TRADE-OFF DECISIONS IN DISTRIBUTION UTILITY MANAGEMENT

By

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ABSTRACT

As a result of the "unbundling" of traditional monopolistic electricity generation and transmission enterprises into a free-market economy, power distribution utilities are faced with very difficult decisions pertaining to electricity supply options and quality of service to the customers. The management of distribution utilities has become increasingly complex, versatile, and dynamic to the extent that conventional, non-automated management tools are almost useless and obsolete.

This thesis presents a novel and unified approach to managing electricity supply options and quality of service to customers. The technique formulates the problem in terms of variables, parameters, and constraints. An advanced Mixed Integer Programming (MIP) optimization formulation is developed together with novel, logical, decision-making algorithms. These tools enable the utility management to optimize various cost components and assess their time-trend impacts, taking into account the intangible issues such as customer perception, customer expectation, social pressures, and public response to service deterioration.

The above concepts are further generalized and a Logical Proportion Analysis (LPA) methodology and associated software have been developed. Solutions using numbers are replaced with solutions using words (character strings) which more closely emulate the human decision-making process and advance the art of decision-making in the power utility environment.

Using practical distribution utility operation data and customer surveys, the developments outlined in this thesis are successfully applied to several important utility management problems. These involve the evaluation of alternative electricity supply options, the impact of rate structures on utility business, and the decision of whether to continue to purchase from a main grid or generate locally (partially or totally) by building Non-Utility Generation (NUG).

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I thank my wife Wilma for her patience, encouragement and support and my son Paul for his support. His teenage years flashed by me whilst I was absorbed in this research work.

I am truly indebted to many people but I am also reminded of life's realities by the words of Thomas Gray (1716 - 1771):

The curfew tolls the knell of parting day,
The lowing herd wind slowly o'er the lea,
The ploughman homeward plods his weary way,
And leaves the world to darkness and to me.

Now fades the glimmering landscape on the sight,
And all the air a solemn stillness holds,
Save where the beetle wheels his droning flight,
And drowsy tinklings lull the distant folds.

Elegy Written in a Country Churchyard (1751)

I dedicate this work to my father and mother.

Rimas Slavickas

TABLE OF CONTENTS

GLOSSARY OF TERMS

COGENERATION: the simultaneous production of useful heat (typically steam) and electricity. Cogeneration can most readily be developed by industry, but there are other opportunities, such as district heating, which would be attractive to municipalities.

CUSTOMER SELF-GENERATION: customers who generate electricity for their own use and therefore reduce electrical demand from the transmission grid.

DSM: Demand Side Management.

ECONOMIES OF SCALE: refers to increased efficiency and reduced unit costs that result from increasing the size of the entity producing the product or service. For example, in generation, economies of scale are present if a single 100 MW unit has lower unit costs than two 50 MW units. Economies of scale are present in distribution to the extent that a single municipal utility can service a concentrated area more cheaply than two or more municipal utilities.

ELECTRIC UTILITY: an electric power company that operates a power transmission system or a distribution system and has the legal right to produce and sell electric power in a given geographic area. It is a form of legal monopoly over electric services in the geographic area.

HORIZONTAL INTEGRATION: the amalgamation of companies or entities within the same segment of the industry. For example, a merger between two generating companies or two distributing utilities constitutes horizontal integration. It is the opposite of horizontal unbundling.

HORIZONTAL UNBUNDLING: the separation of a single company involved in one segment of the industry into two or more companies. For example, the creation of multiple generating utilities from a single generating utility constitutes horizontal unbundling.

INDEPENDENT POWER / NON-UTILITY GENERATION (NUG) / PARALLEL GENERATION: electric power produced by an entity other than the electric utility in the area.

INSTITUTIONAL CHANGES: involves both changes to the infrastructure of the electric power industry and changes to the existing legislation to enable the transition of this industry from a monopolistic organization into a competitive market.

INTANGIBLE (in the context of thesis): conceptual, logical, non-conventional, not readily defined or easily quantified.

NATURAL MONOPOLY: a market in which demand can be satisfied at lower cost by a single firm than by multiple firms. For example, the presence of two distributors on a street, each with its own distribution lines and serving alternate houses, is wasteful of resources. The fact that the street could be serviced considerably more cheaply by a single distributor implies that distribution to this market is a natural monopoly.

OBLIGATION TO SERVE: the requirement that a utility, particularly one having a franchise monopoly, must provide access to electricity to all customers and must meet all reasonably expected demands for electricity.

POOL CONCEPT: refers to the pooling of generation and transmission costs in order to provide uniform bulk power rates to customers with similar load characteristics.

PRIVATE POWER: power produced from privately-owned generation facilities.

PRIVATE UTILITY: an electric utility that is privately owned, regardless of whether its shares are publicly traded or privately held.

PRIVATIZATION: refers to the privatization of ownership of a public utility. Does not necessarily imply the reduction of a utility's monopolistic powers, or the purchase of independent power.

PUBLIC UTILITY: in Canada, a provincial crown corporation, such as Ontario Hydro, that is owned by the government. In the US, a public utility may be government-owned, non-profit, cooperatively owned, or a combination of the above.

PURCHASE GENERATION: electricity from generators who have formal agreements to sell power to the transmission grid.

TANGIBLE (in the context of thesis): definite, distinct, conventional, ordinary, materialistic, directly able to be perceived.

THIRD-PARTY ACCESS: an electricity transaction between two distinct entities, other than the transmission company, that requires the use of the transmission grid.

VERTICAL INTEGRATION: the amalgamation of companies performing different services in an industry. For example, the amalgamation of generation, transmission, and distribution services within a single company constitutes vertical integration. It is the opposite of vertical unbundling.

VERTICAL UNBUNDLING: the creation of separate companies to perform different services within an industry. For example, the creation of separate generation, transmission, and rural distribution companies would constitute vertical unbundling.

WHEELING: the transmission of electricity by a single entity from one location to another through the transmission grid.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

Electricity, due to its versatility in usage, has become a commodity that society is taking for granted and upon which it has become highly dependent. It has many diverse applications in the energy utilization process. Electricity is utilized in entertainment, communications, manufacturing, and modifying the human environment. Through the process of energy transfer, electricity can partly or totally solve problems, influence the standard of living, and result in various levels of user satisfaction. Society, with its continuously evolving social structure, has laws, regulations, values, economic and financial constraints, technological innovations and applications formed within nature's physical environment of a self-contained ecosystem.

Many complex parameters, variables, and constraints which require human evaluation, judgement, and re-evaluation of standards and social values, are associated with a distribution utility. These include sensitivity to costs and sensitivity to impact upon the ecological and social environment. Scarcity of resources and safety are contributing factors for consideration to maintain equilibrium between demand and supply for this product and associated services.

Due to the rapid technological advances in generation and changes in society's values, the procurement of an adequate and reliable supply of electricity at a reasonable price is a dynamically evolving process. This may be viewed as being both challenging and opportunistic within the constraining ecosystem, which includes the ecological environment, the social structure, and the traditional infrastructure of the electrical power industry. In North America, for example, this industry consists of a main supplier, or central public utility, which generates and transmits electricity directly to some large industries and also to regulated distribution utilities. People who purchase electricity, both individual customers and distribution utilities, have become much more informed and proactive [132]. The management of this industry is undergoing substantial change as society moves from a philanthropic acceptance of service as provided, to insisting upon direct, or at least partial, involvement. The whole industry now faces dilemmas and major challenges and this thesis presents a novel, analytical approach to optimal decision-making involving customer satisfaction constraints.

1.1 SCENARIO OF CHANGE

1.1.1 Changing Environment

The following factors combine to change the environment for the electrical power industry. Due to rapid technological advances in generating electricity, a distribution utility has, in addition to the power pool, other cost-effective sources of electricity available. Improvements in communication and relative ease of access to information make the public more enlightened and knowledgeable, thus increasing expectations.

Globalization of industries, pressures of competition, and the accelerating technological changes require the distribution utility to strive for improved efficiency and effectiveness in order to survive as a viable business [132]. Capital markets are also changing, mainly due to global, rather than strictly local or national needs. All these changes can be seen in various parts of the world [34]. For example:

- In Europe, the transition to a common market will not sustain existing national policies and trading among the states will require a new regulatory framework within the open-market concept.
- In Eastern Europe, as a result of changing to a market economy, large and inefficient state monopolies are being replaced. In the case of the electrical industry, private power is being promoted to compete with established sources of generation. Market forces are gaining more prominence with respect to determining signals for changes, as opposed to past policies of strict central planning.

- In the developing world, electrical utilities are dominated by state ownership. The combination of poor performance and financial difficulties has resulted in greater involvement by the private sector. The general trend is to encourage competition among plants with the purpose of improving efficiency.
- In general, the public monopolies, which are considered to be relatively efficient, are turning to passive, private capital markets for new sources of investment funds. Hence, there is a shifting of policy from the public sector to the private sector for required funds.

Therefore, there appears to be links between improved performance, efficiency, and competition in both public and private industries.

1.1.2 Obligation to Serve and Competition

In the past, the electrical industry was technologically driven. It has evolved into the present system of one central public utility or, becoming a single supplier which generates and transmits electricity directly to large industrial customers and local municipal distribution utilities. These utilities evolved as natural monopolies based upon the perception of economies of scale as a result of earlier technologies. This meant the larger the plant, the greater the efficiency and the lower the unit cost. This concept was especially prominent in generation [118]. Generation and transmission costs of the central supply utility are pooled in order to provide uniform bulk power rates to customers with similar load characteristics.

Legislation requires that public utilities operate responsibly and in the best interest of the general public. Therefore:

- Public utilities, in exchange for monopolistic privileges, have an obligation to provide service to any customer willing to pay the cost determined by the regulatory process. This ensures that all members of the public who pay the regulated price will be served.
- The existing regulations enable public utilities to receive an adequate average rate of return through a regulated rate structure. In this process, subsidies to one class of customers are offset by rates which are above cost to others.

These class subsidies are important components because of the obligation to provide service, but they would be difficult to maintain in a competitive environment. Selling to some customers well above cost will result in the formation of new competitors, and regulating a utility to sell below cost will force it out of business.

The introduction of competition, in the case of the generation of electricity, has advantages and disadvantages. The advantages are that it creates a market discipline which, in the long-term, increases the efficiency of operations and leads to lower electrical prices. Competition also reduces the government's influence and ability to use the central utility for political purposes. Otherwise, it would impair the utility's ability to compete [35]. The added feature of introducing privatization results in the capital risk being shifted from the central utility to the private sector.

The disadvantage may occur if there is excess generation as a result of Non-Utility Generation (referred to as NUG units in the industry)[1], whether it be from private companies or from distribution utilities. If this surplus results in the reduction of purchases from the central public utility, then it may lead to price increases by the central utility to those customers remaining in its power pool.

1.1.3 Unbundling of Services

There is an increased interest by the government and the public to restructure the electrical power industry. This industry presently has three main functions: generation, transmission, and distribution of electricity. The separation of generation, transmission, and distribution functions is known as "unbundling" and includes 'third-party access' for non-utility generators. This would increase competition in generation and increase the efficiency of this industry. The unbundled structure would make the costing procedure more visible and result in a smoother transition to change as the electrical power industry adjusts to varying degrees of competition.

From the 1900's to the 1970's, technological advances also reflected economic

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1. Glossary of Terms, pages xi-xiii

advantages due to the economies of scale. Customers were provided with the benefit of systematic decline in the price of electricity [119]. Therefore, increasing plant size favoured a monopolistic approach to generation. Using the same rationalization about the whole electrical power industry, the aspects of transmission and distribution were also formed as natural monopolies. However, further technological improvements, as in the case of generation, resulted in levelling off and then declining efficiency gains from increasing plant size. There is now no longer the economic rationale for a sole, monopolistic supplier. Multiple generation companies could not only co-exist, but could also compete against each other within the existing market. The declining natural gas prices have made non-utility generation even more economically attractive. This has created public pressures, and economically justified for regulatory changes. Generation is no longer considered a natural monopoly. However, transmission and distribution continue to be natural monopolies, for it would not be efficient to have competing transmission and distribution lines parallel to each other and serving the same area [156].

There are various changes or levels of integration to the electrical power industry that can be made as illustrated in Figure 1.1.

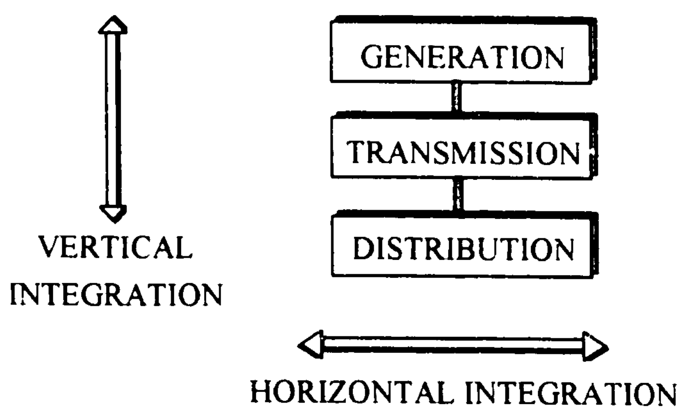

Figure 1.1 : System Integration

Vertical integration refers to the degree the functions of generation, transmission, and distribution are merged. If a supply authority has both functions of generating and transmitting, for example, then it is vertically integrated. Horizontal integration implies that within each of the three functions shown in Figure 1.1, there exists a single organization or a multiple of organizations all acting as one. For example, if some of the distribution utilities who presently purchase wholesale power from the central public utility merge, or form collective cooperatives, then these become horizontally integrated. A group of distribution utilities who merge and build their own non-utility generation would be involved in both horizontal and vertical integration. Therefore, integration is conceptually the opposite of unbundling.

The involvement of a larger number of participants in generation (horizontal unbundling) enhances the potential for competition. It improves efficiency, facilitates the introduction of non-utility generation, encourages the introduction of new technologies, and shifts away from central planning. It is important that all participants involved in the supply of electricity clearly know their roles and responsibilities and, as the clarity of purpose increases, visibility of performance enhances accountability and promotes efficiency [61].

The principal role of the electricity producer is to provide electricity at the lowest feasible cost, consistent with health, safety, and environmental standards. The role of government is to set environmental goals, to set health and safety standards, and to ensure that adequate protection exists against exploitation. The principal role of the regulator is to interpret and administer government legislation, and to promote competition wherever possible. The separation of these functions enhances regulatory success in the evolving process of the electrical power industry.

1.1.4 Open-Market Concept for Generation

The past successes of the electrical power industry caused institutional inertia and complacency in public utilities which are monopolies. In the case of generation, the economies of the past technology meant "the bigger, the better". The large amount of capital and relatively long lead time that was required to build these projects did not meet very strong objections, and validated the concept that centralized planning was both necessary and desirable. The forecasts reflected confidence that the growth of the electrical load would be rapid and this industry had a wide latitude of tolerance. These past successes provided cheap and reliable sources of electricity, reinforcing public confidence. Consequently, these institutional structures underwent little or no change.

However, the times have changed and governments are no longer willing to financially support large mega-projects which may risk the government's credit rating. The objective for the proposed institutional change, which is now both economically and technologically justifiable, is to increase competition in the generation of electricity. The recent rapid increases in electrical costs and price reductions of natural gas, as well as the prospects of generating from burning municipal waste, have added to the pressure for institutional changes. These changes have enhanced the appeal of self-generation and co-generation for distribution utilities. Therefore, non-utility generators are now in a position to compete on both the technical and economic level with traditional supply utilities.

This pressure for change is further reinforced by reduced electrical load growth and increased uncertainty regarding load forecasts, as well as the effects of a worldwide recession. Long-term generation planning is being replaced by planning over shorter terms. Future load demands favour smaller generating units with shorter lead time for the construction of facilities which would more economically track the load growth and require less capital. Private sector funds could be made available for cost-effective generation and the privatization of generating companies would be viewed as a sound business investment.

The unbundling of the electrical power industry, and subsequent partial integration, would mean that the central supply utility would be in competition with other sources of generation and all would be supplying the load of the main grid. It would also mean that some larger industries and distribution utilities could, and would, construct their own generation, but the importance of the transmission system would not be reduced [120].

The transmission network, the high voltage grid, is a complex system which has not only the function of transmitting electricity, but also of ensuring the reliability of the whole electrical system of generation, transmission, and distribution. The activities of any generating station, or deficiencies of components of any transmission lines, may cause other failures within the system. Therefore, the transmission network is a single entity having the three main functions of transmission, reliability, and dispatch. It is also responsible for the stability of the interconnected grid and ensuring the balance of demand with supply.

1.1.5 From Captive to Competitive Markets

The formation of a fully open-market for the sources of supply of electricity will create business-like institutions with a mandate of a low cost producer of safe and reliable electricity. This competition will decentralize planning and will enable wholesale customers, such as distribution utilities, to choose their supplier subject to technical constraints and limitations. This will also fulfil the distribution utility's obligation to its customers to purchase power from the lowest cost supplier.

The regulatory control should encourage competition and focus on technical aspects rather than on regulating the market price. Under third-party access, the transmission system would be used as a common carrier and purchasers could choose from various suppliers subject to transmission limitations. The decision to purchase would be based on availability, price, and reliability. Little intervention would be required from the regulatory authority on the generation side, but this introduction of 'wheeling' would not be compatible with the present power pool concept.

1.1.6 Trading kWh in the Commodities Market

Unbundling the electrical power industry and the introduction of competition should cause a downward pressure upon electrical tariffs. The approach of least-cost planning in the past, where the planners and not the market made the investment choices, resulted in cost-based electricity rates. This would be replaced by market-based electricity rates. If the electricity prices were similar from a number of suppliers, then there would be more responsiveness to other customers' needs and other cost-effective services would be offered.

The transmission of electricity involves distance-related costs. These costs, combined with the economies of scale, make transmission a natural monopoly. It would remain a regulated service with some government intervention. Load dispatch functions will be combined with transmission services. Generation firms will bid their plant's capacities and the operators of the transmission grid will decide, on the basis of price and customer demand, where to place the orders. One scenario is that since distribution utilities have been established around this natural transmission monopoly, the regulatory authority will focus on entry and exit conditions of the sources of electricity, and prices will be left to the market. The entry and exit conditions will not be intended to result in "fair" returns, but the purpose will be to develop fairness amongst the sources of supply.

With the opening up or unbundling of the electric power industry, and the modified role of the transmission system, electricity will become just another commodity for speculation. Buyers and sellers of electric energy will not need the services of integrated monopolies to establish markets, but will rely on financial instruments and contractual arrangements to hedge their risks. Therefore, trading will take place in "paper" kilowatt hours in the electric power market. Prices will reflect costs, but will also be influenced by surpluses and shortages of electrical energy available to the grid network. Costs of electricity will become more complex: in the short-term, by the time of day, seasons of the year, and class of customer and, in the long-term, by the quality of service.

The producers' competitive position, their profits or losses, and their very survival will depend on their relative pricing policy. The approach to marketing will no longer be identifying new customers, but ensuring that each new additional load covers its marginal costs. Pricing will become a marketing tool. The past obligation to serve, in exchange for a guaranteed market, will no longer be the instrument of social control. A competitive environment will place a greater emphasis on making the right investment decisions. Costs of excess capacity from over-investment will affect shareholders, rather than ratepayers, and under-investment will result in penalties for failure to meet contractual obligations. An agreement with a purchaser will cover the risk of a failure to deliver by entering into contingency arrangements with a broker who covers risks through a variety of future purchases and sales contracts. The cooperative agreements between utilities will evolve into more market-oriented instruments with third-party brokers and financial institutions.

These changes will encourage the establishment of integrated generators and local municipal distribution utilities will actively pursue local self-generation as a partial or total alternative for wholesale purchases from the main transmission power grid. Therefore, distribution utilities will operate more economically using Non-Utility Generation, or by partial or total purchase from specialized firms operating in a competitive market supplying power to the main transmission grid system.

1.2 THESIS METHODOLOGY

The science of management and engineering needs the kind of integrative thought given to the science of chemistry by a Russian named Dmitry Ivanovich Mendeleyer (1889). Before the development of the periodic table, chemists knew many seemingly unrelated elements, just as managers and engineers today know seemingly unrelated models. The periodic table established the systematic interrelationship between chemical elements and thus, pointed the way to the discovery of new elements. By reflecting upon the work of others, Mendeleyer achieved a new synthesis which demonstrated a pattern and gave meaning to formerly unconnected elements [129].

This thesis addresses a need to approach management and engineering with a similar kind of integration. Existing knowledge in these fields is expanded in both depth and breadth. The approach synthesizes the current information and, through generalization and systematization, shows its interconnections, interrelations, and limitations.

1.3 THESIS OUTLINE

A brief overview of the electrical power industry and its interwoven complexities has been outlined earlier in this chapter. It is a complex infrastructure which not only involves economic and technical influences, but also political, social, and environmental influences, as the industry continues to evolve over time from a monopolistic entity into a quasi open-market concept. There is also a clear need to provide computer-based assistance in the management and decision-making processes of public utility operation.

In general, the thesis addresses the trade-off decisions in distribution utility management relating to the new realities of the changing operating environment. In this new environment, technical solutions addressing only technical problems are, in many cases, no longer sufficient to provide a balanced engineering, social, and political solution for distribution utilities' operations. The selection of technology is influenced by business, politics, and environmental matters which have become the driving forces influencing technical decisions. New realities have led to the evolvement of different types of problems and, therefore, a new approach is needed to address and unify these influencing factors within the evolving social fabric and working environment. To date, there has not been a balance in the relative importance of technical, financial, and social components. The integration of such tangible and intangible components within the electrical system has not been previously addressed and is addressed in this thesis.

Chapter 2 reviews the engineering and management methodologies and complexities associated with the composition and operation of organizations, with an emphasis upon distribution utilities. It reviews the shortcomings and limitations of the problem-solving methods to date and their lack of unification. The aspects of logistics in utility operations, planning, and corporate decisions are introduced and some of the general terms outlined in the introduction are later incorporated in the calculations of a cost evaluation process. This methodology involves the grouping of separate, but related, activities together into a central, coordinated arrangement to achieve a common objective.

Chapter 3 structures an important practical problem to be solved and describes the development and implementation of a simulation model. This model addresses the delicate and important balance between electricity pricing and the quality of delivery and customer perception. The modelling process involves the formation of a cost-objective function which is the sum of both direct and indirect costs as functions of many continuous and integer decision variables. The cost function is minimized subject to a set of constraints. The solution uses a Mixed Integer Programming (MIP) algorithm to determine the optimal decision-making scenarios. Economic comparisons are made between continuing total load purchases from the main grid and the introduction of local generating units. This includes technical, economic, and social components to assist distribution utility management in assessing the feasibility and merits of building Non-Utility Generation (NUG) for specific time periods.

Chapter 4 extends the concepts of Chapter 3 and represents a comprehensive, logical approach to the utility decision-making process. Financial and technical issues are addressed in managing a distribution utility as a business, with consideration for cost-effectively fulfilling customers' electrical needs. It is shown that time variable retail rates provide customers with flexibility, choice, and more control over their own costs. Advanced formulation has been developed together with a novel, logical, decision-making algorithm to extend the boundaries of numerical solutions, and to enable utility management to better assess various cost components and their time-trend impacts. The solution process includes both tangible and intangible components represented as logical variables and classified into parameters, states, driving forces, and goals. These logical variables include customer expectation, customer perception, social pressures, and public response to service deterioration. Such a general framework is then applied to the practical problem of finding the optimal time-phased retail rate structure of the distribution utility, taking into account various physical, social, and financial constraints.

Chapter 5 summarizes the work and includes the main contributions of the thesis, as well as suggestions regarding future investigations. Publications based on the work of this thesis are found in [50, 51, 143 - 148].

CHAPTER 2

BACKGROUND AND REVIEW OF THE STATE OF THE ART

This chapter reviews approaches taken regarding distribution utility planning and operation. References are made to published articles in the IEEE Power Engineering Reviews and other literature. These are statements and keynote addresses made by invited panelists, recognized leaders, and pioneers in their respective fields in the electrical power industry. They were presented at the general sessions of the semi-annual meetings of the IEEE Power Engineering Society. The main ideas of these speakers, who set the trend and influence the direction of change in the electrical power industry, are captured and presented as a realistic direction in which the power industry is heading. From such speakers and other leaders, one can use descriptions of methodologies and transform them into management algorithms which can then be subjected to more rational scrutiny. Development, functionality, and management of distribution utility operations is examined and a concept similar to a biological system regarding growth, development, and survival is perceived to exist in the business sector.

This chapter develops the building blocks for management algorithms that can be examined, tested, and verified in a traditional scientific manner.

2.1 EXISTING DISTRIBUTION UTILITY OPERATIONS

The composition and functions of an electrical system, which is part of the electrical power industry, may be grouped into three main components:

i) sources of electricity

ii) distribution utility

iii) customers

The first two components of this system were technologically based and have evolved through time by adapting to the changing environment. These changes over time have improved the efficiency and effectiveness of power delivery and service reliability. This system, in the past, had relatively clearly defined boundaries with the environment. The perception was that problems were technologically based and these problems were solved using technology. The technological improvements were not only restricted to technology, but influenced the development of the social structure. The rapid advancement in information and the utilization of computers expanded the public's range of vision, expectations, and the general social values of society. The boundary of this technologically-based system expanded and became more complex with the ongoing merging of this system and the environment. The concerns of utility management are now not only technological, but also pertain to the ecological environment, customer perception, and the cost and value of the service provided. These aspects of social complexity should be included in a modelling process to provide a truer representation of the system. Technology, subject to the constraints of the laws of physics, provides tools to service society which itself changes as a result of new technology. This is a recurring process.

2.1.1 Composition and Functions

A distribution utility is a public municipal organization in the province of Ontario consisting of people, plant, and equipment and following established business practices and procedures subject to various legislated acts as described in Table 2.1. The utility's function is to provide safe and reliable electrical power and energy (electricity) to its customers within the municipality. Electricity cannot be stockpiled and is an essential commodity in our society.

The supply of electricity is fragile and is subjected to interruptions by accidents, overloading, sabotage, and adverse forces of nature [93]. Distribution utilities usually purchase electricity wholesale from the main transmission grid. Electricity is distributed at the retail level, via its plant and equipment which includes the distribution network, to meet the load requirements of its various customers. The utility may self-generate (NUG) or purchase energy to meet these load requirements. There are two aspects to consider regarding the utilization of electricity. The first consists of a variety of specialized appliances requiring electrical energy as input to provide a desired output. This may be heat from an electric heater or mechanical energy from an electrical motor and there are many other types of devices for this energy transfer process. The second aspect is the customer of the distribution utility who uses this electrical utilization to fulfil a need, such as to solve a problem and to obtain satisfaction using the appropriate electrical appliance. These appliances are highly predictable and have a clear and precise quantitative designation of rating and efficiency. This allows accurate predictions and forecasts of usage based on past events. For example, a 1.5 kW rated heater will convert the same amount of electrical energy into the same amount of heat.

Customers are people with various habits and are the 'intelligence behind the switch' [135]. They are the recipients of the effects of the electrical utilization process; who are not specifically interested in the actual device in itself, but require solutions to problems and want satisfaction. If one 'feels' cold, then one can obtain 'heat'; if one feels 'heat', then the climate can be modified using electricity and an air-conditioning device to cool. Customers collectively require 'value' for their 'money' and their evaluations and judgements are complex. They are the reason why the generation is provided and why the utility was formed. Unlike the appliance component, people's expectation and perception is very subjective. Making sense of what one sees varies with time -- 'what I see today is very important but perhaps less important tomorrow'. Generally, no two customers perceive the same thing in the same way. The customer's perception is partly based on past experience, as well as narratives and values. Physical and mental make-up are tools for judgement. Therefore, human values and standards are difficult to quantify, but may be designated as 'good', 'bad', or something 'in-between'. Each person's opinion may be unique; nevertheless, there can be a generalization of results and standards established to satisfy the majority of customers.

2.1.1.1 Responsibilities and Constraints: These are outlined as follows:

i) Municipal Councils and Utility Commissions in the Province of Ontario, in Canada, have the following characteristics:

There are 307 Municipal Electric Utilities in Ontario, delivering a common product using similar strategies. A Municipal Council, established under the Municipal Act [62], is responsible for a broad range of policies and services and is administered by staff and supported by tax revenues. A Commission of a Municipal Electric Utility, established under the Public Utilities Act [63], is responsible for a specialized service or services and is administered by staff and supported only by revenues from services provided to the consumer. Funds may not be used for other purposes.

ii) Services provided by a Utility Commission:

There are several types of Utility Commissions, depending on the service(s) provided. Most municipal utilities, usually called Hydro-Electric Commissions, only distribute electricity and some of these commissions also bill customers for water and sewer charges on behalf of the local or regional government. Other utilities called Public Utilities Commissions may, in addition to electricity, be responsible for the provision of other services, such as water and sewer services, public transit, and park facilities, deriving revenues from these services. Taxes may be involved in the provision of services other than electricity.

iii) The Roles of a Commissioner and Staff of a Utility:

The role of a Commissioner is similar to that of a member of a Board of Directors; in the case of a commission, the municipality-controlled business is a public utility. As with a private business, a hydro-electric utility is required to meet its financial obligations from its own resources and revenues, from rates, and from charges.

- The Commission is comprised of either three or five members and it:
  - reviews, modifies, and approves the annual utility capital and operating budgets,
  - makes policy decisions on proposed major capital or special programs,
  - is responsible for long-range planning of utility services giving due regard to customer needs and service, employee and public health and safety, and the environment,

- is responsible for the setting of rates and charges for electricity and services, key decisions and because of legislation, requires Ontario Hydro's approval,
- is responsible for the approval of financing for the utility, including borrowing, if and when necessary,
- must submit debenture requests to council for approval, although utility debentures are not reflected in the municipality's debt load.

• Individual Commissioners should:
  - represent the needs of utility customers through the manager,
  - be aware of legislation and other regulations affecting the operation of the utility,
  - be aware of other hydro-electric operations and related issues such as rate and environmental hearings,
  - undertake public appearances,
  - be aware of interfaces and relationships with municipal council and other public bodies whose activities may interact with, or reflect upon, the utility operation.

• Integration of Commissioners and staff in the role of:
  - the development and oversight of commission operating policy is the responsibility of Commissioners,
  - implementation and administration of commission policy is the responsibility of management,
  - technical operation is the responsibility of management,
  - decision-making processes require good cooperation and communication between the commission and management.

iv) Affects of Legislation:

• Under the Public Utilities Act, the majority of municipal utility Commissioners are elected to office by the municipal electorate, to whom they are accountable.

- Legislation providing for the establishment of Regional Governments provided a "window" during which municipalities could exercise the option to appoint Commissioners, rather than have them elected.
- The head of council, usually the Mayor, is a voting member of the Commission "ex officio". This provides a liaison with municipal activities.
- The other acts of legislation that have specific impact on utility operation are listed as Table 2.1.

Table 2.1 : Acts of Legislation

Name	Jurisdiction	Description
"The Municipal Act" [62]	Provincial	provides the authority and direction for the operation of municipal corporations
"The Public Utilities Act" [63]	Provincial	provides the authority for the operation of municipal utility commissions for the distribution and control of appropriate electrical and/or water services
"The Power Corporation Act " [64]	Provincial	provides Ontario Hydro authority to operate, generate, and distribute electricity
"The Municipal Conflict of Interest Act" [65]	Provincial	requires the disclosure by a member of council or local board of any pecuniary interest, direct or indirect, of a matter before the board and that the member shall not discuss or vote on the matter
"Regional Municipalities Acts" [66]	Provincial	provides the authority and direction for the operation of upper-tier regional municipal corporations
Specific City Acts such as the "City of London Act" (continued on next page) [67]	Municipal	deals directly with specific matters affecting a subject municipality. (Some acts directly impact utilities and others do not.)

Table 2.1 : Acts of Legislation (continued)

Name	Jurisdiction	Description
"The Environmental Assessment Act" [68]	Provincial	provides for assessment of the effects on the environment of commercial or business enterprises or activities
"The Municipal Freedom of Information Act" [69]	Provincial	provides a right of access to information under the control of institutions and to protect the privacy of individuals with respect to personal information
"The Occupational Health and Safety Act" [70]	Provincial	sets out the responsibilities and penalties related to workplace practices and contravention of the responsibilities
"Public Service Works on Highways Act" [71]	Provincial	provides the authority and apportionment of costs for work on highways, i.e., poles, wires, transformers, etc.
"Labour Relations Act" [72]	Provincial	provides the practices and procedures of collective bargaining between employers and trade unions as the designated representatives of employees
"Pay Equity Act" [73]	Provincial	provides for the redress of systemic gender discrimination in compensation for work performed by female employees in both the public and private sectors
"Employment Standards Act" (continued on next page) [74]	Provincial	provides the standards of employment for work in Ontario, including hours of work, statutory holidays, vacations, minimum wages, etc.

Table 2.1 : Acts of Legislation (continued)

Name	Jurisdiction	Description
"Weights and Measures Act" [75]	Federal	sets out the use of measurements particularly related to metering of electricity
"Bank Act" [76]	Federal	provides for the establishment and regulation of banks within Canada
"Charter of Rights" [77]	Federal	sets out the fundamental freedoms and democratic rights of Canadian citizens including the freedom of religion, expression, peaceful assembly and association, the freedom of the press, and the right to vote
"Regional Municipality of Niagara Act" [78]	Municipal	sets out municipal rules and regulations for land zoning, road construction, etc. and are complement to and not in conflict with all other legislated acts

2.1.1.2 Operational Survival: The basic instinct of survival, which exists in living creatures may also be considered to exist in some form in a distribution system. The term "survival of a utility" is the continuity of service, the retention of customers, and obtaining sufficient revenue to operate. This can be achieved in two ways. The first is by network redundancy, surplus energy sources, surplus funds, etc. to meet most, if not all, unexpected variations of components within the system. This 'slackness' in the system is costly. The second method is by a complex adaption or a form of functional evolution. This involves a learning and reasoning process utilizing diverse senses, memory, and information based on internal states and internalized models of reality. In this manner, realistic and clearly defined goals may be pursued, attained, and optimized subject to various constraints. These goals may be higher profit, cost reduction, improvements in service, protect the environment, load growth, etc.

2.1.2 Trade-Off Decisions

During times of financial constraints, many functions of a distribution utility are closely examined. Namely, the utility's revenue-collecting abilities, extent of popularity, influence upon the operation, cross-subsidization of rates, political, and regulatory involvement. The challenge is to establish the level of rates to obtain sufficient revenue to maintain good services but also to be sensitive to what the customers and the local community are prepared to pay.

High retail electricity rates for the same amount of electricity sold will require customers to pay more and provide, in the short-term, more revenue for the utility, but this may stifle growth and the development of high-energy users. Rates that are too low may help the customers in the short-term, but the financial burden upon the utility may curtail the quality and availability of service. If the utility borrows funds, both the interest and capital must eventually be repaid and, if interest rates are high, the utility's debt/equity ratio may become excessive, resulting in serious financial problems. The combination of rate increases and borrowing can be used to lessen the impact of financial irregularities associated with distribution utility operation. Customers and the utilities are interdependent and the survival of both is determined by the survival of each. Therefore, the utility, like any other organization, must strive to adopt cost-reducing measures that include increases in operational efficiency and to investigate the economic and technical feasibility of alternate electrical sources, such as self-generation. This view of dilemmas facing distribution utilities is outlined in Table 2.2 in terms of the conventional IF-THEN rule-based scenario. This is also addressed in Sections 3.2 and 4.7.7.

Table 2.2: Distribution Utility Dilemmas

IF **Condition**	**THEN** **Conclusion**	**CONSEQUENCE** **Result**
1. High Rates	High Customer Bills	- high impact cost just to customer (long-term) - high revenue for utility (long-term)
2. High Customer Bills (short-term)	Immediate Customer Dissatisfaction	- customer surprise followed by complaints - re-evaluation of habits of electrical usage and the financial impact - (short-term concerns) Can this bill be paid?
3. High Cost to Customers (long-term)	Affects electrical usage (price, consumption, elasticity)	- political involvement at the municipal or provincial levels - fuel substitution by customers - re-evaluation of habits and attempts for reduction of usage - extra financial strain - possible plant usage of electricity and output reductions - some plant closings due to inability to compete - some customers may install their own supplies - (long-term concerns) Is electricity affordable? - reduction of retail sales of some electrical appliances - high revenue for utility
4. High Utility Revenue	Utility potentially financially sound	- utility has finances available to provide high quality of service
5. Political Involvement	Re-evaluation of cost of services	- cost reduction to customers
6. Cost Reduction to Customers	• Utility reduces its costs • Utility reduces its rates or freezes rate increases	- financial stimulus is to local community
7. Plant Closings	Reduction in electrical purchases from utility	- reduction in revenue for utility - increase in local unemployment - customers' and public's general dissatisfaction with utility
8. Reduction in Utility Revenue (continued on next page)	Income shortage for utility	- higher retail rates - reduction in utility reserve - reduction in quality of service - utility borrows money

Table 2.2: Distribution Utility Dilemmas (Continued)

IF **Condition**	**THEN** **Conclusion**	**CONSEQUENCE** **Result**
9. Increase in Local Unemployment	Less income within the municipality	- further reduction in electrical usage (income, usage, elasticity) - less revenue for utility - less local expenditure
10. Reduction of Quality of Service	Customer dissatisfaction (quality, price, elasticity)	- customer complaints - customer evaluation of financial impact of the deterioration of service - customer may relocate or install own supply
11. Raise Rates	Increase in customer bills	- higher cost impact to customer - higher revenue for utility
12. Borrow Money	Short-term, more revenue for utility	- more available revenue for improvements of service (short-term)
13. More Revenue	More available money for utility	- may reduce rates and maintain good services
14. Lower Rates	Lower customer bills	- customer satisfaction (customer perception, price, elasticity)
15. Lower Customer Bills and Good Services	Increase in customer confidence and satisfaction	- utility growth potential
16. Low Rates	Low customer bills	- low cost impact to customers - lower revenue for utility
17. Low Customer Bills (short-term)	Customer satisfaction (price elasticity, customer satisfaction)	- popularity of utility may increase - improvement in perception of value for cost
18. Low Customer Bills (long-term)	Affect upon electrical usage (price, consumption, elasticity)	- customers may expand plant - utility attracts new industries - customers may establish an unrealistic long-term comfort zone and cost expectation
19. Low Utility Revenue	Utility may face financial difficulties	- utility may reduce quality of service, raise rates and/or borrow money (go to items #10, #11 and #12)

Summary of Table 2.2

a) Increases in utility rates increase utility's revenue which can be used to maintain or improve the quality of service. However, in the long-term customers may not be able to afford this increases in cost, either as a residential user supporting a family or a business attempting to remain competitive.

b) Low rates may mean low utility revenue and may result in a shortage of funds for normal operations. The quality of service may deteriorate. The reduction in the quality of service causes hardships and costs to customers. This may result in customer loss and a further reduction in revenue. Borrowing funds may enable the utility to improve the quality of service, but this long-term debt would be another financial burden to repay.

c) High rates provide a high source of revenue and provide funds to enable the utility to maintain good quality of service but may be too expensive, unaffordable, and unacceptable to customers. Too low rates deprive the utility of needed income; the system could become run-down and the quality of service would deteriorate. Low quality of service at low cost is usually unacceptable. The optimal combination is an acceptable quality of service and perceived value for cost by the customer while the utility receives sufficient revenue to operate.

The question of what is acceptable and what is value as perceived by the customer is addressed in this thesis. This is further elaborated in Section 4.8.5.

2.1.3 Characteristics of the Distribution System

For the deterministic power flow equation:

$$\text{Electrical Supply} = \text{Electrical Load}$$

or

$$S = L$$

the three main components required to achieve this balance are the source (S), the customer's load (L), and the electrical network (N) or a link to make the energy transfer possible. This is illustrated in Figure 2.1.

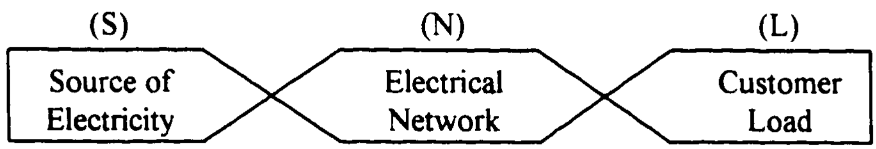

Figure 2.1: The Distribution System

Complex changes constantly occur within the distribution system, such as the magnitude of the customer load, electrical network changes resulting from power interruptions, and changes in the magnitude of supply. Figure 2.2 is a representation of the distribution network of the electrical system shown conceptually in Figure 2.1. It illustrates that the capacity boundary of an existing network can be expanded. Later, in Section 4.1, various distribution utility entities and functions will be introduced and analyzed.

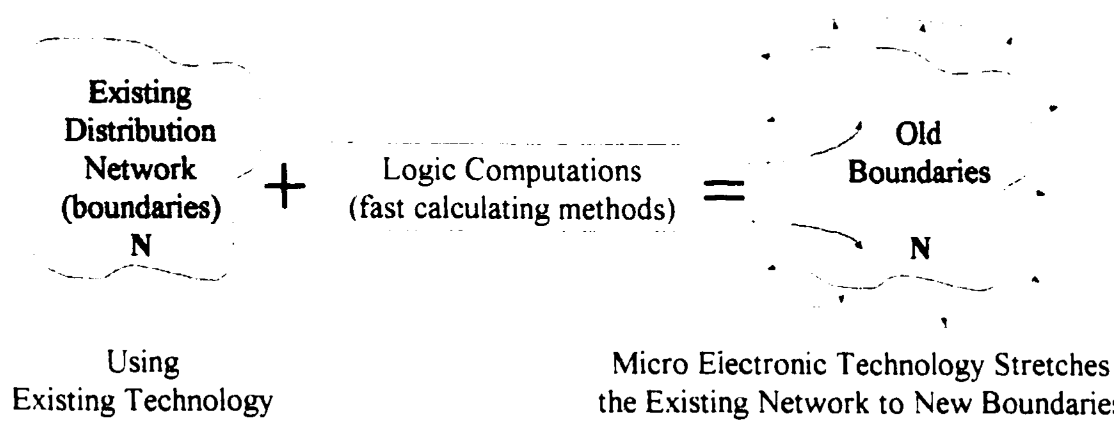

Figure 2.2 : Changes in Distribution System Network

Figure 2.2 illustrates a management objective to improve the quality of delivery and more effectively utilize an existing distribution network. This can be achieved using fast calculation methods and microelectronic-based technology of 'smart' relays, switching circuits, and distribution automation. The line impedance can be changed by inserting capacitors. Voltage controls can change the flow of kWh. Dynamic security analysis can be performed by isolating parts of circuits and paralleling other circuits. The diversity of loads can be exploited and transformer capacities can be optimally utilized. Such control techniques improves both the efficiency and effectiveness of the network and more value is obtained from existing equipment. This results in delivering larger amounts of power and also reducing service interruptions, using the same basic network.

Due to load variations, the supply changes in synchrony with the load changes. The network configuration may also change due to overloading, fault in the network, or switching in order to improve the quality of service -- namely, improving the voltage levels in the network.

In addition to load variations and shortages of supply, the electrical network may experience network failures -- all of which tend to destabilize the distribution system. During such fault conditions, the automated protection of the network isolates these faults using pre-programmed equipment which protects the network. This protection coordination is intended to minimize the number of customers affected and isolates the failed equipment for repairs. The source of supply "pulsates" to customer load variations. If the load increases and there is sufficient supply and also network capacity, the source increases and the customers' load requirements are met. The quality of service (namely, the level of reliability and voltage regulation) depend upon the characteristics of the network and the source. The two variables are time and finances. The short-term changes have been described as the operation of the system. Revenue is obtained by the utility for the product delivered. In the long-term, the boundary of S in Figure 2.1 will also change. Due to anticipation in load growth, plans are made to increase the sources of supply and more distribution lines are built. More power may be purchased and NUG's may be built and the electrical network expanded to meet the additional load requirements. Should L decrease, S will be less and there will be surplus power available, decreasing generation or purchases, but may result in locked generation or carrying charges for the cost of the spare capacity not utilized. The network's increased capacity could be used for improvement in the quality of service (for example, higher reliability and improved voltage regulation). The network losses may be reduced by switching and rearranging parts of the redundant circuitry. However, the cost of utility operations are higher when surplus assets are not fully utilized. See Tables 2.3(a) and 2.3(b).

Redundancy or slackness in both S and N enables variations in L to occur within the system's capacity limits. Capital expenditure for both S and N occurs when there is substantial growth in L. This results in higher direct cost to the utility which, however, receives increased revenue due to a higher value of L. Permanent reduction in L results in stranded assets in N and possibly S. However, if S supplies other utilities, the reduction in load in one area may be offset by an increase in load in another area due to load diversity. Then some or all of the perceived surplus in S may be utilized.

Table 2.3 (a) : Different Modes of Components of the Distribution System

Source of Electricity (S)	Electrical Network (N)	Customer Load (L)
i) Shrinkage (reduction in the source of supply)	i) Shrinkage (take some lines out of service for maintenance or repairs but rest of circuitry has sufficient capacity or redundancy or slackness for service continuity)	i) Shrinkage (load reduction)
ii) Expansion (additional source of supply available)	ii) Expansion (the load in some of the lines increases and some extra available lines are put into service)	ii) Expansion (load increases)
	iii) Network modification (re-arrange the circuitry of the network and/or equipment status change to increase or decrease the load)	

The requirements of continuity of service are shown in Table 2.3 (b).

Table 2.3 (b) : Continuity of Service

Available supply not less than load requirements.	Network capacities at all times not less than maximum load or maximum supply used.	Load requirements equals supply used.
$S \geq L$	$N \geq S_{max}$; $N \geq L_{max}$	$L = S$

The previous analysis applies to a utility which either purchases or self generates electricity and supplies the electrical load via its electrical network. The total system can be represented by a modelling process using discrete and continuous variables, parameters, and constraints (Chapter 3). The inclusion of non-equality constraints establishes the bounds of the system in a stable state which occurs when supply meets the dynamic load requirements on a continuous basis. When small perturbations occur, these may be absorbed by the utility's inbuilt characteristics of robustness, flexibility, or adaptability. These perturbations may be increases in line loading due to small increases in load. These extra line capacities or redundancies or "slackness" in parts of the system enable the network at different times to carry more load. The utility may also have extra financial reserves as part of the slackness to deal with sudden cost increases. This may be in the form of investments or obtaining additional inventory reserves. These funds are used to pay for repairs when there is a requirement for the immediate availability of materials and parts. Therefore, the utility with slackness can absorb some changes in its given state without the utility itself changing as an entity by simple rearrangement or redistribution of some of its internal components.

If major 'disturbances' occur to a utility, such as major cost increases involving construction of very costly new lines or political influence which redirects the utility's functions, then the utility may not regain its original equilibrium or state and modifications or internal changes will occur in the attempt to adapt to the new environment. For the utility to regain its equilibrium, structural changes are required which may cause a permanent change in some of the utility's composition, function, and operation. The magnitude of these changes may be as small as the slight modifications to some of the utility's objectives, standards, and procedures. Large changes, such as major policy changes, may be perceived to be disruptive and far-reaching relative to the original utility composition. The utility may change from promotion of sales to energy conservation or publicizing brownouts or blackouts when power shortages occur.

The utility with slackness in technical, social, and economic areas is able to absorb perturbations up to the limit of internal resource capacities of these areas without itself changing from the original composition and functions. The internal rearrangement of utility's components is then a relatively smooth transition in terms of absorbing the perturbation and regaining its stability. This transition occurs with a minimum time of disruption to the system in regaining its stability. However, slackness of resources carries a cost of having extra reserves that are not used under normal operations. Therefore, if the environmental perturbations are minimized in magnitude and consequent effects upon the utility, the amount of slackness within the utility can also be reduced. For direct cost reduction, the trend is to maximize the utilization of components thereby minimizing investment costs. The objective of a true "global optimal" solution may be the balance or trade-off between the utility having reserves greater than presently needed (to enable future variations in variables such as load and costs to occur), and maintaining or exceeding pre-set levels of quality of service at reasonable and affordable cost to customers.

2.1.3.1 Adaptability: In order for a distribution utility to survive and to flourish as a business, it must be able to adapt to variations of the environment. These include compliance with rules and regulations, ecological/environmental constraints, and attention to customers' needs. It must be adaptable and capable of functioning in an uncertain environment which includes escalating interest rates, periods of inflation, and rapid increase or decrease in electrical demand. Adaptability may be viewed as the ability to cope with the uncertainty of the environment and it is a necessary condition to maintain a relatively permanent form of organization. It reflects the organization's level of stability [39]. The accuracy of information about the environment and information-processing must be reliable. The challenge within a utility or any organizational structure is to adapt adequately to the uncertainty of the environment, to use these adaptions to compensate for internal and external perturbations, and to maintain the stability of purpose and objective of the organization. The disturbances could be internal labour unrest, slowdowns, or strikes which may be reduced by addressing the source of the disturbance. Similarly, customer concerns and perceptions may be improved by better communication and improving the quality of service. In both examples the utility's efforts are internalized to deal with such perturbations and to retain stability.

Adaption determines the direction of the evolution of the utility and determines whether it can exist. This characteristic enables the utility to keep changing until it reaches a stable or equilibrium state while retaining its basic identity. (i.e. a utility does not become a car manufacturing plant.) Logical expressions can be written as logical equations, as shown in Table 2.4.

Table 2.4 : Management Phraseology and the Equivalent Logical Form

Managerial Expression (Decision-making phraseology)	Equivalent Logical Expression (Logical variables reference Chapter 4)
Electricity Supplied meets Customer Needs	ES = CN
Services Rendered meets or exceeds Customer Expectation	SR > CE
Utility Revenue meets or exceeds Utility Costs	UR > UC

2.1.3.2 Disturbance: The utility consists of various sub-units such as departments. Each unit is a bounded pattern of activity with a potentiality for variation and growth. The growth of the activity of each department requires input across the boundary (reference Figure 2.5, page 78). Each unit is integrated into the system as a unit of function and can be described in terms of certain relevant properties and diversity of components. For example: the line department has line people (who have common specialized skills but are also diverse in outlook, political affiliations, etc.), vehicles (trucks, cars), tools and equipment.

If the organization is perturbed by the environment, which is usually unpredictable, it will assume states which are both unanticipated by and disturbing to the whole organization or to one of its sub-systems. For example: in the case of a minor power interruption, there are two possibilities. The first is that the disturbance is 'forgotten'. In that case, any attention which it produces in the organization is completely dissipated. The time scale may be short if the power interruption is, for example, automatically restored. The interruption may be relatively long if a line crew is called on unplanned overtime to repair the damage. The initial disturbance only rearranges the states of the components of the system such as opening some circuit-breakers and closing others. The time scale of the dissipation process, similar to the automatic power restoration, is then relatively short. If the disturbance is absorbed in distinct and functional states, the dissipation process is longer. The incidence of a major power interruption results in rebuilding of major portions of the network using material from inventory and results in major modifications in the network circuitry. This work will take a relatively long time.

The second possibility is that the disturbance is not completely "forgotten". In that case evolution of change occurs and "adaptability" takes the special form as the "development" of an adaption process [166]. For example, due to very costly and dangerous power interruptions in a specific industrial area, the utility's policy is changed by replacing all overhead distribution feeders with underground cables. Due to higher installation cost and longer repair times for cables than for overhead conductors, much larger cables with higher current-carrying capacity are installed for both present and future loads. As redundancy increases, function-preserving reliability increases.

A close examination of the organization and its constraints will determine the extent of development of acceptable forms of adaptability. For example, when the economy is slow, the customers may be given various options to pay for the service but within specified time limits. It is also possible to determine the relative importance of the different components of adaptability by introducing correlation into the sequence of environmental changes. For example, electricity may be promoted by offering customers special rates during times of surplus capacity and conservation promoted when there are power shortages or higher costs. This is addressed in greater detail in Section 4.6. The responses by customers would be rated as results from cause and effect. In order to study the relationship between changes in adaptability and the particularities of utilities, the relation between given degrees of adaptability and the particularities of the utility under different environmental stresses should be examined. The extent to which adaptability is optimized should be noted in the course of evolution such as when there is competition. The philosophy of a cost-based product is then replaced by a market value price. The transformation of function is the essence of the evolutionary process and the basis of such a transformation is the transfer of information.

Increasing the adaptability of an organization increases its stability. The number of alternative options into which the organization can diverge in response to perturbations increases with adaptability, since the more adaptable system has more potentialities. A predictable system can be viewed as static; reducing the uncertainty reduces the adaptability. Competition generated uncertainty provides a natural supply of variabilities which often convert into adaptability when the environment changes (for example, the de-regulation of the electrical power industry). Suppressing this variability reduces the capacity to cope with disturbances. The structure of uncertainty is real, not a matter of ignorance, and there is no way of eliminating it without eliminating adaptability [96]. There are two sources of uncertainty (in addition to the uncertainty of the environment). The first is an internally generated uncertainty within the organization in terms of the direction in which it is moving. The second is the uncertainty associated with the recognition of changes in the surrounding environment which occur at the level of transfer of information.

2.1.3.3 Efficiency Improvements: Factors which determine efficiency are processes that characterize the system and not the variables. These processes are themselves determined by the organization of the utility and its relation to the environment and the approach to optimal utilization of these processes. Increases in efficiency are based on adaptive advances which increase in complexity as adaptability increases [40]. Such processes can be improved by designing and then controlling in greater detail the sequences of the process.

2.1.3.4 Trends: The constraints regarding adaptability are language, financial structures, and beliefs which influence decision-making. Financial systems allow for shifts of money and resources between specialized classes within society, leading to a cycle of economic activity. For example, an industry buys electricity from the distribution utility, manufactures insulators which are sold back to the distribution utility which then sells more electricity to that industry.

There is a high degree of institutionality and politicization in society. The society which adopts regimentation loses not only adaptability but also may undergo transitions into adaptability-poor states. Utilities produce and deliver electricity and services to satisfy criteria established by society and are connected with activities necessary to retain the quality of life. These are essential non-evolutionary adaptabilities [96]. They enable services produced in a variety of environmental conditions to continue to supply electricity and services to meet established criteria despite long-term changes in environmental conditions. The solution to this problem requires evolutionary adaptabilities, that is, adaptabilities which can lead to the discovery of new sources of electricity -- namely, not only continually buying electricity from the main grid but evaluating the use of NUG units or purchases from the private sector or from practical application of the discovery of new technologies. This could range from organizational adaption and change, such as the unbundling of the electrical power industry, to a technological breakthrough and application of fusion as an energy source.

2.1.3.5 Inertial Resistance: The alternative to this development of adaptability is for an organization to develop a wall of indifference, that is, to attempt to isolate its own economy from external influences and prevent internal changes which could destabilize its present form of existence. This line of development is incompatible with the development of efficiency and increasing internal specialization. It is inevitable that the organization's indifference will eventually break down and then there will be a crisis due to inadequate adaptability. The firm which moves in developing more external business relations becomes more externally specialized, but also more dependent on events of other organizations. However, efficiency increases due to the fuller utilization of comparative advantages. Therefore, the requirements on all modes of adaptability increase due to pressures for compensating change in the organization's structure of adaptability.

Connections between adaptability and policies pursued are either not recognized or undervalued. It is important to consider to what extent beliefs, which an organization has about the amount of adaptability it needs, are free and to what extent they are constrained. It is also important to recognize that the problem of deciding how a utility ought to be organized in order to effectively convert its variability into adaptability is not the same as the problem of deciding how much adaptability is needed. The decision of how much adaptability is needed would depend on the uncertainty which the utility judges is appropriate to associate with the future survival and prosperity.

Organizations may be able to maintain their identity and continue in competition with one another, provided that the choice of operation is not incompatible with the stability of society and the regulations of the environment. Organizations having too little adaptability and too little creative capacity will fail to meet whatever reasonable criteria they otherwise establish for themselves. Adaptability prolongs the probable lifetime of an organizational structure that incorporates it correctly.

2.1.3.6 New Horizons: New tools have become available that extend the domain which can be influenced by human decision-making. The creative intelligence of humans, rather than halting the progression to instability, accelerates it. The proportion of human concerns are changing. Technological-based industries are reviewed, their economic decisions, their effects upon society and the impact upon the environment are all evaluated [160]. Therefore, the blind chance of evolution and random change should be replaced by modelling, planning, calculating, predicting, and constructing a definite objective or goal. The possibilities for analyzing and modifying social values and institutions are increasing. If classical paradigms are used, poverty-stricken organizations will evolve in terms of their adaptability to survive.

2.2 PROBLEMS TACKLED TO DATE

2.2.1 Evolutionary Trend

Some 100 years ago in the decade of the 1880's, the growing knowledge and the use of electricity made the age of technology possible.

The 1950's were the dawn of computer applications to power system analysis problems. Starting at universities, studies such as load flow analysis, short circuit, and stability calculations were performed. Increasing sophistication in analyzing technical problems emerged with the involvement of larger utilities and consulting companies [114].

In the 1960's, more significant advances in methods for solutions were used. Newton power load flow methods, sparsity storage, and forward and backward substitution methods made the studies of larger systems feasible on the components of the day.

In the 1970's, the basic power load flows and dynamic simulation methods of earlier years became faster, more versatile, and more sophisticated. Computer performance also steadily improved and smaller minicomputers came into use at more and smaller utilities.

During the 1980's, technical problems for utilities became much more complex. The search was for cost reduction in network design and operation due to stricter imposed limitations of available capital. The requirement was for cost reduction and improved overall performance. The price decrease and performance improvements of computers reduced or eliminated restrictions for many methods of calculation and made computers accessible to engineers in both large and small utilities.

The electrical industry is technologically based, and has evolved with a thrust for technical efficiency and effectiveness and quality excellence [159]. The transmission and distribution concepts utilize the most efficient and effective characteristics of voltage, conductor sizes, and their arrangements. The constant improvements in technology from supply to the delivery of electricity not only aim to minimize losses but also deal with concepts of reliability and availability. The system should not only be technologically based but some considerations should be for the end user. The view of the distribution system should not be limited to a highly specialized technical entity but should also include variables which both directly and indirectly influence the system's social infrastructure [163]. The challenges of the future are the inclusion in the representation of the system of the role of society, and customers served [107]. Therefore, the specialized and restrictive view of technical efficiency should be replaced by the notion of "total efficiency", incorporating not only technical and economic aspects which can be represented by variables, parameters, and constraints, but also social concerns. Therefore, environmental and social characteristics such as customers' perception and levels of customer satisfaction must be considered as part of the system for a truer, more complete representation. These are the challenges of tomorrow which will be built upon the foundations of the rapidly evolving and expanding technological age of today [164]. The inclusion of such interacting variables and parameters have to date been largely ignored, but both directly and indirectly shape the direction which technology itself evolves and changes.

2.2.2 Utility, Environment, and Information

2.2.2.1 Traditional Concept: The classical organization is hierarchical based on the division of labour and the specialization of skills and resources. It increases efficiency but also increases a need for cooperation in order to overcome the narrow perspectives created by specialization. This is the traditional concept of line and staff organization.

Management must bond:

- functions
- facilities
- cost relationships and
- capacities together through one integrated approach.

Utility operations may be viewed as having Analytic and Synthetic system components.

The analytic system component involves a homogeneous product flow of electricity, from production (local or wholesale purchases) via multiple sequence states to the user. The flow starts from generation to transformation to transmission or sub-transmission to transformation and distribution to the final customer. These stages are divided by product level, namely, low voltage to high voltage to low voltage, geographic regions and customer class. This electrical power industry produces energy, heat, and pollution; this energy conversion is combined with an eventual single basic output -- customer satisfaction.

The synthetic component is the converging series of flows of different materials and components and emerges as a relatively homogeneous output -- "electricity" -- for distribution to the market. The input components for that to occur are: fuel, equipment, generators (NUG), transformers, finances (wholesale purchases), etc. The problems involved are associated more with supply than distribution. Fuel, materials, and components move in individual flows towards the point of generation and are converted into the end product for distribution. The analytic component pulls the organization towards the market and concentrated load centers. The synthetic component pulls towards supply areas, such as the location of fuel for NUG. This is further elaborated in Section 4.1.

2.2.2.2 Controlling the Environment: The information coordination is controlled by limiting the environmental characteristics transmitted to the system. This is influenced by requirements of external organizations. Customers influence the need for coordination by the size of load and range of service requirements. The requirement that all customers are to be serviced imposes a limit on what loads the system can accept in a given time frame. This can be managed through long-term agreements and commitments to reduce uncertainty. Control can be imposed through organizational policies that limit external influences and, once established, stabilize the system in the short-term and reduce the need for coordination.

Changing the level of customer perception may lead to changes in service requirements. Table 2.5 shows the extent of interface between internally and externally produced information as input to the organizational structure of the utility. Top management requires a summary of more external information than internal information. Operating and middle management are oriented towards short-term decisions relating to technical characteristics of operations [155].

Table 2.5: Management Information Requirements

	Internal Information	External Information
Strategic (Top) Management	**Summary Report**	**Environmental Data**
Middle Management	**Operating Summary Data**	**External Coordinated Data**
Operating Management	**Routine Operating Data**	**External Operating Data**

2.2.2.3 Planning and Controlling: There are four main steps in the control of operations and decision-making:

1. Identify key and control variables
2. Enter variables into the planning process
3. From the output of the planning process, set a short-term direction
4. Track the short-term performance.

The above steps are repeated and the short-term performance in one period produces data for control over operations in the next period. Strategic management listed in Table 2.5 differs from other levels, since it is less concerned with current operations than with the long-term environment. Less standardized information is available because of the non-recurring nature of the problems. Therefore, it may be difficult to quantify measurements in some problem areas [38].

The role of strategic planning is to develop optimal system designs. It establishes direction for the organization and the emphasis is to identify change and formulate courses of action. It identifies potential opportunities and threats and matches them to the characteristics of the organization. It anticipates problems and, through contingency planning, protects the system from unforeseen difficulties. Chapter 3 illustrates the application of these concepts.

2.2.2.4 Information Characteristics: Each level of management requires different characteristics of information and this is shown in Table 2.6.

Table 2.6: Information Characteristics

	Information	Strategic Planning	Operational Control
i)	Accuracy	Low	High
ii)	Level of Detail	Aggregate	Detailed
iii)	Time	Future	Present
iv)	Frequency of Use	Infrequent	Frequent
v)	Scope of Information	Wide	Narrow
vi)	Source of Information	External	Internal
vii)	Type of Information	Qualitative	Quantitative
viii)	Currency of Information	Historic	Current

Table 2.6 illustrates that strategic planning deals with generalities and the future, and the specific accuracy is usually low. Operational control, however, deals with precise quantitative details to ensure correct procedure as a result of sequencing of events in the present and relative short time in the future. This is also addressed in Section 2.2.4.8.

i) Accuracy -- is highest at operational level and lowest at the strategic level since outputs of planning levels are estimates rather than precise measures of actual events.

ii) Level of detail -- is highest at operating level and lowest at strategic level.

iii) Time -- longest for strategic decisions due to the long-term commitment for capital and system change. Operational decisions can be extremely short-term.

iv) Frequency of use -- it is assumed that strategic planning is an intermittent activity while routine management control is a daily, hourly, or minute-by-minute occurrence.

v) Scope of information -- reflects the number of variables and other items of data reporting. Operational management works from limited data. Strategic planning encompasses more variables and the task is to determine which are important. Galbraith [56] categorized information systems according to the scope and frequency of reporting:

- periodic reporting is a scheduled presentation of data.
- real time reporting is available data on request from a currently updated system.
- local systems involve only the immediate location or functional area.
- global reporting is comprehensive, extending over the entire system.

Local periodic systems include daily load reports used for load management and the possible improvement of the system's load factor, thereby affecting the cost of electricity. Local systems in real time focus on specific activities such as work schedules, vehicle movement, and switching the circuitry of the network. Global real time systems provide management with continuous control. Managers are able to react immediately to short-term changes.

vi) Sources of information -- include both internally generated and external data. Operational and middle management concerns are mainly with current, internally generated data. The needs of top management are less immediate and are evaluations of trends over time to establish stable planning relationships.

vii) Type of information -- strategy requires external data and non-routine information. The type of information is more qualitative at the strategic level and more quantitative at the operational level; problems are well-defined, dealing with certainty or measurable risk. According to the studies by House [88], most computer models have been oriented towards specific functional applications reinforcing piecemeal analysis rather than toward strategic management decisions. These results would be sub-optimal since they were not combined into an integrated decision process for the system as a whole.

viii) Currency of information -- reflects the nature of the decision process. At the operating level, decisions are made routinely and frequently and require current and relevant information. Strategic planning is usually an infrequent occurrence. The overemphasis on immediate data is not necessary and may introduce distortions into the decision. Data collected over long time periods is useful in detecting trends in the environment.

2.2.2.5 Communication and Design Effectiveness: Marriott and Miller [108] attribute design errors not to a real lack of expertise in the design teams but rather to the non-representation of existing expertise at key decision points. Therefore, it is not sufficient to consider the existence of expertise without considering the organization and effective application of these resources. The advantage of teams over individuals is from resource additivity, where the overall performance of any group tends to increase directly with the sum of combined members' abilities [83]. Nevertheless, the barriers which exist to coordination of diverse specialized resources degrades the group performance. The goal of interdisciplinary design team members is to minimize process loss [139].

Management defines, assigns, and coordinates the design tasks [154]. The task definition is the partitioning of the project into a number of simpler, separately solvable sub-tasks. Bavelas observed [14] that when a task is performed by a group rather than by a single individual, the problem of working relationships arises. Communication is the principal means by which group members help their groups achieve goals [12]. Maier [106] observed that many organizational problems can be traced to inadequate communication of decisions. Within the sphere of engineering activities, design is believed to be more susceptible to communications variables than technical operation efforts [6]. Task achievement is related to communication, particularly in complex tasks [10, 82]. The manager exercises coordination through carefully thought-out task definition and assignment strategies during the planning stage before design begins. The nature of tasks is assigned to groups and to subgroups. These determine the design information that needs to be exchanged between them, the modes of communication, and the participants between whom the exchanges take place. These factors determine the effectiveness of communication. The nature of the task affects the communicative competencies required to solve the problem [54, 81, 161]. The modes of communication required for problem solving will affect the group's ability to communicate [23, 29]. Changes in the information to be communicated influence choice of communication channels [165] with varying probabilities of communication error [27, 112]. A communication-based approach subsumes those based only on artifact or human-centered behavioral factors because a communication event is defined behaviorally by the participants and functionally by the artifact with which it is concerned [157]. Section 2.2.4.6 deals with media selection.

2.2.2.6 Cognitive Choice: Cognitive models[2] [3, 55, 126] provide a framework which can explain the mechanism of the human design process. Engineering design is a process performed by humans aided by technical means through which information in the form of descriptions of technical systems occurs [49]. The design process is an information-

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2. "Modelling" is dealt with in section 2.3.2, page 64

processing activity, undertaken by a team, with its progression depending on the decisions made [162]. Design is an information-processing mechanism of decision-making given the available information. The information being supplied can be the specialized expertise of discrete communication members in a group, or various fields of expertise within the mind of a single designer.

A decision is a choice of a course of action. It not only requires information on which to base the choice, but also creates information that will give significance to later decisions. A decision point is the event where a decision is about to be made. It is defined by the need for a decision and the presence of information on which the decision will be based. Information is knowledge about objects, events, and their relationships [22]. An information sphere is the hypothetical place and form in which design information resides within the design system from which it can be retrieved for decision-making [151].

2.2.2.7 Organizational Politics: Prasad and Rubenstein [128] note that organizations frequently encounter a phenomenon of politics. It is a process by which individuals and groups attempt to influence decision-making. The manoeuvring associated with these influences is an attempt aimed at reconciling the interests of various coalitions and can be complex and dynamic. Politics may be treated as a multifaceted phenomenon, consisting of many dynamics in the underlying complex human interactions and behaviours. It is a dynamic social activity concerning the arrangements for ordering social affairs, and the degree of control individuals and groups have over this ordering. There may also be trade-offs between what you know and whom you know.

2.2.3 Customer Service

2.2.3.1 Customer's Judgement: Customer service is the quality of performance of the system by providing electricity and associated services to customers. It involves the integration and management of all the elements of the customer interface within a predetermined cost service interface. Customer service may also be viewed as a system to provide a continuing link between the utility, its services, and the provision of that service with the objective of satisfying customer needs on a long-term basis [33]. It also links the utility to the customer in hopes of influencing further sales and long-term commitments.

Utility and customers are together in a common system. Management must balance two apparently conflicting objectives: cost minimization and improvements in service quality. Service is important to customers and they use electricity and the continuity of supply to solve their own problems. The characteristics of service, such as availability and reliability, influence customer costs and profits and their interest in continuing the relationship [98]. The requirement, therefore, is to determine how much to spend and where to spend it by determining which elements of the services provided, are most important to customers.

A business-oriented utility tries to create a value-satisfying product and services. What it offers for sale is not only the generic product -- electricity - but how it is available to the customer, under what conditions the service is provided and the terms of sale [102]. Customers do have a choice. They may buy or not buy or substitute.

According to Dudion, Dunegan, and Barton [47], knowing "just the facts" in a decision-making situation is insufficient for predicting choice. Understanding choice requires an understanding of the decision-maker's frame of reference. Different frames of reference can lead to different choices because different reference frames lead to different interpretations of what the facts mean. Therefore, "facts" do not speak for themselves but are interpreted in terms of a frame of reference. The group may adopt a common frame within which all "facts" are interpreted.

2.2.3.2 Cultural Influences: Socioculture has an affect upon one's decision-making process. As noted by many authors, culture is a learned, shared, compelling, inter-dated set of symbols whose meanings provide a set of orientations for members of a society. These orientations, taken together, provide solutions to problems that all society must solve if it is to remain viable. There is also the corporate culture within the secondary socialization of a business culture, which is within the primary socialization called culture. The process by which an individual develops one's actual behaviour is influenced by what is customary and acceptable according to the standards of one's group. Current methods of behaviour are based on past experience derived from a set of behaviours that is deemed proper in its sociocultural setting. This is also addressed in Chapter 4 regarding the formation of customer perception.

2.2.3.3 Service as a Product: The sale of electricity can be enhanced by providing specific benefits to customers, such as a special rate structure. Section 4.2 deals with time-variable rate structures. The repetition of transactions is characterized by routine operations and there are many sources of interference with the routine. The service product is described in terms of statistical measures which emphasize a level of performance over time against predetermined limits and standards.

As price increases (for example, the annual escalation of rates) factors such as quality of service and what service is available become more important [101]. Service improvements may be evaluated against potential increases in the long-term revenue potential. The task is to identify the components which are important to individual customers or customer groups and to translate them, as many of these as practicality allows, into service packages to meet the needs of customers. This could consist of equal billing payments, payments by instalments, advice regarding energy management, improvements in the utilization process, load factor, power factor, etc. In response to an increasingly heterogeneous and demanding market, the utility may diversify to provide the perception of customized products [105].

2.2.3.4 Costs and Benefits in Solution Methodology: Kassicieh, Ravinder, and Yourstone [94] review analysis and quantification of costs and benefits through interactive accounting, simulation, and optimization.

A Mixed-Integer Programming (MIP) model [104] determines the number of generators in which to invest, the labour costs, etc. The objective function minimizes the sum of the acquisition costs of new equipment, labour costs, installation costs, and incremental costs. The objective function is subject to a set of constraints[3]. Simulation has become a

3. A prototype model will be set up in Chapter 3.

standard tool for the analysis of complex systems: building a model and then modifying the model to suit various scenarios or "what if" kinds of questions by comparing an existing and an alternative system. This concept was introduced in Section 2.1.2. The decision-maker may incorporate the results of the optimization and simulation models with the results of the ranking model. Figure 2.3 shows this process.

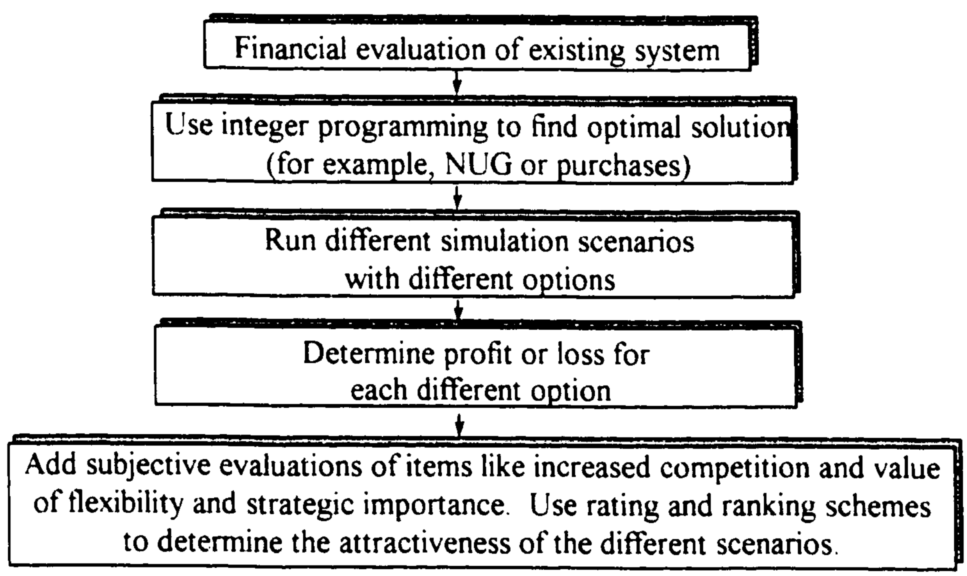

Figure 2.3 : A Solution Methodology

Most traditional justification approaches fail to include all of the important factors that drive the optimal decision. Economic models, mathematical programming models, and accounting models have limited abilities if used singularly to capture the essence of a "whole picture" or the broader and more complete viewpoint. If they are used together, they can capture most of the important issues that need examination. Different functions of engineering, design, production, financial, and marketing require quantification through simulation, optimization, and other mathematical models separately and then again collectively to capture the interaction between them.

2.2.3.5 Benefit, Outcome, and Resource Interactions: Schmidt [134] reviews the following types of interactions associated with capital budgets within a set of projects:

i) Benefit interactions,

ii) Resource interactions,

iii) Outcome interactions.

The approach is to build a model that accounts for the combined effect of cost, value, and outcome interactions and a method capable of solving problems. The objective is to maximize the expected net present value of the project while remaining within a given budget.

Project portfolios can contain combinations of interactions. A project selection problem that involves all three types of interactions (cost, benefit, and outcome) is called a combined internal interaction problem. No models to date have been developed for problems in which all three types of interactions are present [134].

2.2.4 Directions of Change

2.2.4.1 Establishing Direction: The management of customer service is necessary to determine the specific elements and level of service that customers want and to which they will respond. A single set of attributes may not match the needs of all customers. The strategy of customer service involves the concept of managing customer requirements. Customer service is a product in which the dimensions or elements have specific value to customers and success involves determining what customers prefer and can actually use. In determining the service package, consideration is given to the combination of elements that most likely match the needs of the customers and the utility. Within this process, the initial stage identifies the potentially relevant elements of service; these are evaluated in terms of effectiveness against the current practices of the utility. Then the cost alternatives and the impact of these service elements on cost and profits are considered. Customers, through surveys, can indicate those areas with the greatest potential for improvement and discriminate on the basis of service provided. This is illustrated in the case studies of Section 4.7.8. The values of retail rates and quality of service influences the level of customer perception.

Customer service objectives or standards should be established through dialogue with customers. The survey results of Figure 4.18 illustrate customers' views regarding quality of service and retail rates. Once determined, they are disseminated to customers and to the utility to establish expectations. These standards become a measure for management's objectives and programs. They can be incorporated into management controls to evaluate the performance of each unit of the organization. The concept of customer service implies that customers respond to increasing quality levels of service with increased purchases. Service is a revenue generating concept, but the precise contribution is complex; therefore, it is difficult to obtain the optimal level of service.

Customer service requirements may be managed either by accepting the variety of customer's requests or only accepting those requests which meet specific criteria within the utility's policies and procedures. The choice depends upon the state of competition or available alternatives, political directions, and specific needs of customers. This may shift the bargaining power from the utility to the customer, requiring the utility to provide the specific service. Reversing this relationship allows the utility to demand more and, in effect, imposing a discipline on the customer. Chen and Adam [30] deal with concepts of production of a quality product at competitive prices, the need to understand customers, and the proper use of capital.

Quality: The product (service) quality is the appropriateness of design specifications of the required function and use, and the degree to which the product (service) conforms to the design specifications (for example, standard voltage and frequency levels of the source of electricity). Quality includes the appropriateness of the design in meeting market expectations. It includes the usefulness of the actual output compared to the design specifications. Quality can be measured by the cost of quality, which is the expense of nonconformance -- the cost of doing things wrong. The cost of quality is the sum of all costs associated with maintaining quality control and absorbing the external costs of loss of business and liability claims [48]. In Chapter 4, Figure 4.16, customer loss has been included as part of utility costs.

The cost of quality can be further segregated into two elements:

1. Cost of control includes prevention of defects reaching customers and involves:
   - inspection to detect deficiencies (e.g. broken insulator, defective cable)
   - quality control of costs which include labour costs and inspection costs (e.g. when a substation is built, it is inspected before it is energized).
2. Total cost includes problems and their prevention in the system. In Section 4.7.6, the utility cost includes cost of maintenance and cost of service restoration. Failures result in scrapping, repairing, and replacing. Total cost is the sum of two curves of component costs:
   - one pertaining to control
   - the other to failure.

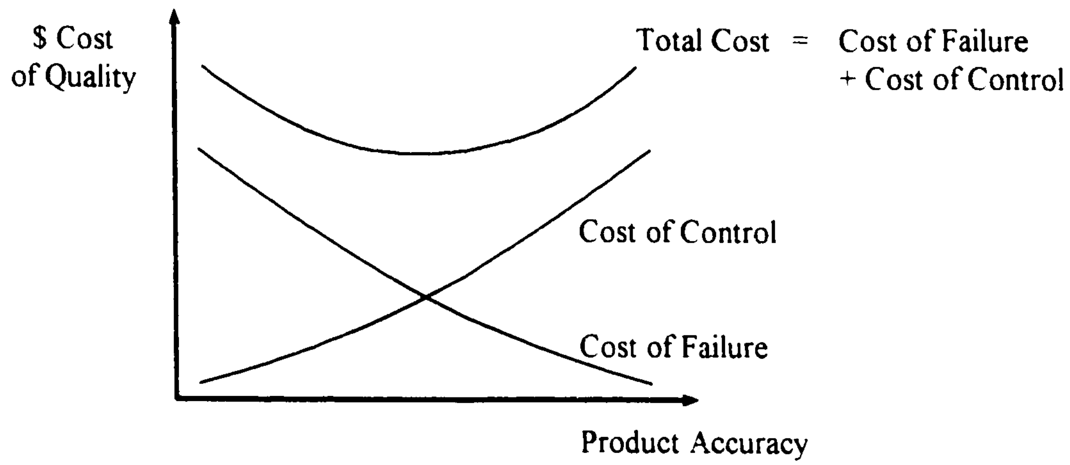

Figure 2.4 : Quality Cost

Control and failure are related; better control reduces the frequency of failure, making lower quality costs an achievable objective. Control has two components:

i) Appraisal -- which focuses on detection of errors.

ii) Prevention -- which focuses on improving the accuracy and coordination of the system.

2.2.4.2 Strategy for Change: Strategy is a response to changing environments and a set of initiatives to realize management objectives. It is built on change and should be continuously examined and evaluated. The general objective is to increase the quality of service and to minimize costs.

Adler [4] points out that competitiveness induces changes in the long run in engineering and management (cooperation is another mode of coordination). According to Adler, there is a shift to more qualitative, less analytical, and more inductive approaches. The growing role of technology and other forms of knowledge in competitiveness is driving parallel changes in management. Technology has the quality of not being used up by being used. The more it is used, the more there is, since new insights and new knowledge are likely to accumulate. In the integration of computer-aided technologies, both costs and benefits span multiple functions and are difficult to capture by traditional procedures. This concept is further addressed in Section 4.8 of Chapter 4. Some measures are:

- responsiveness
- productivity
- quality
- lead time
- design excellence
- flexibility
- consistency with corporate objectives

Many such variables are implicit in the traditional valuation procedures and should be explicit. Increasing levels and spans of automation make inherited approaches to the management of technological change obsolete. Bohn and Jaikumar [17] have outlined the traditional method, which illuminates an important range of issues under the following general conditions:

- the technologies are known
- the environment is stationary and known
- labour's task is to follow well-defined procedures
- inputs are available in complete markets
- goals are well-defined

The assumptions permit rigorous model building and deductive analysis; their restrictive character allows tractability. The traditional methodology is to generate increasingly sophisticated models and to progressively relax those restrictions and reveal ever-expanding subsets of the issues faced by the managers in the real world. The requirement is to approach the central issues created by the new competitive role of technology and organizations which have to continually redefine new goals. Automation feeds on its own accomplishments. The rate of change of technology draws automation levels upward on an accelerating curve.

2.2.4.3 Innovation: According to Mogee [115], a new paradigm for the field of engineering and technology management has not yet arisen. A company can be an originator, a user, or a victim of technological change. There are risks posed by new technology and how to respond to the special challenges of managing innovation. Today there are no standard, accepted practices for managing technological innovation [97]. The task is to apply existing knowledge to innovation management practice, building and strengthening that body of knowledge and developing reliable innovation management tools.

A cyclical type of innovation process is critically important to competitive advantage which focuses on achieving continual, speedy improvements to existing technologies. It is cyclic in the sense that it is driven by the production improvement cycle. It often begins with customer need. (Section 4.4 in Chapter 4 addresses both time dependent and time independent customer needs.) Management challenges in market-driven commercialization relate to finding and applying the most appropriate technology, regardless of its origin, and making the product available to market before the competitors (e.g. utility builds a NUG which is both more economical and reliable than those from other suppliers in an open market system). What is required is an application that meets the requirements of the market-place, which shifts the nature of competition to emphasize price, quality, and performance.

2.2.4.4 Decisions in Solution Methodology: Keeney and Von Winterfeldt [95] deal with the value of quantifying judgements to complement qualitative thinking and reasoning. Judgement is applied in searching for the solution to any significant technical problem. A judgement is initially required in determining that a problem is even worth attention. Judgements should be made by experts who have the knowledge and experience to make them. Judgement may be implicit or explicit. Implicit judgements are more difficult to communicate precisely. Clear communication requires that judgements be explicit for review and appraisal. One is required to explain the reasons, assumptions, and thought processes underlying a particular set of conclusions. Judgement can be quantitative or qualitative and quantification facilitates communication. In Chapter 3, a practical problem has been formulated which is associated with obtaining sources of electricity.

Buchowicz [20] argues for the use of qualitative methods for strategic process because so many of the goals and important concepts are intangible and difficult to define. Quantitative methods utilize numerical measures of key variables and attempt to estimate the strength of hypothesized relationships. In contrast, qualitative methods include the approaches that attempt to find questions for which numerical measures are not available or possible given the current level of understanding of the phenomenon in question. This is demonstrated in Section 4.8 of Chapter 4. As process models are developed, quantitative methods are justified and needed to test such models and refine understanding. The strategy of an organization simply reflects the aggregate of countless strategic decisions or behaviours that have taken place, one at a time, over a period of years [113].

2.2.4.5 Design Team Management: Safoutin and Thurston [131] review the organizations and the effective application of these resources to design problems. The advantage of teams over individuals is that the overall performance of any group increases directly with the sum of combined member abilities -- namely, resource additivity. Nevertheless, there are also barriers to coordinate a diverse pool of specialized resources which degrade the group performance -- a phenomenon known as process loss. Potential productivity is the maximum productivity that can occur when an individual or group optimally employs its fund of resources to meet task demands. Prescribed process is the hypothetical series of acts that would permit potential productivity to occur. Process loss stems from informational, behavioral, and organizational factors that impede the application of existing group resources to the problem.

Interdisciplinarity is the number of separate disciplines involved, the number of persons in each discipline, and the communication between persons of different disciplines. Task definition is the partitioning of the project into a number of simpler, separately solvable sub-tasks. Task assignment is the appointment of individuals or sub-groups to each sub-task. Task coordination is the management or integration of information exchange between sub-groups. Communication[4] is the principal means by which group members help their groups achieve goals. Design is more susceptible to communication variables than technical service efforts. Task achievement is related to communication, particularly in complex tasks. Communication event is defined behaviorally by the participants and functionally by the artifact with which it is concerned.

2.2.4.6 Media Selection: Jones, Saunders, and McLeod [92] deal with how sources and media used by managers change over time and across decisional roles as decision-making processes unfold. The rate of information acquisition affects media selection. Engineers need to be skilful at acquiring information for decision-making purposes. They are problem solvers and seldom have enough information about a problem to begin solving it without first gathering more data. Information use is critical to the process of decision-making. How the actual decision-makers acquire the information needed to make decisions is important. The selection of media during decision-making may be mechanisms such as meetings, telephones, and memos, etc., selected to transfer information from a source to the decision-maker. The selection should be based on the media's characteristics; however, there is a tendency by engineers to use the most accessible source of information, whether or not it supplies the needed quality of information. Telephones, electronic mail, or computer conferencing is used more frequently where decision-makers are simultaneously involved in a number of high priority decisions. These media provide quick, easy access to information sources when the decision-maker is experiencing pressure to react quickly.

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4. **Information and Communication is dealt with in Section 2.2.5, page 70**

Smilor and Gibson [149] view the success of organizations in terms of four key variables: communications, motivation, distance, and technological equivocality (ambiguity).

1. Communications -- between the technology transmitter and receptor involves both passive and active links. Communication interactivity is closely related to information carrying capacity, which refers to the degree to which a medium efficiently and accurately relays task-relevant information.
2. Motivation varies with culture.
3. Distance involves both geographical and cultural proximity or separation.
4. Equivocality refers to level of correctness of the technology to be transferred (low equivocality is easily understood, unambiguous, and more likely to be transferred).

Erengüç [52] points out that where knowledge is dynamic and adaptive, learning methods are needed. People can be aided by decision support systems having machine learning components. Learning systems provide three major advantages for support of real-time control of complex systems:

1. They provide an understanding and explanation of the underlying systems which may not be available through other strategies. The size and complexity of such systems often preclude the formation of accurate mathematical models that contain the structural and procedural details necessary for meaningful use.
2. Large volumes of (possibly noisy) data can be reduced into compact distillations of knowledge.
3. Learning methods can build upon prior knowledge and new observations to provide meaningful assistance to decision-making.

There are three areas in which the environment is rapidly changing. The emphasis is not on production but on the identification of future problems:

1. Markets are changing and affect the following:
   i) changes in electrical demand, and
   ii) changes of supply of electricity and its distribution.

The long-term approach may be to obtain self generation for larger companies and local municipalities and not to depend solely upon wholesale purchases from the main grid as the only economical source of power. The consumer product channels have long-term tendencies for direct utility and NUG relationships, hence the increased importance of customer service. The delivery of products, such as electricity, to a highly technological society have value within trade-offs. This changes the cost emphasis to availability over distribution. These strategies emphasize customer sensitivity and service quality to distribution which emphasizes availability and reliability over cost.

2. Technology: The expected significant future changes would not be so much technological as institutional [149]. The technological development focuses on three main areas:

   i) Distribution which is limited by constraints imposed by previous technical, institutional, and policy decisions.

   ii) Quality of service costs have been capital intensive. These involve fixed cost facilities and taking advantage of increasing economies of scale for larger distribution networks. Major problems are not usually technical but organizational.

   iii) Information and improved coordination linked by communication using common data prevents diverging trends in the utility distribution process. Communication changes the performance of activities and provides more precise signals of change such as the transition from a cost-based operation to a competitive environment in an open-market economy.

3. Public policy is unstable and least predictable. Although the electorate is ideally the public's choice, nevertheless, rival political philosophies of government intervention and reliance on market forces are themselves generally in flux. The policy of a distribution utility may be volatile if it is linked directly to political philosophy regarding the role of the government

and its relation to the electrical power industry. A new set of skills is required to address and coordinate this very complex and important aspect of political involvement.

2.2.4.7 Environment of Distribution: There are four groups of variables which affect the system regarding distribution:

1. Customer variables measure the extent of demand. This includes time preferences, service levels, usage patterns, magnitude of individual loads and other factors relating to the sale of electricity and services. These are addressed in Chapter 4, Section 4.5. These can be changed by altering their characteristics, for example, price variations, time of availability of services, control of loads, etc.
2. Channel variables involve an intermediary between the organization and its ultimate customers, such as the relationship which exists between Ontario Hydro, the municipal distribution utilities in Ontario, and customers. The structure of the channel is the bargaining power by intermediaries, such as Municipal Electric Association (MEA) on behalf of all the distribution utilities in Ontario, large industrial group representation (Association of Major Power Consumers of Ontario - AMPCO), and others. Their interest in performing specific functions and their own terms are important in determining the channel system. The ability to negotiate depends on the relative dominance of the seller over the buyer, influencing the costs as well as the requirements for service.

   Strategic planning is concerned with the performance and operations of each succeeding stage in the path from the source of supply to the final customer. The channel is also a system involving functions and separate decisions integrated into a single entity. This is efficient and services the need to control the conditions of delivery for all channel members.

3. Product variables are the characteristics of the product influencing the distribution. These are load density (which is influenced by customer density), the need for special environments (such as various physical clearances due to voltage levels), electric and magnetic field concerns by the public, safety, etc. These usually increase the cost of distribution.
4. Distribution variables identify the available services required (such as the construction of a new line) to provide the product of electricity and services at different geographical locations and their relative costs. The extent of this availability and the internal development of the utility determines the extent of the potentially available options. Namely, is there enough capacity in the present network or should that new line be built? Distribution strategy combines two views: one view is the capacity of the utility's distribution system and the other view is the distribution channel or the demand for electricity. Previously, one was considered a technical issue and the other a marketing issue, yet both are concerned with the delivery of the product to the final consumer.

2.2.4.8 Future Directions: Management of information for operations and decisions in a distribution utility has the greatest potential for development and may be crucial for future business success. It provides the means to coordinate logistic activities throughout the utility by crossing organizational boundaries. The concept of logistic information and the concept of an integrated system requires linking functions through a common database. It becomes the central element in functional integration and in management planning and control.

The focus of logistics is on the movement of the products (electricity and services) and the principal tool of control is the management of information. The decision-making perspective in modern management is changing because of the computer and the dual role of analysis and communication. The cumulative effects of repetitive decisions can be the basis for determining rules to be incorporated into computer programs to control specific functional areas. The performance of the logistics system is less well understood. The utility and management of information are considered as parts of a common decision-making system, rather than as separate elements with occasional interaction. Logistics management continues to evolve. According to Van Dierdonck [158], there are three central variables which influence the development of logistics organizations:

i) The need for organizational integration.

ii) The role of the information-processing system.

iii) The presence of slack resources.

These three are reviewed in terms of the influential variables on integration, the information environment, and the evolutionary development of a logistic organization.

i) Integration is a response to uncertainty. Uncertainty characterizes decisions involving human judgement, such as scheduling the source of supply, setting priorities, or deciding which services are required for which customers. Decisions with low uncertainty can be performed by computers. Decisions with high degrees of uncertainty may require coordination with other departments of the utility to find joint solutions. To reduce uncertainty may require new information, broader participation in the decision, and commitment to implementation after the decision is made. Integration is a measure of interdepartmental communication and addresses the need for more information to reduce uncertainty.

ii) Information-processing systems are a response to a need for information. This is also addressed in Section 2.2.2.4. This involves collecting, managing, disseminating and making available common information. These processes are usually computer based due to the sheer volume of transactions. Information-processing system involvement is a response to this volume measured by the degree of complexity. Logistics decisions can be simple, with few transactions and variables, or complex, with large numbers of both. Van Dierdonck [158] identifies four potential environmental situations.

1. A low-complexity, low-uncertainty environment makes few demands for coordination of information. Each part of the system can operate

with minimal supervision following individual decision rules, such as economic order quantity and reorder point calculations for materials and equipment (e.g. hydro poles, cables, transformers perform their respective functions and are replaced when failures occur).

2. A high-complexity, low-uncertainty environment is characterized by a large number of repetitive transactions. Management involvement can be low as little coordination is necessary. Logistics management departments may manage the electricity power flow with little external input.
3. A low-complexity, high-uncertainty environment is characterized by careful coordination of transactions in order to deal with ambiguous and unpredictable situations. This includes technology-based products, such as power source and availability, whose lead times, demand, and supply requirements have not been clearly established.
4. A high-complexity, high-uncertainty environment is one in which large amounts of detail are managed by functional managers. They are assisted by a logistics management department and by the information system, such as customer responses and perception due to changes in the quality of service and rates, and the impacts of such intangible components upon the utility.

iii) Slack variables are the additional resources that allow logistics activities to be operated in isolation from each other without need for coordination. Slack resources can be material inventory, prolonged lead time in meeting customer service requirements, or extra power capacity from self generation or from availability of wholesale purchases.

2.2.5 Information and Communication

Distribution utilities often face simple problems such as repairing overhead conductors or more complex problems of recognizing customer concerns and fulfilling some of their needs. The solution requires the correct use of components of information and communication before the problem is evaluated and solution proposed. Therefore, the composition and importance of information and communication is briefly reviewed.

2.2.5.1 Information: Information is organized according to some logical relationships which are referred to as a body of knowledge. Information is communicated and signs are the irreducible elements of communication and the carriers of meaning. The following are the three dimension of signs [142]:

i) the medium of the sign
ii) the object that the sign designates
iii) the interpretation of the sign.

The fundamental relations of information are essentially triadic in contrast to the relations of the physical sciences which are reducible to dyadic or binary relations. The possession, manipulation, and correct use of information can increase the cost-effectiveness of both physical and cognitive processes. Hence the rise in information-processing activities in organizational operations, as well as in human problem solving.

The characteristics of information are that it is compressible (both syntactically and semantically), it is transportable at very high speeds, and it imparts advantages to the beholder of information. It has become an economic resource. According to Reisman and Xu [129], the concept of entropy of the system is connected with the ignorance or the incompleteness of information about the system or the lack of information about the detailed structure of a system. Then all efforts are directed at unifying, classifying, and systematizing. Knowledge tends to decrease the system's entropy and the knowledge becomes more transmittable and becomes part of a clear pattern or "gestalt". The more systematic the knowledge becomes, the easier it is for one to learn that information.

2.2.5.2 Communication Processes: Petrie describes [127] information-processing as the generation, access, transfer, and application of information to the making of decisions. It is the transfer of information between information spheres and decision points. The information-processing mechanism directs information between decision points and information spheres via channels, which may take the form of internal exchanges made by a single individual or external communications along verbal or other channels among separate individuals. Pentony [125] compares the single individual and group activities representing specialized spheres of expertise. These spheres, according to Taylor [152], reside within a single mind, but the end requirements for the artifact, the knowledge pertinent to its design, and the set of existing solutions do not change. Therefore, the mechanism of the design process need not change because of the change in the number of members. The change only affects the mode of information exchange by which one of the existing solutions will be discovered and chosen. This exchange can take two forms. In individual design, there is a single decision-maker and a single mind in which all expertise resides and this transfer of information is called internal exchange [112]. The external exchange of information is referred to as communication. A communication event is defined by the presence of an encoder (sender), a decoder (receiver), a channel (means of transmission), a reference (topic), and a message.

2.2.5.3 Failure of Information-Processing: Information-processing encounters barriers due to unavailability of information and inaccuracy of communication, producing information error by presenting incorrect or incomplete information to a decision point. The communication accuracy of transmitted information depends on attributes of the encoder, decoder, channel, referent, and message. The concern is not only with simple losses or alterations of information in transmission, but also with the match between intended and perceived meaning [138]. An information error occurs when erroneous or incomplete information is present at a decision point. Information unavailability is an availability error causing an information error. A communication error is an information error in which the decoded meaning does not match the encoded meaning. Information errors result in corrective effort costs during the design or production, depending on their detection.

The two types of information error effects are:

i) A micro information error effect is the temporary, unexpected symptom of erroneous information flagging the presence of error during the design process and prompting corrective effort. For example, errors in a prototype model. If an information error does not cause a visible micro effect during design or it is not corrected, a "product flaw" may emerge.

ii) Macro information error effects the design process and results in the cost of rebuilding the model correctly. A cognitive model establishes the relevance of information communication in design. The errors in information are a form of process loss which result in product flaws and corrective efforts. The model allows the development of a methodology aimed toward reducing information-related process loss.

2.2.5.4 Task Definition Strategies: The goal is to increase effectiveness by effecting control over the occurrence of information errors. The strategy is to reduce the risks of potential information errors by controlling communication accuracy, information availability, error detection, and corrective effort. Mehrabian and Reed [112] point out that the accuracy of a communication is directly correlated with the communicator's or addressee's level of cognitive development and determined by the lower of the two levels. Cognitive development is the level of independence of judgement, verbal aptitude, lack of authoritarianism, tolerance of ambiguity, and decentering ability. (Decentering is the ability to explain one's knowledge to another who is not so trained). Critical tasks involving dissimilar fields require cognitive similarity between their designers and, in the case of a team effort, the co-ordination should be assigned to a multidisciplinary member. Accuracy is correlated with the degree of feedback available to the encoder [131]. A communicator is most effective when the level of success of communication is monitored by observing the behaviour of the recipient, forming a feedback system. Prompt evaluation of the results of applied information is another form of feedback [124].

Many exchanges of information are only momentary in observable duration and provide physical evidence. Information might also be transmitted subliminally, or might represent common domain knowledge between design participants which does not require explicit exchange. The importance of such information might not be obvious if it does not travel along observable communication channels. If the modelling process method [90] uses functionality, then critical components are more easily identified.

2.3 EXISTING SOLUTION TECHNIQUES

2.3.1 Real Time Operations

The electrical demands of customers are met by the continuity of supply of electricity and the maintenance of good quality of service. The supply authority must establish realistic and attainable goals to maintain the continuity of supply and to anticipate and compensate for variations in the system, such as customer loads and faults in the electrical network. The main function of the distribution of supply is monitoring, control, and protection within specified and acceptable standards with consideration for reliability and the management of loads. Voltage reductions can be part of the load management control strategy. Based on customers' loads and the availability of supply, automated equipment may be an alternative to increasing the delivery capacity. Information and valid data collection is important with regard to present and future decisions. There are two modes of data forwarding [21]: one is automatic, which is the recording in automatic mode based on predetermined conditions; the other is manual.

The general trend is from passive to active network design. Passive network contains resistance, inductance, and capacitance. The laws of physics determine the network design since this type of network possesses no ability to apply logic or control. (Historically, electrical distribution systems have utilized logic capability to a limited degree, such as voltage control and system protection). The active network incorporates control, logic, and, in general, the ability to respond with intelligence or logic capability to inputs.

Fuzzy set theory and fuzzy logic were used by many researchers to describe the fuzzy nature of interaction between system inputs and outputs [79]. Based on the results of numerical analysis, the relationships of the inputs and outputs are identified as fuzzy rules.

That is, the inputs are fuzzified based on their membership functions and the relationship of inputs and outputs are described by fuzzy rules. The outputs are then defuzzified to be a crisp output based on the output member function [109]. This is the typical process used in fuzzy logic. The outputs can be fine tuned by modifying fuzzy rules and membership functions.

Technological innovations, such as the installation of sectionalizers, improve service restoration times and also transfer load between feeders. This reduces the effects of interruptions perceived by customers [26]. The restoration process method of prioritizing sections results in the minimization of disruption of critical loads that provide essential services, such as hospitals [143]. Supervisory Control And Data Acquisition (SCADA) installation was initially made for reliability considerations and this aspect of economics was of secondary importance. Now economics has become of primary importance and there are advantages to integrating load-management and SCADA functions into one system [28].

Operation and control methods for active electrical distribution systems enables the coordination, optimization, and "tuning" of the distribution system [53]. The choice to use a specific technology should be made with reasonable certainty that the particular technology will best fit the intended purpose [86]. Therefore, the function of a technologically based system with economic constraints is to decrease the frequency and duration of customer outages and maintain quality service. This is achieved by multi-user [110], multi-tasking real time operating systems which:

- Monitor the system for abnormal conditions
- Provide information and load management through remote intelligence
- Trip, reset, and transfer loads between feeders
- Determine fault locations
- Build up a database regarding power system behaviour and disturbances. This helps to provide a lead time regarding the system's expandability, sudden load increases, or general variations in some of the systems parameters.

These established and practical techniques address the technical concerns of meeting the customers' load needs with respect to cost, efficiency, and reliability. The aim is to maintain or even exceed pre-established, cost-effective levels of quality of service. The aim is also for the fullest utilization of components to satisfy customer needs at affordable prices for the services. The technical system in itself does not fully address issues of environmental concerns, political involvement, customer perception, or levels of customer satisfaction. A very high quality of service may be an optimal solution with respect to supply, but may be generally too expensive or even unaffordable for the customer.

2.3.1.1 Forecasts: Early forecasts always precede design decisions and by their very nature are imprecise [141]. Cost planning provides designers with continual cost evaluation and feedback as the design evolves and is guided towards a budget or target.

2.3.2 Modelling

2.3.2.1 The Concept of Modelling: When a technical problem is complex, engineers build models to aid their thinking. If knowledge of several disciplines is required on a specific technical problem, then no individual has the expertise to make overall implicit judgements. The problem must be decomposed so expertise can be utilized from the various disciplines. This knowledge can be integrated reasonably if it is explicit. Then a model can be constructed to integrate and appraise the parts. Complex systems such as the electrical power system generally have attributes with complex interdependencies and rules of interaction which are not always obvious. They have strong behaviourial components in that a utility responds to many contingencies which are time-dependent. It may be difficult to understand their full behaviour and one approach to achieve some input into such a system is through the use of models [58].

The meaning of the word "model" may include:

i) A self-consistent systematization of the understanding of a phenomenon and the facts concerning it.

ii) An ideal or simple representation of more complex forms, phenomena, and ideas.

iii) A convenient, systematic scheme for consolidating data or information compression.

Therefore:

- A model representing a fundamental idea is called a "principle".
- If a model is tentative it is called a "hypothesis".
- A well-established model is acceptable as a "law".

Models are developed for the following two important reasons:

i) To better understand, explain, control, and predict the events or phenomena being modelled. A model of retail rates might be made to include several factors such as inflation, quality of service, and wholesale purchases of electricity.

ii) To introduce new concepts and new techniques to explain observed phenomena such as changes of customer perception over time. Section 4.7.8 of Chapter 4 illustrates some case studies.

2.3.2.2 Development of a Model: The following are the steps of model development:

i) Establish the main purpose for the model. To develop a model to explain and account for "all" aspects of utility operations is difficult, very complex and, perhaps, unmanageable. However, a model with limited purpose is amenable to detailed investigation and scrutiny [57].

ii) By analyzing the observations and known facts about the system being modelled, one can identify possible elements, such as observations, measurements, and ideas related to the purpose.

iii) Study analogous systems which have elements in common to the system being modelled. This helps in identifying an approach to, and techniques for, developing the model. For example, the adoption of a new electrical appliance by consumers may be similar to the spread of an epidemic, etc.

iv) Develop a hypothesis for explaining the phenomena and incorporate it in a simple model with as few parameters as possible but still enough to incorporate the most important known aspects of the phenomenon under investigation.

v) Investigate a simple model, make predictions with it comparing the results with known observations. This model is made more complex only if the simple model cannot account for some of the observations, and then investigate the complex model. By gradually increasing the complexity of the model, a deeper understanding of the basic principles of the system is ensured. (Starting with a complex model, one may miss out on this understanding).

The conclusion is then drawn from the accumulated facts obtained, which enable one to foresee new facts which are not yet known.

2.3.2.3 Classification of Models:

i) Causal and correlative models:

Causal models reflect cause and effect, while correlative models may simply reflect statistical correlation. For example, the amount of electrical power sold by a distribution utility increases every year. This data can be used to develop a correlation model using regression analysis, relating load increase to time and then to predict future loads in future years. That this prediction will be independent of any other event is an incorrect conclusion. One can also develop a causal model relating power sold to increases in new major electrical appliances in a given year. This model then reflects that electricity is needed for the new appliances and if the sales of the new appliance go up, so will the use of electricity.

ii) Deterministic and stochastic models:

The deterministic model for a given set of values of the parameters, at any given time, is determined or well-defined. Stochastic models deal with uncertainty and their behaviour cannot be precisely predicted. They deal with probabilities [59].

iii) Isomorphic and homomorphic models:

In isomorphic models, there is a one-to-one correspondence between the elements of the system being modelled and those of the models. In homomorphic models, many elements of the system being modelled are integrated into one to make the model simpler and more amenable to detailed investigation.

iv) Static and dynamic models:

Static models represent the behaviour of the system at a given time. Dynamic models represent the trajectory followed by the system as a function of time.

v) Decision models:

These provide the users with "IF-THEN" scenarios and are used in policy analysis and subsequent management decisions.

vi) Simulation models:

These involve the creation of an artificial system which displays either the same behaviour as the one being modelled or related to it in some simple way. Simulation is a mathematical technique that involves building a model and then performing experiments on it in order to infer properties of the real system. It produces representation under one specific set of conditions. It provides reasonable results to permit the testing of assumptions within the model. Computer simulation takes the form of a computer program containing entities representing the elements of the real system. It produces an output from which the behaviour of the system can be deduced. One can study the impacts of various plans and decisions and then select and implement the plan with maximum benefits and minimal drawbacks. This has the following advantages [80]:

a) It allows controlled experimentation, in which many factors can be considered and manipulated and alternative policies analyzed.
b) It allows compression of real future time into the present time.
c) It provides insights, thereby making management more effective.

2.3.2.4 Principle of Optimization: To optimize is to minimize or maximize a certain function, which can be referred to as an objective function.

i) Optimization Procedures:

The optimization procedure is used to determine the configuration for which the objective function is optimal, say minimal. The objective function is repeatedly calculated for various values of the parameters describing the configuration. The object of this process of iterative calculation is to select successive sets of parameter values in such a way as to converge step-by-step to the minimum of the objective function. The criteria used in choosing an algorithm are that the number of iterations required to reach the optimal set of parameter values should be as small as possible.

ii) Evolutionary Optimization:

A theory of evolution is based on the concept that random change, coupled with natural selection, will result in progressive transformation of form, which can give rise to novel structures and functions. This evolutionary process is a type of self organization and depends on the algorithmic self organization process which optimizes a fitness function, thereby affecting the chances of long-term survival of the organization. For example, the utility may change from only distributing electricity to both generation and distribution. This may be due to rapid wholesale power cost increases and the unbundling of the whole electrical industry. The process of natural selection, acting in conjunction with random change, is a high-order self organization of the company's components.

2.3.2.5 Programming Methods:

i) Linear Programming (LP):

The object is to minimize total distribution costs. When economies of scale are considered in conjunction with distribution costs, the optimal solution may change.

ii) Mixed Integer Programming (MIP):

These models solve multiple problems in a joint solution. This involves a number of constraints in addition to the formation of integer and continuous variables and parameters. The branch-and-bound approach successively improves solutions which become the bounds of acceptable answers. Each solution narrows the bounds, converging towards a final solution. By establishing upper and lower bounds, the non-productive calculations are avoided.

iii) Dynamic Programming (DP):

The problem of changes in response to changing environment introduces an application of dynamic programming. It traces an optimal path through location decisions at successive time periods. Fixing facilities involves planning over a specific period of time. During that time period, changes in markets, sources of supply, or distribution costs can alter the relative value of the original decision [123]. Hence, the need for a method that will accommodate changes over time within a given location decision.

2.3.2.6 The Manifold of Modelling: Deming's approach [42] is to draw the workforce not only into the production of electricity and services, but also into the production of knowledge about the improvement of service procedures.

Sociotechnical systems approach to organizational design is to consider optimal relationship between data and knowledge as parallel with the classical relationship between responsibility (for) and authority (over). There should be a close correspondence for all four terms:

i) knowledge

ii) data

iii) responsibility, and

iv) authority.

Analytic models are not easily managed when confronted by the irreducible complexity of continually evolving shared values. Simulation is an approach, but because of the degree of complexity of this phenomenon, simulation results may be opaque. Hence the approach may be broadened by adopting more inductive and qualitative techniques, putting the analytic models in a subordinate role. These would be organizational issues of cooperation and motivation.

Teece and Winter [153] have similarly pointed out that traditional economic approaches cannot capture the real-world complexity of the truly central factors such as:

i) Dynamic competition

ii) Critical rule of knowledge

iii) The internal structure of the organization

iv) The role of entrepreneurial creativity

v) The institutional molding of markets

vi) Real-world cost formation process.

The optimal strategy may be more inductive and qualitative than deductive and formal. An inductive approach helps to identify the more effective knowledge-management practices. Greater conceptual clarity may be developed on the nature of those practices. In this way, one may grasp useful theoretical frameworks and conceptual assembly. The optimal strategy will probably be more qualitative than formal.

2.3.3 Past, Present, and Future Methodologies

According to Johnston [91], engineers are agents of innovation and change contributing considerably to the evolution of management practice. The role of the engineer has three distinct phases:

i) He was a "master" of the enterprise in the pioneer days of opening new territory or starting new industries.

ii) Consolidation and conservation of money.

iii) The ongoing phase; finance remains a crucial element, but "value for money" is the objective.

The engineer as initiator brings a positive can-do attitude, backed by the concepts of scientific method. This is based on the four point rule established by Francis Bacon in the 17th century:

i) Observe

ii) Measure

iii) Explain

iv) Verify.

When formulating strategies and implementing them, notice must be taken of peripheral interests of the stakeholders. In the electrical industry there are customers, suppliers, employees, community, environmental issues, national interest, international influence, etc. Communications and electrical power systems enhance living standards and can make work more productive. The trend towards automation will continue as it becomes economically and technically attractive. By reducing or eliminating random events, higher and more static levels of quality and reliability can be achieved. Computer developments have made automation technically feasible and economically attractive.

2.3.3.1 Engineering and Management Synthesis: Bailetti and Callahan [8] point out the importance of communication and the engineering-management synthesis. Increased competition and technological advances have induced long-term changes in the engineering-management practices. All are anchored to the same technological infrastructure -- telecommunications. Some changes may be forced and others may be the result of personal choice. The engineer, as an individual, must be prepared to adapt and to alter circumstances. Engineers are agents of change and they must be adaptable to a changing environment. The historic perspective is useful as a means of predicting the nature and breadth of change through extrapolation. There is uncertainty in this, but change will continue and probably at an accelerated rate. Adaption generally comes from self-development and awareness is needed of what has gone before.

The existing solution techniques are technologically based solutions subject to economic constraints and are limited in scope in these times of new realities. The utility may achieve cost reduction through the avoidance or delay of new capacity construction. This could be achieved by load management and conservation strategies after obtaining results from a simulated model. The objective of cost reduction may also be achieved by the pursuance of rigorous internal cost reduction strategies and making use of economies of scale whenever they are applicable. Electrical utility systems are constantly progressing to automate new systems and develop or obtain new software. Substations are becoming more intelligent, with advanced diagnostics leading to a greater functionality, reduction in operating costs, and greater operating stability and flexibility. The introduction of competition into the electrical power industry will require operating costs to be under further tight control [24]. The most competitive electric utility will not be the one with the least head count, but the one which employs the most advanced technology in its distribution facilities. The battle for competitiveness will be won on the field of technological use and application. Therefore, the struggle for competitiveness is bound to lead to deployment of new and better technologies in the electric power industry.

Past leadership of utilities, due to political influence, has been mainly concerned with short-term profits rather than promoting business growth [25]. Utility management must now shift the focus of its decision-making from local matters to more of a global approach. There should be a balance between competition, coordination, and collaboration between enterprises [89]. The concerns should not only be strongly technologically based, but they should also address more and broader problems in our society. This social awareness and the effects of various actions should be incorporated in the planning and operation of the electrical power industry. In the design, not only technical and economic matters should be considered but also environmental and social effects. Therefore, in order to see what is important, there is a need to obtain all the necessary information. There is a need to redefine the relationship between the power industry and the government, for both work for the same "boss": the customers who pay the electric bill and customers who pay the tax bill are the same.

The structures of the electrical industry are partly based on the view that electricity is a strategy and publicly provided benefit, and customers have the right to electricity at low prices. The encouragement of least-cost planning and marginal-cost pricing addresses the aspects of direct costs and technological innovations. These are highly specialized but limited information systems and are profit motivated and the minimum cost approach is the driving force for solutions. Abdel-Hamid, Sengupta, and Hardebeck [1], indicated that the focus in projects has been limited to the study of a single project in isolation -- namely, no interactions among projects. Project-in-isolation perspective is a tempting simplification.

The need is now to blend and unify the views of engineers and management. This broader and stronger bond between management and engineers will solve problems more fully and with a higher degree of certainty of obtaining a more complete solution. The new social controls should include social influences and values such as the green movement and environmental concerns. There is now a requirement to address and solve that need which includes customer perception, customer sensitivity, and direct political influence -- a true global optimization. Therefore, there is a requirement for a new way of thinking:

The world we have created today
as a result of our thinking thus far
has problems which cannot be solved
by thinking the way we thought
when we created them.

. . . . . Albert Einstein

2.4 INTRODUCTION OF LOGISTICS IN UTILITY OPERATIONS

2.4.1 The System, Boundary, and The Environment

Logistics is a process to implement change and strive for efficiency and effectiveness. Concept of Logistics [121] involves a process in which electrical energy and power are obtained from a source. This could be wholesale purchases of electrical energy or self generation by a local municipal utility which is supplied to customers -- the ultimate consumers. Logistics process organizes the supply and the purpose is to overcome time and fulfil customer requirements (namely, when electricity is required, an adequate supply exists). This energy produced can be local or from the other side of the country, supplied through the interconnection of the transmission network [87]. It may be required now or in the future and logistics performs the essential function of matching "available supply" to the "demand" by the customers of the utility. Logistic management is important to any business' survival and for that to be feasible, there is a requirement to use logistic concepts which consist of grouping of separate but related activities together in a centrally coordinated arrangement to achieve a common end [43]. For both a private enterprise or public monopoly, the very survival and success of an organization depends upon the ability to sell its products and services. Increases in sales imply increases in revenue.

The two central ideas of logistics regarding utility operation and planning are: the supply of electricity and the system trade-offs, the details of which are:

- Cost minimizations and the total cost concept identifies the costs involved and their corresponding interrelationships.
- Balancing cost and quality of service involves cost-minimizing strategies at various levels of service or levels of quality of service.

The concept of business logistics involves the flow of the distribution or the service process through the organization to the consumer market and balancing of activities to achieve management objectives of efficiency and cost-effectiveness. The activities involve the flow of electricity and services from a source of supply via the distribution utility to a point of final consumption. This involves the customers' habits and their requirements to fulfil a need and solve problems using various types of electrical appliances. This is achieved by the conversion process of electrical power and energy and obtaining various levels of customer satisfaction. Customer service establishes a link between distribution costs and profits and may be viewed as a constraint against costs, but service influences the customers' perception and decisions and therefore enlarges the scope of logistic decisions. The aim is to serve and the utility strategy is to match the system to customer requirements; the emphasis is on planning and operations. This is illustrated in Section 4.5.3 of Chapter 4.

Therefore, logistics management becomes the "heart and mind" of the utility's organization [18]. The production of electricity and services and the application of the logistics concept presents an opportunity to reduce unnecessary costs and provide the quality services that the consumer requires or wants. Due to variations in customer perception, these may not be the same. Logistics involves activities which interact with each other. According to Reisman and Xu [129], the resultant whole may be greater than the sum of the parts. The output of the logistic system depends on the effect of combinations of inputs. The cost of supplying electricity includes the wholesale purchases from a main grid or the capital cost of the local generating station. It also includes the cost of fuel and its availability, reliability of the distribution network and the availability or adequate capacity of the source of electricity (S), and the capacity of the distribution network (N) to supply the required customer load (L). Therefore, even though adequacy may exist in some components of the system, the supply (S) may not get through to meet the required load (L).

$$L = \min(S, N, \ldots\ldots)$$

Using similar logistics, other constraining regulations are also included such as environmental sensitivity, maximum limitation of levels of generated pollution, the curtailment of economically justifiable rate increases and the curtailment of major construction, etc. These and other political influences result in restraints between the source of electricity and the customer load requirements. This is addressed in Section 3.4 of Chapter 3. The premise of the logistics concept is that all of these influences and activities can be managed as an integrated system. Planning, operating, coordinating, and controlling activities and resources involves the product flow which is electricity and associated services; originating from a source and delivered to the final customer. The direction of this flow is towards the point of final consumption and these activities are directed by information, initiated by customer requirements, that provides coordinating signals that progress backward towards the source of supply and the distribution utility [100]. This is addressed in Section 4.1 of Chapter 4.

The breadth of activities involved requires the coordination among the utility's marketing, distribution, generation and/or purchasing of electricity, and coordination with customers' wants and needs and operating requirements of fuel and materials, etc. to achieve that task. The emphasis is on the span of control rather than the control over separate functions [46]. Each of the tasks in this product flow is managed to achieve a balanced performance to meet the utility's goal of survival, which includes the minimizing the total cost and also providing electricity and services as required or desired by customers. Therefore, instead of concentrating on each functional area's individual objectives, logistics management emphasizes coordination of several activities across functional areas and organizational boundaries at the same time.

The system concept consists of a source of electricity (self generation or wholesale purchases from a monopolistic utility or the open generating market), a municipal distribution utility, and customers in a global environment of man-made values and nature's influences. It is a system which is interactive and those components that interact with and influence each other are part of the system. This is further illustrated in Section 4.1. Components that do not show this interaction are outside the system. The external components that influence the performance of the system but are not significantly influenced in return are considered part of the system environment [19].

Figure 2.5 defines the system in terms of these types of components, the interaction of:

i) (S) Source of Electricity
   (D) Municipal Distribution Utility
   (C) Customers
   together which form the system.

ii) The environment (E), in which the system operates

iii) The boundary (B) between the system and the environment is defined by the extent of the interaction between the system and the environment.

The central core of logistic functions is to supply electrical energy and services at a reasonable cost. The prices for these products must be financially sustainable to customers. The utility must attain acceptable levels of customer perception, which are satisfaction and fulfilment of customer's expectations. The sale of these products must provide a reasonable profit for the utility [11]. Figure 2.6 are the details of Figure 2.5 and Figure E.1 of Appendix E illustrates the process flow.

Primary Interaction: involves the production (generation or purchase) of electricity, its distribution, and maintenance of an acceptable level of customer perception. This requires the utility to maintain an acceptable quality of service which includes reliability and availability of these services.

Secondary Interaction: involves the operation, maintenance, and consideration of redundancies in the distribution network. The information system plans and controls the logistic system. It is the link and flow of relevant information between the supplier, consumer, and environment. The purpose is to inform, explain, and justify utility's actions and to maintain a social equilibrium between the supplying utility and the level of acceptance by customers.

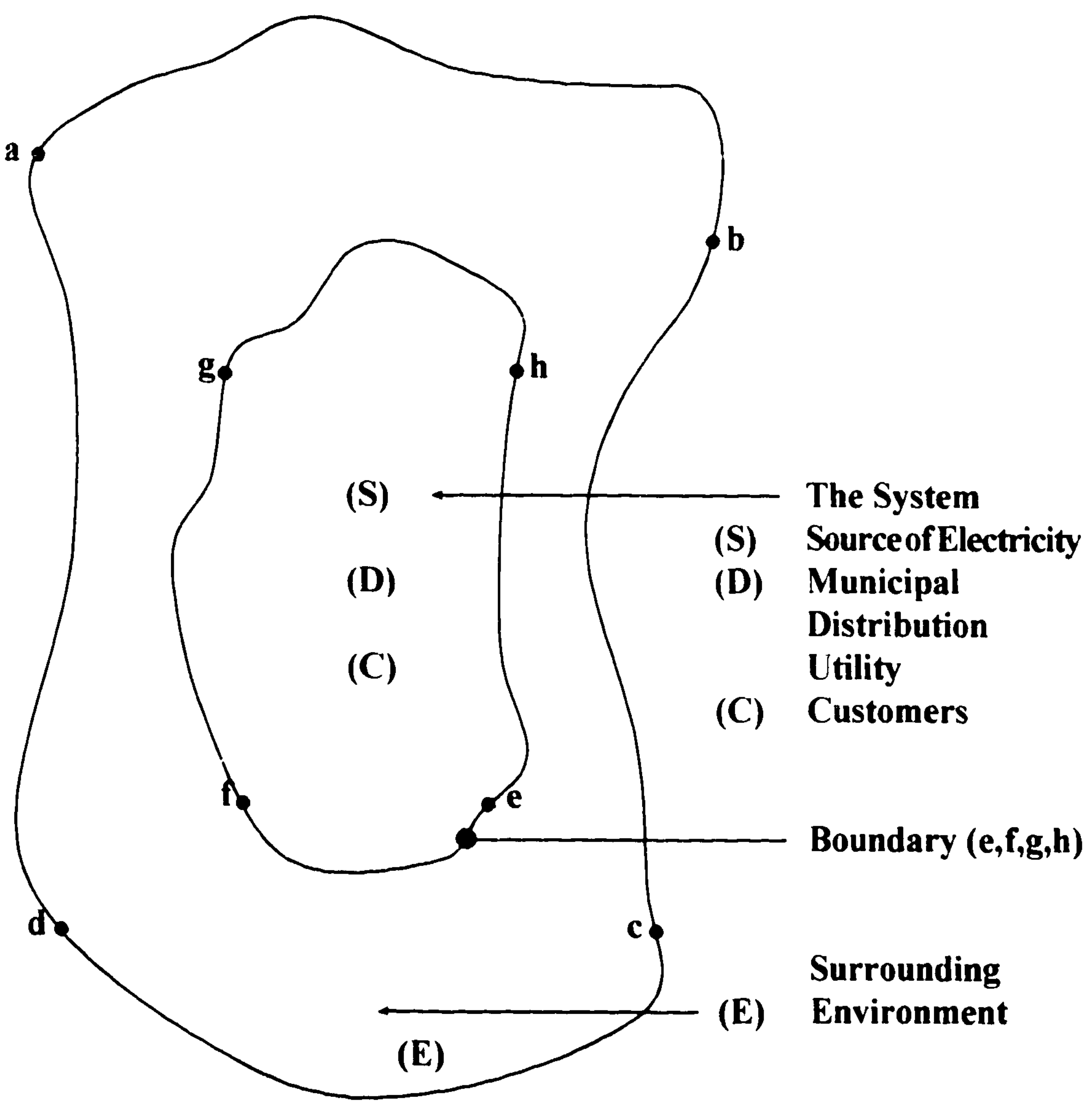


Figure 2.5 : The System, Boundary, and Surrounding Environment

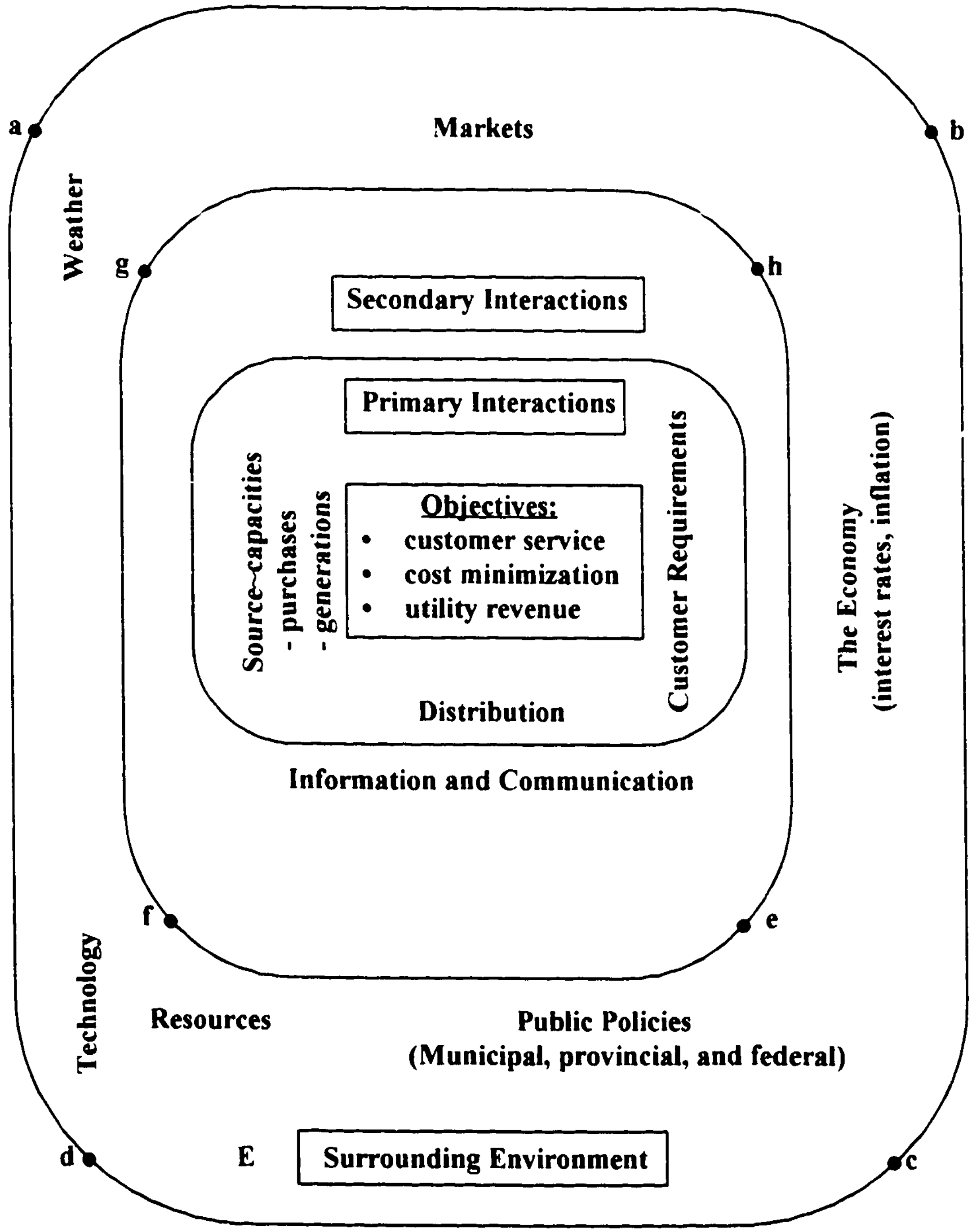


Figure 2.6 : Composition of the System and Surrounding Environment (Details of Figure 2.5)

2.4.1.1 Environment: The logistics system is affected by components of the environment and trends [133]. These changes affect management perception and decisions which influence the direction pursued by the system. These main influences are:

i) Markets and customers: form patterns of demand and service requirements.

ii) Functional channels: determine which activities are to be performed within the system or externally to the system. This could be considerations of local generation or wholesale purchases, work performed by the utility's forces, or contracting out, etc.

iii) Quality of service and commodity cost characteristics: are determined by the levels of service reliability, availability, extent of voltage regulation, and rate stability or reliability. Uniform, reasonable rate increases are considered rate reliable; sudden large increases indicate loss of rate reliability. The rate of these changes is a major influence upon customer perception.

iv) Technology: a variety of logistic processes involves the distribution, supply evaluation, communication, controlling and evaluating customer loads, computer-based information systems and distribution substation automated operations, etc.

v) Public policies: include provincial, federal, and municipal policies which are directly related to logistics. Other factors could be the availability of land, availability or restrictions of right-of-ways for transmission and distribution lines which influence the development of parts of the system.

vi) The economy: includes levels of interest rates and inflation, general customer affordability of utility's services, and levels of unemployment.

vii) Resources: such as fixed and liquid assets, inventory, materials, equipment, fuel, specialized labour, etc. influence logistic decisions through their scarcity or abundance. These factors influence the cost of the supply compared to other available sources [89].

viii) Organizational interactions: logistics adds value through activities enabling the distribution of electricity through "Space" (network, physical location, and load concentrations) and "Time" (the availability of the service), when the supply is available for the new loads. This involves the connection and interaction with marketing, finance, and sources of electricity and other functional areas.

- Marketing is the approach to sell more electricity and services. It determines many operating characteristics of the system through its approach to markets, such as the influence of customers who have a perception to judge the quality of services and the value provided. The service may be of higher reliability at higher cost or marginal reduction in reliability at a marginally lower cost. Logistic limits the scope of marketing activities by cost and feasibility.
- Finance involves the need to manage utility's assets, to obtain sufficient funds to pay for the cost of the required plant and equipment for the system to function.
- Source is wholesale purchases or self-generation. It is the inbound of and the outbound of electrical energy as viewed from the utility operation. It involves the coordination and balancing of the deterministic equation of supply at any one point in time to meet the required load.

ix) Weather could vary from inclement, such as high winds, freezing rain, cold and then hot temperatures affecting equipment, plant, and also influencing the magnitude of the electrical load.

2.4.2 System Objectives

i) Pursuance of improved efficiency requires the minimization of total system costs. This is achieved by evaluating the costs of each functional area and organizational unit within the system [44, 103].

ii) Effectiveness in meeting the needs of the users who are the utility's customers.

The level of the quality of service to customers and efficiency of the system may appear to pose conflicting objectives [37]. Service is classically presumed to increase revenues in the long-term by satisfying customers which then results in increases of sales of electricity and services. Improved service in the form of increased availability of supply and higher reliability of supply may increase utility's direct costs [150]. Therefore, the full evaluation of this service depends on the customers' perception of the performance of the logistic system which is not easily measured in quantitative terms. All these must be related to costs because costs are tangible measures related to specific activities and are, potentially, within management control. The balancing of all these costs usually involves system trade-offs: accepting more than the minimum in any one area in order to minimize the cost for the whole system, i.e. sub-optimization versus global optimization [37]. The system analysis and the modelling for Linear Programming involves recognizing the effect that each element has upon the objective. This is to minimize the total cost, rather than accepting the sub-optimizing solutions of the decision-making process. This is illustrated in Section 3.6 of Chapter 3.

The two orientations of the utility's logistic system are Internal and External. The Internal orientation increases the efficiency and effectiveness within the utility itself. The External orientation links the utility further into the system which could be the evaluation of wholesale purchases of electricity and partial or total self-generation. It may also include demand management.

2.4.3 The Distribution Utility

The utility organization is a set of departments with individual tasks and functions. These include the responsibilities associated with generation or purchasing of electricity, marketing, distributing the energy, and collecting the revenue. Coherent operation requires that each department is responsible for its own area of expertise. Logistics is a process with many different functions and activities [41]. The logistic flow moves across departmental boundaries and every department participates in varying degrees in the general flow process of supplying the electricity and consequently fulfilling the needs of the customers. The objective of this lateral inter-departmental flow is mission orientation. The emphasis is on the end products of the utility, which is electricity and services, rather than a functional orientation in which each department is only concerned with its own area. This inter-functional flow makes management more difficult, since no specific centre of responsibility is automatically identified. The customer may deal with one department on the assumption that it has the responsibility and authority to manage the logistic process. The product flow of electricity and associated services moves across, rather than within, functional boundaries and the created dilemma is that only the total organization is large enough to contain the full potential scope of any single decision.

The logistic flow in External Orientation may begin with external sources such as suppliers of electrical energy, availability of fuel, materials, and equipment, etc., but it always finishes with customers. The flow process may utilize independent marketing channels, contractors, and suppliers which may lead to problems of inter-organizational coordination. Although the objectives of each may vary from one to another, the paradox is that all who are involved have a stake in the outcome -- namely, in order for each to survive, the total system must survive. This is illustrated in Figures 4.2 and 4.3 of Chapter 4.

Logistic requirements necessitate the linking of these organizations to the system in order to bring electricity and services optimally to the ultimate user. Logistic management coordinates among participants to achieve efficient system performance. The role of management is to plan, execute, and control these operations as an integral unit by establishing procedures, coordinating activities, securing resources, such as energy, fuel, manpower and materials, and planning facilities such as network and plant in order to minimize costs and provide acceptable service to customers.

According to Barnard [13], cooperation within an organization depends on three factors:

- Physical
- Environmental
- Social

The formal organization structure is supplemented by an informal organization which contributes to the vitality of the organization as a whole, stressing the importance of "upward" communication. McGregor [111] views human behaviour as either pessimistically or optimistically motivated based. His conclusion was that the desirable objective could be achieved by:

- recognizing the needs of the individual
- recognizing the needs of the organization
- creating conditions to reconcile those two needs.

Drucker [45] points out that there are positive and negative motivating factors. In loose-tight management, there is much freedom and high motivation but rules must be respected.

Over time, the norms and social expectations within a managerial group (or customers) can lead to a set of common assumptions. The group may adopt a common frame within which all "facts" are interpreted. This process makes certain kinds of communication easier, but may lead to "intellectual blind spots". Having a common frame of reference, the group tends to identify and solve problems repetitively. There are few questions or doubts because all agree on what "facts" mean and the "facts" provide the only course or the best course of action. Therefore, management needs to consider problems from different points of view or different frames. Multiple frames ensure less biased views of the "facts" associated with a problem and, therefore, result in better decisions. The development of different frames of reference may lead to conflict which will not be about "facts", but rather about "interpretation of facts". The conflict can be resolved by identifying the frame of reference used in understanding the facts. Frame of reference is an important concept for people accustomed to dealing with facts. It is important to note the sensitivity to interpretational differences among people and how the frame of reference can be influenced.

2.4.4 Logistic Applications

The logistic system is not an abstraction, but an operating entity which has the following characteristics:

- It is a physical network of facilities with the linkages among them.
- It is a sequence of coordinated functional activities that take place as electrical power and energy and associated services flow to the end user.
- It is a management decision system in which decisions in each area affect the decisions made in other areas. This is illustrated in Section 4.8.5 of Chapter 4.

Customer usage is also a logistic function because the customer's consumption is the trigger of the system. It initiates an order-filling activity of "supply" following "demand" and the customers' usage habits provide data for forecasting future requirements and possible constraints. Generation scheduling is a logistic function and wholesale purchasing is related to production as a procurement process.

Information system follows the same pattern; customer requirements provide the means to coordinate the system. Existing conditions of the system, such as levels of reliability, availability, and redundancy are compared to a standard. This comparison determines the modifications required and provide the basis for change [41]. Signals are released within the system to begin compensating activities when changes occur. From the customers' viewpoint, these could be a sudden increase in load, future load growth, higher customer expectations, and rate stability, etc. From the utility's viewpoint, these could be utility's objectives and availability of electricity with different time constraints, etc. Logistic cost evaluation can be made to customers for each component associated with the energy flow. This may be the cost of transformation and distribution of electricity, repairs to plant and equipment, environmental impacts, and the influence of management. Utility's costs are incurred at each part of the process and they accumulate in the final price of the supply, even though these costs are unseen by the ultimate consumer.

The impact of logistic services to provide electricity and services for customers when and where needed has an impact on both the costs involved and upon decisions made elsewhere in society. Surplus or redundant power to meet changes in loads increases the total cost of operation and the impact of this service is not a direct measure. The lack of convenience, the need to wait for electrical connections to be available, and the lack of choices may be intangible costs to customers [101]. Service availability that society takes for granted involves complexities and costs for the utility. The expected short or no lead time for the required services add costs to the logistic operation. A low quality service system is "efficient" in that it incurs low direct logistic costs. However, it transfers the impacts of the intangible costs to society as a whole. A long lead time for available service for new industrial loads delays employment and there is a loss of sales and utility revenue. The case studies in Section 4.7.8 further illustrate such concepts. However, there may be substantial initial capital savings for the utility by not building or upgrading plant and equipment, but this view can be changed by incremental and marginal cost evaluations. For a public municipal utility, what society has learned to expect has become a major determinant of logical costs.

Therefore, the highlights of a logistics system can be viewed in the following way:

- The emphasis of logistics is not the performance of a single element in the system but the balance of several elements together to achieve a central objective. This is normally expressed in terms of cost minimization and attainment of an acceptable level of quality of service. These concepts are expanded in Section 3 3.2 of Chapter 3.
- Logistics focuses on the 'flow' of electricity and associated services from the source to the utility to the customer. It involves both the individual organization and inter-organizational coupling, including major functional areas within the system. This is further dealt with in Section 4.1 of Chapter 4.
- The 'system' in logistics can be interpreted in a variety of ways. One way is to view it as a set of functions which is divided into primary and supporting activities illustrated previously in Figure 2.6:
    i) primary activities are the available sources of electricity and its distribution.
    ii) secondary activities involve decisions beyond routine operations to longer time spans and involve coordination with other areas

affecting the utility.

iii) all logistics activities are affected by environmental factors that influence the direction the system must take to grow and flourish if it is to survive as a viable business organization.

The task of logistic management involves the broad vision and the ability to perceive relationships in a variety of areas. It may require the balancing of the objectives of different organizations, differing standards of performance for general functional areas, and then weighting or attaching weights of influence upon the relative importance of essentially opposite goals. In this way cost minimization and attainment of acceptable service performance can be achieved in an atmosphere where these tasks, goals, and directions are not always certain.

This chapter illustrates the complexities of the components and composition and the processes involved with the planning and operation of an electrical distribution system. One has to consider what is important, what is significant, and what are the impacts upon the results by recognizing the limitations of available data from which relevant information can be extracted. Existing knowledge and the state of the art techniques are limitations which are imposed upon the desirability and appropriateness of modelling processes. These factors are addressed in the following chapters.

The problem formulation of an objective function has been developed in Chapter 3 which includes both tangible and intangible components of cost. The objective is to minimize total electrical distribution system cost by evaluating alternate sources of electricity for individual time periods. Included in this managerial decision are the intangible influences, such as customer perception.

Chapter 4 further extends the concepts developed in this chapter and those of Chapter 3. A time-trending process is used which includes the impact of accumulation of past and present events upon future events and solutions. Limitations and restrictions of numerical solutions, which are associated with intangible components, are alleviated by logical formulation and analysis methodology in which the numerical solution is replaced by word character string manipulation.

CHAPTER 3
DISTRIBUTION UTILITY'S TRADE-OFF DECISIONS IN OBTAINING SOURCES OF ELECTRICITY

3.1 INTRODUCTION

Globalization of industries and corporations have influenced political boundaries and historical precedents. Competition and customer choice have become driving forces which now influence changes to the electrical power industry.

3.1.1 Present System

The existing electrical system was planned and constructed on an integrated basis, having major components of generation, transmission, and distribution. The current pricing structure means that the system in North America operates as a whole, rather than as a series of transactions. In such an integrated structure, any additional costs from locating facilities in remote areas are absorbed elsewhere in the system.

3.1.2 Future Changes

The introduction of de-regulation and the breakup of generation will have an impact on the existing power pool and influence the development of bilateral power markets. Such competitive markets will influence the price and behaviour of sources of electricity. The development of generation and load centres is expected to occur where these competitive gains are the highest. However, transmission system interconnections among power pools may impose additional power flow constraints across some localized regions and may segment some local markets [99].

Transmission prices would reflect the cost of moving power between two locations; however, each transmission system has some areas where limitations restrict transfer capabilities. The thrust will be to use the system efficiently in the short-term while attempting to locate the generators in the most effective manner and developing fair prices for various loads in the long-term [143].

An efficient and fair price structure means that prices vary by location of load. Generators in remote areas, which amplify transmission constraints, will cost more than those located in regions which reduce congestion on the system or are near load centres. Similarly, load centres further away from generators or which are in a congested area are expected to pay higher prices. Applying such principles to an existing system not only promotes efficiency, but also creates instant "winners" and "losers" by virtue of their location. Therefore, the evaluation of the installation of local generation by an existing distribution utility with existing loads at a specific geographical location is a realistic alternative [145].

The continuous structural evolution of distribution utilities is no longer restricted to distribution but has been broadened, in these present rapidly changing times of technological advancement, to include financial restrictions and social values [9]. There is more attention and concern directed towards the customer, who purchases the commodity (electricity and services) and forms a perception which is based upon the perceived value obtained for the payments made and costs incurred.

Since the wholesale electricity costs for a distribution utility range from 85% to 90% of all costs, the pursuit of appropriate cost reductions is not only an obligation to its customers and shareholders, but also makes good business sense. The objective is to produce a quality commodity at a reasonable price by minimizing various costs. Therefore, there is a necessity to investigate the economic feasibility and reliability of Non-Utility Generation (NUG) as an alternative source of electrical power and energy [140].

Consumers have become more sophisticated and more informed, reviewing and questioning the available options and costs. Technical development and utilization are not entirely within the properties of physical objects, but rather depend upon perception in the minds of utility's customers and planners. The Customer Perception (CP) is a function of his or her expectations. These are important and influential aspects in the human decision-making process involving value and judgement [135]. Ultimately, perceptions influence how much electrical energy is used by the customer, which energy source is obtained and at what acceptable price [84].

This chapter describes the results of a major study, performed as part of this research work in which a general framework and meaningful solution methodologies were developed, to assist distribution utility management in assessing the feasibility and merits of building Non-Utility Generation (NUG). The complex nature of the problem requires careful formulation and advanced solution methodology to address intangible issues, such as customer perception and quality of service.

The modelling process involves the formation of a cost-objective function, which is the sum of both direct and indirect costs, as functions of many continuous and integer decision variables. The cost function is minimized subject to a set of constraints. The solution uses a Mixed Integer Programming (MIP) algorithm to determine the optimal decision-making scenarios.

3.2 AN ILLUSTRATIVE SCENARIO

A simple illustrative scenario is presented here to demonstrate how intangible issues (for example, customer perception) would influence the distribution utility cost-revenue balance. It is a "chain reaction" process that may have significant impact on the utility business' survival. The model considered here involves only a sub-set of the key issues but is sufficient to demonstrate the concepts. A full formulation and solution methodology are presented in subsequent sections.

As depicted in Figure 3.1, the following cycle of events is naturally present in the distribution utility business environment:

i) In a market-driven environment, the customer choice of purchasing energy from a particular utility depends on his/her perception of the service quality provided by that utility at specified retail rates.

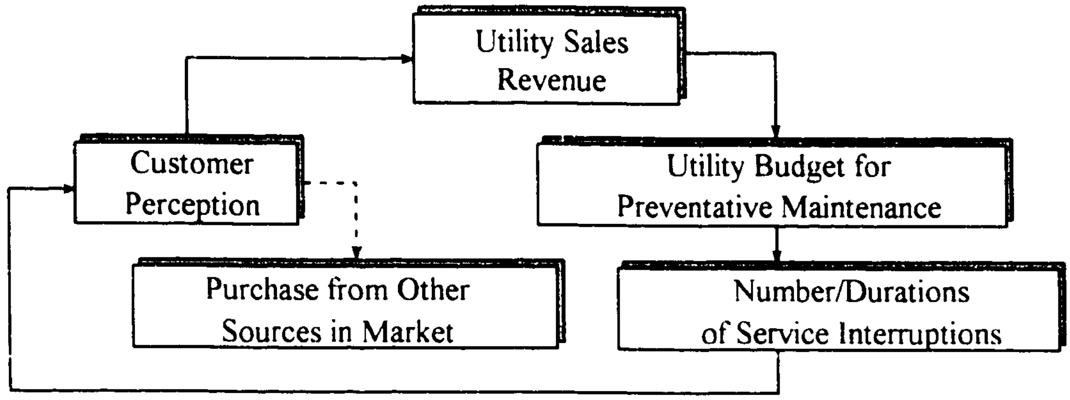


Figure 3.1: Effect of Customer Perception on Utility Business

ii) The utility revenue depends on the number of customers, which affects the amount of electricity purchased.

iii) The utility's available budget to carry out preventative maintenance depends on the total utility revenue.

iv) The number and duration of service interruptions depends on the extent of preventative maintenance carried out by the utility.

v) Customer perception is influenced by the number and duration of service interruptions.

vi) Go to i) (repeat cycle).

A model for the above scenario can be developed from pertinent customer surveys and historical utility records. Table 3.1 shows typical distribution utility data gathered over a six-year period. This data was used in a decision analysis software package [51] which evaluates various relevant cost components as shown in Figure 3.2. These results demonstrate that, for the particular utility data considered, if a utility reduces its maintenance costs, the initial reduction in utility costs is at a greater rate than increases in customer costs. However, such short-term savings eventually result in long-term increases in utility costs due to deteriorating plant and customer perceptions.

Table 3.1: Utility Costs and Customer Concerns

Year	Amount of Preventative Maintenance $K	No. of SI *	Number of Recorded Customer Complaints	System Peak Load MW
1991	$ 1,172.3	116	172	86.23
1992	$ 1,207.1	142	205	81.68
1993	$ 1,247.3	109	191	88.24
1994	$ 1,142.5	150	181	91.92
1995	$ 1,272.1	148	160	99.13
1996	$ 1,467.1	152	168	91.17

* SI = Service Interruptions

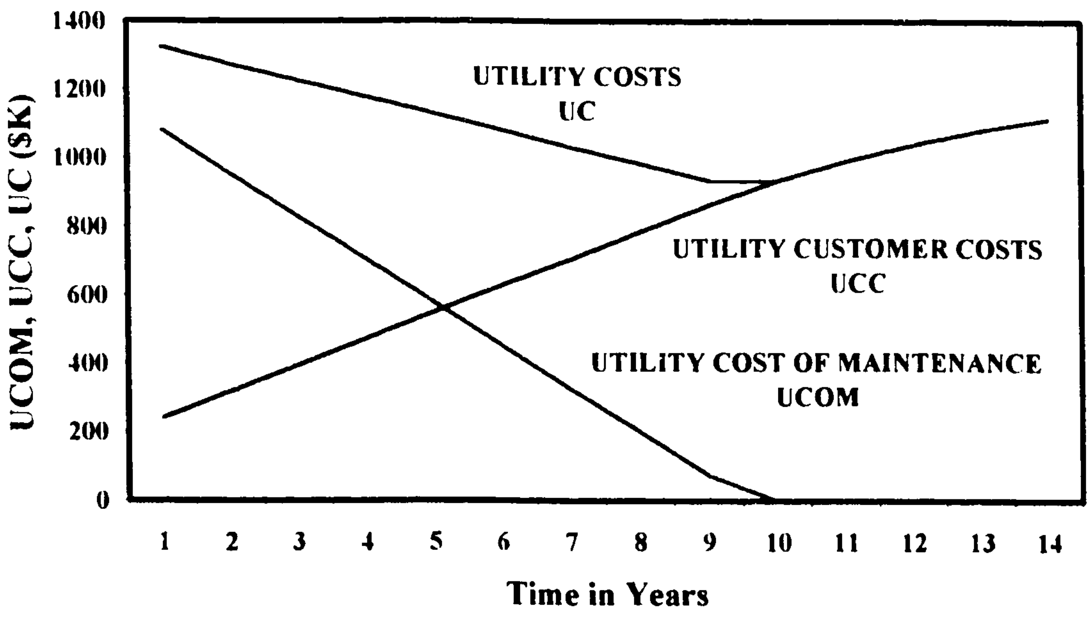


Figure 3.2: Effects of Reduction in Utility Maintenance on Total Costs

3.3 DISTRIBUTION UTILITY'S DILEMMA

A distribution utility has many financial pressures and its functions are closely and publicly examined. This involves the utility's revenue collecting abilities, extent of popularity and credibility, its policies, operational procedures, cross subsidization of rates, as well as services and political and regulatory influences.

3.3.1 Economic Evaluation and Trade-Offs

Currently, monopolistic entities, such as large public utilities, are becoming unpopular and are required to be more accountable with the public's money. Customers are often unhappy if there are no service improvements while electricity rates increase. Utilities are seeking ways to reduce their costs and improve efficiency as the customer, being wiser, is requiring more for less. The economies of scale no longer apply in all cases; namely, bigger plants with higher outputs no longer mean that electricity is cheaper (in view of the large amount of capital required to be raised that may come from the international marketplace). The repayment is not only influenced by interest rates, but also by fluctuations of foreign currencies. In addition, general environmental concerns make it difficult and costly to obtain transmission corridors. Therefore, other options are being actively pursued by the electrical industry to produce a quality product, at a reasonable price, by minimizing various costs. This involves new innovations and the pursuit of alternatives, especially with improvements in technology [36].

In all cases the energy balance equation applies;

$$\sum_{n_i} \text{Generation } (G_i) = \sum_{n_j} \text{Load } (L_j) + \sum_{n_k} \text{Loss } (T_k).$$

Since transmission losses are a function of load and distance, an attractive solution is to bring the source of generation closer to the load, whenever technically feasible and economically justifiable.

3.3.2 Approach and Requirements

The challenge facing a distribution utility is to establish retail rates to obtain sufficient revenue and also maintain good services. The process outlined in this chapter takes into account the financial impact of the cost of electricity and services upon the customers, community, and society. Such analysis involves the recognition of the interaction and interdependency among technical, social, and financial components which are modelled as variables and parameters. High retail rates will require customers to pay more and provide the utility with more revenue in the short-term, but will result in low customer perception and may stifle the growth and full development of high usage energy customers. Low retail rates may help customers financially in the short-term, but such a financial burden upon the utility may reduce the quality of service to customers by affecting the level of continuity of supply. This involves the reliability of the source and the availability of supply which is the capacity of the system to supply existing demand increases and new loads. If the utility borrows funds, then both the interest and capital must eventually be repaid. If interest rates are high, then the utility's debt equity ratio may become too large resulting in major financial problems. Therefore, customers and utilities are interdependent and the "survival" and "prosperity" of both is determined by the "survival" and "prosperity" of each [119].

The requirement is to solve the utility's dilemma of whether to continue to purchase electricity or to build self generation (NUG). The solution to the problem involves logistic managerial decisions which incorporate technical, economic, and social concerns within the context of constraints and limitations [145]. The practical and economic solution to this dilemma involves risk capital for building generating facilities; the study considered in this chapter involves the following possibilities:

i) Continue to purchase wholesale.

ii) Build own generating facilities.

iii) Partly build and partly self-generate to meet all of the customer's load requirements over an extended period of time.

3.4 SOLUTION METHODOLOGY

Mixed Integer Programming (MIP) is used in order to find the optimal product mix of values of various decision variables which include both continuous (**x**) and integer (**y**) variables [104]. The objective function $f(\mathbf{z}, \mathbf{p})$ and constraints $\mathbf{c}(\mathbf{z}, \mathbf{p})$ are assumed to be linear combinations of the problem variables **x** and **y**, which are the amount of wholesale purchases, the number and size of NUG units built, etc. The problem is expressed as follows:

Minimize the total cost-objective function $f(\mathbf{z}, \mathbf{p})$ (3.1)

with respect to $\mathbf{z}$ such that:

$$\mathbf{c}(\mathbf{z}, \mathbf{p})(\leq, =, >) \; \mathbf{0} \tag{3.2}$$

where $\mathbf{z}$ is the column vector of all decision variables, $\mathbf{x}$ is a vector of continuous variables, $\mathbf{y}$ is a vector of integer variables, $\mathbf{p}$ is a column vector of constant parameters.

$$\text{and} \quad \mathbf{z} = \begin{bmatrix} \mathbf{x} \\ \mathbf{y} \end{bmatrix} \tag{3.3}$$

These decision variables are restricted to be positive and the constraints of (3.2) are linear functions of $\mathbf{z}$. The solution minimizes the total cost-objective function $f(\mathbf{z}, \mathbf{p})$ such that:

$$\mathbf{A}\,\mathbf{z} > \mathbf{b} \tag{3.4}$$

The input vector $\mathbf{b}$ contains various parameter values and its elements are subsets of the parameter vector $\mathbf{p}$. Matrix $\mathbf{A}$ contains the linear coefficients of the constraints. Figure 3.3 shows the main components of the MIP decision-making model. Appendix A contains the full problem formulation and the detailed structure of the variables $\mathbf{x}$ and $\mathbf{y}$, parameters $\mathbf{p}$, components of the cost function $f(\mathbf{z}, \mathbf{p})$ and the constraints $\mathbf{c}(\mathbf{z}, \mathbf{p})$.

3.5 RESULTS

In this section, sample results from a practical case study are presented. The decision-making problem is to determine, for a given planning period, whether it is beneficial to build local generation and how such a decision is influenced by various technical, financial, and social issues. The planning time periods range from 2 to 25 years (year 1 is considered to be the present). Some of the basic input data items and assumptions are:

- Customer load (maximum demand) = 102 MW with an annual increase of 1.6% and 70% load factor.

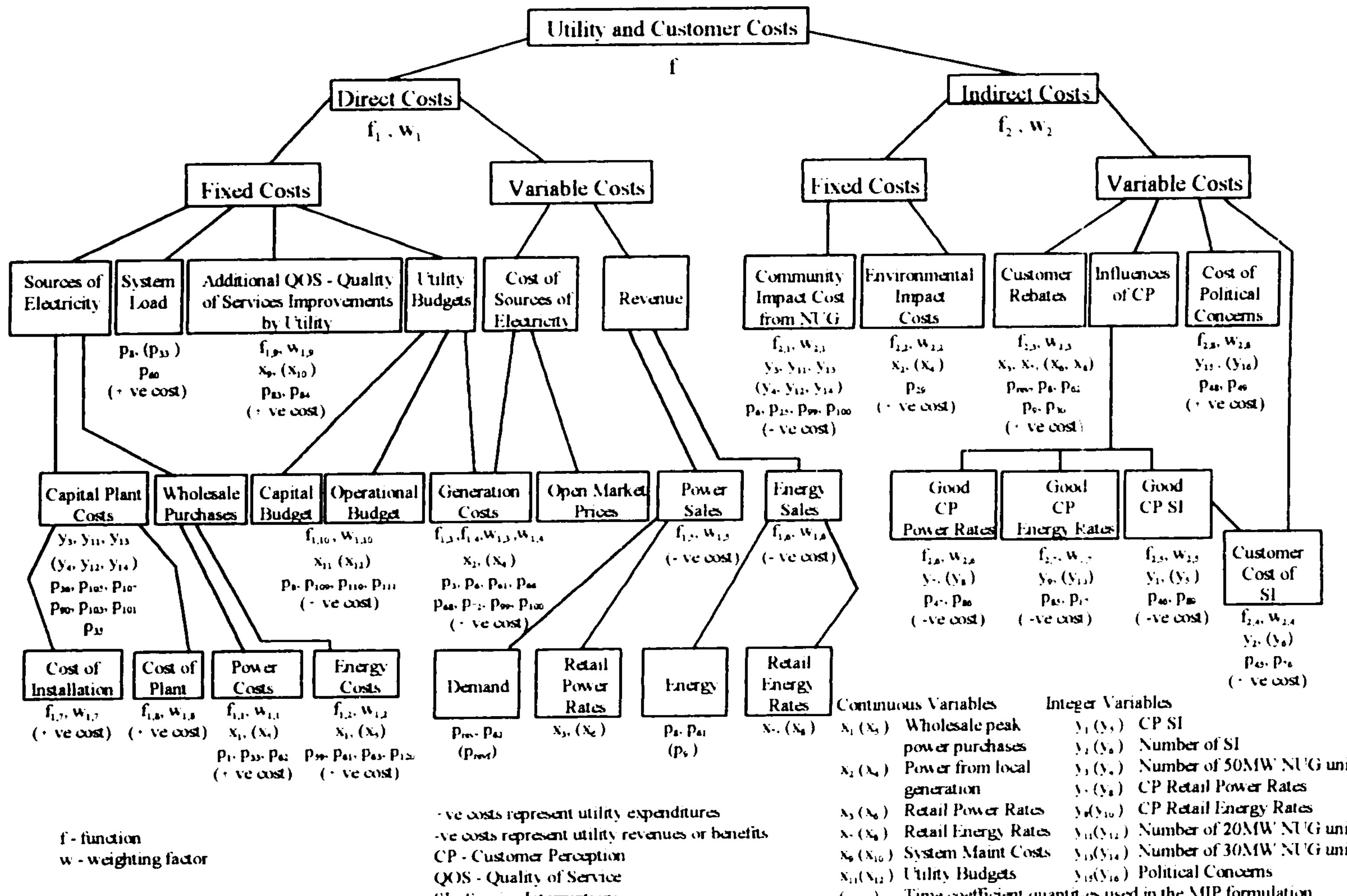


Figure 3.3: Structure of The MIP Decision-Making Model

- Average wholesale electrical prices:
  - $10.43/kW with an annual increases of 2%.
  - 4.36¢/kWh with an annual increases of 3%.
- Average capital cost for NUG = $1100/kW.
- Price of natural gas $3.60 per 1000 ft^3 (8,000 BTU) plus annual increase in cost of 2%
- Interest rate on capital = 5% per annum.
- The base results were:
  - Average retail energy rates = 8.8¢/kWh
  - Average retail demand rates = $4.20/kW

Figures 3.4 and 3.5 are economic comparisons between continuing total wholesale purchases and the introduction of NUG units for planning time periods of 13, 19, and 25 years (see Figure 3.7 for the number and rating of NUG units). Figure 3.4 shows the potential savings for the utility by using NUG units when the wholesale electricity prices increase. In Figure 3.5, the NUG alternative is economically justifiable if the annual fuel price increases are less than 4%.

3.6 CUSTOMER INFLUENCES

Customers form perceptions (CP) which are represented symbolically as:

$$CP = \frac{\text{Benefits Obtained (as perceived by customer)}}{\text{Incurred Costs (as perceived by customer)}} \tag{3.5}$$

i) The perceived benefits obtained may consist of:

- Fulfil a need. (e.g. change environment - heating or cooling)
- Solve a problem using electricity and appropriate appliances. (reflected as an electrical load)

CP levels can be measured and normalized on approximate scales (e.g. 1 to 50) from relevant consumer data such as surveys and questionnaires, number of complaints, etc. [60].

ii) The incurred costs consist of:

- Cost of using electricity = (rate structure × magnitude of load × duration of usage).
- Cost of service interruptions (SI), which is the denial of the commodity (electricity) to the customer when the customer has a need to use electricity. This cost is influenced by frequency, duration, and time of occurrences.

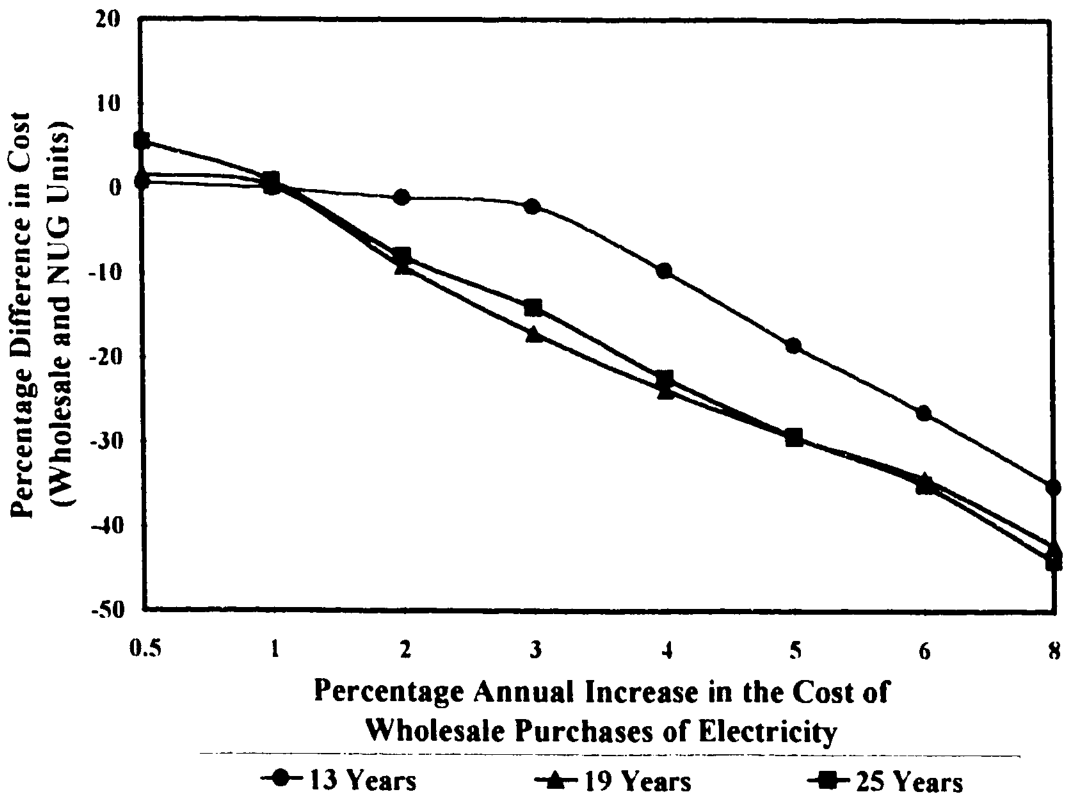


Figure 3.4: Cost Variations From the Cost of Total Wholesale Purchases

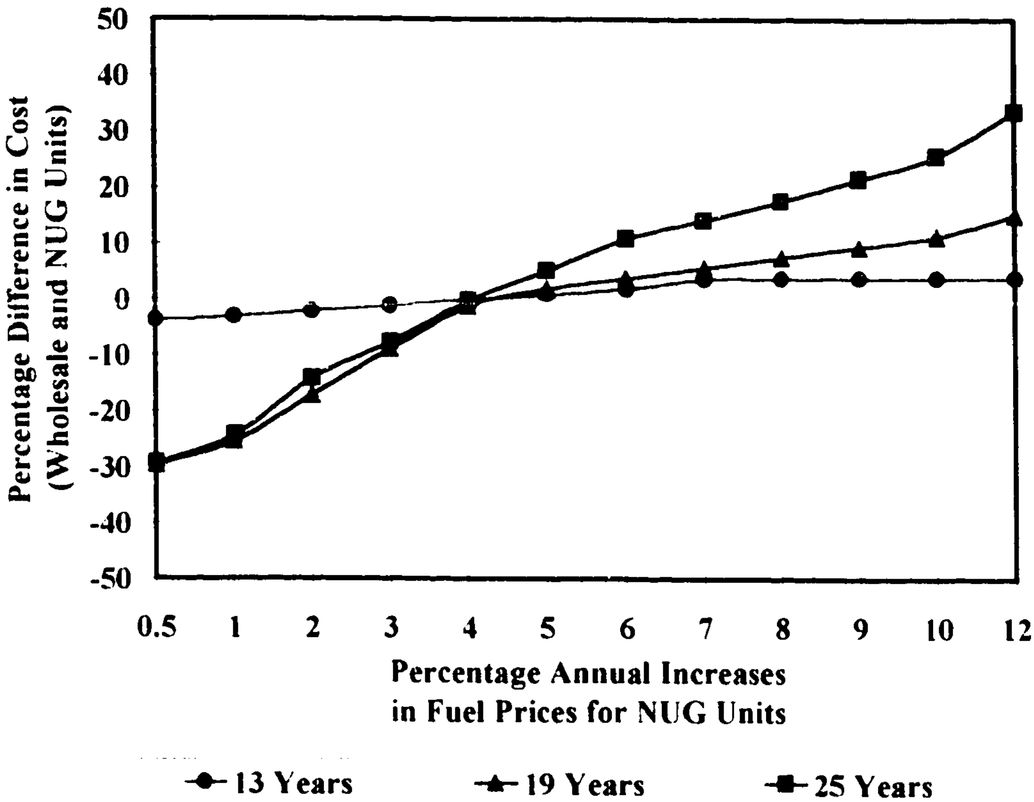


Figure 3.5: Cost Variations From the Cost of Total Wholesale Purchases

3.6.1 Quality of Service Improvements

In the present application, the following cost figures were obtained:

Average Service Interruption cost . . . . = $16.29

Average cost of using electricity if SI had not occurred . . = $ 0.69

Therefore, the average cost of service interruption (SI) to customers for these particular circumstances is 23.6 times the cost of actual usage of electricity. Another view is that the average value to the customer to fulfil a need is 23.6 times the cost of the commodity to fulfil that need [143]. The optimization study results have illustrated that by decreasing the average annual number of SI from 5 outages (each having an average duration of 1.63 hours) to 4 outages, the level of CP index increased from 29.0 to 39.0. Although the utility incurred additional direct costs for such improvements, the system cost decreased by approximately 13.5%.

3.6.2 Retail Rate Variation

Customer Perception (CP) regarding retail rates improves when retail rates are reduced and the customer has a lower electricity bill, but the utility has less revenue. However, less funds for the utility may mean that less Quality Of Service (QOS) is provided, and there is a reduction of CP with respect to the quality of such service.

Short-term savings for the utility, due to lower expenditure of funds for maintenance, is outweighed by the QOS deterioration effects which reduce the CP due to lower quality of service. Although the CP increases resulting from retail rate reduction, the total system cost increases.

Figure 3.6 shows that the total system cost increases because of variations of CP from the optimal solution. Curve ① illustrates that, in order to improve CP with respect to retail rates from an optimal value of 0 (a minimum total system cost), the total system cost must increase. Curve ② is the consequence of Curve ①; that is, by improving CP with respect to retail rates, the CP with respect to QOS decreases because of reduction in maintenance due to less revenue which results in more SI costs and the total system cost increases.

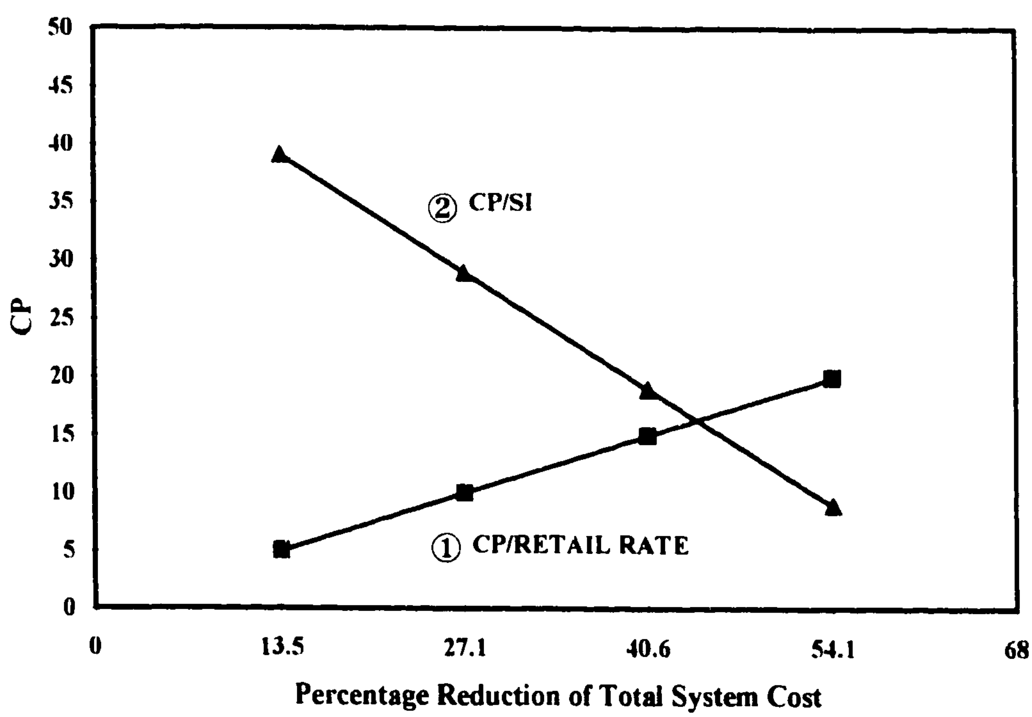


Figure 3.6: Effects of Retail Rate Variation Upon CP and Total Cost

The mission of most utilities is to provide a reliable supply of electricity at the lowest feasible cost while (giving consideration to) safety, health, and the environment. Therefore, the goal is to adopt cost-effective measures with a minimal negative impact upon revenue.

The NUG unit ratings selected were 20 MW, 30 MW and 50 MW. Figure 3.7 shows the increase in NUG units for a 19 year planning period if the annual wholesale price of electricity increases at a rate greater than 2%. Figure 3.8 illustrates the decrease in the number of NUG units with fuel prices increasing by more than 3% for the same 19 year period.

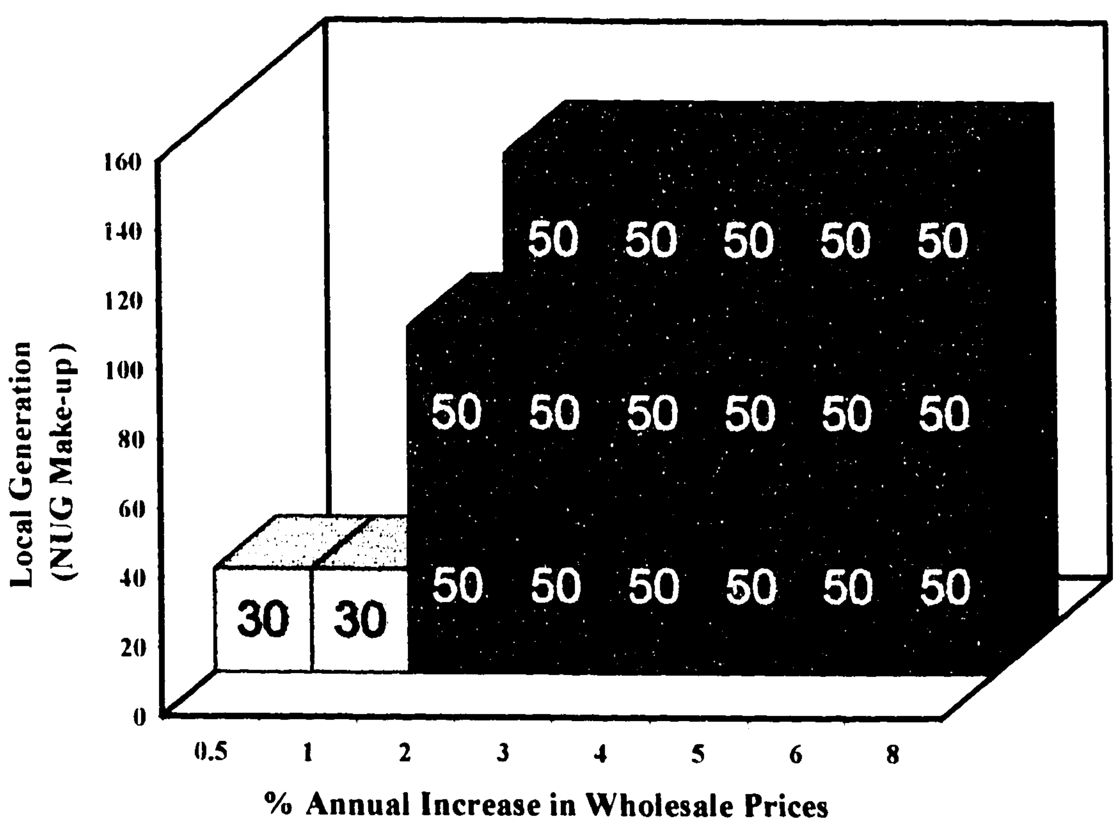


Figure 3.7: Increase in NUG Units with Increases in Wholesale Prices

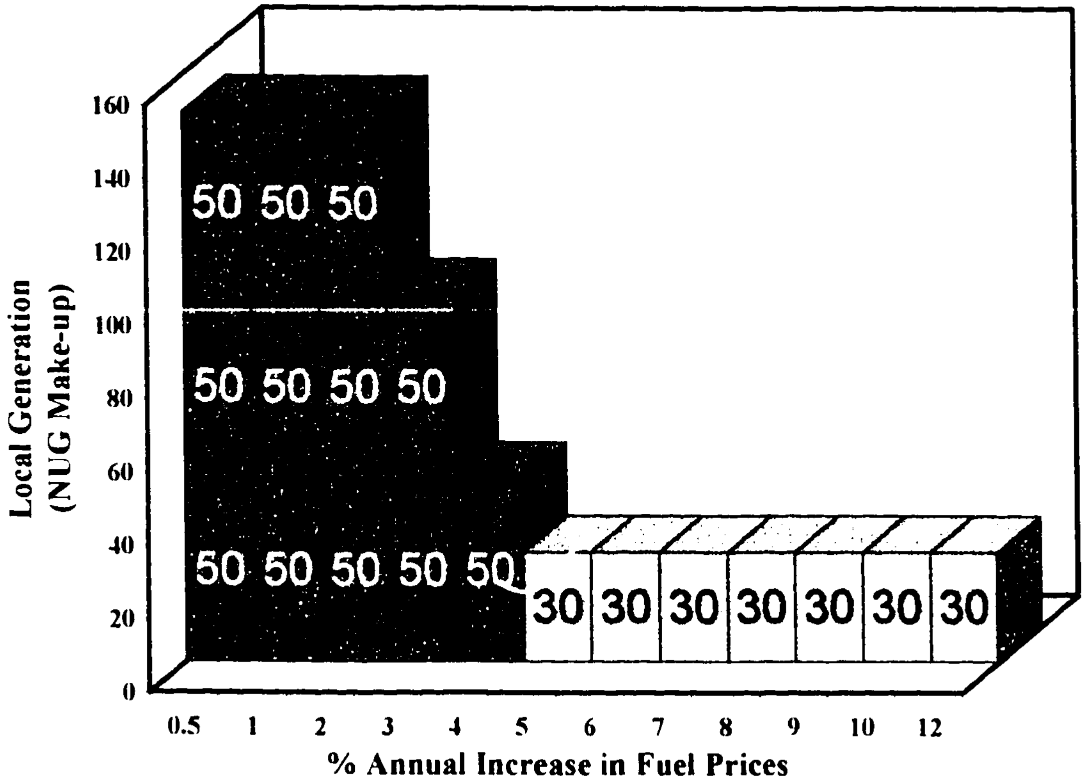


Figure 3.8: Decrease in NUG Units with Increases in Fuel Prices

3.7. DISCUSSION AND CONCLUSIONS

This chapter has addressed the delicate balance between the importance of electricity pricing, and the importance of the quality of delivery and customer perception. A distribution utility's major cost is for wholesale electricity. This cost, and the cost of its delivery to customers, is recovered from customers. The cost of both delivery and the quality of delivery ranges from 10% to 15% of utility total cost. Customers form perceptions regarding both the Quality of Service (QOS) and the magnitude of the retail rate structure. When QOS is high and there are few SI, the service continuity is taken for granted and the customers' main concern becomes the magnitude of the electricity bill. This cost has two controllable components: the utility establishes the magnitude of retail rates, while the customer establishes the magnitude of the electrical load and the time when that load occurs. The combination of rates and load constitutes the customer direct cost. This amount also represents the utility's revenue.

The customer total cost is the sum of the costs of SI and the cost of using electricity. The magnitude of this cost is a combination of the retail rate structure and the amount of usage. The SI costs are random and generally infrequent. The major component of customer cost is the electricity bill, which is cyclic and predictable, and influenced by customer choice of usage and the utility's rate structure. Quality of Service improvements can partly offset reduction in CP due to retail rate increases, if the QOS is low. Improvements in QOS result in increased customer perceived value. Therefore, higher retail rates at a higher level of QOS may then be more acceptable to customers if the perception is that a higher net value has been obtained.

The major cost to a distribution utility is the source of electricity. The sources considered in this chapter are wholesale purchases and local generation. High initial capital costs are required for NUG units. It was found, for the practical case analyzed, that a local NUG installation is not economical if the period of amortization is less than 13 years, even for a wide range of parameter variations. Using these base values, it was found that the greatest impact on building local generation occurs when there are high price increases in the wholesale cost of electricity. The cost of fuel and the annual fuel escalations are also important influences regarding the economic viability of NUG units but have a smaller impact than wholesale price increases.

From the base data used in the model, local generation becomes an economical alternative if:

i) Wholesale price increases are greater than 2% per year.

ii) Cost of fuel increases are not greater than 3% per year.

iii) Interest rates on capital are low (less than 3%) for short-term projects (amortized over 13 years) but have less of an effect than i) and ii) for longer-term projects such as 19 or 25 years. For a 19 year project, the solution regarding the number and size of NUG units is not affected by interest rate variation from 3% to 7%. Within these time periods, NUG units are an economically viable alternative to wholesale purchases of electricity.

An additional benefit that a NUG unit provides to the distribution utility is more control of quality and price. It is regarded as an additional local industry providing local employment. The construction of a NUG unit could be a joint financial venture between the local municipality, distribution utility, and some of the larger industrial customers. All would contribute to the required amount of capital and all could share in the benefits.

The relative importance of some variables, parameters, and constraints, compared to others, depends upon the emphasis placed by the utility. This in turn depends upon the utility's operating environment. For example, if the local utility is monopolistic and has a captive market, the customer may be viewed by the utility as a beneficiary of its actions and low levels of customer perception may have little impact upon utility operations generally. The customer has little choice, apart from some substitution and continues to purchase from the local utility. Low levels of customer perception may result in additional utility costs from public protest, negative customer vocality, unfavourable news coverage, and political intervention. Public hearings may be held which could result in changes in the utility's operations. Nevertheless, customers are still retained and serviced by the utility, unless they depart from the area served by the utility.

In the case of a de-regulated and competitive market, the customer can choose other electricity suppliers. The local utility then faces competition and challenges to retain its customers. Utility costs, associated with customer loss, become very important components in the utility's decision-making process. The level of customer perception then becomes a very important component in utility's operations. This is addressed in Chapter 4.

CHAPTER 4
MANAGING CUSTOMER AND DISTRIBUTION UTILITY COSTS

4.1 INTRODUCTION

This chapter presents choices which may be available to both customers and the utility to more effectively manage their respective costs. In order to obtain true total costs, it is important to understand the system process and to include both tangible and intangible costs such as customer satisfaction, customer perception, and public response to retail rate increases and service deterioration. Such items are important in the present era of market competitiveness, unbundling, and complex electricity pricing. This chapter incorporates the commodity cost, viewed as the price of electricity, to both the utility and customers in terms of dominant technical, financial, and social factors which include customer perception and quality of service.

Electricity is viewed as a commodity in a distribution process of supplying it to residential customers for direct payments. Magnitude and amount are synonymous with demand and energy respectively, and both concepts are used throughout this chapter. Retail rates are mechanisms to designate unit cost to customers, to obtain revenue, to pay expenses, and for the distribution utility to make a profit. Since utility costs vary with time, retail rate variations between small time intervals more accurately track incurred costs and more fairly pass on such variations to the users who contribute to them at the corresponding times [116, 117].

An electrical distribution system is formed from complex entities logically assembled into components that have both physical and functional characteristics. This is illustrated in Figure 4.1 and was briefly introduced in Sections 2.1.3 and 2.2.1 [148].

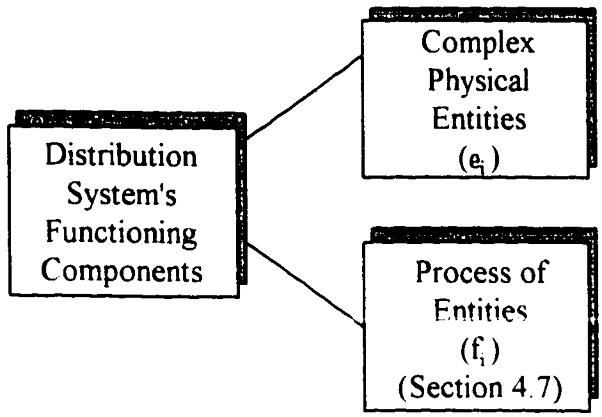


Figure 4.1: Distribution Utility's Components

The distribution system dynamics, which illustrate the distribution system process, involve both entities (e_i) and corresponding processing attributes (f_i) as shown in Figures 4.2 and 4.3 respectively. For example, the commodity (e_1) is supplied (f_1) via wholesale or NUG units as a source of electricity (e_2) which is flowing (f_2) through the electrical network (e_3). The electrical network (e_3) is the technical linkage (electricity transfer media) which delivers (f_3) the commodity. The appliances (e_4), controlled and manipulated via customers, use (f_4) the commodity in an energy conversion process to fulfil (f_5) customer needs (e_5). The benefits and costs involved form a level of customer satisfaction. Payments to the utility are customer costs (e_6). This function of paying (f_6) for the cost (e_6) of fulfilling customer needs is by means of financial institutions which deliver the payments (f_7) using a financial linkage (e_7). For example, this involves customer payments of money, cheques, and other symbolic representations of value (Section 4.7.4). These payments are received (f_8) by the utility as revenue (e_8). Some of the revenue is used in the procurement function (f_1) for the commodity (e_1) and associated services [148].

The utility's commodity $\{e_1, f_1\}$ and other services provided are transformed into levels of customer satisfaction $\{e_5, f_5\}$ which, over time, form customer perception. Customer perception, in turn, has a direct influence upon some of the components of the system process and over time, upon the whole system process. Customer payments $\{e_6, f_6\}$ are transformed into utility revenue $\{e_8, f_8\}$ which also has an influence on the system process. For example, amount of revenue and profit obtained by the utility will influence the amount of maintenance to be performed, which will influence customer perception, etc., introduced in Section 3.1.2.

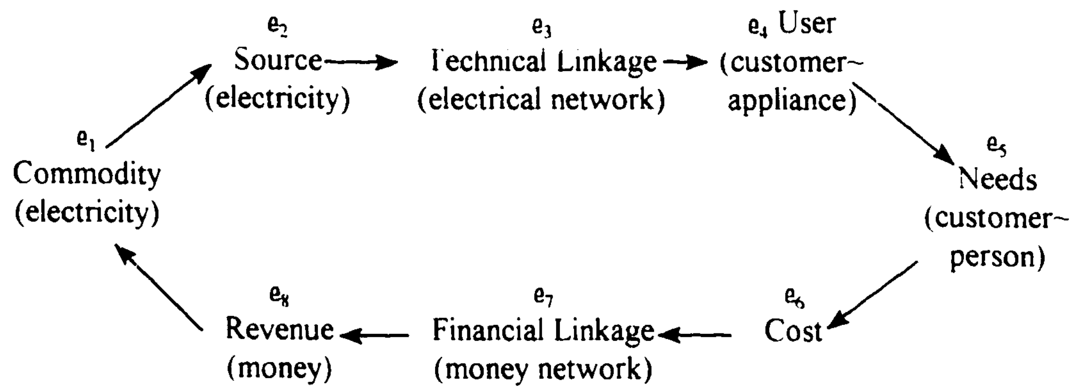


Figure 4.2: Entities of the Distribution System

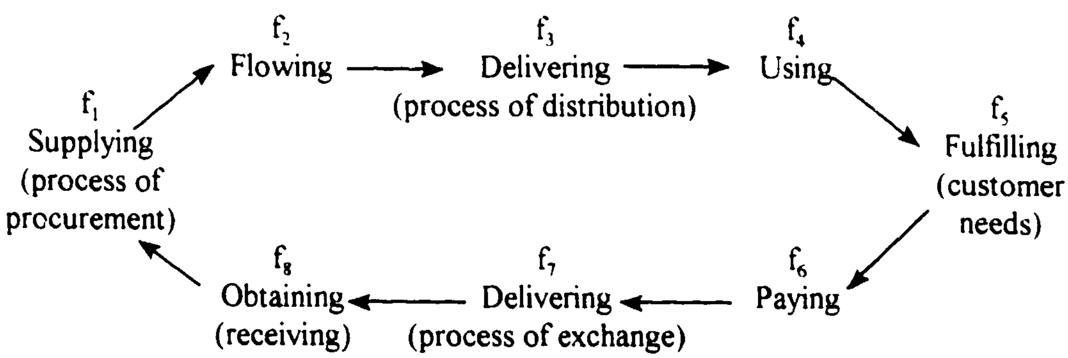


Figure 4.3: Component Functions of the Distribution System

The distribution system is sustainable, if each of the sequence components of the processed entities $\{e_i, f_i\}$ is also sustainable. That is, the processed entities must be active periodically (recurrently) for a minimum period of time. The extent of robustness of the system determines this period of time. The distribution system process is, therefore, a time-phase process which is recursive and involves the following logical hierarchical interdependencies:

i) The system must exist in order for it to function.

ii) The system must function in order for it to process entities.

iii) The system must process entities in order to achieve its intended goal (to fulfil customer needs) which itself is one of the processed entities.

As will be demonstrated in Section 4.8.5, this line of analysis involves logical equations of the form:

$$e_i = \mathcal{L}(e_j, e_k, \ldots) \tag{4.1}$$

where $\mathcal{L}$ is a logical function which determines the correct logical sequential assembly of the physical entities to form a resultant entity. Section 4.8.3 explains the formation of logical functions in more detail.

The distribution utility management process is customer driven whose needs are socially driven. Technology and finances are the means of fulfilling many such customer needs such as attaining customer comfort by changing the local environment, solving problems, locomotion, etc. These needs are partially or totally fulfilled using electricity. The system process commences to fulfil customer needs when they arise, as shown in Figure 4.4.

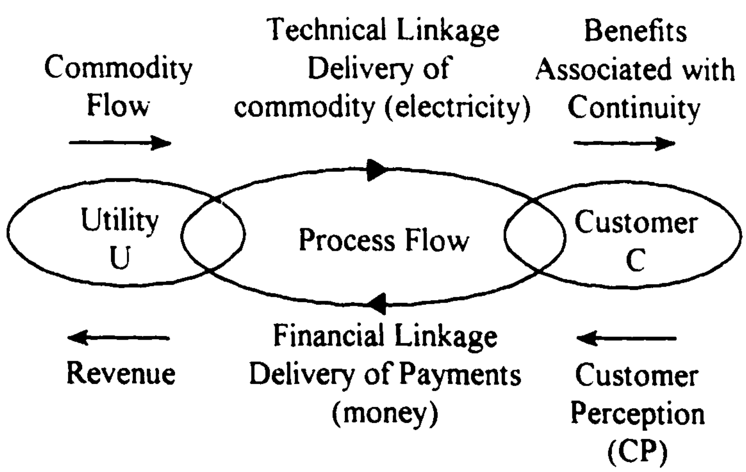


Figure 4.4: Process Flow Between Utility and Customer

The ongoing evolution of the electrical industry has resulted in cost-effective technological advancements. The distribution utility's mandate of operation has been broadened to include social values in addition to technological and financial concerns [2, 32]. There is more attention directed towards the customer, who purchases the commodity (electricity and services), and forms a perception which is based upon the perceived value obtained for the payments made and costs incurred [148].

4.2 ELECTRICAL RATE STRUCTURE

The main types of rate structures:

i) Fixed rate structures are predetermined and fixed units of cost of electricity extended over a longer period of time, such as 12 months. Such a structure averages the projected utility costs to customers over that time period to obtain sufficient revenue. Customers have choices and controls over their own costs through the rating of appliances and duration of their usage. Such costs are independent of the time of usage and are directly proportional to the magnitude and duration of usage. Such long-term fixed rates may result in excess or insufficient utility revenue for the duration of time they are fixed.

ii) Time variable rates include time-of-use (TOU) pricing. These rates are cyclic within a 24 hour period -- higher rates during defined on-peak hours, and lower rates at other times. The objective is to pass on to customers real time anticipated utility time variable costs. Real-Time-Pricings (RTP) are rate changes influenced by external market forces. They have relatively short time intervals between changes. Therefore, these and other incremental utility cost variations result in variations in retail rates to customers. Time variable rate structures more fairly allocate marginal cost variations to customers at the times when they contribute to such costs. They also provide customers with more choices and controls. In addition to available choices and controls outlined in i), customers may purchase the same amount of commodity at different prices at different times. The utility's cost may decrease and revenue may increase by providing customers with such rate mechanisms and enabling them to share some of the benefits. Utility costs are not only for the magnitude and amount of the commodity, but also for the extent of its continuous delivery which is viewed as the quality of service [2, 32].

4.2.1 Fixed Rate Structure

Customers' costs depend upon:

i) magnitude of load $\ell(t)$

ii) duration of usage d

iii) fixed rate structure r(T) over long time period (T) is a constant in the short-term (t).

Customers balance the time variable need against the cost of the commodity using a constant rate structure:

$$\text{Cost of Fulfilling Need} = \begin{pmatrix}\text{magnitude}\\ \text{of load}\end{pmatrix} \times \text{duration} \times \text{rate structure}$$

$$\begin{aligned} CFN(t) &= \ell(t) \times d \times r(T) \qquad (4.2)\\ &= \ell(t) \times d \times \text{constant} \qquad \text{since } T >> t\\ &= \text{commodity cost for the duration (d) of usage} \end{aligned}$$

Hence, depending upon the importance of the need, the available retail rate structure at that time will influence the magnitude of load and duration of usage. Customers can control usage or substitute energy types.

4.2.2 Time Variable Rate Structure

Customers' costs depend upon:

i) magnitude of load $\ell(t)$

ii) duration of usage d

iii) when the energy is used (TOU) rates r(t)

Then equation (4.2) becomes (4.3):

$$CFN(t) = \ell(t) \times d \times r(t) \qquad (4.3)$$

If the customer need is independent of time when it is to be fulfilled, then so is the electrical load. The customer is then not adversely affected and, for the same duration, an off-peak rate structure could be chosen to reduce the total cost of usage for the same amount of energy. The need is fulfilled at a lower cost and customer perception increases. This is due to time displacement of loads as a result of customer self-imposed partial or total (si) at that time, when the cost of the commodity is higher.

If the customer is not prepared to time displace loads or to use appliances at a later time, then the customer pays the higher premium willing-to-pay wtp(t) at such a time of usage. The self-imposed quality of service is not affected, since the customer maintains the continuity of usage, even though there had been a cost increase for the commodity.

4.3 ELECTRICAL LOADS

The commodity has two components: D-demand (kW) and E-energy (kWh). The magnitude of load changes with time. The commodity, "electricity", is used by various electrical appliances in a process of fulfilling customer needs. Time variable electrical loads reflect the variation of customers' needs. For a chosen number and rating (capacity) of appliances, the duration of electrical usage is controlled by customers to fulfil their needs [7].

Needs also change with time due to changes in environmental conditions (e.g. heating in winter, cooling in summer, cooking meals), and so does the amount of electricity and duration of usage. There is a daily cyclic consumption pattern of load variation due to time-dependent variation of customers' needs during the hours of a day and seasons of the year. For simplicity, the seasonal variation is modelled as two distinct states -- Summer and Winter, illustrated in Figures 4.5 and 4.6. Customers choose when and how much electricity to use, irrespective of the rate structure. It is the utility's responsibility to fulfil the requirement of continuity of supply.

The customer can evaluate what to use, when to use it, and for how long, to maximize comfort and minimize costs. The utility's costs vary with time. Such costs should be reflected as incremental cost variations to those customers who use the commodity at those times. This is a fairer method than averaging out the total costs over all the customers. Monetary incentives, in the form of special time-dependent rates influence customer usage. Consequently, the time and magnitude of the load changes, thereby changing the magnitude of the utility's load factor. The value of peak load may decrease if customers are provided with monetary incentives to use more during periods when the system load is smaller. This is done by offering special reduced time-of-use electricity rates during off-peak periods. The effectiveness of such monetary incentives depends upon the price/demand elasticity of customer usage characteristics. The network's operating efficiency may be improved and there may be some postponement of capital projects. Capital expenditures are not cost-effective if funds are spent only to increase plant capacity for short duration peak load periods. Improving the load factor is an efficient method to more effectively utilize the existing plant, releasing 'stranded capacity', and postponing the upgrading of plant and equipment. Uniform loading increases the efficiency of distribution by reducing network losses, and also improves network reliability.

The total or partial fulfilment of customers' needs can also be viewed as an output "O", affected by the operational factor "F", using average electrical power of kw, for a time duration "t" [2], expressed in Equation 4.4:

$$\begin{aligned} O &= F(kw, t) \\ &= F(kwh) \end{aligned} \qquad (4.4)$$

Customers pay directly for the commodity and its continuance of supply, and also pay indirectly when service is interrupted, expressed in Equation 4.5.

$$\begin{array}{c} \text{Customer} \\ \text{Total Costs} \end{array} = \underbrace{\text{Commodity} + \begin{array}{c} \text{Quality} \\ \text{of Service} \\ \text{Provided} \end{array}}_{\text{(Retail Rates)}} + \underbrace{\begin{array}{c} \text{Quality} \\ \text{of Service} \\ \text{Not Received} \end{array}}_{\begin{array}{c}\text{(Service} \\ \text{Interruption (SI))}\end{array}} \qquad (4.5)$$

Fulfilment of Customer Needs

= Amount of Energy Used Effectively

= Amount of Energy Acquired - Waste (4.6)

By reducing waste, which includes both appliance inefficiencies and inappropriateness of usage, greater fulfilment of customers' needs at a lower cost can be achieved. Customers' needs vary over a cyclic 24 hour period and so does the amount of energy used. (Reference Figures 4.5 and 4.6).

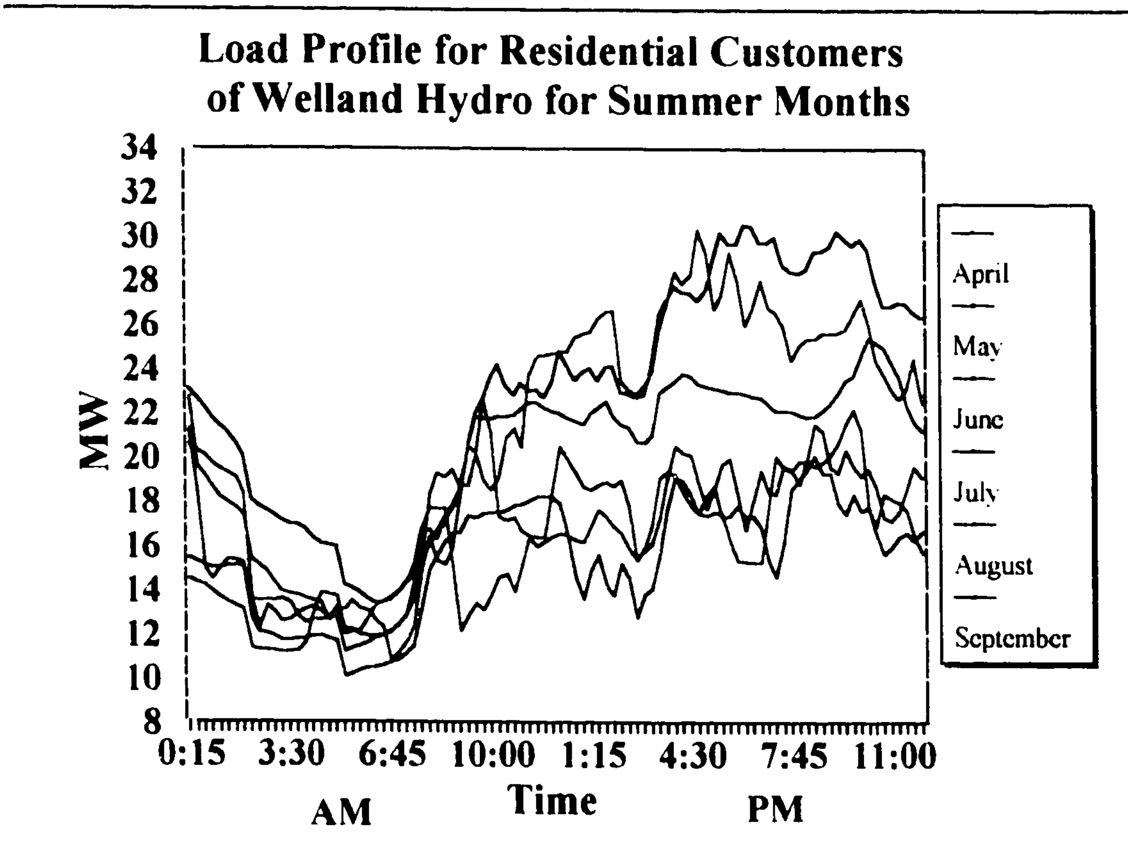


Figure 4.5: Individual Summer Monthly Loads

If customers' needs can be postponed or advanced in time without increasing costs, then they are dependent upon the magnitude of supply of electricity and are independent of time of usage. Such needs are fulfilled electrically by the total magnitude of energy used and duration of usage, irrespective of when that occurs (for example, washing or drying clothes may occur during the day or night without a great deal of inconvenience). In such cases, a service interruption, by network failure or customer time displacement of usage to a later time, would not affect customer indirect cost. However, critically important loads, such as

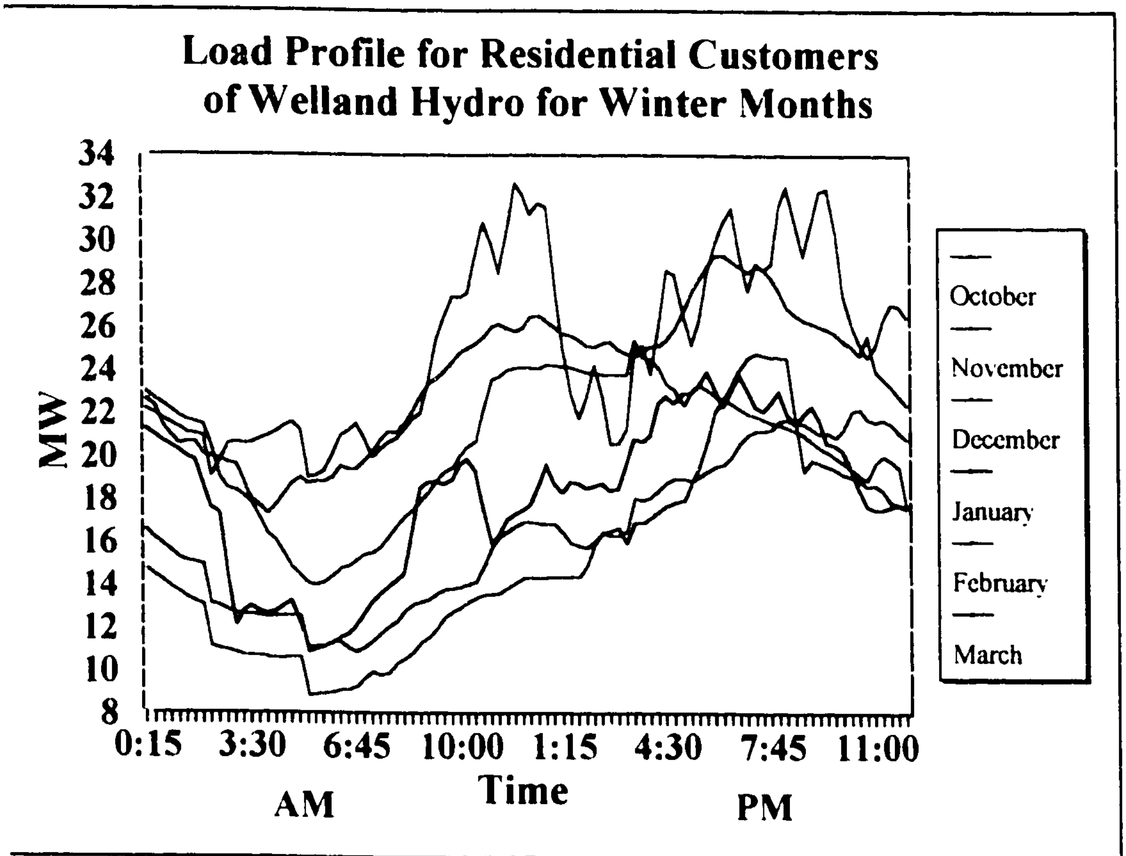


Figure 4.6: Individual Winter Monthly Loads

life-support systems and important schedules, could mean high incurred costs from service interruptions. This is due to the relatively high dependency upon the continuance of service by customers for such loads at all times. Customers are then willing-to-pay WTP(T) extra in the form of annual rate increases to reduce and to minimize the SI costs from network failures. The commodity cost for the utility is both for demand and energy. Higher peak costs, reflected as higher customers' needs, also results in higher utility costs. Such time variable costs can be directly passed on to the customers in terms of higher time variable rates coinciding with higher utility costs. The electrical costs depend upon the extent of fulfilling customers' needs at a time when a specific rate structure is available.

4.3.1 Electrical Load Characteristics

Once the magnitude of the commodity is available and delivered, it can be used by customers in various shapes, magnitudes, and durations [147]. The commodity comes in small or large magnitudes, D_i for the corresponding time intervals t_i. The product $D_i\, t_i$ is the amount of the commodity, E_i (electrical energy) used in the time interval t_i, illustrated in Figure 4.7. In general:

$\sum_{i=0}^{k} D_i\, t_i \simeq E_k$ (defining and summing the product of $D_i\, t_i$ over the time period t_k as E_k which is the amount of the commodity)

Then $$\int_0^{t_k} D(t)\, dt = E_k \qquad (4.7)$$

Peak value of maximum demand:

$D_m = \max_{i=1}^{k} (D_i)$ (defining the largest magnitude of D_i as D_m within the specified time interval t_k).

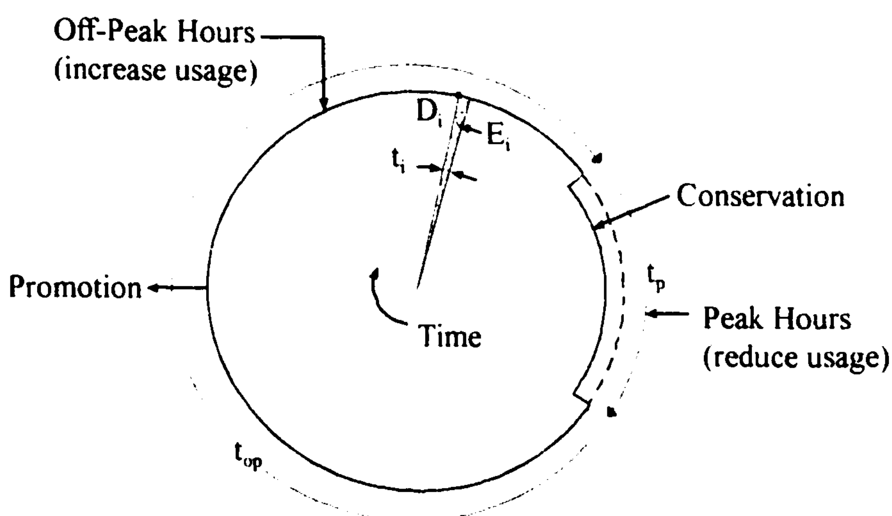


Figure 4.7: Reduction of Peak Demand and Energy

Therefore, for each magnitude of commodity D_i, maximize the amount of usage of commodity only during the off-peak hours of t_{op}. A portion of the circle of Figure 4.7 should be further 'compressed' during the peak hours of t_p to reduce cost if the utility has peak energy charges in addition to peak demand charges.

4.4 CUSTOMERS' NEEDS

Customers have direct needs which involve a process of changing the environment and solving problems using electricity and appropriate appliances. They also have indirect need to sustain this energy conversion process and to obtain satisfaction for payments made. The direct fulfilment of customer need is classified as time independent need and time dependent need [135, 136].

4.4.1 Time Independent Need

The fulfilment of such needs does not depend upon a specific time, but rather on a large range of time.

4.4.1.1 Fixed Rate Structure: The relationship between customers' needs and energy used:

- Fulfilment of customers' needs are electrical loads.
- Customers' needs have characteristics of:
  - Magnitude of wanting, which may or may not change over time
  - Duration
  - Time (of usage when the energy is required).

The desire to fulfil the need F_u (t) tends to increase the usage; the opposing force F_{pi} (t) for its fulfilment is the cost. This is shown as Figure 4.8. Curve XYZ is the energy usage over time t_k. $F_{ni}(t)$ is the force or desire to fulfil customers' needs and reflects the amount of usage. F_{pi} (T) is the opposing force due to the cost of energy usage. The reshaping of the distorted area (a) by reducing and minimizing the perimeter of (a) for the same area, forms area (b). This circle has a reduced and a constant radius of magnitude D_{av} less than the maximum value of D_m of area (a). The ideal result is to minimize the magnitude of the commodity and not change the amount for non TOU or constant rates. The result is a unity system load factor which, in practice, maximizes energy sales and minimizes demand charges.

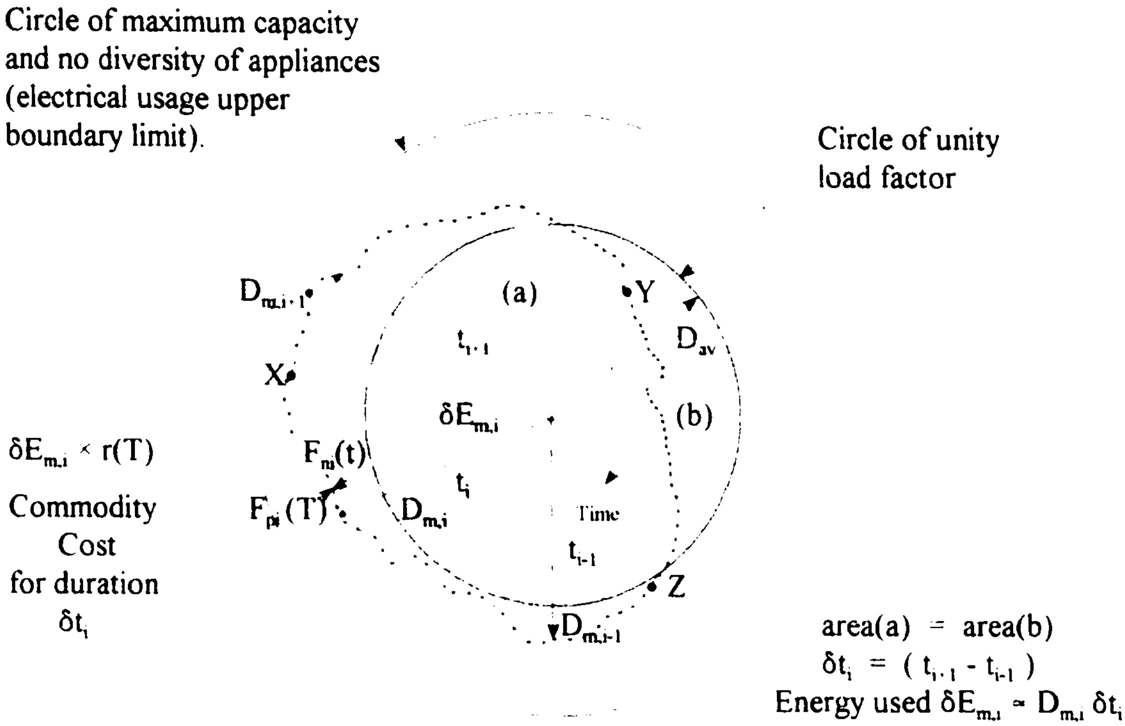


Figure 4.8: Customer Usage Characteristics

The extent of fulfilment of customers' needs is the amount of electricity used effectively. Increases in the magnitude of rate structure tend to decrease usage influenced by price/demand elasticity of customers' responses to price changes. This is dealt with in Section 4.6. Equilibrium is attained (between the amount of electricity used and the extent of fulfilment of the customers' needs) when the level of importance of fulfilment of need equals the amount the customer is prepared to pay for the energy, which will fulfil a partial or total need.

4.4.1.2 Time Variable Rate Structure: The total fulfilment of customer need is likely to be reduced when the rates are higher. The fulfilment of the need is more likely when the rates are lower. Therefore, if the fulfilment of the need can be displaced to a time when the rates are minimum, the customer's electricity cost will be a minimum. At the reduced rates, the need can even increase and be fulfilled at a much lower cost for the same or a greater amount of energy used.

4.4.2 Time Variable Need

The fulfilment of such needs is dependent upon a specific time or a relatively small range of time.

4.4.2.1 Fixed Rate Structure: If the rate structure is independent of time (in the short-term (t)), then the extent of fulfilment of a need at any time (t_i) depends upon the magnitude of the rate structure and magnitude of usage. The extent to which customers will adopt conservation measures or total energy usage, the extent of fulfilment of need at time t_i, will be based on Equation (4.8).

$$\begin{array}{c}\text{Importance of}\\ \text{need at time } t_i\end{array} = \begin{array}{c}\text{Customer}\\ \text{cost of fulfilment}\\ \text{of need at time } t_i\end{array} \qquad (4.8)$$

4.4.2.2 Time Variable Rate Structure: Both the customers' cost of fulfilling needs CFN(t) and the utility's rate structure r(t) vary with time. The higher the need, the higher the rate structure can be for the partial or total fulfilment of the need. Customers will pay more at time t_i if the requirement to fulfil the need is more important at time t_i (Equation (4.8)) than at another time t_{i-1}. If the need is time displaced, its magnitude may increase, decrease, or remain the same. If the load decreases, customers practice conservation and customers' energy costs are reduced for a reduced fulfilment of the need, or the need has been fulfilled and some waste has been eliminated. If the load remains the same at another time, it is time displaced at a reduced or higher cost.

4.4.3 Reshaping the Commodity Usage Over Time

At each time interval t_i (reference Figure 4.8), an equilibrium state is eventually attained. The customers' usage, shown by the shape XYZ, either expands or shrinks by usage to the stable equilibrium point when the customers' desires to fulfil a need $F_{ni}(t)$ equals the retail cost of the commodity $F_{pi}(t)$.

If $F_{pi}(t) > F_{ni}(t)$: customers' tendency is to reduce usage.

If $F_{pi}(t) < F_{ni}(t)$: customers' tendency is to increase usage.

The elasticity of the "membrane" of the curve shape are values of customers' usage characteristics τ_{ij} , ϕ , η_i , w_j - (reference Appendix B for details). The changes in the shape depend upon the extent of price/demand and intraday elasticities of customers' usage characteristics. This may be conservation or time displacement of usage and depends upon characteristics of customers' needs.

For a constant retail rate structure r(T), the commodity cost is a function of magnitude and duration of usage. Customers' needs may decrease with partially increased levels of fulfilment. In a partly heated room, lowering the thermostat is better than no heat at all. Equilibrium of usage is attained when F_{pi} (T) = F_{ni} (t).

For time variable rate structure r(t), the commodity cost, in addition to magnitude and duration, changes by the short-term $\delta F_{pi}(t)$ due to the time of usage. $\delta F_{pi}(T)$ are long-term retail rate changes. Equilibrium is attained when:

$$F_{pi}(T) - \delta F_{pi}(t) \pm \delta F_{pi}(T) = F_{ni}(t) \tag{4.9}$$

This is a reduction of usage during on-peak hours. Usage is affected by the extent to which customers are willing-to-pay wtp(t), δF_{pi} (t) extra to use electricity at higher prices during on-peak hours:

$$F_{pi}(T) + \delta F_{pi}(t) \pm \delta F_{pi}(T) = F_{ni}(t) \tag{4.10}$$

This is a promotion of usage during off-peak hours. Usage is affected by the extent customers are willing-to-accept wta(t) δF_{pi} (t) lower costs to use electricity during off-peak hours. δF_{pi} (T) is the long-term change in the commodity price. This may be due to an annual rate change designated as WTP(T) (increase) or WTA(T) (decrease) associated with the quality of service. F_{pi} (T) is associated with the base retail rate.

4.5 UNIFICATION OF UTILITY AND CUSTOMERS' COSTS

A distribution utility experiencing cost increases may reduce its profits, pass such increases on to its customers, or a combination of both. Customers experiencing increases may pay more, or reduce the amount of usage to stabilize the cost or a combination of both. Such is the interactive effect within the electrical system represented by Figure 4.9 and represented as 3 main components [84]. The source of the commodity may be wholesale purchases, local self-generation, or a combination of both. The physical link between the source and customers' loads is the distribution network, providing the continuity of supply which is viewed as the quality of service. The short-term (t) service interruptions reflect the extent of service Reliability R(t). The extent of network capacity, regarding load variations, load growth, and maintaining continuity of supply, is service Availability A(T) over the long-term (T).

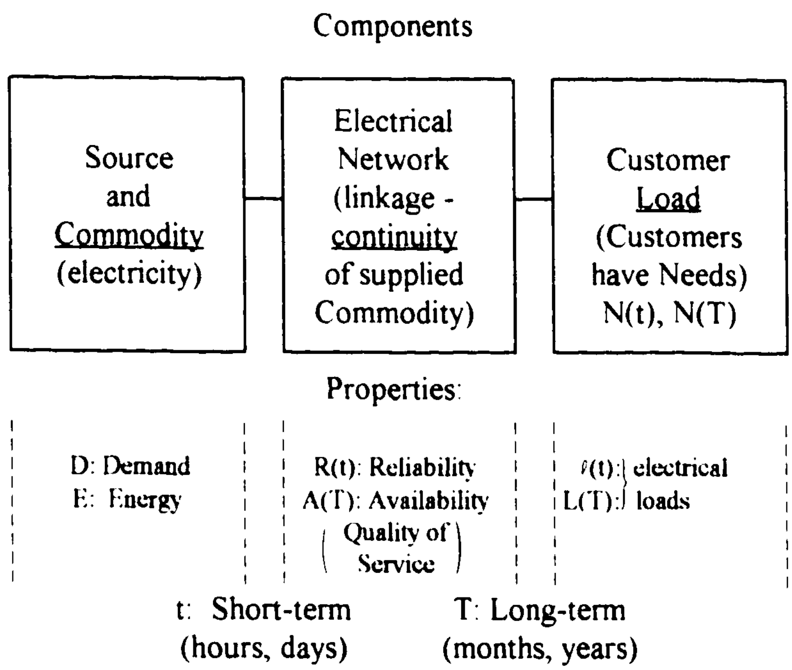


Figure 4.9: Electrical System

4.5.1 Utility's Revenue and Customers' Costs

Utility's net revenue is affected by both customer payments from purchases of the commodity and cost reduction within utility operations (Figure 4.10) [36, 85].

Increases in revenue may mean more profit and more funds available to improve the quality of service and/or reduce the cost of the commodity to customers. Such action influences customers' usage and consequent payments. If the unit cost of the commodity is reduced, customers' payments may be less for the same amount received. The net utility revenue may be unaltered, or may increase, if customers increase the amount of usage. These are the concepts in this price/demand elasticity analysis.

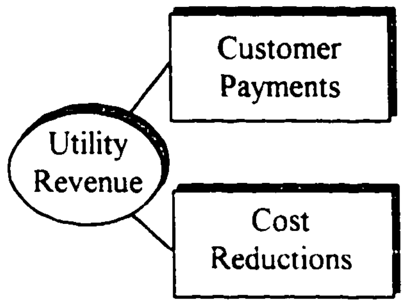


Figure 4.10: Increasing Utility's Revenue

4.5.2 Commodity and Quality of Service Costs

The utility includes in its decisions customers' willingness-to-pay (WTP) for service improvements, or willingness-to-accept (WTA) compensation in lieu of improvements (see Figure 4.11). This results in establishing an acceptable and cost-effective level of quality of service, having components of Reliability R(t) and Availability A(T). Customers may pay incrementally increased payments (WTP) for improvements, or are willing-to-accept incremental cost reductions (WTA) in lieu of improvements. These are usually in the form of long-term (T) annual retail rate changes [147].

If the commodity is available and continuously supplied, customers may choose and control which appliance and when to use it. If the cost of usage is time-dependent, higher at peak periods, then the extent of service continuity is self-regulated and is influenced by the extent of customers' willingness-to-pay (wtp) more during such times. The amount of electricity used during off-peak periods is influenced by customers' willingness-to-accept (wta) lower cost incentives to displace part or all of usage to those periods [5, 143].

The two nodes of Figure 4.11 represent the utility and customers respectively in the rate adjustment process. The sign convention for each node is shown by arrows:

i) Flow out; incremental reduction in revenue or increase in cost.

ii) Flow in; incremental increase in revenue or reduction in cost.

The short-term and cyclic rate variation (wtp), (wta) is superimposed upon the long-term rate changes (WTP), (WTA) and this sum forms the customers' retail rates shown in Figure 4.12.

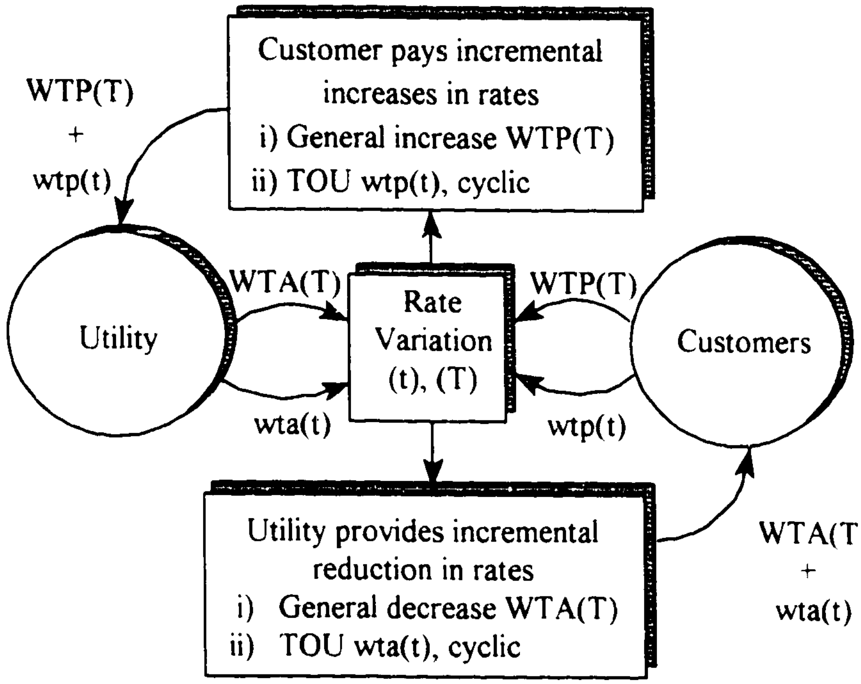


Figure 4.11: Retail Rate Variation Over Short (t) and Long (T) Time Periods

The magnitude of time variable rates, (wtp), on-peak, and (wta) off-peak, are referenced to retail base line r_b which is a fixed block structure. Long-term rate increases displace this base, resulting in an incrementally higher (WTP) or incrementally lower (WTA) and affect the variable rate structure (wtp) and (wta).

Customers' costs:

Peak Periods.

Maximum: (WTP) + (wtp) or Minimum: (WTA) + (wtp)

Off-Peak Periods.

Maximum: (WTP) + (wta) or Minimum: (WTA) + (wta)

and (WTP) > 0 (adds to both base and time variable rates)

(WTA) < 0 (subtracts from base and time variable rates)

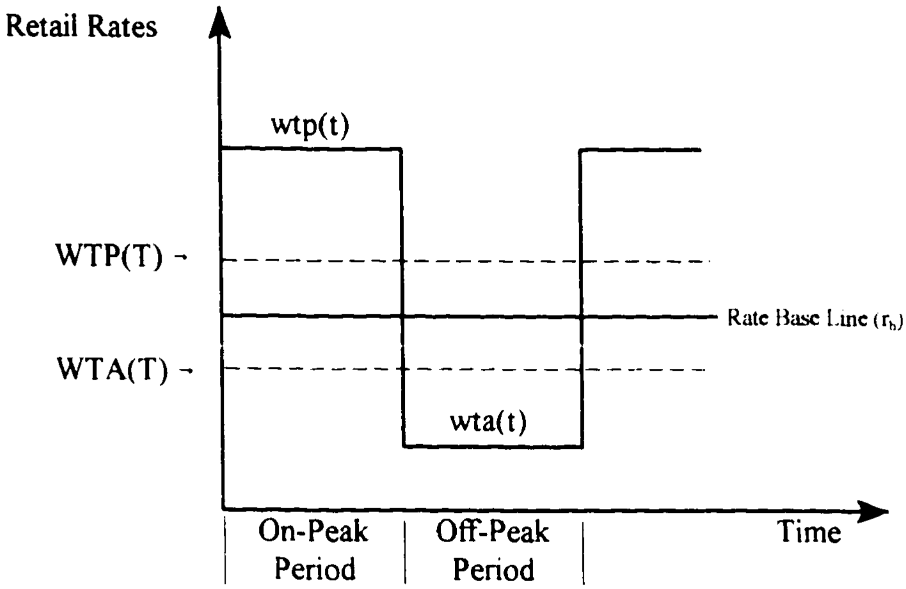


Figure 4.12: Retail Rate Adjustment and Cyclic Variation

4.5.3 Customers' Needs, Commodity, and Quality of Service

Some customers' needs can be fulfilled at any time only by the magnitude and duration of usage of the commodity. Other needs require magnitude, duration, and specific times of electrical usage. Therefore, some needs are time dependent and others are not. Customers have some choices and controls regarding their own costs of using the commodity:

i) They can choose and control the magnitude (rating), duration (time), and beginning/end of usage (on/off switch) for a fixed and time-independent unit cost structure.

ii) In addition to i), they can further choose and control their costs if a time variable unit cost structure is available. Namely, the price of the commodity varies upon the hour of the day or night.

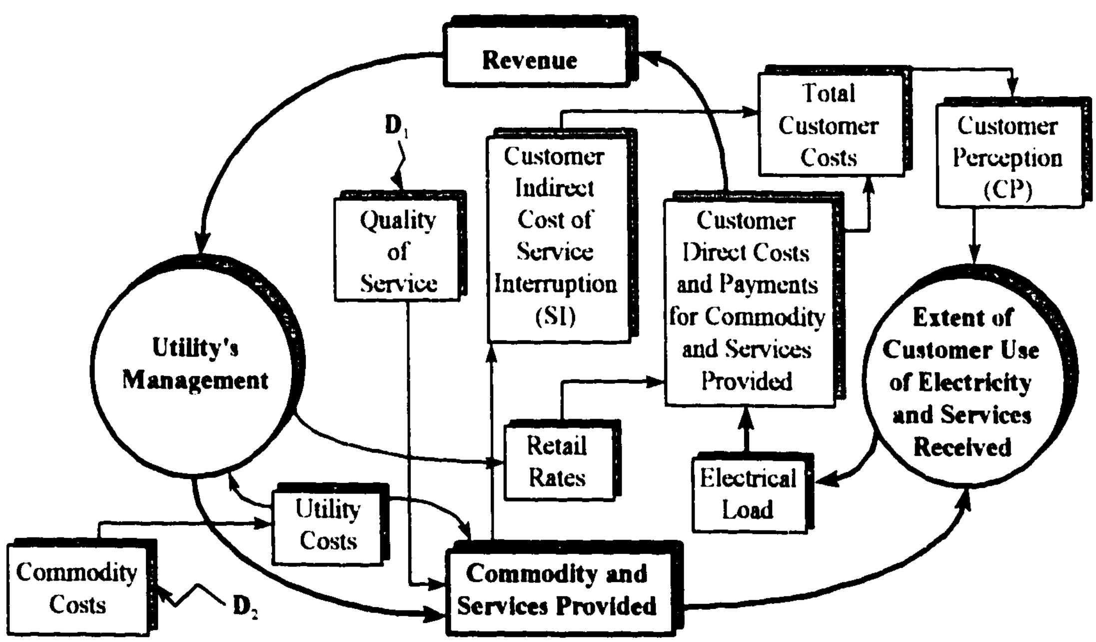
By introducing flexible time variable rate structures, customers have more choices and control regarding 'what', 'when', and at 'what cost' the 'extent' of their needs will be fulfilled. This may be conservation, time displacement, or increases in usage at different times, for different durations. This is viewed as a form of self-imposed service interruption (si), which can also be viewed as a customer self-imposed and self-managed quality of service and associated costs. Therefore, when the commodity has been delivered to the customers, they have choices and controls regarding the extent of modifying their own quality of service [15, 16]. The level of customer perception (CP) over time (t) is the averaged accumulated levels of customer satisfaction (CPS) with respect to their expectations (CPE) and can be expressed symbolically as:

$$CP = \frac{1}{t} \int_{1}^{t} \{CPS(\tau) - CPE\}\, d\tau \qquad (4.11)$$

Customer perception is also influenced by the benefits obtained relative to the incurred costs and can also be symbolically represented as:

$$CP = \frac{\text{Benefits Obtained (as perceived by customer)}}{\text{Incurred Costs (as perceived by customer)}} \qquad (4.12)$$

Figure 4.13 illustrates the relationship between utility operations and total customer costs, which include using electricity and service interruptions.



D_1 changes in quality of service.
D_2 changes in the commodity cost.

Figure 4.13: Unified System

4.6 A PRACTICAL APPLICATION

The average values of the system load curves of Figures 4.5 and 4.6 (Summer and Winter seasons) are given in Figures 4.14 and 4.15. This data will be analyzed to demonstrate that the pricing structure affects usage and the costs to both the customer and the utility. The change in customers' usage, based on price differentials over defined time periods, was investigated (reference Appendix B for details). This involved calculating indices associated with customer usage characteristics; for example, the calculation of τ_{ij} -- the price elasticity between on-peak and off-peak periods. Changes in customers' usage during on-peak and off-peak periods are affected by changes in prices for both periods.

The on-peak periods are designated as (i=1), and off-peak periods are designated as (i=2). Expenditure elasticity, η_i, and overall elasticity of demand, ϕ, also have an impact on the total consumption and are included in the calculation (reference Appendix B for details). Values were obtained from published data [117]. The allocated period of usage indices, w_j, is the ratio of energy used during the on-peak and off-peak periods, relative to the total energy used over the whole time period considered. The price, P_i, of electricity includes both time varying and fixed rates [146]. The analysis was performed on the average daily seasonal customer load (See Figures 4.14 and 4.15).

4.6.1 Effects Upon System Load

Tables 4.1 and 4.2 are the results of using time variable rates and varying the duration of on-peak and off-peak hours for both Winter and Summer seasons. The average fixed-rate block structure was 9.1¢ per kwh and this was used as the base rate for comparison purposes with time-variable rate structures.

Three scenarios are investigated: 1, 2, and 3. As can be seen from Tables 4.1 and 4.2 (for each of the Summer and Winter load patterns), these scenarios depict different pricing structures with progressively longer peak periods. We will now look at two specific situations from the results depicted on Tables 4.1 and 4.2 to see the affect upon system load.

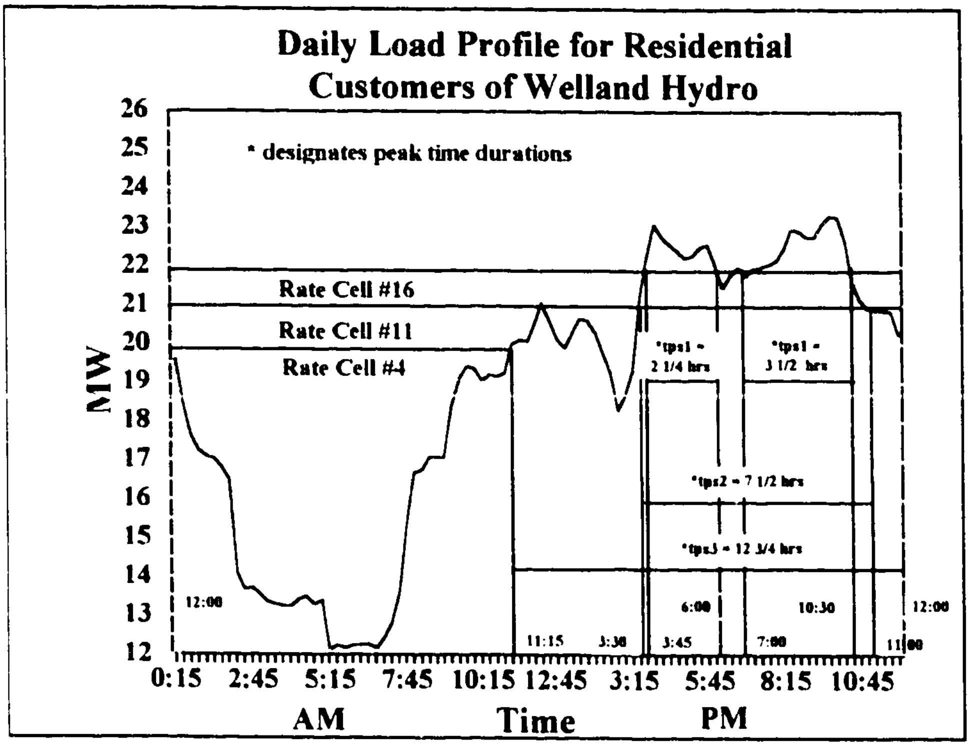


Figure 4.14: Average Load for Summer Months

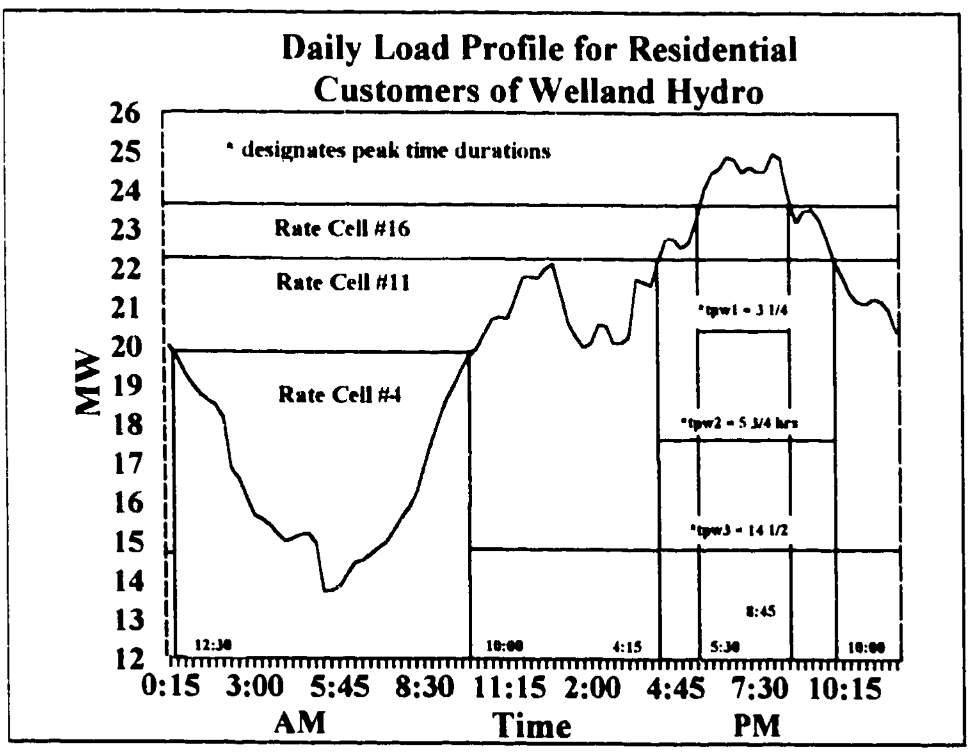


Figure 4.15: Average Load for Winter Months

Table 4.1: Summer Season: Effects of Price/Demand Elasticities on Electrical Consumption

(Conservation and Time Displacement of Electricity Usage)

Description	Range of Hours	Duration in hours	Retail Rates TOU ¢/kW	Ratio of TOU / NON TOU Rates	Ratio of NON TOU / TOU Usage	Normal Usage if Energy with No Customer Elasticity (kWh)	Modified Daily Energy Usage Due to Customer Elasticity (kWh)	Change in Energy Usage δE (kWh)	Average Change in Peak Usage (kW)
Scenario #1 - Rate Class #16									
1.1 a_1 Peak	3:45 p.m. - 6:00 p.m.	2¼	10.39	1.14	0.9898	44,311.22	43,860.43	-450.79	- 200.35
1.2 a_2 Peak	7:00 p.m. - 10:30 p.m.	3½	10.39	1.14	0.9869	69,118.11	68,210.62	-907.49	-259.28
1.1 b_1 Off-peak	6:00 p.m. - 3:45 p.m.	21¾	3.35	0.37	1.0498	347,650.82	364,971.14	+17,320.32	+796.34
1.2 b_2 Off-peak	10:30 p.m. - 7:00 p.m.	20½	3.35	0.37	1.0496	322,843.93	338,856.56	+16,012.63	+781.10
Totals of a_1 and b_1						**391,962.04**	**408,831.57**	**+16,869.53**	
Original System Load Factor						**0.700**	**Modified Load Factor**		**0.737**
Totals of a_2 and b_2						**391,962.04**	**407,067.18**	**+15,105.14**	
Original System Load Factor						**0.700**	**Modified Load Factor**		**0.735**
Scenario #2 - Rate Class #11									
(a) Peak	3:30 p.m. - 11:00 p.m.	7½	18.98	2.09	0.9084	151,055.25	137,221.53	-13,833.72	-1,844.50
(b) Off-peak	11:00 p.m. - 3:30 p.m.	16½	4.86	0.53	1.0356	240,906.83	249,481.51	+8,574.68	+519.68
Totals						**391,962.08**	**386,703.04**	**-5259.04**	
Original System Load Factor						**0.700**	**Modified Load Factor**		**0.750**
Scenario #3 - Rate Class #4									
(a) Peak	11:15 a.m. - 12:00 a.m.	12¾	10.39	1.14	0.9837	238,999.04	235,092.31	-3,906.73	-306.41
(b) Off-peak	12:00 a.m. - 11:15 a.m.	11¼	3.85	0.42	1.0431	152,963.00	159,551.62	+6,588.62	+585.66
Totals						**391,962.04**	**394,643.93**	**+2,681.89**	
Original System Load Factor						**0.700**	**Modified Load Factor**		**0.714**

Table 4.2: Winter Season: Effects of Price/Demand Elasticities on Electrical Consumption

(Conservation and Time Displacement of Electricity Usage)

Description	Range of Hours	Duration in hours	Retail Rates TOU ¢/kW	Ratio of TOU / NON TOU Rates	Ratio of NON TOU / TOU Usage	Normal Usage if Energy with No Customer Elasticity (kWh)	Modified Daily Energy Usage Due to Customer Elasticity (kWh)	Change in Energy Usage δE (kWh)	Average Change in Peak Usage (kW)
Scenario #1 - Rate Class #16									
(a) Peak	5:30 p.m. - 8:45 p.m.	3¼	12.78	1.40	0.997032	69,131.04	68,925.86	- 205.18	- 58.62
(b) Off-peak	8:45 p.m. - 5:30 p.m.	20¾	4.72	0.52	1.036988	344,842.47	357,597.66	+12,755.19	+614.71
Totals						**413,973.51**	**426,523.52**	**+12,550.01**	
Original System Load Factor						**0.690**	**Modified Load Factor**		**0.713**
Scenario #2 - Rate Class #11									
(a) Peak	4:15 p.m. - 10:00 p.m.	5¾	26.76	2.94	0.968412	118,982.32	115,223.95	-3,758.37	-653.63
(b) Off-peak	10:00 p.m. - 4:15 p.m.	18¼	6.82	0.75	1.012488	294,991.17	298,674.97	+3,683.80	+201.85
Totals						**413,973.49**	**413,898.92**	**-74.57**	
Original System Load Factor						**0.690**	**Modified Load Factor**		**0.708**
Scenario #3 - Rate Class #4									
(a) Peak	10:00 a.m. - 12:30 a.m.	14½	14.63	1.61	0.980412	274,225.26	268,853.65	-5,371.61	-370.45
(b) Off-peak	12:30 a.m. - 10:00 a.m.	9½	5.39	0.59	1.030934	139,747.89	144,071.25	+4,323.36	455.09
Totals						**413,973.15**	**412,924.90**	**-1,048.25**	
Original System Load Factor						**0.690**	**Modified Load Factor**		**0.699**

4.6.1.1 Scenario #1 - Winter Season: The on-peak or maximum demand period was of relatively short duration (3¼ hours). The rate was increased by 1.4 times the base rate and the on-peak energy usage decreased by 0.3% during this on-peak period. The off-peak rates were reduced by 0.52 times the base rate and the energy usage increased by 3.70% . The small reduction of on-peak usage indicates the high customer need for the commodity during Winter for this on-peak duration from 5:30 p.m. to 8:45 p.m. This reduction of on-peak usage may be due to time displacement of load to off-peak hours. The net usage increased by 3.03% over the total 24 hour period.

4.6.1.2 Scenarios #1.1 and #1.2 - Summer Season: The rates were 1.14 times the base rate during on-peak and 0.37 times the base rate during off-peak. The durations of on-peak were 2¼ hours and 3½ hours respectively within each defined on-peak period. The reduction of energy during on-peak hours was 1.01% for scenario #1.1 and 1.3% for scenario #1.2. The increase in usage during the off-peak hours was 4.98% and 4.96% respectively. The difference in on-peak energy usage is due to the relatively higher requirement of customers' needs during the on-peak hours from 3:45 p.m. to 6:00 p.m., than from 7:00 p.m. to 10:30 p.m. The net effect, in both cases, was a relatively small amount of energy usage reduction during on-peak hours and increase in usage during off-peak hours. The increase in usage is possibly due to time displacement of loads and increases in usage due to relatively low rates during the off-peak periods.

4.6.2 Utility and Customers' Costs

Table 4.3 illustrates the impact of different retail rate structures upon system load and utility cost. Table 4.4 illustrates customer response regarding amount of usage and corresponding electricity costs for various utility retail rate structures.

4.6.2.1 Scenario #1: A comparison of scenarios #1 for Winter with #1.1 and #1.2 for Summer shows that there was a net reduction in utility revenue when using time-of-use rates as compared to non time-of-use rates. This is shown in the right-hand column of Table 4.3.

Table 4.3: Utility Commodity Costs

(Cost of Wholesale Purchases of Power and Energy)

Description and Season	Change in Daily On-Peak Energy		Change in Daily Off-Peak Energy		Change in Seasonal Energy Cost ($)	Change in Monthly Maximum Demand		Seasonal Change in Demand and Energy Cost ($)	Seasonal Changes in Revenue ($K)	Seasonal Impact of Cost Changes upon Revenue Changes ($K)	Seasonal Impacted Revenue from Non TOU Rates (%)
	Amount (kWh)	Cost ($)	Amount (kWh)	Cost ($)		Demand (kW)	Cost ($)				
Scenario #1 Winter	-205.17	-8.60	+12,755.2	+427.30	+76,465.09	-63.13	-1,040.44	+70,102.45	-2,258.82	-2,328.92	-33.85
Scenario #1.1 Summer	-450.80	-15.10	+17,320.3	+398.37	+69,994.68	-200.34	-2,356.00	+55,858.68	-3,501.71	-3,557.57	-54.61
Scenario #1.2 Summer	-907.49	-30.40	+16,012.61	+368.29	+61,707.16	-259.28	-3,049.09	+43,412.65	-3,195.95	-3,239.37	-49.73
Scenario #2 Winter	-3,758.38	-157.43	+3,683.92	+123.41	-6,222.03	-653.64	-10,771.96	-70,853.79	+2,542.13	+2,612.98	+37.98
Scenario #2 Summer	-13,833.72	-463.43	+8,574.68	+197.22	-48,617.04	-1,844.48	-21,691.14	-178,763.88	+630.88	+809.59	+12.42
Scenario #3 Winter	-5,371.61	-225.07	+4,323.02	+144.82	-14,655.66	-370.45	-6,105.00	-51,285.63	+1,753.10	+1,804.39	+26.23
Scenario #3 Summer	-3,906.74	-130.88	+6,588.62	+151.54	+3,773.03	-306.42	-3,603.56	-17,848.30	-915.76	-897.91	-13.78

+ increase
- decrease

Table 4.4: Customer Commodity Costs

(Cost of Retail Purchase Comparison Between Impacts of Non TOU and TOU Rates)

Description and Season	Seasonal Usage and Cost using Non TOU Rates (Avg. cost 9.1¢/kWh)	Seasonal Usage and Cost using TOU Rates and no Customer Elasticity	Seasonal Usage and Cost using TOU Rates and Customer Elasticity	Variations in Amount of Usage and Seasonal Cost (col. 4 – col. 2)	Average Seasonal TOU Rates (Column 4) (¢/kWh)	Percentage Change in Customer Bill from Non TOU Rates
Scenario #1 Winter	4,202.10 kWh ($382.39)	4,202.10 kWh ($254.90)	4,329.99 kWh ($259.09)	+ 127.89 kWh (- $123.30)	5.98¢ per kWh	-32.24%
Scenario #1.1 Summer	3,979.35 kWh ($362.12)	3,979.35 kWh ($164.97)	4,152.22 kWh ($168.80)	+ 172.87 kWh (- $143.32)	4.07¢ per kWh	-53.38%
Scenario #1.2 Summer	3,979.35 kWh ($362.12)	3,979.35 kWh ($182.61)	4,136.33 kWh ($185.01)	+ 156.98 kWh (- $177.11)	4.47¢ per kWh	-48.91%
Scenario #2 Winter	4,202.10 kWh ($382.39)	4,202.10 kWh ($527.06)	4,202.12 kWh ($515.41)	+ 0.2 kWh (+ $133.02)	12.27¢ per kWh	+34.79%
Scenario #2 Summer	3,979.35 kWh ($362.12)	3,979.35 kWh ($405.30)	3,941.02 kWh ($369.02)	- 38.33 kWh (+ $6.90)	9.36¢ per kWh	+1.91%
Scenario #3 Winter	4,202.10 kWh ($382.39)	4,202.10 kWh ($483.54)	4,193.68 kWh ($474.98)	- 8.42 kWh (+ $92.59)	11.36¢ per kWh	+24.22%
Scenario #3 Summer	3,979.35 kWh ($362.12)	3,979.35 kWh ($311.89)	4,008.45 kWh ($306.90)	+ 29.10 kWh (- $55.22)	7.64¢ per kWh	-15.24%
1	2	3	4	5	6	7

4.6.2.2 Scenario #2: In the Winter months, the net effect of customers' energy usage did not change due to rate changes. The amount reduced during on-peak approximately equalled the increase in energy usage during the off-peak period. The utility's demand and energy costs were reduced, and the revenue increased during both seasons. Customers paid more for the same amount of commodity. The Winter season provided an excess of $2.6 million extra revenue compared to a fixed rate structure. This was due to a 37.98% net increase (considering both on-peak and off-peak periods) in retail revenue. The commodity cost reductions of $0.178 million, plus a $0.631 million increase in revenue, resulted in a total net increase of 12.42% in revenue (Table 4.3) for only a 1.91% increase in customer cost (Table 4.4). This is a cost-effective rate structure which benefits the utility financially with a relatively small increase in customer rates. Such extra funds could be used by the utility to improve the quality of service and retain some profits. Customers may be more WTP(T) for quality of service improvements if their total cost is reduced [143].

4.6.2.3 Scenario #3: Utility commodity costs are reduced for both Winter and Summer seasons. The utility's revenue increases in the Winter by $1.753 million, but is reduced in the Summer by $0.916 million. The net effect, due to customer actions in the Winter months, is a larger decrease in on-peak usage, rather than an increase in off-peak usage (Table 4.3). The marginal higher rates in the Winter, even at marginally reduced amounts of usage, result in a net increase in revenue for the utility. However, customer bills in the Winter increased compared to non time-of-use rates, even though the amount of energy used decreased (Table 4.4). Customers' time-variable rates in the Summer were less than time-variable Winter rates and the Summer total net consumption increased. Customers' Summer bills were $55.20 less, compared to fixed non time-variable rates. Therefore, using time-variable rates, customers altered their usage patterns and reduced their costs, even though the amount of energy used increased.

4.6.3 Impacts of Costs

It is shown in Tables 4.3 and 4.4 that the cost to the utility of the commodity supplying time-variable customer loads is reduced by changing the customer usage pattern so that the utility can purchase at off-peak times. This meant a reduction in the utility's system on-peak demand and energy costs paid by the utility and charged to customers. Time-variable retail rates 'reshape' the commodity and provide customers (in addition to switching on or off, choice of rating, type of appliance, and duration of usage) with more choices and controls over their own costs. Customers have the opportunity to time displace the load to a time of lower price; thus, obtaining the same amount, or even more of the commodity, at a lower price. This has a significant impact on the utility cost.

The amount of usage is influenced by the customers' perception of the value obtained for payments made. Users of any commodity respond to price variations. In general, the higher the price, the less usage; the lower the price, the more usage. In the case of time-variable rates, customers respond in one or more of the following ways:

i) Load reductions

ii) Load time displacement

iii) Load increases

These results illustrate the financial relationship between the amount of fulfilment of customers' needs and the extent customers are willing-to-pay (wtp) for that fulfilment. The extent of fulfilment is influenced by the amount of time-dependency of the need, coinciding with times of lowest retail rates which customers are willing-to-accept (wta).

If the utility reduces its own cost of the commodity, even with slight cost increases to customers, these extra funds obtained from customers, and from reductions in wholesale cost, can be used to improve the quality of service. This could maximize customer benefits by reducing customers' total costs. Customers are willing-to-pay more (WTP) if their total cost is reduced [143]. If quality of service improvements are not cost-effective, then the utility may incrementally reduce customer rates to values which customers are willing-to-accept (WTA), such as retail rate reduction in lieu of improvements.

4.7 UNIFIED CUSTOMER-UTILITY COST MODEL

In this section, a unified model for customer and utility costs is presented. In order to address complex problems such as customer perception, causes, and influences, the following analysis is presented.

4.7.1 Introduction

The world is viewed as consisting of physical particles or elements described as entities. These entities exist and are organized into components and then systems. The boundaries of systems are set by causal relations. Some of these systems are living systems and some of these living systems have evolved consciousness. With consciousness comes intentionality, which is the capacity to represent objects and states in the world. The capacity of the mind is to represent objects and states of affairs in the world other than itself [137].

The view of the world depends on one's objective and subjective perspective. Customer inconvenience or customer costs are subjective entities since their mode of existence depends upon their impact upon people. A distribution line is a physical object as its mode of existence is independent of any perceived or any mental state [122, 137].

Intrinsic features of reality, like a stone or an insulator, are those that exist independently of any attitude. These objects may be regarded as two different paperweights. These observer-relative features are created by the user.

4.7.2 Functions

The analysis of a process requires the assignment of functions to objects. These objects may be classified as:

a) Those which are naturally occurring.

b) Those created specifically to perform specific functions.

Naturally occurring phenomena can be assigned functions and assessed as "good" or "bad", depending on what functions one chooses to assign to them and how well they perform these functions (aesthetic, utilizable, practical). For example, the river is "good" to generate electricity, this tree is "good" to be used as a hydro pole. Some objects are built (from components into a system) to perform a specific function, for example, a line truck. Such functions are not intrinsic to the physics of the phenomena but are assigned by users and are observer related. The discovery of natural function takes place only within a set of prior assignments of value, including purpose and natural processes [130].

A function is recursive and the properties obtained can be reproduced under the same or similar circumstances. There are no functional facts beyond causal facts and further assignment of a function is then observer related. Functional attributes, unlike causal attributes, are intentional. They are just causes and a furtherance of a set of values (e.g. improvements in the quality of service, attainment of comfort when using electricity, etc.) and are observer related.

4.7.2.1 Intentional and Natural Functions: Intentional functions do not occur naturally but are assigned functions based on concepts of usefulness. They require continuous control on the part of the user for their maintenance -- for example, burning fuel for NUG generation requires replenishment of fuel whilst in hydraulic generation there is no need for direct replenishment. Natural functions continue without any effort from the user -- for example, the continuous flow of the river is the fuel which is readily available without direct effort from the user.

Natural functions occur in nature independently of human intentions or activities, such as the effects of the sun upon heating and cooling of the environment. Some intentional functions can replace natural functions (such as when it is cold, one can heat the surroundings using electricity).

4.7.3 Language and Meaning

By the use of language, one imposes specific functions onto marks and sounds. Language is essential for the formation of organizational facts [31]. Symbolic devices such as words represent or symbolize something beyond themselves. Something is correctly called a "pole" only relative to a linguistic system. The features in virtue of which it is a pole are features that exist independently of language. One can tell which objects are trucks, wires, or insulators because one can read off the function from the physical structure. However, with money, easements, electricity accounts, etc., one cannot read off the function or status from the physics. One needs labels for recognition. Therefore, there is a requirement for some linguistic or symbolic way of representing such newly-created facts about functions because they cannot be read off the "physics" of the objects themselves.

Complex facts require a complex system of representation for their existence and a complex system of representation is a language.

4.7.4 Natural and Organizational Facts

Physical facts are independent of any human organizations and require organizational language. Organizational facts exist only within human organizations. Physical facts themselves exist independently of language or of organizations.

Institutions require "regulative" and "constitutive" rules which regulate activities. For example, the rule "in order to use electricity, payments must be made" regulates the cash flow of an organization, but payment can still exist prior to the existence of that rule. Rules of repair and maintenance of an electrical system do not regulate the assembly of materials and components into piles They create the methodology (sequence) when applied to components and entities, resulting in restoration of services. The rules for repair are to restore services quickly and safely at the lowest cost.

Organizational facts cannot exist without natural facts and a process is required prior to the production of a product. There is nothing in the physical or chemical composition of the paper that makes it a dollar bill. It is a symbolic device for marking an organizational fact. Organizational facts, such as the formation of an electrical utility, have many combinations and impose status: for example, in a public utility, the classification of employees (people) under different responsibilities and authorities. Such facts persist through time independently of the duration of the inclination of the participants. People, objects, and events interact in systematic relationships. The imposition of status-functions on objects occurs only in relation to people.

4.7.5 Hierarchical Structures

Within an organization, there are 3 components: initial creation of organizational facts, the continued existence of the organization, and its linguistic representation.

(i) Creation of Organizational Facts - Certain types of organizational facts are created by acts whose performances are themselves organizational facts. In these cases, new status-functions are imposed on phenomena that have already had status-function imposed on them. For example, with new regulations regarding the provision of services, a policy is formed which changes the existing rules; its declaration is a status function.

(ii) The Continued Existence - Society recognizes and accepts the existence of facts. The status of a person or a system is constituted by collective acceptance. The function, in order to be performed, requires the status. It is essential to the functioning of a system that there be continued acceptance of its status. For example, if people in a society refuse to acknowledge utility rights, then utility rights cease to exist in that society. Globally, there is a steady erosion of acceptance of large monopolistic organizational structures and physical facts always prevail over organizational facts.

(iii) Linguistic Representation - Organizational facts exist by human agreement and require official representation or status indicators. They cannot generally be read from physical facts of the situation. A bill is "one dollar" which defines "money" and explanations are self-identifying for those who know the language.

4.7.6 Formation of Organizational Hierarchy

A hierarchy structure consists of social, organizational, and mental reality within a single physical reality. In the context of the present work, an electrical system consisting of a distribution utility and customers is depicted in Figure 4.16.

All cases of collective intentional facts are social facts. Organizational facts are a special sub-class of social facts and the assignment of a function creates functional facts. Sometimes functions can be imposed on other functions, but ultimately such hierarchies level out on physical and on mental phenomena. Linguistic and non-linguistic organizational functions can be functions on top of functions. For example, the distribution utility (U) at

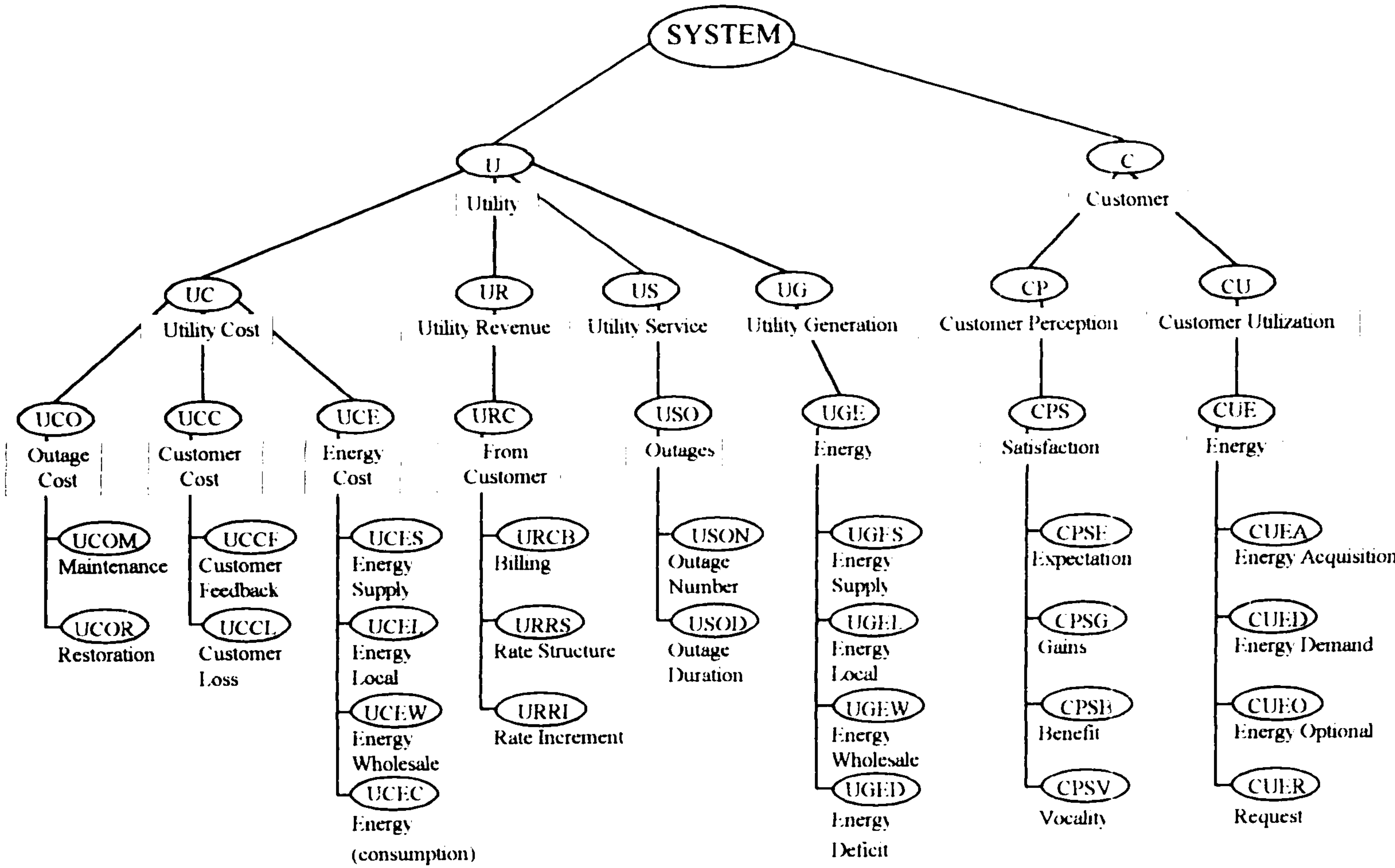


Figure 4.16: Symbolic Description of Hierarchical Logical Tree of System Components
(Reference Appendix C, Table C 1 for component relationships)

one level of a hierarchical representation of components can be viewed as being synonymous with utility revenue (UR) or utility cost (UC) at another lower level.

4.7.7 An Illustrative Scenario

The simple illustrative scenario presented here represents a more general case to the scenario of section 3.2. Figure 4.17 demonstrates how intangible issues (for example, customer perception) would influence the distribution utility cost-revenue balance in which the utility rate structure is also considered. Again, it is a "chain reaction" process that may have significant impact on the utility business' prosperity or even survival [143, 147].

As depicted in Figure 4.17, the following cycle of events is naturally present in the distribution utility business environment:

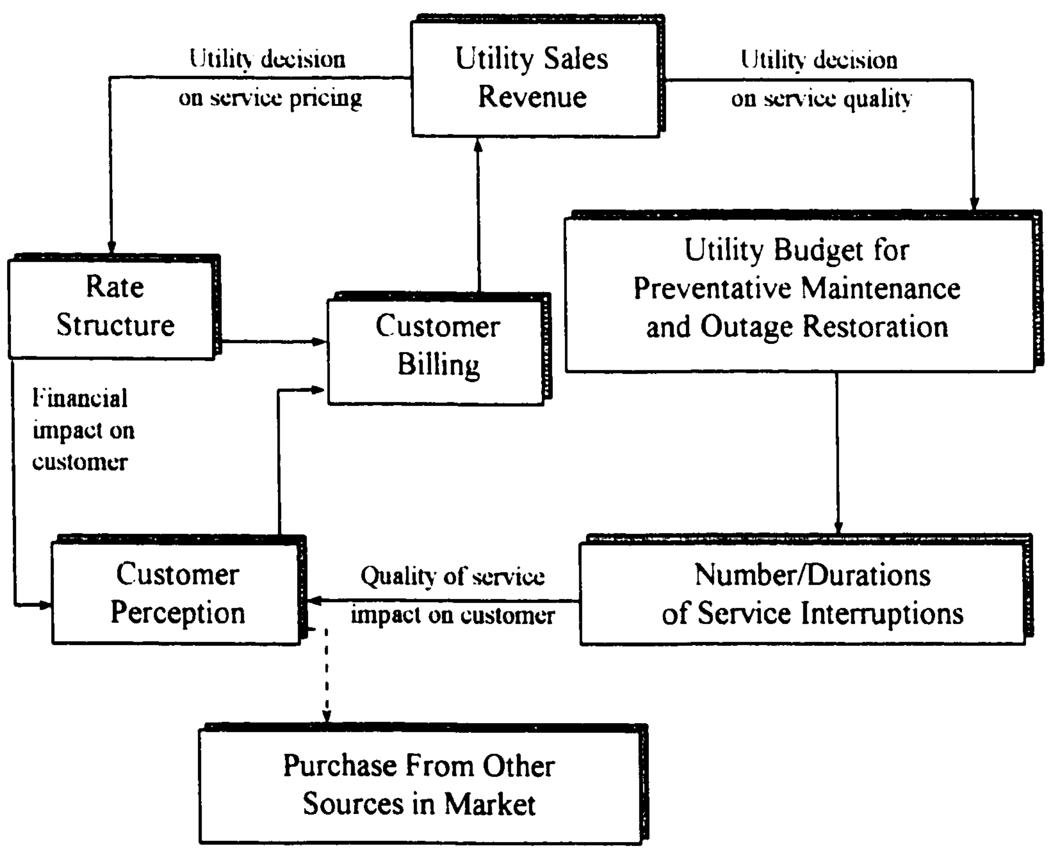


Figure 4.17: Effect of Customer Perception on Utility Business

(i) In a market-driven environment, the customer choice of purchasing energy from a particular utility depends on his/her perception of both price of electricity and the service quality provided by that utility.

(ii) The utility revenue depends on the number of customers, which affects the amount of electricity purchased, as well as the electrical rate offered to customers.

(iii) The utility's available budget to carry out preventative maintenance depends on the total utility revenue.

(iv) The number and duration of service interruptions depends on the extent of preventative maintenance carried out by the utility.

(v) Customer perception is influenced by the price of electricity (electrical rates), as well as the number and duration of interruptions.

(vi) Go to i) (repeat cycle).

A model for the above scenario can be developed from pertinent customer surveys and historical utility records. Table 4.5 shows typical distribution utility data gathered over a six-year period from which the data was used in a decision analysis software package [51] which evaluates various relevant cost components as shown in Figure 4.16. It illustrates the distribution utility and customer components which form the system. The respective components are associated with the process of supplying and using electricity. Appendix C, section C.2, illustrates the relationships of these components.

These results demonstrate that, for the particular utility data considered, if a utility reduces its maintenance costs, the initial reduction in utility costs occurs at a greater rate than increases in customer costs. However, such short-term savings eventually result in long-term increases in utility costs due to deteriorating customer perceptions, especially if the customer has substitute energy sources available. Figure 4.18 is a summary which illustrates that customers are more concerned with retail rates than quality of service.

Table 4.5: Utility Costs, Quality of Service, and Customer Costs

Year	Average Energy Retail Rates (Retail and Commercial)	% Annual Increase in Retail Rates	Number of Service Interruptions			Number of Recorded Complaints	Average Duration of SI (Hours)	Maintenance Costs		System Peak Load (MW)
			During Regular Working Hours	After Regular Working Hours	Total Number of SI			Preventative (SK)	Restoration (SK)	
1991	7.2¢/kWh	8.37%	18	98	116	172	3.54	\$1,172.3	\$84.73	86.23
1992	8.18¢/kWh	12.94%	24	118	142	205	1.36	\$1,207.1	\$53.30	81.68
1993	8.84¢/kWh	6.89%	30	79	109	191	1.39	\$1,247.3	\$55.26	88.24
1994	8.84¢/kWh	0%	26	124	150	181	1.95	\$1,142.5	\$65.90	91.92
1995	8.84¢/kWh	0%	15	133	148	160	2.56	\$1,272.1	\$77.71	99.13
1996	8.43¢/kWh	-5.6%	23	129	152	168	1.63	\$1,467.1	\$85.47	91.17

Total Responses - 407

	No Opinion	Very Low	Low	Moderate	High	Very High
Rates	20	1	19	214	117	36
Outages	24	79	115	149	30	10

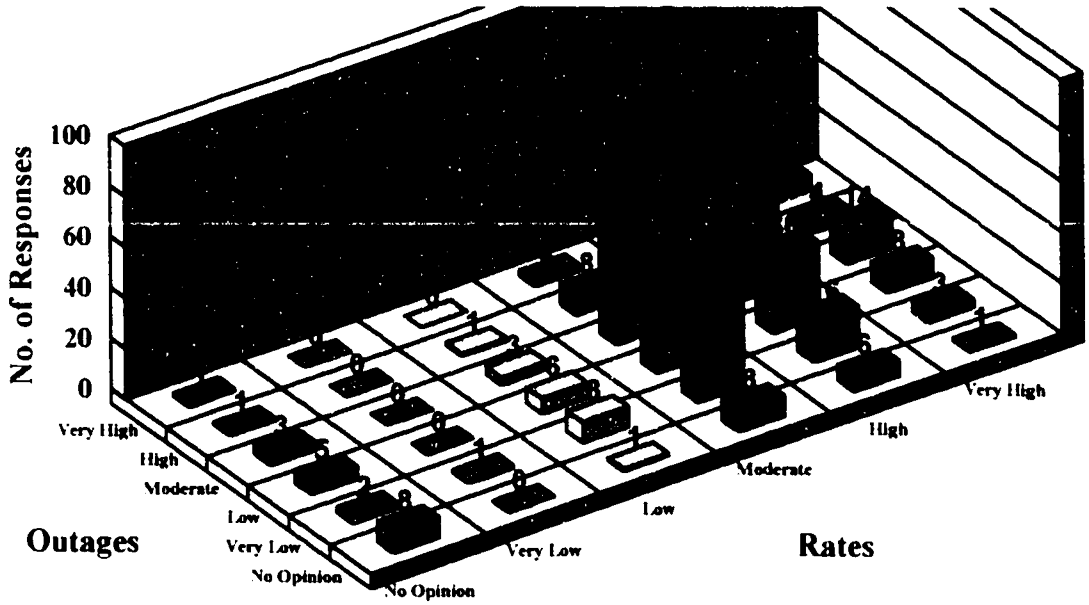


Figure 4.18: Customer Survey Regarding Customers' Views of Quality of Service and Retail Rates

4.7.8 Case Studies

The following three cases of a time-trending process address typical distribution utility concerns [147].

Case #1: The effect upon customer perception of varying both the magnitude and annual increase of retail rates for the same total utility revenue.

Case #2: Utility compromises made between changes in maintaining the electrical system to offset some of the need for annual retail rate increases.

Case #3: Impacts upon utility cost of insufficient and excessive local generation capacity.

Case #1: Varying retail rates to obtain the same total revenue. The results of Figure 4.19 were obtained from the data input of D.1 of Appendix D and using the relationships of Figure 4.18 and Table C.1 of Appendix C. Management decided to improve the efficiency of utility operations by partly replacing wholesale purchases by NUG generation. Preventative maintenance costs and restoration of services costs were reduced. Increases in retail rates resulted in decrease in customer perception and, although the utility costs increased over time, the utility increased profits at a greater rate. The results of this test case (Figure 4.19) illustrate the effect of two different retail rate structures upon utility profits and customer perception levels over time. The left-hand axis represents the utility's accumulated profit (aUP) in millions of dollars. The right-hand axis represents an index level of customer perception (CPSV).

Study #1.1: Higher initial rates and smaller annual increases provide more initial revenue which can be used to improve plant and equipment (reference Figure 4.19 and Table 4.6). This could include upgrading of the network, building local generation, and/or higher profits.

Study #1.2: Lower initial rates may attract new customers by the utility who recognizes that the initial years are usually financially difficult for many new businesses.

In both studies, the total utility revenue is the same over the time period, but differing in the process of customer payment [147] (see Appendix D, Tables D.2 and D.3 for details). The results indicate that customers prefer rate stability (Study #1.1) equivalent to smaller annual increases. The initial level of customer perception for Study #1.1 is 5.4% less than for Study #1.2 but the overall level of customer perception over this time period is 4% greater for Study #1.2 than for Study #1.1 and the utility's accumulated profits increased by 0.3% .

Table 4.6: Case #1 - Retail Rate Increases

Study #	Base Retail Rate	Annual Increase
Study #1.1	8¢/kWh	0.5¢/kWh
Study #1.2	7¢/kWh	0.705¢/kWh

Accumulated total revenue over 10 year period (aUR) = $520.6 million.

(see Appendix D, Table D.1 for details)

Case #2: Utility compromises maintenance to offset the need for annual retail rates increases (Figures 4.20 and 4.21). A distribution utility has been instructed to either reduce retail rates or at least not increase them. Interest rate to borrow money is high and the reliability of the supply is good.

The utility reduces maintenance cost (UCOM) and increases restoration cost (UCOR). There is a net reduction in utility costs and this reduction in cost (savings) is used to change retail rates. This is based on the results [143] that customer costs for each service interruption (SI) of duration d_i and frequency f_i is smaller than for the same total time of SI but smaller frequency f_j and longer duration d_j.

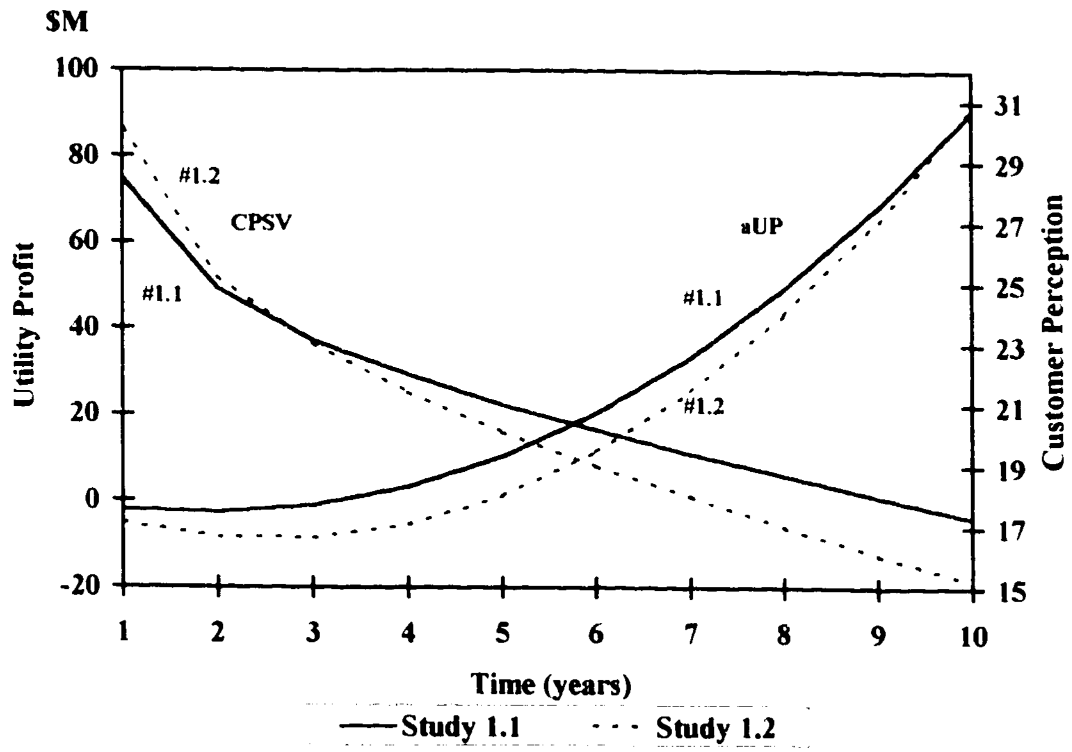


Figure 4.19: Same Total Revenue Using Different Retail Rates

Study #2.1 - Figure 4.20 illustrates that for the same retail rates, the level of customer satisfaction decreases as the quality of service decreases. The utility's profit increases as illustrated in Figure 4.21.

Study #2.2 - Customer satisfaction slightly increases over time (Figure 4.20). There is a slight annual rate decrease and the profits are in the tenth year (Figure 4.21).

Study #2.2: The level of customer perception can be maintained at a relatively constant value or can increase by further decreasing the retail rates (Figure 4.20).

Study #2.3 - A high initial rate structure (18.75% higher than the base value) and a large annual rate decrease (3.125%) improves the level of customer satisfaction from a low to the high value (Figure 4.20). The utility's profit increases and peaks in the fifth year and then decreases due to a large annual decrease in retail rates (Figure 4.21).

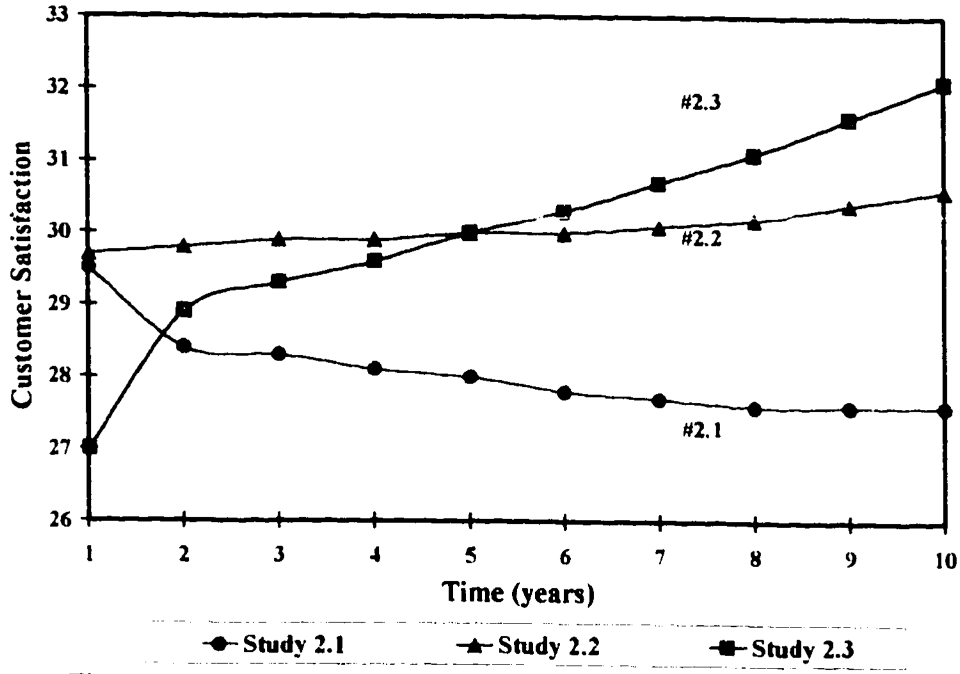


Figure 4.20: Variation of Customer Satisfaction with Respect to Changes in Quality of Service and Retail Rates

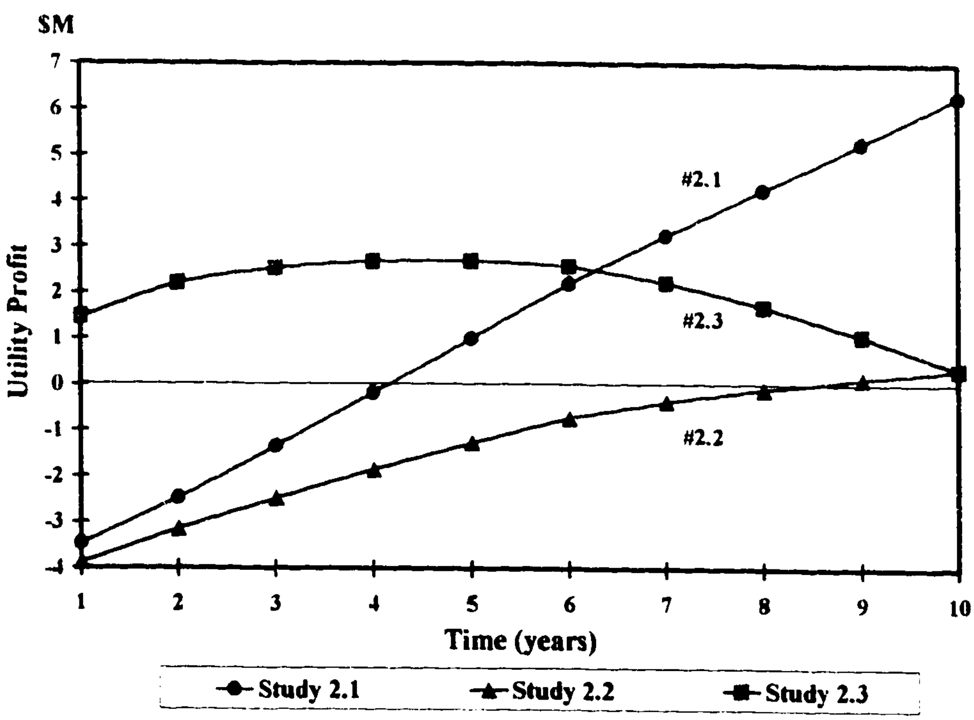


Figure 4.21: Variation of Utility Profit Due to Changes in Quality of Service and Retail Rates

These three case studies illustrate that, in the short-term, by decreasing the preventative maintenance costs and increasing the restoration costs, and thereby reducing the time of restoration of services, the retail rate can be slightly reduced and the utility can still make a profit.

Case #3: A distribution utility has some local generation which is increased annually to reduce future wholesale purchases from the main grid. Suddenly, the majority of nuclear generators supplying the main grid have been taken out of service resulting in a shortage of electricity. The study period is 10 years, during which time a policy directive to management is to reduce costs and minimize retail rate increases.

Study #3.1: Since available supply is less than customer demand, there is a cost of customer loss to the utility and the retail rates are to be held constant. The utility decides not to speed up the construction of local generation and experiences customer loss throughout the 10 year period. The level of customer satisfaction among the utility's customers slightly decreases over this time (Figure 4.22). The accumulated profit for a 10 year period is $30.47 million and the utility has a market to sell more electricity.

Study #3.2: The utility speeds up the construction of local generation to supply all electricity requirements and the retail rates are held constant. The utility correctly anticipates present and future customer load requirements and fiscally speeds up the construction of local generation capacity. After the sixth year, all customers are supplied and there is no longer customer loss (see Appendix D, Table D.3 for details).

Study #3.3: The utility overbuilds local generation and supply exceeds demand and the rates are held constant. There is a decrease in profit and the accumulated financial loss over the 10 year period is $18.6 million (Study #3.3(a)). In order to make the same profit in the tenth year as in Study #3.2, the utility annually increases its retail rates by an average of 1.7% (Study #3.3(b), Figure 4.23) (see Appendix D, Table D.3 for details).

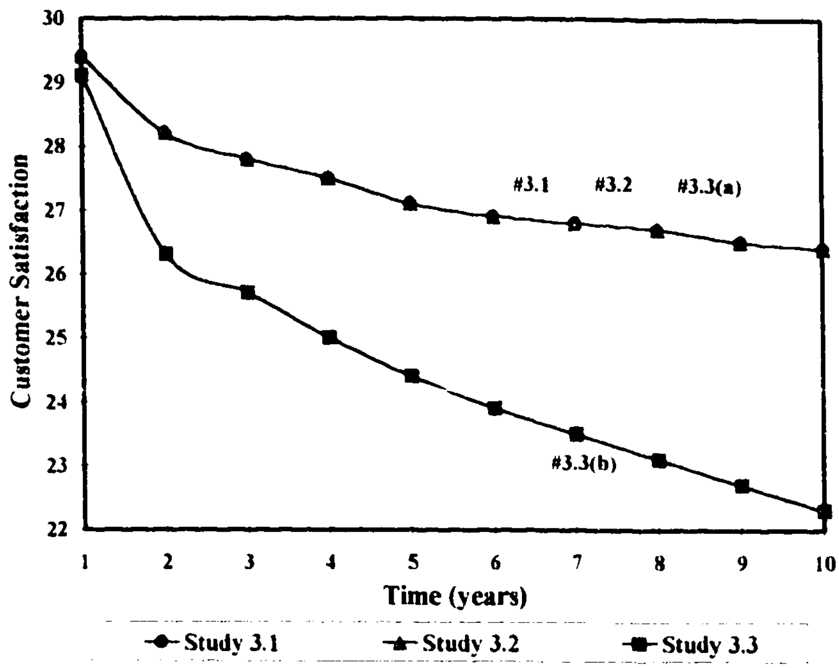


Figure 4.22: Customer Satisfaction Levels Due to Retail Rates and Availability of Electricity

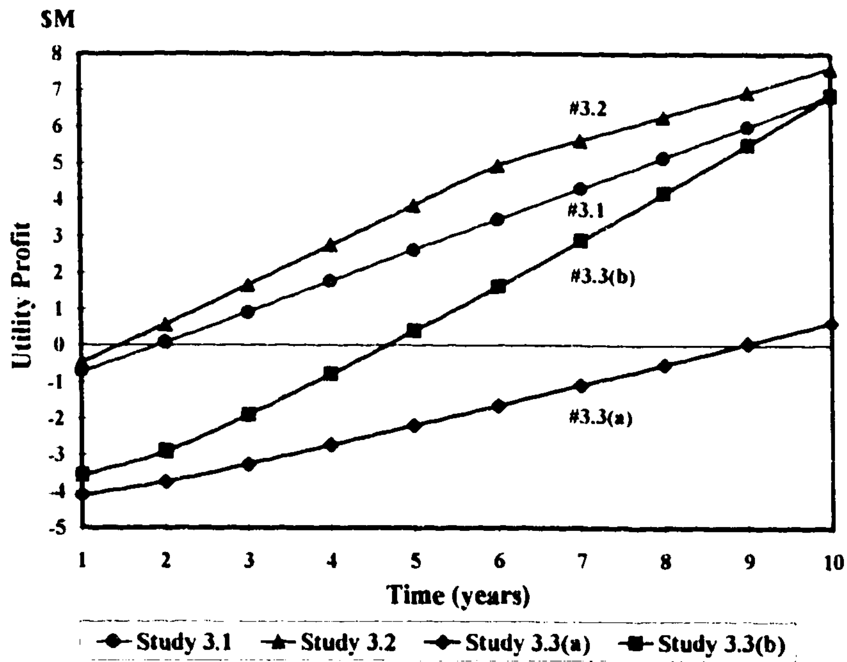


Figure 4.23: Utility Profits Due to Variation in Amount of Available Electricity

Observations: The previous three cases represent important issues facing utility management. The first case illustrates that for any given time period, there are various retail rate structures which can be used to obtain the same total utility revenue. Customer perception is influenced by both the magnitude of rates and rate stability. Figure 4.19 illustrates that customers prefer higher rates and smaller increases to lower initial rates and higher increases for the same total payment. In the second case, a utility reduces system maintenance in order to obtain funds to reduce retail rates. The reduction of the restoration time of service interruptions alleviates, in the short-term, the full cost impact of the increased number of service interruptions. Some utilities, facing rising labour and material costs, reduce their budgets to offset such cost increases in order to maintain low retail rates. The reduction of maintenance may become increasingly significant in future years, if there is a rapid deterioration of plant and equipment. Since distribution utilities are municipally owned, the most acceptable solution in case #2 would be Study #2.2, Figures 4.20 and 4.21 - small profit and improvements in customer satisfaction.

Case #3 addresses partial or total local generation to meet customer needs as a realistic alternative to wholesale purchases from the power pool. Electricity shortages can also be associated with high wholesale prices. These four studies illustrate that it is more economical to underbuild and lose customers (Study #3.2) than to overbuild and have stranded assets (Study #3.3(a)). The exception is either a guarantee of a certain market for electricity sales or that the utility has the legislated obligation to serve.

4.8 COGNITIVE LOGIC IN MANAGEMENT DECISIONS

The process of using cognitive logic in management decisions involves the definitions of five entities, as are described in Table 4.7. They are described in detail in the following subsections [148].

4.8.1 Formation of States

For a given set of parameters (p), a scenario involving the assignment of controls (u) to some values would lead to corresponding values of the states (x). For example, the state of customer satisfaction (x) is observed based on the values assigned to the control variable representing utility rates and the assumed given value of the parameter denoting customer wealth.

Table 4.7: Characteristics of Cognitive Decision Elements

Entity	Description	Example
parameter (p)	Constant problem data	Customer Wealth (CW)
control (u)	Manipulated variables	Utility Rates (URC)
state (x)	Function of (p) and (u)	Customer Satisfaction (CPS)
driving force (q)	The bias or a sensor of (x)	Customer Expectations (CPSE)
goal (g)	Ultimate or intermediate objective	Customer Perception (CP)

4.8.2 Realization of Goals

For all observed states (x) measured in relation to some driving forces (q), the goal (g) is said to be realized to a certain degree. For example, the goal of attaining a "high" degree of customer perception is realized based on the logical interaction of customer expectation and the state of customer satisfaction. These logical interactions take place by means of logical functions. The following are the details of such a formalized cognitive logical process.

4.8.3 Logical Functions

The notion that a given state (x) is influenced by both parameters (p) and controls (u) is formalized by saying that x is a logical function of p and u. For a given logical parameter (p), which is a logical constant, accessible and acceptable within its extent (range) from p_1, p_2, ... p_{N_p}, where N_p is the number of designations (logical values on the measuring scale) of p.

Similarly, a manipulated control (u) assumes a range of logical values from u_1 to u_{N_u}, where N_u is the number of designations of u. The logical function $\mathcal{L}_f$ is then a process of mapping or transforming the parameter (p) and control (u) into the state (x) using a set of optional guidelines.

That is, $x = \mathcal{L}_f(N_x, p, u)$ where p and u are arguments of the logical function and N_x is the required number of designations of x. The above concept can easily be generalized to multi-parameter and multi-control functions. Furthermore, the same notion applies to the goals (g) being logical functions of states (x) and driving forces (q).

4.8.3.1 Logical Proportion: One very important example of a logical function is the logical proportion function which maps increasing or intensifying values of the argument into increasing or intensifying values of the output variable.

4.8.3.2 Logical Inverse Proportion: Another important logical function is the logical inverse proportion which maps increasing or intensifying values of the argument into decreasing or decaying values of the output variable.

4.8.4 Logical Indices

We say that a state (x) is observed (measured) as designations $x_1, x_2, \ldots x_{N_x}$ based on a logical sense of ordering. The indices $1, 2, \ldots N_x$ represent the "ticks" on the logical scale on which x is observed. Any pair of designations p_i, u_j gives an observed designation of x. In the absence of any biasing effects (see Section 4.8.4.1), the number of grouped combinations of (p, u) designations for each designation of x_i; i = 1 to N_x is given by:

$$M_{x_i} = \frac{N_p N_u}{N_x}$$

The logical processing engine manipulates the indices of the variables involved in order to perform the mapping required. In this regard, the following principles are used.

4.8.4.1 Biasing: Biasing of the output quantity (for example, x) influences the number of combinations of (p , u) designations that define each designation of x . That is, (M_{x_1} $\neq$ M_{x_2} $\neq$ ... $\neq$ $M_{x_{N_x}}$). In general, x can be biased towards lower-order designations (M_{x_1} > M_{x_2} > ... > $M_{x_{N_x}}$) or towards higher-order designations (M_{x_1} < M_{x_2} < ... < $M_{x_{N_x}}$).

4.8.4.2 Weighting: Weighting affects the relative impact which each argument (for example, p or u) has on the output quantity (x). This, in effect, would determine where a particular combination of (p , u) designation is located within the designations of x .

4.8.5 Illustrative Application

Consider the dilemma of minimizing total utility cost (UC), the components of which are shown in Figure 4.24. Utility cost (UC) include cost of maintenance of the electrical system (UCOM), cost of repairs of service interruptions (UCOR), and the cost of reduced customer satisfaction (CPSB). Increases in the number (USON) and duration (USOD) of service interruptions would increase utility cost (UC) by reducing the customer satisfaction level (CPSB). On the other hand, the frequency (USON) and duration (USOD) of service interruptions are decreased and the cost of (loss of) customer satisfaction (CPSB) is reduced by increasing utility maintenance cost (UCOM) and service restoration cost (UCOR).

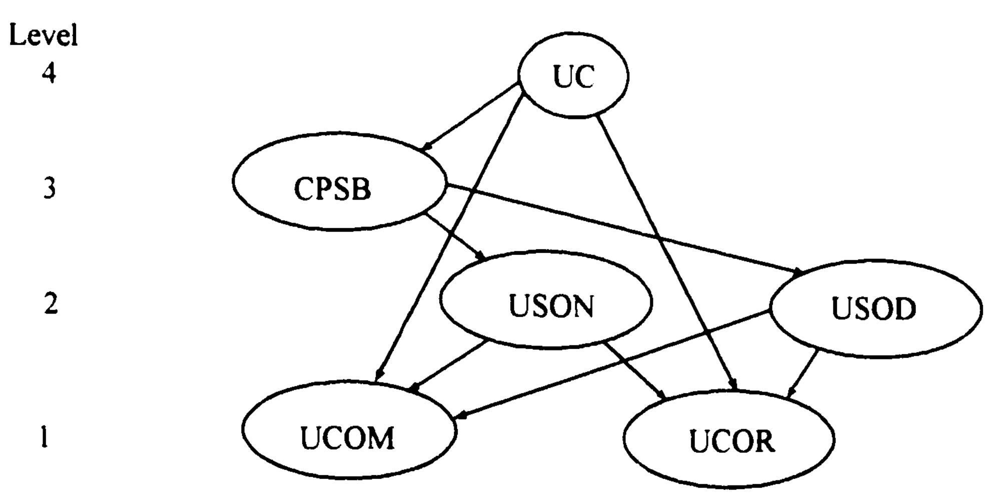


Figure 4.24: Hierarchical Logical Tree of Entities of Utility Cost

Level 4: Utility Cost (UC), which is a sub-goal for this relatively simple decision-making problem, is formed from the following states and controls:

i) Customer Perception Service Benefit (CPSB):

If customers do not receive benefits and are not satisfied, they may reduce usage or seek compensation.

ii) Utility Cost of Outage Maintenance (UCOM):

Utility spends funds to maintain the system in order to improve continuity of services.

iii) Utility Cost of Outage Restoration (UCOR):

Utility spends funds to repair damages and restore services due to power outages.

The utility cost (UC) can be expressed as a logical function:

$$UC = \mathcal{L}_4 \{ I_p(CPSB), P_r(UCOM, UCOR) \} \quad (4.13)$$

That is, utility cost (UC) increases as (CPSB) decreases (Logical Inverse Proportion (I_p), section 4.8.3.2) and both (UCOM) and (UCOR) increase (Logical Proportion (P_r), section 4.8.3.1).

It should be noted that in a more general and complex decision-making problem involving , for example, utility revenue (UR), both UC and UR may denote super-states (high-level states) formed from low-level states and/or controls. In this case, the sub-goal denoting utility profit (UP) may be defined as a logical function of UC and UR.

Level 3: Customer Perception of Service Benefit (CPSB) is a state formed from the following states:

i) Utility Service Outage Number (USON):

More outages mean more cost to customers and customer perception is reduced.

ii) Utility Service Outage Duration (USOD):

Longer outages are more costly to customers and customer perception is reduced.

CPSB can be expressed as a logical function:

$$CPSB = \mathcal{L}_3 \{I_p(USON), I_p(USOD)\} \quad (4.14)$$

That is, customer perception increases as both USON and USOD decrease (Logical Inverse Proportion (I_p), section 4.8.3.2).

Level 2: has two states (USON and USOD) described as follows:

(a) Utility Service Outage Number (USON) is a state formed from lower level controls:

i) Utility Cost of Outage Maintenance (UCOM):

More maintenance reduces the number of outages.

ii) Utility Cost of Outage Restoration (UCOR):

Faster restoration of more service interruptions reduces the number left to be restored and improves customer electricity supply.

The USON can be expressed as a logical function:

$$USON = \mathcal{L}_{2.1} \{I_p(UCOM), I_p(UCOR)\} \quad (4.15)$$

That is, the number of service interruptions increases as both UCOM and UCOR decrease (Logical Inverse Proportion (I_p), section 4.8.3.2).

(b) Utility Service Outage Duration (USOD) is a state formed from lower level controls:

i) Utility Cost of Outage Maintenance (UCOM).

ii) Utility Cost of Outage Restoration (UCOR).

The USOD can be expressed as a logical function:

$$USOD = \mathcal{L}_{2.2} \{I_p(UCOM), I_p(UCOR)\} \quad (4.16)$$

That is, the duration of service interruptions increases as both UCOM and UCOR decrease (Logical Inverse Proportion (I_p), section 4.8.3.2).

Level 1: has two controls (UCOM and UCOR) described as follows:

(a) Utility Cost of Service Maintenance (UCOM).

(b) Utility Cost of Outage Restoration (UCOR).

4.8.6 Solution

A logical proportion software program (CGLPR) [50] was used to solve the above problem. All logical variables are assumed to be measured on scales of three designations each. The three most favourable and feasible solutions are shown in Table 4.8.

Table 4.8: Study Case Results

V #	Name	Value	Description
Feasible Solution Number 1			
1	UC	Small	Total-Utility-Cost
2	UCOM	Small	Preventative-Maintenance-Budget
3	UCOR	Small	Outage-Restoration-Budget
4	CPSB	Negative	Customer-Perception
5	USON	Excessive	Number-of-Service-Interruptions
6	USOD	Long	Duration-of-Service-Interruptions
Feasible Solution Number 2			
1	UC	Medium	Total-Utility-Cost
2	UCOM	Small	Preventative-Maintenance-Budget
3	UCOR	Medium	Outage-Restoration-Budget
4	CPSB	Negative	Customer-Perception
5	USON	Excessive	Number-of-Service-Interruptions
6	USOD	Long	Duration-of-Service-Interruptions
Feasible Solution Number 3			
1	UC	Medium	Total-Utility-Cost
2	UCOM	Small	Preventative-Maintenance-Budget
3	UCOR	Large	Outage-Restoration-Budget
4	CPSB	50/50	Customer-Perception
5	USON	Moderate	Number-of-Service-Interruptions
6	USOD	Medium	Duration-of-Service-Interruptions

Table 4.8 illustrates that the lowest feasible utility cost (measured on the logical scale as small, medium, high) is small if the state CPSB and two controls UCOM and UCOR are at their extreme logical designations. For this solution, see Appendix E for details. The comparison of solutions #1 and #2 illustrates that, although UCOR was increased from "small" to "medium", the quality of service USON and USOD did not change and, consequently, CPSB remained "negative" resulting in UC increase from "small" to "medium". Solutions #1 and #3 show that by further increasing UCOR from "small" to "large", the quality of service improves; USON decreased from "excessive" to "moderate" and USOD from "long" to "medium" and, hence, CPSB increased from "negative" to "50/50". Nevertheless, the UC remained at "medium".

4.9 CONCLUSIONS

This chapter has addressed complex issues of managing a distribution utility as a business and cost-effectively fulfilling customers' electrical needs/requirements. It was shown that time variable retail rates provide customers with flexibility, choices, and more control over their own costs. Such rates are the utility's incentives to persuade the customers to use less electricity when the utility's cost is high, and to use more when the corresponding costs are lower. Any resulting utility savings can be used to either improve services, reduce the cost to customers or increase the utility's profits. Customer costs include the cost of the commodity and also the cost of service interruptions. The level of customer satisfaction depends upon the benefits obtained for the costs incurred, taking into account customer expectations. The customer forms a perception regarding the utility's operations based on the perception of accumulated benefits obtained over time.

The case studies of a time-trending process illustrate the available management decision alternatives. It has been shown that a utility can still obtain the same total revenue over a specified period of time, even if it uses different rate structures. Some rate structures are more acceptable to customers than others. Customer perception is influenced by both the magnitude of retail rates and retail rate stability. Therefore, if the utility adopts higher initial rates and smaller annual increases, rather than smaller initial rates and larger annual increases, the same total revenue can be collected and the rate structure is more acceptable to customers. The utility also makes a slightly higher profit.

It has been shown that the impact of a rate reduction has a more positive effect in terms of improving customer satisfaction, than the negative impact due to reduction in the quality of service. Satisfying customers reduces some utility costs, but there is an overall increase in the utility's total cost and revenue due to increased electrical usage. The utility can, in the short-term, reduce both maintenance costs and retail rates, in order to satisfy customers and fulfil the directives of elected officials to hold down electricity prices.

An important issue facing distribution utilities is to obtain sufficient electricity, either from local generation or from wholesale purchases, to meet customer load requirements. It has been shown that a utility incurs costs when it loses customers due to electricity shortages. However, the utility incurs higher costs when the commitment to supply exceeds customer load. Costs associated with either shortages or surpluses of electricity are important in the utility's operations, since over 85% of all costs for most utilities is for wholesale electricity. Such costs are addressed differently by a monopolistic public utility, which has an obligation to serve, than by a de-regulated utility or a private company whose main objective is to maximize profits and minimize costs.

The application of Logical Proportion Analysis (LPA) methodology illustrates a logical non-numerical decision solution process. Results obtained using this concept were similar to the previous cases. The objective was to minimize utility cost. Numerical solution methodology was replaced by manipulation of word entities. The cost of quality of service improvements, which increased customer satisfaction, were evaluated against the cost of not making such improvements. This methodology, using cognitive decision elements, provided three feasible solutions for the given number of indices.

In these three solutions, UCOM was "small" and UC ranged from one solution as "small" to two solutions as "medium". UCOR ranged from "small" to "medium" to "large". The corresponding CPSB ranged from "negative" in solutions #1 and #2 to "50/50" in solution #3. This was a trade-off for increasing the cost of UCOR from "small" to "large" and corresponding improvement in quality of service USON from "excessive" to "moderate" and USOD from "long" to "medium". This improved CPSB from "negative" to "50/50" and maintained the UC as "medium" for both solutions #1 and #2.

CHAPTER 5
CONCLUSIONS

5.1 SUMMARY

This thesis addresses the challenges and uncertainties facing the electrical power industry. As a result of the "unbundling" of the monopolistic generation and transmission enterprises into a free-market economy, power distribution utilities are faced with very difficult decisions pertaining to electricity supply options and quality of service to the customers. In this regard, the management of distribution utilities has become increasingly complex, versatile, and dynamic to the extent that conventional, non-automated management tools are almost useless and obsolete.

An important issue facing electrical distribution utilities is the decision of whether to continue to purchase from a main grid, or to generate locally (partially or totally) via building Non-Utility Generation (NUG). This dilemma has been modelled, formulated, and solved in the thesis using advanced Mixed Integer Programming (MIP) optimization techniques. In addition, the optimization methodology enables a wide class of other distribution utility management problems to be analyzed and solved accurately. The formulation identifies various management components as cost functions, dynamic data, decision variables, and operating constraints. The decision variables are, in turn, classified into continuous variables and discrete variables in a coherent hierarchical structure. Different management problems are then addressed via proper selection of the cost functions, variables, and constraints.

The thesis also addresses the delicate and important balance between the price of electricity, and the quality of delivery, and customer perception. In the general and unified framework established, electricity is viewed as a commodity. Customers form perceptions regarding both the quality of service and the magnitude of the retail rate structure. The customers' electricity bill has two controllable components. One component – electrical rates – is controlled by the utility, and the other component – electrical load – is controlled by the customer. The utility establishes the magnitude of retail rates, while the customer establishes the magnitude of the electrical load and the time when that load occurs. The combination of rates and load affect the customers' direct cost. This amount is also the utility revenue. The major cost to a distribution utility is the source of electricity – wholesale purchases and/or local generation. The major influence on whether or not to build local generation is the impact of increases on wholesale electricity prices.

It has been shown that time-variable retail rates provide customers with flexibility, choices, and more control over their own costs. Existing numerical techniques, which may have been sufficient in the past, are no longer adequate to solve complex utility problems. Both tangible and intangible components have now become important in the utility's operations. The nature of utilities is no longer monopolistic, and customer perception - an intangible quantity - becomes an important influence. Environmental influences also require the inclusion of intangible components. In the past, these were considered unimportant, and solution methodologies were not available to include them. The structure of the present system, which has become a consumer-oriented society, requires the inclusion of customer views and concerns for the utility's very survival.

While conventional optimization techniques are very effective in solving a range of utility management problems, their "number-crunching" nature prevents full realization and incorporation of complex intangible quantities, such as customer loss of confidence, public response to service deterioration, etc. In a further development, a logical framework of the problem has been constructed which enables utility management to optimize all cost components, whether tangible or intangible, and assess their time-trend impacts. Chapter 3 deals with the trade-off solutions associated with wholesale purchases and local generation for specified periods of time. Chapter 4 introduces the concept of time-trending. Using this process, it has been demonstrated that past events, including intangible components, such as levels of customer satisfaction accumulated over time, create a level of customer perception which has an impact upon the utility's costs.

The above concepts were generalized and a Logical Proportion Analysis (LPA) methodology and MATLAB-based software were developed which accommodate various problem entities involving parameters, controls, states, driving-forces, sub-goals, and goals. This novel technique has been applied to the practical problem of finding the optimal time-phased rate structure of a distribution utility, taking into account various physical, social, and financial constraints. Solutions using numbers have been replaced with solutions using words. This is an advancement in the art of decision-making, formulating, and solving.

This process removes limitations associated with numerical data by enabling the inclusion of any defined intangible components. This is important, since customer views and opinions are usually expressed first in words, then transformed into numbers for numerical solution. The numerical outcome is then transformed back into words, or interpreted as concepts which are based on words. The Logical Proportion Analysis (LPA) methodology processes words and provides the solution in words, which more closely emulates the human decision-making process, thus ensuring higher accuracy of representation and more completeness of solutions. The input of such broad-based solutions, which include both tangible and intangible cost components, is to minimize unforeseen and unexpected consequences due to the utility's actions.

5.2 MAIN THESIS CONTRIBUTIONS

The following are the main contributions of this thesis:

- Identified and included intangible components of the cost of utility operations. In the past, these intangible components, such as customer perception, have not been formally included in any cost analysis.
- Developed a tool, using an advanced Mixed Integer Programming (MIP) optimizing technique, to minimize this new, expanded cost function. Different management problems can then be addressed via proper solution of cost functions, variables, and constraints.
- Developed a time-trending solution, using the novel UCOST computer program, to include intangible cost components and their cumulative effect upon customer costs over time. These include the level of customer satisfaction resulting from customers evaluating the cost of the commodity and quality of service provided. Over time, customers form

perceptions which influence their actions of either continuing purchases from the utility or to seeking substitutes.

◆ Developed a tool, using Logical Proportion Analysis (LPA) methodology and MATLAB-based software, to obtain various managerial decision solutions. This novel technique has been applied to the practical problem of finding the minimum cost of distribution utility operations.

5.3 SUGGESTIONS FOR FUTURE WORK

This thesis has laid the foundation for a new, comprehensive, and meaningful approach to the distribution utility decision-making process. Future research work could build upon this foundation in the following three areas:

- Extend the range of intangible factors included in this work, for example, environmental impacts and government fiscal policies. This would require more in-depth analysis, as well as pertinent user surveys and financial data.
- Expand the size of decision-making models to better reflect the complexities of our social structure by using more advanced optimization techniques, such as large-scale separable programming.
- Apply the approach developed in this thesis to areas of management outside the power utility industry.

APPENDIX A: DETAILED MIP FORMULATION

The following expressions are used in the formulation of variables, parameters, and constraints required for the solution of the cost-objective function described in Chapter 3, Section 3.4.

A.1 VECTOR VALUES OF DECISION VARIABLES

$$\mathbf{z} = \begin{bmatrix} x \\ y \end{bmatrix} \quad \mathbf{x} > \mathbf{0} \ , \ \mathbf{y} > \mathbf{0} \qquad \text{(A1)}$$

where

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \ \text{(A2)}, \qquad \mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix} \ \text{(A3)}, \qquad \mathbf{p} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_t \end{bmatrix} \qquad \text{(A4)}$$

continuous variables — discrete variables — parameters (input data)

Linear constraints:

$$\mathbf{c}\,(\,\mathbf{z}\,,\mathbf{p}\,) \begin{bmatrix} \le \\ = \\ \ge \end{bmatrix} \mathbf{0} \qquad \text{(A5)}$$

Equation (A5) written in matrix form:

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1(n+m)} \\ a_{21} & & & \\ \vdots & & & \\ \vdots & & a_{ij} & \\ \vdots & & & \\ a_{s1} & a_{s2} & \cdots & a_{s(n+m)} \end{bmatrix} \times \begin{bmatrix} x_1 \\ \vdots \\ \vdots \\ x_n \\ y_1 \\ \vdots \\ \vdots \\ y_m \end{bmatrix} > \begin{bmatrix} b_1 \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ b_s \end{bmatrix} \qquad \text{(A6)}$$

A.2 TOTAL COST-OBJECTIVE FUNCTION $f(\mathbf{z}, \mathbf{p})$

The cost-objective function $f(\mathbf{z}, \mathbf{p})$ consists of two parts, $f_1(\mathbf{z}, \mathbf{p})$ and $f_2(\mathbf{z}, \mathbf{p})$.

where:

$f_1(\mathbf{z}, \mathbf{p})$ = total direct monetary cost-objective function weighted by w_1.

$f_2(\mathbf{z}, \mathbf{p})$ = total indirect monetary cost-objective function weighted by w_2.

$$f(\mathbf{z}, \mathbf{p}) = w_1 f_1(\mathbf{z}, \mathbf{p}) + w_2 f_2(\mathbf{z}, \mathbf{p}) \qquad \text{(A7)}$$

and

$$f_1(\mathbf{z}, \mathbf{p}) = \sum_{j=1}^{q} w_{1j} f_{1j}(\mathbf{z}, \mathbf{p}) \qquad \text{(A8)}$$

w_{1j} are weighted components associated with the respective components $f_{1j}(\mathbf{z}, \mathbf{p})$ of direct costs.

$$f_2(\mathbf{z}, \mathbf{p}) = \sum_{k=1}^{r} w_{2k} f_{2k}(\mathbf{z}, \mathbf{p}) \qquad \text{(A9)}$$

w_{2k} are weighted components associated with the respective components $f_{2k}(\mathbf{z}, \mathbf{p})$ of indirect costs.

A.2.1 Variables, Parameters and Constraints

The objective cost function $f(\mathbf{z}, \mathbf{p})$ is minimized with respect to this set of optimizing variables $\mathbf{z} = \begin{bmatrix} x \\ y \end{bmatrix}$ subject to a given set of constraints $\mathbf{c}(\mathbf{z}, \mathbf{p})$ and parameters $\mathbf{p}$.

A.2.1.1 Variables $\mathbf{x}, \mathbf{y}$

$\mathbf{x}$ = Continuous Variables

x_1 = Amount of wholesale power purchased (MW)

x_2 = Amount of Self Generation (MW)

x_3 = Retail power rate to customers ($K/MW)

x_4 = Change in amount of power generation (MW/time-period)

x_5 = Change in amount of wholesale power purchased (MW/time-period)

x_6 = Retail power rate change ($K/MW/time-period)

x_7 = Retail energy rate ($K/MWh)

x_8 = Retail energy rate change ($K/MWh/time-period)

x_9 = Cost of maintenance ($K)

x_{10} = Change in cost of maintenance ($K/time-period)

x_{11} = Utility budgets (operating and capital)

x_{12} = Change in utility budgets ($K/time-period)

y = Integer Variables

y_1* = Level of CP in relation to number of service interruptions (SI) (Number)

y_2 = Number of SI (Number)

y_3 = Number of 50MW NUG units

y_4 = Change in number of NUG units (Number/time-period)

y_5* = Change in CP due to changes in number of SI

y_6 = Change in number of SI (Number/time-period)

y_7* = CP in relation to retail power rates (Number/$K/MW)

y_8* = Change in the level of CP due to changes in retail power rates (Number/$K/MW/time-period)

y_9* = Level of CP in relation to retail energy rates (Number/$K/MWh)

y_{10}* = Change in CP due to changes in retail energy rates (Number/$K/MWh/time-period)

y_{11} = Number of 20MW NUG units

y_{12} = Change in number of 20MW NUG units (Number/time-period)

y_{13} = Number of 30 MW NUG units

y_{14} = Change in number of 30MW NUG units (Number/time-period)

y_{15} = Political concerns (Number)

y_{16} = Change in political concerns (Number/time-period)

* In some case studies, these were processed as continuous variables.

A.2.1.2 Parameters **p** (data)

(p_1 to p_{14}): Wholesale rate, system load and increases. NUG characteristics, employee wages, and pollution levels.

(p_{15} to p_{50}): Customer social and financial values. Environmental impacts, equipment rating, physical space limitations, costs for NUG capital, installations, labour, and fuel. Time coefficient relating CP to SI, QOS, retail rates and operating standards.

(p_{51} to p_{116}): Variations in budgets, cost of maintenance, and cost for improvements in CP. Boundary conditions and limitations of CP, QOS, and retail rates. Political costs and scaling factors.

(p_{117} to p_{135}): Billing diversity factors and revenue. Critical values of CP and relative importance of CP with respect to QOS and retail rates. Political impacts.

A.2.1.3 Constraints **c (z , p , t)** : where t = the time period and ranges from t = 1 (the present) to n_t and t for computation purposes.

c_1 (**z** , **p** ,t): Deterministic, Nominal Source of Electricity = Nominal Customer Load

$$x_1 + x_2 = p_8$$

c_2 (**x** , **p** , t) Probabilistic: Sources and load assumed to be random variable having Gaussian Distribution with confidence level of 95%

Lowest Amount of Available Electricity	>	Largest Load Requirement

$$p_{10}(x_1 + t\,x_5) + p_{11}(x_2 + t\,x_4) \geq p_{14}(p_8 + t\,p_9)$$

c_3 (**y** , **p** , t): Number and ratings of NUG units required for local generation.

$$p_5\,(y_3 + t\,y_4) + p_{95}\,(y_{11} + t\,y_{12}) + p_{96}\,(y_{13} + t\,y_{14}) \geq x_2 + t\,x_4$$

c_4 (**y** , **p** , t): Physical space restrictions for NUG units.

$$p_4\,(y_3 + t\,y_4) + p_{97}\,(y_{11} + t\,y_{12}) + p_{98}\,(y_{13} + t\,y_{14}) \leq p_{19}$$

c_5 (**x** , **p** , t): Limitations of transmission line capacity regarding wholesale electricity purchases.

$$p_{12}\,(x_1 + t\,x_5) \leq p_{18}$$

$c_6(\mathbf{x}, \mathbf{p}, t)$: Retail power rates must not be less than wholesale power rates.

$$(p_8 + t\, p_9)(x_3 + t\, x_7) \geq (p_1 + t\, p_{33})(x_1 + t\, x_5)$$

$c_7(\mathbf{x}, \mathbf{p}, t)$: Retail energy rates must not be less than wholesale energy rates.

$$(p_8 + t\, p_9)(x_7 + t\, x_8) \geq (p_{59} + t\, p_{63})(x_1 + t\, x_5)$$

$c_8(\mathbf{y}, \mathbf{p}, t)$: Present and future service interruption standards.

$$(y_2 + t\, y_6) \leq p_{40}$$

$c_9(\mathbf{y}, \mathbf{p}, t)$: Influences of service interruptions upon customer perception.

$$(y_1 + t\, y_5) = p_{41} - p_{42}(y_2 - t\, y_6)$$

$c_{10}(\mathbf{y}, \mathbf{p}, t)$: Constraints of customer perception with reference to the number of service interruptions.

$$(y_1 + t\, y_5) \leq p_{41}$$

$c_{11}(\mathbf{x}, \mathbf{p}, t)$: Constraints for retail power rates and increases.

$$(x_3 + t\, x_6) \leq p_{17}$$

$c_{12}(\mathbf{x}, \mathbf{p}, t)$: Constraints for retail energy rates and increases.

$$(x_7 + t\, x_8) \leq p_{70}$$

$c_{13}(\mathbf{x}, \mathbf{p}, t)$: Constraints for % power cost increases.

$$p_{77}\, t\, x_6 \leq x_3$$

$c_{14}(\mathbf{x}, \mathbf{p}, t)$: Constraints for % energy cost increases.

$$p_{78}\, t\, x_8 \leq x_7$$

$c_{15}(\mathbf{y}, \mathbf{p}, t)$: Relationship of power rates and effects upon customer perception.

$$(y_7 + t\, y_8) \leq p_{43} - p_{16}(x_3 - t\, x_6)$$

$c_{16}(\mathbf{y}, \mathbf{p}, t)$: Relationship of retail energy rates and effects upon customer perception.

$$(y_9 + t\, y_{10}) \leq p_{79} - p_{71}(x_7 - t\, x_8)$$

$c_{17}(\mathbf{x}, \mathbf{p}, t)$: Environmental concerns and pollution restrictions.

$$p_{26}(x_1 + t\, x_5) + p_{27}(x_2 + t\, x_4) \leq p_{28}$$

$c_{18}(\mathbf{z}, \mathbf{p}, t)$: Relationship of maintenance and the number of SI.

$$x_9 + t\, x_{10} = p_{81} - p_{82}(y_2 - t\, y_6)$$

$c_{19}(\mathbf{y}, \mathbf{p}, t)$: Relationship of CP and political concerns.

$$y_1 + t\, y_5 + y_7 + t\, y_8 + y_9 + t\, y_9 + y_{15} + t\, y_{16} \leq p_{131}$$

c_{20} (**x** , **p** , t): Limitations upon total utility expenditures in abbreviated form.

Utility capital and operating budgets (present and future changes)	+	Utility's extra maintenance, repair costs, and QOS improvements	≤	Not to exceed (p_{130}) specified as 30% of utility's total revenue
(x_{11}, x_{12}, p_8, p_{109}, p_{110}, p_{111} , t)		(x_9, x_{10}, p_{83}, p_{84} , t)		(x_3, x_6, p_{rev}, p_{revf}, p_{62} , t)

A.2.2 Direct and Indirect Costs

The total cost of utility operations is the sum of direct and indirect costs.

A.2.2.1 Direct Costs

A.2.2.1 Direct Costs f_1 (**z** , **p** , t): The time period of study ranges from t = 1 to n_t and t = t - 1 for computation purposes.

$f_{1,1}$ (**x** , **p**): Wholesale power purchase costs.

$$= \sum_{t=1}^{n_t} (x_1 + t\, x_5)\,(p_1 + t\, p_{33})\, p_{62}$$

$f_{1,2}$ (**x** , **p**): Wholesale energy purchase costs.

$$= \sum_{t=1}^{n_t} (x_1 + t\, x_5)\,(p_{59} + t\, p_{63})\, p_{61}\, p_{120}$$

$f_{1,3}$ (**y** , **p**): Cost of labour for NUG's.

$$= \sum_{t=1}^{n_t} [\, y_3 (p_3 + t\, p_{35}) + t\, y_4 (p_3 + t\, p_{35})]\, p_6$$

$$+ \sum_{t=1}^{n_t} [\, y_{13} (p_3 + t\, p_{35}) + t\, y_{14} (p_3 + t\, p_{35})]\, p_{99}$$

$$+ \sum_{t=1}^{n_t} [\, y_{11} (p_3 + t\, p_{35}) + t\, y_{12} (p_3 + t\, p_{35})]\, p_{100}$$

$f_{1,4}$ (**x** , **p**): Cost of fuel for NUG's.

$$= \sum_{t=1}^{n_t} (x_2 + t\, x_4)\,(p_{64} + t\, p_{68})\, p_{61}\, p_{66}$$

$f_{1,5}(\mathbf{x}, \mathbf{p})$: Revenue from retail power rates.

$$= -\sum_{t=1}^{n_t} (x_3 + t\,x_6)(p_{rev} + t\,p_{revf})\,p_{62}$$

Where: p_{rev}: present revised billing demand value.

p_{revf}: future revised billing demand value.

$f_{1,6}(\mathbf{x}, \mathbf{p})$: Revenue from retail energy rates

$$= -\sum_{t=1}^{n_t} (x_7 + t\,x_8)(p_8 + t\,p_9)\,p_{61}$$

Installation Costs for the various NUG units $f_{1,7}(\mathbf{x}, \mathbf{p})$

= sum of present costs for present installations

+ sum of present installation costs and future increases in installation costs amortized over the n_t time period.

$f^{5}_{1,7}(\mathbf{y}, \mathbf{p})$: For 50MW NUG units.

$$= \sum_{t=1}^{n_t} y_3\,p_{36} + t\,y_4\,(p_{36} + t\,p_{37})$$

$f^{3}_{1,7}(\mathbf{y}, \mathbf{p})$: For 30MW NUG units.

$$= \sum_{t=1}^{n_t} y_{13}\,p_{105} + t\,y_{14}\,(p_{105} + t\,p_{106})$$

$f^{2}_{1,7}(\mathbf{y}, \mathbf{p})$: For 20MW NUG units.

$$= \sum_{t=1}^{n_t} y_{11}\,p_{107} + t\,y_{12}\,(p_{107} + t\,p_{108})$$

Capital Cost for NUG units $f_{1,8}(\mathbf{z}, \mathbf{p})$

Amortized over the n_t time period.

$f^{5}_{1,8}(\mathbf{y}, \mathbf{p})$: For 50MW NUG units.

$$= \sum_{t=1}^{n_t} y_3\,p_{90} + t\,y_4\,(p_{90} + t\,p_{91})$$

$f_{1.8}^{3}(\mathbf{y}, \mathbf{p})$: For 30MW NUG units.

$$= \sum_{t=1}^{n_t} y_{13}\, p_{103} + t\, y_{14}\, (p_{103} + t\, p_{104})$$

$f_{1.8}^{2}(\mathbf{y}, \mathbf{p})$: For 20MW NUG units.

$$= \sum_{t=1}^{n_t} y_{11}\, p_{101} + t\, y_{12}\, (p_{101} + t\, p_{102})$$

$f_{1.9}(\mathbf{x}, \mathbf{p})$: Annual cost of system maintenance.

$$= \sum_{t=1}^{n_t} (x_9 + t\, x_{10})\, (p_{83} + t\, p_{84})$$

$f_{1.10}(\mathbf{z}, \mathbf{p})$: Annual capital and operating budgets.

$$= (p_8\, p_{110} / p_{111}) \sum_{t=1}^{n_t} [x_{11} + t\, x_{12}\, p_{109}]$$

A.2.2.2 Indirect Costs $f_2(\mathbf{z}, \mathbf{p}, t)$

$f_{2.1}(\mathbf{y}, \mathbf{p})$: Community impact costs

$$= -\sum_{t=1}^{n_t} [\,(y_3 + t\, y_4)\, p_6\, p_{25} + (y_{13} + t\, y_{14})\, p_{99}\, p_{25} + (y_{11} + t\, y_{12})\, p_{100}\, p_{25}\,]$$

This is a negative cost in that the formation of an industry in a local community has a positive financial impact (e.g. creation of jobs, spending of funds locally, etc.).

$f_{2.2}(\mathbf{x}, \mathbf{p})$: Pollution Associated Costs

$$= \sum_{t=1}^{n_t} p_{29}\, (x_2 + t\, x_4)$$

$f_{2,3}(\mathbf{x}, \mathbf{p})$: Customer Credits and Regulatory Distribution Costs

$$= [\sum_{t=1}^{N_t} (x_3 + t\, x_6)(p_{rev} + t\, p_{revt})\, p_{62}$$

$$+ \sum_{t=1}^{N_t} (x_7 + t\, x_8)(p_8 + t\, p_9)\, p_{61}\,]\,(1 - p_{30})$$

$f_{2,4}(\mathbf{y}, \mathbf{p})$: Customer Service Interruption Costs

$$= \sum_{t=1}^{N_t} (y_2 + t\, y_6)(p_{45} + t\, p_{76})$$

(Customers incur costs when their services are interrupted.)

$f_{2,5}(\mathbf{y}, \mathbf{p})$: Customer Perception Costs Due to Quality of Service

$$= -\sum_{t=1}^{N_t} (y_1 + t\, y_5)(p_{46} + t\, p_{89})$$

i.e. If customers view the utility well, then the utility benefits (higher sales, more tolerance regarding utility operations, and even rate increases).

$f_{2,6}(\mathbf{y}, \mathbf{p})$: Retail Power Rates Effects Upon Customer Perception (CP)

$$= -\sum_{t=1}^{N_t} (y_7 + t\, y_8)(p_{47} + t\, p_{86})$$

$f_{2,7}(\mathbf{y}, \mathbf{p})$: Retail Energy Rates Effects Upon Customer Perception (CP)

$$= -\sum_{t=1}^{N_t} (y_9 + t\, y_{10})(p_{85} + t\, p_{87})$$

$f_{2,8}(\mathbf{y}, \mathbf{p})$: Political Costs Associated with Levels of CP

$$= \sum_{t=1}^{N_t} (y_{15} + t\, y_{16})(p_{48} + t\, p_{49})$$

APPENDIX B: TIME VARIABLE RATES

The availability of time variable rates provides customers with more choices. The amount of electricity used may increase, decrease or shift to another time period. The following is a description of relationships and values of customer elasticity coefficients used in the problem formulation in Chapter 4, Section 4.6.

B.1 EXPRESSION FOR CONSERVATION AND LOAD SHIFTS [116, 117]

$$\ln\left(\frac{q_{i,t}}{q_{i,t-1}}\right) = \sum_{j=1}^{2} (\tau_{i,j} + \eta_i \phi w_j) \ln\left(\frac{P_{j,t}}{P_{j,t-1}}\right) \qquad \text{(B1)}$$

i = 1; for off-peak

i = 2; for on-peak

where q_i is the energy (kWh) consumption:

$q_{i,t}$; time-of-use rates

$q_{i,t-1}$; non time-of-use rates

$\tau_{i,j}$; aggregate compensation price elasticity

$$= \frac{\text{\% change in quantity of electricity used in period i}}{\text{\% change in price of electricity in period j}}$$

η_i ; expenditure effects; (expenditure elasticity for period i)

$$= \frac{\text{\% change in the quantity of electricity in period i}}{\text{\% change in total expenditure on electricity}}$$

ϕ ; overall elasticity of demand for electricity;

ϕ = - 0.02 for Winter

ϕ = - 0.01 for Summer

w_j ; % of expenditure in time j (i.e. relative energy usage of on-peak and off-peak periods relative to the total energy usage over the time period considered).

P_j ; relative prices of electricity rates

$P_{j,t}$ = price of electricity at time-of-use rates

$P_{j,t-1}$ = price of electricity at non time-of-use rates.

Expression (B1) means that the change in the ratio of the amount of electricity used, due to the change from non TOU rates to TOU rates, has two components for each of the two time periods:

i) Increase or decrease in usage in a given time period (on-peak or off-peak) as a result of price variation within that time period (on-peak or off-peak).

PLUS

ii) Increase or decrease in usage in a given time period (on-peak or off-peak) as a result of price variation within another time period (on-peak or off-peak).

If the rates are higher during on-peak periods, a portion of usage may be curtailed and another portion may be time displaced to the off-peak period where the rates are less. Similarly, during the off-peak period, due to rate reduction, customers may use more. The increased usage may simply be due to the cost of the commodity being cheaper. The price/demand elasticity at that period of day, and the time displacement of loads due to price escalations during the on-peak hour periods, may encourage further increases in overall usage of electricity.

B.2 TABULATION OF PRICE/DEMAND ELASTICITIES

Aggregate compensation time elasticity $\tau_{i,j}$ reflects the effect of electricity usage at one time due to price changes at another time. Four coefficients are utilized to quantify these interactions:

$\tau_{1,1}$: Effect of off-peak price upon off-peak usage.

$\tau_{1,2}$: Effect of off-peak price upon on-peak usage.

$\tau_{2,1}$: Effect of on-peak price upon off-peak usage.

$\tau_{2,2}$: Effect of on-peak price upon on-peak usage.

From published data [117] are the following usage tables;

Table B.1: Aggregate Compensation Price Elasticity Values

Winter			Summer		
Scenario #1: Rate Cell #16					
	off-peak usage	on-peak usage		off-peak usage	on-peak usage
off-peak price	- 0.033	0.015	off-peak price	-0.040	0.040
on-peak price	0.013	- 0.018	on-peak price	0.019	- 0.019
Scenario #2: Rate Cell #11					
	off-peak usage	on-peak usage		off-peak usage	on-peak usage
off-peak price	- 0.011	0.011	off-peak price	- 0.025	0.025
on-peak price	0.022	- 0.022	on-peak price	0.071	- 0.071
Scenario #3: Rate Cell #4					
	off-peak usage	on-peak usage		off-peak usage	on-peak usage
off-peak price	- 0.034	0.034	off-peak price	- 0.040	0.040
on-peak price	0.017	- 0.017	on-peak price	0.019	- 0.019

Table B.2: Summary of Calculation of Electricity Expenditure Elasticities η_i By Time of Day For Winter and Summer Seasons
(Electric Expenditure elasticities reflect customer preference of usage during certain hours of the day.)

B.2.1 Winter Conditions

Scenario #	Rate Cell	On-Peak Period (i = 2)			Off-Peak Period (i = 1)		
		Period	Duration	η_2	Period	Duration	η_1
#1	Rate Cell #16	5:30 pm - 8:45 pm	3¼ hrs	0.81	8:45 pm - 5:30 pm	20¾ hrs	1.02
#2	Rate Cell #11	4:15 pm - 10:00 pm	5¾ hrs	0.85	10:00 pm - 4:15 pm	18¼ hrs	1.10
#3	Rate Cell #4	10:00 am - 12:30 am	14½ hrs	0.94	12:30 am - 10:00 am	9½ hrs	1.20

B.2.2 Summer Conditions

Scenario #	Rate Cell	On-Peak Period (i = 2)			Off-Peak Period (i = 1)		
		Period	Duration	η_2	Period	Duration	η_1
#1	Rate Cell #16 #1.1	3:45 pm - 6:00 pm	2¼ hrs	0.99	6:00 pm - 3:45 pm	21¾ hrs	1.00
	Rate Cell #16 #1.2	7:00 pm - 10:30 pm	3½ hrs	0.71	10:30 pm - 7:00 pm	20½ hrs	1.06
#2	Rate Cell #11	3:30 pm - 11:00 pm	7½ hrs	0.82	11:00 pm - 3:30 pm	16½ hrs	1.07
#3	Rate Cell #4	11:15 am - 12:00 am	12¾ hrs	0.97	12:00 am - 11:15 am	11¼ hrs	1.03

Table B.3: Calculation of Values of w_j Relative Energy Usage Between On-Peak and Off-Peak Periods For Winter and Summer Seasons

B.3.1: Winter Conditions

Scenario # and Rate Cell	Relative Amount of Energy Used On-Peak Period / Total Period (w_2)	Relative Amount of Energy Used Off-Peak Period / Total Period (w_1)
#1 Rate Cell #16	$\frac{69{,}130.00}{413{,}973.50} = 0.17$	0.83
#2 Rate Cell #11	$\frac{118{,}791.55}{413{,}973.50} = 0.29$	0.71
#3 Rate Cell #4	$\frac{274{,}225.26}{413{,}973.50} = 0.66$	0.34

(Total amount of energy used in an average 24 hour period = 413,973.50 kWh)

B.3.2: Summer Conditions

Scenario # and Rate Cell	Relative Amount of Energy Used $\frac{\text{On-Peak Period}}{\text{Total Period}}$ (w_2)	Relative Amount of Energy Used $\frac{\text{Off-Peak Period}}{\text{Total Period}}$ (w_1)
#1.1 Rate Cell #16	$\frac{44{,}311.22}{391{,}962.06} = 0.11$	0.89
#1.2 Rate Cell #16	$\frac{69{,}118.11}{391{,}962.06} = 0.18$	0.82
#2 Rate Cell #11	$\frac{151{,}055.24}{391{,}962.06} = 0.39$	0.61
#3 Rate Cell #4	$\frac{238{,}999.05}{391{,}962.06} = 0.661$	0.39

(Total amount of energy used in an average 24 hour period = 391,962.06 kWh)

Table B.4: Calculation of Relative Retail Rates For On-Peak and Off-Peak $(P_{j,t-1})$

Description	1983 figures (Base Rate 3.76¢/kWh)	Relative TOU Price Ratio to Base Rate of 3.76¢	1995 figures (Base rate of 9.08¢/kWh)	Relative Price Ratio to Summer Off-Peak	Relative Price Ratio to Winter On-Peak
Winter	Rate Class #16				
On-Peak Off-Peak	5.34¢ 1.97¢	1.42 0.52	12.78 4.72	3.8 1.4	1 0.37
Summer	Rate Class #16				
On-Peak Off-Peak	3.79¢ 1.40¢	1.01 0.37	9.17 3.35	2.7 1	0.71 0.26

Table B.4 (continued)

Description	1983 figures (Base Rate 3.76¢/kWh)	Relative TOU Price Ratio to Base Rate 3.76¢	1995 figures (Base rate 9.08¢/kWh)	Relative Price Ratio to Summer Off-Peak	Relative Price Ratio to Winter On-Peak
Winter	Rate Class #11				
On-Peak Off-Peak	11.18¢ 2.85¢	2.97 0.76	26.96 6.88	5.5 1.4	1 0.25
Summer	Rate Class #11				
On-Peak Off-Peak	7.93¢ 2.03¢	2.10 0.54	19.15 4.90	3.9 1	0.71 0.18
Winter	Rate Class #4				
On-Peak Off-Peak	6.11¢ 2.25¢	1.63 0.60	14.80 5.43	3.79 1.4	1 0.37
Summer	Rate Class #4				
On-Peak Off-Peak	4.34¢ 1.61¢	1.15 0.43	10.48 3.88	2.7 1	0.71 0.26

APPENDIX C: TIME-TRENDING PROCESS COMPONENTS

Listed in this appendix are the meaning of the terms, expressions, and their respective relationships within the time-trending process UCOST [51] described in Chapter 4, Section 4.7.8.

C.1 TERMINOLOGY

The following are the abbreviations and meanings for the functions of C.2.

U = Utility

- UC = Utility-Cost
  - UCO = Utility-Cost-Outage
    - UCOM = Utility-Cost-Outage-Maintenance
    - UCOR = Utility-Cost-Outage-Restoration
  - UCC = Utility-Cost-Customer
    - UCCF = Utility-Cost-Customer-Feedback
    - UCCL = Utility-Cost-Customer-Loss
  - UCE = Utility-Cost-Energy
    - UCES = Utility-Cost-Energy-Supply
    - UCEL = Utility-Cost-Energy-Local
    - UCEW = Utility-Cost-Energy-Wholesale
    - UCEC = Utility-Cost-Energy-Consumption
- UR = Utility-Revenue
  - URC = Utility-Revenue-Customer
    - URCB = Utility-Revenue-Customer-Billing

URRS = Utility-Revenue-Rate-Structure

URRI = Utility-Revenue-Rate-Increment

US = Utility-Service

USO = Utility-Service-Outages

USON = Utility-Service-Outages-Number

USOD = Utility-Service-Outages-Duration

UG = Utility-Generation

UGE = Utility-Generation-Energy

UGES = Utility-Generation-Energy-Supply

UGEL = Utility-Generation-Energy-Local

UGEW = Utility-Generation-Energy-Wholesale

UGED = Utility-Generation-Energy-Deficit

C = Customer

CP = Customer-Perception

CPS = Customer-Perception-Satisfaction

CPSE = Customer-Perception-Satisfaction-Expectation

CPSG = Customer-Perception-Satisfaction-Gains

CPSB = Customer-Perception-Satisfaction-Benefits

CPSV = Customer-Perception-Satisfaction-Vocality

CU = Customer-Utilization

CUE = Customer-Utilization-Energy

CUEA = Customer-Utilization-Energy-Acquisition

CUED = Customer-Utilization-Energy-Demand

CUEO = Customer-Utilization-Energy-Optional

CUER = Customer-Utilization-Energy-Request

C.2 FUNCTIONS

Programmed functions of UCOST [51].

Decisions:

1) UCOM(t) = Max {0, [UCOM0t + UCOM1t * t]}

2) UCOR(t) = Max {0, [UCOR0t + UCOR1t * t]}

3) UGEL(t) = Max {0, [UGEL0t + UGEL1t * t]}

4) UGEW(t) = Max {0, [UGEW0t + UGEW1t * t]}

5) URRS(t) = Max {0, [URRS0t + URRS1t * t]}

Given:

6) CUED(t) = Max {0, [CUED0t + CUED1t * t]}

7) CPSE

Interrelationships:

8) UCEL(t) = UCEL0UGEL + UCEL1UGEL * UGEL(t)

9) UCEW(t) = UCEW0UGEW + UCEW1UGEW * UGEW(t)

10) UCES(t) = UCEL(t) + UCEW(t)

11) UGES(t) = UGEL(t) + UGEW(t)

12) USON(t) = Max {0, [USON0UCOM + USON1UCOM * [Sum {e=1:t} * UCOM (e)] / t + USON0UCOR + USON1UCOR * UCOR(t - 1)] }

13) USOD(t) = Max {0, [USOD0UCOR + USOD1UCOR * UCOR(t)] }

14) CPSB(t) = CPSB0USON + CPSB1USON * USON(t) + CPSB0USOD + CPSB1USOD * USOD(t) + CPSB0URRS + CPSB1URRS * URRS(t) + CPSB0URRI + CPSB1URRI * URRI(t)

15) CPSG(t) = [Sum {e=1:t} * (CPSB(e) - CPSE)] / t

16) CPSV(t) = CPSV0CPSG + CPSV1CPSG * CPSG(t)

17) UCCF(t) = UCCF0CPSV + UCCF1CPSV * CPSV(t)

18) CUEO(t) = CUEO0CPSG + CUEO1CPSG * CPSG(t)

19) CUER(t) = Max {0, [CUED(t) - CUEO(t)] }

20) CUEA(t) = Min {UGES(t), CUER(t) }

21) UCEC(t) = UCEC0CUEA + UCEC1CUEA * CUEA(t)

22) UGED(t) = Max {0, [CUER(t) - UGES(t)] }

23) UCCL(t) = UCCL0UGED + UCCL1UGED * UGED(t)

24) URCB(t) = URRS(t) * CUEA(t)

Table C.1: Relationship Between Time-Trending Components (Explanation of C.2)

COSTS							
#1	UCOM(t)	=	UCOM0t	+	UCOM1t	×	t
	Utility Cost of Outage Maintenance at time (t)	is	Initial Utility Cost of Outage Maintenance	and	Utility Cost of Outage Maintenance (Coefficient)	times	time (t)
#2.	UCOR(t)	=	UCOR0t	+	UCOR1t	×	t
	Utility Cost of Outage Restoration at time (t)	is	Initial Utility Cost of Outage Restoration	and	Utility Cost of Outage Restoration (Coefficient)	times	time (t)
GENERATION							
#3.	UGEL(t)	=	UGEL0t	+	UGEL1t	×	t
	Amount of Local Energy Generation at time (t)	is	Existing Amount of Local Energy Generation	and	Local Utility Energy Generation (Coefficient)	times	time (t)
#4.	UGEW(t)	=	UGEW0t	+	UGEW1t	×	t
	Amount of Wholesale Energy Purchases at time (t)	is	Existing Amount of Wholesale Energy Purchases	and	Utility Wholesale Energy Purchases (Coefficient)	times	time (t)
COSTS							
#5.	URRS(t)	=	URRS0t	+	URRS1t	×	t
	Utility Revenue Rate Structure at time (t)	is	Existing Utility Revenue Rate Structure	and	Utility Revenue Increment Rate Structure (Coefficient)	times	time (t)

GIVEN INFORMATION							
#6.	CUED(t)	=	CUED0t	+	CUED1t	×	t
	Customer Utilization of Energy Demand at time (t)	is	Initial Customer Utilization of Energy Demand	and	Customer Utilization of Energy Demand (Coefficient)	times	time (t)
#7.	CPSE (t) at time (t)	is	Customer - Perception - Satisfaction - Expectation at time (t)				
COSTS							
#8.	UCEL(t)	=	UCEL0UGEL	+	UCEL1UGEL	×	UGEL(t)
	Utility Cost of Local Energy Generation at time (t)	is	Initial Utility Cost of Local Energy Generation	and	Utility Unit Cost of Local Energy Generation (Coefficient)	times	Amount of Local Energy Generation at time (t)
#9.	UCEW(t)	=	UCEW0UGEW	+	UCEW1UGEW	×	UGEW(t)
	Utility Cost of Wholesale Energy at time (t)	is	Initial Utility Cost of Wholesale Energy Purchases	and	Utility Unit Cost of Wholesale Energy Purchases (Coefficient)	times	Amount of Wholesale Energy Purchases at time (t)
COSTS							
#10.	UCES(t)	=	UCEL(t)	+	UCEW(t)		
	Utility Cost of Energy Supply at time (t)	is	Utility Cost of Local Energy Generation at time (t)	and	Utility Cost of Wholesale Energy Purchases at time (t)		
MAGNITUDE							
#11.	UGES(t)	=	UGEL(t)	+	UGEW(t)		
	Amount of Utility Energy Supply at time (t)	is	Amount of Local Utility Energy Generation at time (t)	and	Amount of Wholesale Energy Purchases at time (t)		

#12.	USON(t)	=	USON0UCOM	+	USON1UCOM	×	$[\sum_{\tau=1}^{t} UCOM(\tau)]/t$
	Utility Service Outage Number at time (t)	is	Initial Number of Utility Service Outages with respect to Utility Cost of Outage Maintenance	and	Number of Utility Service Outages per Unit Cost of Preventative Maintenance (Coefficient)	times	Average Utility Cost of Outage Maintenance During time (t)
		+	USON0UCOR	+	USON1UCOR	×	UCOR (t - 1)
		and	Initial Number of Service Outages Which Have Been Repaired	and	Utility Service Outage Number with respect to Utility Cost of Outage Restoration (Coefficient)	times	Utility Cost of Outage Restorations at previous time (t - 1)
#13.	USOD(t)	=	USOD0UCOR	+	USOD1UCOR	×	UCOR (t)
	Utility Service Outage Duration at time (t)	is	Initial Utility Service Outage Duration with respect to Utility Cost of Outage Restoration	and	Utility Service Outage Duration per Unit Cost of Service Restoration (Coefficient)	times	Cost of Utility Outage Restoration at time (t)
#14.	CPSB(t)	=	CPSB0USON	+	CPSB1USON	×	USON(t)
	Customer Perception Satisfaction Benefit at time (t)	is	Initial Customer Perceived Benefit with respect to Number of Utility Service Interruptions	and	Customer Perception Satisfaction Benefit per Unit Number of Utility Service Outages (Coefficient)	times	Number of Utility Service Outages at time (t)
		+	CPSB0USOD	+	CPSB1USOD	×	USOD(t)
		and	Initial Customer Perceived Satisfaction Benefit with respect to Duration of Service Interruptions	and	Customer Perception Benefits per Unit Utility Service Outage Duration (Coefficient)	times	Utility Service Outage Duration at time (t)

#14 (cont)		+	CPSB0URRS	+	CPSB1URRS	×	URRS(t)
		and	Initial Customer Perception Satisfaction Benefit with respect to Utility Rate Structure	and	Customer Perception Satisfaction Benefit per Unit Utility Rate Structure (Coefficient)	times	Utility Revenue Rate Structure at time (t)
		+	CPSB0URRI	+	CPSB1URRI	×	URRI(t)
		and	Initial Customer Perception Satisfaction Benefit with respect to Utility Rate Changes	and	Customer Perception Service Benefit per Unit Revenue Rate Increment (Coefficient)	times	Utility Revenue Rate Increment at time (t)
		Retail Rate Stability					
#15.	CPSG(t)	=	$[\sum_{\tau=1}^{t}(CPSB(\tau)$		$CPSE(\tau))]/t$		
	Customer Perception Satisfaction Gains at time (t)	is	Averaged Customer Perception Satisfaction Benefits over time (t)	less	Averaged Customer Perception Satisfaction Expectation over time (t)		
#16.	CPSV(t)	=	CPSV0CPSG	+	CPSV1CPSG	×	CPSG(t)
	Customer Perception Satisfaction Vocality at time (t)	is	Initial Customer Perception Satisfaction Vocality with respect to Customer Satisfaction Gains	and	Customer Perception Satisfaction Vocality per Unit Customer Perception Satisfaction Gains (Coefficient)	times	Customer Perception Satisfaction Gains at time (t)

COSTS							
#17.	UCCF(t)	=	UCCF0CPSV	+	UCCF1CPSV	×	CPSV(t)
	Utility Cost of Customer Feedback at time (t)	is	Initial Utility Cost of Customer Feedback with respect to Customer Perception Satisfaction Vocality	and	Utility Cost of Customer Feedback per Unit Customer Perception Satisfaction Vocality (Coefficient)	times	Customer Perception Satisfaction Vocality at time (t)
MAGNITUDE							
#18.	CUEO(t)	=	CUEO0CPSG	+	CUEO1CPSG	×	CPSG(t)
	Customer Utilization of Energy Options at time (t)	is	Initial Customer Utilization of Energy Options with respect to Customer Perception Satisfaction Gains	and	Customer Utilization of Energy Options per Unit Customer Perception Satisfaction Gains (Coefficient)	times	Customer Perception Satisfaction Gains at time (t)
#19.	CUER(t)	=	CUED (t)		CUEO(t)		
	Customer Utilization of Energy Request at time (t)	is	Customer Utilization of Energy Demand at time (t)	less	Customer Utilization of Energy Options at time (t)		
#20.	CUEA(t)	=	Min [UGES(t)	,	CUER(t)]		
	Customer Utilization of Energy Acquisition at time (t)	is	Minimum Value of [Utility Generation Energy Supply at time (t)	or	Customer Utilization Energy Request at time (t)]		

COST							
	UCEC(t)	=	UCEC0CUEA	+	UCEC1CUEA	×	CUEA(t)
#21.	Utility Cost of Energy Consumption at time (t)	is	Utility Cost of Energy Consumption with respect to Customer Utilization of Energy Acquisition	and	Utility Cost of Energy Consumption per Unit Customer Utilization of Energy Acquisition (Coefficient)	times	Customer Utilization of Energy Acquisition at time (t)
MAGNITUDE							
	UGED(t)	=	[CUER(t)		UGES(t)]		
#22.	Utility Generation Energy Deficit at time (t)	is	[Customer Utility Energy Request at time (t)	less	Utility Generation Energy Supply at time (t)]		
			(shortage or surplus)				
COSTS							
	UCCL(t)	=	UCCL0UGED	+	UCCL1UGED	×	UGED(t)
#23.	Utility Cost of Customer Loss at time (t)	is	Initial Utility Cost of Customer Loss Due to Utility Energy Deficit	and	Utility Cost of Customer Loss per Unit Utility Energy Deficit (Coefficient)	times	Utility Generation Energy Deficit at time (t)
	URCB(t)	=	URRS(t)	×	CUEA(t)		
#24.	Utility Revenue Customer Billing at time (t)	is	Utility Revenue Rate Structure at time (t)	times	Customer Utilization of Energy Acquisition at time (t)		
OTHER TERMS							
	URRI(t)	=	URRS(t)	-	URRS(t-1)		
#25.	Utility revenue Rate Increment at time (t)	is	Difference in Utility Rate Structure at time (t) and earlier time (t-1)				

#26.	UC(t)	=	UCO(t)	+	UCC(t)	+	UCE(t)
	Utility Cost at time (t)	is	Utility Cost of Outage at time (t)	and	Utility Cost of Customer at time (t)	and	Utility Cost of Energy at time (t)
#27.	aUC(t)						
	Accumulated Utility Cost Over time (t)						
#28.	URC(t)	=	URCB(t)	+	URRS(t)	+	URRI(t)
	Unit Revenue from Customer at time (t)	is	Utility Revenue Customer Billing at time (t)	and	Utility Revenue Rate Structure at time (t)	and	Utility Revenue Rate Increment at time (t)
#29.	UR(t)	=	URC(t)				
	Utility Revenue at time (t)	is	Utility Revenue Customer				
#30.	aUR(t)						
	Accumulated Utility Revenue over time (t)						
#31.	UP(t)	=	UR(t)		UC(t)		
	Utility Profit at time (t)	is	Utility Revenue at time (t)	less	Utility Cost at time (t)		
#32.	aUP(t)						
	Accumulated Utility Profit over time (t)						

APPENDIX D: TIME-TRENDING PROCESS DATA AND CALCULATIONS

Listed in this appendix are the data used and results obtained from the time-trending program UCOST [51] described in Chapter 4, Section 4.7.8.

D.1 CURRENT INPUT DATA VALUES:

{# 1}	nt	=	10	
{# 2}	UCOM0t	=	1251	
{# 3}	UCOM1t	=	-106	
{# 4}	UCOR0t	=	68	
{# 5}	UCOR1t	=	-13.1	
{# 6}	UGEL0t	=	12264	
{# 7}	UGEL1t	=	24528	
{# 8}	UGEW0t	=	502824	
{# 9}	UGEW1t	=	-12264	
{#10}	URRS0t	=	0.08	(0.07)
{#11}	URRS1t	=	0.005	(0.007)
{#12}	CUED0t	=	613200	
{#13}	CUED1t	=	9811	
{#14}	UCEL0UGEL	=	2864	
{#15}	UCEL1UGEL	=	0.005	
{#16}	UCEW0UGEW	=	0	
{#17}	UCEW1UGEW	=	0.015	
{#18}	USON0UCOM	=	433	

{#19}	USON1UCOM	=	-0.245
{#20}	USON0UCOR	=	93
{#21}	USON1UCOR	=	-0.067
{#22}	USOD0UCOR	=	12
{#23}	USOD1UCOR	=	-9.5
{#24}	CPSB0USON	=	4
{#25}	CPSB1USON	=	-0.07
{#26}	CPSB0USOD	=	8
{#27}	CPSB1USOD	=	-0.33
{#28}	CPSB0URRS	=	27
{#29}	CPSB1URRS	=	-1.88
{#30}	CPSB0URRI	=	11
{#31}	CPSB1URRI	=	-0.87
{#32}	CPSE	=	0
{#33}	CPSV0CPSG	=	0
{#34}	CPSV1CPSG	=	1
{#35}	UCCF0CPSV	=	-15.2
{#36}	UCCF1CPSV	=	15.2
{#37}	CUEO0CPSG	=	640405
{#38}	CUEO1CPSG	=	-12808
{#39}	UCEC0CUEA	=	35.32
{#40}	UCEC1CUEA	=	-706
{#41}	UCCL0UGED	=	0
{#42}	UCCL1UGED	=	0.01

Table D.1: Case #1 For UCOST [51] Example of Output

QUANTITY	Time #1	Time #2	Time #3	Time #4	Time #5	Time #6	Time #7	Time #8	Time #9	Time #10
T	1	2	3	4	5	6	7	8	9	10
UCOM	1145.0	1039.0	933.0	827.0	721.0	615.0	509.0	403.0	297.0	191.0
UCOR	54.9	41.8	28.7	15.6	2.5	0.0	0.0	0.0	0.0	0.0
UGEL	147168.0	171696.0	196224.0	220752.0	245280.0	269808.0	294336.0	318864.0	343392.0	367920.0
UGEW	490560.0	478296.0	466032.0	453768.0	441504.0	429240.0	416976.0	404712.0	392448.0	380184.0
UGES	637728.0	649992.0	662256.0	674520.0	686784.0	699048.0	711312.0	733576.0	735840.0	748104.0
URRS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
URRI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CUED	623011.0	632822.0	642633.0	652444.0	662255.0	672066.0	681877.0	691688.0	701499.0	711310.0
UCEL	3599.8	3722.5	3845.1	3967.8	4090.4	4213.0	4335.7	4458.3	4581.0	4703.6
UCEW	7358.4	7174.4	6990.5	6806.5	6622.6	6438.6	6254.6	6070.7	5886.7	5702.8
UCES	10958.2	10896.9	10835.6	10774.3	10713.0	10651.6	10590.3	10529.0	10467.7	10406.4
USON	152.5	254.8	268.6	282.5	296.4	310.2	323.4	336.4	349.4	362.3
USOD	9.3	9.9	10.6	11.2	11.9	12.0	12.0	12.0	12.0	12.0
CPSB	28.4	21.2	19.8	18.5	17.1	15.9	14.8	13.7	12.5	11.4
CPSG	28.4	24.8	23.1	22.0	21.0	20.2	19.4	18.7	18.0	17.3
1.1 CPSV	28.4	24.8	23.1	22.0	21.0	20.2	19.4	18.7	18.0	17.3
1.2 CPSV	30.0	25.2	23.0	21.4	20.1	19.0	18.0	17.0	16.1	15.2
UCCF	4315.8	5039.7	5371.3	5604.9	5799.2	5968.1	6121.0	6264.0	6400.3	6531.9
CUEO	138294.3	161474.2	172092.9	179571.2	185793.4	191200.9	196098.5	200676.2	205040.6	209255.6
CUER	484716.7	471347.8	470540.1	472872.8	476461.6	480865.1	485778.5	491011.8	496458.4	502054.4
CUEA	484716.7	471347.8	470540.1	472872.8	476461.6	480865.1	485778.5	491001.8	496458.4	502054.4
UCEC	19388.7	18853.9	18821.6	18914.9	19058.5	19234.6	19431.1	19640.5	19858.3	20082.2
UGED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
UCCL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
URCB	41200.9	42421.3	44701.3	47287.3	50028.5	52895.2	55864.5	58921.4	62057.3	65267.1
UCO	1199.9	1080.8	961.7	842.6	723.5	615.0	509.0	403.0	297.0	191.0
UCC	4315.8	5039.7	5371.3	5604.9	5799.2	5968.1	6121.0	6264.0	6400.3	6531.9
UCE	37705.3	36925.3	36647.7	36495.7	36394.0	36324.8	36276.1	36240.2	36212.7	36191.3
UC	43221.0	43045.8	42980.7	42943.2	42916.7	42907.9	42906.1	42907.7	42910.0	42914.2
aUC	43221.0	86266.8	129247.5	172190.7	215107.3	358015.3	300921.4	343828.6	386738.6	429652.8
URC	41200.9	42421.3	44701.3	47287.3	50028.5	52895.2	55864.5	58921.4	62057.3	65267.7
UR	41200.9	42421.3	44701.3	47287.3	50028.5	52895.2	55864.5	58921.4	62057.3	65267.7
aUR	41200.9	83622.2	128323.5	175610.8	225639.3	278534.4	334399.0	393320.4	455377.7	520644.7
UP	-2020.1	-624.5	1270.6	4344.1	7111.8	9987.2	12958.4	16014.3	19147.3	22352.8
1.1 aUP	-2020.1	-2644.5	-923.9	3420.1	10531.9	20519.2	33477.6	49491.8	68639.1	90991.9
1.2 aUP	-5178.3	-8410.1	-8599.5	-5428.8	1264.6	11599.8	25681.9	43604.2	65451.6	91304.5

Table D.2: Case #2
10 Year Time-Trending Period

Study #	Retail Rates $/kWh	Range of Utility Costs (UC) $M	Range of Customer Satisfaction (CPSB) (Index Max 50) (see Figure 4.16)	Range of Utility Profit (UP) $M (see Figure 4.17)
#2.1 (Base Study)	0.08 + 0t	43.613 → 47.519	29.5 → 27.6	- 3.472 → 6.293
#2.2 (1.25% annual rate reduction)	0.08 - 0.001t	43.624 → 47.632	29.7 → 30.1	- 3.885 → 0.3509
#2.3	0.095 - 0.0025t (Initial + 18.75% - 3.125% annual reduction)	43.472 → 47.632	27.0 → 32.1	1.4585 → 0.3509

Cost of Maintenance UCOM $M (1.251 - 0.2t) Cost of Restoration UCOR $M (0.068 + 0.005t)

Table D.3: Case #3
10 Year Time-Trending Period

Study #	Utility Cost of Customer Loss (UCCL) $M	Retail Rates $/kWh	Range of Utility Costs (UC) $M	Range of Customer Satisfaction (CPSB) (Index Max 50) (see Figure 4.18)	Range of Utility Profit (UP) $M (see Figure 4.19)
#3.1	0.5622 → 0.2081	0.08 + 0t	35.51 → 36.77	29.4 → 26.4	- 0.713 → 6.856
#3.2	0.5074 → 0.0091 (6^{th} year)*	0.08 + 0t	35.697 → 37.665	29.4 → 26.4	- 0.467 → 7.623
#3.3(a)	0	0.08 + 0t	43.395 → 44.649	29.4 → 26.4	- 4.104 → 0.638
#3.3(b)	0	0.08 + 0.00136t	43.379 → 44.497	29.1 → 22.3	- 3.563 → 6.859

* Zero after that time. Cost of Maintenance UCOM $M (1.251 - 0.106t), Cost of Restoration UCOR $M (0.068 - 0.0131t)

D.2 DESCRIPTION OF INPUT DATA PARAMETERS

{# 1}	nt	=	{Number of Study Time Periods}
{# 2}	UCOM0t	=	{0-Coef-wrt-Time: Utility Cost of Maintenance for Outages}
{# 3}	UCOM1t	=	{1-Coef-wrt-Time: Utility Cost of Maintenance for Outages}
{# 4}	UCOR0t	=	{0-Coef-wrt-Time: Utility Cost of Restoration for Outages}
{# 5}	UCOR1t	=	{1-Coef-wrt-Time: Utility Cost of Restoration for Outages}
{# 6}	UGEL0t	=	{0-Coef-wrt-Time: Utility Generation of Energy from Local}
{# 7}	UGEL1t	=	{1-Coef-wrt-Time: Utility Generation of Energy from Local}
{# 8}	UGEW0t	=	{0-Coef-wrt-Time: Utility Generation of Energy from Wholesale}
{# 9}	UGEW1t	=	{1-Coef-wrt-Time: Utility Generation of Energy from Wholesale}
{#10}	URRS0t	=	{0-Coef-wrt-Time: Utility Revenue re Rate Structure}
{#11}	URRS1t	=	{1-Coef-wrt-Time: Utility Revenue re Rate Structure}
{#12}	CUED0t	=	{0-Coef-wrt-Time: Customer Utilization Energy Demand}
{#13}	CUED1t	=	{1-Coef-wrt-Time: Customer Utilization Energy Demand}
{#14}	UCEL0UGEL	=	{0-Coef-wrt-Time: Utility Cost of Energy from Local}
{#15}	UCEL1UGEL	=	{1-Coef-wrt-Time: Utility Cost of Energy from Local}
{#16}	UCEW0UGEW	=	{0-Coef-wrt-Time: Utility Cost of Energy from Wholesale}
{#17}	UCEW1UGEW	=	{1-Coef-wrt-Time: Utility Cost of Energy from Wholesale}
{#18}	USON0UCOM	=	{0-Coef-wrt-Time: Utility Service Outages Number}
{#19}	USON1UCOM	=	{1-Coef-wrt-Time: Utility Service Outages Number}
{#20}	USON0UCOR	=	{0-Coef-wrt-Time: Utility Service Outages Number}
{#21}	USON1UCOR	=	{1-Coef-wrt-Time: Utility Service Outages Number}
{#22}	USOD0UCOR	=	{0-Coef-wrt-Time: Utility Service Outages Duration}
{#23}	USOD1UCOR	=	{1-Coef-wrt-Time: Utility Service Outages Duration}
{#24}	CPSB0USON	=	{0-Coef-wrt-Time: Customer Perception Satisfaction Benefit}
{#25}	CPSB1USON	=	{1-Coef-wrt-Time: Customer Perception Satisfaction Benefit}
{#26}	CPSB0USOD	=	{0-Coef-wrt-Time: Customer Perception Satisfaction Benefit}
{#27}	CPSB1USOD	=	{1-Coef-wrt-Time: Customer Perception Satisfaction Benefit}

{#28} CPSB0URRS = {0-Coef-wrt-Time: Customer Perception Satisfaction Benefit}

{#29} CPSB1URRS = {1-Coef-wrt-Time: Customer Perception Satisfaction Benefit}

{#30} CPSB0URRI = {0-Coef-wrt-Time: Customer Perception Satisfaction Benefit}

{#31} CPSB1URRI = {1-Coef-wrt-Time: Customer Perception Satisfaction Benefit}

{#32} CPSE = {Customer Perception of Satisfaction Expectation (Level)}

{#33} CPSV0CPSG = {0-Coef-wrt-Time: Customer Perception Vocality re Utility}

{#34} CPSV1CPSG = {1-Coef-wrt-Time: Customer Perception Vocality re Utility}

{#35} UCCF0CPSV = {0-Coef-wrt-Time: Utility Cost of Customer Feedback}

{#36} UCCF1CPSV = {1-Coef-wrt-Time: Utility Cost of Customer Feedback}

{#37} CUEO0CPSG = {0-Coef-wrt-Time: Customer Utilization Energy Optional}

{#38} CUEO1CPSG = {1-Coef-wrt-Time: Customer Utilization Energy Optional}

{#39} UCEC0CUEA = {0-Coef-wrt-Time: Utility Cost of Energy Consumption}

{#40} UCEC1CUEA = {1-Coef-wrt-Time: Utility Cost of Energy Consumption}

{#41} UCCL0UGED = {0-Coef-wrt-Time: Utility Cost Due to Customer Loss}

{#42} UCCL1UGED = {1-Coef-wrt-Time: Utility Cost Due to Customer Loss}

D.3 DESCRIPTION OF OUTPUT DATA PARAMETERS

{# 1} T = {Time Period Index Array}

{# 2} UCOM = {Utility Cost of Maintenance for Outages}

{# 3} UCOR = {Utility Cost of Restoration for Outages}

{# 4} UGEL = {Utility Generation of Energy from Local}

{# 5} UGEW = {Utility Generation of Energy from Wholesale}

{# 6} UGES = {Utility Generation of Energy Supply (T)}

{# 7} URRS = {Utility Revenue re Rate Structure}

{# 8} URRI = {Utility Revenue re Rate Increment}

{# 9} CUED = {Customer Utilization Energy Demand}

{#10} UCEL = {Utility Cost of Energy from Local}

{#11} UCEW = {Utility Cost of Energy from Wholesale}

{#12} UCES = {Utility Cost of Energy Supply (Tot. L+W)}

{#13}	USON	=	{Utility Service Outages Number}
{#14}	USOD	=	{Utility Service Outages Duration}
{#15}	CPSB	=	{Customer Perception Satisfaction Benefit}
{#16}	CPSG	=	{Customer Perception Satisfaction Gains}
{#17}	CPSV	=	{Customer Perception Vocality re Utility}
{#18}	UCCF	=	{Utility Cost of Customer Feedback}
{#19}	CUEO	=	{Customer Utilization Energy Optional}
{#20}	CUER	=	{Customer Utilization Energy Request}
{#21}	CUEA	=	{Customer Utilization Energy Acquisition}
{#22}	UCEC	=	{Utility Cost of Energy Consumption}
{#23}	UGED	=	{Utility Generation Energy Deficit}
{#24}	UCCL	=	{Utility Cost Due to Customer Loss}
{#25}	URCB	=	{Utility Revenue from Customer Billing}
{#26}	UCO	=	{Utility Cost of Maintenance (Total)}
{#27}	UCC	=	{Utility Cost of Customer (Total)}
{#28}	UCE	=	{Utility Cost of Energy (Total)}
{#29}	UC	=	{Utility Cost (Grand Total)}
{#30}	aUC	=	{Accumulated Utility Cost (Grand Total)}
{#31}	URC	=	{Utility Revenue from Customer (Total)}
{#32}	UR	=	{Utility Revenue (Grand Total)}
{#33}	aUR	=	{Accumulated Utility Revenue (Grand Total)}
{#34}	UP	=	{Utility Profit (Grand Total)}
{#35}	aUP	=	{Accumulated Utility Profit (Grand Total)}

APPENDIX E: INPUT AND OUTPUT OF LOGICAL PROPORTION PROGRAM

Listed in this appendix are, as displayed on the computer screen, the data used and results obtained from the Logical Proportion Program [50].

E.1 INPUT DATA FOR SOLUTION OF USON

```
"U13:USON - [Level #1] {Service-Interruption}        <USON = f(UCOM,UCOR)>"
2, 9, 0
3, 1, 1.0, "{UCOM}: Preventative-Maintenance-Budget"
"Small"
"Medium"
"Large"
3, 1, 1.0, "{UCOR}: Outage-Restoration-Budget"
"Small"
"Medium"
"Large"
3, "{USON}: Number-of-Service-Interruptions"
"Few"
"Moderate"
"Excessive"
0
```

E.1.1 Solution for USON

"U13:USON - [Level #1] {Service-Interruption} <USON = f(UCOM,UCOR)>"

Output Logical Variable: {USON}: Number-of-Service-Interruptions

Designation #1 - {Few}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Large

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Medium

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Large

Designation #2 - {Moderate}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Small

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Medium

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Large

Designation #3 - {Excessive}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Small

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Small

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Small

E.2 INPUT DATA FOR SOLUTION OF USOD

"U13:USOD - [Level #1] {Outage-Duration} <USOD = f(UCOM,UCOR)>"

2, 9, 0

3, 1, 1.0, "{UCOM}: Preventative-Maintenance-Budget"

"Small"

"Medium"

"Large"

3, 1, 1.0, "{UCOR}: Outage-Restoration-Budget"

"Small"

"Medium"

"Large"

3, "{USOD}: Duration-of-Service-Interruptions"

"Long"

"Medium"

"Short"

0

E.2.1 Solution for USOD

"U13:USOD - [Level #1] {Outage-Duration} <USOD = f(UCOM,UCOR)>"

Output Logical Variable: {USOD}: Duration-of-Service-Interruptions

Designation #1 - {Short}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Large

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Medium

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Large

Designation #2 - {Medium}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Small

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Medium

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Large

Designation #3 - {Long}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Small

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Small

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Small

E.3 INPUT DATA FOR SOLUTION OF CPSB

"U23:CPSB - [Level #2] {Customer-Perception} <CPSB = f(USON,USOD)>"

2, 9, 0

3, 1, 1.0, "{USON}: Number-of-Service-Interruptions"

"Few"

"Moderate"

"Excessive"

3, 1, 1.0, "{USOD}: Duration-of-Service-Interruptions"

"Long"

"Medium"

"Short"

3, "{CPSB}: Customer-Perception"

"Negative"

"50/50"

"Positive"

0

E.3.1 Solution for CPSB

"U23:CPSB - [Level #2] {Customer-Perception} <CPSB = f(USON,USOD)>"

Output Logical Variable: {CPSB}: Customer-Perception

Designation #1 - {Negative}

Combination #1

{USON}: Number-of-Service-Interruptions IS Excessive

{USOD}: Duration-of-Service-Interruptions IS Long

Combination #2

{USON}: Number-of-Service-Interruptions IS Excessive

{USOD}: Duration-of-Service-Interruptions IS Medium

Combination #3

{USON}: Number-of-Service-Interruptions IS Moderate

{USOD}: Duration-of-Service-Interruptions IS Long

Designation #2 - {50/50}

Combination #1

{USON}: Number-of-Service-Interruptions IS Excessive

{USOD}: Duration-of-Service-Interruptions IS Short

Combination #2

{USON}: Number-of-Service-Interruptions IS Moderate

{USOD}: Duration-of-Service-Interruptions IS Medium

Combination #3

{USON}: Number-of-Service-Interruptions IS Few

{USOD}: Duration-of-Service-Interruptions IS Long

Designation #3 - {Positive}

Combination #1

{USON}: Number-of-Service-Interruptions IS Moderate

{USOD}: Duration-of-Service-Interruptions IS Short

Combination #2

{USON}: Number-of-Service-Interruptions IS Few

{USOD}: Duration-of-Service-Interruptions IS Medium

Combination #3

{USON}: Number-of-Service-Interruptions IS Few

{USOD}: Duration-of-Service-Interruptions IS Short

E.4 INPUT DATA FOR SOLUTION OF UC

"U33:UC - [Level #3] {Total-Utility-Cost} <UC = f(UCOM,UCOR, CPSB)>"

3, 27, 0

3, 1, 1.0, "{UCOM}: Preventative-Maintenance-Budget"

"Small"

"Medium"

"Large"

3, 1, 1.0, "{UCOR}: Outage-Restoration-Budget"

"Small"

"Medium"

"Large"

3, 1, 1.0, "{CPSB}: Customer-Perception"

"Negative"

"50/50"

"Positive"

3, "{UC}: Total-Utility-Cost"

"Little"

"Medium"

"High"

0

E.4.1 Solution for UC

"U33:UC - [Level #3] {Total-Utility-Cost} <UC = f(CPSB, UCOM, UCOR)>"

Output Logical Variable: {UC}: Total-Utility-Cost

Designation #1 - {Little}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Small

{CPSB}: Customer-Perception IS Positive

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Small

{CPSB}: Customer-Perception IS 50/50

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Medium

{CPSB}: Customer-Perception IS Positive

Combination #4

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Small

{CPSB}: Customer-Perception IS Positive

Combination #5

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Small

{CPSB}: Customer-Perception IS Negative

Combination #6

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Medium

{CPSB}: Customer-Perception IS 50/50

Combination #7

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Large

{CPSB}: Customer-Perception IS Positive

Combination #8

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Small

{CPSB}: Customer-Perception IS 50/50

Combination #9

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Medium

{CPSB}: Customer-Perception IS Positive

Designation #2 - {Medium}

Combination #1

{UCOM}:	Preventative-Maintenance-Budget IS Large
{UCOR}:	Outage-Restoration-Budget IS Small
{CPSB}:	Customer-Perception IS Positive

Combination #2

{UCOM}:	Preventative-Maintenance-Budget IS Small
{UCOR}:	Outage-Restoration-Budget IS Medium
{CPSB}:	Customer-Perception IS Negative

Combination #3

{UCOM}:	Preventative-Maintenance-Budget IS Small
{UCOR}:	Outage-Restoration-Budget IS Large
{CPSB}:	Customer-Perception IS 50/50

Combination #4

{UCOM}:	Preventative-Maintenance-Budget IS Medium
{UCOR}:	Outage-Restoration-Budget IS Small
{CPSB}:	Customer-Perception IS Negative

Combination #5

{UCOM}:	Preventative-Maintenance-Budget IS Medium
{UCOR}:	Outage-Restoration-Budget IS Medium
{CPSB}:	Customer-Perception IS 50/50

Combination #6

{UCOM}:	Preventative-Maintenance-Budget IS Medium
{UCOR}:	Outage-Restoration-Budget IS Large
{CPSB}:	Customer-Perception IS Positive

Combination #7

{UCOM}:	Preventative-Maintenance-Budget IS Large
{UCOR}:	Outage-Restoration-Budget IS Small
{CPSB}:	Customer-Perception IS 50/50

Combination #8

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Medium

{CPSB}: Customer-Perception IS Positive

Combination #9

{UCOM}: Preventative-Maintenance-Budget IS Small

{UCOR}: Outage-Restoration-Budget IS Large

{CPSB}: Customer-Perception IS Negative

Designation #3 - {High}

Combination #1

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Medium

{CPSB}: Customer-Perception IS Negative

Combination #2

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Large

{CPSB}: Customer-Perception IS 50/50

Combination #3

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Small

{CPSB}: Customer-Perception IS Negative

Combination #4

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Medium

{CPSB}: Customer-Perception IS 50/50

Combination #5

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Large

{CPSB}: Customer-Perception IS Positive

Combination #6

{UCOM}: Preventative-Maintenance-Budget IS Medium

{UCOR}: Outage-Restoration-Budget IS Large

{CPSB}: Customer-Perception IS Negative

Combination #7

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Medium

{CPSB}: Customer-Perception IS Negative

Combination #8

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Large

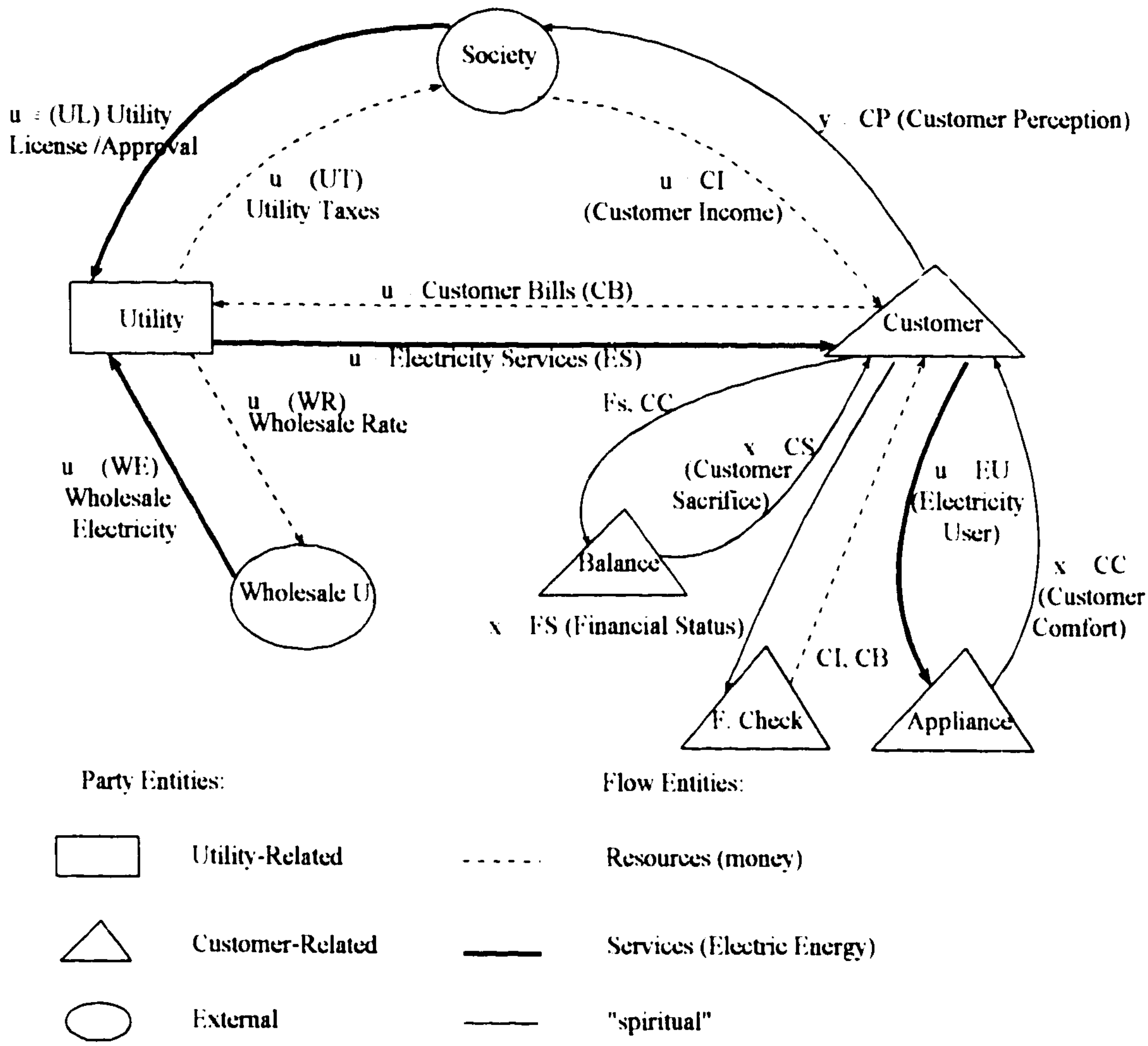
{CPSB}: Customer-Perception IS 50/50

Combination #9

{UCOM}: Preventative-Maintenance-Budget IS Large

{UCOR}: Outage-Restoration-Budget IS Large

{CPSB}: Customer-Perception IS Negative



	Logical Symbol Types	**Analogous Conventional Numeric**
g	Goal [US (Utility Survival) = True]	Minimize f (x) [Maintain Security]
p	Prevailing Conditions (Trans. Capacity)	Parameters (fixed)
y	Driving Forces (CP)	System changes (Δp_t , Δy_t)
x	Quality State (CS)	State Variables ($\mid V_t \mid$, δ_t)
u	Manipulated Entity (CB)	Control Variables (P_g , $\mid V_g \mid$)

Figure E.1: Relationship and Process Flow Between Utility, Customers, and Society (Environment)

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INDEX OF KEY TERMINOLOGY

Bolded page numbers best describes the terminology.