PUBLIC UTILITY OPERATION AND GROWTH: A SYSTEM SIMULATION MODEL

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ABSTRACT

An organizational model of a public utility is described in this paper. The system is conceptualized as an informational feedback structure with four major sectors. The sectors deal with production, financial growth, and pollution management in a utility. The model is computerized in the System Dynamics language DYNAMO and provides a research vehicle for executives developing policy for utility management.

INTRODUCTION

An increasing concern for dwindling energy reserves has accelerated study into the way that energy resources are obtained and used. This study generally has been technically oriented. The procurement of the natural resources of energy and their conversion into consumer products, however, present some unique and interesting problems for managers responsible for this process. Complex forces exert competing pressures on managers of energy acquisition and consumption. This is true for managers of public electric utilities, because they are faced with difficult choices between the use of oil and coal with their differing costs and pollution factors; between increasing (or stimulating) demand and the need for conservation; and between costs of production and the ability of the consumer to bear the costs. Analysis of these and other competing forces has led to a theory about how utility executives operate their organizations and respond to the pressures that constitute their decisional system.

The research required to support a viable theory of the organization and operation of electric utilities was embodied in development of a generalized model of a representative utility. Explanation of the general model structure is the purpose of this paper. The proposed interrelationships within the model structure constitute a theory about the management of electric utility operation and growth and the decisional structure of this process.

The model is based upon detailed study and analysis of the Tallahassee, Florida, city utilities organization. The power system is operated by the City of Tallahassee and generates, through operations, the revenue to support itself and to provide limited revenue for other city operations. Financing for capacity growth comes from the sale of bonds in the capital market.

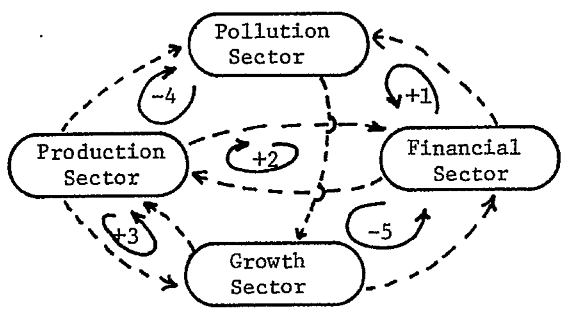
The model has been broadened, however, to make it generally applicable to public utilities operated privately as well as to those operated solely in the government sector. This more general approach has been taken so that more detailed research can be completed in the four basic areas of production operations, pollution effects, financial structure, and growth (expansion pressure) within the utility system. These four basic areas constitute the major sectors of the model. The model has been computerized using the System Dynamics technology DYNAMO and the results of some of the simulation runs of the model also will be presented in the paper. This will follow development of the required theory.

THEORETICAL BASIS

A representation of the relationships between the four primary sectors of an electric utility is shown in Figure 1. The utility executive makes decisions in each of these sectors and attempts to balance forces in their interrelationships. The numbered loops (1) shown indicate interaction between given variables in each of the sectors. A positive loop (+) indicates that movement up or down in one sector leads to a reinforcement of

FIGURE 1

Sector Interactions

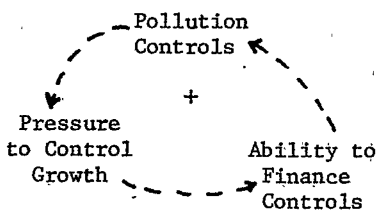


the movement in that sector through a series of interactions with other sectors. A negative loop (-) indicates that movement up or down in one sector leads to the opposite movement in that sector through the interactions with other sectors. The operation of the utility system, therefore, may be visualized as a set of positive and negative feedback loops. The interaction of these positive and negative forces determines the behavior of the organization over time. The theory of the relationships has been developed from analysis of the Tallahassee utility study and from accepted economic and managerial theory.

Loop 1 defines the interaction between the financial, pollution, and growth sectors through the variables shown. As funds are expended for pollution controls, pollution becomes less visable removing pressure to control growth because of observed pollution. The improved outlook for growth contributes to favorable conditions for raising funds which could be used to finance further controls. The loop, therefore, is positive.

FIGURE 2

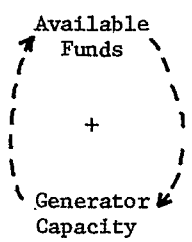
Loop 1 Interactions



Loop 2 defines the ability of the firm to actually produce electric power to meet demand. As funds are available for full operating expenses and capacity expansion, electricity can be produced to meet any foreseeable demand. The production of electricity creates revenue, improving the potential of the firm to meet debt requirements. The loop, therefore, is positive.

FIGURE 3

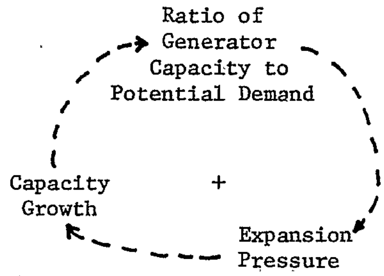
Loop 2 Interactions



Loop 3 defines the effects of expansion pressure on electricity production. As demand increases and production capability approaches capacity, the pressure to expand production facilities increases. The increasing growth pressure will be met by expanding capacity. The loop, therefore, is positive.

FIGURE 4

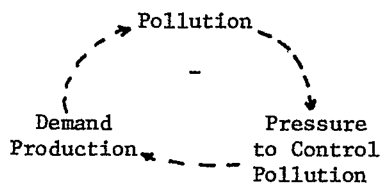
Loop 3 Interactions



Loop 4 defines the effects of pollution on the expansion of electricy production. Increased production causes a rise in pollution visibility. Pressure to control pollution has a dampening effect on demand and increasing capacity. The loop is negative.

FIGURE 5

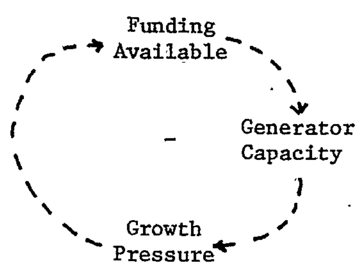
Loop 4 Interactions



Loop 5 defines the interaction between the financial, production and expansion pressure or growth sectors. As funds are available to increase capacity, expansion pressure is relieved. The financial market is not willing to finance further increases until demand again approaches capacity. The loop, therefore, is negative.

FIGURE 6

Loop 5 Interactions



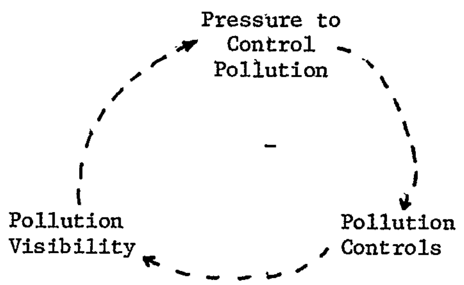
These five major loops are the significant feedback mechanisms in operation; however, a number of other minor loops are at work in and between the various sectors of the model. These minor loops, along with the five major loops, form the basis for the theory used in model construction. The minor feedback loops operate within the major loops and will be explained later.

The utility is part of a complex system of funds supply, electricity demand, and production factors. The manager must balance the forces in this system to insure long-term viability. The manager's internal decisions strongly influence (and are influenced by) the financial and consumption sectors of the system. The conceptualization of the organization as a feedback system is based upon this feature of utility operation. The minor loops in the model further reinforce this idea.

A loop is in operation within the pollution control sector. As pollution visibility increases, pressure to control pollution increases causing an increase in pollution controls and a decrease in visibility.

FIGURE 7

Pollution Control Loop



There is an interrelationship between actual growth, expected potential demand and potential demand desired. Potential demand is the maximum demand the firm could face if all circuits were placed in operation. It is a function of actual net growth. Expected potential demand is a function of executive expectations concerning growth. An executive develops a forecast of demand and uses that forecast in decision making. This forecast is developed from past actual potential demand and the executive's expectations of growth. The further into the future the projection is made, the less reliable are the estimates of potential demand. If expected potential demand exceeds an executive's potential demand (or growth goal), an increase will occur in pressure within the organization to influence growth in the community and control the organization's capacity. If the pressure becomes severe enough, growth will decrease. These relationships are shown in Figure 8.

A loop in the financial sector defines the interrelationship between factors in the market, the organization's debt-service potential and its ability to attract long-term financing. If financial market factors are favorable, long-term financing is more available. When long-term debt increases, debt-service potential decreases, causing less favorable conditions in the financial market. These relationships are shown in Figure 9.

FIGURE 8

Growth from Demand Loop

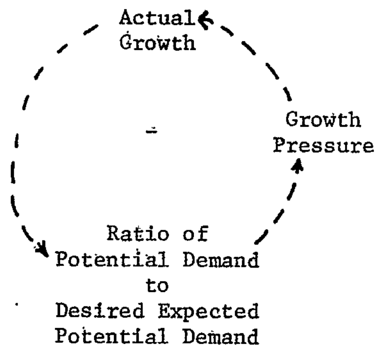
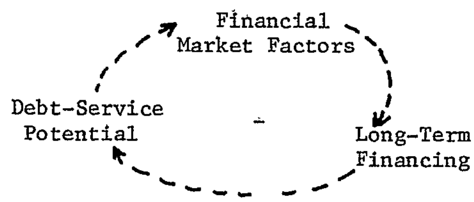


FIGURE 9

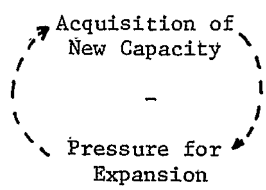
Financial Factor Loop



A relationship exists between pressure for expansion and acquisition of new capacity. As capacity increases, internal and external pressure for expansion decreases, as shown in Figure 10.

FIGURE 10

Acquisition of Capacity Loop



Pressure for expansion also influences utility rates. An increase in pressure results in pressure for rate increases to service the debt incurred with expansion. These rate increases affect the willingness of consumers to conserve electricity. An increase in the willingness to conserve leads to a decrease in demand and a reduction in expansion pressure. These relationships are shown in Figure 11.

Current revenue affects the ability to secure long-term financing through its effect on debt-service potential. This has a positive effect, because an increase in revenue leads, through funds available, plant capacity, and production potential, to further revenue growth. Revenue also will have some effect on rates through funds and pressure for expansion. Relationships are shown in Figure 12.

FIGURE 11

Conservation Willingness Loop

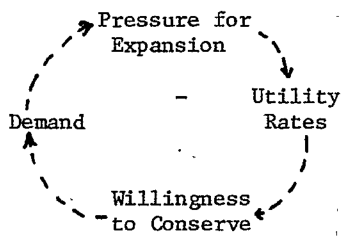
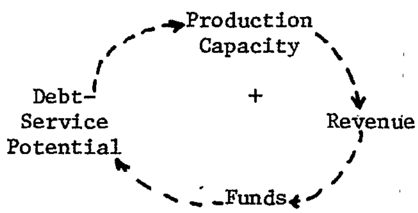


FIGURE 12

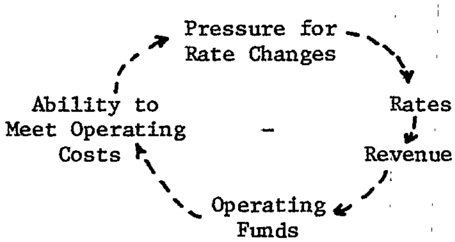
Revenue Factors Loop



A significant relationship exists between fuel and operating costs and utility rates. Rising fuel and operating costs cause increased pressure to adjust rates upward. Increased rates result in revenue increases which provide the funds required to meet rising costs. There would be only a slight pressure to decrease rates once they are raised, even though costs of production factors might decline, as shown in Figure 13.

FIGURE 13

Rate Structure Loop



The major and minor loops have been expanded into detailed flow diagrams and equations that are used to construct a computer simulation model. Although the phase of the research using the computer model is continuing, preliminary operation of the model has been quite encouraging. The data from these initial operations illustrate how the competing forces upon management are balanced. The remainder of the paper deals with detailed structure of the model and its operation and validation.

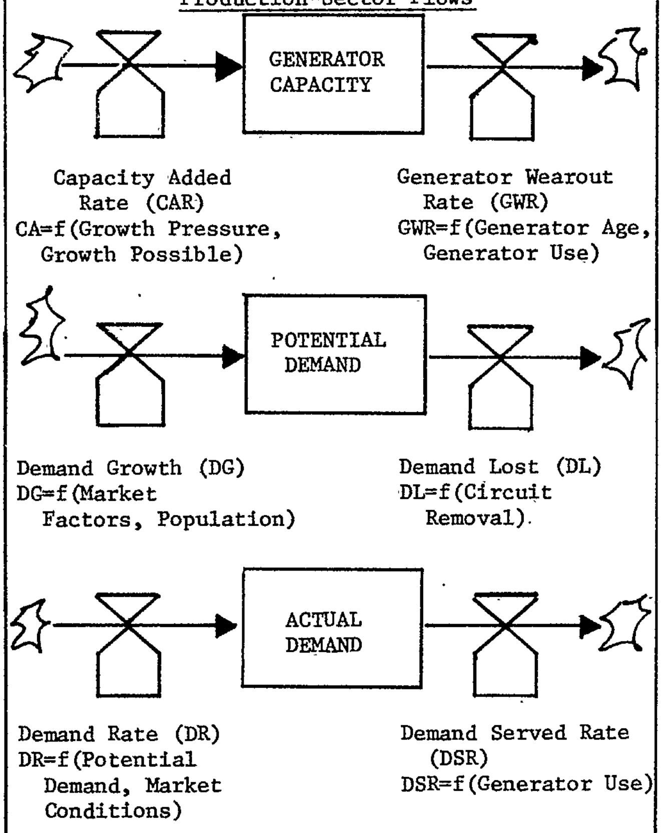
DETAILED MODEL-FLOWS

The interactions within the loops determine the nature of the forces in the decisional structure the utility executive faces. These forces were discussed in the last section. The way in which these variables actually form an informational feedback structure will be discussed in this section.

The detailed structure of the production sector of the model is represented by the flows shown in Figure 14. The symbols are in the System Dynamics notation with the levels represented by a rectangle ( ), a decision point controlling the inflow and outflow from a level by a valve ( ), and the flow by a solid line (⟶). Executives add to the capacity to generate electricity when potential demand in a community approaches current capacity or

FIGURE 14

Production-Sector Flows

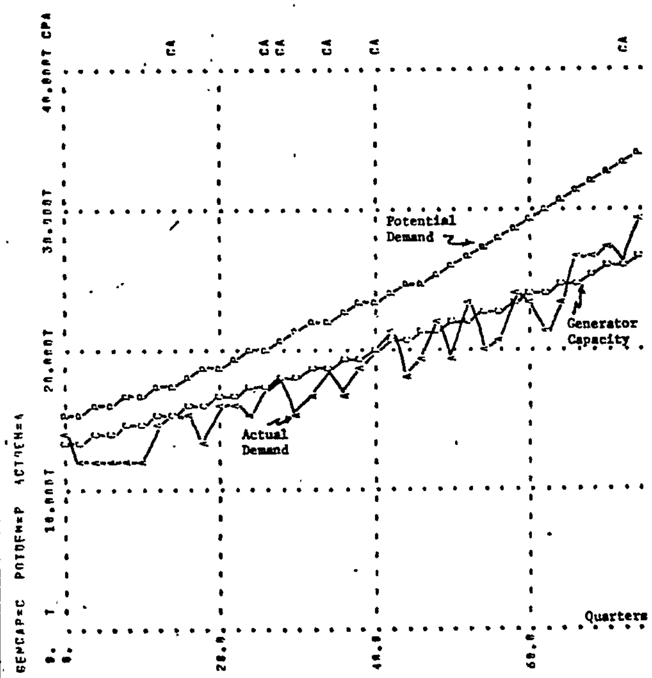


when government policy makes expansion attractive. The ability to expand is, of course, affected by the ability of the organization to attract debt financing. The potential demand in a community is the maximum load that could be placed on the system if all circuits in existence were activated at once. The actual demand is some percentage of the potential demand. It fluctuates in the range of 90% of potential demand depending upon consumer conservation efforts, market conditions, and season. The actual ratio between these variables must be understood by the utility executive and is the point of continuing research.

The movement of the three level variables over a nineteen-year period is shown in Figure 15. A basic community-growth-rate of about five percent each year was employed in the model. This figure was

FIGURE 15

Production Sector Level Movement

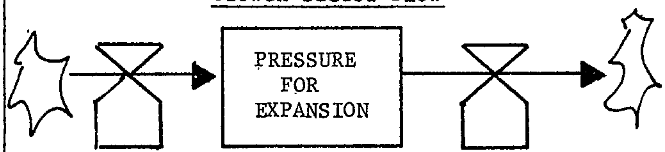


based on a study of community growth. The growth is reflected in the movement of potential demand. Actual demand follows the potential demand with the fluctuations because of the factors previously noted. Generator capacity also grows with potential demand and is a reflection of the realized capacity a utility actually possesses. Learning curves and start-up problems mean the realized capacity is reached gradually and not immediately with installation of new equipment. Generator capacity is sufficient to meet demand during most of the period of operation. When it is not, the utility must purchase electricity from other sources or reduce service. In the utility studied, electricity was purchased from other utilities when demand could not be satisfied. The pattern of movement is consistent with what occurred in the actual system. The slight divergence of generator capacity and actual demand toward the end of the period was caused by allowing expansion pressure to fall. This pressure variable is the subject of the subsequent discussion.

The flow of pressure to expand existing facilities is portrayed in Figure 16. The pressure is a strong determinant of the generator capacity added.

FIGURE 16

Growth-Sector Flow



Growth Pressure (GP)
GP=f (Capacity/Demand, Management, Government Policy)

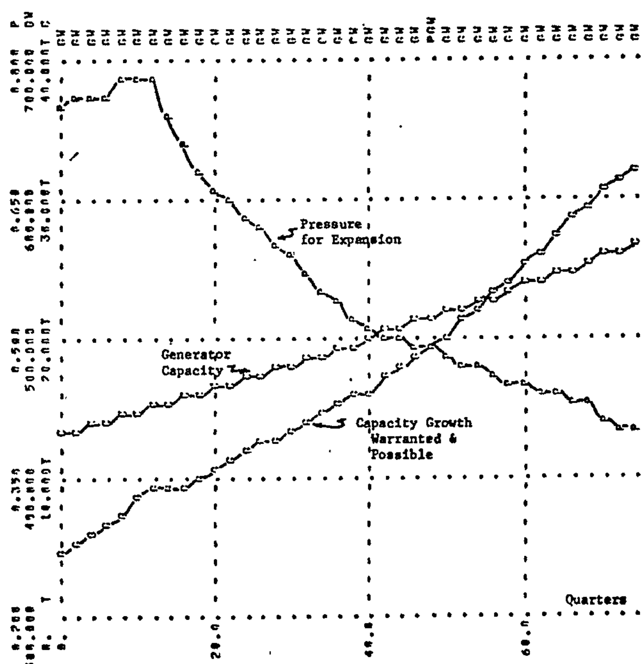
Pressure Relief (PR)
PR=f (Capacity Added)

This is implemented through a transfer function with additional capacity a dependent variable and pressure an independent variable. The exact shape of the transfer function between these variables is critical and is the subject of continuing research. The growth pressure is a function of the ratio between generator capacity and a combination of actual and potential demand. The pressure is relieved as the generator capacity grows.

The movement of the pressure for expansion variable is shown in Figure 17.

FIGURE 17

Pressure for Expansion and Growth Movement

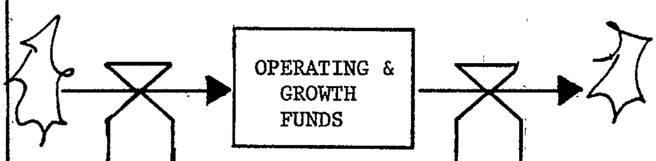


The pressure is a complex variable that is determined chiefly by the capacity to demand ratio. When the generator capacity to demand ratio is what the executives desire, expansion pressure is not severe. If the ratio is unfavorable, pressure would grow to add more capacity. In the period represented, capacity is allowed to grow as warranted to track potential demand. Pressure, as a result, falls rather than builds. The things that determine the pressure for expansion are also points of continuing study. Several experiments show the model to be very sensitive to this pressure and the shape of the function that transmits the pressure to the amount of growth allowed. The shape of the pressure function in the experiment shown in Figure 17 did not allow sufficient growth of generator capacity. This caused the previously discussed divergence between actual demand and growth warranted and generator capacity. Pressure causes a certain warranted growth. The actual growth possible is, of course, strongly dependent upon funds availability. The financial aspects of the model are the subjects of the next discussion.

The ability of the organization to grow (add capacity) is dependent upon its ability to attract debt financing which is itself a function of a favorable outlook for demand and operations. As demand grows, funds from operations grow and the ability of the organization to attract debt funding, and thus grow, is enhanced. The actual level of funds available is reduced by the funds required for operations, for growth, and for debt service. The availability of funds is a key informational flow in determining the growth of the organization and in its ability to control pollution. These relationships are displayed in Figure 18.

FIGURE 18

Financial-Sector Flow



Funds Growth (FG)
FG=f(Debt
Acquisition,
Net Receivable)

Funds Required (FR)
FR=f(Operations
Costs, Growth,
Debt Service)

Financial movements are reflected in the patterns shown in Figures 19 and 20. Operating funds follow the growth in demand as do the growth funds. Long-term debt and receivables also show the same pattern. Several experimental features of the model are not illustrated specifically in this paper. The effects of inflation, unstable fuel costs, consumer resistance, fluctuating production costs, and instability in financial markets were not activated

FIGURE 19

Operating and Growth Fund Movement

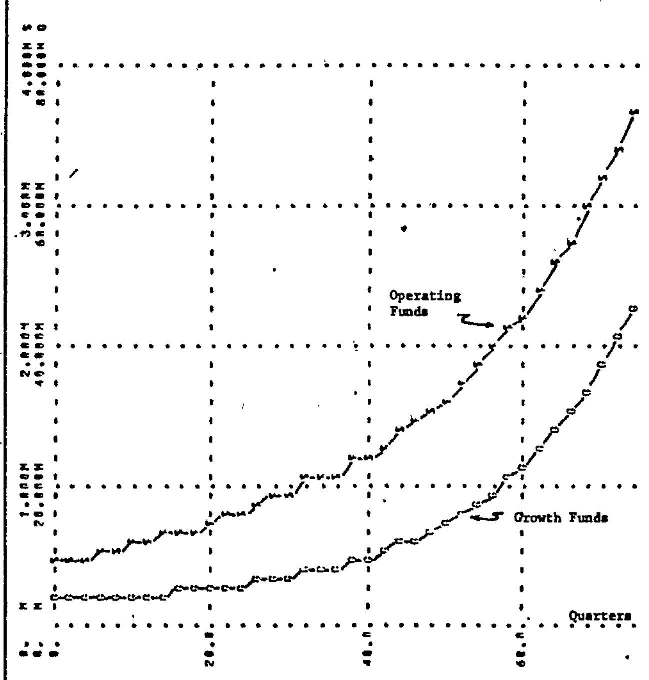
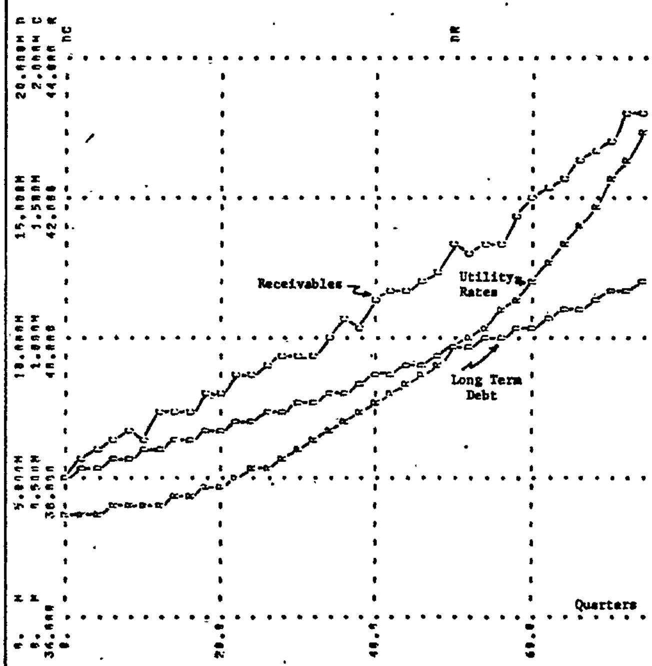


FIGURE 20

Financial Sector Movements



in the basic runs of the model. Achieving a stable growth pattern in the model was the objective of initial efforts. The stable model may now be used to investigate these factors. To illustrate how these experiments are conducted, an experiment with the availability of capital funding was conducted.

The movement of generator capacity when sufficient growth funds are not available is shown in Figure 21. This movement results in the face of prolonged absence of sufficient expansion or capital funds. In quarter thirty, expansion funds become insufficient resulting in the long-term decline in capacity. The decline, even in the face of excellent potential demand, is self-reinforcing. The ability to attract debt and the exact relationship of this to the condition of the utility is critical. Managers must be aware of the normal conditions of the capital market and their effect on the organization's ability to grow, for once an organization finds itself in an unfavorable capital position, recovery is most difficult. The exact structure of the mechanisms which cause such movements is the point of continuing research. The investigation is focused upon the amount of capacity allowed by the pressure variable and the factors necessary to attract debt.

Operation of generators creates pollution. The amount of pollution actually released into the atmosphere depends upon the type of fuel used and the level of pollution controls employed. Once released, the pollution is more or less visible depending upon general environmental conditions. The flow of pollution is shown in Figure 22.

FIGURE 21

Generator Capacity Decline

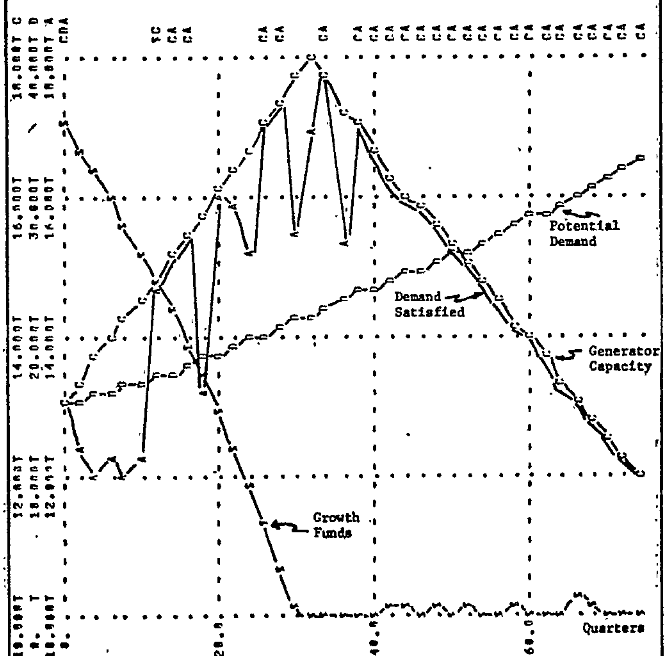
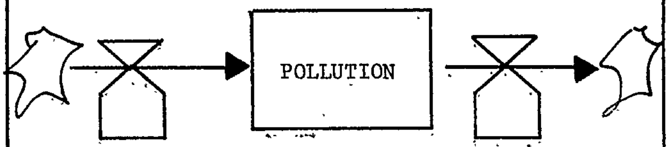


FIGURE 22

Pollution-Sector Flow



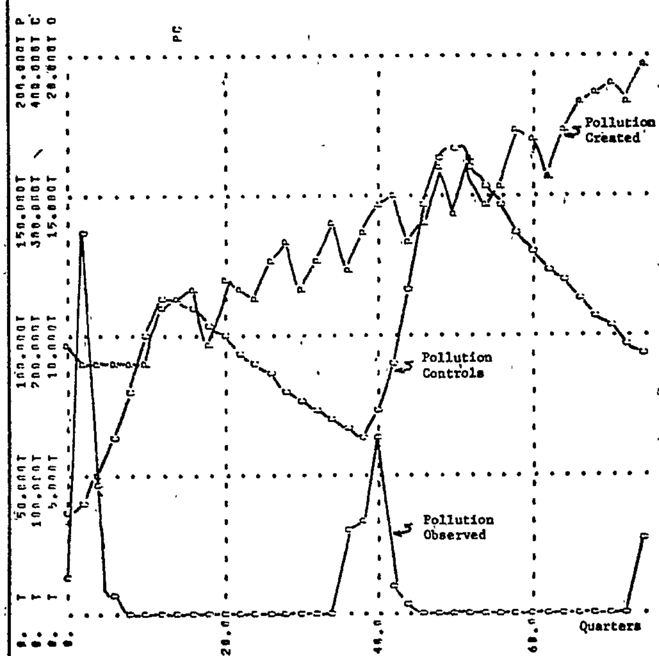
Pollution Increase (PI)
PI=f (Generator Use, Fuel Type, Pollution Controls)

Pollution Decrease (PD)
PD=f (Environmental Conditions)

The movement of the pollution sector variables is shown in Figure 23. When pollution controls are adequate, the pollution actually allowed into the environment is very small. If controls are not sufficient, observed pollution grows causing an increase in pressure to control it. This pressure is translated into controls through a complex transfer function. The true shape of this function for a given utility varies and must be investigated thoroughly.

FIGURE 23

Pollution Sector Movements



The results of the model support the theory outlined in the causal loop diagrams about the structure and organization of an electric utility. Results are consistent with the movements observed in the specific utility studied. The structural validity of the model adds to its potential as a research device and as an executive decision-making aid.

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