*MODELING OF ELECTRIC POWER DEMAND GROWTH

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MODELING OF ELECTRIC POWER DEMAND GROWTH

1.0 Introduction

Electricity has become and will continue to be a very important source of energy in our society (it accounts for 25% of the energy consumed today and it is growing at 8%). Therefore, there is a great need to understand the behavior and growth dynamics of the electric load. Questions like: "How will the load grow and change over the next twenty years?", "What are the factors which will influence this growth and change?", and "How may we control or alter this growth pattern?" may only be answered by a thorough and in-depth study of the many factors which create the electric load on an hour-by-hour basis.

In this paper we will consider three general areas of application for such a load (or demand) model: system expansion planning for electric utilities; designing and evaluating regulatory policies for state and federal governmental agencies; and evaluating the effects of new technology on a power system for utilities, regulatory agencies, and agencies responsible for the allocation of R & D funds. We will discuss these areas of application in order to specify the capabilities which a load model must possess if it is to be a meaningful and useful tool. Having specified the desired capabilities, we will look at the model structure which we believe is the appropriate basis from which to construct a load model. Finally, we will briefly discuss the problems of actually developing such a model; in particular, the data requirement and the technical details of estimating model parameters and the steps involved in verifying the validity of the model.

Matching the model's capabilties to the requirements of its applications is a difficult task, and will require an extensive model development effort. One of the purposes of this paper is to emphasize the importance of making such an effort.

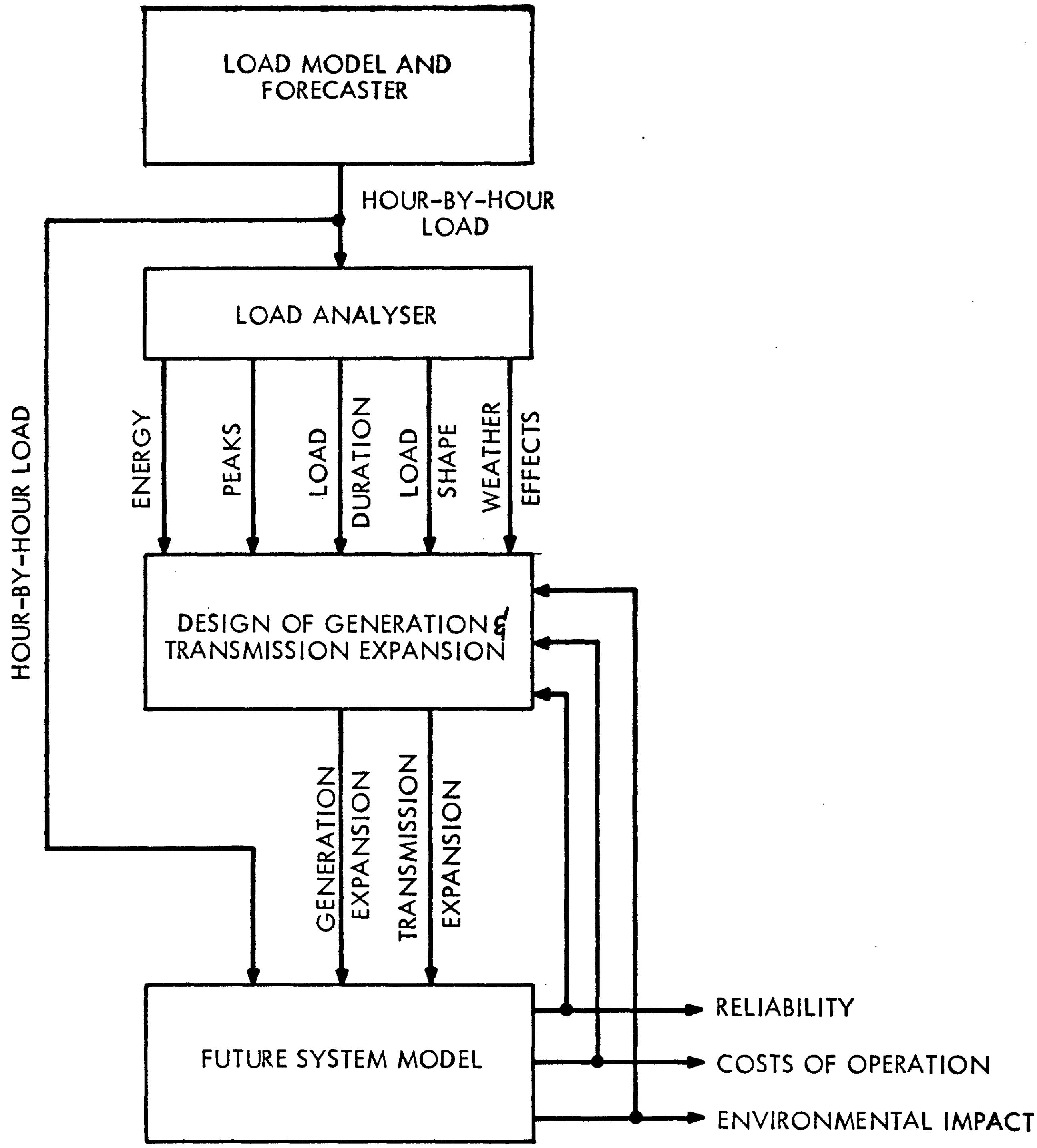
2.0 Applications for Electric Load Models

In any modeling effort it is important for the modeler to know how his model will be employed. This knowledge helps him choose the emphasis of his model, make appropriate basic assumptions, and identify the capabilities that his model must possess. In this section we will consider three general areas of application for an electric load model. We will be primarily concerned with identifying the capabilities required by each of these applications. Figures 1.A, 1.B, and 1.C may help clarify how the load models are to be used in these applications.

2.1 Expansion Planning for Electric Power Systems

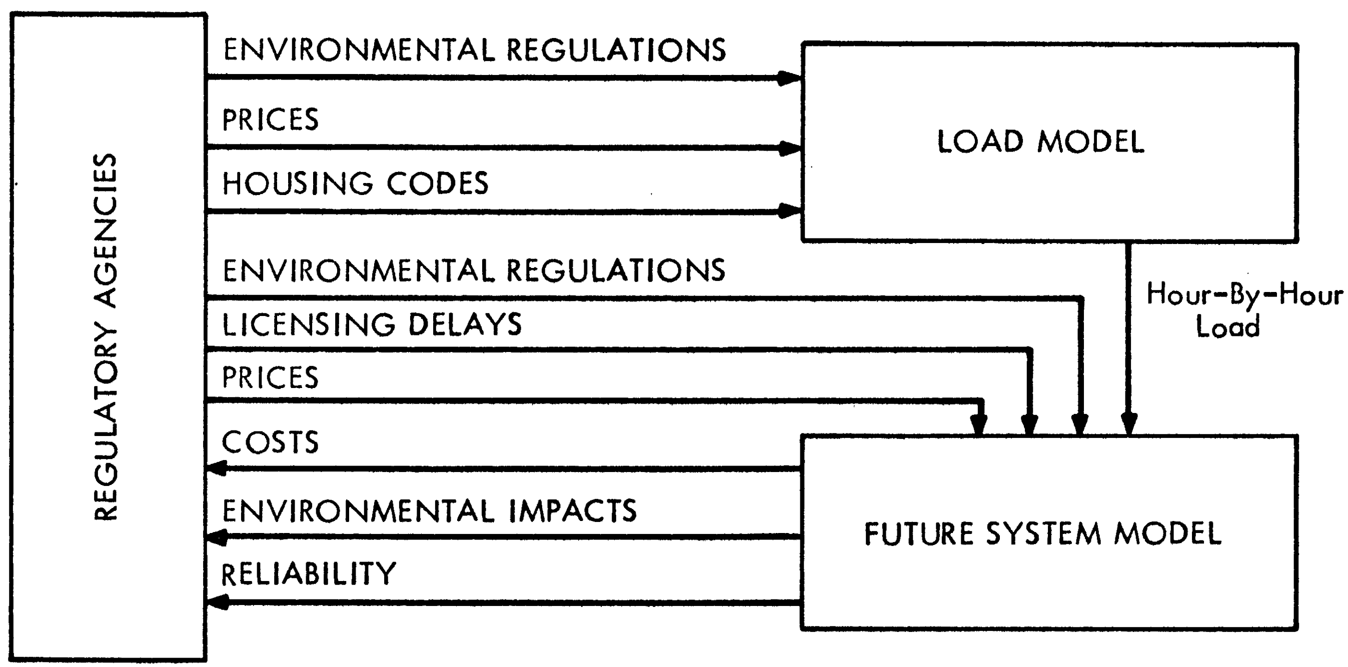
One of the most important functions performed by the management of an electric utility is planning system expansion to allow the utility to supply its future load with the most economical means possible. This is an increasingly difficult task, requiring increasing amounts of foresight and forecasting. Due to the increased time delays in siting, designing, constructing and putting new generation and transmission equipment into operation, decisions must be made now on plants which will not go into operation for 10 to 15 years. Making decisions this far in advance places a heavy emphasis on the forecasts of system load. It may no longer be sufficient to base these decisions on simple extrapolations of the past.

In order to design a system which is capable of supplying the future load, the system planner needs detailed information about his load. To



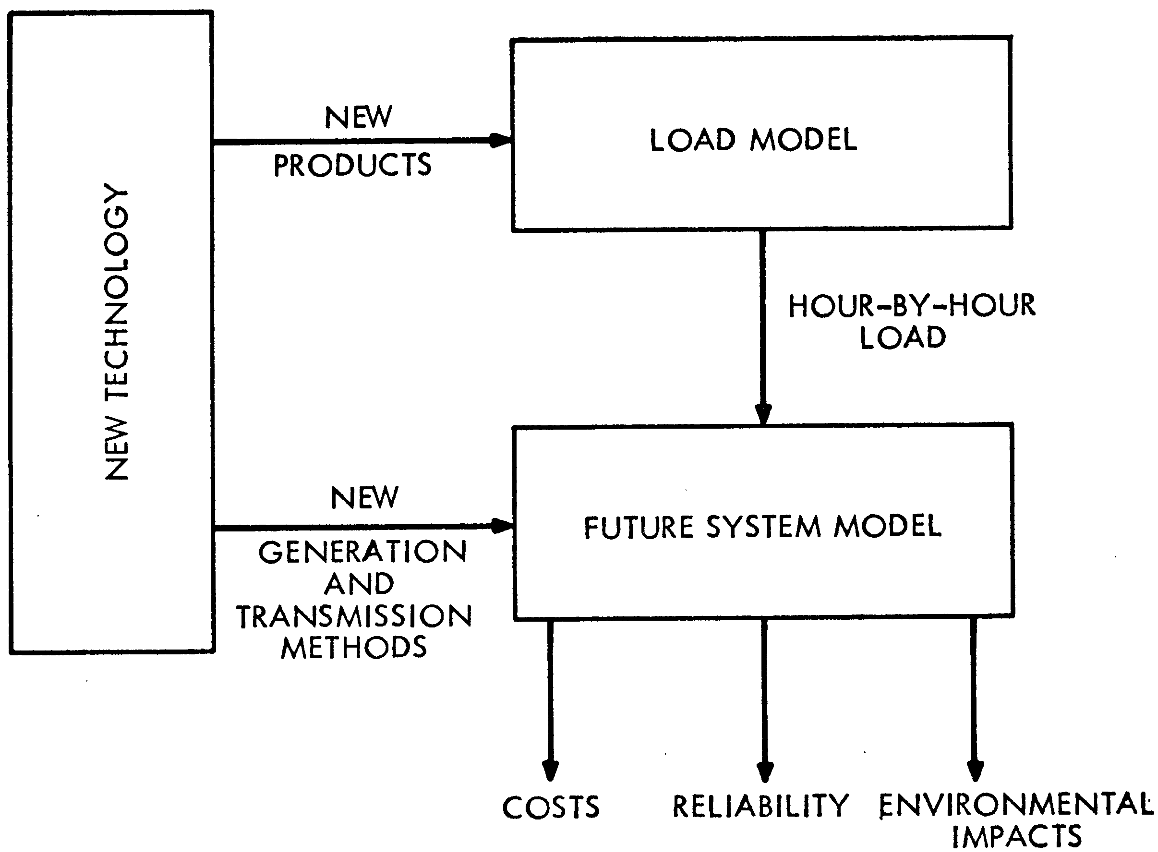
USE OF LOAD MODEL IN SYSTEM EXPANSION PLANNING

FIGURE 1.A



USE OF LOAD MODEL IN EVALUATION OF REGULATORY POLICIES

FIGURE 1.B



USE OF LOAD MODEL IN EVALUATION OF NEW TECHNOLOGY

FIGURE 1.C

determine the necessary capacity, he requires forecasts of the peak loads. To ensure that sufficient time is allowed for routine maintenance, these peak forecasts must be on a weekly basis. To determine the most efficient generation mix (base, cycling, peaking, and reserve) he needs detailed load shape and load duration forecasts throughout the year. To ensure the system's ability to follow the load, the system planner needs to know how the future load will be influenced by the weather and other short term external factors. In short, the system planner needs a load model capable of forecasting the hour-by-hour load and the sensitivity of the load to the weather. (For further discussion see Appendix A.)

Load forecasts also serve as inputs in many other aspects of electric utility expansion. Load forecasts are used, for example, in financial planning, determining the emphasis for advertising campaigns, and in evaluating the usefulness of new or alternative means for generating and transmitting electricity. In financial planning, the management is primarily interested in energy forecasts, since revenue is tied to electric energy sales. In advertising the management is concerned with pushing off-peak uses for electricity; thus, load shape forecasts are required. In the evaluation of new generation and transmission technology, the management is concerned with the compatibility of the new technology and the load behavior over a day, a week, and over the year.

For each application a different forecast is required. These forecasts must often be obtained from completely different forecasting routines. Thus, the various forecasts may not be consistent. If a single load model were capable of modeling and forecasting the load on an hour-by-hour basis, the forecasts of energy, load factors, load shapes, and peak loads could all be produced by one model and would therefore be consistent. The block diagram in Figure 1.A should help illustrate how a load model could be used in system expansion planning.

2.2 Regulatory Policy Evaluation

Various state and federal agencies have been given the responsibility for regulating many aspects of electric utility operation. These agencies are involved in setting the price for electricity; issuing permits for siting, construcion, and operating generation and transmission facilities; and establishing and enforcing environmental regulation. The regulatory policies adopted by these agencies can have significant long term effects on the demand for electric power. Therefore, it is important that any policy under construction by these agencies be evaluated both for its effectiveness and its side effects. To be more specific, let us consider one aspect of pricing policy.

Recently, there has been some discussion of revising the rate structure for pricing electric energy. Let us suppose that the special rates paid by electric heating customers were eliminated. Under this assumption, customers using electric heat would have to pay more for this service. As a result, we would probably see a reduction in the number of new installations of electric heating units, and we might even see some customers switch from electric heat to some cheaper alternative to heat their homes. In the long run, we would see a change in the load shape, and in the load's sensitivity to winter weather. This change in load shape would alter the economics of operation for the utilities and hence force a change in the price of electricity. Thus, in the long run, eliminating the special rates to customers using electric heat could have the effect of changing the price of electricity to all customers.

We are entering into a period of vast social change; more and more people are beginning to question the exponential growth patterns of the past. There is concern over the environmental impacts of continued growth in energy consumption and the threat of resource shortages. Whether the result of these concerns is more or less governmental regulation of the energy industries, there is a great need to evaluate the effects and side effects of new and existing regulatory policies. One important part of the evaluation of any energy-related regulatory policy is its effect on the demand for electricity. For a load model to be useful in this evaluation, it must be capable of accepting detailed "what if" questions (such as "What if the electric heating rate base is eliminated?"), and answering them, in both the short and long run, with the resulting hour-by-hour electric load. To do so the uses for electricity (such as home heating) must be explicitly identified and represented. Thus, in addition to the detailed load forecasting capabilities needed for system expansion planning, a load model must specifically represent those factors and functional needs which create the electric load. Figure 1.B may help summarize the load model's relation to this area of application.

2.3 New Technology Evaluation

Into a modern industrial society such as ours, there is a constant influx of new technology, appearing, for example, as a new electric device to replace an old one (electric heat pump heater); a new electric device to replace a non-electric device (electric car); a new electric device which replaces nothing, but rather creates a new need (TV); or a non-electric device to replace an electric one (solar water heater). This new technology could also appear as an alternate means to transmit or generate electricity (MHD, super-conducting transmission lines). Let us consider the effects of one specific new technological inovation.

The electric car has received some attention in the last few years; let us suppose that by the end of this decade an electric car is commercially available. It would, of course, take several years for this device to be accepted. It would probably first appear on the streets of the largest cities. As the electric car became more popular, the electric utilities would begin to notice the recharging load; and the cities would begin to see the shift from automotive exhaust pollution to the thermal and air pollution of electric power plants. If the electric car were really successful, it could alter the economics of power system operation and the regulating agencies might be called upon to create a new rate base for electric car users. It would be fun to continue this analysis in more detail, but our purpose here is only to show how a new technology could change the system.

Once again we see the complex interactions between the dynamics of load growth and change, and the dynamics of power system planning and operation. A use of the load model would be to evaluate the effects of new technology so that those agencies responsible for allocating R & D funds would have some means of assessing their impact on the electric system. For a load model to be useful in this area, it must be capable of representing these new products and evaluating their long term effects on the hour-by-hour load. Figure 1.C may help to illustrate the load model's application in the evaluation of new technology.

2.4 Summary of Desired Load Model Capabilities

In the previous discussions we considered three broad areas in which a load model could play a role. We have seen that many applications require a load model capable of forecasting the load on an hour-by-hour basis. We have also seen that many applications require a load model capable of addressing "what if" type questions. The model must be capable of depicting the effects of alternate policy decisions involving pricing, public policy, and technological change.

It is also essential that a load model be capable of representing the uncertainty associated with its outputs. Each of these areas of application may be sensitive to different "types" of uncertainty, but in all cases, the uncertainty must be considered. The uncertainty measures are required so that proper confidence levels can be placed on the model's results.

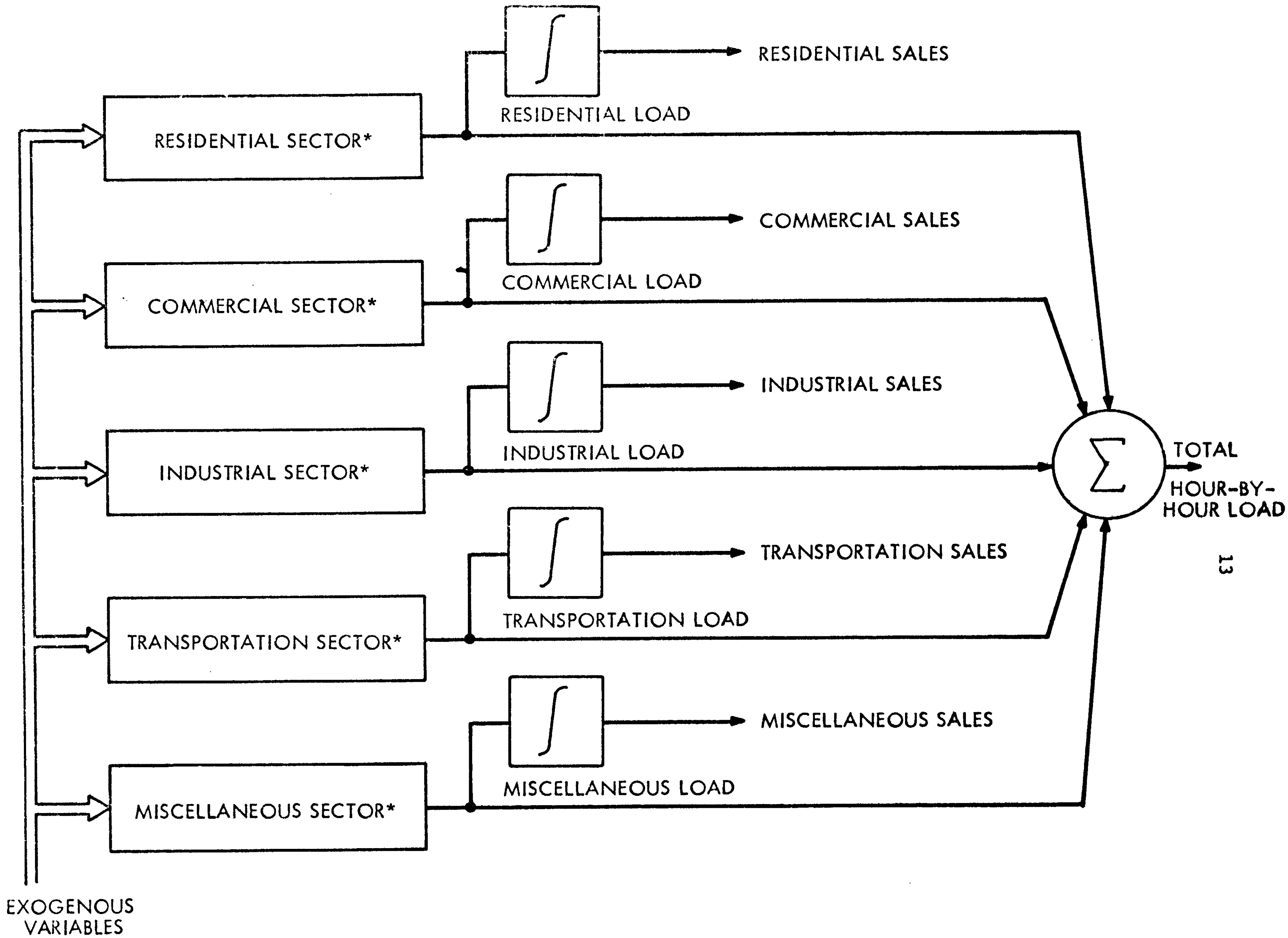
3.0 Load Model Structure

Discussions of the potential applications of a load model provide guidelines for the load model structure. We now consider the structure of a load model which we feel is well-suited to all three of the applications discussed in Section 2.

As a first step in establishing the structure of the load model we separate the customers into five consuming sectors as follows:

1) Residential Sector
2) Commercial Sector
3) Industrial Sector
4) Transportation Sector
5) Miscellaneous Sector.

These sectors were chosen because they provide a homogeneous, and yet not too detailed, classification of the customers; furthermore, sales data is often available for this grouping of customers. Figure 2 shows a block diagram of this structure, including the sales aspects.



* EACH CONSUMING SECTOR TO BE FURTHER SUBDIVIDED INTO USAGE CATEGORIES.

LOAD MODEL BLOCK DIAGRAM

FIGURE 2

The approach we will take in modeling each of these consuming sectors is to consider them along two essentially orthogonal axes: use and time. The two "axes" will be discussed separately.

3.1 Use Axis

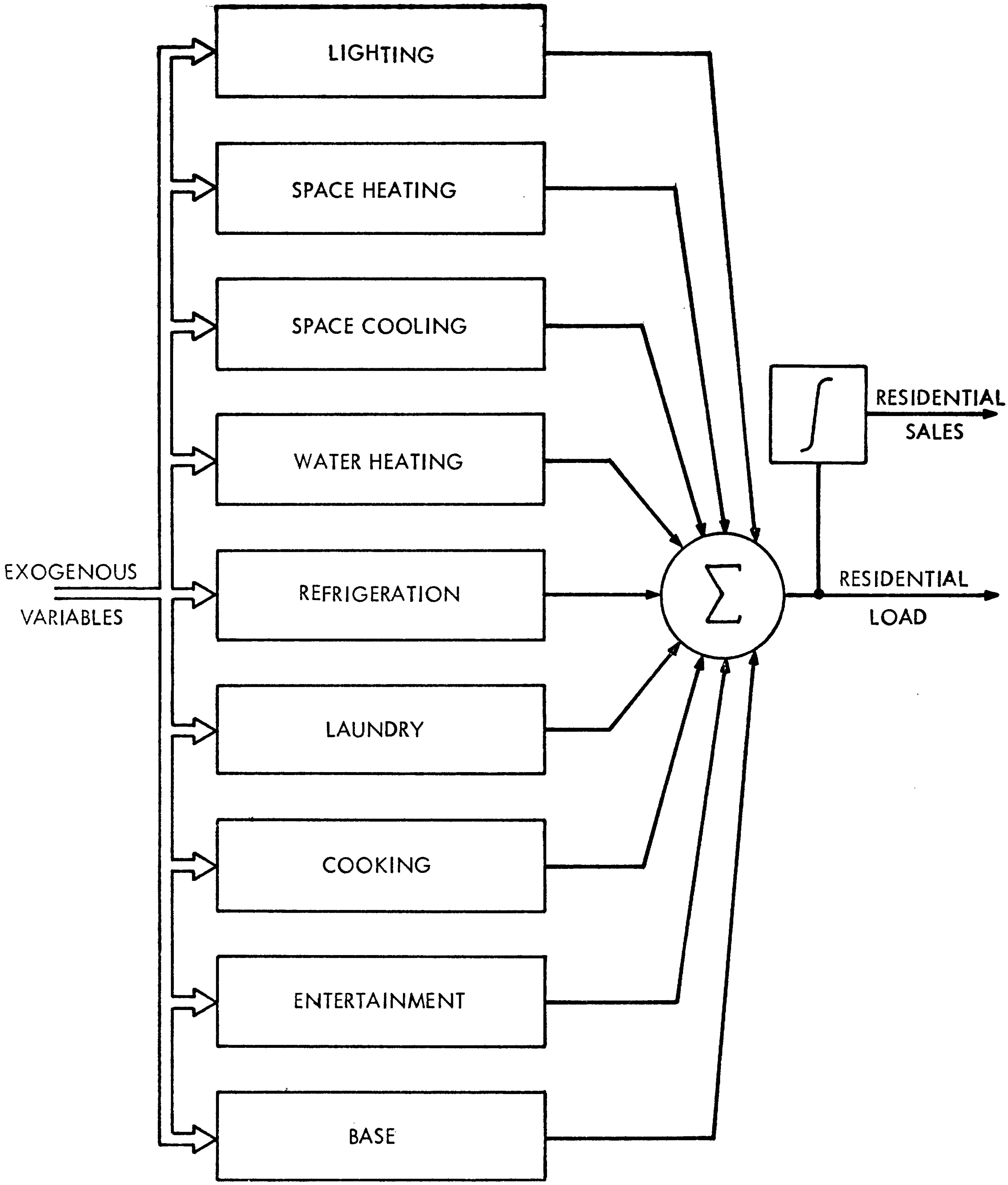
We will first analyze the electric load from each sector by the "usage" categories which give rise to the electric load in each sector. For example, a possible classification of the use of electric power in the Residential Sector is:

1) Lighting
2) Space Heating
3) Space Cooling
4) Water Heating
5) Refrigeration
6) Laundry
7) Cooking
8) Entertainment
9) Base Load.

Figure 3 shows a block diagram for the Residential Sector with these usage categories. Each of the other four consuming sectors will also be divided into usage categories.

3.2 Time Axis

The next step is to analyze each of these usage categories along the time axis. Analyzing and modeling the usage of electric power in time is a challenging problem. Even the most casual look at the power requirements for any usage category as a function of time reveals a highly cyclical pattern. The residential lighting load, for example, has a very pronounced



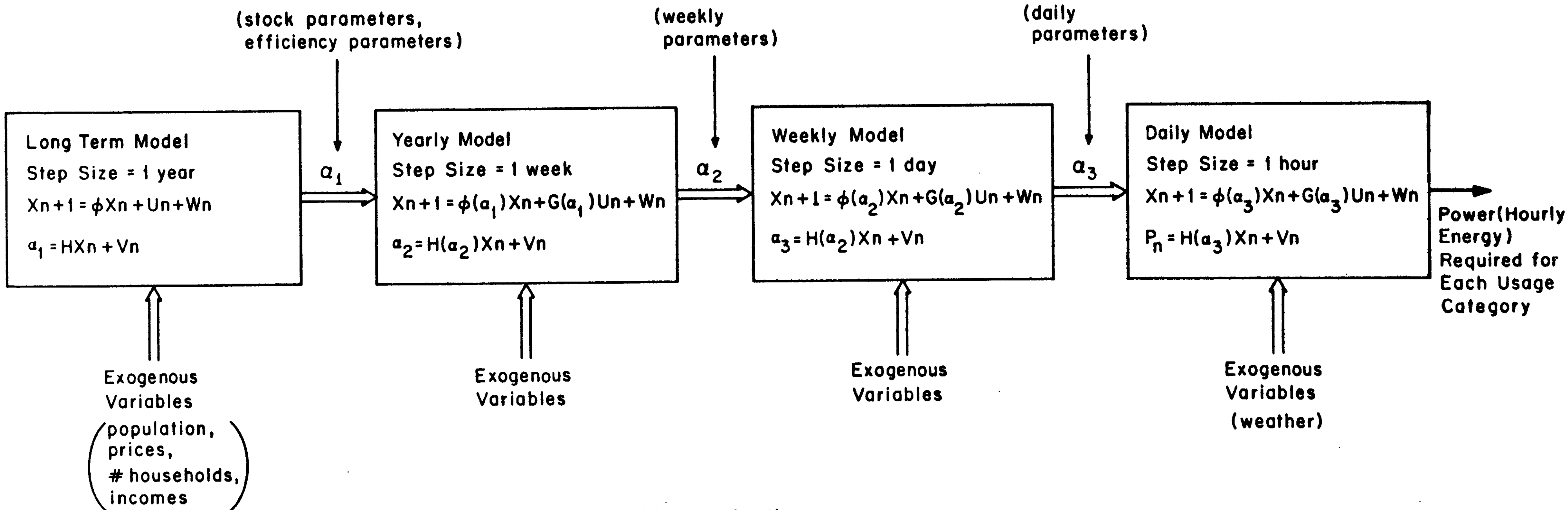
RESIDENTIAL SECTOR BLOCK DIAGRAM

FIGURE 3

daily cycle, a weekly cycle, and a yearly cycle. Moreover, the power required for residential lighting can be expected to deviate from these normal cycles, on an hourly basis due to changes in the local weather conditions. Finally, the amplitude, and possibly the shape, of these cycles can be expected to change over the years as a result of growth and change within the area served by the power system.

To take these various cycles and external factors into account, we will model the electric power requirements for each usage category along the time axis with the hierarchical model shown in Figure 4 (the white processes, V_n and W_n, shown in Figure 4 will be discussed later). We will model the dynamics of the load for each usage category as the combination of two separate effects. The first is the relatively long term stock effects; and the second is the utilization of these stocks. The stock effects will be modeled on a yearly basis, corresponding to the first block of Figure 4; while the effects of the utilization of these stocks will be modeled for the most part on a shorter time basis, corresponding to the next three blocks of Figure 4.

The first block of Figure 4 corresponds to a dynamic system with a step size of one year. Long term effects, such as changes in the number and efficiency of the individual units serving the usage category, and long term changes in life style and energy needs, are modeled in this section. This long term model may be thought of as a description of the dynamics of the number and type of units which require electricity for their operation. The dynamics of the model corresponding to this block are dependent upon a number of exogenous variables, including population, consumer incomes, households, and the relative costs of competing sources of energy. The long term model combines these physical dynamics with the effects of



Vn and Wn: white stochastic process

HIERARCHICAL MODEL IN TIME FOR ONE USAGE CATEGORY

FIGURE 4

the exogenous variables to yield parameters which characterize the stock of goods and equipment which consume electricity.

The second block of Figure 4 corresponds to a dynamic system with a step size of one week. Seasonal effects such as vacation periods, seasonal weather patterns, electrical requirements, and life style patterns are modeled in this section. This yearly model combines the parameters from the long term stock model with the exogenous variables (seasonal weather patterns, etc.) into a characterization of the annual cyclical utilization of electrical consuming stocks, on a weekly basis. The second block, in turn, connects with the weekly model (third block) via the set of time varying weekly parameters of Figure 4. These weekly parameters characterize the nature of electricity utilization for each week of the year.

The third block of Figure 4 corresponds to a dynamic system with a step size of one day. Daily variations due to weekly life style patterns, weekend electric power needs, and the weekly industrial cycle are represented in this section. Likewise, this weekly model yields daily parameters which characterize the daily utilization of electricity as a function of the day of the week and the weekly parameters of the yearly model.

The fourth block of Figure 4 corresponds to a dynamic system with a step size of one hour. Hourly load variations due to daily life style patterns, daily industrial cycles, and deviations from this cycle due to external factors, such as the weather, are represented in this section.

Finally, the output of the daily model, the hourly load for that usage category, is determined by the exogenous weather variables as well as the daily parameters which characterize the load behavior for any given day. These daily parameters, in turn, are a function of the week of the year and the stock parameters of the long term model. Each of the blocks shown in Figure 4 are self-contained dynamic systems. However, they interact via the transfer parameters which will change through time to account for the changing character of the load as time progresses.

3.3 Properties of the Model Structure

A model of this form has many attractive features. Assuming for the moment we have the structure complete and the parameters identified, for each usage category of each consuming sector, the model would be used in the following way. Suppose a forecast of the load for the year 1985 was desired. First the long term model would be used to project the configuration of consuming capital stocks in 1985. This forecast would be contingent upon the exogenous inputs to the long term model (population, incomes, fuel prices, etc.). Given these stocks and the weather variables input to the model (this might be average weather, worst case weather, or actual weather data of some past year), each hierarchical model in time would be used to give the time behavior of the load in 1985. From this the total energy demand, as well as the behavior of the load on a daily, weekly, and annual basis could be obtained.

However, due to the way in which the forecast is to be constructed, much more can be done. The load behavior will be constructed from the utilization vs. time of electricity for each usage category. These categories would each have different characteristics, some contributing mostly to base load, others to cycling load, and others to load on the peaks. Each usage category would also, in general, have different elasticities to changes in price, population, incomes, etc. So not only can forecasts of the overall load behavior be obtained, but changes in the behavior that result from different usage categories growing at different rates can be obtained. The effects of different forecasted or hypothesized inputs into the long range model can be traced through to their overall effects on daily, weekly, annual load patterns. New usage categories, such as the electric car, can be included. Given the typical daily, weekly, annual consumption patterns, the effects on total electricity demand as well as the shape of the load curve for a variety of forecasted or hypothesized scenarios can be studied. It is this capability that makes this model structure so attractive.

3.4 Uncertainty Modeling

In modeling the electric load it is necessary to include uncertainty measures into the model for at least three reasons: the very nature of the load is uncertain; the data available for identifying the parameters is "noisy"; and uncertainty is needed to compensate for the omitted factors which influence the load. Without these uncertainty measures we could easily be misled into placing too much confidence in the model results. One approach to modeling this uncertainty is to assume that the structure of Figure 2, 3, and 4 is exact and that the uncertainty arises because of errors (uncertainty) in the actual values of the parameters of the model. This approach must be rejected because it ignores the inherent uncertainty in the load itself and because it is not effective in handling the uncertainty arising from the omitted factors. The chosen approach is to include the "white stochastic processes" indicated in Figure 4 as inputs to the model. We feel this approach is "more physical" as it results in a representation of the load which is inherently a stochastic process. The uncertainty measures of the load model then follow automatically by determining how the input white processes "propagate through" the dynamics of the load model with time.

3.5 Inclusion of "Extraneous" Structure

During the development of this load model, it will be necessary to construct various appendages to the central core of the model which are relatively unimportant to forecasting, but which allow the model to make maximum use of the available data. An example of such an appendage is the sales modeling shown in Figures 2 and 3. From a forecasting standpoint alone, there is little need to model the process of energy consumption through meter reading to dollars billed monthly. However, if sales data is to be used for identification of model parameters, then the process of generating this data must be incorporated into the model structure. Thus, it will be necessary to depict these seemingly "extraneous" processes in the overall structure of the model.

The ability to make use of all possible data is a very important aspect of this modeling effort. This is made possible by the detailed hour-by-hour load structure which we are employing.

4.0 Model Development

Clearly, the overall development of the model discussed in Section 3 is a difficult task. However, the process of development may be viewed as consisting of three parts:

1) hypothesize the model structure;
2) estimate the model parameters; and
3) verify the model.

This three step process can become an iterative loop if the verification tests fail, for it is then necessary to return to the first step and alter the structure or even hypothesize a different model structure, and repeat the process.

An hypothesized structure is given in Section 3, and in this section we will briefly discuss the other aspects of this process, parameter estimation, and model verification.

4.1 Parameter Estimation

The model of Section 3 has many parameters whose values must be specified. These unspecified parameters include both structural parameters (elasticities, time constants, etc.) and parameters related to the stochastic processes used to model the uncertainty (variances and covariances).

The basic way to obtain numerical values for these parameters is to estimate them from data on the past behavior of load and related variables. For the complex, stochastic model described in Section 3, such estimation is not a simple task. Fortunately, the necessary technology exists in the form of maximum likelihood criterion for the identification of multiple input-output dynamic systems. The actual parameter estimation requires the solution of a high dimensional system of nonlinear equations, but proven iterative algorithms are available.

However, many of the "what if" questions which the model will address will involve situations which have not occurred in the past, so past data will not be available. In such cases, parameter values will have to be deduced by techniques ranging from detailed engineering analysis to educated guesses. Even for historic situations there is still a data availability problem, since the model structure of Section 3 will require data of a detail which does not exist.

One approach to this limited data problem is to modify the model structure to fit the available data. This approach is rejected because it can easily result in a model which is not matched to the needs of any application.

The chosen approach is to combine the physical model structure with analysis techniques to specify exactly what data is needed so that the necessary effort can be expended to obtain the data. This method of pre-specifying the data needed can result in major costs savings over brute force techniques of gathering all possible data. This points out another important aspect of the structure of Section 3. It is a physical structure so that the various parameter values have explicit interpretations. Until the new data is obtained, the unspecified parameters of the model can be determined by hypothesizing parameter values just as in the case of parameters for phenomena which have never occurred in the past.

4.2 Model Verification

The last step in the process of model development, model verification, is an important subject in its own right. A complete discussion of the problems and techniques of model verification is far beyond the scope of this paper, but we want to discuss briefly two aspects of model verification which must be considered.

Verification relative to past data can be done by statistical techniques. Hypothesis testing methods based on the whiteness of the residuals and the size of the likelihood function have proved very effective in past work when combined with maximum likelihood parameter estimation. The Cramer-Rao inequality provides a useful tool for checking the significance of parameter values. However, these techniques are only available if past data exists.

Verification of those aspects of the model which may not be determined from past data consists of making sensitivity studies and reasonability arguments. In fact, such reasonability arguments must be applied to all aspects of the model since statistical tests using past data can never prove the validity of a model; they may only be used to reject invalid models.

5.0 Conclusion

The purpose of this paper has been to summarize an approach to load (demand) modeling which is explicitly directed towards specific applications. The result of this application orientation is a complex model capable of expressing detailed load shape time behavior, answering "what if" questions, and providing a measure of its uncertainty. Proven techniques to estimate the model parameters and test the model's validity are available, but the development of the load model is a large task whose difficulty cannot be ignored. However, we feel that the importance of obtaining application oriented load models justifies the effort required.

Although there is little precedent for a detailed load model like that discussed in Section 3, there are two studies which should be mentioned. The first is by Fisher and Kaysen [1]. This is an econometric study which models long and short term yearly electric energy usage by appliances and equipment in the Residential and Commercial Sectors as a function of personal income, population, number of households, relative costs of competing sources of energy, etc. This excellent study, however, stops short of a complete load model by only considering yearly energy demand. The second is the work by Stanton and Gupta [2] which looks at the weather effects on the weekly peaks using regression and extrapolation of past data along with a postulated weather-load model. This is also a fine study, but it does not consider the long term econometric aspects of the load, and it falls short of a full hour-by-hour load model by only considering weekly peak loads.

There are, of course, many other excellent studies which lie near these two in their basic approach, but they are too numerous to mention explicitly. A good survey of load forecasting techniques may be found in the Methodology of Load Forecasting section in the 1970 National Power Survey [3].

The philosophy of modeling discussed here can be viewed as a combination of two different approaches to modeling:

1) Hypothesize a nonlinear dynamic feedback model and use reasonable values for the parameters. Test validity using reasonability arguments.

2) Apply econometric (statistical) techniques to estimate all parameter values of linear, essentially static model. Test validity in a statistical sense.

We feel it is best to hypothesize a dynamic model based on physical reasoning and then to combine statistical techniques and reasonability arguments to estimate parameter values and test validity.

The ideas expressed in this paper are based on an on-going research effort at MIT; and the details of the model structure described in Section 3 are presently being worked on. Past MIT work directly related to load modeling can be found in Galiana [4] and Baughman [5]. A general discussion on the system identification technique (maximum likelihood parameter estimates and validity testing) is found in Schweppe [9], while applications to complex models (related to electric power systems) are discussed in Moore [6], Masiello [7], and DeVille [8]. The immediate goal of the MIT load modeling effort is to determine what type of new data (if any) will be most useful so that future data gathering can be done on an application oriented basis.

APPENDIX A: Importance of Load Shape in Generation Expansion

In Section 2.1 we discussed the need for detailed load forecasts in planning future system expansion. While it was probably quite clear that peak and energy forecasts are essential in the design of generation expansion, perhaps the load shape or load duration curve forecasts seemed to be unnecessary "extra" inputs into this process.

In this appendix we want to discuss the importance of such forecasts. We will consider the "costs" of using two different systems to supply two different load shapes for one week. System A will consist mostly of fossil-fueled plants, whereas System B will include some nuclear and pumped-hydro generating facilities. The table in Figure A.1 presents a brief description of the plants which make up these two systems. Each of these systems was simulated by a computer program for one week using both of the load shapes shown in Figure A.2. These two load curves have the same peak and the same total energy, but their shapes are significantly different. The "costs" of supplying these two load shapes were computed by the program, and the results will be summarized in this appendix. They will show that under certain conditions System A can supply Load Shape "a" more cheaply than can System B; while, under these same conditions, System B can supply Load Shape "b" more cheaply than can System A. Thus, it is important to look at more than the weekly peaks and total energy; the load shape must also be considered.

The computer program used to simulate the two systems was developed by Mr. J. Gruhl; and the authors would like to thank Mr. Gruhl for putting together the simulation runs discussed in this appendix. A detailed discussion of both the program and the simulations considered here is contained in Gruhl [10].

S Y S T E M A

PLANT 1: is a relatively expensive (to operate) fossil-fueled plant of 160 MW, with a moderately heavy air pollution factor (which varies, of course, as meteorological conditions change) and a cooling tower, and thus, very little thermal water pollution.

PLANT 2: is a 70 MW plant fueled with low sulfer content fossil fuel, making it slightly more expensive to operate, but reducing its impact on the atmosphere.

PLANT 3: is an 80 MW gas turbine.

PLANT 4: is a 100 MW hydro-electric station.

PLANT 5: is a typical 120 MW fossil-fueled unit.

PLANT 6: is a 240 MW slightly cheaper fossil-fueled facility.

PLANT 7: is a typical 460 MW, relatively cheaply operated, fossil-fueled unit.

PLANT 8: is identical to Plant 6.

(Plants 1, 2, 3, and 4 are the same for both System A and System B.)

Figure A.1-a Description of Plants Making Up System A

S Y S T E M   B

PLANT 1: is a relatively expensive (to operate) fossil-fueled plant of 160 MW, with a moderately heavy air pollution factor (which varies, of course, as meteorological conditions change) and a cooling tower, and thus, very little thermal water pollution.

PLANT 2: is a 70 MW plant fueled with low sulfer content fossil fuel, making it slightly more expensive to operate, but reducing its impact on the atmosphere.

PLANT 3: is an 80 MW gas turbine.

PLANT 4: is a 100 MW hydro-electric station.

PLANT 5: is a 560 MW nuclear facility with cheaper power, relatively more water pollution and little air pollution when compared to the fossil units.

PLANT 6: is identical to Plant 5.

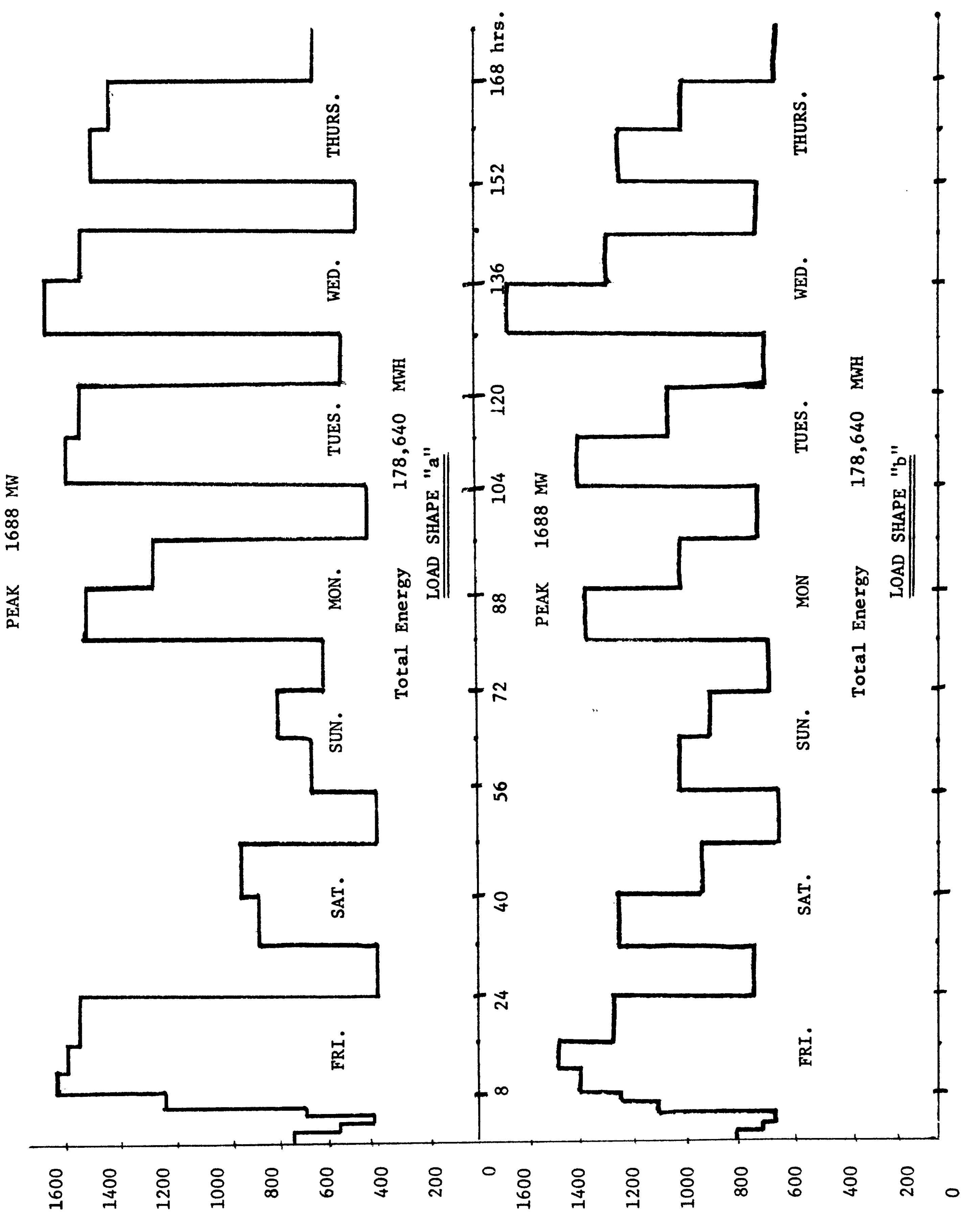
PLANT 7: is a pumped storage facility with 80% input efficiency, 83% output efficiency,80 MW storage capacity, and enough storage for the equivalent of 1000 MWH of water power.

PLANT 8: is identical to Plant 7.

(Plants 1, 2, 3, and 4 are the same for both System A and System B.)

Figure A.1-b   Description of Plants Making Up System B

FIGURE A.2


PEAK 1688 MW
Total Energy 178,640 MWH
LOAD SHAPE "a"
FRI.
SAT.
SUN.
MON.
TUES.
WED.
THURS.
8
24
40
56
72
88
104
120
136
152
168 hrs.
0
200
400
600
800
1000
1200
1400
1600
PEAK 1688 MW
Total Energy 178,640 MWH
LOAD SHAPE "b"
FRI.
SAT.
SUN.
MON
TUES.
WED.
THURS.
0
200
400
600
800
1000
1200
1400
1600

Although an in-depth discussion of this program is far beyond the scope of this paper, we do want to briefly outline its operation before presenting the results.

First, the program chooses the "optimal" unit commitment schedule based on the following factors:

1) plants available for use and their characteristics;
2) short range load forecast (based on a weather forecast);
3) environmental impact factors (based on a weather and pollution forecast);
4) generation constraints;
5) weekly nuclear and hydro-electric production quotas (with penalties for missing these quotas); and
6) the various mixes of dollar costs, air pollution impact, and water pollution impact.

After selecting the optimal unit commitment schedule for one week, the program may then be used to simulate the system and compute the dollar costs, the air pollution impact, and the water pollution impact of supplying some specified load, not necessarily that of the forecast (however, in these runs the forecast and the load supplied were identical).

This unit commitment/cost computation procedure may be performed using <u>any</u> relative weighting of the importance of the following three "costs" of supplying the load:

1) dollar costs;
2) air pollution impacts; and
3) water pollution impacts.

The table in Figure A.3 gives the "costs" of supplying the two load curves "a" and "b", for both systems, A and B, using seven different weightings:

1) DO - minimize dollar costs only
2) AO - minimize air pollution impacts only
3) WO - minimize water pollution impacts only
4) DA - minimize dollar costs and air pollution impacts equally weighted
5) DW - minimize dollar costs and water pollution impacts equally weighted
6) AW - minimize air pollution and water pollution impacts equally weighted
7) DAW- minimize dollar costs, air pollution impacts and water pollution impacts equally weighted.

The graphs in Figure A.4 summarize the dollar cost results for four of these seven weightings (DO, DA, DW, and DAW). From these diagrams we can see that in three of these four cases (DO, DA, and DAW) Load Shape "a" is more cheaply supplied by System A, while Load Shape "b" is more cheaply supplied by System B, even though the peak and total energy of these two load shapes are the same. In the DO case these cost differences sum to almost 11%: 5% for Load Shape "a" and 6% for Load Shape "b".

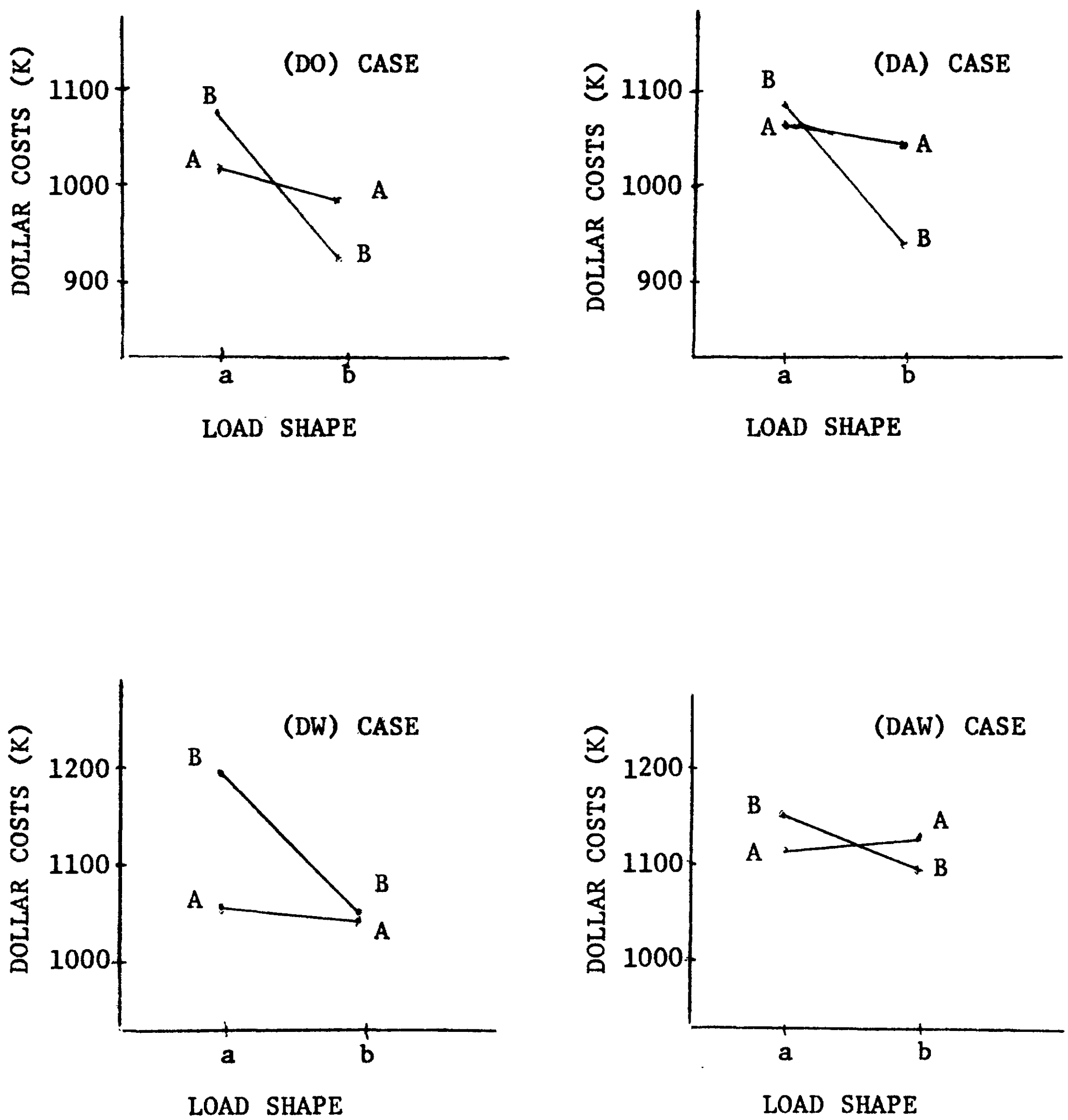
Of course caution must be exercised when drawing conclusions from such a simple example. We have only considered the costs for a single week, as if the system were being built from scratch to produce electric power for one week only. This, of course, is incorrect; the system is developed by adding one plant at a time to the system, and the system must supply its customers with electric power while the construction is going on. Furthermore, we have not considered that there may exist a System C which

FIGURE A.3

THE RESULTS

Minimizing Conditions	Cost	System A Load Shape a	System A Load Shape b	System B Load Shape a	System B Load Shape b
DO	D	1018880	994709	1070522	935102
	A	1184550	1210161	284822	255502
	W	703880	724663	1245172	1286622
AO	D	1245360	1252720	1178442	1040622
	A	884340	890410	245262	213592
	W	580980	573320	1190742	1255702
WO	D	1155070	1154530	1294492	1181282
	A	980820	964850	356102	355052
	W	537020	526510	931602	925292
DA	D	1073030	1046480	1076402	941812
	A	948210	958520	265042	235652
	W	601300	596630	1218192	1265902
DW	D	1059610	1043490	1186642	1046722
	A	1047090	1060170	340932	337682
	W	573100	569080	1001282	1015132
AW	D	1233940	1224530	1294492	1181282
	A	893810	889260	356102	355052
	W	564450	557430	931602	925292
DAW	D	1117320	1122810	1141322	1000692
	A	920340	904200	303712	291752
	W	568040	557170	1066712	1197432

FIGURE A.4


(DO) CASE
DOLLAR COSTS (K)
1100
1000
900
B
A
A
B
a
b
LOAD SHAPE
(DA) CASE
DOLLAR COSTS (K)
1100
1000
900
B
A
A
B
a
b
LOAD SHAPE
(DW) CASE
DOLLAR COSTS (K)
1200
1100
1000
B
A
B
A
a
b
LOAD SHAPE
(DAW) CASE
DOLLAR COSTS (K)
1200
1100
1000
B
A
A
B
a
b
LOAD SHAPE

could supply both Load Shape "a" and Load Shape "b" more cheaply than either System A or System B. But this simple example does clearly show that a detailed forecast of the future load, including the load shape, is required if the system planner is to design the most efficient system to supply the load.

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