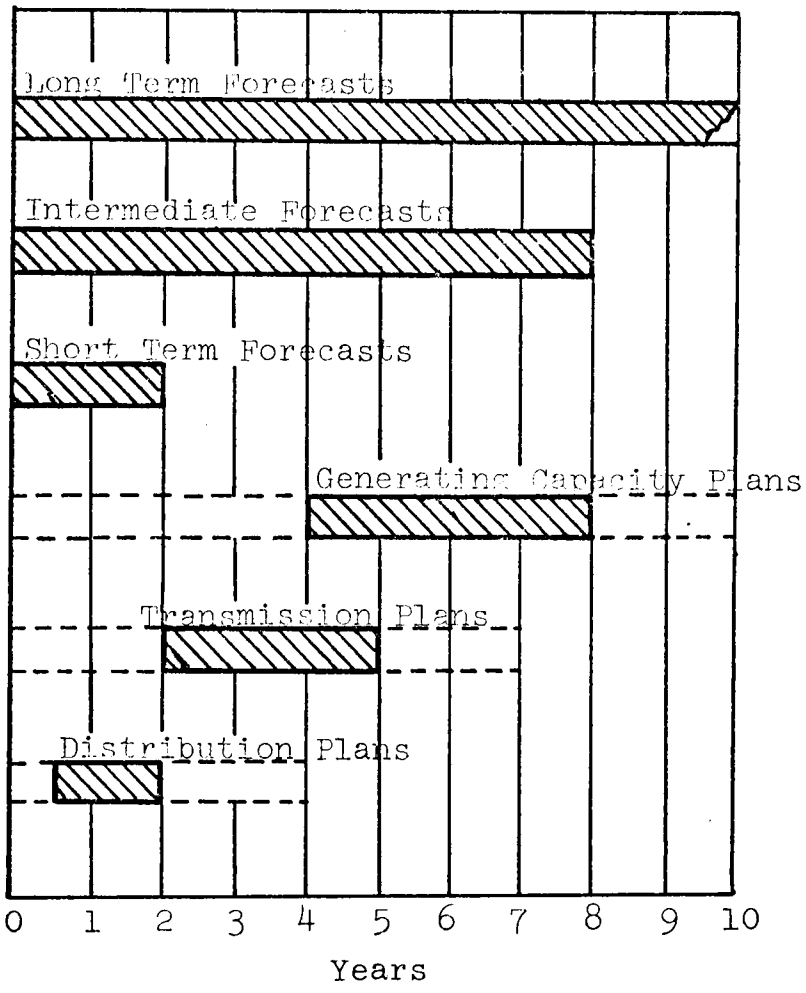


Figure 1. Forecasting and Planning Boundaries

Immediate Future

Forecasting for the immediate future (day or week) is used in preparing the schedule for the operation of generating units, determining spinning reserve requirements, controlling equipment maintenance schedules, estimating gross revenue and planning outlays for fuel and purchased power. In such a short period, the fixed costs of utility plant, as well as the fuel reserve, are not subject to change. The forecasts become the means for operating the existing utility plant at the lowest incremental energy cost.

Short Term

This is used to establish maintenance schedules, firming up interchange potential, evaluating reservoir and stream flow conditions of hydro-electric projects, etc. besides being the basis for budgeting and planning operations for the lowest incremental energy costs.

Intermediate Term

This forecast covers the most crucial time span in term of planning of physical facilities since lead times for adding generating capacity are generally of this length. So final commitment to build generating facilities must be made on the basis of this forecast. This is also useful in outlining distribution needs, performing rate and

economic studies and undertaking associated corporate planning.

Long Term

Long-term forecasts (10 to 30 years) are used for planning corporate strategy, including evaluating fuel requirements and resources, determining goals and objectives, identifying the need for technological developments and for allocating funds to accomplish objectives and provide for necessary research. In preparing such forecasts, it is necessary to have an understanding of the trends of various load classifications, load elements, and trends in various geographical areas of the system.

III. ACCURACY

Significance

Reliance on a dependable supply of electricity has been an important element in the evolution of living habits as well as all industrial operations. The reliability of service demanded by the consumer requires that power be available for use whenever the demand occurs and whatever its magnitude. The fact that there may be equipment failure or natural disturbances that render certain equipment inoperative is seldom considered as an acceptable reason for the interruption of the bulk supply of electric power. As a result, the industry must plan reserve and

standby systems to meet such contingencies. Accurate demand forecasts play an essential part in providing effective reserve and standby arrangements.

The needs for additions to generation, transmission and distribution facilities, the carrying costs of which represent such a major portion of the total annual cost of a utility system, are largely determined from demand and energy forecasts. Provisions for adequate service to the consumer at the lowest cost, compatible with maintaining an adequate net income for the utility system, depends heavily on accurate demand and energy forecasts. Inaccurate forecasts, therefore, can lead to inadequate service, unduly high costs to the consumer and/or inadequate income for the system.

Consequence of Errors

The degree of accuracy needed cannot be neatly categorized but is dictated by the probable consequences of error between predicted and recorded results. The impact and duration of the consequence of errors in demand and energy forecasts will vary among systems. Such differences surely depend on the alternatives available to the system and upon the time period for which the forecast is made. Some of the consequences are as follows:

1. Immediate Future and Short Term. Since the primary use of these forecasts is to permit operation at

the lowest incremental energy cost, the main consequence of error is the non-optimum use of resources. Inaccuracy in such forecasts could lead to a shortage in available capacity. Because distribution facilities have a minimum planning period of about one year, error in short-term forecasts could result in inappropriate distribution construction schedule.

2. Intermediate Term. Because of the critical role intermediate-term forecasts play, as mentioned above, the consequences of error of such forecasts are the most serious.

Forecasts which are too low could result in the use of high-cost resources, heavily loaded transmission and distribution facilities with associated higher losses and reduced reliability. Low forecasts could also reduce the opportunity for power and energy sales with neighboring utilities and could even result in curtailment of load. Forecasts which are too high, on the other hand, could also cause problems of serious nature. They could lead to the construction of unneeded generation, transmission and distribution facilities and thus to higher cost electric service.

3. Long Term. The consequences of error in long-term forecasts are broad in scope and vary widely in accordance with the specific programs developed. While

errors could lead to management decisions that in retrospect would appear faulty and take years to correct, some errors may be such that the utility would be able to recover with little or no consequence when studying intermediate-term forecasts.

CHAPTER III

CURRENT FORECASTING METHODS

Forecasting techniques are tools. No single method or group of techniques in itself assures success in forecasting. Knowledge and judgment of the forecaster in applying selected techniques in a given utility load situation are essential. The number and kinds of forecasting methods used vary considerably from utility to utility. Utilities with large heating and cooling loads have an interest in developing estimates of historical heating and cooling loads and load weather relationships and use these in forecasting heating and cooling loads. Utilities serving industrial loads which are highly responsive to the business cycle and which constitute a large proportion of total load usually put more emphasis upon analysis of industrial loads than do utilities serving a stable and small industrial load.

I. BASIC FORECASTING METHODS

Basically, forecasting methods can be grouped into two categories, extrapolation and correlation.

Extrapolation

It is based on the assumption that future growth will

be a continuation of a similar pattern of past growth. Specific methods include compound rates of growth, annual increments, fitting of mathematical growth curves and use of graphs of treated or untreated data. This method often produces acceptable results because electric loads exhibit stable growth over rather long periods. Residential, outdoor lighting and service loads appear to be largely insulated from the business cycle. However, forecasters relying predominantly upon this method may fail to recognize underlying changes which eventually will affect future growth.

Correlation

Correlation relates electric power loads to selected associated factors. Correlation methods include scatter diagrams, simple correlation, multiple correlation and simple or complex models. While results from these techniques, especially the more sophisticated methods, cannot be accepted at face value but must be evaluated in terms of the theories underlying the techniques, including their limitations, they provide insight into the causes of past growth and its variation and quantify relationships between load and factors which affect load. This leads to a clearer understanding of the factors which cause growth and of their relative importance. One problem associated with correlation methods is the need to obtain and select forecasts of these associated factors, i.e., independent

variables, such as population, income, appliance saturation, etc. There is no assurance that this can be done with any greater accuracy than forecasting electric loads directly.

II. SPECIAL INFORMATION AND JUDGMENT

Although extrapolation and correlation are fundamental to the art of load forecasting, they are not generally sufficient to assure the best results. Two additional ingredients that are often important to the development of a sound load forecast are the use of special information and the exercise of informed judgment.

Special Information

Special information is used to modify or reinforce the forecast. This includes such inputs as opinions of industrial plant managers as to probable future loads, planned utility promotion programs, the results of appliance surveys to determine present saturations and buying intentions, predictions of business activity and area. Such information is not only an important indication of definite future planning for electric consumpiton by others, but it is also a stimulant to the forecaster in thinking about the possibility of new trends.

Informed Judgment

In forecasting, informed judgment is necessary in the selection of the factors to be analyzed and in the

selection of the forecasting methods to be employed. It is also essential in determining the weight to be given to differing forecasts derived from use of several techniques. In uncertain situations when information is incomplete or when forces affecting load are not quantified, the informed judgment of the analyst is of particular importance.

III. NEED FOR NEW TECHNIQUES

The wider daily and seasonal swings in loads experienced in the last few years and growth of new kinds of loads or changing patterns of growth of existing loads have been among the reasons for the search for new forecasting techniques. Another reason can be the increasing need for improved accuracy and more detailed forecasts to enable economic planning for greater use of energy interchange and larger generating units. Possibly, improved forecasting methods developed outside the industry along with the development and availability of greater computational capability also could be responsible for changes in load forecasting methods.

What is usually being done by the utilities for preparing hour-to-hour and day-to-day load forecasts is to add expected load changes to current or recent past loads. Though weather conditions are considered in preparing such forecasts, all the variables, to which the weather dependent part of load is sensitive, are not fully identified.

The temperature, which is a dominant variable in the weather sensitive component of the demand, is considered but the variables such as wind velocity, humidity, cloud cover are not generally considered in the analysis. This causes inaccuracies in the forecasting of daily loads.

Due to this fact, it was felt necessary to closely identify the problem and to direct studies in this direction for properly evaluating the effect of weather on the system load by identifying the variables to which the weather dependent part of the load is sensitive. By doing so, the load estimating errors can be reduced and system performance improved. This is because the effect of weather is primarily responsible for making major load swings in daily system loads. The analysis of more variables can easily be done with the help of the computer and relative importance of each independent variable is known.

CHAPTER IV

APPROACH TO THE PROBLEM

A sound theory of forecasting may be defined in two steps. The first step is to separate the whole into components that are more easily analyzed and reasoned than the whole. The second step is to forecast the components and to reunite them to obtain a forecast as a whole. This theory provides a better estimate of the whole than can be obtained by merely forecasting the whole itself (9).

The initial step in the application of this theory means separation and isolation of historical data into the desired components so that past trends can be used as an aid in future trends. In order to do this, the system load is studied first and the components of which it is composed.

I. COMPONENTS OF SYSTEM LOAD

It is an accepted theory that the load of an electric power company is composed of two major components and a special component (6).

Base Load

This is the fixed component of the system load that has a definite value for any particular time of the

day and may be considered as reflecting the business cycle of the territory served.

The Weather Component

This is a variable part of the load that reflects the effect of the weather.

The Special Component

This covers the other variables that influence the load at times, such as televised broadcasts of events of special interest to the public. These variables will be evident when the main variable in the load, the weather effect, is segregated.

The special component of the load is calculated independently without charts or curves since it can be closely estimated. If, for instance, a strike occurs in the industry, the industrial load would drop down; and, therefore, this amount of load would be arithmetically subtracted from the normal expected base load. Television broadcasts of popular sporting events, popular political figures and the like, at times when TV is not normally in general use, will produce an increase in load. A bad snow storm such that people have difficulty getting to work and such that schools are closed will cause a drop in load. Such like effects can be considered separately based on experience gained during former similar events.

This component is a minor variable part of the system load and only influences the load at times. So, for our purposes of forecasting daily loads and in making the study simpler this component can safely be avoided. Because of this, historic load data has been collected for, and calculations based upon, an area where the load growth has been rather smooth; and it is anticipated that major loads will not be coming up in the near future. The assumption made, in avoiding this component under the circumstance, appears to be quite reasonable.

The system load can now be represented by two components, base load and weather-sensitive component such as

$$Y(i, j) = B(i, j) + W(i, j)$$

where

$Y(i, j)$ = System load measured at hour j and day i.

$B(i, j)$ = Basic component of the load at hour j and day i.

$W(i, j)$ = Weather-induced component of the load at hour j and day i.

The nature of the two components constituting the load is very different. $B(i, j)$ can be considered more or less constant where as $W(i, j)$ is a rapidly changing component containing fast hour-to-hour variations in the load.

A sound principal of forecasting, in such cases, where the components of a whole have been growing at different

rates, is to forecast each component separately and then obtain the whole by summation.

1. Base Load. The base load, being the fixed component of the system load, has a definite value at any particular hour of each day of the week. It is the base to which the weather component of the load is applied to form the system load.

For the purposes of calculating base load, daily peak demand recorded by the Knoxville Utilities Board for the year 1971 was obtained. A scatter diagram as shown in Figure 2 was then plotted with points on the diagram representing paired daily peak demand--coincident dry bulb temperature as recorded. It was observed from the diagram that between two temperatures 60°F and 72°F, which may be termed as heating significant dry bulb temperature and cooling significant dry bulb temperature, respectively, the system load had minimum effect either from the heating load or the cooling load. The value of this load was thought to be reckoned as the base load for doing further calculations of winter weather coefficient and summer weather coefficient. This was to be done by fitting a straight line by simple linear regression technique to each set of data distinguished by temperatures below 60°F and above 72°F and the slopes of the two lines giving the winter and summer weather coefficients. Mathematically, the calculations

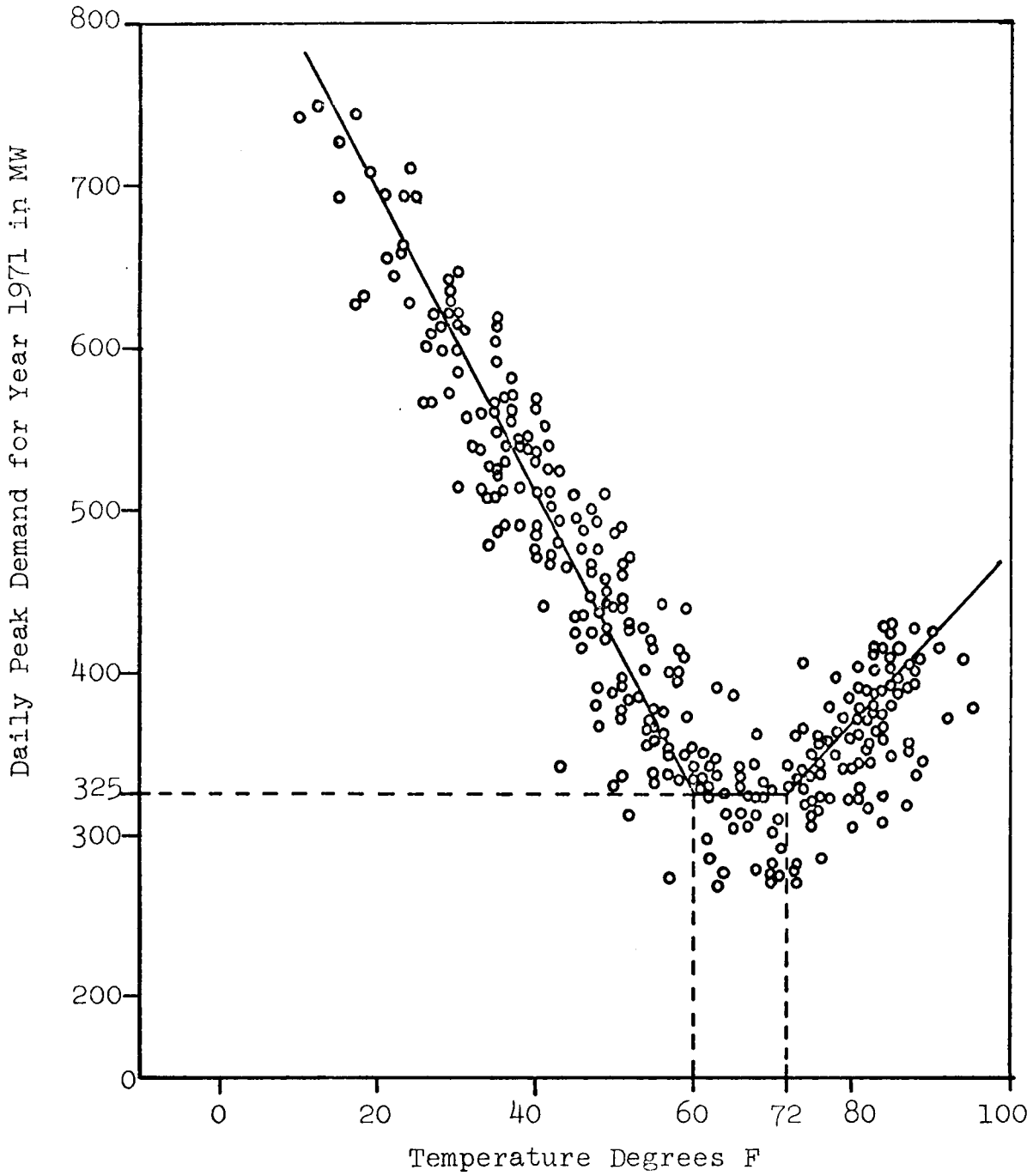


Figure 2. Daily Peak Demand-Temperature Curve

of winter and summer weather coefficients can be done by fitting the equations

$$Y_{wp} - B_0 = C_w \cdot (T - T_1)$$

$$Y_{sp} - B_0 = C_s \cdot (T - T_2)$$

where Y_{wp} = daily winter peak demand for temperature below T_1

Y_{sp} = daily summer peak demand for temperature above T_2

T = daily recorded coincident dry bulb temperature associated with either Y_{wp} or Y_{sp} as the case may be

B_0 = non-weather sensitive component of peak demand associated with temperatures between T_1 and T_2

T_1 = heating significant dry bulb temperature

T_2 = cooling significant dry bulb temperature

C_w = winter weather coefficient

C_s = summer weather coefficient

This approach appeared to be quite reasonable but the assumption on which this method is based that temperatures T_1 and T_2 are fixed and do not change from year to year could not be established. Moreover the peak demands occur at different hours of the days and it was very hard to anticipate the probable time of occurrence of peak demand in order to include weather forecast information for that period in the forecasting model. These reasons demanded

that some improved method to evaluated the base load be sought.

As an alternative, it was decided to avoid the break points T_1 and T_2 of the slopes for winter and summer lines and instead let these lines make V to intersect at a point, the value of which should be taken as the base. Secondly, establish the best suited temperature which should distinguish the two data sets for winter and summer. Another drawback in the former method, the difficulty experienced in using the peak demand due to its occurrence at different times of the day, was also avoided by considering the system load at a particular hour of the day of the week. Then the forecasting model could be developed for that hour and the weather forecast information could be utilized in it.

The hour chosen for this purpose was 11:00 a.m. of Wednesdays. The specific reason for selecting this particular hour was that the variations of temperature, a dominant factor in the weather component of electric demand, are rather rapid around this time. It was desired that the model developed should respond reasonably for such variations of temperature.

The values of B_0 were obtained by fitting straight lines employing a simple linear regression technique and by separating the two data sets at different temperatures between 60°F and 70°F. The data for this purpose was obtained for the year 1971 recorded at Dixie Sub-Station on

Kingston Pike for 11:00 a.m. on Wednesdays. The scatter diagram appears in Figure 3. The relative values of B_0 against different temperatures have been tabulated in Table 1. It was observed that the value of B_0 was nearly same for temperatures between 62°F and 70°F and that 65°F temperature could be adopted for separating the two data sets for getting fairly reasonable results. This could be established by checking with different data. Similar observations have been made by some other utilities also (6).

Once the pattern and the value of the base load had been established, it was necessary to determine the effect of cloud cover, wind speed and temperature on the system load and their representation in the weather load model.

2. The Weather Component. There are different variables constituting this component and the effect of each will be discussed individually.

The effect of wind speed is a slight increase in the load during the winter months only. Winds in excess of nearly ten miles per hour in cold weather increase the heat loss from buildings, and consequently the diversity in operation of heating equipment will decrease. There is no marked effect of wind above approximately thirty miles per hour where its effect reaches saturation (6).

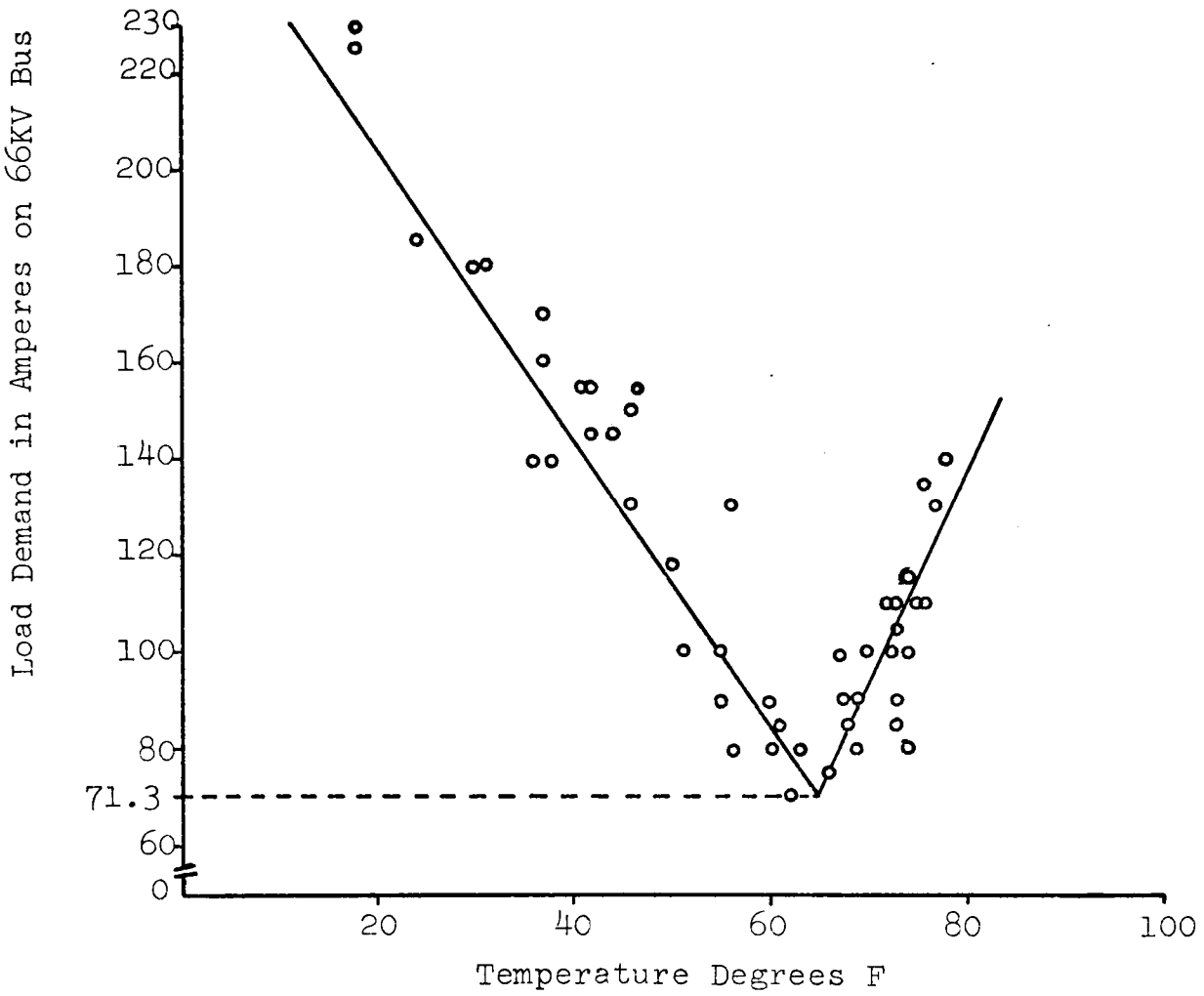


Figure 3. Hourly Demand-Temperature Curve

TABLE I

BASE DEMAND FOR TEMPERATURES
BETWEEN 60°F AND 70°F

Temperature	Demand
60	76.24
62	72.76
63	72.76
65	71.30
67	71.19
68	71.20
70	72.75

At temperatures below 65°F, humidity has no noticeable effect on load. Since the temperature controlled load is primarily heating equipment, air conditioning for cooling or dehumidification is not really necessary and is shut down. A sudden drop in temperature to 60 to 65°F or below from temperatures in the 70's may not necessarily produce an immediate increase in load. This is due to heat retention properties of buildings and to the natural reluctance of people to start up heating equipment. The effect may be felt if the low temperature continues a little longer.

Temperatures in excess of 65°F will cause operation of air cooling equipment, mostly in commercial and industrial establishments. The heat produced by artificial illumination, electrical equipment, and human body heat will raise the temperature inside a building to a point of discomfort, and air cooling equipment will be started. As the temperature rises further, residential air conditioners will start. As in winter with a drop in temperature, there is a heat storage effect of buildings; so in summer with a rise in temperature, there is a heat storage effect.

Depending upon the season of the year, a clear blue sky or fair weather with high, thin clouds will not have noticeable effect on the load; but a rapid change of a clear sky to a darkening sky can result in increase in load.

All these variables constitute the weather component which changes rapidly containing fast hour-to-hour variations in load. This component is assumed to be a linear function of the weather variables such as temperature, wind speed* and cloud cover. Useful weather-load models are obtained by correlating demand with these variables. An available stepwise linear regression program was adapted for the problem. For given separate observations of a dependent variable Y and the coincident independent variables X_1 through X_n (weather variables) the program will calculate, by method of least squares, the coefficients C of the linear equation

$$Y = C_0 + C_1X_1 + C_2X_2 + \text{-------} + C_nX_n$$

In addition, the relative importance of each independent variable X is calculated. The steps in determining the growth of the weather-load can be summarized as follows:

1. Choose suitable weather variables and fix the structure of the model.
2. Use historical load and weather data to compute the coefficients of the model, season-by-season, winter and summer.

These steps will be used in the analysis of actual substation data to calculate a forecasting model.

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*The independent variable wind speed is assumed to be linear function as no observation has been recorded more than thirty miles per hour where its effect reaches saturation.

CHAPTER V

CALCULATION OF THE MODEL

I. DATA REQUIREMENT

Once the approach to the problem has been decided, all the attention can be paid to the actual calculation of the model. It was observed in the last chapter that the two components constituting the system load, the base load and weather-sensitive component, grow at different rates. So the components are first to be separated, the forecast made for each separately and then combined to get the whole. To accomplish this, the historical data was required and since it was decided to develop the model for 11:00 a.m. on Wednesdays, the historical data was obtained for this time for the purposes of calculations. The data was collected from two sources.

Knoxville Utilities Board

The demand recorded at Knox 66KV Sub-station for the period from 1968 to 1971 on Wednesdays at 11:00 a.m. was obtained. Further available demand for six months of the year 1972 was also obtained for the purpose of comparing the recorded demand and the predicted demand obtained with the help of the model developed.

U. S. Weather Bureau

The following weather variables recorded coincident to the load demand and for the same period were obtained from the Weather Bureau Office located at McGhee Tyson Airport.

1. Temperature
2. Wind Velocity
3. Cloud Cover

These three variables were selected as appropriate weather variables and their effects studied individually. But a different set of variables may be more appropriate for other utilities. Although it is possible to obtain reasonably good correlation between selected weather factors and total system loads, use of such correlations of past data for forecasting future loads is impaired by the lack of certainty about future weather conditions.

Now in designing a forecast system, it is desirable to first examine the available data and decide whether they do give an adequate representation of the process to be controlled. On managing to get a bit of real data, one should not rush off and stuff it into the computer. It needs to be properly analyzed before feeding to the computer.

One of the easiest ways to become thoroughly familiar with the characteristics of the data is to plot them as a graph. This procedure has invariably been adopted in the course of the study. It is well worth the

time and effort to plot the data, because on each point plotted one starts guessing what the next one will be; and this is the objective of the forecasting system.

II. DETAILS OF FORECASTING METHODOLOGY

The overall forecasting methodology is shown in the block diagram, Figure 4. Two sets of data are required, one the demand and coincident temperature and the other demand and coincident weather variables responsible for the load variations.

Base Load

Each year of recorded demand for 11:00 a.m. on Wednesdays is separated into two sets of data distinguished by 65°F. Then, by the standard linear regression technique, a straight line is fitted to each of the two sets of data. It is evident that K_W, the winter weather coefficient, is always negative and is the slope of the winter daily demand, at the particular hour, coicident temperature linear regression line. Similarly K_S, the summer weather coefficient, is always positive and is the slope of the summer daily demand, at the particular hour, coincident temperature linear regression line. The intersection of these two slope lines gives the value of the base load. Each of the four years' data was treated in a similar way, and the values of base load obtained have been tabulated in

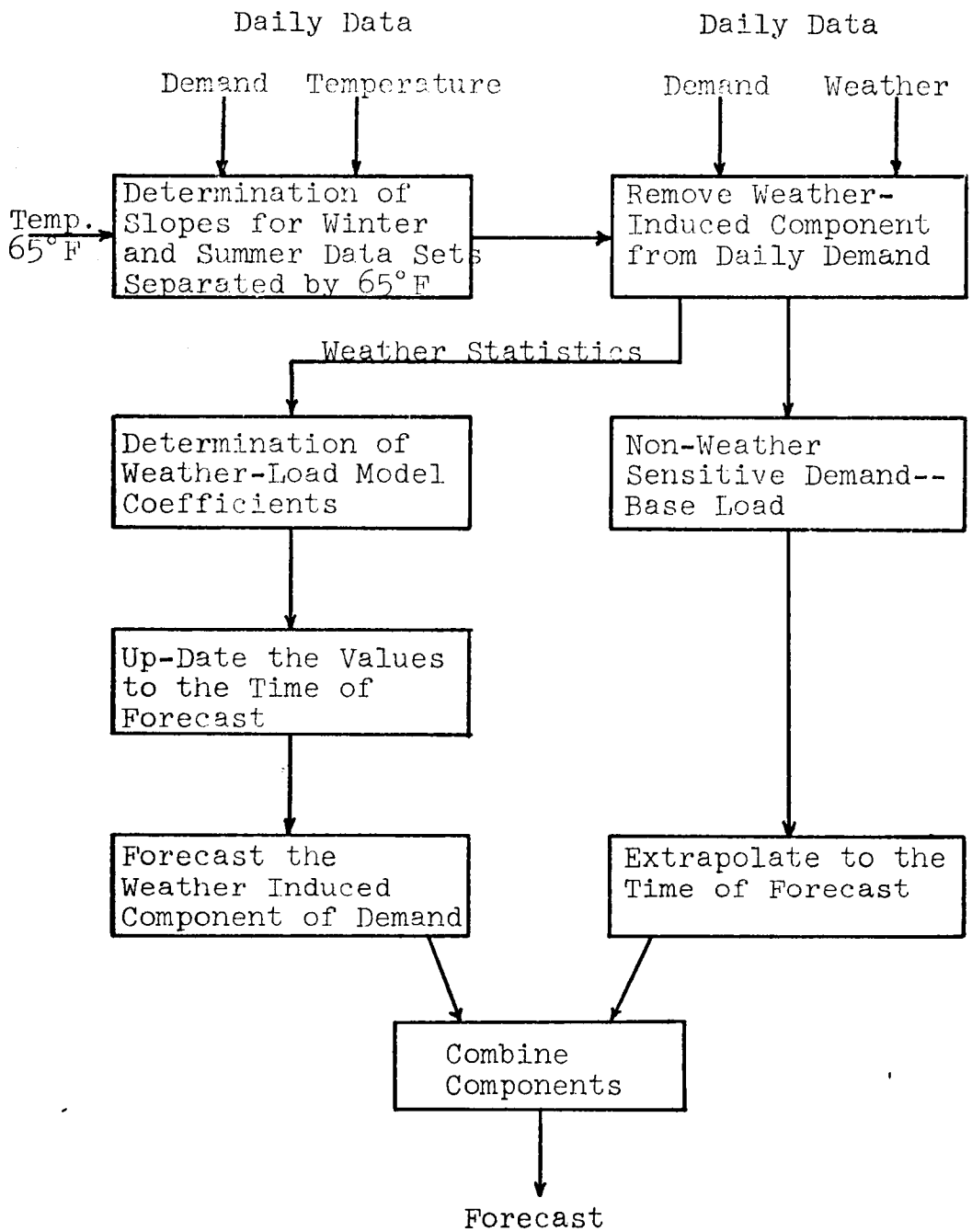


Figure 4. Hourly Demand Forecasting Methodology

Table II. The growth of base load is extrapolated to the time of forecast with the help of these values which comes out to be 30.5 amperes.

Weather Load Model

The base load calculated is used to separate the weather sensitive load from the daily demand. If the temperature T_1 corresponding to the demand is less than 65°F, then the demand less the base load gives the heating component. The temperature correlating this demand component is $(65 - T_1)$ apart from the other variables such as wind speed and cloud cover. Similarly, if the temperature T_2 coincident to the demand is more than 65°F, then the demand less the base load gives the cooling component. The temperature correlating this demand component is $(T_2 - 65)$ apart from the variables like wind speed and cloud cover. The different set of equations for data of temperatures less than and more than 65°F can be represented as

$$Y_{wd} - B_0 = C_{0w} + C_{1w} (65 - T_1) + C_{2w} \cdot WS + C_{3w} \cdot CC \text{ ------ (i)}$$

$$Y_{sd} - B_0 = C_{0s} + C_{1s} (T_2 - 65) + C_{2s} \cdot WS + C_{3s} \cdot CC \text{ ---- (ii)}$$

where WS = Wind speed coincident to the demand

CC = Cloud cover coincident to the demand

TABLE II

VALUE OF BASE LOAD FOR DIFFERENT YEARS BETWEEN 1968 AND 1971

Years	Base Load
1968	29
1969	29
1970	30
1971	30

All other Y_{wd}, Y_{sd}, B_0, etc. have been defined previously. After this stage, there remains the evaluation of the different variable coefficients of the two sets for temperatures below and above 65°F by fitting the above equations. To achieve this an available stepwise regression program is used which functions as follows.

This program computes a sequence of multiple linear regression equations in a stepwise manner. At each step one variable is added to the regression equation. The variable added is the one which makes the greatest reduction in the error sum of squares. Equivalently, it is the variable which has highest partial correlation with the dependent variable partialed on the variables which have already been added; and, equivalently, it is the variable which, if were added, would have the highest F value.

No effort has been made to describe the computer program in detail. Input data requirements, the format for printed output and logic flow charts are of little interest to anyone but users of the program. The discussion will be limited to the description of the forecasting technique.

The weather sensitive demands corresponding to temperatures below 65°F and above 65°F were fed to the computer separately for employing the multiple regression technique along with the transformed values of the temperature. At each step a variable was added, first the wind

speed and then the cloud cover. The observations made with both sets of data, individually, have been tabulated in Tables III to V and VI to VIII.

Data Set for Temperatures Less Than 65°F

The first independent variable chosen by the computer was the temperature which has the highest partial correlation with the dependent variable Y, the load demand. This is true as most of the weather oriented load is the heating load which varies inversely with the temperature. The multiple correlation coefficient recorded is 0.9162 which is reasonably good. This shows that the temperature variable is dominating among all the independent variables. The weather load model with this variable comes out to be

$$Y = 5.508 + 1.653\ X_1 \text{ -------- (i)}$$

The second variable selected in order of preference is the wind speed which reduces greatly the error sum of squares. This is due to the fact that wind speed is responsible for apparent reduction of temperature and thereby increasing the load required for heating. For example, a 25°F temperature with no wind speed has apparent effect of 25°F. But a wind speed of nearly 10 miles per hour reduces the apparent temperature to 20°F. The model with the two variables is as follows:

$$Y = 8.650 + 1.679\ X_1 - .506\ X_2 \text{ ---- (ii)}$$

TABLE III

CORRELATION OF WEATHER-SENSITIVE DEMAND WITH ONLY TEMPERATURE TAKEN INTO CONSIDERATION

Step 1

Variable Selected Is ... X 2
Sum of Squares Reduced in This Step.... 12795.3000
Proportion of Variance of Y Reduced.... 0.8394
Partial F (D.F. = 1, 26)..... 135.9223

Cumulative Sum of Squares Reduced..... 12795.3000
Cumulative Proportion Reduced..... 0.8394 (of 15242.8600)

Multiple Correlation Coefficient..... 0.9162
F for Analysis of Var. (D.F. = 1, 26).. 135.9223
Standard Error of Estimate..... 9.7024

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	1.65314	.141796	11.6586

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
1	70.000	61.715	8.285	0.854
2	40.000	22.040	27.960	2.882
3	70.000	73.287	-3.287	-0.339
4	70.000	83.206	-13.206	-1.361
5	70.000	61.715	8.285	0.854
6	90.000	83.206	6.794	0.700
7	50.000	43.531	6.469	0.667
8	45.000	43.531	1.469	0.151
9	50.000	53.450	-3.450	-0.356
10	50.000	43.531	6.469	0.667
11	40.000	50.143	-10.143	-1.045
12	50.000	51.797	-1.797	-0.185
13	40.000	20.387	19.613	2.021
14	40.000	40.225	-0.225	-0.023
15	15.000	20.387	-5.387	-0.555
16	10.000	10.468	-0.468	-0.048
17	0.000	10.468	-10.468	-1.079
18	0.000	8.815	-8.815	-0.909
19	10.000	13.774	-3.774	-0.389
20	15.000	22.040	-7.040	-0.726
21	0.000	12.121	-12.121	-1.249
22	40.000	36.918	3.082	0.318
23	20.000	13.774	6.226	0.642

TABLE III (continued)

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
24	40.000	51.797	-11.797	-1.216
25	45.000	45.184	-0.184	-0.019
26	20.000	28.653	-8.653	-0.892
27	40.000	36.918	3.082	0.318
28	40.000	36.918	3.082	0.318

Y = Load Demand

X_2 = Temperature

TABLE IV

CORRELATION OF WEATHER-SENSITIVE DEMAND WITH TEMPERATURE AND WIND SPEED TAKEN TOGETHER

Step 1

Variable Selected Is ... X 2	
Sum of Squares Reduced in This Step....	12795.3000
Proportion of Variance of Y Reduced....	0.8394
Partial F (D.F. = 1, 26).....	135.9223
Cumulative Sum of Squares Reduced.....	12795.3000
Cumulative Proportion Reduced.....	0.8394 (of 15242.8600)
Multiple Correlation Coefficient.....	0.9162
F for Analysis of Var. (D.F. = 1, 26)..	135.9223
Standard Error of Estimate	9.7024

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	1.65314	.141796	11.6586

Intercept (A) 5.50865

Step 2

Variable Selected Is ... X 3	
Sum of Squares Reduced in This Step....	94.6080
Proportion of Variance of Y Reduced....	0.0062
Partial F (D.F. = 1, 25).....	1.0052
Cumulative Sum of Squares Reduced.....	12889.9100
Cumulative Proportion Reduced.....	0.8456 (of 15242.8600)
Multiple Correlation Coefficient.....	0.9196
F for Analysis of Var. (D.F. = 2, 25)	68.4773
Standard Error of Estimate.....	9.7014

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	1.67977	.144248	11.645
3	-.506814	.5055	-1.0026

Intercept (A) 8.65047

TABLE IV (Continued)

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
1	70.000	62.215	7.785	0.802
2	50.000	22.914	27.086	2.792
3	70.000	77.521	-7.521	-0.775
4	70.000	79.491	-9.491	-0.978
5	70.000	62.722	7.278	0.750
6	90.000	83.545	6.455	0.665
7	50.000	44.751	5.249	0.541
8	45.000	42.724	2.276	0.235
9	50.000	52.296	-2.296	-0.237
10	50.000	42.724	7.276	0.750
11	40.000	51.470	-11.470	-1.182
12	50.000	52.643	-2.643	-0.272
13	40.000	21.741	18.259	1.882
14	40.000	39.364	0.636	0.066
15	15.000	17.687	-2.687	-0.277
16	10.000	9.128	0.872	0.090
17	0.000	11.156	-11.156	-1.150
18	0.000	6.942	-6.942	-0.716
19	10.000	17.049	-7.049	-0.727
20	15.000	22.914	-7.914	-0.816
21	0.000	11.315	-11.315	-1.166
22	40.000	36.512	3.488	0.360
23	20.000	15.022	4.978	0.513
24	40.000	52.136	-12.136	-1.251
25	45.000	42.883	2.117	0.218
26	20.000	29.633	-9.633	-0.993
27	40.000	32.964	7.036	0.725
28	40.000	38.539	1.461	0.151

X_3 = Wind Velocity

TABLE V

CORRELATION OF WEATHER-SENSITIVE DEMAND WITH TEMPERATURE, WIND SPEED AND CLOUD COVER

Step 1

Variable Selected Is ... X 2	
Sum of Squares Reduced in This Step....	12795.3000
Proportion of Variance of Y Reduced....	0.8394
Partial F (D.F. = 1, 26).....	135.9223
Cumulative Sum of Squares Reduced.....	12795.3000
Cumulative Proportion Reduced.....	0.8394 (of 15242.8600)
Multiple Correlation Coefficient.....	0.9162
F for Analysis of Var. (D.F. = 1, 26)..	135.9223
Standard Error of Estimate.....	9.7024

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	1.65314	.141796	11.6586

Intercept (A) 5.50865

Step 2

Variable Selected Is ... X 3	
Sum of Squares Reduced in This Step....	94.6080
Proportion of Variance of Y Reduced....	0.0062
Partial F (D.F. = 1, 25).....	1.0052
Cumulative Sum of Squares Reduced.....	12889.9100
Cumulative Proportion Reduced.....	0.8456 (of 15242.8600)
Multiple Correlation Coefficient.....	0.9196
F for Analysis of Var. (D.F. = 2, 25)..	68.4773
Standard Error of Estimate.....	9.7014

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	1.67977	.144248	11.645
3	-.506814	.5055	-1.0026

Intercept (A) 8.65047

TABLE V (continued)

Step 3

Variable Selected Is ... X 4
Sum of Squares Reduced in This Step.... 0.4793
Proportion of Variance of Y Reduced.... 0.0000
Partial F (D.F. = 1, 24)..... 0.0049

Cumulative Sum of Squares Reduced..... 12890.3800
Cumulative Proportion Reduced..... 0.8457 (of 15242.8600)

Multiple Correlation Coefficient..... 0.9196
F for Analysis of Var. (D.F. = 3, 24) 43.8359
Standard Error of Estimate..... 9.9005

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	1.68035	.147445	11.3965
3	-.498785	.528496	-.943781
4	2.92695E-02	.418574	6.99266E-02

Intercept (A) 8.41124

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
1	70.000	62.344	7.656	0.773
2	50.000	22.955	27.045	2.732
3	70.000	77.306	-7.306	-0.738
4	70.000	79.407	-9.407	-0.950
5	70.000	62.843	7.157	0.723
6	90.000	83.397	6.603	0.667
7	50.000	44.858	5.142	0.519
8	45.000	42.746	2.254	0.228
9	50.000	52.446	-2.446	-0.247
10	50.000	42.863	7.137	0.721
11	40.000	51.433	-11.433	-1.155
12	50.000	52.468	-2.468	-0.249
13	40.000	21.539	18.461	1.865
14	40.000	39.268	0.732	0.074
15	15.000	17.549	-2.549	-0.257
16	10.000	9.256	0.744	0.075
17	0.000	11.251	-11.251	-1.136
18	0.000	6.784	-6.784	-0.685
19	10.000	17.106	-7.106	-0.718
20	15.000	23.014	-8.014	-0.809
21	0.000	11.172	-11.172	-1.128
22	40.000	36.640	3.360	0.339

TABLE V (continued)

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
23	20.000	14.818	5.182	0.523
24	40.000	52.262	-12.262	-1.239
25	45.000	43.047	1.953	0.197
26	20.000	29.735	-9.735	-0.983
27	40.000	32.856	7.144	0.722
28	40.000	38.635	1.365	0.138

X_4 = Cloud Cover

TABLE VI

CORRELATION OF WEATHER-SENSITIVE DEMAND WITH ONLY TEMPERATURE TAKEN INTO CONSIDERATION

Step 1

Variable Selected Is ... X 2

Sum of Squares Reduced in This Step....	6.8477
Proportion of Variance of Y Reduced....	0.3287
Partial F (D.F. = 1, 4).....	1.9585
Cumulative Sum of Squares Reduced.....	6.8477
Cumulative Proportion Reduced.....	0.3287 (of 20.8333)
Multiple Correlation Coefficient.....	0.5733
F for Analysis of Var. (D.F. = 1, 4)...	1.9585
Standard Error of Estimate.....	1.8699

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	.222089	.158695	1.39947

Intercept (A) 3.20528

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
1	5.000	6.537	-1.537	-0.822
2	5.000	6.092	-1.092	-0.584
3	5.000	4.094	0.906	0.485
4	5.000	4.760	0.240	0.128
5	10.000	7.203	2.797	1.496
6	5.000	6.315	-1.315	-0.703

TABLE VII

CORRELATION OF WEATHER-SENSITIVE DEMAND WITH TEMPERATURE AND WIND SPEED TAKEN TOGETHER

Step 1

Variable Selected Is ... X 2		
Sum of Squares Reduced in This Step....	6.8477	
Proportion of Variance of Y Reduced....	0.3287	
Partial F (D.F. = 1, 4).....	1.9585	
Cumulative Sum of Squares Reduced.....	6.8477	
Cumulative Proportion Reduced.....	0.3287	(of 20.8333)
Multiple Correlation Coefficient.....	0.5733	
F for Analysis of Var. (D.F. = 1, 4)...	1.9585	
Standard Error of Estimate.....	1.8699	

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	.222089	.158695	1.39947

Intercept (A) 3.20528

Step 2

Variable Selected Is ... X 3		
Sum of Squares Reduced in This Step....	2.8713	
Proportion of Variance of Y Reduced....	0.1378	
Partial F (D.F. = 1, 3).....	0.7750	
Cumulative Sum of Squares Reduced.....	9.7191	
Cumulative Proportion Reduced.....	0.4665	(of 20.8333)
Multiple Correlation Coefficient.....	0.6830	
F for Analysis of Var. (D.F. = 2, 3)...	1.3117	
Standard Error of Estimate.....	1.9248	

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	.26874	.171735	1.56485
3	.343898	.390633	.880362

Intercept (A) .53254

TABLE VII (continued)

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
1	5.000	7.315	-2.315	-1.203
2	5.000	5.058	-0.058	-0.030
3	5.000	4.703	0.297	0.155
4	5.000	4.477	0.523	0.272
5	10.000	7.777	2.223	1.155
6	5.000	5.670	-0.670	-0.348

TABLE VIII

CORRELATION OF WEATHER-SENSITIVE DEMAND WITH TEMPERATURE, WIND SPEED AND CLOUD COVER

Step 1

Variable Selected Is ... X 2
Sum of Squares Reduced in This Step.... 6.8477
Proportion of Variance of Y Reduced.... 0.3287
Partial F (D.F. = 1, 4)..... 1.9585

Cumulative Sum of Squares Reduced..... 6.8477
Cumulative Proportion Reduced..... 0.3287 (of 20.83333)

Multiple Correlation Coefficient..... 0.5733
F for Analysis of Var. (D.F. = 1, 4)... 1.9585
Standard Error of Estimate..... 1.8699

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	.222089	.158695	1.39947

Intercept (A) 3.20528

Step 2

Variable Selected Is ... X 4
Sum of Squares Reduced in This Step.... 4.9918
Proportion of Variance of Y Reduced.... 0.2396
Partial F (D.F. = 1, 3)..... 1.6651

Cumulative Sum of Squares Reduced..... 11.8396
Cumulative Proportion Reduced..... 0.5683 (of 20.83333)

Multiple Correlation Coefficient..... 0.7539
F for Analysis of Var. (D.F. = 2, 3)... 1.9746
Standard Error of Estimate..... 1.7314

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	.289347	.155918	1.85577
4	.291805	.226137	1.29039

Intercept (A) 7.49521E-02

TABLE VIII (continued)

Step 3

Variable Selected Is ... X 3

Sum of Squares Reduced in This Step....	6.1547
Proportion of Variance of Y Reduced....	0.2954
Partial F (D.F. = 1, 2).....	4.3358
Cumulative Sum of Squares Reduced.....	17.9943
Cumulative Proportion Reduced.....	0.8637 (of 20.8333)
Multiple Correlation Coefficient.....	0.9294
F for Analysis of Var. (D.F. = 3, 2)..	4.2255
Standard Error of Estimate.....	1.1914

Variable	Reg. Coeff.	Std. Err-Coeff.	Computed T
2	.3845	.116615	3.29717
4	.393929	.163153	2.41447
3	.52791	.253527	2.08226

Intercept (A) -5.12346

Obs. No.	Y Observed	Y Estimated	Residual	Std. Resid.
1	5.000	5.261	-0.261	-0.219
2	5.000	4.216	0.784	0.658
3	5.000	5.105	-0.105	-0.088
4	5.000	4.675	0.325	0.273
5	10.000	9.432	0.568	0.477
6	5.000	6.310	-1.310	-1.100

This variable combined with the temperature greatly reduces the difference between the Y observed and the Y estimated. The multiple correlation coefficient is improved to 0.9196.

The independent variable cloud cover has been selected next. It can be seen that the sum of squares reduced in this step is 0.4793 which is negligible and the proportion of variation of Y reduced is absolutely nil. There is also no improvement in the multiple correlation coefficient. This gives a clear evidence that the independent variable cloud cover is ineffective in comparison to the temperature and the wind speed; and, therefore, this can be safely ignored.

Keeping the above in view the model selected for temperatures below 65°F is

$$Y = 8.650 + 1.679\ X_1 - .506\ X_2$$

Data Set for Temperatures More Than 65°F

The first independent variable selected in this case also is the temperature even when it is combined with wind speed and cloud cover. This clearly shows the maximum partial correlation of this variable with the weather-sensitive demand. Undoubtedly, most of such demand is due to the cooling load which is directly proportional to the temperature. The model with only this variable is

$$Y = 3.205 + .222\ X_1 \text{ ------- (i)}$$

The second variable selected, in order of its highest partial correlation with the dependent variable, is the cloud cover partialed on the temperature variable which has already been added. This is unlike the wind speed which had more effect for temperatures less than 65°F than the cloud cover. The multiple correlation coefficient has been improved to .7539 in this step. The model with the two variables can be represented as

$$Y = .07495 + .289\ X_1 + .291\ X_3 \text{ ---- (ii)}$$

The wind speed has the least effect, but its significance cannot be ignored. With addition of this variable, the multiple correlation coefficient has been improved to .9294 and the variance between the Y observed and Y estimated has been reduced to a great extent. The weather load model, including this variable, chosen for temperatures above 65°F is as follows

$$Y = -5.123 + .384\ X_1 + .393\ X_3 + .527\ X_2$$

Combination of Two Component Forecasts into Total Forecast

The forecasts made individually of base load with the historical data and of the weather-sensitive load with the help of the weather-load models developed utilizing the latest weather information are combined to get the total forecast.

CHAPTER VI

PERFORMANCE OF THE PROCEDURE

The forecasting methodology has been run on actual load data obtained from Knoxville Utilities Board. For this purpose, as has already been mentioned, the following data were obtained from the Utility.

1. Load recorded at 11:00 a.m. on Wednesdays for the year 1972 from January to June months at Knox 66 K Sub-station.

2. Historical, weather data recorded by the Weather Bureau for the same period as load data.

The actual weather data were used since the weather forecast record was not readily obtainable.

The actual loads, model-calculated loads and the percentage error have been tabulated in Table IX. It can be seen that the error has exceeded 10 percent only for four observations. Otherwise, it is below 10 percent which is the accuracy required by the industry (private communication with Mr. J. W. Keller, Knoxville Utilities Board, Knoxville, Tennessee). The readings taken of the demand are with a difference of 5 amperes which also affect the accuracy when the base load is just 30 amperes. Certainly a better accuracy in the forecast can be expected if the demand is taken for the system as a whole and with no error in the reading of the demand. Figure 5 shows the plot of the actual loads and the model-calculated loads.

TABLE IX

ACTUAL LOADS AND MODEL-CALCULATED LOADS

Wednesdays	Actual Loads	Model-Calculated Loads	Error
1	2	3	4
1	95	93.52	1.48
2	65	65.20	-0.20
3	80	74.41	5.49
4	80	78.55	1.45
5	80	81.05	-1.05
6	90	80.31	9.69
7	80	74.44	5.56
8	80	85.25	-5.25
9	45	38.50	6.50
10	70	62.41	7.59
11	55	57.62	-2.62
12	50	53.65	-3.65
13	40	38.50	1.50
14	60	61.30	-1.30
15	35	39.30	-4.30
16	30	30.91	-0.91
17	45	49.75	-4.75
18	35	41.35	-6.35
19	40	46.75	-6.75
20	30	35.15	-5.15
21	40	38.11	1.89
22	40	35.49	4.51
23	30	34.61	-4.61

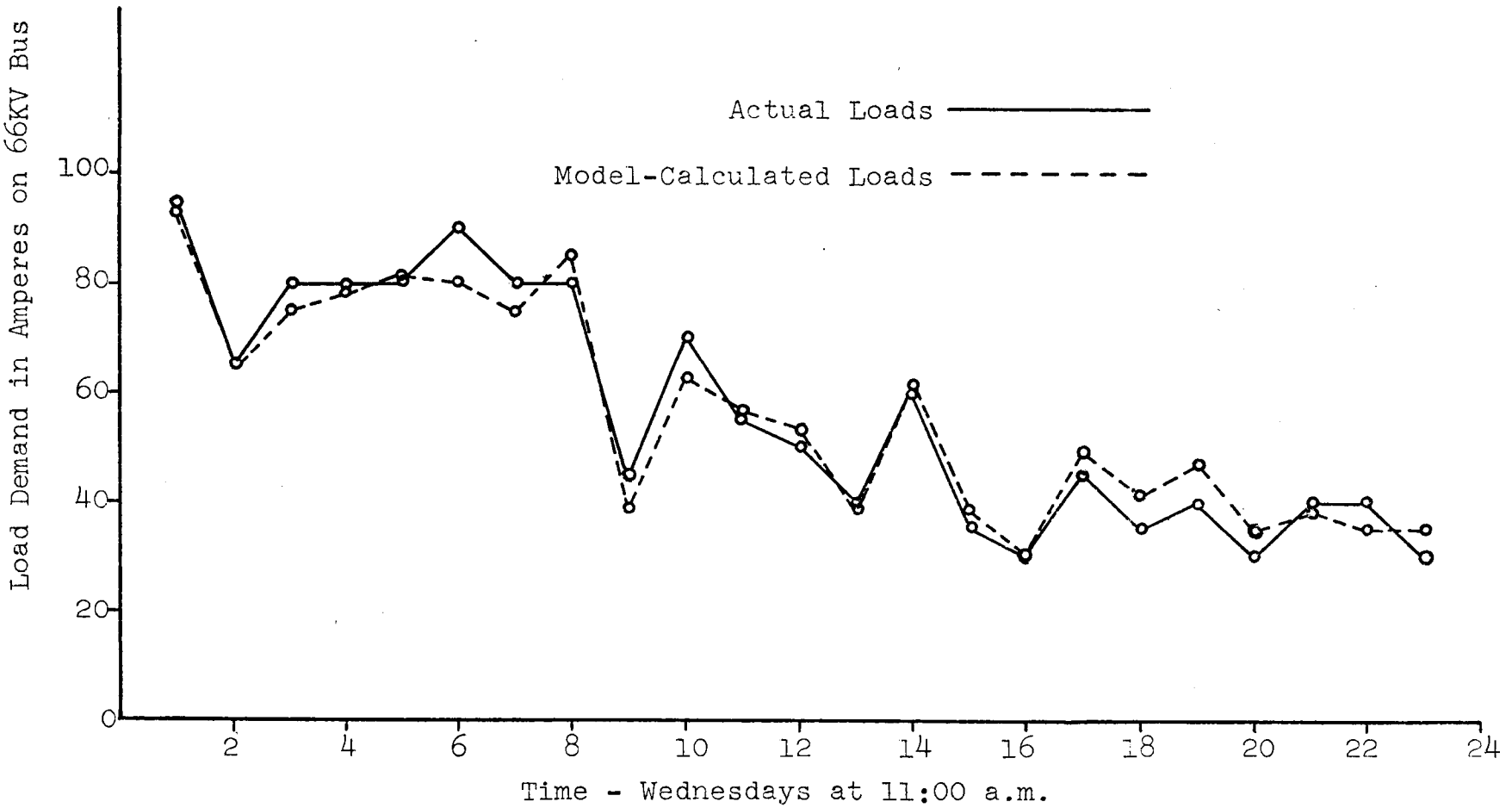


Figure 5. Actual Loads - Model-Calculated Loads

CHAPTER VII

FULL SCALE USE OF TECHNIQUE

In the development of this thesis, a model has been obtained which forecasts the demand utilizing the historical load data and the latest weather information; but this is for a particular hour for a day of the week. The technique can be extended to obtain models for all hours of the day and for all days of the week.

A prerequisite condition to accomplish the above is to be able to get the weather forecast with a lead time from 1 to 24 hours. The utility interested in daily forecasting of the load demand needs to manage this with the Weather Bureau.

On predicting the hourly demand for the day, the daily peak demands can be obtained.

This technique can easily be extended to several sub-stations and to the system as a whole.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop a model for producing daily load forecasts. Because of the load variations caused due to the change of weather conditions, it was intended to identify closely the variables to which weather dependent part of the load is sensitive. It was necessary for this to separate the load demand into the two components, the non-weather sensitive and the weather sensitive, as the rate of growth of the components is different. The components could be forecasted separately and then combined to get the total forecast, thereby, improving forecasting accuracy.

With the technique developed in this thesis, the above objectives have been achieved.

1. The methodology separates the load demand into the two components.
2. It takes both historical data and weather information into account in forecasting hourly loads.
3. The technique has made it possible to separate the effect of various weather elements.
4. The forecast demand obtained with the help of the model as compared to the recorded demand shows that the forecasting method is quite accurate; and, therefore, the value of technique is established.

5. This technique can be extended for producing daily forecasts of load demands of the areas fed by different sub-stations.

6. This technique can also be extended for predicting daily peak demands.

BIBLIOGRAPHY

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