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A CAPITAL BUDGET OPTIMIZATION MODEL FOR SUBSCRIBER LOOP FACILITIES IN THE TELECOMMUNICATIONS CARRIER INDUSTRY

PREPARED
UNDER THE DIRECTION OF
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March 29, 1979

Mr. G. Henter
Dept. of Communications
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Dear Mr. Henter:

This report discusses a model which optimizes the subscriber loop facilities in the telecommunications carrier industry. Special emphasis has been placed on developing construction plans and capital budgets.

The model described in this report utilizes the forecast information, along with the layout of physical facilities, cost data, and details of alternative networks, to develop a construction program for the first year and capital budgets for all the periods within the planning horizon.

Recommendations have been made concerning the length of the short range and the long range planning periods. The report also discusses the results of a test on the model, conducted using a hypothetical problem (which simulates practical conditions).

The model should be useful to the regulator as well as to the carrier companies and can be adopted by any company with marginal changes to its budgeting system.

Yours truly,

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JCS/tb

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1. INTRODUCTION

1.1 Purpose

The purpose of this study is to develop a capital budgeting model for the telecommunications network within an urban area (e.g. city). The total system will have the capability of forecasting telecommunications demand by switching center area and pinpointing the demand within the switching center area. The short term forecast (over the immediate three years) which allocates the demand to modules within the switching center area and a long term forecast for the whole switching center area (until its ultimate growth) will serve as the basis of the optimization model for budgeting purposes and the recommendations for actual physical plant to be installed. This information will be utilized to develop capital budgets for the immediate three years and a construction program for the first period. Figure 1.1 is a schematic of the basic steps in the capital budgeting process.

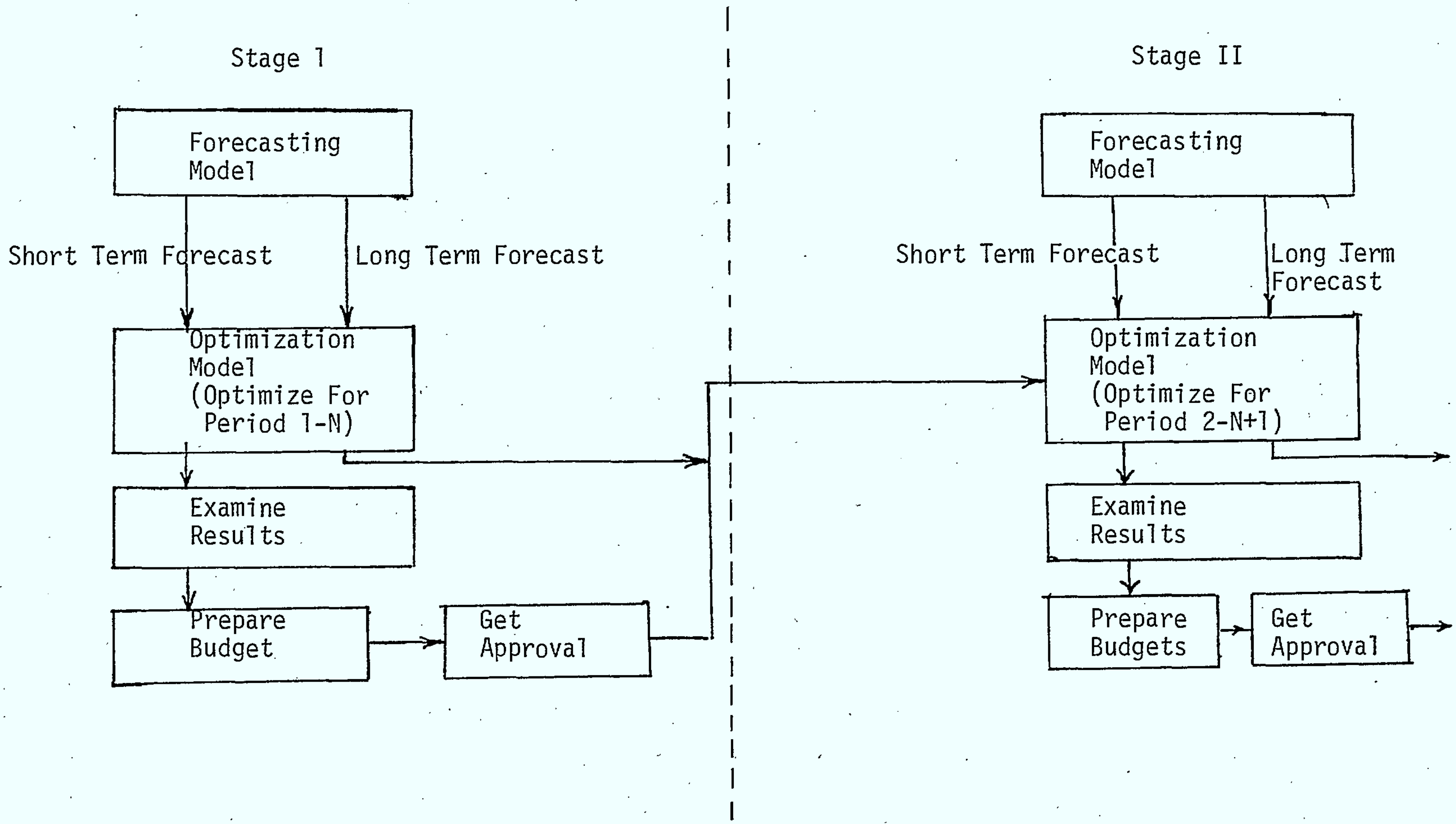


Figure 1.1 Schematic Representation of the Computer Based System For The Development of A Capital Budget For the Subscriber Loop Facilities.

1.2 Background Information

The telecommunications industry is highly capital intensive and most of the facilities have a life span in excess of 20 years. The industry experiences major advances in technology on a continuing basis and life spans of facilities appear to be decreasing with new technology developments and the customer environment. These factors emphasize the need and the difficulties experienced in designing an optimal strategy for physical facilities.

Telecommunication facilities consist of a physical network that allows verbal and written communication between users of the system.

Telecommunications plant within an urban area can be best classified under two major headings from a costing point of view.

1) Support facilities (service and administration)
   (a) land,
   (b) buildings,
   (c) office furniture and equipment, and
2) Operating facilities
   (a) subscriber station equipment,
   (b) subscriber loop facilities,
   (c) exchange trunking and toll trunking facilities, and
   (d) local switching facilities (central office).

The support facilities include all physical facilities necessary to perform the administrative and service functions such as accounting, corporate planning, research and development and engineering. Support equipment (e.g. vehicles and tools) required as part of the direct functions performed by plant personnel should be allocated directly to each class of plant.

The subscriber station equipment represents the equipment utilized by the subscriber at point "A" to communicate with the subscriber at point "B". The network facilities (outside plant, drop facilities, inside wiring and central office equipment) represent the telecommunications equipment necessary to transport the message from point "A" to point "B". For ease of developing an optimization model, the following classifications as outlined in Figure 1.2 are useful.

1.2.1 Classification of Plant

Telecommunications plant within an urban area may be classified under the following categories:

1. subscriber station equipment,
2. subscriber loops,
3. local switching,
4. exchange trunking - between exchanges,
5. toll connecting trunks between local

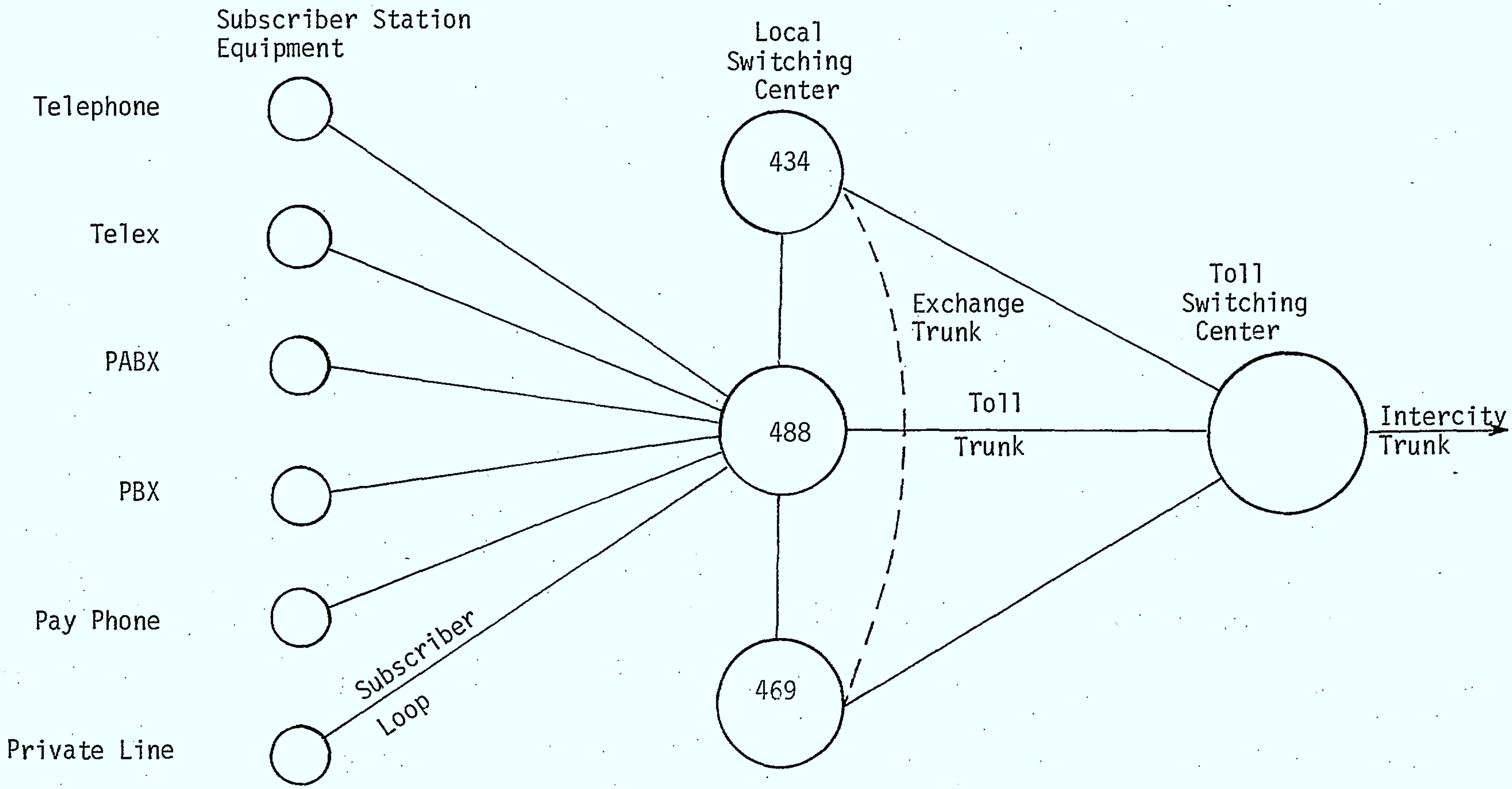


Figure 1.2 Physical Plant Facilities Within a Telecommunications Network

exchanges and toll switching centers,

6. toll switching (toll switching centers) and,

7. inter toll trunking (connecting trunks between toll switching centers).

1.2.2 The Method of Optimization within an Integral System

The switching center area (exchange area) is considered the critical building block within an integral system (a switching center area is the area serviced by an individual switching center). Therefore, all information with respect to the design of a near optimal network such as forecasting data and equipment requirements will be generated by switching center area. The interaction between other individual switching center areas within the system (e.g. city) and the impact of each area on the toll system must be carefully monitored and converted into capital and operating budget requirements. Figure 1.2 is a schematic of the physical facilities within a telecommunications network. Figure 1.3 is a schematic representation of the switching center area as a building block.

1.3 Scope and Methodology

The study treats a representative Canadian city as a total integral system. This reseach considers the important criteria of: 1) urban area size, 2) switching center service

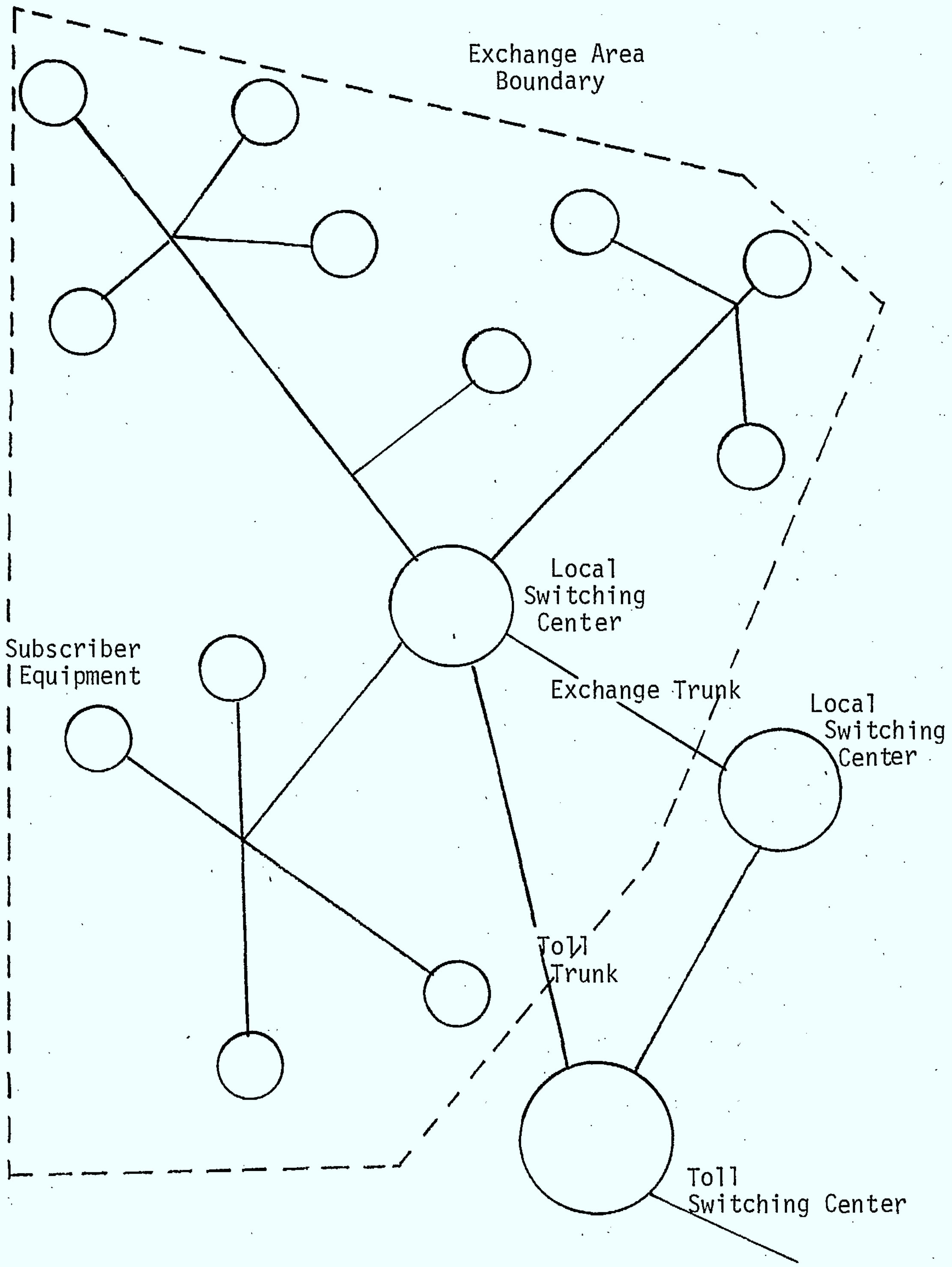


Figure 1.3 The Switching Center Area As A Building Block

area 3) subscriber density 4) traffic patterns 5) geographic terrain 6) economies of scale 7) growth rates, and 8) technology. These factors allow adaptability of the model to various cities across the country.

The study limits itself to the analysis of the subscriber loop portion of the telecommunications plant. The subscriber loop facilities are discussed under the following classifications of physical plant:

1) underground paired cable,
2) aerial paired cable,
3) buried paired cable,
4) underground coaxial cable,
5) aerial coaxial cable,
6) buried coaxial cable,
7) manholes, conduits,
8) poles, and
9) line concentrators.

The drop wire and inside wiring from the access terminal to the station subscriber equipment is omitted in the analysis.

1.3.1 Basic Framework of the Design System

The schematic of the optimization model chosen for design is shown in Figure 1.4. It consists of two major components: the cost development system and the solution

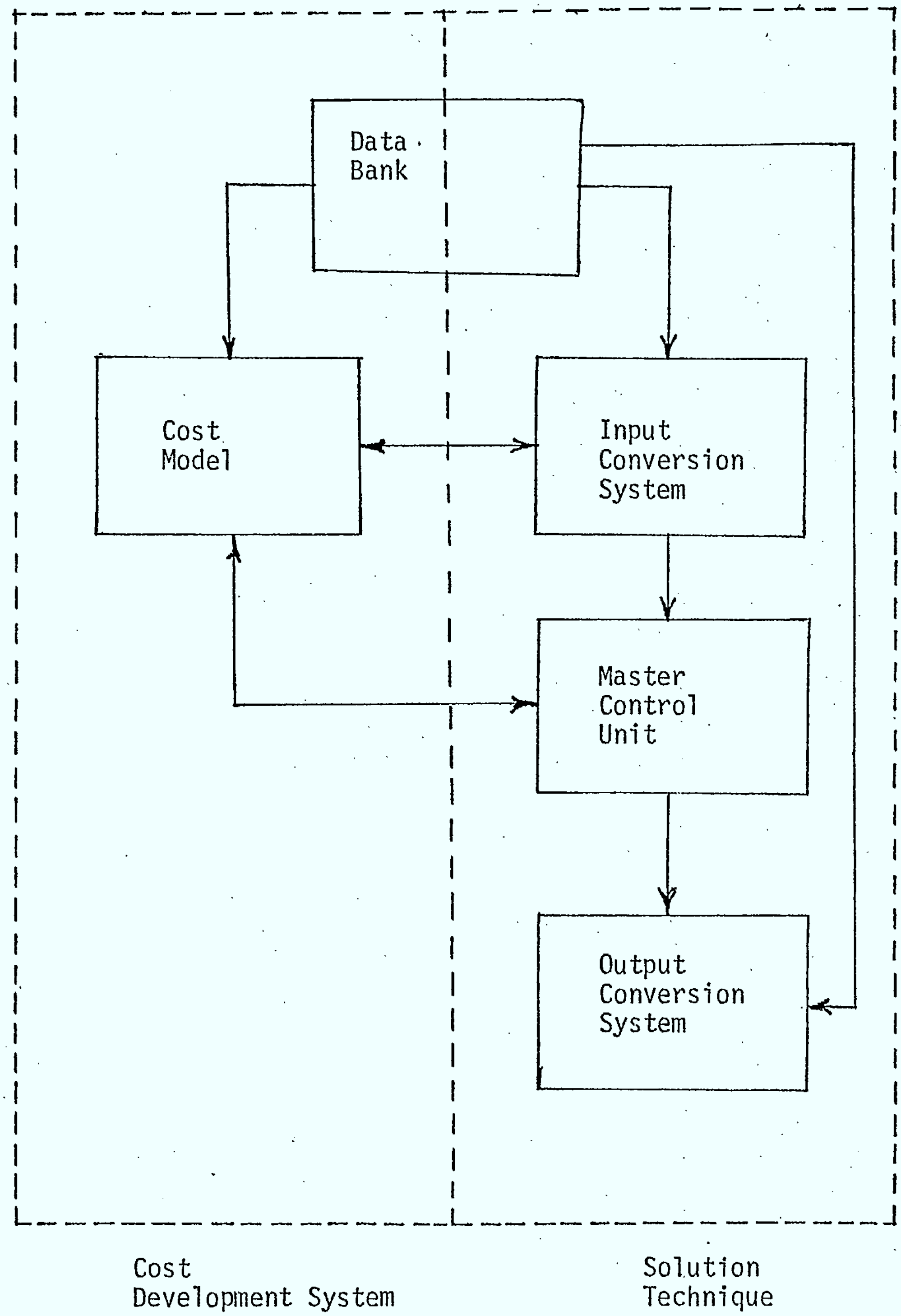


Figure 1.4 Schematic of the Optimization Model for Telecommunications Facilities Within an Urban Area

technique. The function of the cost development system is to compute the unit cost of installing plant in any segment of a switching center area, given the conditions of the area in question. The solution sub-system will use these costs as well as information on the network in developing a near optimal policy for the planning period considered.

The total optimization system can be sub-divided into five sub-systems, which are 1) the data bank, 2) the input conversion system, 3) the cost model, 4) the master control unit, and 5) the output conversion system.

The data bank stores the information that is necessary for the functioning of both the cost development system and the solution technique of the optimization model. It contains:

1) cost related information such as:
   a) rate of inflation ,
   b) impact of technology,
   c) rate of growth of the company,
   d) the cost of capital,
   e) the labor rates in the region,
   f) the sizes of cable, conduits and poles available and the associated costs, and
   g) the number of periods in the planning horizon and the duration of each period,
2) network details including:
   a) the layout and details of existing plant,

b) the possible future routes,

c) the distance (e.g. length of cable required) between various nodes (e.g. manholes, poles) in the network,

d) the geographic conditions, i.e., the topography and the climatic conditions of the area, and

e) the constraints on type of plant such as governmental regulations and technical requirements, and

3) forecast data which consist of:

a) the locations of the demand points in the area,

b) the total demand at each of these points upto and including the first period, and

c) the incremental demands for the remaining periods within the planning horizon.

The input conversion system will use the network and forecast data to restate the problem so that it can be readily fed into the optimization program. In the process this sub-system will supply the cost model with the information on the conditions in any segment in the area to obtain the unit cost of adding plant. The system distinguishes between time periods by creating one complete network for each period. These networks will be interlinked to allow for the excess capacity in one period to be made available for the succeeding period. In such a formulation, the first three periods refer to the first three years, while the last period covers the remaining years in the planning horizon, which is the time required for the ultimate fill of the switching center area. Different technologies are handled by creating parallel networks for each type foreseen.

The cost model will draw on the cost related information in the data bank to define the parameters associated with the cost function(s) to be used. The cost function(s) will be used to calculate the cost per line for any arc in the network, when information relating to topography, length, etc. are supplied. The cost model will interact with the input conversion system as well as the master control unit.

The master control unit contains:

1) a command program that controls the optimization program,
2) the optimization program, PNET, and
3) programs to update the cable sizes and costs so that they correspond with those cable sizes that are available in the market, and to introduce additional arcs necessary and to verify whether or not the final near-optimal solution has been obtained.

The main source of input to this system is the input conversion system. After a basic feasible solution has been obtained this unit will progressively update the cable sizes and costs, period by period until the last period is completed. The revised costs for the arcs thus modified are obtained by invoking the cost model. The output of this unit, which is the near-optimal plan, is fed into the output conversion system.

The output conversion system is a buffer between the optimization program and the user. Its purpose is to convert the output of the PNET program into a form which is easily comprehendable in practice. Thus, the information output by the system can be used directly in the planning of operations and in capital budgeting.

The remaining chapters of this report discuss the organization of the model, the tests conducted on it and the results obtained on testing the model. The various computer programs used as parts of the total optimization model are given in the appendices.

2. SUMMARY AND CONCLUSIONS

This study has developed a model that will give valuable assistance to the planning of outside plant facilities in a telecommunications carrier industry. The technique developed can be used with a forecasting model to yield a capital budget and a construction program.

A switching center area was chosen as the integral unit that can be used as a building block for planning purposes. Thus, the model developed can be directly applied to the optimization and planning of subscriber loop facilities in a telecommunications industry. The output of the model can be classified under two major headings:

1. capital budgeting information, and
2. a construction program.

The capital budget is useful in planning the financial requirements of the carrier company. The budget, along with the details of the investment in existing plant, can also be used as the basis for the development of just and reasonable rate structures. The construction plan will assist manpower planning, job scheduling and control and in arriving at the operating budget for the first period.

The solution technique is structured around a minimum cost flow network algorithm, PNET, developed at the University of Texas, Austin. Several programs were developed to transform the input and output information and to structure the problem so that it can be solved using the program PNET. The program PNET requires costs calculated on a unit basis. The cost model calculates the arc cost per unit of plant for the different plant classifications. The cost computed will be that based on the present value of all expenses such as installation costs, maintenance costs and salvage value. Factors considered in such a calculation include changing technology, rate of inflation and varying geographic conditions. It should be noted here that the cost of plant in a telecommunications industry depends also on several other factors such as the municipal rights, management policy, economies of scale, growth rates, and the size and age of plant in service. So the costs do not vary linearly with the size of plant and are non-continuous functions. Therefore, no procedure developed for planning purposes can be mathematically proved to be optimal. The technique developed by the study yields a near optimal solution which can be termed as the "practical optimum".

The tests conducted on the model revealed that the model can be adopted in a practical situation, using a planning range consisting of at least four periods. The last period in the planning range should represent the time spanning the end of the short range through to the point when the switching center area reaches ultimate fill. Short range forecasts should cover a period which is longer than the economic interval and one period is necessary to denote each year within this short range planning horizon.

The costs of operating the model and using it for capital budgeting depend on the size of the switching center area and several other considerations. Using this optimization technique involves studying the switching center area considered and developing a network that consists of the existing as well as other alternative routes. So the actual size and therefore, the cost of operating the model is directly affected by the ingenuity of the user in eliminating those routes that are not critical to decision-making.

2.1 Recommendations for Further Study

This study developed a model for the optimization of subscriber loop facilities within an urban area in the telecommunications industry. Several additional studies are necessary to achieve the ultimate goal of evaluation of capital expenditure proposals in a telecommunications industry and a related system to develop just and reasonable rate structures. Outlined in this section are some suggestions for future research.

1) Development of cost models for specific technologies. The optimization model can be used to decide on the timing of the introduction of new technologies if suitable cost models can be developed for specific technologies.
2) Extension of the model to include the switching center,

exchange trunks and toll trunks.

Procedures for planning investment in subscriber loops were developed by the study. These procedures can be extended to encompass the switching center and exchange and toll networks. Since the switching center and trunk facilities affect the subscriber loops and vice versa, any attempt to consider subscriber loops in isolation will only result in a sub-optimal solution. Studies should be undertaken to integrate switching and trunking costs into the model.

3) Development of rate structures.

The capital investment in a telecommunications system has a direct impact on the rate structure. In addition to the capital investment, several factors including the demand for telecommunication services, management, government and regulatory policies and regulations also affect the rates. An in depth study should be undertaken to develop a methodology for the development of just and reasonable rate structures in the telecommunications industry.

3. DEVELOPMENT OF THE OPTIMIZATION MODEL

3.1 Overview of the Total System

The optimization model to be designed for the telecommunications industry will be developed considering the switching center area as the basic element and the city as the integral system. This section outlines the characteristics of the total model.

3.1.1 Output of the Optimization Model

The optimization model will output:

1) the additions/replacements to be made to the existing plant throughout the planning period,
2) the nature of these additions, i.e., the size and type of changes to be made during each period,
3) the timing of the additions/replacements, and
4) the investment costs for each period within the planning horizon under the near optimal plan.

3.1.2 Inputs to the Model

The model requires the following input information in order to accomplish the functions indicated in the previous section:

1) network information including

a) the geographic area considered,

b) the location within the specified area,

c) the existing and utilized plant capacities in the area, and

d) the possible future routes,

2) the cost information such as:

a) the cost by size and type of plant,

b) the prevailing labor rates,

c) the growth rate of the firm,

d) the cost of capital, and

e) the rate of inflation,

3) the number and duration of the periods in the planning horizon,

4) the forecast data comprising:

a) the locations of demand points,

b) the total demand upto and including the first period in the planning horizon, and

c) the incremental demand for the remaining periods, and

5) technology assessment, i.e.,

a) the expected number and type of telecommunication carrier technologies for each period, and

b) the cost trends of the past and future expectations in the case of each technology.

The optimization model will develop a near optimal capital investment plan based on the information discussed above. In developing such a program, the model will consider the entire planning period of thirty years and the impact of customer demand and future technologies on the physical plant.

3.2 Problem Formulation

The philosophy adopted in formulating the optimization of subscriber loop facilities in a telecommunication industry is listed below:

1) The switching center area, in most towns, can be divided into a series of arcs.

2) The arcs can be identified by beginning and ending nodes, both of which represent a point where lines can be branched (e.g. manholes, access terminals).

3) Demand is aggregated at certain convenient points and these points have to be identified based on factors such as the city development plans, the type of customers in the area, etc.

4) The goal of the company is to determine the minimum cost route as opposed to the minimum length route.

However, usually, both routes are identical.

Figure 3.1 portrays a representative switching center area, with its constituent arcs and nodes. If the total number of periods in the planning period is equal to 'N', the total cost function can be simply described by,

$$Z = \sum_{n=1}^{n} \sum_{i=1}^{m} \sum_{j=1}^{m} (\Delta_{ijn} F_{ijn} + C_{ijn} X_{ijn})$$

where,

'n' is the subscript representing the period,

'i','j', are the beginning and ending nodes of the arc considered,

'm' is the total number of nodes in the entire area,

'C_{ijn}' is the variable cost per line for the arc i-j in period,n,

'X_{ijn}' is the capacity of plant installed in period,n, between nodes,'i' and 'j',

'F_{ijn}' is the fixed costs of installing plant across i-j in period,n, and

$\Delta_{ijn}=0$ if $X_{ijn}=0$

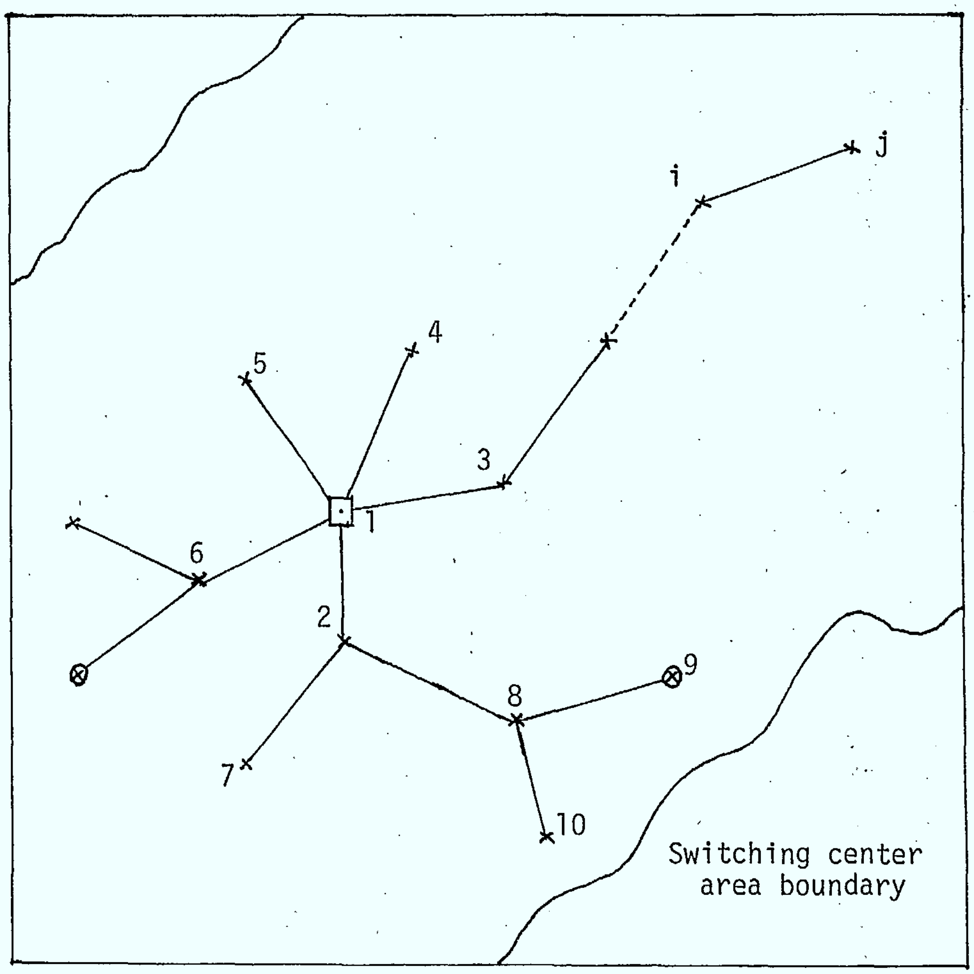
$=1$ if $X_{ijn}>0$

The constraints on this simplified objective function, which is to be minimized, include:

(i) non-negativity of arc capacities, i.e., X_{ijn}20,

(ii) the dependency of costs, C_{ijn}, on the actual capacities, X_{ijn},

(iii) the relationship between existing plant,



Switching Center

Demand Points

Nodes, numbered 1,2...,m
1-2,1-3,... Arcs

Figure 3.1 Representation of Subscriber Loop Facilities as a Series of Arcs additions/replacements and total plant at the end of a period, which is,

$$P_{ijn}=P_{ij(n-1)}+X_{ijn}$$
$$=P_{ij(n-1)}+AP_{ijn}-RP_{ijn}$$

where

"AP_{ijn}" is the additions made in arc segment i-j during period, n

"RP_{ijn}" is the amount of plant retired in the arc i-j during period, n

'P_{ijn}' is the total capacity of plant between nodes 'i' and 'j' at the end of period, n,

(iv) the demand requirements which can be stated as

$$\sum_{i=1}^{m} P_{ijn} \geq D_{jn} \text{ , where}$$

'D_{ijn}' is the total demand at node 'j' upto period, n,

and,

(v) the sizes of plant available in the market (e.g. cable sizes).

3.3 Alternative Systems Studied

Two alternative systems, namely, the Simplex method of linear programming and the network analysis approach were studied for the problem formulated as outlined in the preceding section.

3.3.1 Simplex Method

This system involves utilizing the simplex algorithm, developed by George B.Dantzig, for solving the optimization problem . Computer packages based on this algorithm are available in almost all computer installations.

Under this method, the costs are initially assumed to be linear. After one run with the program, the results are examined to see whether or not the costs and the flow for all the arcs match and if the plant size additions recommended are available in the market. The plant capacities and the costs are then updated to correspond to the next higher size available. The resulting problem is again solved using the simplex method. This process is repeated until all the arcs in the network satisfy the constraints.

3.3.2 Network Analysis Approach

This approach utilizes the integer programming methodology, PNET, developed at the University of Texas, Austin. This formulation requires the problem to be stated as a network flow problem. The network problem must be of the form shown in Figure 3.2. All the flows are assumed to emanate from a super-source (shown by "1" in the diagram). The fundamental constraint in this network is that the net inflow into a node equals the net outflow. All the flows

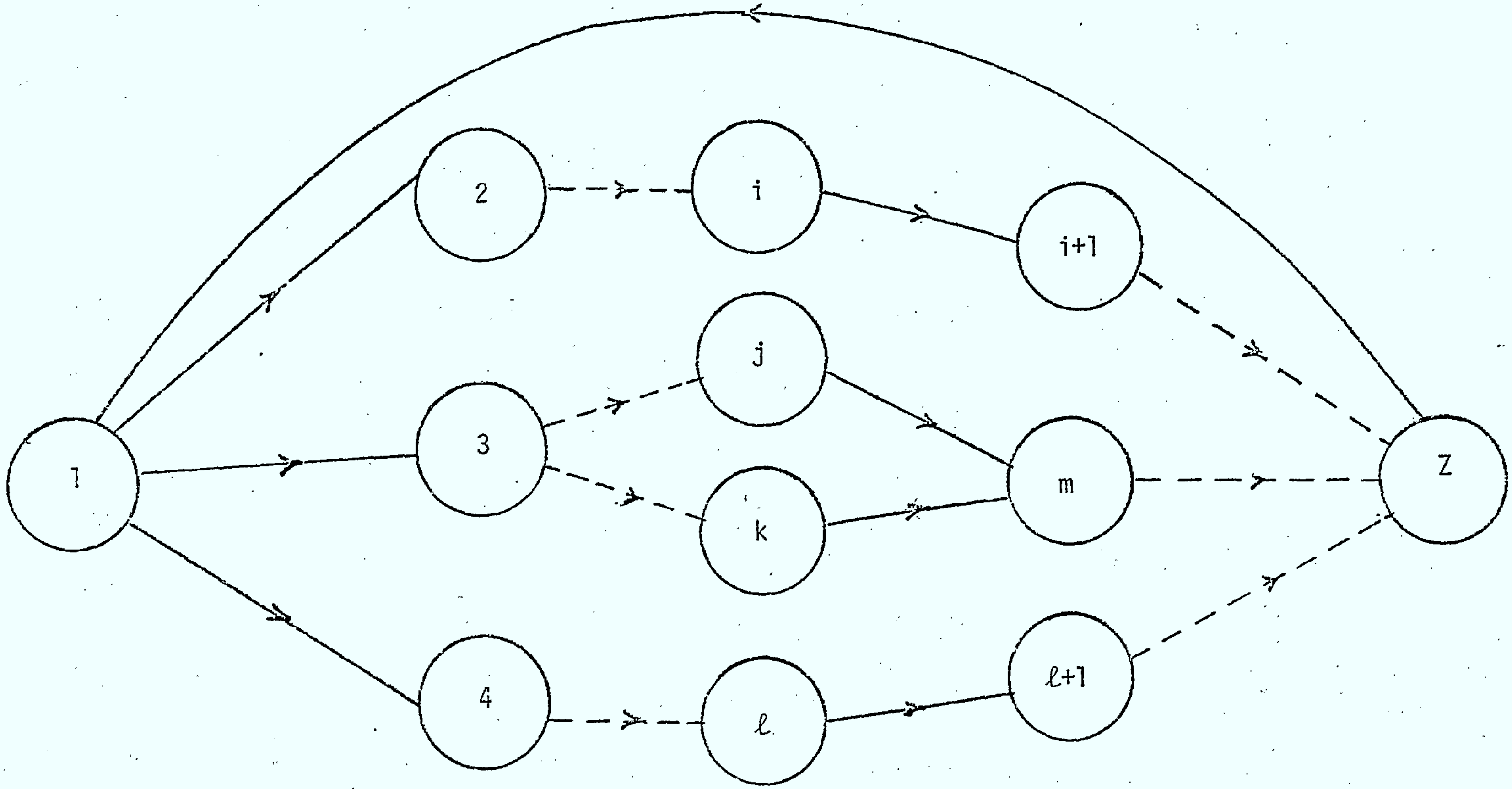


Figure 3.2 Basic Structure of PNET, The Network Algorithm

ultimately go to the super-sink, which in turn is connected back to the super-source to complete the cycle. A unit cost is attached to each arc and the cost of an arc is computed by the product of the unit cost and the flow across the arc. The flow through any arc in the network can be restrained by specifying lower and upper bounds for the arc. So the basic flow constraints and the objective of cost minimization are already built into the PNET program and it can be used, after a few modifications are made, to solve the problem of optimization of outside plant in the telecommunications carrier industry.

The PNET program uses a simplex primal algorithm and is specifically designed for the solution of minimum cost transshipment problems. It outputs the optimal solution and the total cost.

3.3.3 Evaluation of Alternatives

The two alternative systems were compared considering several criteria, mainly 1) the ease of operating the model, 2) the validity of results, and 3) the cost of operation.

Since both the simplex methodology and the network model are basically linear programming algorithms, they represent about the same degree of accuracy with respect to the results. Both of these methods assume that the total cost function is linear and this assumption makes it impossible to find a solution which can be mathematically proved to be the optimal. Computer packages using the simplex method are easy to operate as they are very common and most often are programmed in an interactive language. However, since the number of variables and the constraints in a telecommunications network are likely to be very large, the cost of running the resulting model is prohibitive. Therefore, the network model was chosen for detailed study and design.

The basic network model will be modified to facilitate optimization of plant in a switching center area. Two buffer systems, one to convert the data with respect to the switching center area into a format that is required by the PNET program and the other to report the results in a usable format are designed herein to increase the ease of operation.

3.4 Structuring the Problem

The PNET program is designed to solve simple transshipment problems. So, it cannot directly handle the problem of optimizing subscriber loop facilities in a telecommunications carrier industry. Several modifications are necessary on the physical network before the PNET program can be deployed. These changes must take into account:

(i) the customer demand,

(ii) the different time periods within the planning horizon,

(iii) the several types of technology encountered,

(iv) the various types and sizes of plant,

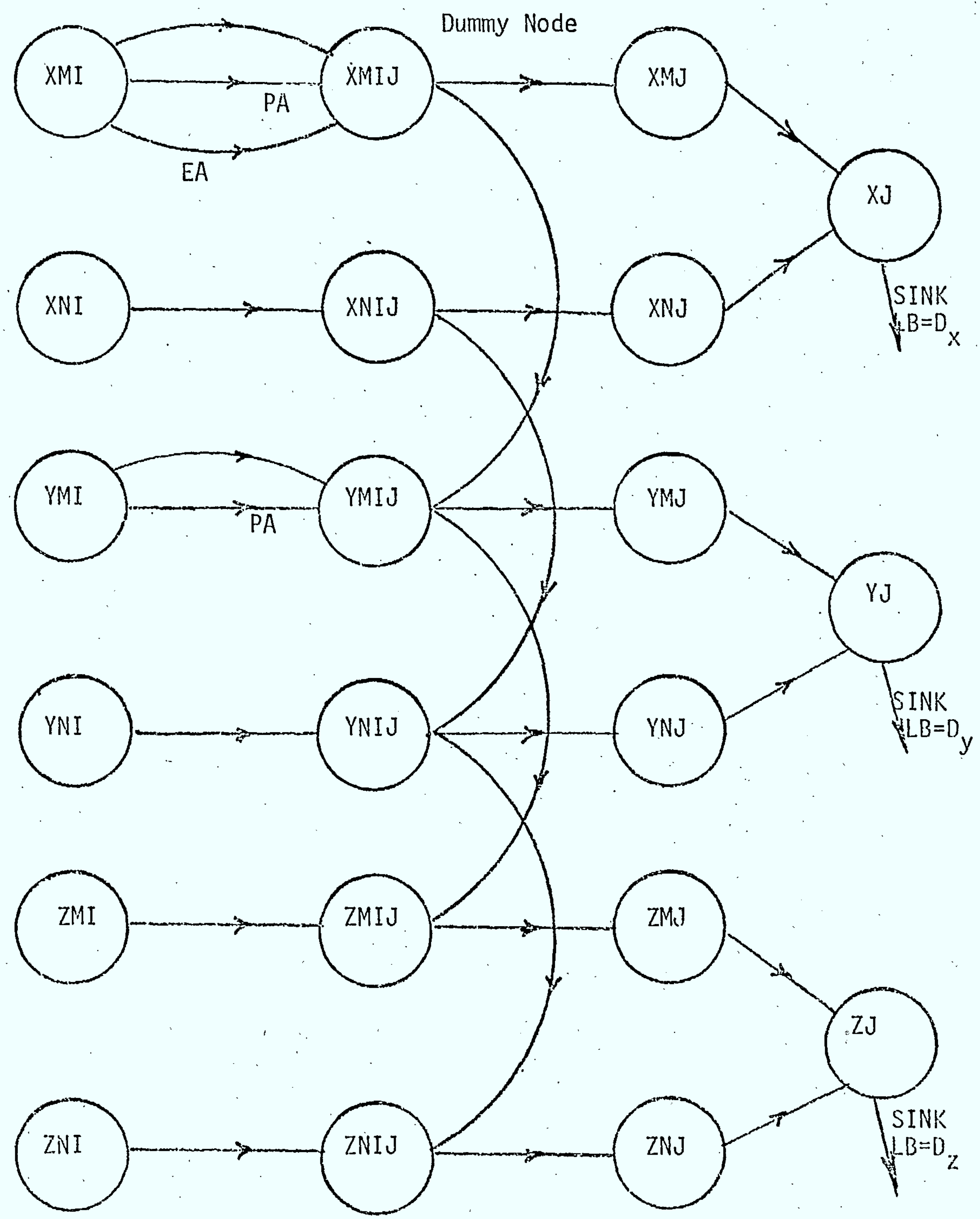
(v) the dependency of costs on the size of plant installed, and

(vi) the existing plant.

Figure 3.3 is a schematic of an arc in the network incorporating all these factors into its structure. Customer demand is taken care of by creating dummy arcs from demand points (representing terminals) to the super-sink with the lower bound equal to the demand.

One complete network is utilized to describe one period in the planning horizon. Intermediate (dummy) nodes are created between each pair of successive nodes. This arrangement is necessary to link the different time periods with one another. The excess capacity in an arc flows through the intermediate node to the corresponding node in the following period allowing for use of the unutilized capacity in the succeeding period.

Assessment of technology is one of the objectives of the total system. Within each time period, parallel networks are created to designate the different types of technology available in that period. The costs used on the arcs representing different technologies are calculated



LB - Lower Bound

X,Y,Z denote time periods

M,N denote technologies

D_i denotes demand in period, i

Figure 3.3 Structure of an Arc, I-J, in the Flow Network considering the full impact of the technologies considered. Thus the technologies compete to supply the demand forecasted.

The PNET program is an integer programming algorithm, which assumes that the arc flows (or the plant capacities) can be any positive integer. In a telecommunications industry, however, plant additions/ replacements can be made only in certain packages and these sizes are dictated by the market specifications. To account for such an occurrence, the plant sizes are updated, progressively by periods, in the manner discussed below. After every run with the PNET program, all the arcs in the period considered will be scanned to verify whether or not the flows correspond to a size of plant available. If the flow in an arc equals a size of plant available, the lower and upper bound for the arc are equated to the flow in the arc. Otherwise, the upper and lower bounds are made equal to the next higher capacity of plant available. These updated arcs are referred to as the primary arcs. There can, at most, be one primary arc between a given pair of nodes. There are certain fixed costs (such as trenching costs, conduiting costs) associated with installing plant that do not change linearly with the size of plant. If there is a primary arc between a certain pair of nodes, these fixed costs would have already been taken care of in the unit cost specified for the arc. Hence any additional plant to be installed will, normally, cost less to install. When a primary arc is updated, this factor is taken care of by introducing an additional arc with a cost equal to the incremental unit cost. The incremental unit cost is obtained by dividing the additional cost involved in placing the next higher size of plant available by the increase in capacity of plant. When the resulting network is run with the program PNET, flow in the new arc will indicate whether or not it is desirable to place more plant to take care of future demand. Between a given pair of nodes, one arc will represent one type of plant (e.g. underground cable, aerial cable, buried cable).

Once again, it is important to note that the dependency of cost on actual flow and the fact that there is a fixed cost associated with installing plant imply that it is impossible to be certain whether or not the solution output by the program is optimal. The unit cost specified for an arc, initially, are those based on the smallest quantum of addition possible. This cost is computed by dividing the cost of plant of the smallest size by the capacity. If the flow, after a run with PNET, is found to exceed the flow used as the basis for cost calculations, the cost is revised to correspond to the new size of plant. For example, if the cost calculations for the initial run were made based on a capacity of 600 lines and the flow in the arc was 850 lines, the next iteration is run using the cost for a 900 pair cable. This process is repeated until the flow and the cost match for all the arcs in the entire network.

The model should be able to decide whether to use existing facilities or to abandon existing plant and install new plant in an arc segment. The true value of any existing plant is obtained by calculating the present equivalent cost considering the material value less the removal charges, the operating costs, and the salvage at the end of its useful life. An arc, with a cost per line equal to the value thus obtained, is used to denote existing plant wherever there is some installed capacity. Original costs are ignored because they are sunk costs and are irrelevant in making decisions and in capital budgeting. The upper bounds for these arcs are specified to be equal to the respective capacities to signify the size available.

Figure 3.3 represents an arc that has both existing plant and an end node that is a demand point. It should be noted that it is not necessary that all arcs have existing plant or that there is demand at the ending node. The arcs denoted by "PA" represent the primary arcs or those that have been updated. The arcs "EA" denote existing plant, while the node "X J" is a dummy node created to represent the terminal with a demand "D". The sum of the flows in the arcs between a certain beginning node (e.g. XMI in Figure 3.3) and the corresponding intermediate node (XMIJ) will indicate the total installed capacity between the nodes at the end of the period in question. If the flow in the existing plant were subtracted from the total installed capacity, the resulting value will be the additions to be made in the period considered between the nodes. The flow in the arc connecting the intermediate node to the corresponding node of the following period (e.g. arc XMIJ-YMIJ in Figure 3.3) represents the excess capacity at the end of the period that can be utilized in later periods. Chapter 4 presents a detailed description of the optimization technique while the cost model is discussed in Chapter 5.

4. DETAILED ANALYSIS OF THE SOLUTION TECHNIQUE

The organization of the total optimization model and the specific role of the solution technique were outlined in the preceding chapter. A detailed report on the solution method is presented in the following sections. The solution method includes the following sub-systems:

1) the data bank,
2) the input conversion system,
3) the master control unit, and
4) the output conversion system.

4.1 Data Bank

The data bank stores the cost information, forecast data and details of existing and alternative routes for the subscriber loops. The cost model utilizes the cost data, a brief description of which was given in section 1.3.1. The format in which the forecast and network information are stored are discussed below.

4.1.1 Network Information

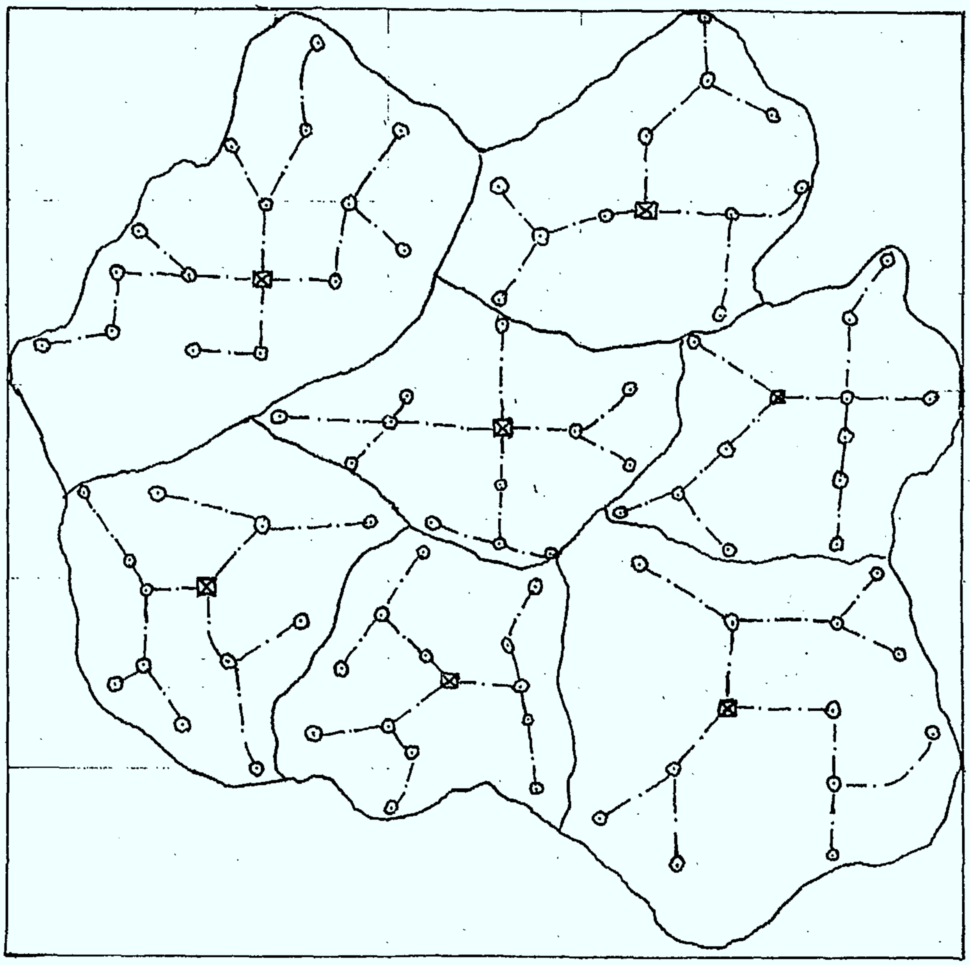
The integral area (e.g. a city) considered is represented on cartesian coordinates as shown in Figure 4.1. The axes can be chosen so that the y-axis runs from the north to the south and the x-axis east-west. The network to be optimized can be described on this grid by specifying the location of switching center(s) and manholes, the type of cable used between two adjacent nodes and the installed and utilized capacities of plant for all pairs of adjacent nodes. The city can be divided into different zones based on the topography. This arrangement is necessary for the estimation of the cost of installing plant in any location within the area.

To facilitate storing this information in a computer, the entire network , proposed and existing, can be visualized as being composed of several series of arcs, each with a preceding and succeeding node. The description of the nodes and arcs can be conveniently stored in a computer by defining:

(i) the names of the nodes and their co-ordinates,

(ii) the names of the beginning and ending node for each arc in the network; these nodes represent the location of either a manhole, pole, access terminal or a switching center,

(iii) the type of plant (e.g. cable) used, or that can be used, in the arc; this is accomplished by utilizing a numerical code to represent each



Legend:

____ Switching Center Area Boundary

—.— Existing / Possible Cable Routes

⊠ Switching Center

⊙ Manholes/Poles

Figure 4.1 Representation of an Integral Telecommunications System (e.g. a city) on Cartesian Co-ordinates type of plant (e.g. cable),

(iv) the number of installed and utilized lines in each arc,

(v) a code for the topographic condition of the arc,

(vi) the length of the arcs,

(vii) the airline distance of the beginning node of an arc from the switching center, and

(viii) the number of additional cables of a certain size (e.g. 100 pair cable) that can be accommodated in the arc with existing facilities (such as conduits).

The airline distances are used, in conjunction with an airline distance to physical plant distance ratio, to design the plant required in the various arcs in the network.

4.1.2 Forecast Data

For the purposes of storing the present and future demand for telecommunication facilities in a data bank, the demand will be assumed to be aggregated at those points that represent the location of access terminals, existing and possible. Thus the forecast pattern can be fully described by defining the coordinates of the demand points on the grid of Figure 4.1 and by specifying against each of these points:

(i) the aggregate demand upto and including the first period, and

(ii) the incremental demand, by period, for all the remaining periods.

The forecast data for a switching center area is specified by modules, which are identified by dividing the entire switching center area based on the subscriber concentration and growth potential. The forecasted demand for the whole switching center area is allocated to the modules considering these two factors.

The PNET program requires a pinpoint demand forecast and hence there arises a need for the allocation of the forecasts within each module to specific points. The process of allocating demand within modules involves the stages outlined below.

1) Find areas within the module with common subscriber density. This stage involves isolating the points where specific developments are foreseen (e.g. locations of apartments, shopping centers) and areas which have single family dwellings, etc. The objective here is to insure, as far as possible, that a single sub-area identified has a uniform subscriber concentration. City development plans, opinion polling and subjective judgement of forecasting personnel are some sources of data that can be useful for this categorization.

2) Locate point(s) in each of the sub-areas of stage (1) that are potential location(s) of access terminal(s).

This phase includes finding the center(s) of gravity of the sub-areas. Factors such as the existing plant and geography (physical barriers) will have to be considered in locating the access terminal points.

3) From past experience and the specific development plans, obtain the expected demand for the sub-areas. For example, consider a sub-area where an apartment complex with a capacity of 200 units is being developed and is expected to be completed in the following year. Further, suppose that it is known that it is likely to house middle income families and that past data indicate that such apartments generate a demand of one line per household. Then, the expected demand for the sub-area is 200 lines.

4) Based on the expected demand figures obtained in stage (3) assign weightage factors for each sub-area. The weightage factor "W_{mn}" described for area "m" and period "n" is given by,

W_{mn} = (Expected demand for the sub-area)/ (Sum of the expected demands for all the sub-areas in the module)

5) Multiply the forecast for the module by the weightage factors of individual sub-areas to obtain the forecasts for the sub-areas.

6) Allocate the demand to the access terminal points by dividing the sub-area demand by the number of access terminal points in the sub-area.

Figure 4.2 is a grid map showing the modules and point forecasts for one module in a switching center area. Considerable judgement has to be exercised in allocating forecasts within modules as the location of the demand points is a critical factor in developing a near optimal project plan.

Table 4.1 shows the format in which the network and demand information will be stored in the computer. The actual demand will be modified to include a certain factor of safety. This factor is necessary to take care of the errors in the forecast, to allow for some bad lines in the plant, and for other reasons which include administrative regulations of the company and the need for some means of communicating between two points in the network while repairs/ rearrangements are done. The factor can also be obtained by determining the useful capacity of a facility for demand service. The additional capacity to be planned for varies depending on the forecast used and the type of plant used. For example, if the forecasts included an allowance for errors, this additional capacity may fall in the range of ten to twenty lines. But if the forecast does not include any allowances for the risk, the factor of safety used may provide for an additional 100 lines of cable. Demand points are identified by creating a dummy arc and placing the forecasts by period on the card/line following the one that contains the arc. The dummy arc has

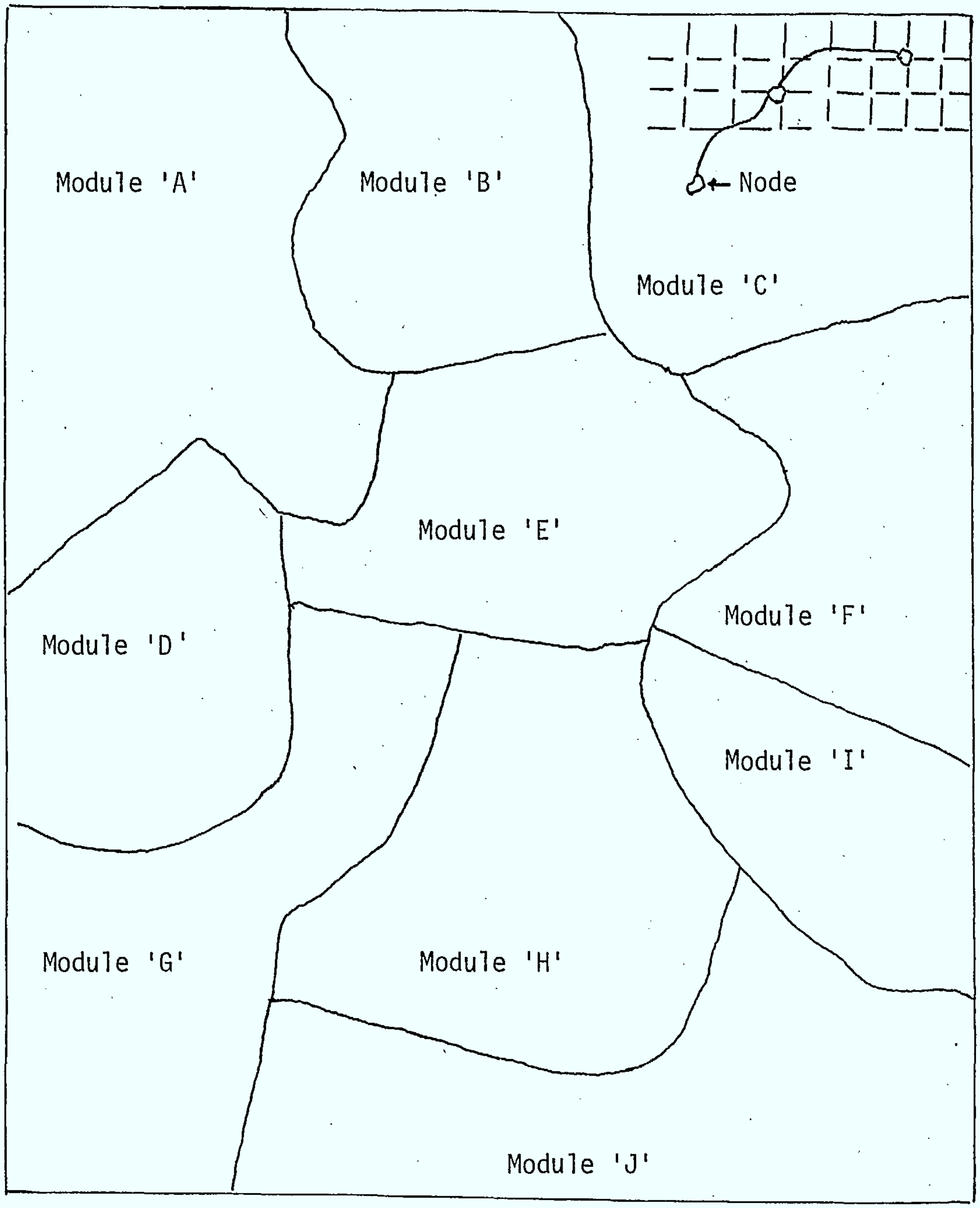


Figure 4.2 Grid Map Showing Telecommunications Demand Modules and the Nodes Within the Modules

Table 4.1 Network Information stored in the data bank

From Node	To Node	Constraints on the type of Plant	Installed Capacity	Utilized Capacity	Geographic Code	Arc Length	Airline Distance of beginning node from the Switching Center	Number of cables that can be accommodated by the existing facilities

the demand point for its beginning node and a dummy zero as its ending node. It is important that all arcs emanating from a node (including the dummy arc representing demand) be placed together in the data bank.

In addition to the forecast and network information, the number of periods in the planning horizon, the duration of each of these periods and the number of different types of technology forseen in each period will also be stored in the data bank and used by the input conversion system. The details of the several different types of plant available, a brief description of the accounts and the unit of measurement of plant in these accounts are also stored in the data bank for use by the output conversion system in developing capital budgets.

4.2 Input Conversion System

The basic function of this sub-system in the optimization model is to transform the information in the data bank in order to facilitate using the network algorithm, PNET, to obtain an optimal plan.

The input conversion system accomplishes the following major objectives:

(i) naming the nodes in a sequential manner and storing their locations to help in transforming the output into an easily comprehendable form,

(ii) creating parallel networks, each of which represents one period within the planning horizon; for each period one complete network will be used to define a particular type of technology,

(iii) connecting all points with non-zero supply (demand) to a dummy source (sink) node; the switching center is usually connected to the source and demand points to the sink,

(iv) specifying the lower bound on the arcs connecting the demand points to the sink equal to the corresponding forecast and thereby insuring that the demand is satisfied,

(v) activating the cost model to obtain the appropriate costs for each arc in the network and specifying the cost per cable pair for each arc,

(vi) placing capacity restraints on existing plant by equating the upper bound for the arcs that represent existing plant to the installed capacity , and

(vii) allowing excess capacity from one period to be used in the following periods by creating intermediate nodes between all pairs of adjacent nodes and linking the intermediate node of one period to the corresponding node of the succeeding period. The intermediate nodes of the last period will be connected to the sink.

Figure 4.3 shows the schematic of the output of this system while the form in which it will be stored in the computer and fed into the master control unit is illustrated in Table 4.2. A complete listing of the computer model that is used to achieve the goals of the input conversion system is given in Appendix A.

The program utilizes the information in the data bank to establish a description of the network similar to Table 4.2 for a given pair of adjacent nodes. The number of arcs between the nodes will equal the number of alternative types of plant. For example, if both underground and aerial cables can be used in a certain portion of the area, two arcs will be created for each pair of manholes/poles in the area. In addition, a third arc, representing existing plant, will be added wherever there is some installed plant. In arranging a table similar to Table 4.2, the sequence in which the arcs are placed is important. The 'PNET' program requires all arcs emanating from a node to be placed together.

4.3 Master Control Unit

The master control unit of the optimization model contains:

(i) the command program that controls the operation

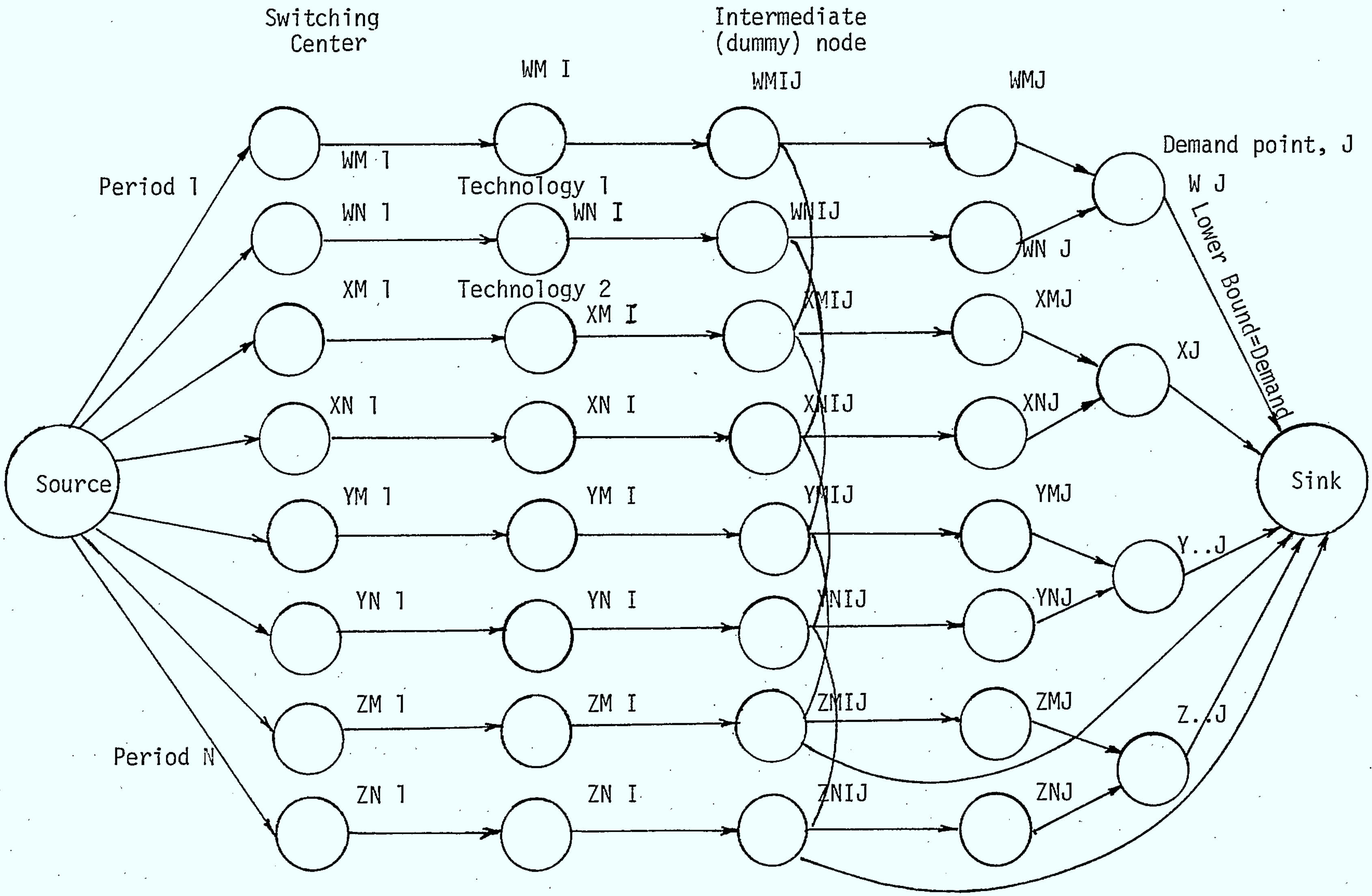


Figure 4.3 A Schematic of the Output From the Input Conversion System

Table 4.2 Output of the Input Conversion System

From Node	To Node	Arc Cost	Upper Bound	Lower Bound
SOURCE	0001	Switching Cost	Capacity	0
SOURCE	0101	Switching Cost	Capacity	0
SOURCE	1001	Switching Cost	Capacity	0
SOURCE	1101	Switching Cost	Capacity	0
0001	0012	Loop Cost	Capacity	0
0101	0112	Loop Cost	Capacity	0
XM I	XMIJ	Loop Cost	Capacity	0
XN J	XNIJ	Loop Cost	Infinity	0
XMIJ	XM J	0	Infinity	0
XNIJ	XN J	0	Infinity	0
XM J	X J	0	Infinity	0
XN J	X J	0	Infinity	0
X J	SINK	0	Infinity	Demand at J
SINK	SOURCE	0	Infinity	0

Capacity is equated to the upper bound only if the arc represents existing plant.

of the optimization program,

(ii) PNET, the main optimization program based on a minimum cost flow network, and

(iii) programs to perform the operations such as required in between iterations.

The purpose of the master control unit is to utilize the basic network and cost information provided by the input conversion system to develop a near optimal route plan that will minimize the cost for the entire planning period.

4.3.1 Operating Sequence

The optimization program works on the principle that the flow in an arc can be any positive integer. The available sizes of plant in a telecommunication carrier industry are discrete, i.e., plant additions can only be made in certain packages. Hence there is a need for modifying the solution as determined by the first run of the optimization program, PNET. This is done by updating the flow in the network, period by period, and running the program with a new network, containing additional constraints, until all the periods in the planning range have been considered. Figure 4.4 shows the operating procedure on a flow diagram. The PNET program is a linear optimization technique wherein the cost of installing plant in an arc is calculated by computing the product of the cost

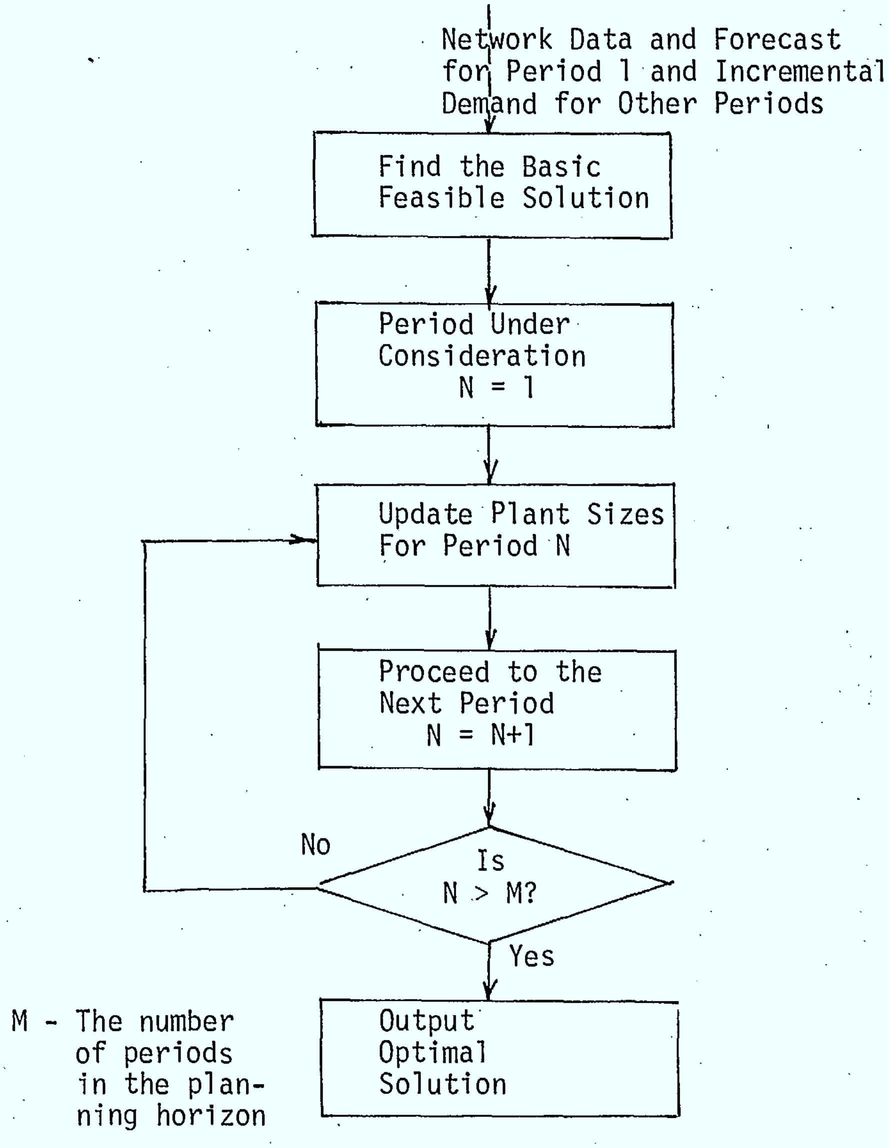


Figure 4.4 The Flow Diagram for the Master Control Unit

per line and the capacity. Thus the program cannot handle fixed costs and variable costs separately. This difficulty is overcome by iterating until the unit costs (the present equivalent cost/ line) specified for the arcs correspond to the respective flows.

The various steps involved in the operating process of the master control unit are summarized below.

1) Obtain a basic feasible solution by running program PNET with the data supplied by the input conversion system. The output of this stage will indicate the flow necessary in each period to satisfy the forecasted demand.

2) Set the lower bound on all arcs connecting the intermediate nodes, XIJ, to ending nodes, XJ, equal to the flow in the respective arcs. The symbol 'X' refers to the period the arc represents and 'IJ' is a dummy node introduced between nodes 'I' and 'J'.

3) Set period for which updating is to be done, N, equal to one.

4) Scan all the arcs connecting 'XI' and intermediate nodes 'XIJ' in period, N.

   (i) No changes are made to those arcs where the flow is zero.

   (ii) If the flow in any of these arcs equals a size of plant available, equate the lower and upper bounds for the arc to the flow.

Otherwise, set lower bound and upper bound equal to the next higher capacity of plant available. These arcs are referred to as primary arcs. Invoke the cost model to obtain relevant unit costs for these primary arcs. Create a new arc between all pairs of nodes linked through a primary arc. This is necessary to allow for installation of more plant if it were found to minimize the cost in the next iteration. The cost on the new arc will be equal to the incremental unit cost of increasing plant capacity to the next higher size available. The incremental unit cost is defined as the difference in cost between two sizes of plant divided by the corresponding difference in size.

5) Run the program PNET with the output of stage (4) to obtain a new solution set.

6) Scan all the non-primary arcs of period N in the new solution to check how many of these arcs have a flow greater than the specified lower bound.

   (i) If none of the arcs have flow in excess of the lower bound, proceed to step (9).

   (ii) If there is at least one arc with flow more than the lower bound continue with step (7).

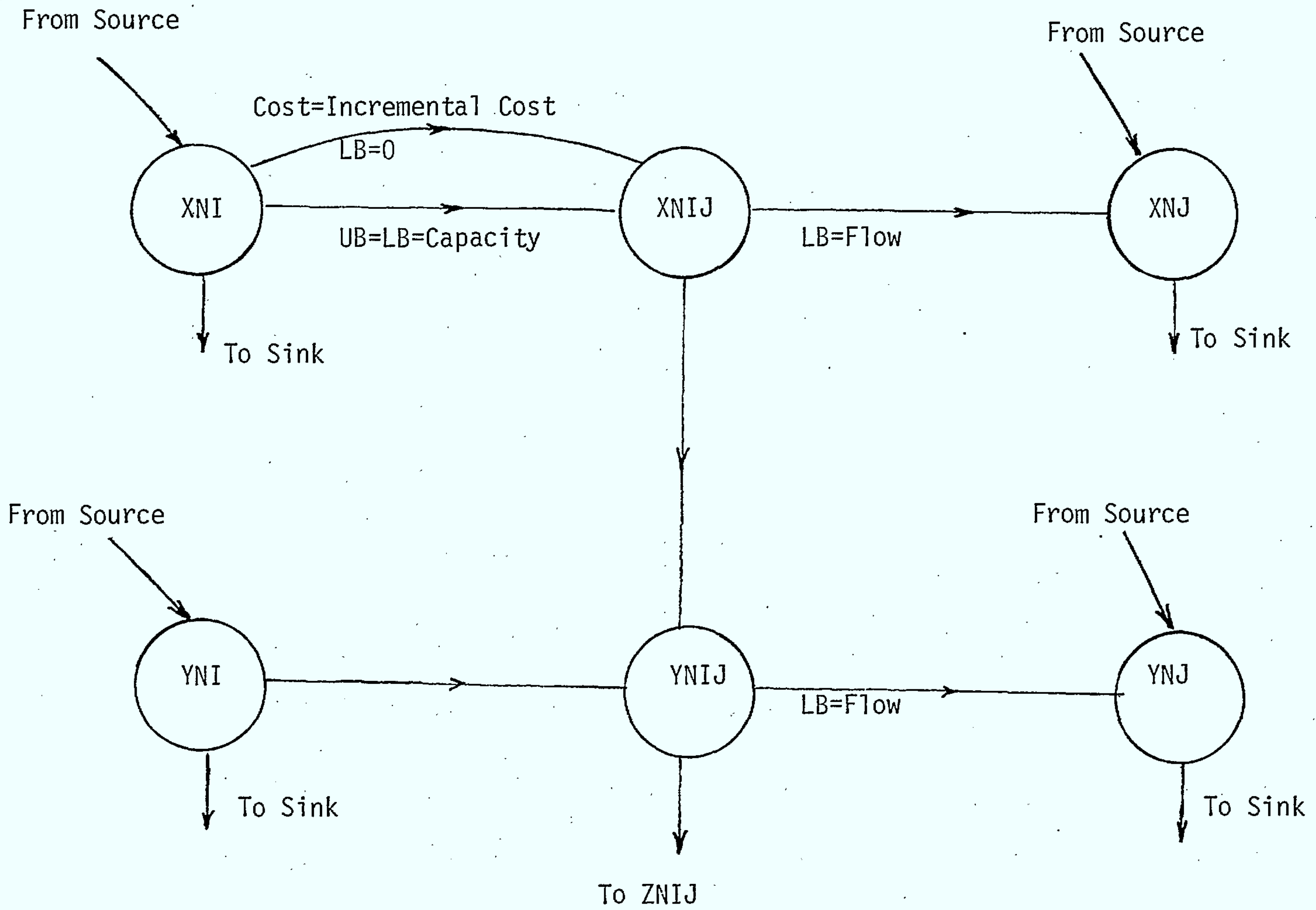
7) Adjust the lower bound on all the non-primary arcs. The new lower bound will be equal to the flow, if plant of that capacity is available. Otherwise, the lower bound will equal the next higher size of plant. Activate the cost model to obtain the relevant unit cost for the arc. No additional arcs need to be introduced because no upper limit is specified for these arcs.

8) Run the program PNET with the output of step (7) to obtain a new solution and return to step (6).

9) Increment the period indicator by one, i.e., the new value of 'N' becomes 'N+1'. If the new value of N exceeds M, the number of periods in the planning horizon, the final solution has been obtained and can be fed into the output conversion system for decoding. Otherwise, return to step (4).

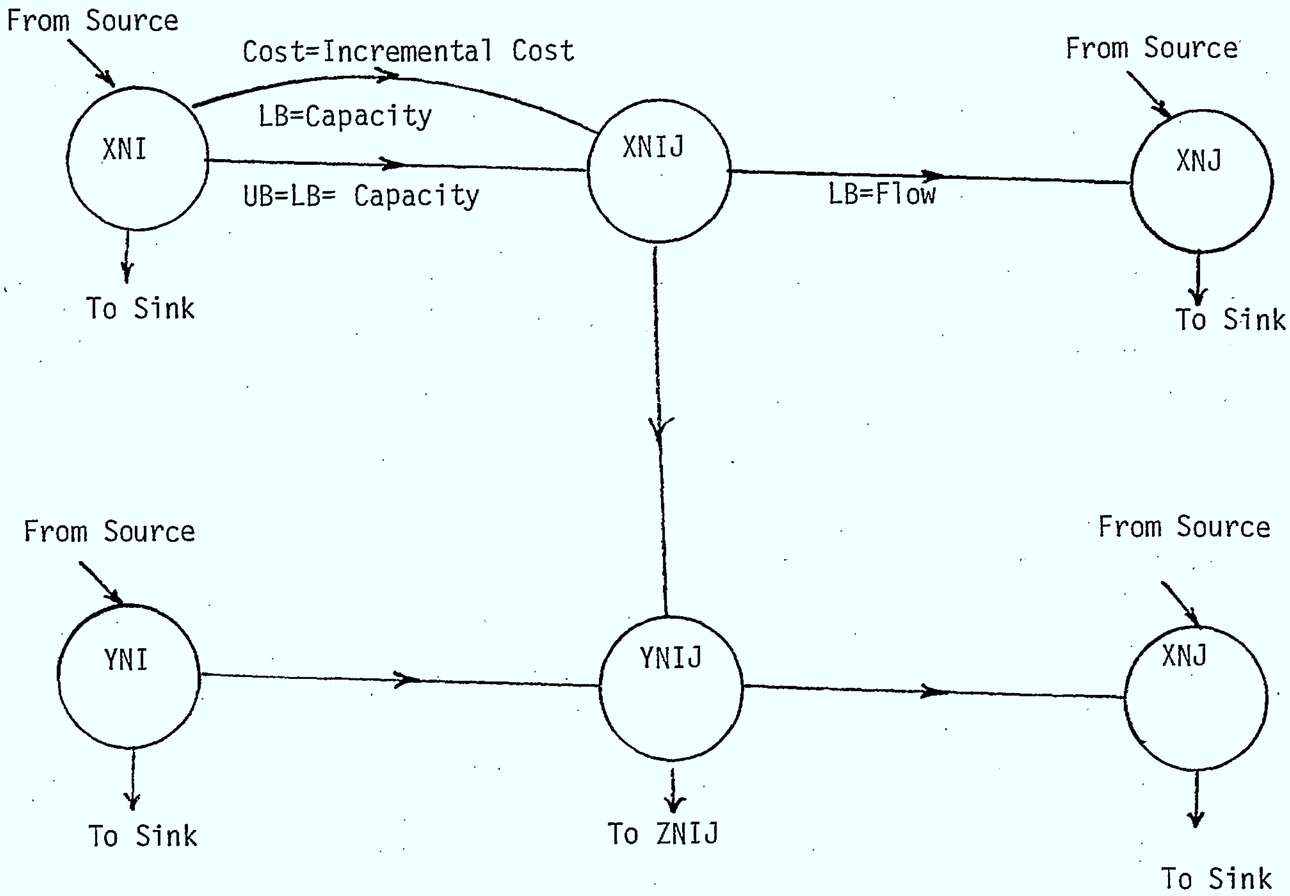
The computer commands necessary to carry out the nine stages in the operation of the master control unit are indicated in Appendix B. Figures 4.5 and 4.6 show schematically the state of the network at the end of stages (4) and (7) respectively.

To illustrate the functioning of the master control unit, consider an arc "I-J" in the physical network. This arc will be initially represented by a series of arcs,



LB = Lower Bound, UB = Upper Bound

Figure 4.5 The State of a Representative Arc After the Fourth Stage of Operation



LB = Lower Bound, UB = Upper Bound

Figure 4.6 The State of a Representative Arc at the end of the Seventh Stage of Operation

"XNI-XNIJ" and "XNIJ-XNJ", where "X" and "N" are integers denoting the different periods and technologies respectively. In addition, the intermediate nodes ,"XNIJ" representing one period are connected to the corresponding nodes, "(X+1)NIJ" of the succeeding period. After one initial run with the program PNET, all the "XNIJ-XNJ" arcs in the network are scanned and the lower bound is equated to the flow in these arcs. At this stage, all the beginning and ending nodes in the network are connected to both the source as well as the sink. This arrangement is necessary to balance the flows in the arcs when they are updated. The output of the initial run symbolizes the arc capacities necessary to satisfy the existing and forecasted demand. Since all the beginning and ending nodes are connected to the source, when the PNET program is run with the new network, it will attempt to satisfy the demands by drawing the necessary flows directly from the source. In practice, the demand cannot be satisfied by just placing plant at the demand points because these points must be connected to the switching center. By specifying lower bounds on the arcs connecting the intermediate and ending nodes, at least that quantity of flow is insured through the entire network, that is necessary to satisfy the demand.

The next stage is to update the arcs in the network that represent the first period. Since plant additions can be made only in certain packages, the lower and upper bounds in all the arcs, "XNI-XNIJ", are made equal to the next higher size of plant addition possible. While these arcs are updated the costs are also adjusted to correspond to the new capacities of plant. For example consider an arc in the following situation:

the cost of installing a 500pr. cable=$600

the cost of installing a 600pr. cable=$700

the cost of installing an 800pr cable=$800

Assume that the additions can only be made in quantities of 500lines, 600lines or 800lines and that the cost originally specified for the arc was that corresponding to a capacity of 500 lines, i.e., $600/500=$1.20. If the flow in this arc was 571, the lower and upper bounds would now be specified to be equal to 600 and the cost would be adjusted to $700/600=$1.16. This arc is termed as the primary arc for the pair of nodes considered. By specifying the upper and lower bound equal to 600, the plant to be added in this segment of the network in the first period has been constrained to be equal to 600. In a practical situation, it would be desirable to place more plant, to take care of future demand, if this were found to be economical. To account for such a possibility, an additional arc is created with cost equal to $(800-700)/(800-600)=0.50. This cost represents the incremental unit cost in placing an 800 pair cable instead of a 600 pair cable.

After the resulting network is run along with the program PNET, the flow and the cost in the non-primary arcs (i.e. the new arc between nodes that have a primary arc and the original arcs in other situations) are compared to verify whether they match. If the flow and the cost for all the arcs match, updating is carried out for the arcs which represent the second period in the planning horizon. This procedure is repeated until all the arcs in the last period have been updated.

4.3.2 Programs in the Master Control Unit

This section enumerates the programs that are required to perform the different stages in the functioning of the master control unit. The coded version of all the programs are given in Appendix B, which also gives the instructions necessary to facilitate the use of these programs.

The command program parameters can be altered, as indicated in Appendix B, to control the functioning and/or the output of the optimization program. With the help of the command program, the PNET program can be controlled to report only the total cost, or the flow pattern and the total cost , as desired by the user.

The optimization program, PNET, reads in the input data in a format similar to that of Table 4.2. It uses a primal simplex algorithm to find the minimum cost routes. The execution of the iterative steps is carried out until an optimal solution is found or until the number of iterations exceed a pre-specified amount. On termination of the computations the program outputs the final network by specifying for each arc:

(i) the beginning and ending nodes,

(ii) the unit cost, i.e., the cost per line,

(iii) the lower and upper bounds that were supplied,

(iv) the flow or the capacity of plant installed,

(v) the total cost of plant, and

(vi) the marginal cost, which is the change in total cost effected by increasing the capacity of the arc by one additional line.

In addition, PNET also reports the total cost, the number of iterations carried out and whether or not an optimal solution has been found.

Several sub-programs are required to assist in examining the output of each successive run of the PNET and to modify the constraints and unit costs. Subroutine CAPACITATE performs stage (2) of section 4.3.1. It also introduces dummy arcs connecting a fictitious switching center to all the initial and final nodes, I and J. The arcs connecting the nodes I, J to the sink are also introduced through the use of 'CAPICITATE'. These arcs are necessary to balance the flows as explained in section 3.3. Programs UPDATE1 and UPDATE2 perform the updating stages 4 and 7 of section 4.3.2.

4.4 Output Conversion System

The output conversion system decodes the near optimal plan of the optimization model and reports it in a format which is readily comprehendable.

The input to this system is composed of:

(i) the output of the PNET, i.e.,

a) the arcs and the number of cable pairs in each arc,

b) the arc costs,

c) the marginal arc costs, and

d) the total cost,

(ii) data bank information comprising:

a) the different classes of subscriber loop plant,

b) a brief description of the accounts within each class of plant, and

c) the units of measurement on which the construction costs are to be calculated, and

(iii) the output of the master control unit, i.e.,

a) the period each arc represents,

b) the type of plant denoted by each arc,

c) the length of each arc, and,

d) the construction costs associated with each arc.

The output conversion system processes these data to obtain:

(i) construction information which includes:

a) the different arcs in the network,

b) the capacity additions to be made to these arcs in the first period,

c) the nature of the additions, i.e., the type of plant and cable used, and

d) the total installed and utilized capacities for the arcs at the end of the first period,

(ii) the switching center capacities by periods and type of technology, and

(iii) capital budgeting information such as:

a) the volume, by type and size, of plant required each period,

b) the projected unit construction costs for each type of plant, and

c) the total estimated costs for the different types of plant.

Table 4.3 shows the format in which the construction plan summary is output. This information, in conjunction with a map of the area showing the locations of the nodes, can be used in operations planning and control. Such an arrangement facilitates continuous monitoring of the construction plans and updating of the physical plant details as plans are implemented. This table can be used as the basis for the preparation of input data for the optimization program in future periods. The switching center

Table 4.3 Subscriber Loop Construction Plan Summary

Switching Center Area --------   Date -----

From Node	To Node	Capacity Additions (Lines)	Installed Capacity (Lines)	Utilized Capacity (Lines)	Class of Plant	Type of Additional Plant

capacities, shown in Table 4.4, give the total capacity in the first period and the incremental capacities necessary to fulfill the demand in later periods.

Table 4.6 depicts the format in which the periodic capital budgets are obtained. The construction costs and the total units required for each type of plant are accumulated by scanning all the arcs that represent a particular period. The unit construction cost for an individual type of plant is calculated by dividing the total estimated cost for that plant by the corresponding volume. Finally, the system also outputs a summary of capital investment by period. These details, arranged as illustrated in Table 4.5, allow a carrier company to integrate all the switching centers in an urban area and prepare the overall budgets for the company.

The output conversion program and the variables used in performing its functions are discussed in Appendix C.

Table 4.4 Switching Center Capacity by Period in Lines

Switching Center Area --------   Date -----

	Technology			
Period	1	2	3	4
1				
2				
3				
4				

Table 4.5 Subscriber Loop Capital Investment Summary

Switching Center Area --------   Date -----

Class of Plant	Investment in Dollars by Period			
	1	2	3	4
Underground Paired Cable				
Aerial Paired Cable				
Buried Paired Cable				
Underground Coaxial Cable				
Aerial Coaxial Cable				
Buried Coaxial Cable				
Underground Conduit				
Poles				
Line Concentrators				

Table 4.6 Capital Budgeting Information by Switching Center Area

Switching Center Area --------   Date -----

Class of Plant ---------------

Account Description	Unit	Total Units	Unit Construction Cost	Total Estimated Cost

5. THE COST MODEL

The cost model is analysed in relation to the following important considerations and developed in a suitable format to perform its intended function. These considerations include:

1. Technology assessment - the specific technology used within any class of plant can have a significant impact on costs. A method of assessing the impact of technology is described in section 5.1.

2. The structure of the cost model in relation to 'PNET' : In the case of already existing plant the carrier company tends to be 'locked into' the past investments. The 'PNET' model recognizes this fact and treats the past investments as a sunk cost. These past investments have a capital cost equal to the depreciated value of the material cost less the removal costs, for economic evaluation purposes.

3. The development of the basic cost functions : There are several important factors that shall be considered in the development of the basic cost functions. These include:

   a. Economies of Scale - for example;

1) the installation cost per pair varies significantly as a function of cable size, and

2) the material cost per pair varies significantly by gauge.

b. Age of plant in service - The age of plant in service directly affects costs and will be reflected in the cost model through operating costs and by the depreciation schedule.

c. Excess capacity - Excess capacity may result for several reasons (e.g. economies of scale, growth rates, inflation and technology) and have an impact on costs.

d. Growth Rates - The rate of growth within switching center areas has a bearing on costs. Growth rates also directly affect the age of plant in service and the excess capacity considerations. However, the impact of the growth rate is implicitly considered by the forecasting model and hence needs little consideration in the actual cost model.

e. Geographic Location - Geographic location may result in differences in costs through differences in such factors as;

1) soil conditions,
2) labor rates,
3) weather conditions,and
4) building and land costs.

The basic cost functions include all of the above factors.

5.1 Technology Assessment

Technology can have a significant impact on the analysis of alternative investment decisions.

5.1.1 Technological Developments

To quantitatively state the impact of technology becomes very difficult due to the many interacting parameters affecting changes in technology. These include:

1. Direct Competition

Many organizations rely primarily on advanced technology for competitive advantage and therefore concentrate major resources on fostering research and development. Clearly a shift in the basic competitive strategy of an industry is likely to have a strong influence on the rate of technological progress.

2. Corporate Strategy

It is clear that technological progress does depend on prevailing corporate strategy, which is in turn conditioned to some degree by non-technological factors.

3. Sunk Costs

The telephone companies have invested large sums of money into plant of a specific technology. These companies may be adverse to adopt an altogether new kind of technology within a short time span because of these sunk costs. The inertia of these past investments will affect the replacement cycle of existing equipment and the learning curve characteristics of the industry which in turn affect the rate of technological change.

4. National and international Political and Economic Environment

Political and economic environments are major controlling factors affecting technological change. The direct impact of defence strategies and the effect of technological spin-off of these strategies on the industrial environment are very significant.

5.1.2 History of Technological Developments

To highlight some of the major technological trends, let us survey briefly the historical developments in the field of transmission medium.

1. Resistance and Induction

The early developments date back to the use of copper wire as the transmitting medium, prior to which the electrical resistance of the telephone line limited the service originally to very short distances. The first copper wire tried made a good conductor, however, it was too soft to be of practical use as it would break of its own weight when used on open wire spans. Hard drawn copper wires overcame this structural difficulty and found large-scale use starting in 1884. The induction or cross talk problem was also solved about the same time by interchanging or transposing the position of the wires in the medium.

2. Need for Placing Lines Underground and the Principle of Loading Coils

The rapid increase in the number of subscribers and the corresponding increase in overhead wires soon resulted in a move to underground circuits . The first underground cables were placed around 1890. The first cables used were large gauge copper conductors (small diameter) and an effort was made to reduce the diameter of the conductor.

The year 1900, marked the important development of applying the loading coil principle (i.e.) the insertion of inductance in small quantities at regular and frequent intervals greatly improves the transmission efficiency.

3. Repeaters or Amplifiers

By 1911, it was apparent that a satisfactory means for amplifying the attenuated telephone currents on a long circuit would be necessary. To accomplish this a new device known as a repeater or amplifier was developed.

4. Carrier Systems

With the distance barrier solved; caring for the increasing volume of calls presented the problem of placing more telephone channels on existing facilities. The electronic vacuum tube by 1918, was available for getting carrier currents which would allow the use of a wider frequency range than the voice frequency range. Other technical advances provided a means to temper, or modulate the carrier currents with the voice currents and to reproduce, or demodulate, the voice currents at the receiving end of the telephone line. In addition filters were developed which were capable of separating into groups a mixture of currents at different frequencies transmitted over the same conductors.

Carrier systems were a substantial factor in meeting the growth requirements in exchange trunking and toll trunking where they naturally provide economies. However, recently they have been used in the subscriber loop facilities . The development of carrier systems has significantly advanced solution to the problem of distance and costs.

5. Coaxial Systems

Another major development of the carrier principle of transmission came into use by the end of 1936. The carrier principle was applied to an entirely new type of line facility known as the coaxial cable. A coaxial system consists of a copper tube, down the center of which runs a copper wire held in place by insulating discs. It is capable of transmitting hundreds of telephone circuits.

6. Radio Relay Systems

Another type of transmission facility more recently developed is known as the microwave radio relay system. The system provides a very broad frequency band and is capable of carrying television channels and hundreds of telephone circuits.

7. Radio Telephones

Although the development dates back to the 1920's, the use in subscriber loop plant is very recent.

In summary, many improvements have been made in transmission capabilities due to the developments in the basic transmitting facility, introduction of various carrier systems and introduction of radio transmission. These changes in technology have come about in an attempt to provide a more ideal transmission system at minimum cost to the subscribers in connection with:

(1) good quality,

(2) sufficient volume,

(3) uniform transmitting and receiving efficiency independent of the lengh of the loop,

(4) freedom from side tone,

(5) freedom from excessive cross talk and noise, and

(6) aesthetic appeal.

5.1.3 Alternative Methods of Evaluating Technological Change

Companies implement technological change in an effort to minimize cost in the long run. With this idea in mind, the following two alternative methods were considered in order to quantify technological change.

The following steps outline the method adopted in the first approach. The alternate technologies considered are those that are applicable in subscriber loop plant and which are in either the application stage or the developmental stage.

Methodology

1. List all the possible technologies that are known at present or will be used in the near future in the subscriber loop plant, such as:

a) voice frequency (VF) cable pair;

b) small analogue carrier systems;

1) Anaconda 56A (7 channels)

2) Superior cont CM8 (8 channels)

c) large digital carrier systems;

1) ITT, DM32S (32 channels, 128 lines), and

2) Northern, DMS1 (48 channels, 256 lines);

d) digital radio: (e.g. Farinon SR radio);

e) cables CXR: (e.g. Lenkust 84A, 1 channel + 1 physical);

f) Vidar SCT: (e.g. 24 or 48 channel dedicated PCM); and

g) fibre optics cable.

2. For each technology, segregate the total cost into the following components and project these costs into the future.

a) the initial cost (B) consisting of:

1) direct labor cost, loadings on labor,

2) direct material cost, indirect material cost, and

3) overheads such as;

(a) motor vehicle and special tools cost,

(b) engineering cost, and

(c) miscellaneous cost (contract bills, cost shared with other utilities);

b) the operating cost or the annual equivalent of operating costs based on a life span of n years, if the plant considered is installed in years 0,1,2 ...... up to the planning horizon. The operating cost will also have the same components (1) to (3) listed above; and

c) the salvage value of plant at the end of the life span.

d) annual depreciation for the different years considered.

The unit of measurement used herein is the cost per subscriber line per unit of distance, based on a particular capacity of plant. If the capacity, actually required is different from the particular capacity considered, then the cost per line per unit of distance will be corrected to reflect the actual cost by multiplying by a factor which is the ratio of cost per subscriber line per unit of distance of new capacity to the cost per subscriber line per unit of distance of the capacity considered. The above factors can be determined from historical cost data. Similarly the operating cost, depreciation and salvage values are determined. The data, for any specific technology, may appear as shown in Figures 5.1 and 5.2.

3. From the above figures the Present Equivalent Cost (PEC) per unit capacity of plant per unit distance in the various years can be determined for the different technologies. These PEC values may then be used as arc costs in the network formulation as suggested in section 5.4.1.

In the second approach, which is the approach suggested herein, the present equivalent costs are not segregated as is suggested in the first method. Instead, the

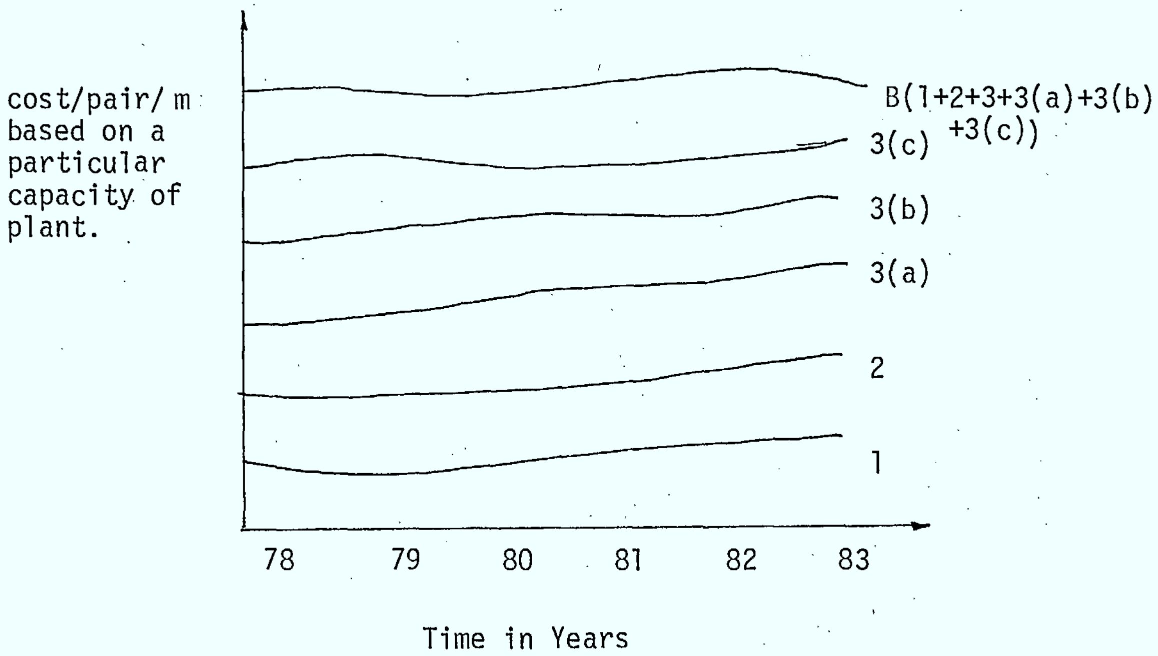


Figure 5.1 Initial Cost - Time Functions for Technology X

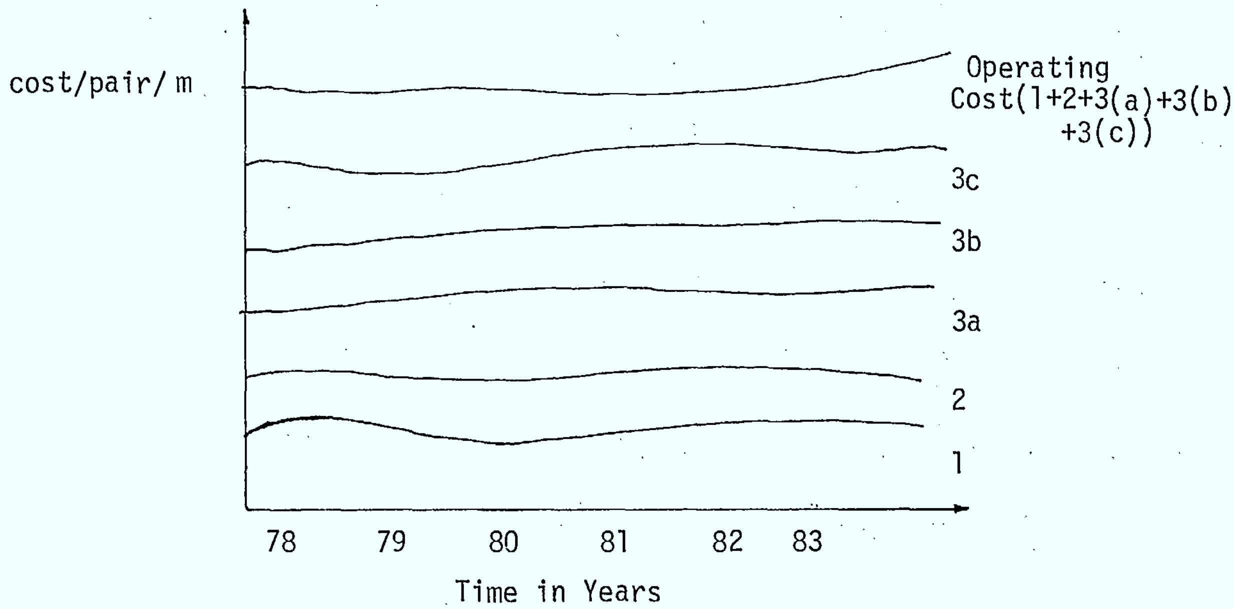


Figure 5.2 Operating Cost - Time Functions for Technology X

overall effect of technology on cost is measured by making use of technology survivor curves. The cost per subscriber line per unit distance forms the inverted 'S' shaped envelope curve gracing the technological survivor curves. This envelope curve is used to find the technological growth factor which is incorporated into the cost model. This method offers significant advantages over the first method in that it concentrates on determining the overall effect of technology on cost per subscriber loop without analysing the specific micro details of the individual technology survivor curves. In addition it saves on the number of nodes and arcs that would have to be considered using the first method , thereby significantly reducing the computer time required. The sections that follow describes this selected method in detail.

5.1.4 Assessing Technology

When a new technology is introduced its initial costs are usually at the maximum level, however over the years the initial costs tend to decrease through technical improvements and economies of scale. The present equivalent cost of each technology drops to a minimum total cost point and then tends to increase in costs giving way to the introduction of new, more efficient technologies. As an illustration, the capital costs of a particular technology behaves as shown in Figure 5.3. Initially the costs will be

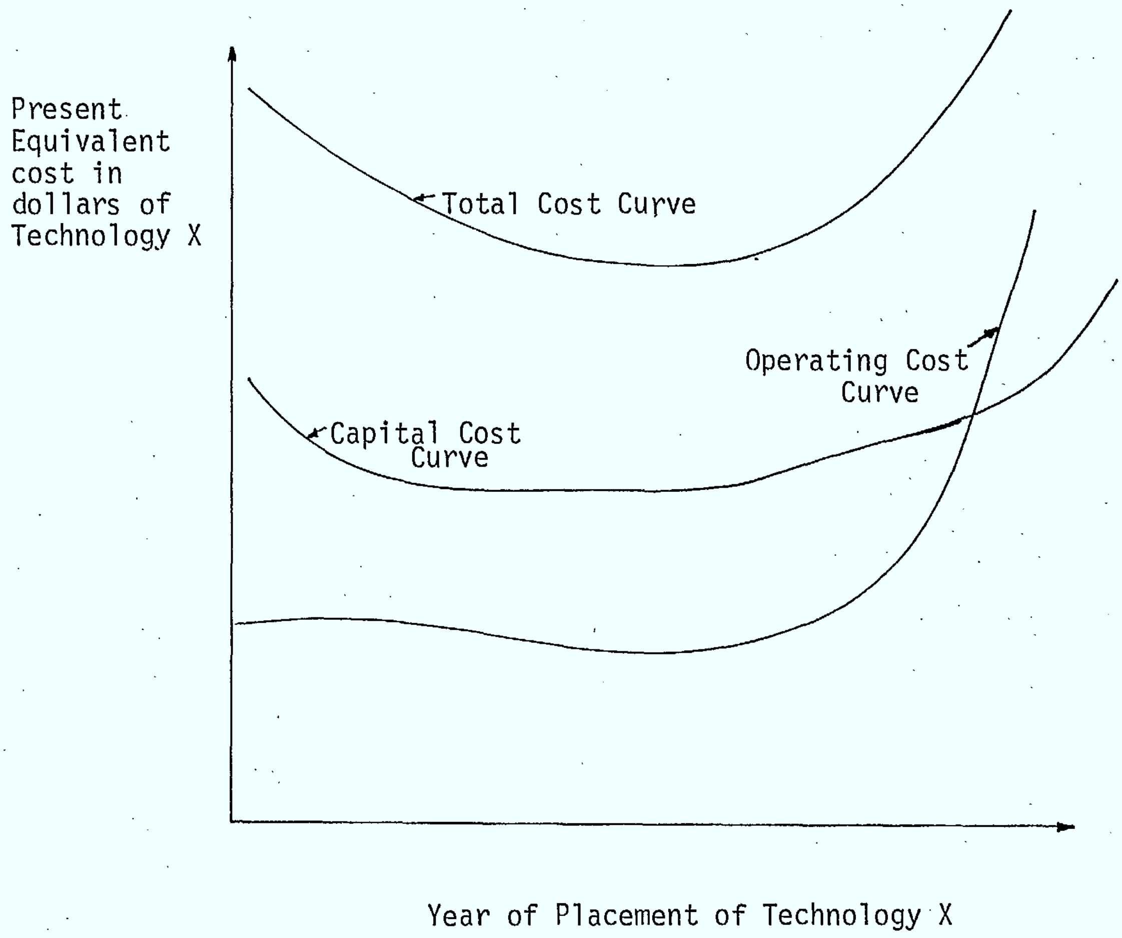


Figure 5.3 Present Equivalent Cost of Technology 'X' Versus Year of Placement

high, followed by a minimum cost period and an increase as the technology becomes obsolete and the manufacturer phases in new technologies. Similarly, the initial operating costs are normally high due to debugging and personnel being unfamiliar with the technology. However, once the personnel are trained and the debugging process is over operating costs decrease. Later, with the introduction of a new technology the operating costs will rise due to the unavailability of spare parts except by special order resulting in makeshift arrangements and an increase in shut-down time. The total costs, which is the sum of the above two curves, behaves basically as shown in Figure 5.3.

Heuristic reasons suggest an exponential law of social and technological change. In most cases the exponential phase of change eventually comes to a saturation level. A convenient mathematical function which has this behaviour is the logistic curve or 'S' curve of the form;

$$f(t) = f(to) - \frac{f(to)}{1+Ae^{-kt}}$$

Where,

f(t) is the cost performance at time t (in years),

f(to) is the cost performance as of today,

A and k are parameters of the curve. (refer APPENDIX E)

Technological change in the fast growing telecommunication field can be pictured graphically by a series of displaced trough shaped curves whose envelope is the 'S' curve mentioned previously. These intersecting curves represent the gradual displacement of old technologies by their successors. In Figure 5.4 the curves of technologies I and II represents the case of well developed old technologies, versus the dotted curve of a new technology in the early stages of development. The company with foresight enough to steer its planning to the new technology will gain substantial advantage in its cost reducing measures.

5.1.5 Measuring Technology

Technological change as depicted by the 'S' curve may be measured in terms of an index; treating the 0th year ordinate as 1, the other ordinates of the future years may then be expressed in terms of the base year. This index will either positively or negatively influence the decision to defer the present technology being used.

In order to plot the 'S' curve, the individual technology curves need to be plotted first. This entails the drawing of two curves for capital cost and the operating cost per subscriber line per unit of distance. From the capital construction accounts of the outside plant equipment, the aggregate capital cost of a certain type of plant in a particular year is derived. This cost when divided by the quantity of lines installed will give the

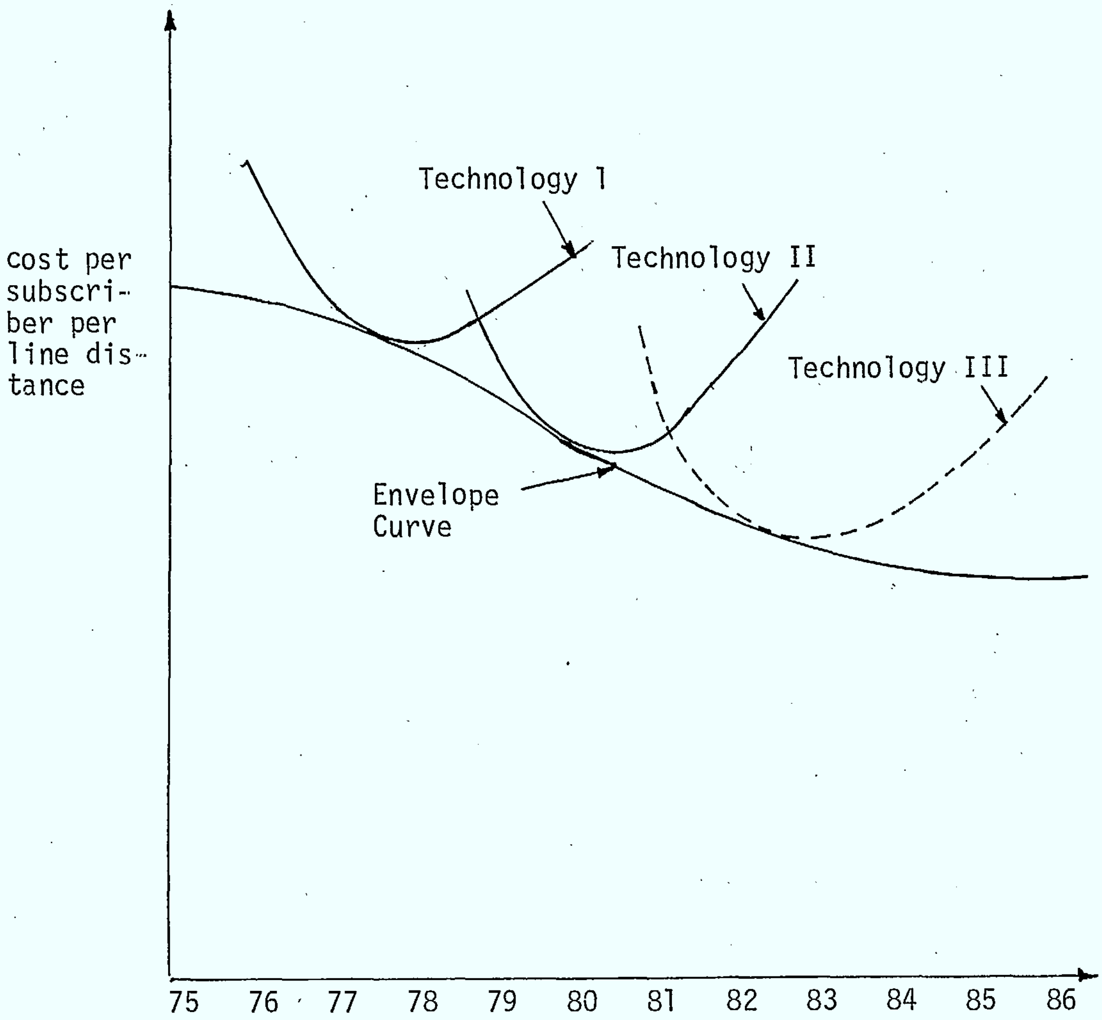


Figure 5.4 Technology Survivor Curves and the Envelope Curve

capital cost per line per unit of distance. In the case of operating cost, it is not realistic to find the figure for a particular vintage. However, if we assume that the operating cost of a certain item of plant is increasing with age at the rate of 'b' per year per dollar, then the following equations may be used to calculate the operating costs attributable to a certain class of plant in a particular vintage. For example if we consider three consecutive years, the equations will be:

$$
\begin{array}{lll}
1^{st} \text{ year} & x & = T1 \\
2^{nd} \text{ year} & (1+b)\,x + Y & = T2 \\
3^{rd} \text{ year} & (1+b)^2\,x + (1+b)Y + Z & = T3
\end{array}
$$

where,

T1, T2, T3 are the operating costs of the respective years considered.

'X' is the operating cost incurred on the surviving plant in 1st year.

'Y' and 'Z' are the operating cost incurred on the vintages installed in the 2nd and 3rd years.

Once a reasonable value for 'b' is established by the maintenance department, that value can be used and the above equations can be solved for the values of 'Y','Z' and so on. From this figure the operating cost per line per unit of distance is easily found.

5.1.6 Logistics Curve

In the logistic curve (normalized 'S' curve), in Figure 5.5:

$$f(t) = f(to)-f(to)/[1+A(EXP(-kt)]$$

dividing by f(to)

$$f(t)/f(to) = 1 - 1/[1+A.EXP(-kt)]$$

If we assume a constant improvement in the technological performance and assuming a 30 year time span, then;

$$TI(t+30)/TI(t) = (1-IT)**30 \quad ....(1)$$

where,

TI =ordinate of the normalized 'S' curve

TI(t) =ordinate of the 'S' curve in year 't'

TI(t+30) =ordinate of the 'S' curve in year 't+30'

IT =constant technological improvement factor.

From equation (1),

$$IT = 1-e^{\frac{[\ell n\{\frac{TI(t+30)}{TI(t)}\}]}{30}} \,/30$$

This factor, IT, will be incorporated into, the interest rate factor, as shown in section 5.4.1.(a).

5.2 The Structure of The Cost Model in Relation to PNET

In order that the cost model performs the computation for the 'PNET' model, it has to be structured in a particular manner. Considering a specific technology, Figure 5.6 explains the situations under which the cost model will

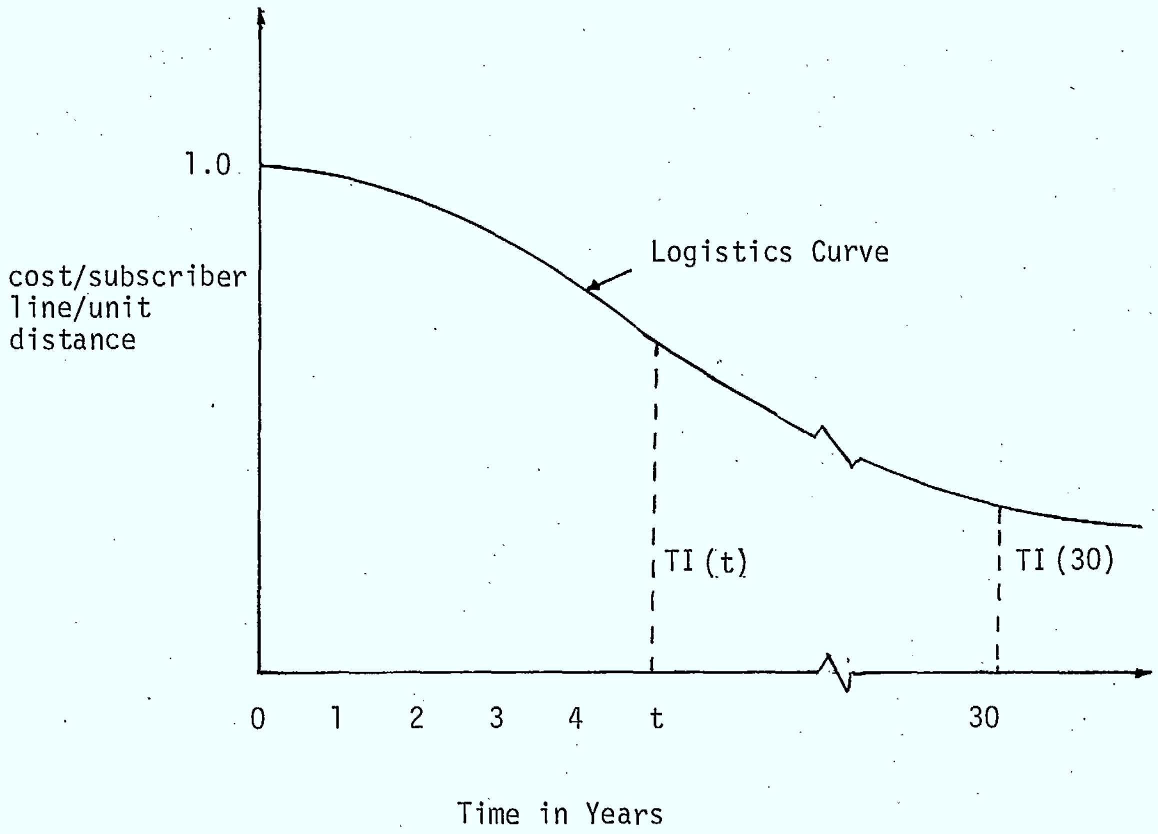


Figure 5.5 The Logistics Curve (Normalized to the Cost in Year Under Consideration)

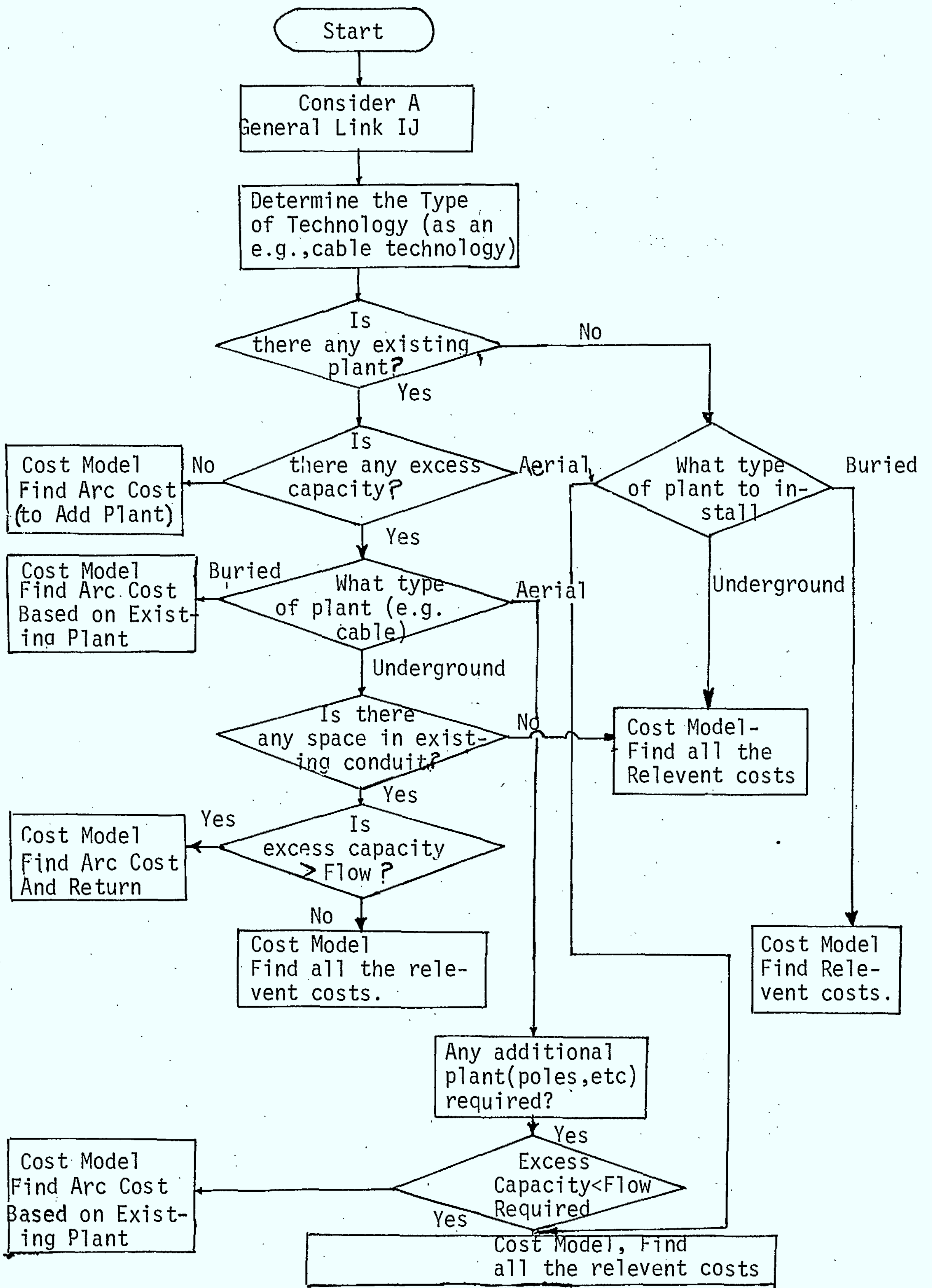


Figure 5.6 The Structure of the Cost Model In Relation to the PNET, Program

be required to do the computations for the 'PNET' model.

5.3 The Development of the Basic Cost Functions

Individual carrier companies use slightly different methods of developing their construction unit costs. Construction unit costs by type of plant forms the basic input to the cost model. Since a uniform system of measuring company performance is desirable or necessary at some stage, it is recommended that a uniform system for the development of costs be adopted. A company may develop its own program to convert its construction unit costs to the arc costs that is required by the PNET program. In this report an effort is made to build the cost model from the basic data. However, it is relatively easy for an individual carrier company to adopt their unit costs to the system in order to arrive at the unit arc cost.

The total cost of the plant is split into three components; (1) capital cost (installed cost), (2) operating cost, and (3) salvage cost. For capital budgeting and monitoring purposes a unit construction cost is desirable. In order to develop unit construction costs by type of plant, the capital cost is divided into the following basic cost components:

1. direct labor and its loadings,
2. direct material and its loadings, and

3. motor vehicle and tools capital cost, engineering overheads, contract work overhead and other overheads.

Although the operating cost could be split into the above basic components, the development of a unit cost for operating costs in the same manner as for capital cost is not practical. The system would require a tremendous amount of effort and additional paperwork on the part of all plant personnel and would be difficult to administer and monitor. Also the usefulness of operating costs to this degree of refinement is marginal in its contribution. Therefore, the operating cost is divided into only two basic components for each type of plant, by switching center area.

1. rearrangements or change (modifications), and,
2. ordinary repairs and maintenance.

These operating costs and any other costs in that category that are not covered are expressed as a percentage of the capital costs.

The direct labor item of the capital cost will be affected by such factors as:

1. seasonal differences
   - rainy weather and cold climate will influence the time taken to do a job;
2. geographic variations in a switching center
   - varying geographic conditions favors the decision of one type of plant in preference to another.

The salvage value and depreciation form a portion of the total cost and will be treated together in the analysis. The division of the total cost into its components is shown diagrammatically in Figure 5.7. The cost functions will be developed in reference to these components considering a general link i-j. Once the cost functions are developed for a specific technology, it is easily extended to cover other technologies.

5.3.1 Direct Labor and its Loadings

Direct labor covers all direct labor costs for productive occupational hours charged directly to final accounts and to other accounts used for billing purposes. It covers the salaries and wages of occupational employees, first line supervisors and all other employees at the local plant administration level. These employees are identified by different craft types in this model. Figure 5.8 shows the components of the direct labor.

The loadings on direct labor are due to the indirect labor force and other associated tool expenses which are supplemental to the direct labor in the completion of the job. For convenience of costing, they are generally expressed as percentages of the direct labor cost. Figure 5.9 shows the components of the loadings applicable to direct labor.

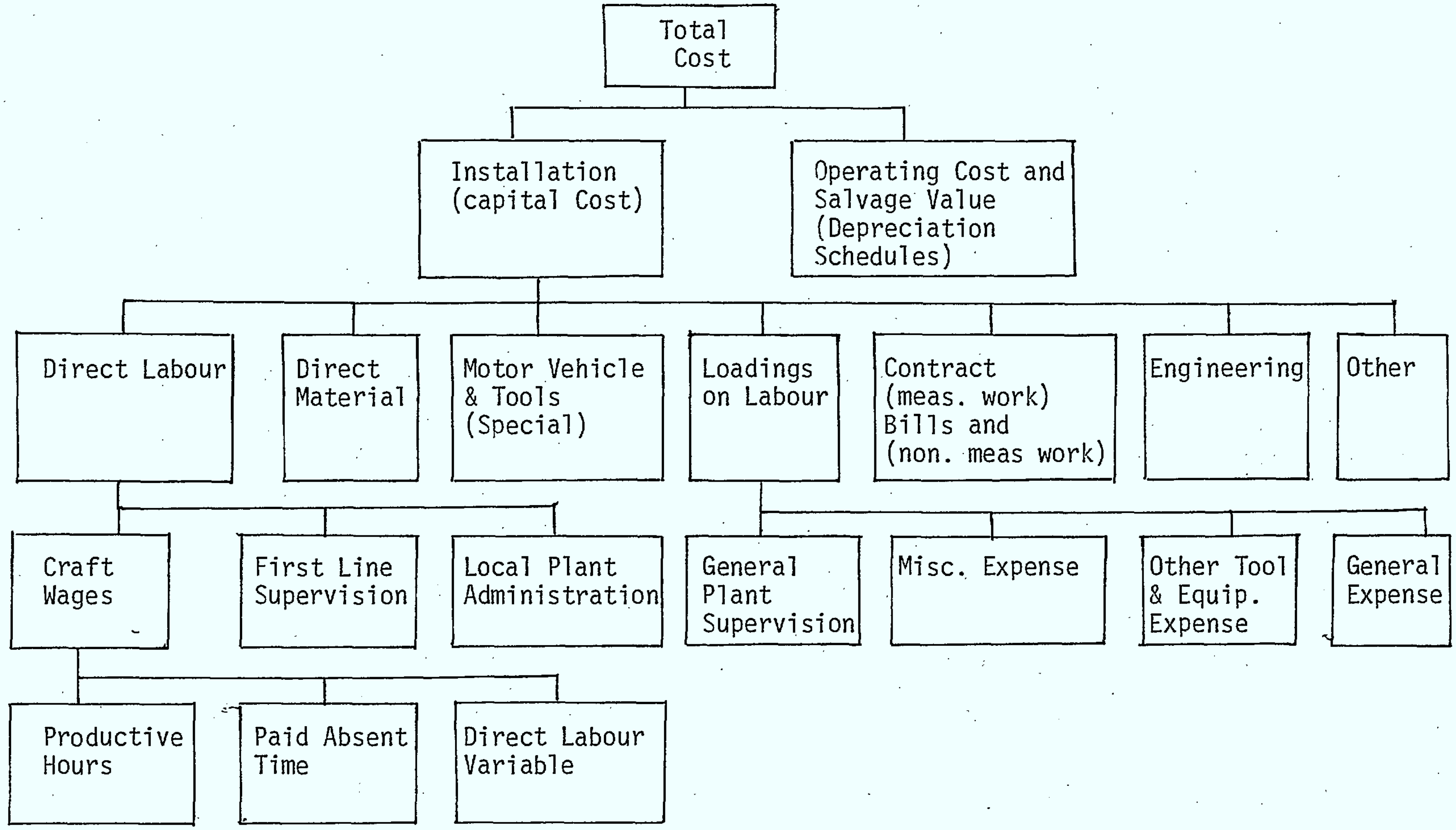


Figure 5.7 Components of Total Cost for Telecommunications Plant

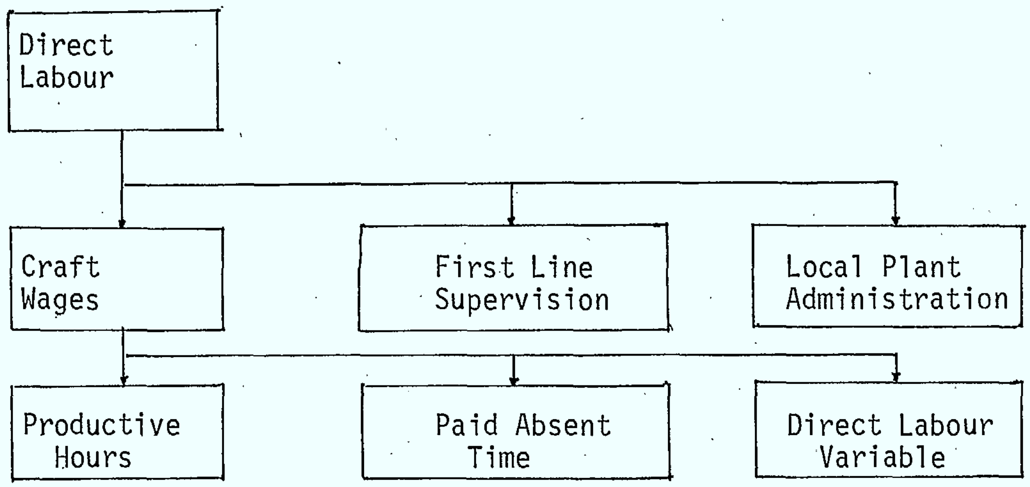


Figure 5.8 Components of the Direct Labour Cost

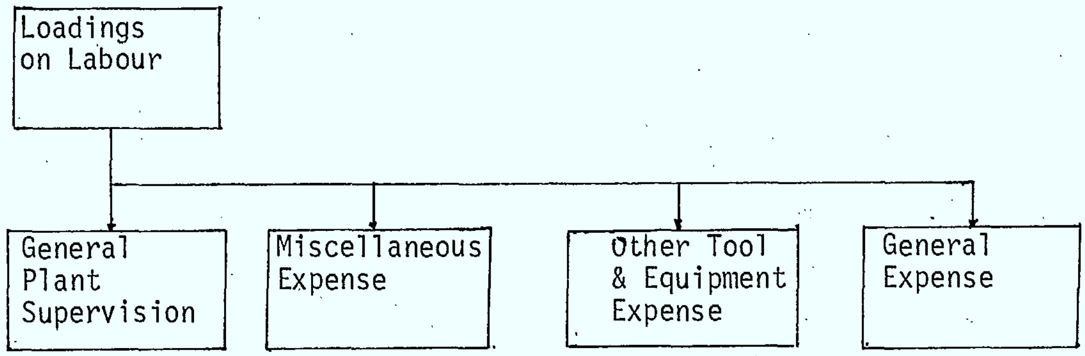


Figure 5.9 Components of the Loadings on the Direct Labour Cost

The total direct labor cost is discussed under the following sub-headings in order to include all the factors that influence the direct labor cost:

1. direct labor time by function performance,
2. direct labor hourly rate by craft type,
3. loadings on labor, (and direct labor cost model),
4. seasonal differences in labor rates,
5. learning curves, and
6. geographic area.

1. Direct Labor Time by Function Performance

The direct work content of a job (Function Performed) is usually estimated by various time study methods. This involves dividing operations into their basic elements, applying time factors to these elements and finally arriving at the total time for each function performed. The carrier companies have a reasonably good estimate of these basic direct labor times. (These basic times such as the time to install a pole, the time to place a meter of cable etc. should be checked periodically by job sampling techniques.)

For the general link i-j, the direct labor time by function performed is computed in the format shown in Table 5.1. If some of the functions are irrelevent to the link considered, then the corresponding time elements are set equal to zero.

Table 5.1 Direct Labour Time by Function Performed

Function Performed	Construction (C) in manhours	Install & Repair (R) in manhours	Removal (X) in manhours	Changes (M) in manhours	Others (O) in manhours	Total hours
Installing Poles	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{aa}
Laying Aerial Cables	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{bb}
Trenching	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{cc}
Laying Under-ground Cable	x_{41}	x_{42}	x_{43}	x_{44}	x_{45}	x_{dd}
Laying Under-ground Con-duits(+Manhole)	x_{51}	x_{52}	x_{53}	x_{54}	x_{55}	x_{ee}
Digging for buried cable	x_{61}	x_{62}	x_{63}	x_{64}	x_{65}	x_{ff}
Laying buried cable	x_{71}	x_{72}	x_{73}	x_{74}	x_{75}	x_{ee}
Installing loading coils etc.	x_{81}	x_{82}	x_{83}	x_{84}	x_{85}	x_{ff}

2. <u>Direct Labor Hourly Rate by Craft Type</u>

Direct labor costs are calculated in proportion to the productive hours of associated occupational employees, using a predetermined direct labor hourly rate. The direct labor hourly rate should represent occupational, first-line supervisory and local administration costs, the cost of paid absent time (vacation, sickness, etc.) premium payments (overtime, night differentials, etc.) and unclassified time. Direct labor hourly rates for plant personnel vary depending on the skill of the individual. Plant personnel are divided into groups representative of their duties, each group being designated by a letter :

Craft A -(line and cable placing forces)- This group also includes employees engaged as unskilled labor for digging and trenching etc.

Craft B -(cable splicing forces)- Employees who are primarily engaged in splicing or repairing aerial, underground, buried cables, e.g. cablemen, cablesplicers. This group also includes occasional employees engaged to assist in splicing work.

Craft C -(equipment installers)- Employees who are primarily engaged in installing, removing, accepting or rearranging central office equipment associated with outside plant facilities.

Craft D - Personnel involved in the inspection of contract work involving the construction, repair rearrangement and removal of outside plant facilities.

They are known as first line supervision.

Craft E - Mainly inspection personnel or local plant administration personnel.

The work force costs are calculated from the components shown in Table 5.2. The total manhours are obtained from the payroll information. The total direct manhours is multiplied by the productivity of the different craft type in order to arrive at the actual manhours for each craft type. The productivity consists of a combination of factors that will have to be estimated by the engineer in charge. The total cost column is divided by the actual direct man hours to arrive at the average direct labor rate by the craft type. The required elements in this matrix are filled with data from the past year, or the past period whichever is appropriate.

In Table 5.1, the productive assignable hours includes manhours resulting from construction, installation and repair, removal, and changes. The unassignable occupational hours consisting of holidays, vacations, sickness, personal absences and other unclassified hours are excluded from the productive hours and they are classified under the column of other manhours. When a contractor performs the functions described above, contract equivalent hours are to be derived by dividing the contractors bill by an appropriate loaded company rate.

Table 5.2 Direct Labour Rate by Crew Type

Craft Type	Regular Payroll $	Overtime $	Hiring/ Training $	Employee Termination $	Shift Premium $	Total Cost $	Total Manhours (hours)	Productivity	Direct Labour Rate ($/hr)
Craft A									DLR_A
Craft B									DLR_B
Craft C									DLR_C
Craft D									DLR_D
Craft E									DLR_E

If 'Xuv' denotes a general direct labor time associated with a function performed 'u' and type of work 'v', in Table 5.1, Xuv can be further split to take account of the percentage work contributed by different crafts. Note Table 5.3.

Once the appropriate elements of the total direct labor cost in a general link i-j are determined, these values are linearly spread over the entire length of the link. This means that for some categories of jobs (e.g. installing poles) the direct labor costs are expressed on a unit linear distance basis (for simplifying the programming). However, for other categories of jobs (e.g. placing cables) the direct labor costs are computed on a unit distance basis from the beginning itself. These values when multiplied by the distance between the nodes i,j will give the value of the direct labor cost in the link i-j.

Using the above format, the direct labor cost can be computed for the different categories of jobs. As an example:

The direct labor cost for the installation of poles equals

$$X_{aa}[(P_{11}.DLR_A) + (P_{21}.DLR_B) + (P_{31}.DLR_C) + (P_{41}.DLR_D) + (P_{51}.DLR_E)]$$

The direct labor cost for the laying of aerial cable

$$= X_{bb}[(P_{11}.DLR_A) + (P_{22}.DLR_B) + (P_{32}.DLR_C) + (P_{42}.DLR_D) + (P_{52}.DLR_E)]$$

Table 5.3 Percentage Work Content by Craft Type

Craft	Poles	Aerial Cable/Coaxial	Trenching	Underground Cable/Coaxial	Conduits (& Manholes)	Digging	Buried Cable/Coaxial	Installing loading coils etc.
Craft A	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}
Craft B	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	P_{26}	P_{27}	P_{28}
Craft C	P_{31}	P_{32}	P_{33}	P_{34}	P_{35}	P_{36}	P_{37}	P_{38}
Craft D	P_{41}	P_{42}	P_{43}	P_{44}	P_{45}	P_{46}	P_{47}	P_{48}
Craft E	P_{51}	P_{52}	P_{53}	P_{54}	P_{55}	P_{56}	P_{57}	P_{58}

Similarly the direct labor cost for other items are developed. If the total cost of the direct labor, which is the sum of the above cost items, is denoted by 'C'; then ,

$$DL = C.dij$$

where,

DL = the direct labor

dij = the distance between the nodes i and j.

3. <u>Loadings on Labor, Direct Labor Cost Model</u>

Expenditures on indirect labor and other associated expenses are grouped under loadings on direct labor and are rormally expressed as a percentage of direct labor. They are:

(a) general plant supervision = P(a)%

(b) tool and equipment expense = P(b)%

(c) fringe benefits and general expense = P(c)%

(d) plant miscelleneous expense = P(d)%

Therefore the total loadings on labor

$$= P = P(a) + P(b) + P(c) + P(d)$$

Since 'DL' is the direct labor cost described in the previous section, the total direct labor cost and the loadings are expressed mathematically by:

DL(1+ P/100) per unit distance per unit of facility between the link i and j.

Therefore, Direct labor cost in the link i-j per unit of plant facility is equal to ;

DL (1 + P/100)dij

The above value when multiplied by the decision variable Xij will give the value of the direct labor cost plus loadings in the link ij. If the annual increase in the direct labor cost IDL is determined, it can be used to find the labor costs in subsequent years. The formula is modified to reflect the annual increase in direct labor. Hence to mathematically express:

Direct labor plus loadings becomes equal to;

$$DL(1+\frac{P}{100})d_{ij}\ X_{ij}[(1+\frac{IDL_n}{100})^n]$$

where,

Xij = the decision variable as determined by 'PNET'

IDL = the percentage increase in yearly direct labor

n = a suffix to indicate the period under consideration.

In that case inflation rate will have to be adjusted to avoid double counting and therefore was not included in that manner.

4. Seasonal Differences in Labor Rates.

Generally most of the construction work is seasonal (e.g. in Edmonton during the summer). If any work is done in the winter months, due to the climatic conditions prevalent, the standard time taken to do a job will likely change. In order to make a correction to the standard times used, the following modification is recommended.

Let Xuv denote a general element in the direct Labor time (Table 5.1). Then:

Standard time, Xuv = 1/100 [(Percentage work done during summer) x(Normal time in summer)+(Percentage work done in winter)x(Normal time in winter)] .

Incorporating the productivity element into the model produces a typical productivity vs temperature graph which will look like the one shown in Figure 5.10.

If P(ref) denotes the productivity with reference to average year round temperature, and P(s) denotes the same for average summer temperature, and similarly P(w) denotes the productivity for average winter temperature, then:

Xuv =1/100 [(% work done in summer) x
(Normal time for Reference temp)}/P(s)
x Pref
+{ (% work done in winter)x
(Normal time for Reference temp)/P(w)
x P(ref)] .

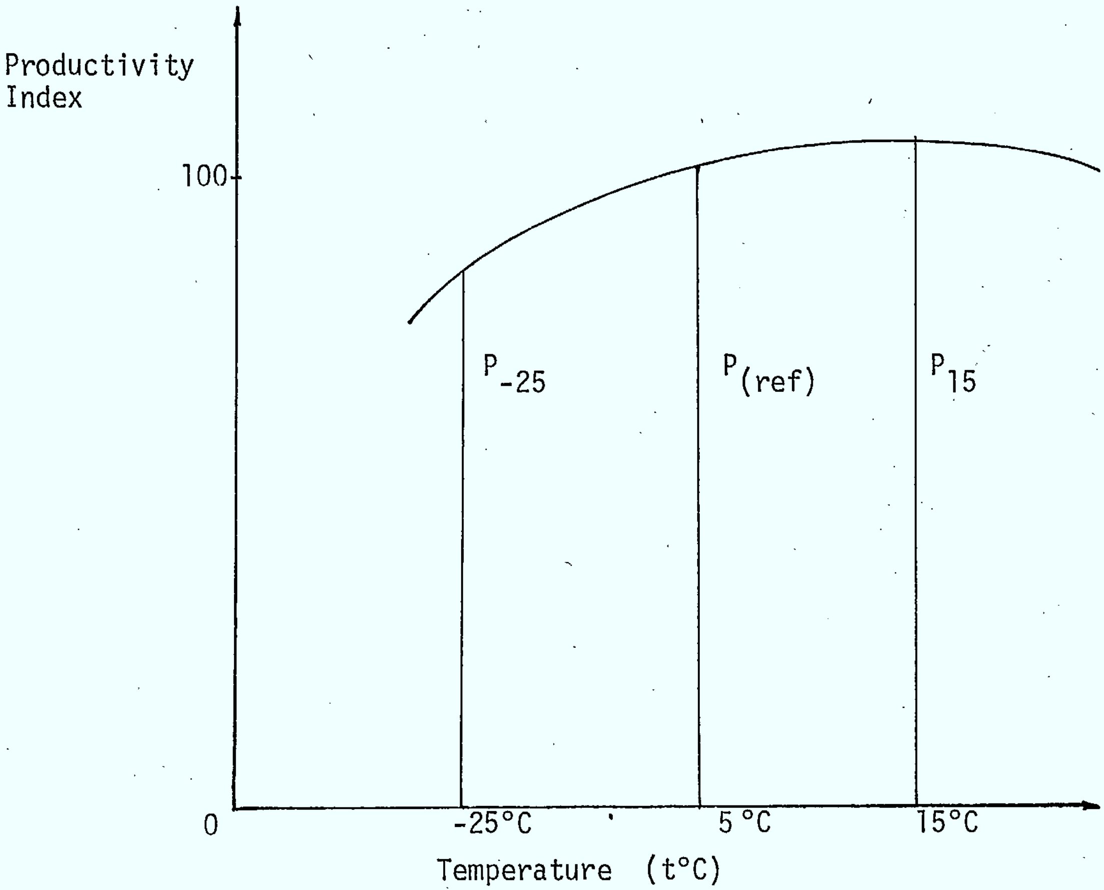


Figure 5.10 Productivity for Various Temperatures

where 'Normal time for the Reference Temperature' is the time taken to do the job at a particular reference temperature, assumed to be the average temperature for the year.

5. Learning Curves

An employee's efficiency is dependent upon the employee's experience in working with a new technology.

When all the employees are treated together the work units per hour index has been a good indicator of their performance. The terms used in the definition of this index are described below.

A. Work Units

Work units are a relative expression of the quantity of work represented by a given task or combination of tasks. They comprise 'measured work units ' and 'total work units' defined as follows:

1) Measured Work Units

Measured work units are the quantities of work units developed by counting selected work operations or plant items and then multiplying these counts by predetermined work unit factors. The factors relate to the system average work time in a past study period and include an allowance for work time on closely associated items which are not separately counted. They also include allowances for vocational training time, travel and access time, job preparation time, etc.

2) <u>Total Work Units</u>

Total work units are measured work units plus an allowance of work units for unmeasured time.

B. <u>Work Units Per Hour</u>

Work units per hour is a comparative index of production based on the ratio of measured work units to measured hours. In reference to a past period, it shows the change that has taken place in work output as the combined result of changes in techniques and changes in operating efficiency. It shows the work output per hour expended.

This index, 'work units per hour' is easily obtained from accounting data and is projected into the future years. Assuming the 'work units per hour' index as 1 in year 0, the future indices can be found. The job times are multiplied by a factor which is the inverse of this index.

Therefore,

Standard time in year n

= (Standard time in year 0)/(work units per hour index in year n)

6. Geographic Area

Varying soil conditions may be encountered in the same switching center area or in different switching center areas that makes one kind of job more difficult than the others. For example, hard rocky areas pose problems for trenching to lay underground cable. It is understood that the varying soil conditions directly affects the labor time. In order to account for these deviations, the switching center area is classified into the following categories of soils and they are identified by number codes. They are:

a) 1 - soft soil - suitable for normal operation,

b) 2 - hard rocky area - difficult for digging, trenching,

c) 3 - ravine or uneven area - poses problem for any aerial work,

d) 4 - paved areas - difficult for digging, trenching cost increases due to repaving, and

e) 5 - muskeg and swamp area - where work will be done in adverse conditions.

A difficulty rating matrix is constructed with the available information. Using 100 as the reference index for soft soil, the matrix will resemble the one shown in Table 5.4.

The switching center area is divided into zones and number codes will identify the difficulty factors applicable to that area under consideration.

Table 5.4 A Difficulty Rating According to Soil Conditions For the Placement of Telecommunications Plant

Function Performed	Code '1' Soft Soil	Code '2' Rocky Area	Code '3' Ravine Area	Code '4' Paved Area	Code '5' Swamps	Total Factor Being Denoted by '$D_{\ell k}$'
Installing Poles	100	D_{11}	D_{12}	D_{13}	D_{14}	πD_{1k}
Laying Aerial Cable	100	D_{21}	D_{22}	D_{23}	D_{24}	πD_{2k}
Trenching	100	D_{31}	D_{32}	D_{33}	D_{34}	πD_{3k}
Laying U.G. Cable	100	D_{41}	D_{42}	D_{43}	D_{44}	πD_{4k}
Laying U.G. Conduits	100	D_{51}	D_{52}	D_{53}	D_{54}	πD_{5k}
Digging	100	D_{61}	D_{62}	D_{63}	D_{64}	πD_{6k}
Laying Buried Cable	100	D_{71}	D_{72}	D_{73}	D_{74}	πD_{7k}
Installing Loading Coils	100	D_{81}	D_{82}	D_{83}	D_{84}	πD_{8k}

Note : π = Sum of the Product of the Difficulty Factors Relating to Different Codes

Total hours column Xaa,,Xbb... etc. in Table 5.1 will be prorated by the factor Dlk, depending on the type of job and whether the link i-j falls into any of the above categories of soil conditions.

5.3.2 Direct Material Cost

The material cost is divided into two components: (1) direct material cost, (2) indirect material cost.

The direct material costs are due to those materials which become a part of the transmission medium in the final subscriber loop and are involved in such a way that the material cost can be estimated. The indirect material costs are due to those materials which are critical to the operation but do not become a part of the transmission medium. These costs may include inventory carrying cost , ordering cost and shortage cost etc. These indirect material costs are normally expressed as a percentage of the direct material cost.

From an analysis standpoint, the direct material is subdivided into the following categories :

a) underground plant (includes cable, manholes, ducts, and loading coils etc.),

b) underground coaxial cable plant,

c) buried coaxial cable plant,

d) buried cable plant,

e) aerial cable plant, and

f) aerial coaxial cable plant.

The rules for the "resistance design" states that the total resistance of the subscriber loop under loaded or unloaded conditions is to be limited to 1300 ohms. This limit varies depending on the type of switching center equipment in use. The resistance limit implies that it is not always possible to use the thinnest gauge cable available, and in the case of long subscriber loops it becomes imperative to use loading and a combination of cables of varying gauges. In the case of composite gauges, the thinner cable is placed closer to the switching center. Normally subscriber loops (with combination of gauges) in excess of 5460 meters (18,000 feet) need loading.

Figure 5.11 shows the subscriber loop design chart. The limiting distance (resistance limit design) for using a 26 gauge cable in a non-loaded loop is approximately 4850 meters (16,000 feet). In the loaded environment, for instance the 24 gauge cable can handle a distance of approximately 7575 meters (25,000 ft.). Normally the routes must follow streets, which are for the most part rectangular in pattern, and the subscriber must be reached over the sum of the x-y coordinates with the switching center at the origin. The mean ratio of conductor route miles to airline miles based on the following mathematical development

SUBSCRIBER LOOP DESIGN CHART [Bell Telephone Co. of Canada]

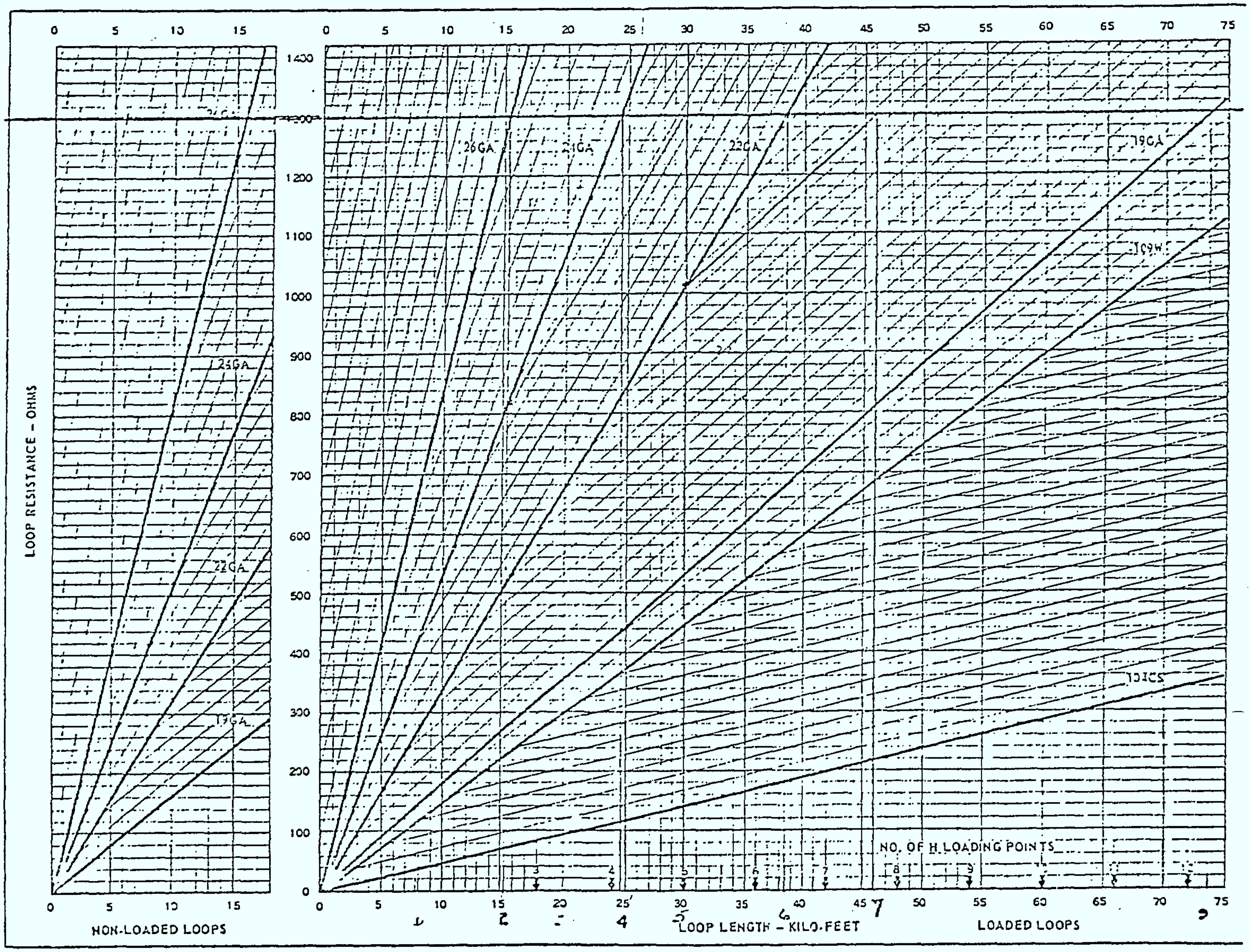


Figure 5.11 Subscriber Loop Design Chart

assuming a uniform arrangement would be:

$$\frac{R}{a} = \frac{\int_0^{\pi/2} \text{Sin}\theta d\theta + \int_0^{\pi/2} \text{Cos}\theta . d\theta}{\int_0^{\pi/2} . d\theta}$$

where R = route distance

a = airline distance

θ = angle between airline route and x axis.

The above ratio called airline ratio works out to be 1.27. Concentric contours (circles) are drawn with the switching center as the origin and a radius equal to the resistance limit length divided by this ratio, in order to arrive at a method of zoning the usage of various gauges. If an appropriate airline ratio specific to a carrier company is found by scientific sampling techniques, then that figure can be used instead of 1.27.

a) Underground cable

Normally the cable used for underground feeder routes is 3600 pair 24 gauge stalpeth cable. However, in any link ij , where the cable to be used is underground cable of cost C1 dollars, then the cost per unit length of cable is equal to C1/L where L is the standard length of the cable. The graph in Figure 5.12, shows the cable cost per unit length against the number of pairs of cable for various gauges.

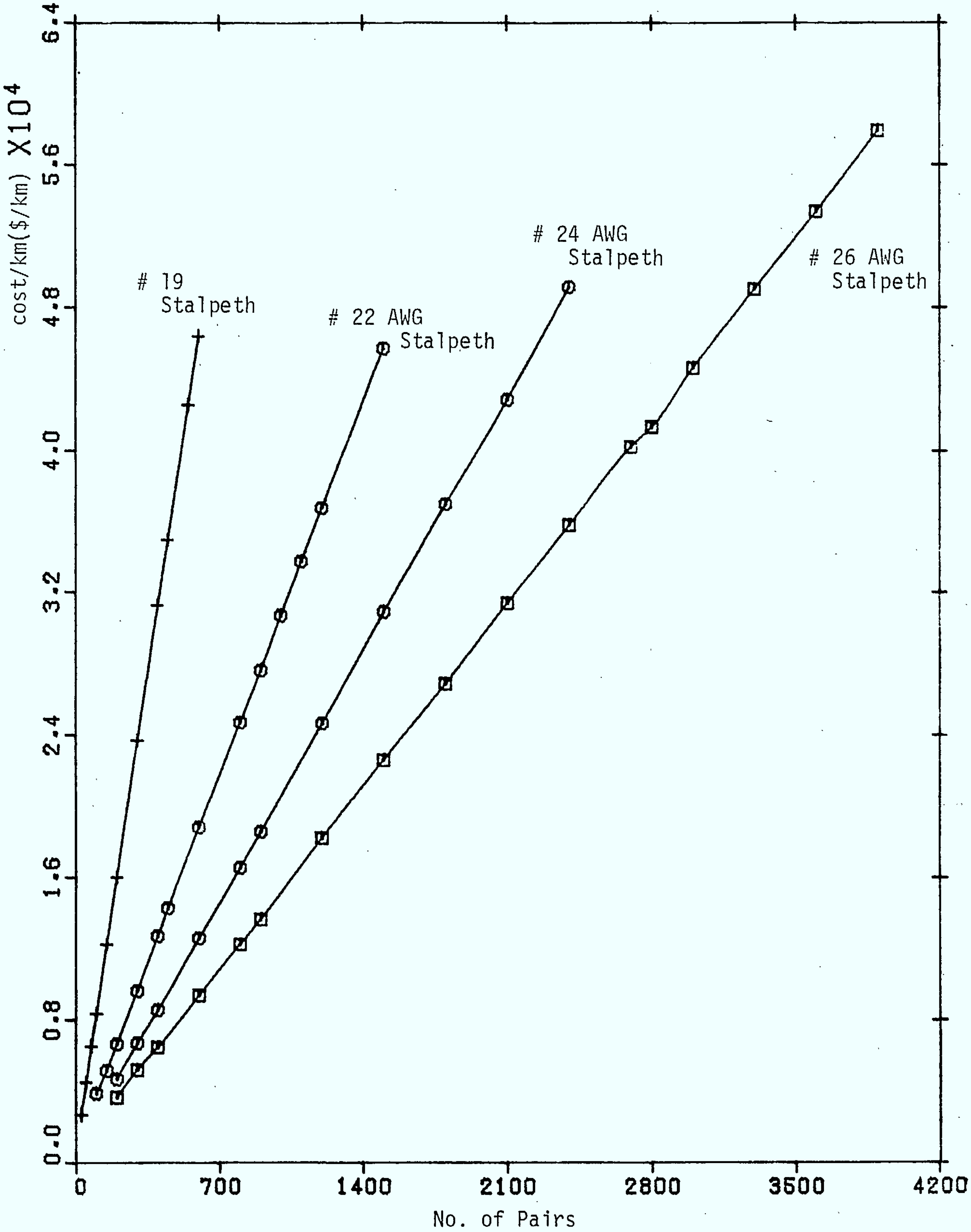


Figure 5.12 Cost per Unit Length of Cable Versus the Number of Pairs (Based on Published Price Lists for 1978)

Let UCC denote the cost per cable pair per foot, then

$$UCC = \$ \ (C1/L)/N$$

Then UCC is represented by the slope of the above curves.

The cost of the cable in the link ij will be equal to:

$$Xij \ [\ \{ (\ 100 \ UCC \ ) / \ F \ \} \ dij \ ]$$

where,

dij = the distance between the nodes

UCC = the cost per cable pair per foot

F = the cable fill percentage

Xij = the decision variable as determined by PNET.

A maximum cable fill percentage of 80% is assumed and the forecasted demand will be updated to reflect the actual plant required in the model. A linear regression of cost of cable per unit distance versus the number of cable pairs is done and the slope and intercept of this line is stored in the program for the different types of cable. These stored values will be used in calculating the cable cost depending on the flow required. The general regression equation will resemble;

$$C1/L = ak + bk.Xij$$

where 'ak' and 'bk' are the intercept and slope respectively of the 'k' th type of cable.

b) Repeaters, Amplifiers and Load Coils

The voice repeaters, amplifiers and load coils are treated as terminal equipment and their weighted average costs are determined for the different sizes of cable plant, considering the frequency of usage.

If C(R), C(A) and C(L) represent the average costs of the repeaters, amplifiers, and load coils respectively that are installed in the circuit, then these costs are distributed over the entire length of the cable. Therefore, the cost function will be:

$$\left[\frac{100UCC}{F} \cdot d_{ij} + \frac{C(R) + C(A) + C(L)}{d_{ij}}\right] . X_{ij}$$

when, $\sum_{i=0}^{m} d_{i(i+1)} > d$ (m denotes the total number of nodes)
> 1.27xair line distance.

where 'd' is the cut off distance beyond which the use of voice repeaters, amplifiers and load coils are necessary. Otherwise the cost function will be:

$$\left[\frac{100UCC}{F.d_{ij}}\right] X_{ij}$$

when, $\sum_{i=0}^{m} d_{i(i+1)} < d$

The limiting distances are stored for each gauge of cable and 1.27 times the airline distance is compared with these figures , in order to find out whether loading is necessary and to include any relevent costs.

c) Underground Conduits

Normally the underground conduits are placed far in excess of the quantity required to meet the immediate demand. They are usually placed to handle ultimate demand. Figure 5.13 represents a typical cross section of a conduit, partly filled with cables.

If

W = the number of way conduits

d(1),d(2) = the diameters of the conduit

C_2/L = the cost per meter of one conduit

F = the percentage fill allowed in any conduit

then, the cost of conduit in link ij is:

$$\left\{ \frac{(C_2/L) \cdot W.d(2)^2}{F \cdot d(1)^2} \right\} d_{ij}/x_{ij}$$

where

d(1) = diameter of the conduit normally used,

and

d(2) = diameter of the conduit selected for use.

The cost per unit length (of different radii conduits) are plotted against the number of ways and is shown in Figure 5.14.

d) The Buried Cable

Let UCC represent the cost of cable per meter and N is the number of pairs in the cable then, (Figure 5.15):

$$UCC = (C3/L) /N$$

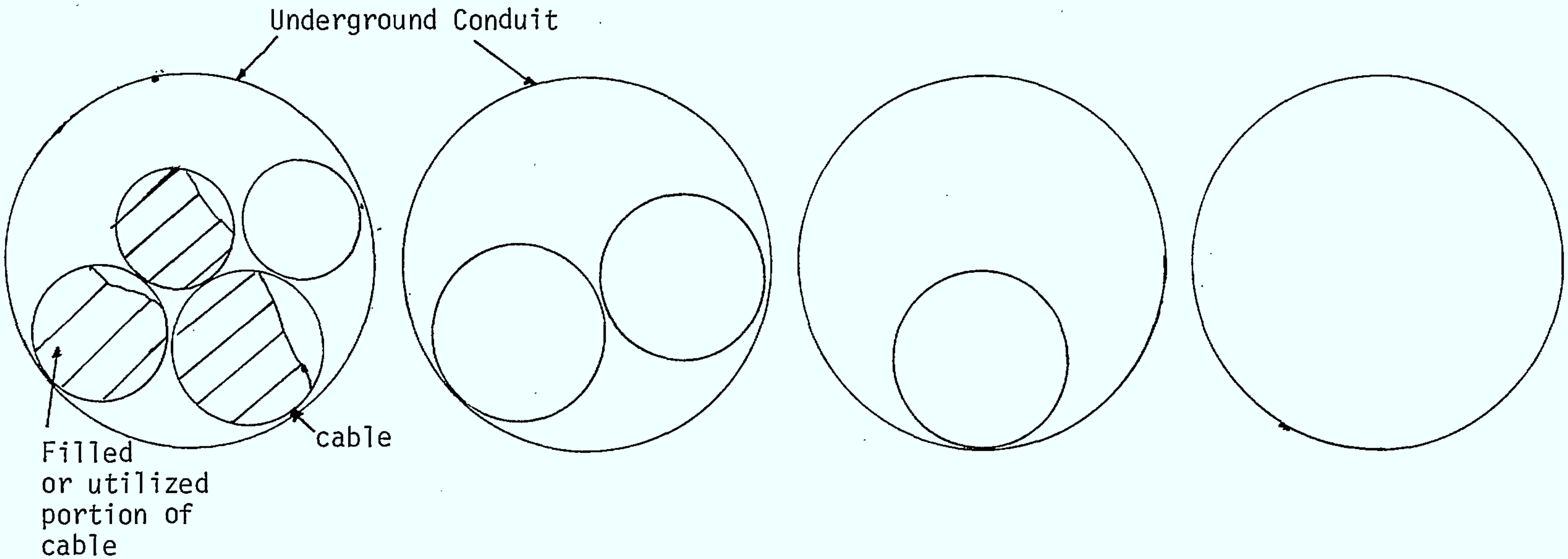


Figure 5.13 Cable Fill in a Four-Way Underground Conduit

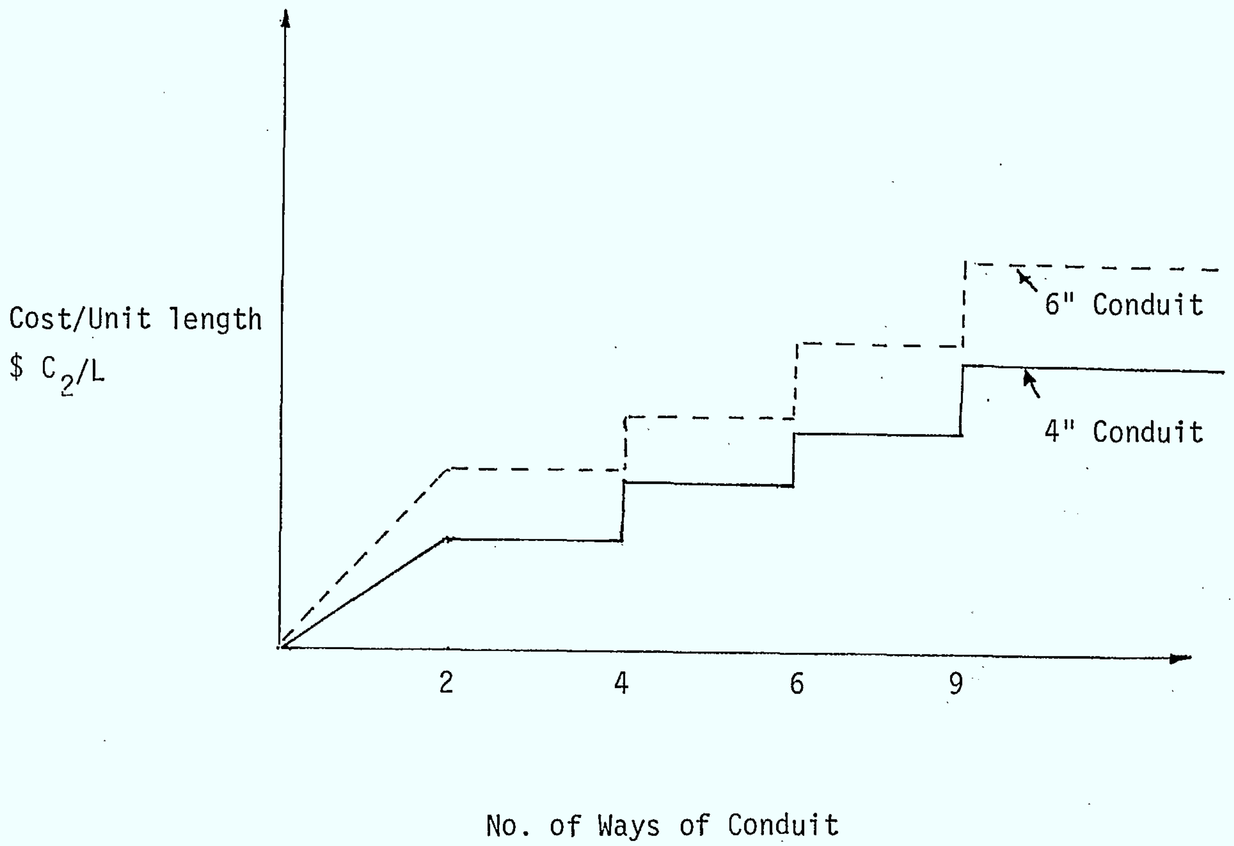


Figure 5.14 Conduit Price Vs. No. of Ways of Conduits

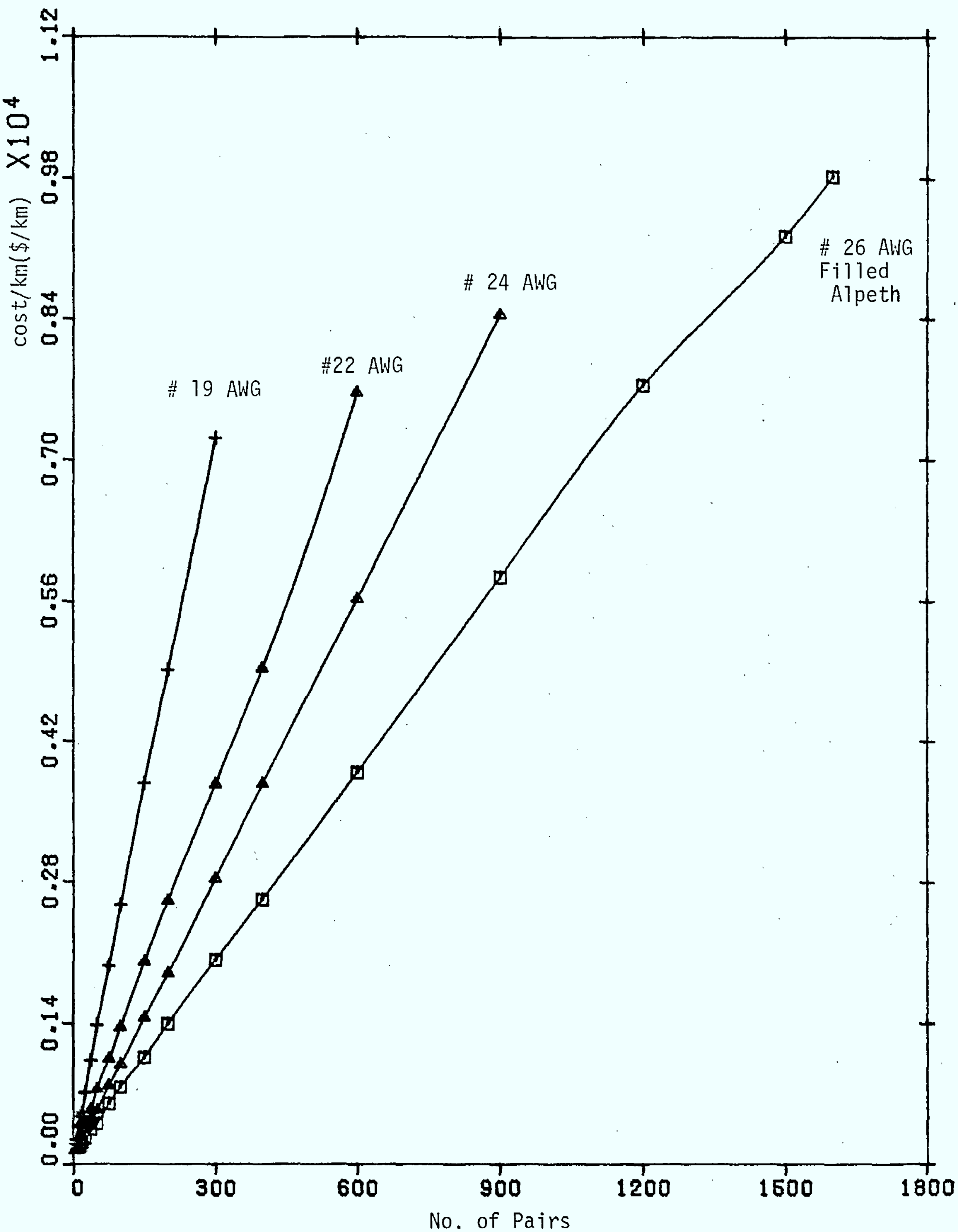


Figure 5.15 Cost per Unit Length of Buried Cable Versus the Number of Pairs (Based on Published Price Lists for 1978)

Therefore the cost per cable pair, assuming a percentage of fill of F% is equal to:

$$(UCC / F) 100.dij$$

which results in the cost of cable between nodes i and j as:

$$Xij [(UCC / F) 100 . dij]$$

A straight line regression is done with respect to the cost of cable per unit distance and the number of pairs of cable . These regression values are utilized to compute the cable cost.

e) <u>Aerial Cable</u>

Normally the cable used is 50-600 pair straight alpeth (unfilled) 24 gauge cable. The average span between poles is 100 feet with a maximum span of 125 feet in some places . The poles are generally 35 feet high and cost approximately $300 per pole. The aerial cable cost is developed under the following classifications:

1. cable cost ;
2. pole cost -(sometimes shared with other utilities); and
3. auxillary pole line equipment
    a) cross arms, and
    b) terminals.

If (C4/L) is the cost of the cable per unit of length, and N is the number of pairs of cable, then the cost per unit length per cable pair is, UCC = \$ (C4/L)/N , where N< 600. (Note Figure 5.16).

Let 'Cp' be the material cost of a pole and '(Σb) Cp/100' is the cost of the auxillary pole line equipment such as cross arms, terminals etc., where 'Σp' is the overall percentage loadings of the above items on the material cost of the pole. In some cases the pole lines are shared with other utilities, and one of the elements of 'Σp' takes a negative value to account for this factor.

If 'r' is the number of poles between nodes I and J, then the cost of the poles between the nodes I & J ,

$$= r[Cp + \frac{(\Sigma p)Cp}{100}]$$

Therefore, cost per cable pair per unit distance (meter)

$$= \frac{r[Cp + \frac{(\Sigma p)Cp}{100}]}{N} \cdot \frac{1}{d_{ij}}$$

The total cost of pole lines in link ij,

$$= [\frac{C_4/L}{N} + \frac{r\{Cp+\frac{(\Sigma p)Cp}{100}\}}{N} \cdot \frac{1}{d_{ij}}] \, d_{ij} . X_{ij}$$

where Xij is the decision variable as determined by the PNET program.

The above procedure was repeated for other types of plant .

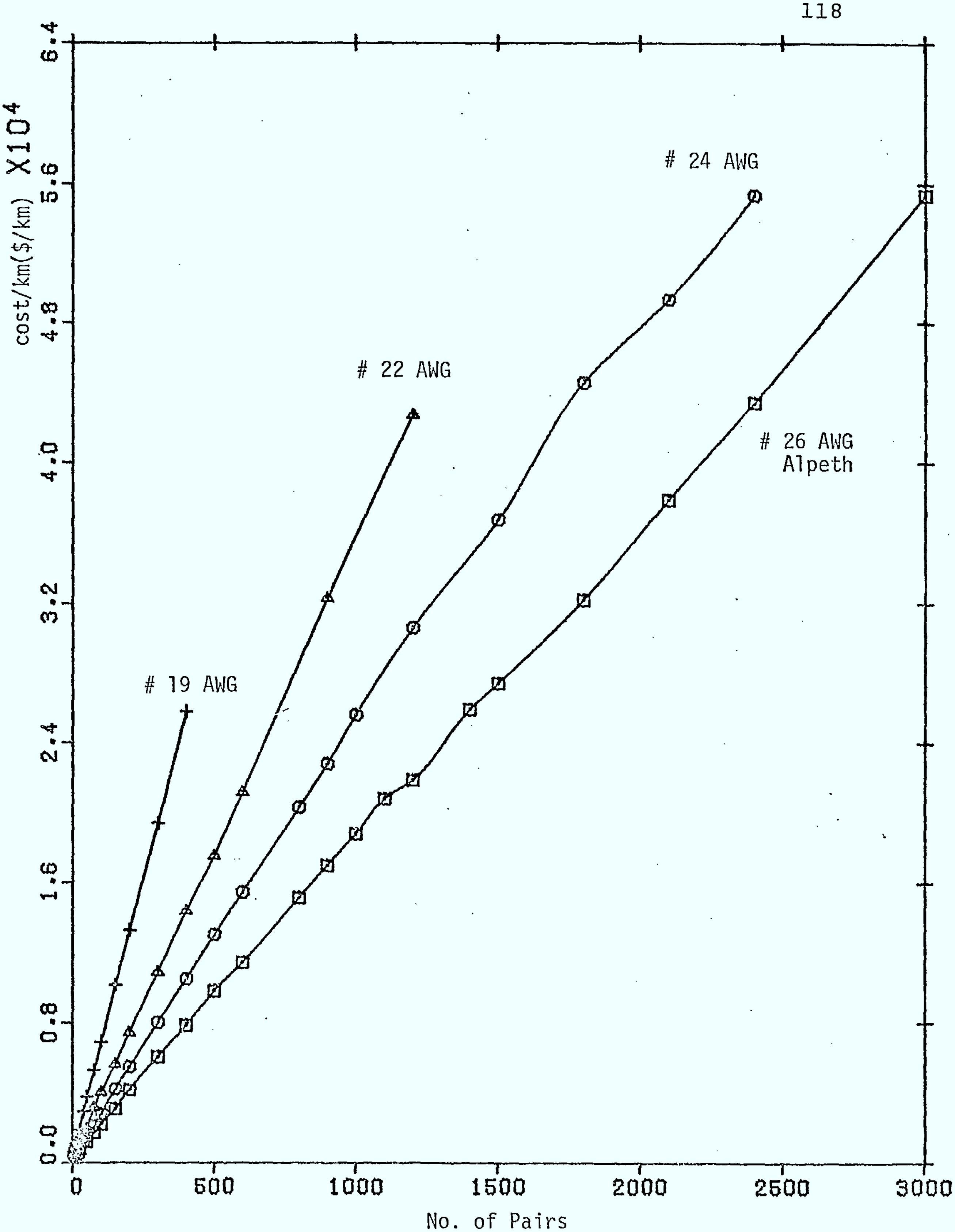


Figure 5.16 Cost per Unit Length of Aerial Cable Versus the Number of Pairs (Based on published Price Lists for 1978)

5.4 Depreciation and Salvage Values

Generally accepted accounting principles state that depreciation is the recovery of capital in a rational and uniform manner over the useful life of the plant. Under ideal conditions of constant dollar value, not only does this recover the capital investment in property in dollar amounts, but it also recovers the same purchasing power. The method of capital recovery that matches capital recovery with capital consumption while recognizing the dispersion about the average service life and which is still considered as a straight line method is the 'unit summation' or 'equal life group (ELG) method.

Most of the carrier companies use this method in order to arrive at a value for the depreciation amount, for rate making purposes.

In the case of a pure economic study involving income tax considerations, however, the capital cost allowance to arrive at taxable income is the prime consideration. Capital cost allowance represents an allowable expense in arriving at taxable income and thus affects the cash disbursements for income taxes. Telecommunication plant (in Canada) is subject to the declining balance method, and the Canadian Government has chosen to group these capital assets by class(class 17)and to state the capital cost allowance rate (8%) that applies to a specific class of assets.

The declining balance method as it implies, allows one to calculate the cost allowance by applying the capital cost allowance rate to the book value of the assets for the particular year in question.

In applying the depreciation rate the plant is grouped into categories as given below;

1. poles,
2. aerial cable,
3. ducts and vaults,
4. underground cable,
5. aerial coaxial cable,
6. underground coaxial cable,
7. buried coaxial cable,
8. buried cable, and
9. miscelleneous equipment.

If 'di' is the depreciation of the i th category of plant (on a unit basis) and 'Vi' is its estimated salvage value, then a capital tax factor (note derivation pp. 124-126) is computed for that plant and applied to the first cost and the salvage value. This factor takes into account all the effects of depreciation for tax purposes. In the case of surviving plant the initial cost is found from the book value.

5.4.1 The Total Cost Model

In designing a uniform system for the measurement of costs, there are three basic components that enter the total cost model.

4. An after-tax cash flow requirement(ATCFR). This requirement includes repayment of capital invested and an after-tax rate of return on the investment (The opportunity cost of capital). The required rate of return to meet the investors threshold of acceptability will be referred to as, (MARR) the minimum attractive rate of return.

5. An income tax requirement, and

6. An operating cost requirement.

Figure 5.17 is a simplified schematic of a corporate cash flow diagram. This diagram specifically shows the major cost factors that contribute to the cost structure. The notations of the variables used in the development of the total cost model will be explained below. Their Fortran equivalents are given in brackets.

ATCFR =after-tax cash flow requirement (ATCFR)

PEC = present equivalent cost (PEC)

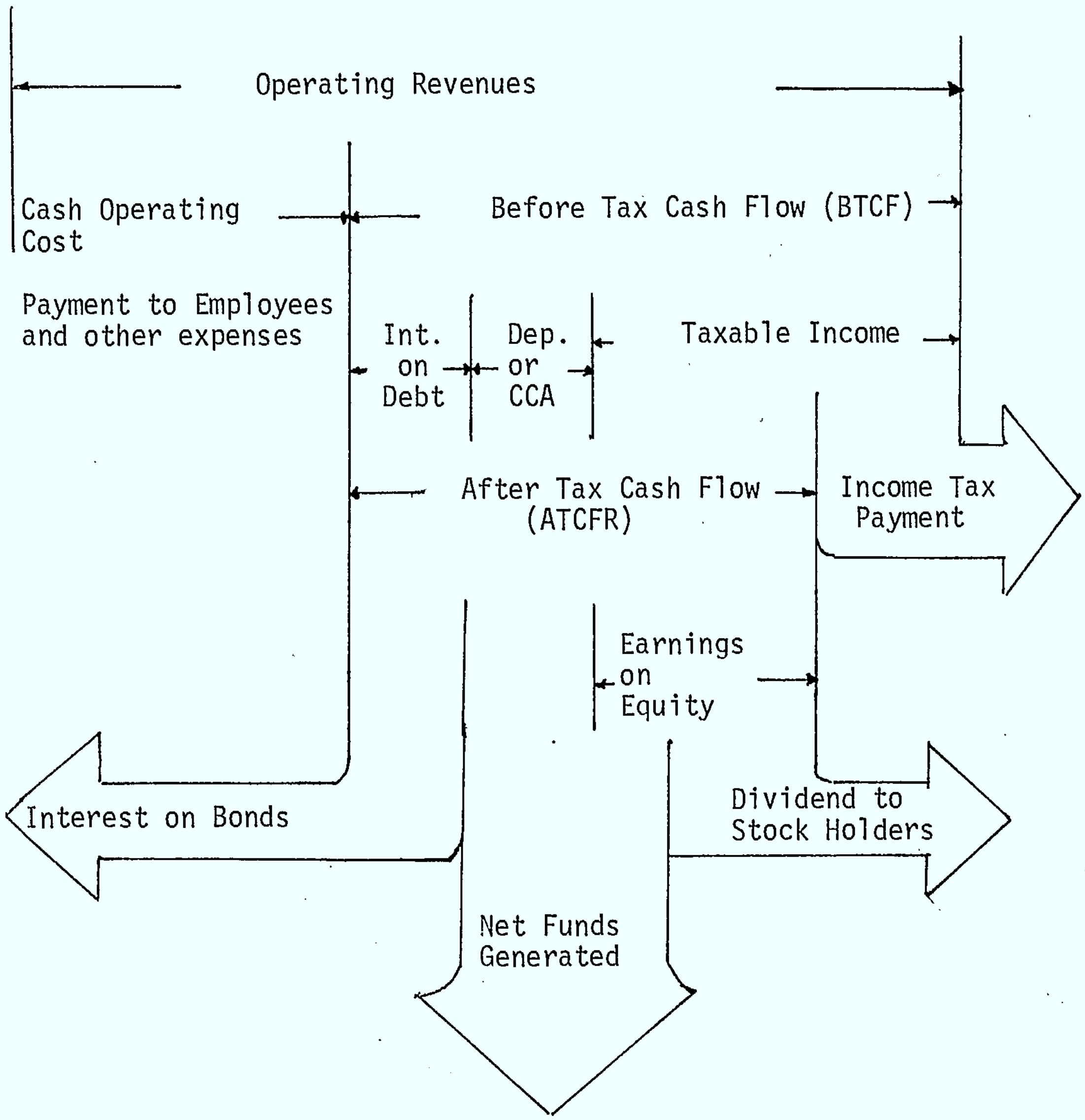


Figure 5.17 A Simplified Corporate Cash Flow Diagram [21]

PEM = present equivalent of operating costs (PEM)

B = first cost (the installed cost) (B)

V = salvage value (V)

n = number of periods in years (N)

N =life of the plant (NN)

t = the income tax rate (TT)

CCA = capital cost allowance (CCA)

PECCA = the present equivalent of the capital cost allowance (PED or PECCA)

$(a/p)_{n}^{ia}$ =annual equivalent of a present sum

$(p/a)_{n}^{ia}$ =present equivalent of an annual sum

$(p/f)_{n}^{ia}$ = present equivalent of a future sum

rd =debt ratio(debt capital/(debt capital + equity capital)) (RD)

id = interest rate on debt capital(ID)

ie = interest rate on equity capital (IE)

ic = composite cost of capital(IC)

ia =minimum attractive rate of return(MARR)

it =technological improvement rate(IT)

if =inflation rate(IF)

d =declining balance depreciation rate(DRZ)

b =operating cost growth rate (b)

c =first cash flow in a geometric series of discrete cash flows

CTF =capital tax factor(CTF)

PPEF =partial present equivalent of a future sum (PPEF)

$(p/c)_{n}^{ia}$ =present equivalent of geometric series

(a) Minimum Attractive Rate of Return

The effect of inflation on debt capital is assumed to be zero. The equity capital is fully responsive to inflation. Similarly the technological improvement on cost performance directly affects the equity capital, whereas the debt capital is unaffected by any change.

Hence, the cost of composite capital is a weighted average cost of capital based on the percentage of debt and equity in the capital structure:

$$i_c = (1-r_d)[(1+i_e)(1+i_f)(1-i_t) - 1] + r_d . i_d \qquad (1)$$

The minimum attractive rate of return, MARR, is

$$MARR = i_a = i_c - t.r_d . i_d \qquad (2)$$

The component '$t.r_d . i_d$' is known as the tax shelter. Those carrier companies that do not pay any tax will have this term equal to 0 in equation (2).

Combining equations (1) and (2)

$$\begin{aligned} i_a &= (1-r_d)[(1+i_e)(1+i_f)(1-i_t) - 1] + r_d i_d - t.r_d . i_d \\ &= (1-r_d)[(1+i_e)(1+i_f)(1-i_t) - 1] + (1-t) r_d . i_d \qquad (3) \end{aligned}$$

This value of 'i_a' will be used in discounting the cash flow streams.

(b) Capital Tax Factor

If d= CCA rate, (declining balance method)

t = tax rate,

i = MARR, and

n = year:

then the installation of a depreciable asset for cost 'B' results in a series of tax credits equal to B.t.d in the first year, B.t.d.(1-d) in the second year, and so on B.t.d.(1-d)**n-1 in the nth year.

The present equivalent cost, after subtracting these series of tax credits is equal to :

$$PEC = B - \frac{B.t.d}{(1+i)} - B.t.d \frac{(1-d)}{(1+i)^2} \ldots\ldots - B.t.d.\frac{(1-d)^{n-1}}{(1+i)^n}$$

Therefore,

$$(1-d)(PEC - B) = -B.t.d[\frac{(1-d)}{(1+i)} + \frac{(1-d)^2}{(1+i)^2} + \ldots\ldots + \frac{(1-d)^n}{(1+i)^n}]$$

A geometric series is convergent with sum Sn = a/(1-r), if modulus of r is less than 1 , and n is very large, where 'a' is its first term and 'r' is its common ratio.

Therefore,

$$(1-d)(PEC - B) = -B.t.d \left[\frac{(1-d)/(1+i)}{1 - (1-d)/(1+i)}\right]$$

$$= - B.t.d(1-d)/(i+d)$$

$$PEC = B (1 - t.d/(i+d))$$

The factor ,(1 - t.d/(i+d)) , is called the capital tax factor.

Assuming the books of the carrier company are open, the capital tax factor by class of plant is found ;

$$CTF = 1 - \frac{t.d}{(i_a+d)} \text{ ------------ } (4)$$

This factor when multiplied by the first cost of the plant (B) or the net salvage (V) in any given year will combine the effect of future tax savings on depreciable assets , and gives the after-tax cash flow of the plant.

(c) Present Equivalent of Maintenance

When the operating costs increase at a rate of b, with the age of plant:

Case 1 when b>IA;

$X=(1+b)/(1+IA)-1$

$$(p/c)_n^{ia} = [1/(1+IA)]\ (f/a)_n^X \text{ -----------} (5a)$$

Case 2 when b=IA

$X=0$

$$(p/c)_n^{ia} = n/(1+IA) \text{ -------------------- } (5b)$$

Case 3 when b is less than IA

$X=(1+IA)/(1+b)-1$

$$(p/c)_n^{ia} = [\ 1/(1+b)]\ (p/a)_n^X \text{ ----------} (5c)$$

The maintenance cost in any given year when multiplied by one of the above proper factors will be brought to the present day dollar amounts. This factor is used extensively in calculating the present equivalent of maintenance cost(PEM).

(d) Total Cost Model

The present equivalent cost of an investment is given by;

$$PEC = PEM + \frac{[B - V(p/f)_n^{i}a - t(PECCA)]}{(1-t)}$$

Introducing the CTF factor given by equation (4), the above equation reduces to,

$$PEC = PEM + \frac{[B.CTF - V.CTF.(p/f)_n^{i}a]}{(1-t)}$$

This equation is used for every arc of the plant considered in the network. All the factors in the above equation will vary depending on the type of plant considered in the arc , the period under consideration, the estimated life of the plant, the operating cost attributable to each class of plant and whether it is an existing plant or a plant to be newly installed.

6. TESTING THE MODEL

The entire optimization model, comprising the solution technique as well as the cost model, was tested on a hypothetical problem to assess the capability of the model.

6.1 Test Problem

The hypothetical problem used for the test was developed after a careful study of several switching center areas in the City of Edmonton, Alberta. Hence it represents a simulated version of the actual problem and was used to test the practical capabilities of the model. The use of a hypothetical problem enabled modifying the input data to test the model for the several different situations that are encountered in practice.

A map of the area used as the test problem is shown in Figure 6.1. The diagram shows locations of the various nodes in the network, both existing and alternative.

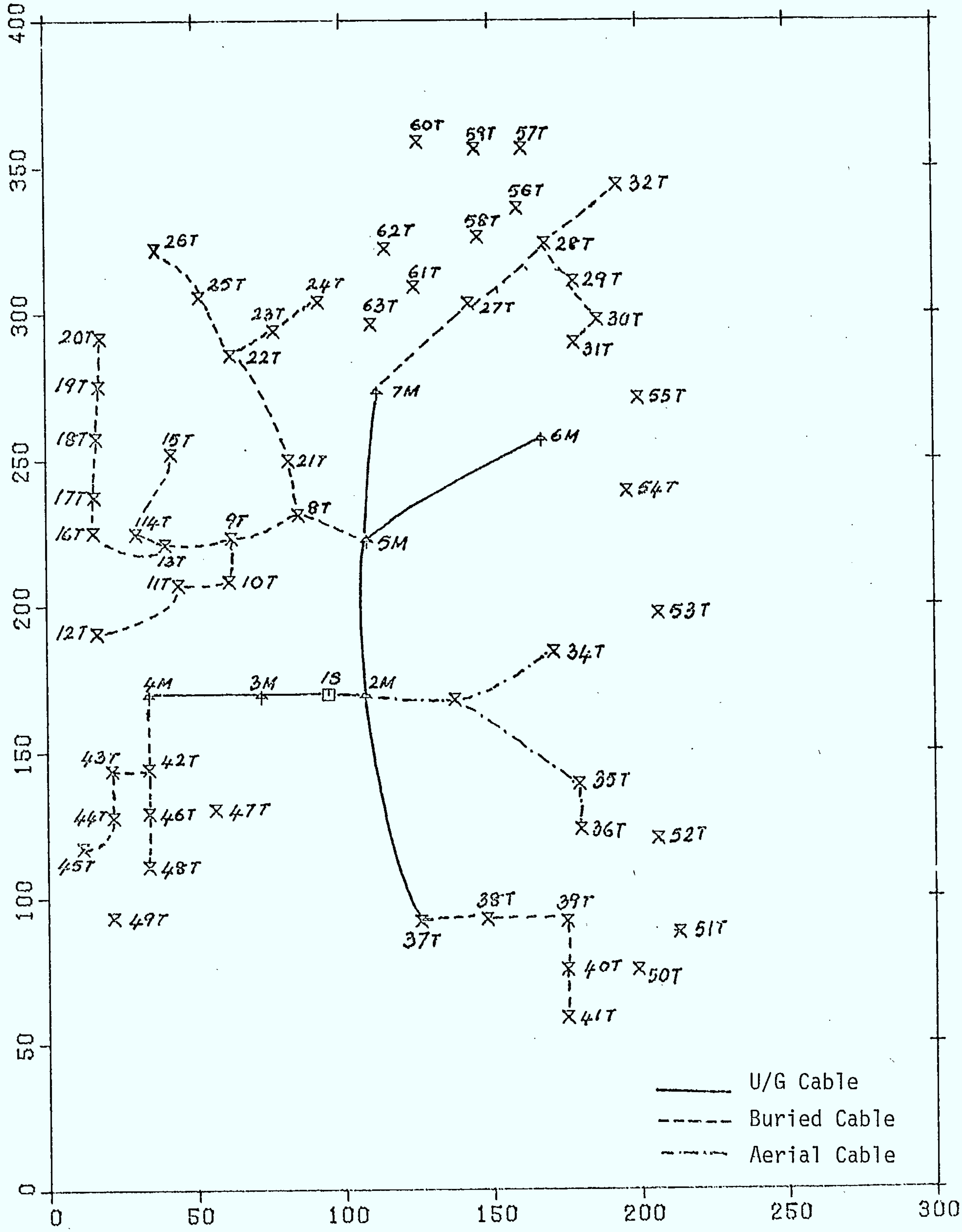


Figure 6.1 Map of the Test Area (Switching Center XYZ) Showing Existing Plant

The switching center(S), manholes(M) and the access terminals(T) form the different categories of nodes. The grid system used to describe the network was one with a scale of 5metres/unit. But, any convenient system can be chosen in practice. Table 6.1 shows the coordinates of all the nodal points on the cartesian grid system chosen. This information is useful in locating the nodes in the physical network and relating the program output to physical facilities. A code consisting of a number followed by a letter is used to denote a node. The letter in the codes used in defining the nodes signifies the type of plant that is used at the node (e.g. switching center, manhole, access terminal).

The forecast information is shown in Table 6.2. To allow for possible bad lines within a cable and to account for errors in the forecast, a maximum permissible cable fill of 80% was used to obtain the number of lines required to satisfy the demand at each point. The map of Figure 6.1, the demand data and a percentage fill of 80% were used as the basis for developing the network information shown in Table 6.3. Note that in Table 6.3 all the arcs emanating from a node are placed together. This arrangement is necessary for the functioning of the optimization program.

Table 6.1 Co-ordinates of the Nodes in the Network (Switching Center Area XYZ)

NODE	X-COORD	Y-COORD
1S	95.00	170.00
2M	107.50	169.00
3M	72.00	169.00
4M	34.00	169.00
5M	108.00	221.80
6M	167.10	256.50
7M	111.80	272.50
8T	85.00	231.00
9T	62.10	223.10
10T	61.30	208.30
11T	44.20	207.10
12T	16.80	190.70
13T	30.00	224.50
14T	16.10	237.20
15T	42.00	252.00
16T	15.80	225.00
17T	16.10	237.20
18T	16.90	257.40
19T	17.80	275.10
20T	18.40	291.50
21T	81.60	249.80
22T	62.10	285.70
23T	76.80	294.00
24T	92.00	303.90
25T	51.80	305.60
26T	40.00	220.90
27T	143.00	303.30
28T	168.90	324.00
29T	178.40	310.90
30T	186.30	297.70
31T	178.40	289.70
32T	193.10	343.80

Table 6.1 Co-ordinates of the Nodes in the Network (contd.)
(Switching Center Area XYZ)

NODE	X-COORD	Y-COORD
33T	137.60	168.10
34T	171.00	184.30
35T	179.40	139.00
36T	180.00	123.30
37T	125.70	92.00
38T	148.00	92.70
39T	175.00	91.90
40T	175.00	75.20
41T	175.00	58.80
42T	34.00	144.20
43T	21.50	143.70
44T	22.00	127.50
45T	11.80	117.00
46T	34.00	129.00
47T	56.40	130.20
48T	34.00	110.80
49T	22.00	93.30
50T	199.00	75.10
51T	213.10	88.00
52T	206.00	120.00
53T	206.10	197.20
54T	195.80	239.00
55T	199.80	270.80
56T	159.50	336.10
57T	161.20	356.20
58T	146.00	326.20
59T	145.40	356.10
60T	126.00	358.50
61T	124.50	309.00
62T	114.70	322.30
63T	110.00	296.20

Table 6.2 Forecast Information for Switching Center XYZ
(in number of lines)

NODE	PERIOD1	PERIOD2	PERIOD3	PERIOD4
8T	55	0	0	0
9T	239	0	0	0
10T	21	0	0	0
11T	4	0	0	0
12T	19	0	0	0
13T	11	0	0	0
14T	11	3	7	0
15T	11	4	0	0
16T	79	39	39	239
17T	19	0	11	0
18T	19	0	0	0
19T	11	0	0	0
20T	79	0	0	95
21T	29	0	0	0
22T	32	0	0	0
23T	18	0	0	0
24T	7	0	0	0
25T	11	0	0	0
26T	11	0	0	127
27T	11	7	0	0
28T	15	7	7	0
29T	7	3	1	0
30T	4	2	4	67
31T	7	3	3	2
32T	39	7	7	103
33T	79	39	39	0
34T	39	39	0	0
35T	56	0	0	0
36T	19	0	0	0
37T	33	0	0	0
38T	17	3	0	0
39T	11	4	0	0

Table 6.2 Forecast Information for Switching Center XYZ
(in number of lines) (contd.)

NODE	PERIOD1	PERIOD2	PERIOD3	PERIOD4
40T	4	2	2	2
41T	19	3	3	211
42T	17	0	0	0
43T	7	3	0	0
44T	4	0	0	0
45T	11	3	3	299
46T	11	0	0	0
47T	19	7	3	0
48T	3	3	0	0
49T	11	4	3	3
50T	4	0	0	4
51T	7	7	3	27
52T	0	0	39	7
53T	13	7	7	15
54T	31	7	7	7
55T	7	7	7	0
56T	4	3	0	0
57T	7	3	3	0
58T	7	7	3	0
59T	3	5	8	2
60T	0	1	2	7
61T	11	11	7	4
62T	0	239	0	79
63T	3	3	3	3

Table 6.3 Network Information for Switching Center XYZ

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
1S	2M	1111	9400	1254	100	77.23	0.0	3
1S	3M	1111	3600	98	100	123.67	0.0	3
2M	5M	1111	7200	898	100	300.59	62.70	5
2M	33T	1111	1200	246	100	167.29	62.70	3
2M	37T	1111	1000	110	100	513.30	62.70	1
3M	4M	1111	3600	98	100	242.25	115.11	2
4M	12T	2151	0	0	100	173.86	305.04	0
4M	42T	1131	1800	98	100	166.40	305.04	0
5M	6M	1111	2400	0	100	453.71	267.03	2
5M	7M	1111	2400	111	100	254.61	267.03	3
5M	8T	1131	2400	787	100	124.26	267.03	0
6M	55T	2151	0	0	100	197.95	563.04	0
6M	54T	2151	0	0	100	191.28	563.04	0
7M	27T	1131	600	111	100	264.23	519.34	0
7M	63T	2151	0	0	100	159.20	519.34	0
8T	21T	1131	1200	104	400	108.18	309.07	0
8T	9T	1131	1200	683	400	158.50	309.07	0
8T	00							
70 0 0 0								
9T	10T	1131	200	58	400	98.14	312.33	0
9T	13T	1131	600	325	400	178.07	312.33	0
9T	00							
300 0 0 0								
10T	11T	1131	100	31	400	92.33	255.08	0
10T	00							
27 0 0 0								
11T	12T	1131	50	25	400	182.41	314.53	0
11T	00							
6 0 0 0								
12T	00							
25 0 0 0								
13T	14T	1131	50	30	400	124.69	424.12	0
13T	16T	1131	800	280	400	74.20	424.12	0
13T	11T	2151	0	0	400	119.84	424.12	0
13T	00							
15 0 0 0								
14T	15T	1131	25	15	400	186.71	518.19	0
14T	00							
15 5 10 0								
15T	00							
15 6 0 0								
16T	17T	1131	300	180	400	79.82	482.12	0
16T	12T	2151	0	0	400	220.77	482.12	0
16T	00							
100 50 50 300								
17T	18T	1131	250	140	400	128.37	518.19	0
17T	00							
25 0 15 0								
18T	19T	1131	225	115	400	91.03	586.05	0
18T	00							
25 0 0 0								

Table 6.3 Network Information for Switching Center XYZ (con'd)

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
19T	20T	1131	200	100	400	104.13	652.03	0
19T	00							
15	0	0	0					
20T	00							
100	0	0	120					
21T	22T	1131	600	104	400	208.33	404.59	0
21T	00							
37	0	0	0					
22T	23T	1131	50	33	400	100.57	601.43	0
22T	25T	1131	300	30	400	143.61	601.43	0
22T	00							
41	0	0	0					
23T	24T	1131	25	10	400	94.58	626.64	0
23T	00							
23	0	0	0					
24T	23T	2151	0	0	400	103.52	669.67	0
24T	00							
10	0	0	0					
25T	26T	1131	200	15	400	449.12	711.58	0
25T	00							
15	0	0	0					
26T	00							
15	0	0	160					
27T	28T	1131	600	96	100	206.33	708.39	0
27T	61T	2151	0	0	100	111.17	708.39	0
27T	58T	2151	0	0	100	117.58	708.39	0
27T	31T	2151	0	0	100	194.04	708.39	0
27T	00							
15	10	0	0					
28T	29T	1131	200	26	100	82.49	854.07	0
28T	32T	1131	400	50	100	165.05	854.07	0
28T	56T	2151	0	0	100	94.93	854.07	0
28T	00							
20	10	10	0					
29T	30T	1131	150	16	100	83.73	818.66	0
29T	00							
10	5	2	0					
30T	31T	1131	25	10	100	62.75	784.90	0
30T	55T	2151	0	0	100	181.69	784.90	0
30T	00							
6	3	6	85					
30T	55T	2151	0	0	100	170.45	784.90	0
31T	00							
10	5	5	3					
32T	57T	2151	0	0	100	184.64	997.87	0
32T	00							
50	10	10	130					
33T	34T	1121	600	50	100	232.74	213.21	4
33T	35T	1121	600	96	100	265.34	213.21	3
33T	00							
100	50	50	0					

Table 6.3 Network Information for Switching Center XYZ (con'd)

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
34T	53T	2171	0	0	100	197.35	386.67	0
34T	00							
50 50	0 0							
35T	36T	1121	200	25	100	102.53	449.57	3
35T	52T	2171	0	0	100	190.29	449.57	0
35T	00							
71 0	0 0							
36T	52T	2171	0	0	100	172.92	484.92	0
36T	00							
25 0	0 0							
37T	38T	1131	600	68	200	138.41	419.12	0
37T	00							
42 0	0 0							
38T	39T	1131	400	46	200	149.00	468.62	0
38T	00							
22 5	0 0							
39T	40T	1131	300	31	200	92.44	559.01	0
39T	51T	2151	0	0	200	247.04	559.01	0
39T	00							
15 6	0 0							
40T	41T	1131	200	25	200	91.14	620.22	0
40T	50T	2151	0	0	200	150.25	620.22	0
40T	00							
6 3	3 3							
41T	00							
25 5	5 265							
42T	43T	1131	100	31	100	81.25	331.16	0
42T	46T	1131	75	45	100	84.42	331.16	0
42T	00							
22 0	0 0							
43T	44T	1131	75	21	100	81.62	390.32	0
43T	00							
10 5	0 0							
44T	45T	1131	50	15	100	87.05	422.35	0
44T	46T	2151	0	0	100	77.23	422.35	0
44T	00							
6 0	0 0							
45T	48T	2151	0	0	100	127.92	493.24	0
45T	49T	2151	0	0	100	139.21	493.24	0
45T	00							
15 5	5 375							
46T	44T	2151	0	0	100	78.20	367.49	0
46T	47T	1131	50	25	100	130.48	367.49	0
46T	48T	1131	11	5	100	96.56	367.49	0
46T	00							
15 0	0 0							
47T	00							
25 10	5 0							
48T	45T	2151	0	0	100	133.64	425.02	0
48T	49T	2151	0	0	100	114.24	425.02	0

Table 6.3 Network Information for Switching Center XYZ (con'd)

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
48T	00							
5	5	0	0					
49T	00							
15	6	5	5					
50T	51T	2151	0	0	200	97.12	703.95	0
50T	00							
6	0	0	6					
51T	50T	2151	0	0	200	124.24	718.88	0
51T	00							
10	10	5	35					
52T	00							
0	0	50	10					
53T	00							
17	10	10	20					
54T	53T	2151	0	0	100	264.27	610.77	0
54T	00							
40	10	10	10					
55T	54T	2151	0	0	100	187.67	727.04	0
55T	00							
10	10	10	0					
56T	57T	2151	0	0	100	129.05	890.92	0
56T	58T	2151	0	0	100	84.69	890.92	0
56T	00							
6	5	0	0					
57T	00							
10	5	4	0					
58T	56T	2151	0	0	100	94.78	821.57	0
58T	59T	2151	0	0	100	155.64	821.57	0
58T	00							
10	10	5	0					
59T	57T	2151	0	0	100	104.47	964.02	0
59T	60T	2151	0	0	100	130.43	964.02	0
59T	00							
5	7	11	3					
60T	00							
0	2	3	10					
61T	58T	2151	0	0	100	173.34	710.48	0
61T	62T	2151	0	0	100	88.26	710.48	0
61T	00							
15	15	10	6					
62T	59T	2151	0	0	100	248.82	767.84	0
62T	60T	2151	0	0	100	224.71	767.84	0
62T	00							
0	300	0	100					
63T	61T	2151	0	0	100	113.29	635.44	0
63T	62T	2151	0	0	100	165.77	635.44	0
63T	24T	2151	0	0	100	122.40	635.44	0
63T	00							
5	5	5	4					

6.1.1 Data Format for the Input Conversion System

The format in which information has to be fed into the computer is very critical for the working of the model. This section outlines the data decks and the sequence in which they are to be supplied to the programs. Specific formats are discussed in the Appendices.

Data set #1 contains information required by the input conversion system. It consists of four control cards followed by the network data illustrated in Table 6.3. The first card in the deck contains the problem title not exceeding 80 characters in length. The title used in the test was "SUBSCRIBER LOOP OPTIMIZATION".

The second data card in the deck contains a string of 36 characters. These characters are used by the input conversion system in designating a code name to the nodes in the network. Such a system enables more nodes to be accommodated with minimum space requirements. To illustrate, consider a situation where only three characters can be used to designate a node. With a numerical code, each node can take on a value between 0 and 999. Therefore, the maximum number of nodes in this case is 1000. With a code using the 26 letters of the English alphabet in addition to the ten digits, as many as 46,656 nodes can be handled in the same situation. The characters used on the second card can be any one among those available on a keypunch/terminal. The only condition that has to be satisfied is that one character may occur only once in the string specified. The string:

0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZ

was used in the test problem.

The third card contains the number of periods in the planning horizon considered. Four periods were considered while testing the programs. The first three periods represented the first, second and the third year respectively and the fourth period covered years four through to the time required by the switching center to reach ultimate capacity. It was assumed that it would take 30 years for the switching center to attain its ultimate capacity.

On the fourth card in data set #1, the number of technologies that are explicitly considered in each period are specified. In testing the model, it was not possible to collect specific cost data for the different technologies available in the telecommunications industry. So only one technology was considered each period, and the general technological trend curve was used to forecast future costs.

The network information shown in Table 6.3 follows the four control cards. The columns occupied by specific variables are discussed in Appendix A. Demand points are identified by placing zeros in place of ending node codes. The card following a demand point so designated, must contain the periodic line requirements; total requirements for the first period and the increments for the following periods.

6.1.2 Cost Related Data

The cost data described herein was required for the subroutine COST which was used in testing the model. Therefore the specific cost information required may be different if other cost models were used. New cost routines can be used by modifying the input conversion, UPDATE1 and UPDATE2 programs as indicated in the Appendices.

The cost subroutine used in testing the model utilizes the different classifications of plant, workforce and activities explained below.

Two different classifications were used for the physical plant. The first of these classifications is based on the six classes of plant, i.e., underground paired cable, aerial paired cable, buried paired cable, underground coaxial cable, aerial coaxial cable and buried coaxial cable. The second classification, which is required for the purposes of accounting and capital budgeting, divides the physical plant into nine categories, which are:

1. aerial paired cable,
2. poles,
3. aerial coaxial cable,
4. buried paired cable,

5. buried coaxial cable,
6. underground paired cable,
7. conduits (or ducts) and manholes (or vaults),
8. underground coaxial cable, and
9. line concentrators (or loading equipment).

The workforce is classified into five craft types, type A, type B, type C, type D and type E. The outside plant activities have been divided into eight major types which are:

1. installing poles,
2. laying aerial cable,
3. trenching,
4. laying underground cable,
5. laying underground conduits,
6. digging,
7. laying buried cable, and
8. installing loading equipment.

Table 6.4 shows the cost data that were used in testing the model. In Table 6.4, lines with an asterisk (*) in the first column are shown only to explain the significance of the values given in the lines that follow. Hence they do not form a part of the input data.

While supplying information on the sizes of plant available within a class of plant, zeros are placed if a certain type of plant is not available. When the model was

Table 6.4 Cost Data Used in Testing the Model

```
                                                                        DATA CARD
                         DATA/ COMMENTS                                   NUMBER
*    THE NUMBER OF PERIODS IN THE PLANNING HORIZON
004                                                                          1
*    THE EQUIVALENT DURATION OF EACH PERIOD
001                                                                          2
001                                                                          3
001                                                                          4
010                                                                          5
*     THE PAYROLL COSTS BY CRAFT TYPE CLSSIFIED UNDER FIVE CATEGORIES
 1254400. 124800.   124800.   62400.    107200.                              6
 1693440. 168000.   168000.   84000.    146160.                              7
 1347720. 134772.   134632.50 67320.    116160.                              8
 1026900. 102690.   102690.   51345.    88200.                               9
 540000.  54000.    54000.    27000.    46350.                              10
*     TOTAL MANHOURS (YEARLY) AND THE PRODUCTIVITY FACTORS FOR EACH CRAFT
 160000.  .72                                                               11
 168000.  .75                                                               12
 132000.  .80                                                               13
 90000.   .70                                                               14
 45000.   .74                                                               15
*     TIME REQUIRED IN HOURS FOR EACH SUB-ACTIVITY (ONE ROW FOR ONE ACTIVITY)
0.385166650.981000010.266500000.606666560.54499990                          16
0.023333330.005450000.006600000.178333280.03050000                          17
0.500000000.383333330.219999970.0       0.16666663                          18
0.010700000.001666670.005616660.045100000.61999995                          19
0.083333310.025000000.036666660.0       0.02000000                          20
0.166666630.111666620.073333320.0       0.20666665                          21
0.010350000.001666670.146666650.045100000.40849990                          22
0.490833280.251166640.766666650.375000000.0                                 23
*     PERCENTAGE OF WORK CONTRIBUTED BY PEOPLE IN ONE CRAFT (ONE ROW FOR EACH ACTIVITY)
 .1       .5       .6       .5       .1       .05      .5       0.        24
 .1       .1       .0       .1       .3       .05      .1       .2        25
 .5       .1       .1       .1       .3       .6       .1       .5        26
 .14      .14      .14      .14      .14      .14      .14      .14       27
 .14      .14      .14      .14      .14      .14      .14      .14       28
*     GEOGRAPHIC DIFFICULTY FACTORS BY TYPE OF TERRAIN AND ACTIVITY
 1.       1.07     1.12     1.05                                            29
 1.       1.05     1.15     1.1                                             30
 1.       1.25     1.18     1.20                                            31
 1.       1.04     1.06     1.1                                             32
 1.       1.07     1.12     1.2                                             33
 1.       1.12     1.14     1.16                                            34
 1.       1.03     1.04     1.04                                            35
*     LOADINGS ON MATERIAL AND LABOR, PLACED ALTERNATIVELY (ONE ROW FOR ONE CLASS OF PLANT)
 45.      2.       25.      2.       7.       0.       25.      -10.      36
 45.      2.       25.      2.       7.       0.       25.      -10.      37
 45.      2.       25.      2.       7.       0.       25.      -10.      38
 45.      2.       25.      2.       7.       0.       25.      -10.      39
 45.      2.       25.      2.       7.       0.       25.      -10.      40
 45.      2.       25.      2.       7.       0.       25.      -10.      41
*     TOTAL NUMBER OF GAUGES AVAILABLE
004                                                                         42
```

Table 6.4 Cost Data Used in Testing the Model (con'd)

```
*     THE DIFFERENT GAUGES AVAILABLE
026                                                                                  43
024                                                                                  44
022                                                                                  45
019                                                                                  46
*     TOTAL NUMBER OF CABLE SIZES
 35                                                                                  47
*     THE DIFFERENT SIZES OF CABLE AVAILABLE (FOUR COLUMNS PER SIZE)
   4   6  11  12  16  18  25  37  50  75 100 150 200 300 400 450 500 550 600 800   48
 900100011001200140015001600180021002400270028003000330036 00                       49
*     CABLE COST DATA
*     UNDERGROUND CABLE
*     NUMBER OF SUBCLASSIFICATIONS
001                                                                                  50
*     DESIGN SPECIFICATIONS
*     THE NUMBER OF DIFFERENT DESIGN CATEGORIES
006                                                                                  51
*     THE DIFFERENT DISTANCES AND THE CORRESPONDING DESIGN SPECIFICATIONS
4850.     01026                                                                      52
5450.     01024                                                                      53
7475.     11026                                                                      54
11670.    11024                                                                      55
22120.    11022                                                                      56
22730.    11019                                                                      57
*     NUMBER OF GAUGES AVAILABLE IN UNDERGROUND PLANT AND SUBCLASS 1 (STALPETH)
*     FOLLOWED BY THE NUMBER OF SIZES OF PLANT AND THE ASSOCIATED COSTS
*     THE COSTS FOR THE PLANT ARE THE MATERIAL COSTS PER UNIT OF MEASUREMENT
  4                                                                                  58
 17                                                                                  59
    200.00       3.63      23.28                                                     60
    300.00       5.17      21.24                                                     61
    400.00       6.45      15.35                                                     62
    600.00       9.39      17.46                                                     63
    800.00      12.26      18.48                                                     64
    900.00      13.67      23.21                                                     65
   1200.00      18.20      19.32                                                     66
   1500.00      22.60      15.46                                                     67
   1800.00      26.91      20.39                                                     68
   2100.00      31.39      18.00                                                     69
   2400.00      35.79      16.29                                                     70
   2700.00      40.23      17.97                                                     71
   2800.00      41.34      19.13                                                     72
   3000.00      44.59      22.30                                                     73
   3300.00      49.04      23.24                                                     74
   3600.00      53.39      18.40                                                     75
   3900.00      57.91      22.29                                                     76
 11                                                                                  77
    200.00       4.67      24.67                                                     78
    300.00       6.70      24.87                                                     79
    400.00       8.57      15.56                                                     80
    600.00      12.61      17.31                                                     81
    800.00      16.55      24.54                                                     82
    900.00      18.55      19.11                                                     83
```

Table 6.4 Cost Data Used in Testing the Model (con'd)

```
   1200.00      24.66      16.46                                                     84
   1500.00      30.89      21.82                                                     85
   1800.00      36.98      19.58                                                     86
   2100.00      42.85      15.93                                                     87
   2400.00      49.16      22.37                                                     88
 13                                                                                  89
    100.00       3.85      19.62                                                     90
    150.00       5.13      20.18                                                     91
    200.00       6.63      24.47                                                     92
    300.00       9.64      23.69                                                     93
    400.00      12.72      18.88                                                     94
    450.00      14.31      19.99                                                     95
    600.00      18.78      15.08                                                     96
    800.00      24.71      19.60                                                     97
    900.00      27.65      23.11                                                     98
   1000.00      30.69      15.53                                                     99
   1100.00      33.74      20.03                                                    100
   1200.00      36.75      24.69                                                    101
   1500.00      45.70      21.17                                                    102
 11                                                                                 103
     25.00       2.68      23.30                                                    104
     50.00       4.46      22.47                                                    105
     75.00       6.50      23.62                                                    106
    100.00       8.36      16.99                                                    107
    150.00      12.26      23.37                                                    108
    200.00      16.02      19.48                                                    109
    300.00      23.68      15.56                                                    110
    400.00      31.25      23.04                                                    111
    450.00      34.96      18.59                                                    112
    550.00      42.57      24.61                                                    113
    600.00      46.38      16.05                                                    114
*      NUMBER OF SUBCLASSES OF PLANT WITHIN AERIAL PLANT
  2                                                                                 115
*      NUMBER OF DESIGN CATEGORIES,  FOLLWED BY THE DESIGN DISTANCES AND THE SPECIFICATIONS
  6                                                                                 116
4850.      02026                                                                    117
5450.      02024                                                                    118
7475.      12026                                                                    119
11670.     12024                                                                    120
22120.     12022                                                                    121
22730.     12019                                                                    122
*      NUMBER OF GAUGES IN SUBCLASS 1(STALPETH)
                                                                                    123
*      THE NUMBER OF GAUGES IN SUBCLASS 2(ALPETH)
  4                                                                                 124
*      NUMBER OF CABLE SIZES FOR EACH GAUGE, THE SIZES AND THE ASSOCIATED COSTS
*        THE CABLE COSTS ARE IN DOLLAPS PER METRE.
 25                                                                                 125
     11.00        0.53     24.66                                                    126
     12.00        0.55     16.29                                                    127
     16.00        0.62     15.11                                                    128
     18.00        0.66     16.11                                                    129
     25.00        0.83     18.12                                                    130
```

Table 6.4 Cost Data Used in Testing the Model (con'd)

50.00	1.24	23.25	131
75.00	1.75	24.40	132
100.00	2.23	24.22	133
150.00	3.11	17.17	134
200.00	4.22	19.46	135
300.00	6.10	21.32	136
400.00	7.88	15.68	137
500.00	9.81	21.58	138
600.00	11.44	16.34	139
800.00	15.13	16.60	140
900.00	17.02	21.67	141
1000.00	18.82	19.18	142
1100.00	20.82	18.87	143
1200.00	21.89	24.63	144
1400.00	25.92	15.75	145
1500.00	27.42	16.48	146
1800.00	32.21	17.12	147
2100.00	37.89	22.00	148
2400.00	43.48	24.68	149
3000.00	55.36	18.80	150
24			151
6.00	0.43	20.19	152
11.00	0.58	21.18	153
12.00	0.59	17.19	154
16.00	0.70	21.17	155
18.00	0.76	16.86	156
25.00	0.91	20.68	157
37.00	1.18	24.21	158
50.00	1.51	18.97	159
75.00	2.13	22.79	160
100.00	2.86	22.25	161
150.00	4.25	19.85	162
200.00	5.53	15.27	163
300.00	8.05	19.13	164
400.00	10.51	20.11	165
500.00	13.05	17.51	166
600.00	15.46	19.33	167
800.00	20.32	22.28	168
900.00	22.80	22.62	169
1000.00	25.63	17.98	170
1200.00	30.65	23.77	171
1500.00	36.75	20.08	172
1800.00	44.61	15.96	173
2100.00	49.35	19.03	174
2400.00	55.34	21.82	175
18			176
6.00	0.49	18.79	177
11.00	0.68	23.53	178
12.00	0.71	21.80	179
16.00	0.82	23.99	180
18.00	0.90	19.17	181
25.00	1.16	18.13	182
37.00	1.52	19.90	183

Table 6.4 Cost Data Used in Testing the Model (con'd)

```
      50.00        1.96       15.55                                                      184
      75.00        3.16       16.95                                                      185
     100.00        4.05       15.30                                                      186
     150.00        5.68       23.52                                                      187
     200.00        7.46       18.78                                                      188
     300.00       10.87       18.41                                                      189
     400.00       14.37       20.31                                                      190
     500.00       17.56       23.89                                                      191
     600.00       21.17       18.86                                                      192
     900.00       32.28       16.36                                                      193
    1200.00       42.77       20.20                                                      194
 14                                                                                      195
       6.00        0.67       21.24                                                      196
      11.00        1.03       21.21                                                      197
      12.00        1.10       16.68                                                      198
      16.00        1.34       20.05                                                      199
      18.00        1.48       18.73                                                      200
      25.00        1.88       15.13                                                      201
      37.00        2.94       16.08                                                      202
      50.00        3.79       24.63                                                      203
      75.00        5.34       24.38                                                      204
     100.00        6.92       18.18                                                      205
     150.00       10.13       24.12                                                      206
     200.00       13.26       18.34                                                      207
     300.00       19.42       19.64                                                      208
     400.00       25.81       15.72                                                      209
*     NUMBER OF SUBCLASSES OF PLANT IN BURIED CABLE
  2                                                                                      210
*     DESIGN SPECIFICATIONS
  6                                                                                      211
4850.      02026                                                                         212
5450.      02024                                                                         213
7475.      12026                                                                         214
11670.     12024                                                                         215
22120.     12022                                                                         216
22730.     12019                                                                         217
*     NUMBER OF GAUGES IN SUBCLASS 1 (STALPETH)
                                                                                         218
*     NUMBER OF GAUGES IN SUBCLASS 2 (ALPETH)
  4                                                                                      219
*     NUMBER OF CABLE SIZES, THE ACTUAL SIZES AND THE ASSOCIATED COSTS FOR EACH GAUGE
*     THE COSTS ARE IN DOLLARS PER METRE
 18                                                                                      220
      11.00        0.17       19.00                                                      221
      12.00        0.17       17.07                                                      222
      16.00        0.20       15.91                                                      223
      18.00        0.23       21.25                                                      224
      25.00        0.26       21.53                                                      225
      37.00        0.35       17.16                                                      226
      50.00        0.41       23.01                                                      227
      75.00        0.60       21.84                                                      228
     100.00        0.77       15.40                                                      229
     150.00        1.07       18.62                                                      230
```

Table 6.4 Cost Data Used in Testing the Model (con'd)

200.00	1.39	15.18
300.00	2.02	17.18
400.00	2.63	22.04
600.00	3.89	23.86
900.00	5.84	18.94
1200.00	7.75	23.42
1500.00	9.23	17.59
1600.00	9.82	19.51
16		
6.00	0.15	19.88
11.00	0.20	15.49
12.00	0.21	19.28
16.00	0.25	21.85
18.00	0.26	16.61
25.00	0.32	18.19
37.00	0.42	20.57
50.00	0.54	22.65
75.00	0.79	17.78
100.00	1.00	16.40
150.00	1.45	15.19
200.00	1.89	15.29
300.00	2.83	23.34
400.00	3.78	22.12
600.00	5.63	18.89
900.00	8.44	19.49
16		
4.00	0.14	18.53
6.00	0.16	24.62
11.00	0.23	17.59
12.00	0.24	17.25
16.00	0.29	17.88
18.00	0.31	15.53
25.00	0.40	18.76
37.00	0.55	16.82
50.00	0.75	19.50
75.00	1.05	16.80
100.00	1.36	20.52
150.00	2.00	18.65
200.00	2.61	16.70
300.00	3.77	19.73
400.00	4.93	15.86
600.00	7.68	15.03
14		
4.00	0.20	17.95
6.00	0.25	19.50
11.00	0.37	15.62
12.00	0.39	24.58
16.00	0.48	19.16
18.00	0.51	23.53
25.00	0.71	16.70
37.00	1.04	15.63
50.00	1.38	22.95
75.00	1.96	21.15
100.00	2.57	22.05

Table 6.4 Cost Data USed in Testing the Model (con'd)

```
    150.00       3.78      22.55                                                   285
    200.00       4.91      23.60                                                   286
    300.00       7.22      20.05                                                   287
*      NUMBER OF SUBCLASSES WITHIN UNDERGROUND COAXIAL PLANT
000                                                                                288
*      NUMBER OF SUBCLASSES WITHIN AERIAL COAXIAL PLANT
000                                                                                289
*      NUMBER OF SUBCLASSES WITHIN BURIED COAXIAL PLANT
000                                                                                290
*      THE NUMBER OF DIFFERENT MANHOLES AVAILABLE
007                                                                                291
*      THE MANHOLE COST AND THE NUMBER OF MANHOLES WITH THAT COST
*      THE COSTS ARE IN DOLLARS PER MANHOLE
3300.          1                                                                   292
3450.          1                                                                   293
3250.          1                                                                   294
3600.          1                                                                   295
3800.          1                                                                   296
5500.          1                                                                   297
1350.          1                                                                   298
*      LOADING INTERVAL IN METERS
  1820                                                                             299
*      THE NUMBER OF DIFFERENT TYPE OF LOADING EQUIPMENT AVAILABLE IN EACH CLASS OF PLANT
*      FOLLOWED BY THE COSTS AND THE NUMBER OF COILS IN THAT CATEGORY
*      THE COSTS ARE IN DOLLARS PER LOADING SET.
  5                                                                                300
563.           1                                                                   301
1045.          1                                                                   302
1497.          1                                                                   303
1932.          1                                                                   304
4668.          1                                                                   305
  5                                                                                306
563.           1                                                                   307
1045.          1                                                                   308
1497.          1                                                                   309
1932.          1                                                                   310
4668.          1                                                                   311
  5                                                                                312
563.           1                                                                   313
1045.          1                                                                   314
1497.          1                                                                   315
1932.          1                                                                   316
4668.          1                                                                   317
  5                                                                                318
563.           1                                                                   319
1045.          1                                                                   320
1497.          1                                                                   321
1932.          1                                                                   322
4668.          1                                                                   323
  5                                                                                324
563.           1                                                                   325
1045.          1                                                                   326
1497.          1                                                                   327
1932.          1                                                                   328
```

Table 6.4 Cost Data Used in Testing the Model (con'd)

```
4668.            1                                                               329
  5                                                                              330
563.             1                                                               331
1045.            1                                                               332
1497.            1                                                               333
1932.            1                                                               334
4668.            1                                                               335
*     THE NUMBER OF DIFFERENT SIZES OF CONDUIT AVAILABLE
*     FOLLOWED BY THE MAXIMUM SIZE OF CABLE THE SIZE CAN ACCOMADATE
*     AND THE NUMBER OF DIFFERENT OF WAYS OF CONDUIT IN EACH SIZE
     3                                                                           336
   400      3                                                                    337
*     CONDUIT MATERIAL COSTS FOR THE DIFFERENT NUMBER OF WAYS
*     THE CONDUIT COSTS ARE IN DOLLARS PER METRE
  11.3283                                                                        338
  22.6566                                                                        339
  33.9849                                                                        340
  1000      3                                                                    341
  11.6726                                                                        342
  23.3452                                                                        343
  35.0178                                                                        344
  3600      3                                                                    345
  11.6910                                                                        346
  23.3820                                                                        347
  35.0730                                                                        348
*     POLE COST, POLE EQUIPMENT COST AND THE INTERVAL BETWEEN POLES IN METERS
 150.       20.       30.                                                        349
*     THE OVERHEAD LOADING PERCENTAGES
 17.        20.       5.        25.                                              350
*     THE TAX RATE, DEBT RATIO, INTEREST ON EQUITY, INTEREST ON DEBT AND THE RATE OF INFLATION
.08         .85       .15       .087      .07                                    351
*     THE EXPECTED LIFE OF PLANT
 30                                                                              352
*     THE PERCENTAGE DEPRECIATION RATES FOR EACH CATEGORY OF PLANT
9.14 4.24 9.14 6.73 6.73 4.22 2.13 4.22 9.14                                     353
*     THE SALVAGE FOR THE NINE CATEGORIES OF PLANT
 0.         0.0       0.        0.        0.                                     354
 0.         0.        0.        0.                                               355
*     TECHNOLOGY PARAMETERS AND THE ANNUAL FRACTIONAL INCREASE IN MAINTENENCE
 1.         25.75889  .2460576  .08                                              356
*     THE EXPECTED LIFE OF EXISTING PLANT BY CLASS OF PLANT
       20        20        20        20        20        20                      357
*     ESTIMATED SALVAGE FOR EXISTING PLANT AT THE END OF THE USEFUL LIFE BY CATEGORY
 0.         0.        0.        0.        0.                                     360
 0.         0.        0.        0.                                               361
*     THE FIRST YEAR'S MAINTENENCE COST BY CATEGORY AND VINTAGE
.001        1.50      .00076    .00003    .00005                                 362
.00045      .300      .00067    32.32                                            363
.0009       1.45      .00072    .000025   .000045                                364
.00040      .250      .00062    31.32                                            365
.0008       1.4       .00067    .00002    .00004                                 366
.00035      .200      .00057    30.32                                            367
.0007       1.35      .00062    .000015   .000035                                368
.0003       .150      .00052    29.32                                            369
.0006       1.3       .00057    .00001    .00003                                 370
.00025      .100      .00047    28.32                                            371
```

tested, the coaxial cables were omitted for simplicity. This was done by placing zeros on data cards numbered 288, 289 and 290, which refer to the number of sub-classes of plant (such as stalpeth cable, alpeth cable) available within underground, aerial and buried coaxial plant respectively.

A listing of the subroutine "COST" and a glossary of the variables used in the program can be found in Appendix D.

6.1.3 Command Data Set

The command data set (data set #2) contains the commands required to operate the optimization program,PNET in the master control unit. This data set contains the following cards in the order shown:

```
LUSOL   0
SKIP    0
SOLVE   1
REPORT  2
STOP
```

An explanation of the command parameters and a description of the use of these commands can be found in Appendix B.

6.1.4 Data Set for Intermediate Problem Update

The third data set is composed of a single card with a character representing the period being updated. This card is read in by the programs UPDATE1 and UPDATE2 in the master control unit and the character has to be changed when updating of a particular period is completed. When the first period is being updated, the first character in the 36-character array on the second card of data set #1 is used. The second character in the array is used to designate the second period, the third character for the third period and so on.

6.1.5 Input Data Required for the Output Conversion

The major source of data for the output conversion system is the master control unit, which supplies the output of the last iteration of the PNET and a description of the arcs from the last update performed. In addition to these data, details of the different types of plant available, the units of measurement for each type, the date on which the test was carried out and the name of the switching center area under study are supplied to the output conversion program directly from the data bank. These information, shown in Table 6.5, form data set #4 required for optimization purposes. In Table 6.5, a description of each line is given in parentheses to explain the significance of

Table 6.5 Input Data Required by the Output Conversion System

```
XYZ (NAME OF THE SWITCHING CENTER)
78:08:01 (DATE OF STUDY)
0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZ (LETTER CODES)
 4 (NUMBER OF PERIODS)
   3 (NUMBER OF CONDUIT SIZES)
   2   3   4 (THE CONDUIT SIZES)
   3  (NUMBER OF DIFFERENT WAYS OF CONDUIT)
   1   2   3 (THE DIFFERENT WAYS OF CONDUIT)
   2 (NUMBER OF SUBCLASSES OF PLANT)
STALPETH
ALPETH  (DESCRIPTION OF SUBCLASSES)
   4   (NUMBER OF GAUGES)
  26   24  22  19 (GAUGE SIZES)
  35   (NUMBER OF DIFFERENT SIZES OF CABLE)
   4   6  11  12  16  18  25  37  50  75 100 150 200 300 400 450 500 550 600 800
 900100011001200140015001600180021002400270028003000330003600 (THE CABLE SIZES)
 U/G PAIRED CABLE (TITLE OF ONE CLASS OF PLANT)
 CABLE      1
 CONDUIT    1
LINECONC    1 (DESCRIPTION AND UNITS OF MEASUREMENT OF THE TYPES OF PLANT)
 AERIAL PAIRED CABLE
 CABLE      1
  POLE      1
LINECONC    1
BURIED PAIRED CABLE
 CABLE      1
LINECONC    1
 U/G CO-AX CABLE
 CABLE      1
 CONDUIT    1
LINECONC    1
 AERIAL CO-AX CABLE
 CABLE      1
  POLE      1
LINECONC    1
BURIED CO-AX CABLE (THE SIXTH AND THE LAST CLASS OF PLANT)
 CABLE      1
LINECONC    1 (THE TYPES OF PLANT WITHIN THE LAST CLASS OF PLANT)
 1  (THE NUMBER OF TECHNOLOGIES EXPLICITLY CONSIDERED IN THE FIRST PEIOD)
 1
 1
 1  (THE NUMBER OF TECHNOLOGIES EXPLICITLY CONSIDERED IN THE LAST PERIOD)
U/G CABLE (THE FIRST CATEGORY OF PLANT- BASED ON CAPITAL BUDGETING REQUIREMENTS)
AERIAL CABLE
BURIED CABLE
U/G COAX CABLE
AER COAX CABLE
BUR COAX CABLE
U/G CONDUIT
POLES
LINE CONC. (THE LAST CATEGORY OF PLANT- FOR CAPITAL BUDGETING PURPOSES)
```

the input parameters. Hence those statements do not form a part of the data required.

The first card contains the name of the switching center under study, the total length of which should not exceed twenty letters. This card is followed by one containing the date the study was undertaken, occupying eight spaces. Three two digit numbers, the first representing the year, the second referring to the month and the third denoting the date of the study, separated by colons was used to indicate the date of testing. However, any other designation can also be used in its place. The next card contains the 36-character array of data set #1. The two cards must be identical because this string is used to decode the node names used at the time of input conversion. The fourth card contains the number of periods under consideration. The remaining cards in the data deck contain the different classes of plant considered and the types of plant within each category. They are arranged in the order shown in Table 6.5.

6.2 Test Procedure

This section summarizes the operation of the entire optimization model. The specific computer commands used to perform the different stages outlined below are shown in the Appendices.

The stages involved in the operational procedure are:

1) Run the input conversion program and the cost subroutine with data set #1 and the cost data to obtain the input in a format required by the program, PNET.

2) Use the output of stage (1) and the command data set to run the program, PNET and obtain an initial solution.

3) Deploy program CAPACITATE to introduce additional dummy arcs and update arcs representing utilized capacity.

4) Prepare data set #3 by setting the input character to that denoting the first period.

5) With the new output and data set #3 run program UPDATE1 to perform the primary update.

6) Perform the next iteration with program PNET using the new network.

7) Use program UPDATE2 and data set #3 to perform updating of the non-primary arcs. If no arcs require updating proceed to stage(8). Otherwise, return to stage (6).

8) Alter the character forming data set #3 to the one denoting the next period. If all the periods have been updated proceed to step (9). Otherwise return to stage (5).

9) Use data set #4 and the output of the last iteration of the PNET to activate the output conversion program and obtain the capital budget and construction plan.

Figure 6.2 is a simplified flow diagram of the optimization process. Stage (1) represents the input conversion, stage (9) the output conversion and the intervening stages the operation of the master control unit. All the programs, except the PNET, require the arc descriptions of the preceeding stage as part of the input.

6.3 Test Results and Inference

The goal of the optimization model as also that of the solution technique is to obtain a capital budget covering the short range and a construction program for the first period. Hence, the construction plan and the capital budget form the major portion of the output of the model. However, other information can also be obtained after each stage in the operation of the total optimization model. This information is discussed in Section 5.3.1.

6.3.1 Secondary Information

Optimization is carried out in a sequential manner with the output of one stage or operation forming the input for the succeding stage. This enables the user to examine the results of one iteration and make changes if required. The input conversion system, the program UPDATE1 and the program UPDATE2 supply information that is in a format readily usable by the optimization program. All these data have a

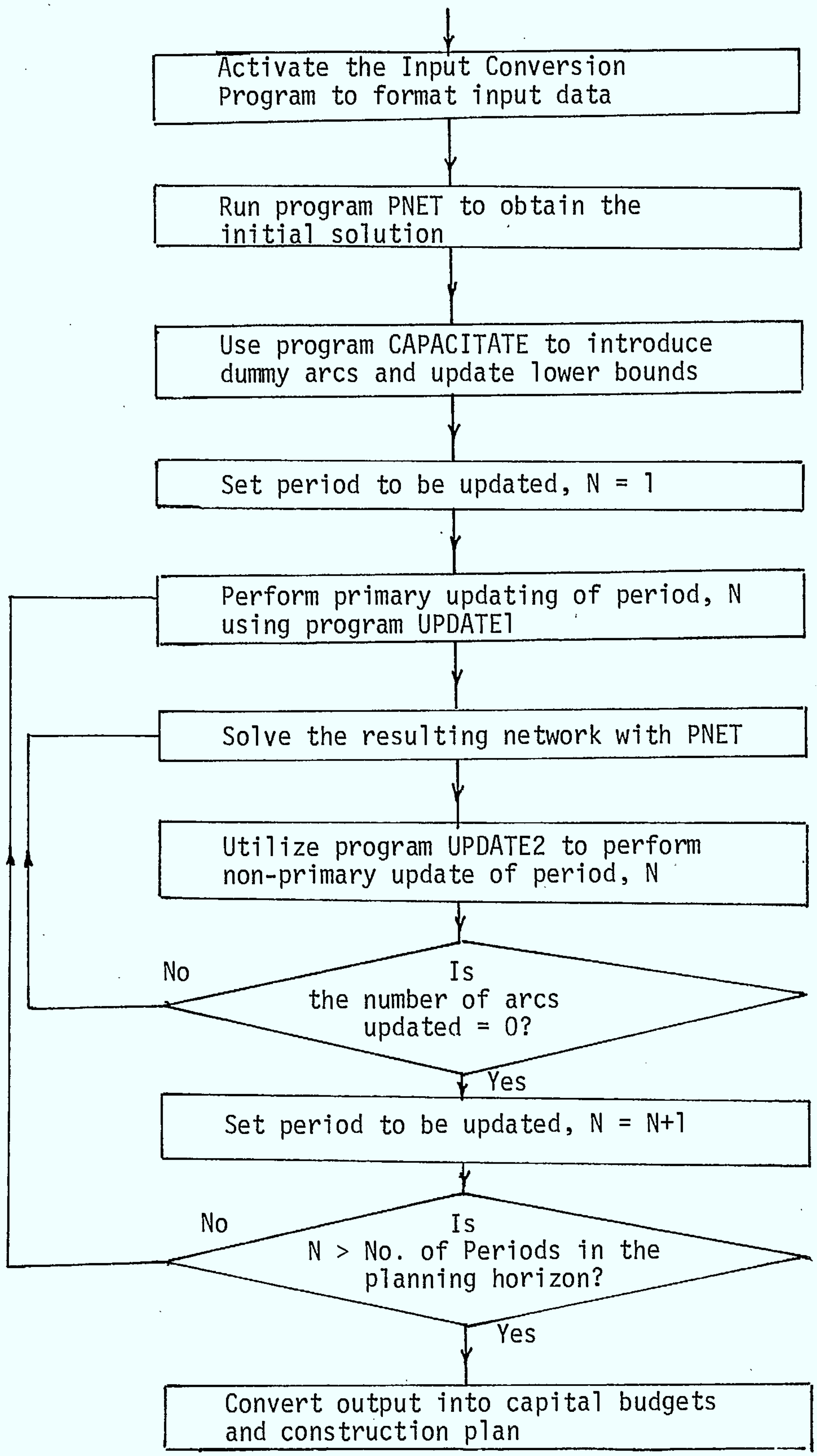


Figure 6.2 Flow Diagram of the Total Optimization Process

structure similar to the one shown in Table 6.6. The column titles have been introduced only to explain the significance of each column and are not part of the computer output. The arc descriptions laid out in computer code are also output by these programs and the program CAPACITATE. These give a brief description of the arc by specifying the arc code, distance, construction costs and the type of plant used. A simple program can be used to transform this information and output it, if required.

The output of each run of the program PNET is in the format shown in Table 6.7. Only a part of the output is shown here for simplicity. The output includes a log of all the commands supplied in data set #2, an indication of whether or not an optimal solution has been found, statistics relating to the number of arcs and nodes in the network and the value of the objective function which is the present equivalent cost of the total plant investment.

6.3.2 Capital Budget and Construction Plan

The capital budgets obtained from the test are shown in Tables 5.8 and 5.9. The first table gives details of the periodic budgets giving the total volume, unit construction cost and total estimated cost for each type of plant involved. Table 6.9 contains a summary of the capital investment for the switching center area, by period.

Table 6.6 Structure of the Input to the PNET program

```
BEGIN
SUBSCRIBER LOOP OPTIMIZATION
ARCS
        FROM        TO         UNIT       UPPER       LOWER
        NODE      NODE         COST       BOUND       BOUND


    00    00100001002           564        9400           0
    00    00100001002          3887       99999           0
    00    00100001003          1551        3600           0
    00    00100001003          4055       99999           0
    0000100200     002            0       99999           0
    000010021000 1002             0       99999           0
    0000100300     003            0       99999           0
    000010031000 1003             0       99999           0
    00    00200002005          2551        7200           0
    00    00200002005          4698       99999           0
    00    0020000200X          4934        1200           0
    00    0020000200X          4214       99999           0
    00    00200002011         17073        1000           0
    00    00200002011         29791       99999           0
    0000200500     005            0       99999           0
    000020051000 2005             0       99999           0
    0000200X00     00X            0       99999           0
    0000200X1000200X              0       99999           0
    0000201100     011            0       99999           0
    000020111000 2011             0       99999           0
    00    00300003004          2994        3600           0
    00    00300003004          4486       99999           0
    0000300400     004            0       99999           0
    000030041000 3004             0       99999           0
    00    0040000400C         14171       99999           0
    00    0040000400C           317       99999           0
    00    00400004016           303        1800           0
    00    00400004016           927       99999           0
    0000400C00     00C            0       99999           0
    0000400C1000400C              0       99999           0
    0000401600     016            0       99999           0
    000040161000 4016             0       99999           0
    00    00500005006          7489        2400           0
    00    00500005006          5254       99999           0
    00    00500005007          4272        2400           0
    00    00500005007          4531       99999           0
    00    00500005008           226        2400           0
    00    00500005008           888       99999           0
    0000500600     006            0       99999           0
END
```

Table 6.7 Structure of the Output of the PNET Program

```
*****   LUSOL    0

*****   SKIP     0

*****   REPORT   2

*****   SOLVE    1
1PROBLEM TITLE      SUBSCRIBER LOOP OPTIMIZATION

OPTIMAL SOLUTION

SOURCES=   830   SINKS=     0   TOTAL NODES=   830   ARCS=   2394

OBJ FCN=          530195968.   NO. ITER=   328
```

ARC NUMBER	FROM NODE	TO NODE	UNIT COST	UPPER BOUND	LOWER BOUND	FLOW	ARC COST	MARG COST
1	00 001	00001002	564	9400	9400	9400	5301600	20564
2	00 001	00001002	3887	99999	0	0	0	23887
3	00 001	00001003	1551	3600	3600	3600	5583600	21551
4	00 001	00001003	4055	99999	0	0	0	24055
5	00001002	00 002	0	99999	2161	9090	0	0
6	00001002	10001002	0	99999	0	310	0	0
7	00001003	00 003	0	99999	159	3220	0	0
8	00001003	10001003	0	99999	0	380	0	0
9	00 002	SINK	0	99999	0	590	0	0
10	00 002	00002005	2551	7200	7200	7200	18367200	2551
11	00 002	00002005	4698	99999	0	0	0	4698
12	00 002	0000200X	4934	1200	0	0	0	4934
13	00 002	0000200X	4232	300	300	300	1269600	4232
14	00 002	0000200X	14323	99999	0	0	0	14323
15	00 002	00002011	17073	1000	1000	1000	17073000	17073
16	00 002	00002011	29791	99999	0	0	0	29791
17	00002005	00 005	0	99999	1227	5766	0	0
18	00002005	10002005	0	99999	0	1434	0	0
19	0000200X	00 00X	0	99999	263	280	0	0
20	0000200X	1000200X	0	99999	0	20	0	0
21	00002011	00 011	0	99999	163	686	0	0
22	00002011	10002011	0	99999	0	314	0	0
23	00 003	SINK	0	99999	0	0	0	0
24	00 003	00003004	2994	3600	3600	3600	10778400	2994
25	00 003	00003004	4486	99999	0	0	0	4486
26	00003004	00 004	0	99999	159	3220	0	0
27	00003004	10003004	0	99999	0	380	0	0
28	00 004	SINK	0	99999	0	1420	0	0

Table 6.8 Capital Investment Budget for Switching Center XYZ

SWITCHING CENTER: XYZ DATE: 78:08:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 1 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	908.	1.52	1377.23
CABLE	18-26ALPETH	1	819.	1.54	1258.72
CABLE	37-26ALPETH	1	174.	1.74	302.42
CABLE	50-26ALPETH	1	118.	2.55	299.44
CABLE	100-26ALPETH	1	385.	2.71	1042.81
CABLE	150-26ALPETH	1	170.	2.12	361.23
CABLE	900-26ALPETH	1	325.	15.75	5117.28

Table 6.8 Capital Investment Budget for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ DATE: 78:08:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 2 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	943.	1.47	1384.94
CABLE	18-26ALPETH	1	95.	2.40	227.04
CABLE	50-26ALPETH	1	113.	2.61	295.83
CABLE	75-26ALPETH	1	118.	2.98	349.93
CABLE	100-26ALPETH	1	190.	2.72	517.65

Table 6.8 Capital Investment Budget for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ DATE: 78:08:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 3 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT	DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT	DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT	DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	721.	1.33	960.86

Table 6.8 Capital Investment Budget for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ DATE: 78:08:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 4 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	862.	1.85	1598.51
CABLE	18-26ALPETH	1	92.	2.56	236.47
CABLE	37-26ALPETH	1	104.	2.63	274.26
CABLE	50-26ALPETH	1	331.	2.08	689.40
CABLE	150-26ALPETH	1	91.	4.62	421.23
CABLE	400-26ALPETH	1	178.	7.96	1416.58
CABLE	600-26ALPETH	1	250.	12.18	3040.17

Table 6.9 Capital Investment Summary

SWITCHING CENTER: XYZ　　　　DATE: 78:08:01

SUBSCRIBER LOOP CAPITAL INVESTMENT SUMMARY

CLASS OF PLANT	1	2	3	4
U/G CABLE	0.0	0.0	0.0	0.0
AERIAL CABLE	0.0	0.0	0.0	0.0
BURIED CABLE	9759.12	2775.39	960.86	7676.61
U/G COAX CABLE	0.0	0.0	0.0	0.0
AER COAX CABLE	0.0	0.0	0.0	0.0
BUR COAX CABLE	0.0	0.0	0.0	0.0
U/G CONDUIT	0.0	0.0	0.0	0.0
POLES	0.0	0.0	0.0	0.0
LINE CONC.	0.0	0.0	0.0	0.0

Table 5.10 Switching Center Capacities (in number of lines)

SWITCHING CENTER: XYZ　　　　DATE: 78:08:01

SWITCHING CENTER CAPACITIES
(BY TYPE OF TECHNOLOGY)

	1	2	3
PERIOD 1	13000		
PERIOD 2	0		
PERIOD 3	0		
PERIOD 4	0		

Tables 5.10 and 5.11 show the switching center capacity for each period and the construction plan respectively.

6.3.3 Conclusions

The test conducted on the optimization model revealed that the model can be applied to planning of plant investment in subscriber loops of telecommunications carrier industry. In designing the test problem, attempts were made to simulate situations parallel to those encountered in the real world.

Computer times required for compiling and execution of the programs on an Amdahl 470V/6 computer are tabulated in Table 6.12. The number of nodes in the test network was 830, while the number of arcs varied from around 1900 for the initial run to about 2400 for the final iteration. The computer time required for optimization increases significantly with the number of nodes involved. Therefore, every effort must be made to eliminate nodes that are not critical. Considerable judgement must be exercised at the time the data are prepared in reducing the number of nodes to a minimum. For example, in areas where only one possible route exists, the series of arcs that forms the route can be replaced by a single arc with a cost equivalent to that of the entire route. The cost of running the test

Table 6.11 Construction Plan Summary for Switching Center XYZ

SWITCHING CENTER: XYZ DATE: 78:08:01

CONSTRUCTION PLAN SUMMARY
(SUBSCRIBER LOOP PLANT)

FROM NODE	TO NODE	CAPACITY ADDITIONS	INSTALLED CAPACITY	UTILIZED CAPACITY	PLANT CLASS	CABLE TYPE
1	2	0	9400	3526	1	
1	3	0	3600	564	1	
2	5	0	7200	2636	1	
2	33	0	1200	413	1	
2	37	0	1000	477	1	
3	4	0	3600	564	1	
4	12	25	25	25	3	26-ALPETH
4	42	0	1800	197	3	
5	6	0	2400	7	1	
5	7	0	2400	1004	1	
5	8	0	2400	1570	3	
6	54	11	11	7	3	26-ALPETH
7	27	0	600	496	3	
7	63	600	600	435	3	26-ALPETH
8	21	0	1200	301	3	
8	9	0	1200	933	3	
9	10	0	200	33	3	
9	13	0	600	599	3	
10	11	0	100	6	3	
13	14	0	50	36	3	
13	16	0	800	400	3	
14	15	0	25	15	3	
16	17	0	300	275	3	
17	18	0	250	250	3	
18	19	0	225	215	3	
19	20	0	200	100	3	
21	22	0	600	264	3	
22	23	0	50	33	3	
22	25	0	300	190	3	
23	24	0	25	10	3	
25	26	0	200	15	3	
27	28	0	600	420	3	

Table 6.11 Construction Plan Summary for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ　　　　DATE: 78:08:01

CONSTRUCTION PLAN SUMMARY
(SUBSCRIBER LOOP PLANT)

FROM NODE	TO NODE	CAPACITY ADDITIONS	INSTALLED CAPACITY	UTILIZED CAPACITY	PLANT CLASS	CABLE TYPE
27	58	37	37	31	3	26-ALPETH
27	31	11	11	10	3	26-ALPETH
28	29	0	200	160	3	
28	32	0	400	50	3	
29	30	0	150	89	3	
30	55	100	100	0	3	26-ALPETH
33	34	0	600	107	2	
33	35	0	600	96	2	
34	53	75	75	17	3	26-ALPETH
35	36	0	200	25	2	
37	38	0	600	422	3	
38	39	0	400	331	3	
39	40	0	300	206	3	
39	51	16	16	16	3	26-ALPETH
40	41	0	200	25	3	
42	43	0	100	85	3	
42	46	0	75	66	3	
43	44	0	75	56	3	
44	45	0	50	30	3	
45	49	16	16	15	3	26-ALPETH
46	47	0	50	25	3	
46	48	0	11	6	3	
48	49	11	11	0	3	26-ALPETH
51	50	11	11	6	3	26-ALPETH
55	54	75	75	33	3	26-ALPETH
56	57	11	11	10	3	26-ALPETH
58	56	16	16	16	3	26-ALPETH
58	59	11	11	5	3	26-ALPETH
62	60	16	16	0	3	26-ALPETH
63	61	16	16	15	3	26-ALPETH
63	62	600	600	15	3	26-ALPETH

Table 6.12 Computer Time Statistics for the Test Run

Number of Nodes in the Network = 830

Average Number of Arcs = 2132

Number of Periods = 4

Program	Compilation Time (sec.)	Average Execution Time (sec.)	Number of Runs
Cost Model	3.215	.....	9
Input Conversion	1.107	4.441	1
PNET	3.679	10.987	5
CAPACITATE	0.437	7.919	1
UPDATE1	0.463	8.335	4
UPDATE2	0.498	8.500	4
Output Conversion	1.665	5.349	1

problem was around $100. The cost to test a switching center area would vary depending on the number of actual nodes in the physical network. This cost should not exceed $1000, but it will vary depending on the ingenuity of the analyst.

Since optimization of outside plant is done every year, detailed yearly plans for the time beyond the short range are not useful. So, one period, representing the time between the end of the short range forecast and the time when a switching center attains full capacity is sufficient for optimization purposes. The test revealed that the economic interval for plant additions in the test problem was at least three years. Since the data used in the test run yielded erroneous forecasts beyond a three year short range, the exact length of the economic interval could not be determined. In a practical situation, it is important to obtain a rough estimate of the economic interval and to have a short range forecast period that is longer than this interval.

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APPENDIX-A THE INPUT CONVERSION PROGRAM

The computer program that performs the functions of the input conversion system is discussed in this chapter. The main function of the program is to codify the input data so that it can be used by the optimization program, PNET. A main routine and a function subprogram, "NAME", comprise the input conversion program. The function "NAME" is used to substitute an alphanumeric code to represent the node names. The input data format and the operation of the program are discussed following a glossary of the variables used in the program. The last part of the appendix contains a listing of the program.

A.1 Variables Used in the Input Conversion Routines

ARCODE(I) A variable used to define the type of existing plant or the type of plant that can be installed in the arc, I. It is a four digit numerical code with digits, IE, IT, IC, and IS, where,

IE=1 for existing plant, and,
  =2 for new plant,
IT represents the type of technology used/permitted,
IC=1 refers to U/G cable,
  =2 refers to aerial cable, and
  =3 refers to buried cable,
  =4 indicates that types 1&2 are permitted,
  =5 indicates that types 1&3 are permitted,
  =6 indicates that types 2&3 are permitted,

and,

=7 means that there are no constraints on the type of plant to be used, and,

IS=1 refers to paired cable,

=2 refers to coaxial cable, and

=3 indicates that either is allowed.

CODARC(J) A code used to refer to the size and type of plant used in an arc. This variable is evaluated inside the cost sub-routine and is stored as part of the arc description for use in later stages. This is an eight digit code which has three parts; the first containing one digit, the second with three digits and the third with four digits. Part one contains the class of plant code,ITYPE, explained below. Part two contains the number of poles if the class of plant is aerial, while for underground plant, it contains the size and number of ways of conduit used. In the case of buried plant this has a value zero. The third part contains a description of the cable used; one digit for the major category under which the cable falls (1 for stalpeth and 2 for alpeth), one digit for the gauge (1 for 26 gauge, 2 for 24 gauge and so on), and two digits for the size of cable (01 for 11 pair, 02 for 25 pair and so on).

CODBEG(I) Refers to the type of plant that the beginning

node of the arc,I represents. It is a one character code with:
"S" representing a switching center,
"M" representing a manhole, and
"T" representing an access terminal.

CODE(K)	An array of length three elements in function "NAME". It is used to form the character string representing the code for a node.
CODEND(I)	A code used to represent the type of plant represented by the ending node of the arc,I. The codes used are the same as those for CODBEG.
COIL(I)	A variable which is equal to the number of line concentrator sets used in an arc. It is evaluated inside the cost routine.
DEMAND(I,J)	A variable used to represent the demand at the demand point,I, for the period,J.
DIST(I)	A variable that denotes the length of cable required for the arc,I.
GAUGE(I)	Stands for the airline distance of the beginning node of the arc,I, from the switching center.
GEOG(I)	A three digit integer describing the geographic condition of the arc,I. The digits have a value between zero and five. "1" denotes soft soil, "2" a hard area, "3" ravine and uneven surface , "4" a paved area and "5" a swamp. If three conditions occur simultaneously the code has no zeros. If less than three conditions are

	prevelent, the code has dummy zero(s) as its last digit(s).
IA	A DO-index used as the counter for the arcs.
ICAP1	An integer referring to the lowest capacity an arc is designed for.
ICAP2	An integer referring to the upper limit on the capacity of an arc.
II(K)	A variable used in function NAME to store the residuals on successive division by 36.
INSTAL(I)	An integer representing the installed capacity in the arc,I.
IP	A DO-index representing the period.
IT	A DO-index representing the type of technology.
ITMAX	A DO-parameter limiting the value of IT to the number of technologies in a particular period.
ITYPE	Denotes the type of plant used in the arc. The number codes used for describing an arc are: 1=underground paired cable, 2=aerial paired cable, 3=buried paired cable, 4=underground coaxial cable, 5=aerial coaxial cable, and 6=buried coaxial cable.
JTYPE1	An integer used in finding ITYPE. It has a value equal to "IC" in ARCODE.
JTYPE2	An integer used in finding ITYPE. It has a value equal to "IS" in ARCODE.

KDEM A counter for the number of demand points.

KINT A counter for the number of intermediate nodes created.

KODBEG The three character alphanumeric code for the beginning node of an arc.

KODE A three digit code used to describe an arc. The different types of arcs and the corresponding digits of CODE are:

SINK-SOURCE	0,0,0
SOURCE-XM I (SWITCHING CENTER)	1,0,0
SOURCE-XM I (OTHER NODES)	0,0,0
XM I-XMIJ (EXISTING PLANT)	2,1,ITYPE
XM I-XMIJ (PRIMARY)	2,2,ITYPE
XM I-XMIJ (NON-PRIMARY)	2,3,ITYPE

(If XM I represents a switching center "6" is used in place of "2" as the first digit)

XM I-SINK	0,0,0
XM I-X I (DEMAND POINT)	0,0,0
XMIJ-XM J	3,0,0
XMIJ-YMIJ	4,0,0
XMIJ-SINK	4,0,0
X I-SINK	5,0,0

KODEND Alphanumerical equivalent for the ending node of an arc.

LETTER(I) An array initially used to read in and write the problem title. The array is then used in the function "NAME" to develop codes for the nodes.

This array is common to both the routines.

LINES(I)	A variable representing the number of 100 pair cables that can be installed in the arc,I with the existing facilities such as poles or conduits.
MAXARC	Used to denote the number of arcs in the physical network.
NAME	The function which returns the alphanumeric codes for a node when the original number is supplied.
NBEG(I)	The number of the beginning node of the arc,I supplied from the data bank.
NCALL	A counter which keeps track of the number of times the cost routine is called.
NEND(I)	The numerical code for the ending node of the arc,I supplied by the data bank.
NPER	The number of periods in the planning horizon.
NTECH(I)	Stands for the number of technologies explicitly considered in the period,I.
UNCOST(I,J)	A 2x3 matrix containing the construction costs for the arc under three categories; cost of loading, cost of conduiting/poles and cost of cabling.

A description of the variables used within the cost routine is given in Appendix D.

A.2 Input Data Format

The sequence in which the data deck is to be arranged and the field occupied by the different variables on a computer card/line are explained below:

CARD NO.	DATA	COLUMN NOS.
1	PROBLEM TITLE	1-80
2	36-CHARCTERS OF LETTER	1-36
3	NPER	1- 2
4	NTECH(I)	1- 2, 3- 4,etc
5-N	ARC DATA CARDS	
	a) Physical Arcs	
	NBEG(I)	1-8
	CODBEG(I)	9
	NEND(I)	11-18
	CODEND(I)	19
	ARCODE(I)	21-24
	INSTAL(I)	26-30
	GEOG(I)	46-48
	DIST(I)	51-60
	GAUGE(I)	61-70
	LINES(I)	76-80
	b) Demand Points	
	NBEG(I)	1- 8
	CODBEG(I)	9
	NEND(I) (=0)	11-18
	CODEND(I) (=0)	19

followed by another card with,

DEMAND(I,1)	1-5
DEMAND(I,2)	5-6
.	.
.	.
DEMAND(I,NPER)	.

A.3 Operational Procedure

Three logical units are required by the input conversion programs. They are:

5 = input data file,

6 = output data file on which the input to PNET is printed,

8 = output data file on which arc descriptions are stored for use in the succeeding stages.

In addition, the cost model requires certain data files through which cost data can be supplied.

It should be noted here that any cost routine can be adopted by removing the COMMON blocks (lines 38 through 44 of the program) and replacing the calling statements by the appropriate statements. However, the cost model used must be capable of calculating the variables CODARC,COIL,UNCOST,ICAP1 and ICAP2.

The program also utilizes a subroutine "SWCOST" to calculate the switching cost per line. Since this study was concerned with subscriber loop plant, a switching cost of

$200/line was supplied using the subprogram "SWCOST", given at the end of Table A.1. This subroutine has to be replaced with a routine that calculates switching costs when the model is used in practice.

Suppose that the cost routine,"COST", is used and that it requires two data files, one on each logical unit one and two. Then, the input conversion program can be used by specifying the following commands:

```
$run *FORTG scards=input conversion program+cost
$run -load# 1=costdata1 2=costdata2 5=inputdata 6=output1
                                                8=output2
```

The program can also be compiled and run on WATFIV and IF compilers.

A.4 Listing of the Program

The following pages contain a listing of the input conversion programs.

Table A.1 Input Conversion Program

```
C ***************  INPUT CONVERSION PROGRAM  ***************
C
C THIS PROGRAM PERFORMS THE FUNCTIONS OF THE INPUT
C CONVERSION SYSTEM.
C IT TRANSFORMS THE DATA IN THE DATA BANK OF A
C TELECOMMUNICATIONS CARRIER INDUSTRY INTO THE FORMAT
C REQUIRED FOR THE OPERATION OF THE PROGRAM "PNET".
C
C DECLARE ARRAYS FOR THE VARIABLES DEFINING THE ARC
C CONDITIONS.
C
      INTEGER NBEG(200),NEND(200),ARCODE(200),
     1INSTAL(200),GEOG(200),DEMAND(100,10),
     2LINES(200),CODARC(2),
     3NTECH(10),SC/'S'/,KODBEG,KODEND,
     4CODEND(200),CODBEG(200)
C
      REAL DIST(200),GAUGE(200),UNCOST(2,3),COIL(2)
C
C DECLARE THE ARRAY FOR THE LETTER CODES USED
C
      LOGICAL*1 LETTER(80)
C
C DECLARE ARRAYS FOR THE VARIABLES REQUIRED BY THE COST
C MODEL.
C
C
      INTEGER  LIMIT(5),GSIZE(5),NNEX(6),PAIRS(35)
C
      REAL DFACTO(7,4),SIZE(6,2,4,40),VO(9),VNNEX(9),
     1LCCOST(6),PERSAL(9),DLCOST(8),LSUM(6),
     2MSUM(6),CONCOS(5,6),INTCPT(6,3,5),SLOPE(6,3,5),
     3EQUIPM(6,2,4,40),OPCOST(5,9),PMC(5),CTF(5,9),
     4SPEC(6,2,10),IAF(5),TINDEX(5),PPEF(5),PEF(5),TIME(5),
     5MHCOST
C
C COMMON BLOCK /Z/ CONTAINS LETTER CODES
C
      COMMON /Z/LETTER
C
C PLACE THE COST MODEL VARIABLES IN THE COMMON BLOCKS
C
      COMMON  /A/DFACTO/B/PARAFO,PARA,PARK/C/NSIZE,SIZE
     1/D/VO,VNNEX/E/CODARC,COIL,UNCOST/G/LCINT,POLDIS
     2/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,NCSIZE,
     3LIMIT,CONCOS,MHCOST,INTCPT,SLOPE,EQUIPM,POLCOS,
     4NGAUGE,GSIZE/J/OPCOST,GFMAIN,NNEX,PMC,IAF/K/CTF
     5//NCALL,NUMDIS,SPEC,TT,TINDEX,PPEF,PEF,NPER,TIME
     6/L/PAIRS
```

```
C
C READ IN THE PROBLEM TITLE AND OUTPUT
C
      READ(5,100) (LETTER(I),I=1,80)
100   FORMAT(80A1)
      WRITE(6,200) (LETTER(I),I=1,80)
200   FORMAT('BEGIN',/,80A1,/,'ARCS')
C
C READ IN THE LETTER CODES,NUMBER OF PERIODS AND
C THE NUMBER OF TECHNOLOGIES IN EACH PERIOD
C
      READ(5,100) (LETTER(I),I=1,36)
      READ(5,300) NPER
300   FORMAT(10I2)
      READ(5,300) (NTECH(I),I=1,NPER)
C
C INITIALIZE THE COUNT
C
      K=0
      NCALL=0
      ZERO=0.0
      IZERO=0
      INF=99999
C
C READ THE ARC DATA
C
      DO 1 I=1,1000
      READ(5,400,END=2) NBEG(I),CODBEG(I),NEND(I),CODEND(I),
     1ARCODE(I),INSTAL(I),GEOG(I),DIST(I),GAUGE(I),LINES(I)
C
C CHECK IF THE ARC REPRESENTS A DEMAND POINT
C
      IF(NBEG(I).EQ.0) GO TO 2
      IF(NEND(I).NE.0) GO TO 1
      K=K+1
      READ(5,500) (DEMAND(K,J),J=1,NPER)
1     CONTINUE
400   FORMAT(2(I8,A1,1X),I4,1X,I5,15X,I3,2X,2F10.2,5X,I5)
500   FORMAT(15I5)
C
C SET VARIBLE MAXARC EQUAL TO THE TOTAL NUMBER OF ARCS
C IN THE NETWORK
C
      I=1001
2     MAXARC=I-1
C
C COMMENCE FORMATTING THE OUTPUT
C ONE COMPLETE NETWORK FOR EACH TECHNOLOGY IN
C THE DIFFERENT PERIODS
C
      DO 6 IP=1,NPER
      ITMAX=NTECH(IP)
      DO 5 IT=1,ITMAX
C
```

```
C INITIALIZE THE COUNTS
C
      INTER=0
      JDEM=0
      KDEM=0
      KINT=0
      DO 23 IA=1,MAXARC
C
C CHECK WHETHER THE PRESENT AND THE PREVIOUS ARCS HAVE THE
C SAME BEGINNING NODE.
C IF THEY EMANATE FROM DIFFERENT NODES, CREATE INTERMEDIATE
C NODES BEFORE FORMATTING THE NEW ARC.
C
      IF(IA.EQ.1) GO TO 3
      IF(NBEG(IA).EQ.NBEG(IA-1)) GO TO 3
7     KINT=KINT+1
C
C CREATE DUMMY ARCS TO SINK FOR ANY DEMAND POINT LEFT
C
      IF(JDEM.EQ.0) GO TO 26
      KODBEG=NAME(NBEG(JDEM))
      KODEND=NAME(NEND(JDEM))
      WRITE(6,800) LETTER(IP),KODBEG,IZERO,INF,
     1DEMAND(KDEM,IP)
800   FORMAT(4X,A1,4X,A3,4X,'SINK',3I10)
      KODE=500
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
      JDEM=0
26    IF(NEND(KINT).EQ.0) GO TO 8
C
C CREATE INTERMEDIATE TO FINAL AND INTERMEDIATE TO NEXT
C PERIODS INTERMEDIATE ARC.
C ALSO STORE ARC DETAILS FOR FUTURE USE.
C
      KODBEG=NAME(NBEG(KINT))
      KODEND=NAME(NEND(KINT))
      WRITE(6,600) LETTER(IP),LETTER(IT),KODBEG,
     1KODEND,LETTER(IP),LETTER(IT),KODEND,
     2IZERO,INF,IZERO
600   FORMAT(4X,2A1,2A3,2A1,3X,A3,3I10)
      KODE=300
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
      IF(IP.EQ.NPER) GO TO 19
      WRITE(6,1100) LETTER(IP),LETTER(IT),KODBEG,KODEND,
     1LETTER(IP+1),LETTER(IT),KODBEG,KODEND,IZERO,INF,IZERO
      KODE=400
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
      GO TO 8
19    WRITE(6,1400) LETTER(IP),LETTER(IT),KODBEG,KODEND,
     1IZERO,INF,IZERO
1400  FORMAT(4X,2A1,2A3,4X,'SINK',3I10)
```

```
1100  FORMAT(4X,2(2A1,2A3),3I10)
      KODE=400
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
C
C CHECK IF INTERMEDIATE NODES HAVE BEEN CREATED FOR ALL THE
C PREVIOUS ARCS.
C
8     IF(KINT.LT.(IA-1)) GO TO 7
      IF(INTER.EQ.1) GO TO 4
C
C IF THE ARC DOES NOT REPRESENT A DEMAND POINT SKIP
C THE FOLLOWING SECTION
C
3     IF(NEND(IA).NE.0) GO TO 9
      KDEM=KDEM+1
      KODBEG=NAME(NBEG(IA))
      WRITE(6,700) LETTER(IP),LETTER(IT),KODBEG,LETTER(IP),
     1KODBEG,IZERO,INF,IZERO
      KODE=0
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
700   FORMAT(4X,2A1,3X,A3,A1,4X,A3,3I10)
      IF(IT.GT.1) GO TO 4
      IF(IA.EQ.MAXARC) GO TO 25
      IF(NBEG(IA).NE.NBEG(IA+1)) GO TO 25
      JDEM=IA
      GO TO 4
25    WRITE(6,800) LETTER(IP),KODBEG,IZERO,INF,
     1DEMAND(KDEM,IP)
      KODE=500
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
      GO TO 4
C
C INSERT ONE ARC FOR EACH TYPE OF PLANT ALLOWED IN
C THE AREA.
C
9     KODBEG=NAME(NBEG(IA))
      KODEND=NAME(NEND(IA))
      ICAP1=0
      ICAP2=0
      JTYPE1=MOD(ARCODE(IA),100)/10
      JTYPE2=MOD(ARCODE(IA),10)
      JTYPE3=200
      IF(CODBEG(IA).EQ.SC) JTYPE3=600
      IF((ARCODE(IA)/1000).NE.1) GO TO 13
      IF(IP.NE.1) GO TO 13
      IF((MOD(ARCODE(IA),1000))/100.NE.IT) GO TO 13
      ITYPE=JTYPE1+3*(JTYPE2-1)
      CALL COST(GEOG(IA),DIST(IA),ITYPE,INSTAL(IA),
     1INSTAL(IA),0,GAUGE(IA),LINES(IA),IT,ICOST)
      WRITE(6,1000) LETTER(IP),LETTER(IT),KODBEG,LETTER(IP),
     1LETTER(IT),KODBEG,KODEND,ICOST,INSTAL(IA),IZERO
```

```
      KODE=JTYPE3+10+ITYPE
      WRITE(8)KODE,COIL(1),CODARC(1),(UNCOST(1,J),J=1,3),
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
13    IF(JTYPE1.GT.3) GO TO 11
      ITYPE=JTYPE1+3*(JTYPE2-1)
      CALL COST(GEOG(IA),DIST(IA),ITYPE,ICAP1,ICAP2,IP,
     1GAUGE(IA),LINES(IA),IT,ICOST)
      WRITE(6,1000) LETTER(IP),LETTER(IT),KODBEG,LETTER(IP),
     1LETTER(IT),KODBEG,KODEND,ICOST,INF,IZERO
1000  FORMAT(4X,2A1,3X,A3,2A1,2A3,3I10)
      KODE=JTYPE3+20+ITYPE
      WRITE(8)KODE,COIL(1),CODARC(1),(UNCOST(1,J),J=1,3),
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
      GO TO 4
11    IF(JTYPE1.EQ.6) GO TO 14
      ITYPE=1+3*(JTYPE2-1)
      CALL COST(GEOG(IA),DIST(IA),ITYPE,ICAP1,ICAP2,IP,
     1GAUGE(IA),LINES(IA),IT,ICOST)
      WRITE(6,1000) LETTER(IP),LETTER(IT),KODBEG,LETTER(IP),
     1LETTER(IT),KODBEG,KODEND,ICOST,INF,IZERO
      KODE=JTYPE3+20+ITYPE
      WRITE(8)KODE,COIL(1),CODARC(1),(UNCOST(1,J),J=1,3),
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
14    IF(JTYPE1.EQ.5) GO TO 15
      ITYPE=2+3*(JTYPE2-1)
      CALL COST(GEOG(IA),DIST(IA),ITYPE,ICAP1,ICAP2,IP,
     1GAUGE(IA),LINES(IA),IT,ICOST)
      WRITE(6,1000) LETTER(IP),LETTER(IT),KODBEG,LETTER(IP),
     1LETTER(IT),KODBEG,KODEND,ICOST,INF,IZERO
      KODE=JTYPE3+20+ITYPE
      WRITE(8)KODE,COIL(1),CODARC(1),(UNCOST(1,J),J=1,3),
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
15    IF(JTYPE1.EQ.4) GO TO 4
      ITYPE=3+3*(JTYPE2-1)
      CALL COST(GEOG(IA),DIST(IA),ITYPE,ICAP1,ICAP2,IP,
     1GAUGE(IA),LINES(IA),IT,ICOST)
      WRITE(6,1000) LETTER(IP),LETTER(IT),KODBEG,LETTER(IP),
     1LETTER(IT),KODBEG,KODEND,ICOST,INF,IZERO
      KODE=JTYPE3+20+ITYPE
      WRITE(8)KODE,COIL(1),CODARC(1),(UNCOST(1,J),J=1,3),
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
C
C IF ALL ARCS HAVE BEEN CONSIDERED GO ON TO THE
C NEXT PERIOD.
C
4     IF(IA.NE.MAXARC) GO TO 23
      IF(KINT.EQ.MAXARC) GO TO 23
      INTER=1
      GO TO 7
23     CONTINUE
5     CONTINUE
6     CONTINUE
C
C CREATE A DUMMY ARC CONNECTING THE SINK TO THE SOURCE
```

```
C THIS ARC COMPLETES THE FLOW CYCLE.
C
      WRITE(6,1300) IZERO,INF,IZERO
      IP=1
      IT=1
      KODE=0
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(1),DIST(1),IP,GAUGE(1),LINES(1),IT
1300  FORMAT(8X,'SINK',2X,'SOURCE',3I10)
C
C CREATE ARCS CONNECTING THE SOURCE TO THE SWITCHING CENTER
C
      DO 17 IA=1,MAXARC
      IF(CODBEG(IA).NE.SC) GO TO 17
      IF(IA.EQ.1) GO TO 16
      IF(NBEG(IA).EQ.NBEG(IA-1)) GO TO 17
16    DO 18 IP=1,NPER
      ITMAX=NTECH(IP)
      DO 18 IT=1,ITMAX
      CALL SWCOST(IP,IT,ICOST)
      KODBEG=NAME(NBEG(IA))
      WRITE(6,1200) LETTER(IP),LETTER(IT),KODBEG,ICOST,
     1INF,IZERO
1200  FORMAT(6X,'SOURCE',2A1,3X,A3,3I10)
      KODE=100
      WRITE(8)KODE,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG(IA),DIST(IA),IP,GAUGE(IA),LINES(IA),IT
18    CONTINUE
17    CONTINUE
      WRITE(6,1500)
1500  FORMAT('END')
      STOP
      END
C
C  *****************  FUNCTION NAME  ***************
C
C THIS FUNCTION IS USED TO CONVERT THE NUMBER CODES INTO
C A THREE CHARACTER ALPHANUMERIC CODE.
C
      FUNCTION NAME(I)
      INTEGER II(3)
      INTEGER NAME,NEW
      LOGICAL*1 CODE(3),LETTER(80)
      COMMON /Z/LETTER
      EQUIVALENCE (NEW,CODE)
      J=I
C
C CONVERSION BEGINS
C FIND THE RESIDUALS AFTER DIVIDING BY 36.
C
      DO 1 K=1,3
      KK=4-K
      II(KK)=J+1
      IF(J.LE.1) GO TO 3
```

```
      II(KK)=MOD(J,36)+1
3     J=J/36
1     CONTINUE
C
C FIND THE LETTER CODE THAT CORRESPONDS TO EACH RESIDUAL
C AND FORM THE CHARACTER STRING TO REPRESENT THE ARC.
C
      DO 2 K=1,3
2     CODE(K)=LETTER(II(K))
      NAME=NEW
      RETURN
      END
C
C *************** SUBROUTINE SWCOST **************
C
C THIS SUBROUTINE, USED TO CALCULATE SWITCHING COSTS
C RETURNS A VALUE OF $200 FOR THE SWITCHING COST PER LINE.
C THIS ROUTINE HAS TO BE REPLACED WITH A SUBROUTINE
C THAT CALCULATES THE CORRECT SWITCHING COST WHEN THE
C SWITCHING CENTER PLANT IS ALSO STUDIED.
C
      SUBROUTINE SWCOST(IP,IT,ICOST)
      ICOST=20000
      RETURN
      END
```

APPENDIX-B NOTES ON THE MASTER CONTROL UNIT

The master control unit of the optimization model for planning of subscriber loop facilities in a telecommunications industry contains the optimization program PNET, the command program that controls it, and programs CAPACITATE, UPDATE1 and UPDATE2. The command program is used to control the functioning of the PNET program. The program CAPACITATE introduces dummy arcs necessary for balancing the arc flows and places lower bounds on the arcs that connect an intermediate node to an ending node. Programs UPDATE1 and UPDATE2 are used to perform the primary and non-primary updates, respectively, on the arcs representing a particular period.

B.1 Glossary of the Variables Used in the Programs CAPACITATE, UPDATE1 and UPDATE2

A(J) — An array used to read the first few lines of PNET output in the programs CAPACITATE, UPDATE1 and UPDATE2. This array is used to signal the beginning of the actual arc descriptions.

ARCODE — A three letter code used in the programs CAPACITATE, UPDATE1 and UPDATE2 to describe an arc. This code is the same as "KODE" in the input conversion program.

BEGNOD(J) — A 16-element array used in CAPACITATE to form the eight letter code that represents the beginning node of the arc considered.

BLANK — An alphanumeric variable which is equivalent to three blank spaces. It is used in all the three programs.

CODARC	A variable used in the program CAPACITATE to describe the type of plant that is utilized in an arc. It has the same function as that of CODARC(I) in the input conversion program.
CODARC(I)	Used in UPDATE1 and UPDATE2 to define the type of plant used in an arc. It serves the same purpose as CODARC in CAPACITATE. An array is required because two different values for CODARC have to be stored when the COST subroutine is evaluating two alternative arcs.
COIL	A variable used in CAPACITATE to denote the number of loading sets used in an arc.
COIL(I)	Serves the same purpose in UPDATE1 and UPDATE2 as COIL in CAPACITATE.
COST	An integer in program CAPACITATE which represents the unit cost for the arc considered.
DIST	Used in all the three programs to describe the length of cable required for an arc.
DUMMY	A dummy variable used in all the programs to read some dummy numbers when lines need to be skipped on the input file.
EMPTY	A parameter equal to a blank space in CAPACITATE.
FLOW	Represents the flow in the arc considered. It is used by all the three programs.

GAUGE	Used in CAPACITATE, UPDATE1 and UPDATE2 to represent the airline distance of the beginning node of the arc considered from the switching center.
GEOG	A code used in all the three programs to represent the geographic terrain of the arc considered.
IARC	Signifies the arc number in all the three programs.
ICAP1	The lowest capacity for which an arc is designed in programs UPDATE1 and UPDATE2.
ICAP2	The maximum capacity for which an arc is designed in programs UPDATE1 and UPDATE2.
ICOST	The value of the unit cost that is computed and returned by the COST subroutine to the programs UPDATE1 and UPDATE2.
INODE(J)	Used in CAPACITATE to find the code for the beginnning node of the arc considered.
IP	Denotes the period an arc represents. It is used in all three routines.
IT	Denotes the type of technology an arc represents. This variable is used in all three programs.
ITYPE	An integer code in UPDATE1 and UPDATE2 representing the class of plant the arc represents. The codes are the same as those used for ITYPE in the input conversion program.

JNODE	An eight digit code used in CAPACITATE that stands for the code for the beginning node of the arc considered.
K	A counter in UPDATE2 that keeps count of the number of arcs updated.
LB	Represents the lower bound for the arc considered in all three programs.
LINENO	A counter in CAPACITATE which counts the number of lines printed.
LINES	The number of 100 pair cables that can be accommodated with existing facilities. This variable is used in all three routines.
NBEG(I)	A four element array in CAPACITATE containing the four parts that compose the code for the beginning node of an arc. The first part contains one character that represents the period. The second, also a single character, defines the type of technology. The third and fourth parts are three characters long and in the case of intermediate nodes (XMIJ), they represent the physical arcs that are linked by the node. If the node is not an intermediate node, the third part has three blank spaces.
NBEG1	A variable used in UPDATE1 and UPDATE2 to denote the first part of the beginning node code as explained under NBEG(I).
NBEG2	A variable in UPDATE1 and UPDATE2 that

represents the second part of the beginning node code.

NBEG3 — The variable that defines the third part of the beginning node code in programs UPDATE1 and UPDATE2

NBEG4 — Used in UPDATE1 and UPDATE2 to signify the fourth part of the beginning node code.

NCALL — Used in UPDATE1 and UPDATE2 to count the number of times the COST subroutine is called.

NEND(I) — The four element array in CAPACITATE that contains the four parts of the ending node code for the arc considered. The parts have the same significance as the four in NBEG(I).

NEND1 — Used in UPDATE1 and UPDATE2 to represent the first part of the code for the ending node of the arc considered.

NEND2 — Used in UPDATE1 and UPDATE2 to represent the second part of the code for the ending node of the arc considered.

NEND3 — Used in UPDATE1 and UPDATE2 to represent the third part of the code for the ending node of the arc considered.

NEND4 — Used in UPDATE1 and UPDATE2 to represent the fourth part of the code for the ending node of the arc considered.

NODE(I) — An array used in CAPACITATE to store the beginning node codes of all the nodes.

NUM1,NUM2	A parameter used in all the three programs to form the letter string in the word, "NUMBER".
OLD	A variable in CAPACITATE which stores the code for the beginning node of the previous arc.
PERIOD	A variable used in UPDATE1 and UPDATE2 to represent the period being updated.
TIT1,TIT2	Parameters used to form the letter string in the word, "TITLE".
UB	Stands for the upper bound placed on the arc considered in all the three routines.
UCOST	Used in UPDATE1 and UPDATE2 to represent the unit cost specified for an arc.
UNCOST(I,J)	Stores the three categories (i.e., loading, conduiting / installing poles, and cabling) of the construction costs for an arc. This array is used in UPDATE1 and UPDATE2.
UNCOST(J)	Used in CAPACITATE for storing the construction costs for an arc under the three categories.
VOID	A parameter in CAPACITATE that is equivalent to a string of eight blank spaces.

B.2 Command Program Structure

The command file controls the functioning of the optimization program, PNET. The file is composed of cards/ lines containing a command word followed by a zero or one numeric arguments The command words must be left justified in columns 1-6 of a card. Arguments are specified as integers and may be placed anywhere in columns 7-16.

A description of the commands and the appropriate default values are indicated below. In the following lines, the command words are capitalized, "lun" denotes a logical unit number and "n" denotes an unsigned integer.

Command	Action
LUCOM lun	Set command file logical unit number to lun. Default is lun =1.
LUDATA lun	Set problem input data file logical unit number to lun. Default is lun = system input data file (5).
LUPRNT lun	Set logical unit number of output file on which printed solution reports are generated to lun. Default if lun = system output file (6).
LUSOL lun	Set solution output data file logical unit number to lun. To suppress this file set lun = 0. Default is lun = 10.
REWIND lun	Rewind file lun.
SKIP n	Skip n problems on the problem input data file. A problem is treated as a set of card images ending with a card containing the word, 'END'.
SOLVE n	Read and solve n problems from the input data file.
REPORT n	Set printed report flag IREPTF = n. If IREPTF = 0, print only objective function value and solution statistics. If IREPTF = 1, print solution giving only arcs with non-zero flow. If IREPTF = 2, print complete solution giving all

arcs regardless of flow. Default is IREPTF = 0.

STOP Terminate run.

B.3 The PNET Program

The PNET program is a mathematical programming algorithm that can be used to solve minimum cost flow networks. The program, developed at the University of Texas, Austin, is written in FORTRAN IV and uses a primal simplex method.

It can be used in the batch or interactive mode and can be controlled by varying the command parameters discussed in Section B.2.

The PNET program package can be obtained by writing to:

Analysis, Research and Computation, Inc.,
P.O.Box 4067, Austin, Texas. 78765.

Some minor modifications are necessary to the PNET program before it can be used for the optimization of subscriber loop plant in a a telecommunications industry. The changes involve altering some FORMAT statements in the program as indicated in Table B.1. The first column in the table gives the number of the line on which the statement is placed in the program and the second column identifies the statement number attached to the FORMAT. The next two columns show the original and the revised forms of the statements respectively.

Table B.1 The modifications to be made to the PNET program

Line Number	Statement Number	Original Statement	Revised Statement
665	602	FORMAT(I10,5X,2(A6,4x),6I10)	FORMAT(I 10,1X,2 (A8,4X),6 I 10)
669	610	FORMAT(2A6,I 10)	FORMAT(2A8, I 10)
726	514	FORMAT(A4,2X,2A6,2X,3 I 10)	FORMAT(A4,2A8,3 I 10)
760	600	FORMAT(2 I 10,2A6)	FORMAT(2 I 10,2A8)
1108	100	FORMAT(2I 10,2A6)	FORMAT(2 I 10,2A8)
1113	101	FORMAT(A3,3X,2A6,2X,3 I 10,I5)	FORMAT(A3,1X,2A8,3 I 10,I5)
1163	105	FORMAT(/6X,A6,5X,A6,3X,3 I 10,5X,3 I 10)	FORMAT(/4X,A8,3X,A8,3X,3 I 10,5X,3 I 10)

The output of the input conversion program and those of the programs UPDATE1 and UPDATE2 are formatted for direct use by the PNET program. Thus, the output from any of these programs may be directly used as the data input to the PNET program. The PNET program uses several files for which the default logical units are specified in lines 23 through 30 of the program. If the input file, LUDATA = 5, the output file, LUOUT = 6, the command file, LUCOM = 1, and the intermediate scratch files LUSCR1 and LUSCR2 equal to 11 and 12 respectively, the program can be activated by the following commands:

```
$run *FORTG scards=PNET
$run -load# 1=command file 5=data file
        6=output file 11=scratch file1 12=scratch file2
```

B.4 Program CAPACITATE

Program CAPACITATE is used after the first iteration with the PNET program is completed. Thus, it is used only once in the entire optimization process. This program uses four logical units on a computer. The unit numbers and the files they represent are explained below:

4 = Arc description file output by the input conversion system.

5 = File containing hte output of the PNET.

6 = Output file on which the formatted network information is printed.

8 = Output file on which new arc descriptions are

stored in machine code.

The program CAPACITATE is written in FORTRAN IV and can be used by issuing the following commands:

```
$run *FORTG scards=CAPACITATE
$run -load# 4=arc description file 5=PNET output
        6=output file1 8=output file2
```

A listing of the program is given in Table B.2, at the end of this Appendix. Program CAPACITATE can also be used with other Fortran compilers such as WATFIV and IF.

B.5 Operating Procedures for Programs UPDATE1 and UPDATE2

The programs UPDATE1 and UPDATE2 perform similar functions in the master control unit of the optimization model. UPDATE1 is used to set the bounds and change the costs on the primary arcs in a period, while the program UPDATE2 is utilized for updating the non-primary arcs in a particular period.

UPDATE1 is used only once for each period. Thus, the number of times it is used in the optimization process is equal to the number of periods in the planning horizon. The program UPDATE2 is used in the subsequent updates on a period. These non-primary updates are carried out on a particular period until the program prints out a message on logical unit number,7, indicating that operations on that period are complete. When such a message is received, the output of the PNET is run with the program UPDATE1 to perform the primary updating on the following period.

Both programs UPDATE1 and UPDATE2 use five logical units, the numbers and the use of which are outlined below:

4 = Arc description file from the previous run of UPDATE1 or CAPACITATE or UPDATE2.

5 = Data from the output of the previous run of PNET or CAPACITATE.

6 = The output file on which input to the next run of the PNET program is printed.

7 = The data file containing one card image which has the character code representing the period to be updated.

8 = The output file on which arc descriptions are stored for use in the next stage.

The only information that has to be prepared before using these two programs is one card/line containing the code for the period to be updated in the first column.

The programs UPDATE1 and UPDATE2 can be used with any cost calculating subroutine by removing the COMMON statement in lines 27 through 33 of the programs and replacing the CALL statements by the appropriate new statements. The new cost routine must be capable of supplying the values for the variables CODARC, ICAP1, ICAP2, COIL and UNCOST to the updating routines.

If the cost subroutine is in a file, "COST", and if it requires two data files one each on logical units, "1" and "2", the programs UPDATE1 and UPDATE2 can be invoked by the following commands:

```
$run *FORTG scards=UPDATE1 /UPDATE2 + COST
$run -load# 4=arc description file 5=network data
          1=cost data1 2=cost data2 7=period data
          6=output file1 8=output file2
```

These programs can also be used with other Fortran compilers. The programs UPDATE1 and UPDATE2 are listed in Tables B.3 and B.4 respectively.

Table B.2 Listing of Program CAPACITATE

```
C ****************   PROGRAM CAPACITATE    ***************
C
C THIS PROGRAM SETS THE LOWER BOUND ON ARCS"IJ-J" AND
C CREATES DUMMY ARCS THAT ARE NECESSARY TO BALANCE THE
C FLOWS
C
C DECLARE ARRAYS
C
      INTEGER NBEG(4),NEND(4),COST,UB,LB,FLOW,
     1BLANK/'    '/,EMPTY/' '/,ARCODE,
     2A(20),TIT1/' TIT'/,TIT2/'LE  '/,NUM1/'NUMB'/
     3,NUM2/'ER  '/,GEOG,CODARC
      REAL UNCOST(3)
      REAL*8 JNODE,NODE(999),OLD/'        '/,
     1VOID/'        '/
      LOGICAL*1 INODE(8),BEGNOD(16)
      EQUIVALENCE (NBEG,BEGNOD),(JNODE,INODE)
C
C INITIALIZE THE COUNTS
C
      ZERO=0.0
      IZERO=0
      INF=99999
      LINENO=0
      I=0
      K=0
C READ IN ARC INFORMATION FROM THE OUTPUT
C OF THE PNET.
C
      DO 6 LINE=1,50
      READ(5,400)  (A(J),J=1,20)
      IF(A(3).EQ.TIT1.AND.A(4).EQ.TIT2) WRITE(6,400)
     1(A(J),J=1,20)
      IF  (A(2).NE.NUM1.OR.A(3).NE.NUM2) GO TO 6
      WRITE(6,400)  (A(J),J=1,20)
      READ(5,500) DUMMY
      WRITE(6,500) DUMMY
      GO TO 1
6     CONTINUE
400   FORMAT(20A4)
500   FORMAT(F5.0)
1     I=I+1
      IF(MOD(I,50).NE.36) GO TO 8
      READ(5,900)  (A(KK),KK=1,20)
900   FORMAT(20A4,/////)
8     READ(5,100,END=4)  IARC,(NBEG(II),II=1,4),
     1(NEND(II),II=1,4),COST,UB,LB,FLOW
100   FORMAT(I10,1X,2(2A1,2A3,4X),4I10)
C
```

```
C EQUATE THE INDIVIDUAL CHARACTERS OF BEGNOD
C TO THOSE OF INODE.
C
C
C SET LOWER BOUND EQUAL TO FLOW IF
C THE ARC REPRESENTS AN "IJ-J" ARC.
C
      INODE(1)=BEGNOD(1)
      INODE(2)=BEGNOD(5)
      DO 21 JJ=1,3
      INODE(JJ+2)=BEGNOD(JJ+8)
21    INODE(JJ+5)=BEGNOD(JJ+12)
      IF(JNODE.EQ.VOID) GO TO 4
      READ(4) ARCODE,COIL,CODARC,(UNCOST(NO),NO=1,3),
     1GEOG,DIST,IP,GAUGE,LINES,IT
      IF(NBEG(3).EQ.BLANK) GO TO 2
      IF(NEND(3).NE.BLANK) GO TO 10
      LB=FLOW
      GO TO 10
2     IF(JNODE.EQ.OLD) GO TO 10
      IF(NBEG(2).EQ.EMPTY) GO TO 10
C
C IF THE BEGINNING NODE IS NOT A SWITCHING
C CENTER, CONNECT IT TO THE "SINK"
C
      IF((ARCODE/100).EQ.6) GO TO 10
      K=K+1
      NODE(K)=JNODE
      OLD=JNODE
      IF(NEND(3).EQ.BLANK) GO TO 10
      LINENO=LINENO+1
      IF(MOD(LINENO,50).NE.36) GO TO 9
      WRITE(6,800)
9     WRITE(6,200) IARC,(NBEG(II),II=1,4),
     1IZERO,INF,IZERO,IZERO
      WRITE(8) IZERO,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG,DIST,IP,GAUGE,LINES,IT
10    LINENO=LINENO+1
      IF(MOD(LINENO,50).NE.36) GO TO 3
      WRITE(6,800)
3     WRITE(6,100) IARC,(NBEG(II),II=1,4),
     1(NEND(II),II=1,4),COST,UB,LB,FLOW
      WRITE(8) ARCODE,COIL,CODARC,(UNCOST(NO),NO=1,3),
     1GEOG,DIST,IP,GAUGE,LINES,IT
      GO TO 1
800   FORMAT('1PROBLEM TITLE',/////)
C
C CONNECT ALL "I" NODES, OTHER THAN
C THE SWITCHING CENTER TO THE SOURCE.
C
4     DO 5 J=1,K
      IARC=I+J
      LINENO=LINENO+1
      IF(MOD(LINENO,50).NE.36) GO TO 11
```

```
      WRITE(6,800)
11    WRITE(6,300) IARC,NODE(J),IZERO,INF,IZERO
      WRITE(8) IZERO,ZERO,IZERO,ZERO,ZERO,ZERO,
     1GEOG,DIST,IP,GAUGE,LINES,IT
5     CONTINUE
200   FORMAT(I10,1X,2A1,2A3,8X,'SINK',4X,4I10)
300   FORMAT(I10,3X,'SOURCE',4X,A8,4X,4I10)
      STOP
      END
```

Table B.3 Program UPDATE1

```
C
C ***************     PROGRAM UPDATE1     ***************
C
C THIS PROGRAM PERFORMS THE PRIMARY UPDATE ON THE
C ARCS REPRESENTING THE PERIOD, "PERIOD"
C
C DECLARE ARRAYS
C
      INTEGER NBEG1,NBEG2,NBEG3,NBEG4,NEND1,NEND2,
     1NEND3,NEND4,UCOST,UB,LB,FLOW,PERIOD,ARCODE,CODARC(2),
     2 BLANK/'    '/,GEOG,
     3A(20),TIT1/' TIT'/,TIT2/'LE  '/,NUM1/'NUMB'/,
     4NUM2/'ER  '/
      REAL UNCOST(2,3),COIL(2)
C DECLARE ARRAYS FOR THE VARIABLES REQUIRED BY THE COST
C MODEL
C
      INTEGER  LIMIT(5),GSIZE(5),NNEX(6),PAIRS(35)
C
      REAL DFACTO(7,4),SIZE(6,2,4,40),VO(9),VNNEX(9),
     1LCCOST(6),PERSAL(9),DLCOST(8),LSUM(6),
     2MSUM(6),CONCOS(5,6),INTCPT(6,3,5),SLOPE(6,3,5),
     3EQUIPM(6,2,4,40),OPCOST(5,9),PMC(5),CTF(5,9),
     4SPEC(6,2,10),IA(5),TINDEX(5),PPEF(5),PEF(5),TIME(5),
     5MHCOST
C
C PLACE THE COST MODEL VARIABLES IN THE COMMON BLOCKS
C
      COMMON  /A/DFACTO/B/PARAFO,PARA,PARK/C/NSIZE,SIZE
     1/D/VO,VNNEX/E/CODARC,COIL,UNCOST/G/LCINT,POLDIS
     2/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,NCSIZE,
     3LIMIT,CONCOS,MHCOST,INTCPT,SLOPE,EQUIPM,POLCOS,
     4NGAUGE,GSIZE/J/OPCOST,GFMAIN,NNEX,PMC,IA/K/CTF
     5//NCALL,NUMDIS,SPEC,TT,TINDEX,PPEF,PEF,NPER,TIME
     6/L/PAIRS
C
C SET COUNTERS TO ZERO.
C
      NCALL=0
      IZERO=0
      INF=99999
      I=0
C
C READ IN THE CODE FOR THE PERIOD TO BE
C UPDATED.
C
      READ(7,100) PERIOD
100   FORMAT(A1)
C
```

```
C WRITE THE INITIAL CONTROL STATEMENTS REQUIRED
C FOR PNET AND GO ON TO READ ARC INFORMATION.
C
      WRITE(6,500)
500   FORMAT('BEGIN')
      DO 2 LINE=1,50
      READ(5,600) (A(J),J=1,20)
      IF(A(3).NE.TIT1.OR.A(4).NE.TIT2) GO TO 3
      WRITE(6,600) (A(J),J=6,20)
      WRITE(6,800)
3     IF(A(2).NE.NUM1.OR.A(3).NE.NUM2) GO TO 2
      READ(5,700) DUMMY
      GO TO 1
2     CONTINUE
600   FORMAT(20A4)
700   FORMAT(F5.0)
800   FORMAT('ARCS')
1     I=I+1
      IF(MOD(I,50).NE.36) GO TO 5
      READ(5,1100) (A(KK),KK=1,20)
1100  FORMAT(20A4,/////)
5     READ(5,200,END=10) IARC,NBEG1,NBEG2,NBEG3,NBEG4,
     1NEND1,NEND2,NEND3,NEND4,UCOST,UB,LB,FLOW
200   FORMAT(I10,1X,2(2A1,2A3,4X),4I10)
      IF(IARC.EQ.0) GO TO 10
      READ(4) ARCODE,COIL(1),CODARC(1),
     1(UNCOST(1,JN),JN=1,3),GEOG,DIST,IP,GAUGE,LINES,IT
C
C IF THERE IS NO FLOW IN THE ARC NO
C ALTERATIONS NEED TO BE MADE.
C
      IF(FLOW.EQ.0) GO TO 9
      IF(NBEG1.NE.PERIOD) GO TO 9
      IF(MOD((ARCODE/100),4).NE.2) GO TO 9
C
C IF THE ARC REPRESENTS EXISTING PLANT, SET LOWER
C BOUND EQUAL TO THE UPPER BOUND.
C
      IF((MOD(ARCODE,100)/10).NE.1) GO TO 4
      LB=UB
      GO TO 9
C
C UPDATE ARC COSTS BY ACTIVATING THE COST
C MODEL AND CHANGE THE BOUNDS.
C
4     ICAP1=0
      ICAP2=FLOW
      ITYPE=MOD(ARCODE,10)
      CALL COST(GEOG,DIST,ITYPE,ICAP1,ICAP2,IP,GAUGE,
     1LINES,IT,ICOST)
      WRITE(6,300) NBEG1,NBEG2,NBEG3,NBEG4,NEND1,NEND2,
     1NEND3,NEND4,ICOST,ICAP2,ICAP2
      WRITE(8) ARCODE,COIL(1),CODARC(1),
     1(UNCOST(1,JN),JN=1,3),GEOG,DIST,IP,GAUGE,LINES,IT
```

```
300   FORMAT(4X,2(2A1,2A3),3I10)
C
C INTRODUCE A NEW ARC WITH COST EQUAL TO
C THE INCREMENTAL UNIT COST.
C
      ICAP2=0
      CALL COST(GEOG,DIST,ITYPE,ICAP1,ICAP2,IP,GAUGE,
     1LINES,IT,ICOST)
      ARCODE=ARCODE+10
      UCOST=ICOST
9     WRITE(6,300) NBEG1,NBEG2,NBEG3,NBEG4,NEND1,NEND2,
     1NEND3,NEND4,UCOST,UB,LB
      WRITE(8) ARCODE,COIL(1),CODARC(1),
     1(UNCOST(1,JN),JN=1,3),GEOG,DIST,IP,GAUGE,LINES,IT
      GO TO 1
C
C WRITE THE FINAL CONTROL STATEMENT AND STOP.
C
10    WRITE(6,400)
400   FORMAT('END')
      STOP
      END
```

Table B.4 Program UPDATE2

```
C ****************      PROGRAM UPDATE2      *************
C
C THE PROGRAM CAN BE USED TO UPDATE THE NON PRIMARY ARCS
C OF A PARTICULAR PERIOD.
C
C DECLARE ARRAYS
C
      INTEGER NBEG1,NBEG2,NBEG3,NBEG4,NEND1,NEND2,
     1NEND3,NEND4,UCOST,UB,LB,FLOW,PERIOD,CODARC(2),
     2BLANK/'    '/,ARCODE,GEOG,
     3A(20),TIT1/' TIT'/,TIT2/'LE  '/,NUM1/'NUMB'/,
     4NUM2/'ER  '/
      REAL UNCOST(2,3),COIL(2)
C DECLARE ARRAYS FOR THE VARIABLES REQUIRED BY THE COST
C MODEL
C
      INTEGER  LIMIT(5),GSIZE(5),NNEX(6),PAIRS(35)
C
      REAL DFACTO(7,4),SIZE(6,2,4,40),VO(9),VNNEX(9),
     1LCCOST(6),PERSAL(9),DLCOST(8),LSUM(6),
     2MSUM(6),CONCOS(5,6),INTCPT(6,3,5),SLOPE(6,3,5),
     3EQUIPM(6,2,4,40),OPCOST(5,9),PMC(5),CTF(5,9),
     4SPEC(6,2,10),IA(5),TINDEX(5),PPEF(5),PEF(5),TIME(5),
     5MHCOST
C
C PLACE THE COST MODEL VARIABLES IN THE COMMON BLOCKS
C
      COMMON  /A/DFACTO/B/PARAFO,PARA,PARK/C/NSIZE,SIZE
     1/D/VO,VNNEX/E/CODARC,COIL,UNCOST/G/LCINT,POLDIS
     2/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,NCSIZE,
     3LIMIT,CONCOS,MHCOST,INTCPT,SLOPE,EQUIPM,POLCOS,
     4NGAUGE,GSIZE/J/OPCOST,GFMAIN,NNEX,PMC,IA/K/CTF
     5//NCALL,NUMDIS,SPEC,TT,TINDEX,PPEF,PEF,NPER,TIME
     6/L/PAIRS
C
C INITIALIZE THE COUNTERS
C
C
C READ IN THE CODE FOR THE PERIOD
C
      NCALL=0
      IZERO=0
      INF=99999
      K=0
      I=0
      READ(7,100) PERIOD
100   FORMAT(A1)
C
C WRITE THE INITIAL CONTROL CARDS BEFORE
```

```
C COMMENCING READIND IN FROM PNET OUTPUT.
C
      WRITE(6,900)
900   FORMAT('BEGIN')
      DO 2 LINE=1,50
      READ(5,600) (A(J),J=1,20)
      IF(A(3).NE.TIT1.OR.A(4).NE.TIT2) GO TO 3
      WRITE(6,600) (A(J),J=6,20)
      WRITE(6,800)
3     IF(A(2).NE.NUM1.OR.A(3).NE.NUM2) GO TO 2
      READ(5,700) DUMMY
      GO TO 1
2     CONTINUE
600   FORMAT(20A4)
700   FORMAT(F5.0)
800   FORMAT('ARCS')
1     I=I+1
      IF(MOD(I,50).NE.36) GO TO 5
      READ(5,1000) A(1)
1000  FORMAT(A4,/////)
5     READ(5,200,END=10) IARC,NBEG1,NBEG2,NBEG3,NBEG4,
     1NEND1,NEND2,NEND3,NEND4,UCOST,UB,LB,FLOW
C
C IF ALL ARCS HAVE BEEN COMPLETED, STOP.
C
      IF(IARC.EQ.0) GO TO 10
      READ(4) ARCODE,COIL(1),CODARC(1),
     1(UNCOST(1,JN),JN=1,3),GEOG,DIST,IP,GAUGE,LINES,IT
200   FORMAT(I10,1X,2(2A1,2A3,4X),4I10)
C IF ARC FLOW EQUALS THE LOWER BOUND OR IF
C THE ARC DOES NOT REPRESENT THE PERIOD UPDATED
C SKIP THE FOLLOWING SECTION.
C
      IF(NBEG1.NE.PERIOD) GO TO 4
      IF(FLOW.EQ.LB) GO TO 9
      IF(MOD(ARCODE/100,4).NE.2) GO TO 4
      K=K+1
      ITYPE=MOD(ARCODE,10)
C
C IF THE ARC REPRESENTS EXISTING PLANT, SET
C LOWER BOUND EQUAL TO THE UPPER BOUND.
C IF IT REPRESENTS A PRIMARY ARC OBTAIN NEW ARC COSTS
C AND BOUNDS.
C IF ARC REPRESENTS A NON-PRIMARY ARC, OBTAIN
C NEW COSTS AND CHANGE ONLY THE LOWER BOUND.
C
      IF((MOD(ARCODE,100)/10)-2) 6,7,8
6     LB=UB
      GO TO 4
7     ICAP1=0
      ICAP2=FLOW
      CALL COST(GEOG,DIST,ITYPE,ICAP1,ICAP2,IP,GAUGE,LINES,
     1IT,ICOST)
      WRITE(6,300) NBEG1,NBEG2,NBEG3,NBEG4,NEND1,NEND2,
```

```
     1NEND3,NEND4,ICOST,ICAP2,ICAP2
      WRITE(8) ARCODE,COIL(1),CODARC(1),
     1(UNCOST(1,JN),JN=1,3),GEOG,DIST,IP,GAUGE,LINES,IT
      ICAP2=0
      GO TO 11
8     ICAP2=ICAP1+FLOW
11    CALL COST(GEOG,DIST,ITYPE,ICAP1,ICAP2,IP,GAUGE,LINES,
     1IT,ICOST)
      IF((MOD(ARCODE,100)/10).EQ.2) ARCODE=ARCODE+10
      UCOST=ICOST
      GO TO 4
9     IF((MOD(ARCODE,100)/10).NE.2) GO TO 4
      ICAP1=UB
300   FORMAT(4X,2(2A1,2A3),3I10)
4     WRITE(6,300) NBEG1,NBEG2,NBEG3,NBEG4,NEND1,NEND2,
     1NEND3,NEND4,UCOST,UB,LB
      WRITE(8) ARCODE,COIL(1),CODARC(1),
     1(UNCOST(1,JN),JN=1,3),GEOG,DIST,IP,GAUGE,LINES,IT
      GO TO 1
C
C WRITE THE LAST CONTROL STATEMENT
C
10    WRITE(6,400)
400   FORMAT('END')
C
C IF NO ARCS NEEDED UPDATING, PRINT
C A MESSAGE INFORMING THAT UPDATING
C ON THE NEXT PERIOD CAN COMMENCE.
C
      IF(K.EQ.0) WRITE(7,1100) PERIOD
1100  FORMAT(//,'OPERATIONS FOR PERIOD "',A1,'" ARE ',
     1'COMPLETE',/,' COMMENCE UPDATING FOR NEXT PERIOD.')
      STOP
      END
```

APPENDIX-C COMPUTER PROGRAM FOR CONVERSION OF OUTPUT INFORMATION

The output conversion system of the optimization model is the buffer unit that converts the results of the optimization process into a capital budget and a construction program. The program outputs the capital budget by period, a summary of capital expenditures, the construction plan for the first year and a table showing the switching center capacities in lines by type of technology and period. These information can be directly used by the company for planning of outside plant.

The output conversion program consists of a main routine and subroutines, "DECODE", "OUT", "SEARCH" and "ACOUNT". The main routine reads the output of the last iteration of the PNET program, the arc descriptions and data from the data bank, and uses them to prepare formatted reports. Subroutine "DECODE" is used to convert the node codes back to those that were originally supplied to the optimization model, while subroutine "OUT" prints out the periodic budgets after information on all the arcs representing that period have been examined. Subroutine "OUT" also stores a summary of all capital investment for output at the end of the run. Subprogram "SEARCH" uses the arc codes to identify the type of plant used in an arc and this information is made use of by the subprogram "ACOUNT" to maintain a cumulative total of the investment in each type of plant.

C.1 Glossary of the Variables Used in the main routine and subroutines DECODE, OUT, SEARCH and ACOUNT

A — Used in "DECODE" to represent the eight character code for a node.

A(I) — An array used in the main program and in "OUT" to read various alphanumeric data.

ADCOST — An integer used in the main routine to account for the total additional cost for a physical arc.

ARCODE — Used in the main routine to read the arc codes off the arc description file. The codes used are the same as those used for ARCODE in programs UPDATE1 and UPDATE2.

ARCOST(I,J) — A 2x3 matrix used in the main program to store the construction costs under the three categories; loading, conduiting/ installing poles, and cabling.

B — A variable used in "DECODE" to form the character string representing the code for a node.

BEG — An eight character alphanumeric variable utilized in the main routine to denote the beginning node code for the arc considered.

CBSIZE(I) — An array used in the main program and the subroutine "OUT" to store the different cable sizes available.

CODARC — Used in the main program to denote the plant used in an arc.

CODE(I)	The 36-element character string used in the main routine and in "DECODE" to store the the characters used in coding the node names.
COIL	Used in the main routine and in "ACOUNT" to signify the number of loading coils used in the arc considered.
COSCAB (I,J,K,L)	Used in the main program and in subroutines "OUT" and "ACOUNT" to store the investment in the varios types of cable available.
COSCON(I,J)	An array which stores the investment in conduits, by type, in the main routine and in "OUT" and "ACOUNT".
COSLC(I)	The array used to maintain a cumulative total of the investment in loading coils by class of plant. It is used in programs "OUT" and "ACOUNT" and in the main routine.
COSPOL	Used in nain, "ACOUNT" and "OUT" to denote the investment in poles.
COST	A variable used in main to represent the unit cost of an arc.
CSIZE(I)	An array used in main and "OUT" to store the different sizes of conduit available.
DATE(I)	Used in main and "OUT" to denote the date of the study.
DESTAL(I,J)	An alphanumeric matrix that stores the sub-class descriptions (e.g. stalpeth, alpeth), in main

and "OUT".

DIST — Represents the length of cable required for an arc in the main program and in "ACOUNT".

DUMMY — A dummy variable used in the main routine to skip line in the data file.

END — A variable that represents the code for the ending node of the arc considered in the main routine.

EQUC — A function, available at the University of Alberta computing library, that is used by "DECODE" to compare an integer variable to a logical variable.

FLOW — Used in the main routine to denote the flow in an arc.

GAUGE — Used in main to read the airline distance of the beginning node of an arc from the switching center.

GEOG — Used in the main program to represent the geographic code for an arc. This variable is not used by the program in any calculations.

GSIZE(I) — Used in the main program and in "OUT" to store the different gauge sizes available.

IA1 — An integer used in "DECODE" to represent the third part in the name code for a node.

IA2 — Used in "DECODE" to represent the fourth part in the code name for a node.

IADCAP — Used in the main program to represent the

	capacity additions to be made to an arc.
IARC	Represents the arc number in the main routine.
IBEG	used in the main program to rpresent the beginning node of an arc in the physical network.
IBEGO	A variable, used in the main routine, to represent the beginning node of the previous arc considered.
IC	Used in "OUT" and in the main routine as a DO-index.
ICLASS	A DO-index used in the main routine.
ICS	Used as a DO-index in main and "OUT" and as a variable representing the size of conduit used in an arc in "ACOUNT" and "SEARCH".
ICW	Used as a DO-index in "OUT" and main, and as a variable representing the number of ways of conduit/ number of poles in "SEARCH" and "ACOUNT".
IEND	Used in main to represent the ending node of a physical arc.
IENDO	Used in main to represent the ending node of the previous arc.
IG	Used in the main routine and in "OUT" as a DO-index and in subroutines "SEARCH" and "ACOUNT" as variable representing the gauge size.
INSTAL	Used in the main routine to represent the the

total installed capacity in a physical arc.

IP	Stands for the current period in programs main and "OUT", and for the period a node represents in "DECODE".
IPP	A variable representing the time period that a an arc represents, It is used in the main program.
IS	Used as a DO-index in the main program and in "OUT" and as a variable representing the sub-class of plant in "ACOUNT" and "SEARCH".
ISZ	Used as a DO-index in the main and "OUT" routines and as a variable representing the size of plant in "ACOUNT" and "SEARCH".
IT	Used in "DECODE" to denote the type of technology an node represents.
ITT	Used in the main program to represent the type of technology an arc represents.
ITYPE	A variable that represents the class of plant an arc represents in in main, "ACOUNT" and "SEARCH".
IUNIT	A variable used in "OUT" to represent the unit of measurement of a certain type of plant. The recommended units are: 1. meters for all types of cable, 2. meters for the underground conduits, 3. one unit for the poles, and 4. one loading set for line concentrators (a

loading set includes a loading coil, a capacitor and other equipment that are installed while placing a loading coil).

JA1	Represents the third part of the character code used for a node in main.
JA2	Represents the fourth part of the character code of a node in main.
JARC	A variable used in main to refer to the type of arc (same as the first digit of KODE in the input conversion program).
JP	Used in main to refer to the time period a node represents.
JT	Used in main to refer to the type of technology a node represents.
KODE	A variable that stands for the type of plant used in an arc in "SEARCH".
KTYPE	Used in the main routine to denote the arc order (e.g. primary, secondary and existing).
LB	Used in main to represent the lower bound for an arc.
LETTER	Used in "DECODE" to identify the individual characters in the code name for a node.
LINE	A counter used in the main routine to keep count of the number of lines read from the data file.
LINENO	A counter used in the main program to count the number of lines read off the input file.
LINES	A variable signifying the excess conduits/ pole

lines available in an arc. It is read off the arc description file in the main program, but is not used in any calculations.

NAME(I)	An array used in the main and "OUT" routines to store the name of the switching center studied.
NCBSIZ	Used in main and "OUT" routines to denote the number of cable sizes available.
NCSIZE	Used in "OUT" and main to store the number of conduit sizes available.
NGAUGE	Used in "OUT" and main to denote the number of different gauges available.
NNWAY	Used in "OUT" and main to represent the number of different number of ways of conduit available
NPER	Used in out and main to denote the number of periods in the planning horizon.
NSTAL	Used in "OUT" and main to refer to the number of subclasses of plant (e.g.stalpeth and alpeth) available.
NTECH	Stands for the number of different technologies explicitly considered in a period, in the main program.
NUM1,NUM2	Used to form the letter string "NUMBER" in the main routine.
NUM(I)	Used in "DECODE" to convert each individual character to the corresponding numerical equivalent.
NWAY	Used in main and "OUT" to represent the

different number of ways of conduit possible.

SCCAP(I,J) A matrix used to store the switching center capacities in lines, by period and type of technology, in the main routine.

SUMRY(I,J) The matrix that stores the summary of capital investment in the programs main and "OUT".

TIT1,TIT2 The variables used to form the letter string "TITLE" in the main program.

UNCAB (I,J,K,L) Used in the main routine and in the subroutines "OUT" and "ACOUNT" to keep account of the total volume of cable required for a period.

UNCOND(I,J) An array that stores the cumulative units of conduit required in a particular period. This array is used by programs main, "ACOUNT" and "OUT".

UNCOST(I) Stores the arc construction costs under three categories in main.

UNLC An array keeping tally of the inventory of line concentrators in the programs main,"OUT" and "ACOUNT".

UNPOLE A variable used to denote the number of poles used in a particular period.

UTILIZ A variable used in the main program to represent the total utilized capacity in a physical arc.

B.2 Operating Procedures for the Output Conversion System

The output conversion program requieres data on the types of plant available for it to output a construction program and a capital budget. These data are to be arranged as indicated below.

CARD NO.	VARIABLE	COLUMNS
1	NAME(I)	1-20
2	DATE(I)	1- 8
3	LETTER(I)	1-36
4	NPER	1- 2
5	NCSIZE	1- 4
6	CSIZE(I)	1- 4,5-8,..
7	NNWAY	1- 4
8	NWAY(I)	1- 4,5-8,..
9	NSTAL	1- 4
10-N	DESTAL(I,J)	1- 8
N+1	NGAUGE	1- 4
N+2	GSIZE(I)	1- 4,5-8,..
N+3	NCBSIZ	1- 4
N+4-M	CBSIZE(I)	1- 4,5-8,..
M+1	CLASS OF PLANT	1-40
M+2	TYPE OF PLANT	1- 8
M+2	UNIT OF MEASUREMENT	9-13
.	.	
.	.	
X	.	
X+1	NTECH FOR PERIOD 1	1- 2
.	.	
.	.	

Y	NTECH FOR PERIOD,NPER	1- 2
(Y+1)-(Y+9)	CATEGORY OF PLANT	1- 8

In the above description the specific number of lines/ cards required depends on the number of cables available, the number of different types of plant within a class of plant, etc. So the letters "N","M","X",and "Y" have been used to denote the number of cards required.

These information will be referred to as the data set #5. The output conversion system uses the following logical unit numbers:

1 = the file containing data set #5,

2 = an intermediate scratch file,

3 = an intermediate scratch file,

4 = arc description file ,

5 = file containing the output of the last iteration of the PNET program,

6 = output file on which the construction plan and switching center capacities are printed, and,

8 = output file on which the capital investment information are printed.

The output conversion system can be activated by issuing the following commands:

```
$run *FORTG scards=output conversion program
$run -load# 1=data set#5 2=scratch file1
        3=scratch file2
        4=arc description file 5=PNET outputfile
```

6=output file1 8=output file2

Table C.1 below contains a complete listing of the output conversion program. This program can also be compiled and executed on other Fortran compilers.

Table C.1 Output Conversion Program

```
C *************   OUTPUT CONVERSION PROGRAM   *************
C
C THIS PROGRAM IS USED TO CONVERT THE OUTPUT OF THE FINAL
C ITERATION OF THE "PNET" PROGRAM INTO A CAPITAL BUDGET AND
C A CONSTRUCTION PROGRAM
C
C DIMENSION THE ARRAYS USED
C
      INTEGER COST,FLOW,ARCODE,A(20),SCCAP(10,10),
     1ADCOST,UTILIZ,GEOG,CODARC,
     2DESTAL(3,2),GSIZE(5),CBSIZE(50),NWAY(5),CSIZE(10)
     3,TIT1/' TIT'/,TIT2/'LE  '/,NUM1/'NUMB'/,NUM2/'ER  '/
     4,NAME(5),DATE(2)
C
      REAL*8 BEG,END
C
      LOGICAL*1 CODE(36)
C
      REAL ARCOST(2,3),UNCOST(3),SUMRY(5,9),UNLC(6),
     1UNCAB(6,3,5,50),COSCAB(6,3,5,50),UNCOND(5,10),
     2UNLC(6),COSCON(5,10)
      COMMON CODE/A/NSTAL,NGAUGE,NCBSIZ,CBSIZE,
     1GSIZE,DESTAL,SUMRY,NCSIZE,NNWAY,NWAY,CSIZE,NPER
     2,NAME,DATE
     3/B/UNCAB,COSCAB,UNCOND,COSCON,UNLC,COSLC,
     4UNPOLE,COSPOL
C
C READ IN THE NAME OF THE SWITCHING CENTER AND THE
C DATE OF THE STUDY
C
      READ(1,600) (NAME(KK),KK=1,5)
      READ(1,1200) (DATE(KK),KK=1,2)
C
C READ IN THE ARRAY CONTAINING CODES
C
      READ(1,400) (CODE(KK),KK=1,36)
C
C READ IN THE NUMBER OF PERIODS
C
400   FORMAT(36A1)
      READ(1,800) NPER
800   FORMAT(I2)
C
C BEGIN READING IN THE TYPES OF PLANT AVAILABLE
C
      READ(1,1100) NCSIZE
1100  FORMAT(20I4)
```

```
      READ(1,1100)  (CSIZE(NO),NO=1,NCSIZE)
      READ(1,1100)  NNWAY
      READ(1,1100)  (NWAY(NO),NO=1,NNWAY)
      READ(1,1100)  NSTAL
      READ(1,1200)  ((DESTAL(IX,NO),NO=1,2),IX=1,NSTAL)
1200  FORMAT(2A4)
      READ(1,1100)  NGAUGE
      READ(1,1100)  (GSIZE(NO),NO=1,NGAUGE)
      READ(1,1100)  NCBSIZ
      READ(1,1100)  (CBSIZE(NO),NO=1,NCBSIZ)
C
C INITIALIZE THE COSTS AND THE VOLUMES
C
      DO 56 NO=1,NPER
      DO 56 ICLASS=1,9
56    SUMRY(NO,ICLASS)=0.0
      DO 57 IC=1,6
      UNLC(IC)=0.0
      COSLC(IC)=0.0
      DO 58 IS=1,NSTAL
      DO 58 IG=1,NGAUGE
      DO 58 ISZ=1,NCBSIZ
      UNCAB(IC,IS,IG,ISZ)=0.0
58    COSCAB(IC,IS,IG,ISZ)=0.0
57    CONTINUE
      DO 59 ICS=1,NCSIZE
      DO 59 ICW=1,NNWAY
      UNCOND(ICS,ICW)=0.0
59    COSCON(ICS,ICW)=0.0
      UNPOLE=0.0
      COSPOL=0.0
      DO  91 INO=1,10
      DO 91 JNO=1,10
      SCCAP(INO,JNO)=0
91    CONTINUE
      DO 92 INO=1,2
      DO 92 JNO=1,3
92    ARCOST(INO,JNO)=0.0
      COIL1=0.0
      COIL2=0.0
      COIL3=0.0
      ITYPE1=1
      ITYPE2=1
      IP=1
      LINENO=0
200   FORMAT(//,15X,'SWITCHING CENTER: ',5A4,23X,
     1'DATE: ',2A4,//,35X,'CONSTRUCTION PLAN SUMMARY',/,
     236X,'(SUBSCRIBER LOOP PLANT)',//,
     316X,'FROM',8X,'TO',2X,'CAPACITY',1X,'INSTALLED',2X,
     4'UTILIZED',10X,'PLANT',7X,'CABLE',/,
     516X,'NODE',6X,'NODE',1X,'ADDITIONS',2X,'CAPACITY',
     62X,'CAPACITY',10X,'CLASS',8X,'TYPE',/)
C
C READ THE PNET OUTPUT
```

```
C
      DO 32 LINE=1,50
      READ(5,600)  (A(J),J=1,20)
      IF(A(3).NE.TIT1.OR.A(4).NE.TIT2) GO TO 33
C     WRITE(8,600)  (A(J),J=6,20)
      WRITE(8,200)   NAME,DATE
33    IF(A(2).NE.NUM1.OR.A(3).NE.NUM2) GO TO 32
      READ(5,700) DUMMY
      GO TO 10
32    CONTINUE
C
C COMMENCE READING THE ARC NAMES AND FLOWS
C
10    REWIND 2
      REWIND 3
2     LINENO=LINENO+1
      IF(MOD(LINENO,50).NE.36) GO TO 22
      READ(5,500) A(1)
22    READ(5,100,END=9) IARC,BEG,END,LB,FLOW,COST
100   FORMAT(I10,1X,2(A8,4X),20X,3I10)
C
C IF TALL THE ARCS HAVE BEEN READ IN, GO ON TO ACCOUNT
C FOR THE COSTS. ELSE, SORT OUT THE ARCS BY THE CODES
C
      IF(IARC.EQ.0) GO TO 9
      READ(4) ARCODE,COIL,CODARC,(UNCOST(NO),NO=1,3),
     1GEOG,DIST,IPP,GAUGE,LINES,ITT
      IF(ARCODE.EQ.0) GO TO 2
      JARC=ARCODE/100
      GO TO (71,72,73,2,2,72), JARC
      WRITE(6,1500)
1500  FORMAT(/,2X,'ARCODE HAS A BIG VALUE')
      STOP
71    CALL DECODE(END,JP,JT,JA1,JA2)
      SCCAP(JP,JT)=SCCAP(JP,JT)+FLOW
      GO TO 2
72    CALL DECODE(END,JP,JT,JA1,JA2)
      JARC=ARCODE-(JARC*100)
      WRITE(2) JP,JT,JA1,JA2,COST,FLOW,JARC,
     1COIL,CODARC,(UNCOST(NO),NO=1,3),DIST
      GO TO 2
73    CALL DECODE(BEG,JP,JT,JA1,JA2)
      WRITE(3) JP,JT,JA1,JA2,LB
      GO TO 2
600   FORMAT(20A4)
700   FORMAT(F5.0)
C
C ACCOUNTING BEGINS
C
9     ENDFILE 2
      ENDFILE3
      REWIND 2
      REWIND3
      LINE=0
```

```
C
C READ IN THE DETAILS FOR AN "I-IJ" ARC
C AND TOTAL UP TO FIND THE INSTALLED CAPACITY
C
75    LINE=LINE+1
      READ(2,END=80) IPP,ITT,IBEG,IEND,COST,FLOW,JARC,
     1COIL,CODARC,(UNCOST(NO),NO=1,3),DIST
      IF(LINE.NE.1) GO TO 76
C
C IF A NEW PERIOD IS TO BE COMMENCED, OUTPUT OLD
C VALUES AND RESET COSTS TO ZERO.
C
      IF(IPP.EQ.IP) GO TO 77
      CALL OUT(IP)
      IP=IP+1
77    IBEGO=IBEG
      IENDO=IEND
C
C PRINT THE TITLE
C
      ADCOST=0
      INSTAL=0
      UTILIZ=0
      IADCAP=0
      GO TO 78
76    IF(IBEG.NE.IBEGO) GO TO 79
      IF(IEND.NE.IENDO) GO TO 79
78    INSTAL=INSTAL+FLOW
      ADCOST=ADCOST+COST
      KTYPE=MOD(JARC,10)
      IF((JARC/10)-2) 75,62,63
62    IADCAP=IADCAP+FLOW
      CALL SEARCH(CODARC,ITYPE1,ICS1,ICW1,IS1,IG1,ISZ1)
      DIST1=DIST
      COIL1=COIL
      DO 64 NO=1,3
64    ARCOST(1,NO)=UNCOST(NO)
      GO TO 75
63    IADCAP=IADCAP+FLOW
      CALL SEARCH(CODARC,ITYPE2,ICS2,ICW2,IS2,IG2,ISZ2)
      DIST2=DIST
      COIL2=COIL
      DO 65 NO=1,3
65    ARCOST(2,NO)=UNCOST(NO)
      GO TO 75
79    BACKSPACE 2
C
C READ IN DETAILS OF THE "IJ-J" ARC
C NOTE THE UTILIZED CAPACITY
C
80    READ(3,END=14) IPP,ITT,IBEG,IEND,LB
      IF(IBEG.NE.IBEGO) GO TO 81
      IF(IEND.NE.IENDO) GO TO 81
      UTILIZ=LB
```

```
      GO TO 80
81    BACKSPACE 3
      IF(INSTAL.EQ.0) GO TO 11
      IF(IADCAP.EQ.0) GO TO 96
      DO 67 NO=1,3
67    UNCOST(NO)=ARCOST(1,NO)+ARCOST(2,NO)
      COIL3=COIL1+COIL2
      IF(ARCOST(2,3).EQ.0.0) GO TO 66
      ITYPE1=ITYPE2
      ICS1=ICS2
      ICW1=ICW2
      IS1=IS2
      IG1=IG2
      ISZ1=ISZ2
66    CALL ACOUNT(UNCOST,COIL3,ITYPE1,ICS1,ICW1,IS1
     1,IG1,ISZ1,DIST1)
      DO 69 MM=1,2
      DO 69 NO=1,3
69    ARCOST(MM,NO)=0.0
      COIL1=0.0
      COIL2=0.0
      COIL3=0.0
      ITYPE1=1
      ITYPE2=1
C
C OUTPUT THE CONSTRUCTION PLAN FOR THE
C SEGMENT IF THE ARC REPRESENTS THE FIRST
C PERIOD.
C
      IF(IP.NE.1) GO TO 11
      WRITE(8,300) IBEGO,IENDO,IADCAP,INSTAL,UTILIZ,
     1KTYPE,GSIZE(IG1),(DESTAL(IS1,NO),NO=1,2)
300   FORMAT(10X,5I10,5X,I10,3X,I3,'-',2A4)
      GO TO 11
96    IF(IP.NE.1) GO TO 11
      WRITE(8,300) IBEGO,IENDO,IADCAP,INSTAL,UTILIZ,KTYPE
11    LINE=0
      GO TO 75
500   FORMAT(A4,/////)
C
C  OUTPUT THE CAPITAL BUDGET FOR THE LAST PERIOD
C AND THEN GO ON TO OUTPUT SWITCHING CENTER
C CAPACITIES AND A SUMMARY OF CAPITAL INVESTMENT
C
14    CALL OUT(NPER)
      WRITE(8,1000)  NAME,DATE
1000  FORMAT(//,20X,'SWITCHING CENTER: ',5A4,10X,
     1'DATE: ',2A4,//,40X,'SWITCHING CENTER CAPACITIES',/,
     242X,'(BY TYPE OF TECHNOLOGY)',//,49X,'1',9X,'2',
     39X,'3')
      DO 41 IP=1,NPER
      READ(1,800) NTECH
      WRITE(8,900) IP,(SCCAP(IP,IT),IT=1,NTECH)
41    CONTINUE
```

```
900   FORMAT(30X,'PERIOD',I2,2X,3I10)
      WRITE(6,1300) NAME,DATE,(IP,IP=1,NPER)
1300  FORMAT(//,2X,'SWITCHING CENTER: ',5A4,20X,
     1'DATE: ',2A4,//,22X,
     2'SUBSCRIBER LOOP CAPITAL INVESTMENT SUMMARY',/,3X,
     3'CLASS OF PLANT',6X,7(I10,4X))
      DO 61 IC=1,9
      READ(1,600) (A(NO),NO=1,4)
1400  FORMAT(2X,4A4,3X,7F14.2)
      WRITE(6,1400) (A(NO),NO=1,4),(SUMRY(IP,IC),IP=1,NPER)
61    CONTINUE
      STOP
      END
C ***************     SUBROUTINE DECODE     ***************
C
C
C THIS SUBROUTINE IS USED TO DECODE THE NODE NAMES
C AND FIND THE ORIGINAL NUMERICAL CODES.
C
      SUBROUTINE DECODE(A,IP,IT,IA1,IA2)
C
C THIS FUNCTION EQUC IS USED TO COMPARE
C AN INTEGER AND A LOGICAL VARIABLE
C THIS ROUTINE IS AVAILABLE AT THE UNIVERSITY
C OF ALBERTA
C
      LOGICAL EQUC
      INTEGER NUM(8)
      REAL*8 A,B
      LOGICAL*1 LETTER(8),CODE(36)
      COMMON CODE
      EQUIVALENCE (B,LETTER)
      B=A
      DO 3 II=1,8
      DO 1 JJ=1,36
      IF(EQUC(CODE(JJ),LETTER(II))) GO TO 2
1     CONTINUE
      NUM(II)=0
      GO TO 3
2     NUM(II)=JJ-1
3     CONTINUE
      IP=NUM(1)+1
      IT=NUM(2)+1
      IA1=((NUM(3)*36)+NUM(4))*36+NUM(5)
      IA2=((NUM(6)*36)+NUM(7))*36+NUM(8)
      RETURN
      END
C ***************     SUBROUTINE OUT     ***************
C
C THIS SUBROUTINE OUTPUTS THE CAPITAL BUDGETS
C FOR EACH PERIODS AND STORES THE TOTAL INVESTMENT IN EACH
C PLANT CATEGORY FOR THE FINAL SUMMARY.
C
      SUBROUTINE OUT(IP)
```

```
C
C DECLARE ARRAYS
C
      INTEGER A(10),DESTAL(3,2),GSIZE(5),CBSIZE(50),
     1NWAY(5),CSIZE(10),NAME(5),DATE(2)
      REAL UNCAB(6,3,5,50),COSCAB(6,3,5,50),UNCOND(5,10),
     1COSCON(5,10),UNLC(6),COSLC(6),SUMRY(5,9)
      COMMON /A/NSTAL,NGAUGE,NCBSIZ,CBSIZE,GSIZE,
     1DESTAL,SUMRY,NCSIZE,NNWAY,NWAY,CSIZE,NPER
     2,NAME,DATE
     3/B/UNCAB,COSCAB,UNCOND,COSCON,UNLC,COSLC,
     4UNPOLE,COSPOL
      WRITE(6,100) NAME,DATE,IP
100   FORMAT(//,5X,'SWITCHING CENTER: ',5A4,
     125X,'DATE: ',2A4,//,5X,'*****     ',
     2'SUBSCRIBER LOOP CAPITAL INVESTMENT',
     3' BUDGET FOR PERIOD',I2,'      *****')
C
C COMMENCE OUTPUTTING OF BUDGET BY CLASS OF
C PLANT.
C
      DO 1 IC=1,6
      READ(1,300) (A(I),I=1,10)
      WRITE(6,200) IC,(A(I),I=1,10)
200   FORMAT(/,5X,I1,'CLASS OF PLANT: ',10A4,//,
     161X,'UNIT',14X,'TOTAL',/,45X,'TOTAL',8X,'CONSTR.',
     210X,'ESTIMATED',/,10X,'ACCOUNT DESCRIPTION',7X,
     3'UNIT',5X,'UNITS',11X,'COST',15X,'COST',/)
300   FORMAT(10A4)
      READ(1,400) (A(I),I=1,2),IUNIT
400   FORMAT(2A4,I5)
      DO 2 IS=1,NSTAL
      DO 2 IG=1,NGAUGE
      DO 2 ISZ=1,NCBSIZ
      IF(UNCAB(IC,IS,IG,ISZ).EQ.0.0) GO TO 2
      ANO=UNCAB(IC,IS,IG,ISZ)/FLOAT(IUNIT)
      UCC=COSCAB(IC,IS,IG,ISZ)/ANO
      WRITE(6,500) (A(I),I=1,2),CBSIZE(ISZ),GSIZE(IG),
     1(DESTAL(IS,I),I=1,2),IUNIT,ANO,UCC,
     2COSCAB(IC,IS,IG,ISZ)
500   FORMAT(5X,2A4,1X,I5,'-',I2,2A4,5X,I5,4X,F6.0,
     15X,F10.2,5X,F14.2)
      SUMRY(IP,IC)=SUMRY(IP,IC)+COSCAB(IC,IS,IG,ISZ)
      COSCAB(IC,IS,IG,ISZ)=0.0
      UNCAB(IC,IS,IG,ISZ)=0.0
2     CONTINUE
      IF(MOD(IC,3).NE.1) GO TO 3
      READ(1,400) (A(I),I=1,2),IUNIT
      DO 4 ICS=1,NCSIZE
      DO 4 ICW=1,NNWAY
      IF(UNCOND(ICS,ICW).EQ.0.0) GO TO 4
      ANO=UNCOND(ICS,ICW)/FLOAT(IUNIT)
      UCC=COSCON(ICS,ICW)/ANO
      WRITE(6,600) (A(I),I=1,2),NWAY(ICW),CSIZE(ICS),IUNIT,
```

```
     1ANO,UCC,COSCON(ICS,ICW)
600   FORMAT(5X,2A4,2X,I5,'-',I4,10X,I5,4X,
     1F6.0,5X,F10.2,5X,F14.2)
      SUMRY(IP,7)=SUMRY(IP,7)+COSCON(ICS,ICW)
      COSCON(ICS,ICW)=0.0
      UNCOND(ICS,ICW)=0.0
4     CONTINUE
      GO TO 5
3     IF(MOD(IC,3).NE.2) GO TO 5
      READ(1,400) (A(I),I=1,2),IUNIT
      IF(UNPOLE.EQ.0.0) GO TO 5
      ANO=UNPOLE/FLOAT(IUNIT)
      UCC=COSPOL/ANO
      WRITE(6,700) (A(I),I=1,2),IUNIT,ANO,UCC,COSPOL
700   FORMAT(5X,2A4,22X,I5,4X,F6.0,5X,F10.2,5X,F14.2)
      SUMRY(IP,8)=COSPOL
      COSPOL=0.0
      UNPOLE=0.0
5     READ(1,400) (A(I),I=1,2),IUNIT
      IF(UNLC(IC).EQ.0.0) GO TO 1
      ANO=UNLC(IC)/FLOAT(IUNIT)
      UCC=COSLC(IC)/ANO
      WRITE(6,700) (A(I),I=1,2),IUNIT,ANO,UCC,COSLC(IC)
      SUMRY(IP,9)=SUMRY(IP,9)+COSLC(IC)
      COSLC(IC)=0.0
      UNLC(IC)=0.0
1     CONTINUE
C
C IF THE CURRENT PERIOD IS NOT THE LAST,
C BACKSPACE THE INPUT FILE SO THAT THE
C TYPES OF PLANT AVAILABLE CAN BE READ IN
C ONCE AGAIN
C
      IF(IP.EQ.NPER) RETURN
      DO 6 KK=1,22
      BACKSPACE 1
6     CONTINUE
      RETURN
      END
C ***************      SUBROUTINE SEARCH      ***************
C
C THIS SUBPROGRAM USES THE ARC CODE TO OBTAIN INFORMATION
C ON THE DIFFERENT TYPES OF PLANT THAT WENT INTO THE ARC.
C
      SUBROUTINE SEARCH(KODE,ITYPE,ICS,ICW,IS,IG,ISZ)
      ITYPE=KODE/10000000
      ICS=MOD(KODE,10000000)/1000000
      ICW=MOD(KODE,1000000)/10000
      IS=MOD(KODE,10000)/1000
      IG=MOD(KODE,1000)/100
      ISZ=MOD(KODE,100)
      IF (MOD(ITYPE,3).EQ.1) GO TO 1
      ICW=MOD(KODE,10000000)/10000
1     RETURN
```

```
      END
C
C ***************     SUBROUTINE ACOUNT     ***************
C
C THIS SUBPROGRAM ADDS THE COST OF THE ARC TO THE
C APPROPRIATE CONSTRUCTION ACCOUNT.
C
      SUBROUTINE ACOUNT(UNCOST,COIL,ITYPE,ICS,ICW,IS,IG,
     1ISZ,DIST)
C
C DECLARE ARRAYS
C
      REAL UNCOST(3),COSCON(5,10),UNCOND(5,10),UNLC(6),
     1UNCAB(6,3,5,50),COSCAB(6,3,5,50),COSLC(6)
      COMMON /B/UNCAB,COSCAB,UNCOND,COSCON,
     1UNLC,COSLC,UNPOLE,COSPOL
      IF(ITYPE.EQ.0) RETURN
      IX=MOD(ITYPE,3)
      IF(IX.NE.1) GO TO 1
      IF(ICS.EQ.0.OR.ICW.EQ.0) GO TO 1
      COSCON(ICS,ICW)=COSCON(ICS,ICW)+UNCOST(2)
      UNCOND(ICS,ICW)=UNCOND(ICS,ICW)+DIST
1     IF(IX.NE.2) GO TO 2
      UNPOLE=UNPOLE+FLOAT(ICW)
      COSPOL=COSPOL+UNCOST(2)
2     UNLC(ITYPE)=UNLC(ITYPE)+COIL
      COSLC(ITYPE)=COSLC(ITYPE)+UNCOST(1)
      IF(IS.EQ.0.OR.IG.EQ.0.OR.ISZ.EQ.0) GO TO 3
      UNCAB(ITYPE,IS,IG,ISZ)=UNCAB(ITYPE,IS,IG,ISZ)+DIST
      COSCAB(ITYPE,IS,IG,ISZ)=COSCAB(ITYPE,IS,IG,ISZ)+
     1UNCOST(3)
      RETURN
3     WRITE(6,100) ITYPE,ICS,ICW,IS,IG,ISZ
100   FORMAT('SUBSCRIPT HAS VALUE ZERO',/,'ITYPE=',
     1I2,5X,'ICS=',I3,5X,'ICW=',I3,5X,'IS=',I3,5X,
     2'IG=',I3,5X,'ISZ=',I3)
      RETURN
      END
```

APPENDIX-D THE COST MODEL COMPUTER PROGRAM

This program is a subroutine of the total optimization system. The program, written in FORTRAN IV, was run on an AMDAHL 470 V/6 machine at the University of Alberta Computing Services.This program run in conjunction with the input conversion system, master control unit(PNET program) and the output conversion system will give the near optimal plant layout and the capital budgeting information, including the construction program by switching center area. The cost model contains eight subprograms, namely MAINT, FCOST, CODE, EXCOST, NEWSIZ, TECH, GAREA, and AVCOST in addition to the main program.

The glossary of the variables used in the program is explained below, followed by the computer listing of the program.

D.1 Glossary of the Variables

CAP1 — An integer referring to the lower capacity of the plant in an arc.

CAP2 — An integer referring to the upper capacity of the plant in an arc. This is a variable.

B — A variable used to refer to the first cost.

CODARC(J) — A code used to refer to the size of plant used in an arc. This code is assembled inside the cost model for describing a particular arc. It is an eight digit code which has three parts: the first part contains one digit, the second contains three digits and the last part has four digits. The first part refers to the code specifying the class of plant, ITYPE. Part two contains the number of poles needed in the case of aerial cable, the size and number of ways of conduit used in the case of underground cable, and zero values in the case of buried cable plant. The third part contains the describtion of the cable used ; one digit for the major category of the cable (1-stalpeth, 2-alpeth etc.),the next digit for the gauge of cable used (1 for gauge 26, 2 for gauge 24,3 for gauge 22, 4 for gauge 19), and the last two digits are for the size of the cable (01 for 11 pair, 02 for 25 pair and so on).

COIL A variable used to account for the number of loadings coils used in the arc considered.

CONCOS(I,J) A variable referring to the cost of conduit . The cost are stored in a matrix referred to by the size and number of ways of the conduit.

COSTL A variable to denote the labor cost.

COSTM A variable to denote the material cost.

CTF The capital tax factor.

DFACTO(I,J)

Difficulty rating matrix (a 7X4 matrix)

DLCOST(I) Total direct labor cost by function performed (an 8 row matrix).

DLRATE(I) The direct labor rate by craft type. (a 5 row matrix).

DLRMAT(I,J)

Components of the direct labor wage payment for the differnt types of craft (a 5X5 matrix).

DRTIME(I) Direct labor time by function performed (an 8 row matrix).

DRZ(I) Depreciation rate applicable to each type of plant (a 9 column matrix).

EQUIPM (I,J,K,L) A variable representing the cost of any additional equipment required at the nodes of the arc in installing the cable plant. (If necessary the cable splicing equipment can be included in this category).

FUNPER(I,J) A matrix containg the time elements to do a particular function.

GAUGE(I) Refers to the airline distance of the beginning node I of the arc IJ, from the switching center.

GFMAIN Percentage growth in maintenance cost of a unit of plant as it ages. This is estimated by the maintenance department.

GSIZE(K) A variable used to refer to the gauge of the cable.

I	A variable used in the do-loops.
ID	The interest rate on debt capital.
IE	The interest rate on equity capital.
IF	The inflation rate .
IFREQ	The frequency of usage of a particular type of equipment .
IGAUGE	A variable counter used in choosing the gauge of the cable .
IIMAX	Maximum number of available cables of different sizes.
INTCPT(I, J,K)	The intercept of the regression line of cable cost per unit length versus the number of pairs.
ISPEC	A variable containing five digits and is used to refer to an arc, as explained below; the first digit =1 means the arc needs loading, =2 means the arc is non-loaded, the second digit =1 refers to stalpeth cable, =2 refers to alpeth cable,and the third, fourth and the fifth digits refer to the gauge of the cable, (e.g. 026).
ISTAL	A code to represent the different types of cable; 1-for stalpeth, 2-for alpeth.
ITYPE	Denotes the type of plant used in an arc. The number codes used for describing an the arc: 1 =underground paired cable, 2 =aerial paired cable,

	3 =buried paired cable,
	4 =underground coaxial cable,
	5 =aerial coaxial cable, and
	6 =buried coaxial cable.
IT	The technological growth rate.
J	A variable used in the do-loops.
KODARC	A code to refer to the size of the plant,(equivalent to CODARC).
KOIL	Refer to COIL.
LCINT	Average distance between loading coils.
LCCOIL	Number of different load coils considered.
LCCOST	Cost of load coils by type.
LLOAD(I,J)	Individual items of indirect labor loadings(a 6X4 matrix).
LPER	Length of each time period considered (normally one year).
LSUM(I)	Total labor loadings expressed as a percentage of the direct labor cost (a 4 row matrix).
MHCOST	The cost of construction of a manhole expressed for different types of manholes considered.
MHOLE	Number of different types of manhole or vaults.
NCALL	A counter to keep track of the number of times the cost model was called.
NCSIZE	The number of different sizes of conduits available.
NGAUGE	The maximum number of gauges of all the cables considered .

NGMAX	The maximum number of gauges of a particular kind of cable that is available.
NN	The planning horizon (normally 30 years).
NNEX(I)	The remaining useful life of the existing plant , expressed for each category of plant.
NPER	The number of periods considered in the planning period.
NSIZE	Number of different sizes of cable that is available.
NUMDIS	The number of resistance limiting distances.
NOWAY(I,J)	The number of ways of conduits for each different sizes of conduits available.
NUMWAY	The number of number of ways of conduits that can be installed.
OHLOAD(I)	The overall loading on the combined direct material and direct labor costs.This is divided into four groups.
OHPERC	Total loading on direct labor and direct material costs, expressed as a percentage.
OPCOST(I,J)	The operating cost by year for the different categories of plant.
PARA	The parameter 'A' in the technology assessment curve.
PARAFO	The parameter 'f(0)' in the technology assessment curve. This will be equated to one in the first period , in order to express the other values interms of this base index.

PARK	The parameter 'k' in the technology assessment curve.
PAIRS(I)	The number of pair count in the cable considered.
PEC	The present equivalent cost.
PMC	The present equivalent of maintenance cost factor.(p/c factor)
PRCENT(I,J)	Percentage work contribution by each craft for different category of function performed.
PRICE(I)	The prices of cables stored in an array.
POLCOS	Average cost of a pole.
POLDIS	Average distance between two poles.
RD	The debt equity ratio.
SIZE(I, J,K,L)	It is a four dimensional array that refers to the cable size (L), to the type of plant (I), the type of cable(J), and to the gauge(K).
SLOPE(I,J,K)	The slope of the regression line.(cost per meter against the number of pairs of cable)
SPEC(I,M,N)	It is an array containing the code ITYPE and the limiting loading distances for various types of plant. It is a three dimensional array.
TINDEX(I)	The ordinates of the 'S' curve in various years.
TIME	A variable representing the different years.
TOTCOS(I)	The total wage payment from the payroll information.

TT	The effective tax rate.
UNCOST(I,J)	A 2x3 matrix containing the construction costs for the arc under consideration. It stores the cost in three categories: cost of loading, cost of conduiting/poles, and cost of cabling.
UNKOST(I,J)	Similiar to the above variable.
VNNEX(I)	Salvage value of the existing classes of plant at the end of their useful life.
VO(I)	Current salvage value of the existing plant.

Table D.1 The Cost Model Computer Program.

```
C***********COST MODEL COMPUTER PROGRAM***********
C THIS PROGRAM CALCULATES THE ARC COST IN ANY GIVEN
C NODE.
C
C DIMENSION THE ARRAYS USED IN THE PROGRAM.
C THE REAL VARIABLES ARE DECLARED FIRST, FOLLOWED
C BY THE INTEGER VARIABLES.
C
      SUBROUTINE COST(IGEO,DIST,ITYPE,CAP1,CAP2,NYEAR,
     %GAUGE,LINES,ITECH,ICOST)
      REAL DLRMAT(5,5),TOTCOS(5),DLRATE(5),TMANHR(5),
     %FUNPER(8,5),DRTIME(8),PRCENT(5,8),DLCOST(8),
     %LLOAD(6,4),MLOAD(6,4),LSUM(6),MSUM(6),
     %SLOPE(6,3,5),INTCPT(6,3,5),EQUIPM(6,2,4,40),
     %MHCOST,LCCOST(6),CONCOS(5,6),OHLOAD(4),IT(5),
     %IE,ID,IF,IA(5),CTF(5,9),PEF(5),PMC(5),PPEF(5),
     %UNDEP(9),OPCOST(5,9),SPEC(6,2,10),VO(9),
     %DIAMTR(50),PERSAL(9),COIL(2),UNCOST(2,3),
     %KOIL,UNKOST(3),FACTOR(5),DFACTO(7,4),
     %SIZE(6,2,4,40),TINDEX(5),DRZ(9),BV(9)
     %,VNNEX(9),PRICE(50),TIME(5)
C
C
      INTEGER NOWAY(5,10),LIMIT(5),CAP1,CAP2,QTY(9),
     %NUMLIN(6),
     %NNEX(6),GSIZE(5),CODARC(2),PAIRS(35)
C
C THE COMMON BLOCKS ARE DECLARED BELOW.
C
      COMMON /F/KODARC,KOIL,UNKOST//NCALL,NUMDIS,SPEC,
     %TT,TINDEX,PPEF,PEF,NPER,TIME
     %/A/DFACTO
     %/B/PARAFO,PARA,PARK
     %/C/NSIZE,SIZE
     %/D/VO,VNNEX
     %/E/CODARC,COIL,UNCOST
     %/G/LCINT,POLDIS
     %/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,NCSIZE,LIMIT
     %,CONCOS,MHCOST,INTCPT,SLOPE,EQUIPM,POLCOS,NGAUGE,GSIZE
     %/J/OPCOST,GFMAIN,NNEX,PMC,IA
     %/K/CTF
     %/L/PAIRS
C
C INITIALIZE THE VARIABLES.
C
      ICOMP=0
      DO 1800 LP=1,2
      CODARC(LP)=0
      COIL(LP)=0.
```

```
      DO 1801 MP=1,3
      UNCOST(LP,MP)=0.
1801  CONTINUE
1800  CONTINUE
C UPDATE THE NUMBER OF TIMES THIS PROGRAM WAS CALLED.
C
      NCALL=NCALL+1
C IF CALLING FOR THE SECOND TIME OR MORE SKIP THE
C CALCULATION OF DIRECT LABOR COST,DIRECT LABOR
C RATES etc.
      IF(NCALL.GT.1) GO TO 100
C READ THE PLANNING HORIZON, LENGTH OF PLANNING
C PERIODS.
      READ(1,6)NPER
      DO 1401 KK=1,NPER
      READ(1,6) LPER
      IF(KK.NE.1)GO TO 1402
      TIME(1)=FLOAT(LPER)
      GO TO 1401
C ADVANCE THE TIME TO INDICATE THE CORRECT PERIOD.
1402  TIME(KK)=TIME(KK-1)+FLOAT(LPER)
1401  CONTINUE
C READ THE WAGES, FRINGE BENIFITS etc. FOR CALCULATION
C OF DIRECT LABOR COST.
      READ(1,1) ((DLRMAT(I,J),J=1,5),I=1,5)
1     FORMAT(5F10.2)
      DO 1000 I=1,5
      TOTCOS(I)=0.0
      DLRATE(I)=0.0
      DO 1001 J=1,5
C CALCULATE THE TOTAL WAGE PAYMENT.
      TOTCOS(I)=TOTCOS(I)+DLRMAT(I,J)
1001  CONTINUE
C READ THE DIRECT MANHOURS BY EACH CRAFT, AND THE
C PRODUCTIVITY FACTOR OF EACH CRAFT.
      READ(1,1)TMANHR(I),FACTOR(I)
      TMANHR(I)=TMANHR(I)*FACTOR(I)
      IF(TMANHR(I).EQ.0)GO TO 1000
C FIND THE DIRECT LABOR RATE BY CRAFT TYPE.
      DLRATE(I)=TOTCOS(I)/TMANHR(I)
1000  CONTINUE
      DO 1002 I=1,8
C READ  THE DIRECT LABOR TIME TO PERFORM DIFFERENT
C FUNCTIONS.
      READ(1,2) (FUNPER(I,J),J=1,5)
2     FORMAT(5F10.4)
      DRTIME(I)=0.0
      DO 1003 K=1,5
      DRTIME(I)=DRTIME(I)+FUNPER(I,K)
1003  CONTINUE
1002  CONTINUE
C
C CALCULATE DIRECT LABOR COST BY FUNCTION PERFORMED.
C
```

```
      READ(1,3)((PRCENT(I,J),J=1,8),I=1,5)
3     FORMAT(8F10.8)
      DO 1004 I=1,8
      DLCOST(I)=0.0
      DO 1005 J=1,5
      DLCOST(I)=DLCOST(I)+PRCENT(J,I)*DLRATE(J)
1005  CONTINUE
      DLCOST(I)=DLCOST(I)*DRTIME(I)
1004  CONTINUE
      READ(1,4)((DFACTO(I,J),J=1,4),I=1,7)
4     FORMAT(4F10.2)
C
C CALCULATE DIRECT LABOR LOADINGS, DIRECT MATERIAL
C LOADINGS.
C
      READ(1,5)((LLOAD(I,J),MLOAD(I,J),J=1,4),I=1,6)
5     FORMAT(8F10.2)
      DO 2105 I=1,6
      LSUM(I)=0.
      MSUM(I)=0.
      DO 1006 J=1,4
      LSUM(I)=LSUM(I)+LLOAD(I,J)
      MSUM(I)=MSUM(I)+MLOAD(I,J)
1006  CONTINUE
2105  CONTINUE
C
C READ THE CABLE DATA : THE NUMBER OF PAIRS,THE GAUGES
C OF CABLE AVAILABLE, AND THEIR PRICE.
      READ(1,6)NGAUGE
      DO 1201 K=1,NGAUGE
      READ(1,6)GSIZE(K)
1201  CONTINUE
      READ(1,6)NSIZE
      READ(1,40)(PAIRS(L),L=1,NSIZE)
40    FORMAT(20I4)
      DO 1507 I=1,6
      READ(1,6)ISTAL
      IF(ISTAL.EQ.0)GO TO 1507
      READ(1,6)NUMDIS
      IF(NUMDIS.EQ.0)GO TO 1507
      DO 1018 N=1,NUMDIS
C
C READ THE CABLE DESIGN SPECIFICATIONS.
C
      READ(1,14)(SPEC(I,M,N),M=1,2)
14    FORMAT(F10.2,F5.0)
1018  CONTINUE
6     FORMAT(I3)
      DO 1607 J=1,ISTAL
      READ(1,6)NGMAX
      IF(NGMAX.EQ.0)GO TO 1607
      DO 1007 K=1,NGAUGE
      READ(1,6)IIMAX
      IF(IIMAX.EQ.0)GO TO 1007
```

```
      DO 1403 II=1,IIMAX
C
C READ CABLE SIZES,PRICEAND ANY OTHER ADDITIONAL
C EQUIPMENT NEEDED ALONG WITH THE CABLES.
      READ(1,4)SIZE(I,J,K,II),PRICE(II),EQUIPM(I,J,K,II)
1403  CONTINUE
C
C DO THE REGRESSION AND FIND THE SLOPE AND THE INTERCEPT
C OF ALL THE CABLES CONSIDERED. STORE THESE VALUES.
C
      MSIZE=0.
      SUMX=0.
      SUMY=0.
      SUMXY=0.
      SUMX2=0.
      DO 1008 ISIZE=1,IIMAX
      IF(PRICE(ISIZE).EQ.0)GO TO 1008
      MSIZE=MSIZE+1
      SUMX=SUMX+SIZE(I,J,K,ISIZE)
      SUMY=SUMY+PRICE(ISIZE)
      SUMXY=SUMXY+SIZE(I,J,K,ISIZE)*PRICE(ISIZE)
      SUMX2=SUMX2+SIZE(I,J,K,ISIZE)*SIZE(I,J,K,ISIZE)
1008  CONTINUE
      SLOPE(I,J,K)=(SUMXY-(SUMX*SUMY)/MSIZE)/
     %(SUMX2-((SUMX*SUMX)/MSIZE))
      INTCPT(I,J,K)=(SUMY-SLOPE(I,J,K)*SUMX)/MSIZE
1007  CONTINUE
C
1607  CONTINUE
1507  CONTINUE
C
C
C READ THE MANHOLE COST,  THE CONDUIT COST, AND THE
C LOADING COIL COST.
      READ(1,6)MHOLE
      MHCOST=AVCOST(MHOLE)
      READ(1,7)LCINT
      DO 1024 I=1,6
      READ(1,6)LCCOIL
1024  LCCOST(I)=AVCOST(LCCOIL)
      READ(1,7)NCSIZE
7     FORMAT(2I6)
      DO 1009 I=1,NCSIZE
      READ(1,7)LIMIT(I),NUMWAY
      READ(1,8)(NOWAY(I,J),CONCOS(I,J),J=1,NUMWAY)
8     FORMAT(I3,F10.2)
1009  CONTINUE
      READ(1,31)POLCOS,POLEQ,POLDIS
31    FORMAT(3F10.2)
      READ(1,1)(OHLOAD(I),I=1,4)
      OHPERC=0.
      DO 1010 I=1,4
1010  OHPERC=OHPERC+OHLOAD(I)
C
```

```
C READ THE FINANCIAL DATA: TAX RATE,DEBT RATIO,INTEREST
C ON EQUITY,INTEREST ON DEBT, AND THE INFLATION RATE.
C
      READ(2,9)TT,RD,IE,ID,IF
9     FORMAT(5F10.5)
C READ THE PLANNING HORIZON , THE DEPRECIATION RATE
C BY TYPE OF PLANT, SALVAGE VALUE BY TYPE OF PLANT
C IN THE CASE OF NEWLY INSTALLED PLANT.
      READ(2,10)NN,(DRZ(I),I=1,9)
      READ(2,22) (PERSAL(I),I=1,9)
10    FORMAT(I3,/,9F5.3)
C
C READ THE TECHNOLOGY CURVE PARAMETERS AND THE GROWTH
C FACTOR ATTRIBUTABLE TO MAINTENANCE COST.
C
      READ(2,11)PARAFO,PARA,PARK,GFMAIN
11    FORMAT(4F10.5)
C CALCULATE THE TECHNOLOGY INDEX FOR VARIOUS YEARS FROM
C THE TECHNOLOGY CURVE.
      DO 1011 I=1,NPER
      TINDEX(I)=TECH(TIME(I))
      IT(I)=1.-EXP(ALOG(TECH(TIME(I)+FLOAT(NN))
     %/TECH(TIME(I)))
     %/FLOAT(NN))
C
C CALCULATE THE MINIMUM ATTRACTIVE RATE OF RETURN.
      IA(I)=(1.-RD)*((1.+IE)*(1.+IF)*(1.-IT(I))-1.)
     %+(1.-TT)*RD*ID
      DO 1012 J=1,9
C
C CALCULATE THE CAPITAL TAX FACTOR.
      CTF(I,J)=1.-(TT*DRZ(J))/(IA(I)+DRZ(I))
1012  CONTINUE
C
C FIND THE PARTIAL PRESENT EQUIVALENT OF FUTURE SUM AND
C THE PRESENT EQUIVALENT OF A FUTURE SUM FACTORS.
      PPEF(I)=1./((1.+IA(I))**NN)
      PEF(I)=1./((1.+IA(I))**TIME(I))
C
C COMPARE THE GROWTH RATE OF MAINTENANCE COST WITH THE
C MARR AND CALCUALTE THE APPROPRIEATE PRECENT EQUIVALENT
C OF MAINTENANCE COST FACTORS.
C
      IF(GFMAIN-IA(I)) 1013,1014,1015
C
1013  X=(1.+IA(I))/(1.+GFMAIN)-1.
      PMC(I)=(1./(1.+GFMAIN))*((1.+X)**NN-1.)/(X*((1.+X)
     %**NN))
      GO TO 1011
1014  PMC(I)=NN/(1.+IA(I))
      GO TO 1011
1015  X=(1.+GFMAIN)/(1.+IA(I))-1.
      PMC(I)=(1./(1.+IA(I)))*((1.+X)**NN-1.)/X
1011  CONTINUE
```

```
C
CIN THE CASE OF THE EXISTING PLANT READ THE LIFE OF EACH
C CATEGORY OF PLANT, THE PRESENT SALVAGE VALUE, AND FUTURE
C SALVAGE AT RETIREMENT.
C
13     FORMAT(6I10)
       READ(2,13) (NNEX(I),I=1,6)
       READ(2,22) (VNNEX(I),I=1,9)
C READ THE ANTICIPATED OPERATING COST PER UNIT SIZE OF
C PLANT FOR A VINTAGE INSTALLED IN THE FIRST , SECOND,
C THIRD, FOURTH PERIODS RESPECTIVELY BY EACH CATEGORY
C OF PLANT.
       NPER1=NPER+1
       DO 1023 I=1,NPER1
       READ(2,22) (OPCOST(I,J),J=1,9)
22     FORMAT(5F10.2,/,4F10.2)
1023   CONTINUE
100    KTYPE=ITYPE
C COMPARE 1.27 TIMES THE AIRLINE DISTANCE WITH THE
C LOADING LIMIT DISTANCES, AND SELECT THE PROPER
C CABLE.
       DIST2=1.27*GAUGE+DIST
       DO 1021 I=1,NUMDIS
       IF(DIST2.LE.SPEC(KTYPE,1,I))GO TO 1022
1021   CONTINUE
C IF NONE OF THE AVAILABLE CABLES IS WITHIN THE
C RESISTANCE LIMIT DISTANCE OUTPUT A SIGNAL.
       WRITE(6,21)
21     FORMAT('ENDING NODE OUT OF RANGE')
       STOP
C SELECTING THE PROPER GAUGE OF THE CABLE.
1022   ISPEC=IFIX(SPEC(KTYPE,2,I))
       JSPEC=MOD(ISPEC,10000)/1000
       JGAUGE=MOD(ISPEC,1000)
       DO 3000 IGAUGE=1,NGAUGE
       IF(GSIZE(IGAUGE).EQ.JGAUGE)GO TO 3001
3000   CONTINUE
3001   KSPEC=IGAUGE
       IF(CAP1.NE.CAP2)GO TO 1019
       IF(CAP1.EQ.0)GO TO 1020
C IN THE CASE OF THE EXISTING PLANT, CALCULATE THE
C PRESENT EQUIVALENT OF MAINTENANCE COST AND THE
C CAPITAL COST OF THE EXISTING PLANT.
       CALL MAINT(10,KTYPE,CAP1,CAP2,0,DIST,ISPEC,LINES,PEM)
       CALL EXCOST(10,KTYPE,CAP1,CAP2,0,DIST,ISPEC,B,V)
C
C
C
C
C CALCULATE THE PRESENT EQUIVALENT COST OF THE PLANT.
C
C
       PEC=PEM+(B-(V/((1.+IA(1))**NNEX(KTYPE))))/(1.-TT)
C FIND THE UNIT COST(IN CENTS) OF THE ARC BY DIVIDING
```

```
C BY THE FLOW IN THE ARC.
      ICOST=IFIX(PEC*100./FLOAT(CAP1))
      RETURN
C
C
1020  CAP1=SIZE(ITYPE,JSPEC,KSPEC,1)
      CAP2=CAP1
      CALL MAINT(20,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(20,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
C EVALUATE THE CODE OF THE CABLE SELECTED AND ITS COST.
      CALL CODE(1,KODARC,KOIL,UNKOST)
      GO TO 1100
1019  IF(CAP1.EQ.0)GO TO 1030
      IF(CAP2.EQ.0)GO TO 1031
C UPDATING THE NON-PRIMARY ARC FOR THE SECOND TIME.
      CALL MAINT(31,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(31,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
      CALL CODE(1,KODARC,KOIL,UNKOST)
      GO TO 1100
C UPDATING THE PRIMARY ARC, FOR THE FIRST TIME.
1030  CAP2=NEWSIZ(ITYPE,JSPEC,KSPEC,CAP2)
      CALL MAINT(21,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(21,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
      CALL CODE(1,KODARC,KOIL,UNKOST)
      IF(MOD(KTYPE,3).EQ.1)GO TO 1100
      ICOMP=1
      CALL MAINT(21,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM2)
      CALL FCOST(21,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B2,V2)
      CALL CODE(2,KODARC,KOIL,UNKOST)
      GO TO 1100
C UPDATING THE NON-PRIMARY ARC FOR THE FIRST TIME.
1031  CAP2=NEWSIZ(ITYPE,JSPEC,KSPEC,CAP1+1)
      CALL MAINT(30,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(30,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
      CALL CODE(1,KODARC,KOIL,UNKOST)
C
1100  PEC=(PEM+TINDEX(NYEAR)*(B-V*PPEF(NYEAR))/(1.-TT))
     %*PEF(NYEAR)
      IF(ICOMP.EQ.0)GO TO 1200
C
C
C
      PEC2=(PEM2+TINDEX(NYEAR)*(B2-V2*PPEF(NYEAR))/(1.-TT))
     %*PEF(NYEAR)
```

```
      IF(PEC-PEC2) 1200,1200,1105
1105  ITYPE=KTYPE
      PEC=PEC2
      CODARC(1)=CODARC(2)
      COIL(1)=COIL(2)
      DO 1220 IL=1,3
1220  UNCOST(1,IL)=UNCOST(1,IL)
1200  IF(CAP2.EQ.CAP1) GO TO 1700
      ICOST=IFIX(PEC*100./FLOAT(CAP2-CAP1))
      RETURN
1700  ICOST=IFIX(PEC*100./FLOAT(CAP1))
      RETURN
      END
C
C **********SUBROUTINE MAINT***************************
C
C THIS SUBROUTINE CALCULTES THE PRESENT EQUIVALENT OF
C MAINTENANCE COST FOR EXISTING PLANT AND NEWLY
C INSTALLED PLANT.
      SUBROUTINE MAINT(KODE,ITYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
C DECLARATION OF VARIABLES.
      REAL OPCOST(5,9),IA(5),PMC(5)
      INTEGER NNEX(6)
      COMMON/G/LCINT,POLDIS/J/OPCOST,GFMAIN,NNEX,PMC
     %,IA
      INTEGER CAP1,CAP2,CAP
C INITIALIZE PEM.
      PEM=0
      NYEAR=NYEAR+1
      CAP=CAP2
      IF((KODE/10).EQ.3) CAP=CAP2-CAP1
C CALCULATE THE PEM FOR MISCELLENEOUS  EQUIPMENT.
C IF CALCULATING FOR THE NON-PRIMARY ARC ONLY THE
C INCREMENTAL PEM IS TO BE CALCULATED.
      IF((ISPEC/10000).EQ.1) PEM=PEM+OPCOST(NYEAR,9)*(DIST
     %/FLOAT(LCINT))
      IF(MOD(ITYPE,3).NE.1) GO TO 2
      IF(KODE.NE.10) GO TO 21
C CALCULATE PEM FOR DUCTS AND VAULTS.
      PEM=PEM+OPCOST(NYEAR,7)*LINES*DIST
      GO TO 22
21    IF(LINES*100.GE.CAP) GO TO 23
C CALCULATE PEM FOR CABLES.
22    PEM=PEM+OPCOST(NYEAR,7)*DIST
23    PEM=PEM+OPCOST(NYEAR,6)*DIST*CAP
      IF(ITYPE.EQ.4) PEM=PEM+(OPCOST(NYEAR,4)-OPCOST(NYEAR,6
     %))*DIST*CAP
      GO TO 10
2     IF(MOD(ITYPE,3).NE.0) GO TO 3
      PEM=PEM+OPCOST(NYEAR,4)*DIST*CAP
      IF(ITYPE.EQ.6) PEM=PEM+(OPCOST(NYEAR,5)-OPCOST(NYEAR,4
     %))*DIST*CAP
      GO TO 10
```

```
3       IF(KODE.EQ.10)GO TO 24
        IF(LINES*100.GE.CAP)GO TO 25
24      PEM=PEM+OPCOST(NYEAR,2)*(DIST/POLDIS)
25      PEM=PEM+OPCOST(NYEAR,1)*DIST*CAP
        IF(ITYPE.EQ.5)PEM=PEM+(OPCOST(NYEAR,3)-OPCOST(NYEAR,1
       %))*DIST*CAP
10      NYEAR=NYEAR-1
        IF(NYEAR.NE.0)GO TO 11
C COMPARE THE GROWTH FACTOR IN MAINTENANCE WITH MARR
C AND CALCULATE THE APPROPRIEATE PEM FACTOR.
        IF(GFMAIN-IA(1))4,5,6
4       X=(1.+IA(1))/(1.+GFMAIN)-1.
        PEM=(1./(1.+GFMAIN))*((1.+X)**NNEX(ITYPE)-1.)/
       %(X*((1.+X)**NNEX(ITYPE)))*PEM
        GO TO 7
5       PEM=(NNEX(ITYPE)/(1.+IA(1)))*PEM
        GO TO 7
6       X=(1.+GFMAIN)/(1.+IA(1))-1.
        PEM=PEM*((1./1.+IA(1)))*((1.+X)**NNEX(ITYPE)-1.)/X
7       RETURN
11      PEM=PEM*PMC(NYEAR)
        RETURN
        END
C
C ************SUBROUTINE FCOST***********8******
C
C THIS SUBROUTINE CALCULATES THE FIRST COST OF NEWLY
C INSTALLED PLANT. IT CALCULATES THE LABOR COST, MATERIAL
C COST AND ANDS THE OVERHEADS TO THEM.
        SUBROUTINE FCOST(KODE,ITYPE,CAP1,CAP2,NYEAR,DIST,LINES
       %,ISPEC,IGEO,B,V)
        REAL CTF(5,9),LCCOST(6),PERSAL(9),DLCOST(8)
       $,MSUM(6),CONCOS(5,6),MHCOST,INTCPT(6,3,5),SLOPE(6,3,5)
       %,EQUIPM(6,2,4,40),SIZE(6,2,4,40),UNCOST(3),LSUM(6)
        DIMENSION OLDCOS(3)
        INTEGER CODARC,GSIZE(5),CAP1,CAP2,LIMIT(5),PAIRS(35)
        COMMON/C/NSIZE,SIZE/G/LCINT,POLDIS
       %/F/CODARC,COIL,UNCOST
       %/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,
       %NCSIZE,LIMIT,CONCOS,MHCOST,INTCPT,SLOPE,
       %EQUIPM,POLCOS,NGAUGE,GSIZE
       %/K/CTF/L/PAIRS
        COSTL=0.
        COSTM=0.
        DO 2 I=1,3
2       UNCOST(I)=0.
        COIL=0.
        CODARC=0
        KOUNT=0
        B=0.
        VM=0.
        VL=0.
        JSPEC=MOD(ISPEC,10000)
        KSPEC=MOD(ISPEC,1000)
```

```
      JSPEC=JSPEC/1000
      DO 11 IG=1,NGAUGE
      IF(KSPEC.EQ.GSIZE(IG))GO TO 12
11    CONTINUE
12    KSPEC=IG
20    DO 13 ICAP=1,NSIZE
      IF(CAP1.EQ.PAIRS(ICAP))GO TO 14
13    CONTINUE
14    MSPEC=ICAP
      CODARC=ITYPE*10000000
      CODARC=CODARC+JSPEC*1000+KSPEC*100+MSPEC
      DO 2222 ICAP=1,40
      IF(CAP1.EQ.SIZE(ITYPE,JSPEC,KSPEC,ICAP))GO TO 2223
2222  CONTINUE
2223  MSPEC=ICAP
      IF((ISPEC/10000).NE.1)GO TO 22
      COSTM=COSTM+LCCOST(ITYPE)*CTF(NYEAR,9)*DIST
     %/FLOAT(LCINT)
      VM=VM+COSTM*PERSAL(9)
      COSTL=COSTL+DLCOST(8)*DIST/FLOAT(LCINT)
      VL=VL+COSTL*PERSAL(9)
      COIL=(DIST/FLOAT(LCINT))
      UNCOST(1)=(COSTL*(1.+LSUM(ITYPE)/100.)
     %+COSTM*(1.+MSUM(ITYPE)/100.))*(1.+OHPERC/100.)
22    IF(MOD(ITYPE,3).NE.1)GO TO 6
      IF((LINES*100).GE.CAP1)GO TO 7
      NCAP1=CAP1-LINES*100
      DO 8 I=1,NCSIZE
      IF(LIMIT(I).LT.NCAP1)GO TO 8
      J=1
      GO TO 9
8     CONTINUE
C
C
C
      I=NCSIZE
      J=NCAP1/LIMIT(NCSIZE)
      IF(MOD(NCAP1,LIMIT(NCSIZE)).NE.0)J=J+1
9     COSTM1=(CONCOS(I,J)*DIST+MHCOST)
      COSTM=COSTM+COSTM1*CTF(NYEAR,7)
      VM=VM+COSTM1*PERSAL(7)
      CODARC=CODARC+I*1000000+J*10000
      UNCOST(2)=COSTM1*(1.+MSUM(ITYPE)/100.)+UNCOST(2)
      CALL GAREA(IGEO,3,GFACTO)
      COSTL1=(DLCOST(3)*GFACTO)*DIST
      COSTL=COSTL+COSTL1*CTF(NYEAR,7)
      VL=VL+COSTL1*PERSAL(7)
      UNCOST(2)=COSTL1*(1.+LSUM(ITYPE)/100.)+UNCOST(2)
      CALL GAREA(IGEO,5,GFACTO)
      COSTL1=(DLCOST(5)*GFACTO)*DIST
      COSTL=COSTL+COSTL1*CTF(NYEAR,7)
      VL=VL+COSTL1*PERSAL(7)
      UNCOST(2)=COSTL1*(1.+LSUM(ITYPE)/100.)+UNCOST(2)
7     JDEP=((ITYPE+5)/ITYPE)*ITYPE
```

```
      CALL GAREA(IGEO,4,GFACTO)
      COSTL1=DLCOST(4)*GFACTO*CAP1
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+(1.+LSUM(ITYPE)/100.)*COSTL1
C
      IF(ITYPE.EQ.4) GO TO 10
      COSTM1=(INTCPT(1,JSPEC,KSPEC)+(SLOPE(1,JSPEC,KSPEC)*
     %CAP1))*DIST+EQUIPM(1,JSPEC,KSPEC,MSPEC)
      COSTM=COSTM+COSTM1*CTF(NYEAR,6)
      VM=VM+COSTM1*PERSAL(6)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
      GO TO 15
10    COSTM1=((INTCPT(4,JSPEC,KSPEC)+SLOPE(1,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(4,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,8)
      VM=VM+COSTM1*PERSAL(8)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
15    COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      COSTL=COSTL*(1.+LSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      VL=VL*(1.+LSUM(ITYPE)/100.)
      B=(COSTM+COSTL)*(1.+OHPERC/100.)
      V=(VM+VL)*(1.+OHPERC/100.)
      GO TO 5
6     IF(MOD(ITYPE,3).EQ.0)GO TO 16
      IF((LINES*100).GE.CAP1)GO TO 17
      NOPOLE=IFIX(DIST/POLDIS)
      IF((FLOAT(NOPOLE)*POLDIS).NE.DIST)NOPOLE=NOPOLE+1
      CODARC=NOPOLE*10000
      COSTM1=FLOAT(NOPOLE)*POLCOS*(1.+POLEQ/100.)
      COSTM=COSTM+COSTM1*CTF(NYEAR,2)
      VM=VM+COSTM1*PERSAL(2)
      UNCOST(2)=UNCOST(2)+COSTM1*(1.+MSUM(ITYPE)/100.)
      CALL GAREA(IGEO,1,GFACTO)
      COSTL=GFACTO*FLOAT(NOPOLE)*DLCOST(1)
C
C
C
      COSTL=COSTL+COSTL1*CTF(NYEAR,2)
      VL=VL+COSTL1*PERSAL(2)
      UNCOST(2)=UNCOST(2)+COSTL1*(1.+LSUM(ITYPE)/100.)
17    CALL GAREA(IGEO,1,GFACTO)
      JDEP=((ITYPE/2)+MOD(ITYPE,2))
      COSTL1=(DLCOST(2)*GFACTO)
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTL1*(1.+LSUM(ITYPE)/100.)
      IF(ITYPE.EQ.5)GO TO 18
      COSTM1=((INTCPT(2,JSPEC,KSPEC)+SLOPE(2,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(2,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,1)
      VM=VM+COSTM1*PERSAL(1)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
```

```
      GO TO 19
18    COSTM1=((INTCPT(5,JSPEC,KSPEC)+SLOPE(5,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(5,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,3)
      VM=VM+COSTM1*PERSAL(3)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
19    COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      COSTL=COSTL*(1.+LSUM(ITYPE)/100.)
      VL=VL*(1.+LSUM(ITYPE)/100.)
      B=(COSTM+COSTL)*(1.+OHPERC/100.)
      V=(VM+VL)*(1.+OHPERC/100.)
      GO TO 5
16    JDEP=5-MOD(ITYPE,2)
      CALL GAREA(IGEO,6,GFACTO)
      COSTL1=(DLCOST(6)*GFACTO)
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTL1*(1.+LSUM(ITYPE)/100.)
      CALL GAREA(IGEO,7,GFACTO)
      COSTL1=(DLCOST(7)*GFACTO)
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTL1*(1.+LSUM(ITYPE)/100.)
      COSTM1=(INTCPT(ITYPE,JSPEC,KSPEC)+SLOPE(ITYPE,
     %JSPEC,KSPEC)*CAP1*DIST+EQUIPM(ITYPE,JSPEC,
     %KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,JDEP)
      VM=VM+COSTM1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
      GO TO 19
C
C
C
5     IF(CAP1.EQ.CAP2)GO TO 3
      IF(KOUNT.NE.0)GO TO 21
      OLDCAP=CAP1
      OLDV=V
      CAP1=CAP2
      OLDB=B
      KOUNT=100
      DO 23 IL=1,3
      OLDCOS(IL)=UNCOST(IL)
      UNCOST(IL)=0.
23    CONTINUE
      CODARC=0
      GO TO 20
21    B=B-OLDB
      V=V-OLDV
      CAP1=OLDCAP
      DO 24 IL=1,3
      UNCOST(IL)=UNCOST(IL)-OLDCOS(IL)
24    CONTINUE
3     DO 25 IL=1,3
```

```
      UNCOST(IL)=UNCOST(IL)*(1.+OHPERC/100.)
25    CONTINUE
      RETURN
      END
C
C **********SUBROUTINE CODE*********************
C
C THIS SUBROUTINE UPDATES THE ARC CODE IN ORDER TO
C ASSIGN THE PROPER COST TO THE ARC CONSIDERED.
      SUBROUTINE CODE(NO,KODARC,
     %KOIL,UNKOST)
      DIMENSION UNCOST(2,3),COIL(2)
      INTEGER CODARC(2)
      REAL UNKOST(3),KOIL
      COMMON/E/CODARC,COIL,UNCOST
      CODARC(NO)=KODARC
      COIL(NO)=KOIL
      DO 1202 IL=1,3
1202  UNCOST(NO,IL)=UNKOST(IL)
      RETURN
      END
C
C
C
C
C ****************THE FUNCTION NEWSIZ**************
C
C THIS FUNCTION IS USED TO SELECT THE PROPER CABLE
C IN AN ORDER.
      FUNCTION NEWSIZ(ITYPE,JTYPE,KTYPE,ICAP)
C DECLARE THE VARIABLES.
      REAL SIZE(6,2,4,40)
      COMMON /C/NSIZE,SIZE
      DO 1 I=1,NSIZE
      IF(SIZE(ITYPE,JTYPE,KTYPE,I).GE.ICAP)GO TO 2
1     CONTINUE
C THE NEW SIZE OF THE CABLE IS SELECTED.
2     NEWSIZ=SIZE(ITYPE,JTYPE,KTYPE,I)
      RETURN
      END
C
C ***************THE FUNCTION TECH***************
C THIS FUNCTION IS USED TO FIND THE TECHNOLOGICAL
C GROWTH FACTOR USING THE LOGISTICS CURVE.
      FUNCTION TECH(YEAR)
      COMMON /B/PARAFO,PARA,PARK
      NYEAR=IFIX(YEAR)
      TECH=PARAFO*(1.-(1./(1.+(PARA/EXP(PARK*FLOAT
     %(NYEAR))))))
      RETURN
      END
C
C *******************SUBROUTINE GAREA**************
C IT IS USED TO EVALUATE THE GEOGRAPHY DIFFICULTY
```

```
C FACTOR, DEPENDING ON THE GEOGRAPHICAL CONDITION
C OF THE ARC.
C
C
      SUBROUTINE GAREA(IGEO,ITEM,GFACTO)
      COMMON/A/DFACTO
      REAL DFACTO(7,4)
      INTEGER CODE(3)
      CODE(1)=IGEO/100
      CODE(2)=(MOD(IGEO,100))/10
      CODE(3)=MOD(IGEO,10)
      GFACTO=1.
      DO 2 J=1,3
      IF(CODE(J).EQ.0)GO TO 3
      GFACTO=GFACTO*DFACTO(ITEM,CODE(J))
2     CONTINUE
3     RETURN
      END
C
C *************THE FUNCTION AVCOST****************
C THIS FUNCTION IS USED TO FIND THE WEIGHTED AVERAGE
C COST OF A MANHOLE OR ANY MISCELLENEOUS EQUIPMENTS.
C
      FUNCTION AVCOST(N)
      DIMENSION COST(30),IFREQ(30)
      READ(1,1)(COST(I),IFREQ(I),I=1,N)
1     FORMAT(F10.2,I10)
      TOTAL=0.
      SUM=0.
      DO 2 J=1,N
      SUM=SUM+COST(J)*FLOAT(IFREQ(J))
      TOTAL=TOTAL+FLOAT(IFREQ(J))
2     CONTINUE
      AVCOST=SUM/TOTAL
      RETURN
      END
C
C
C **************SUBROUTINE EXCOST*********************
C
C THIS SUBROUTINE IS USED TO FIND THE COST OF EXISTING
C PLANT.IT CONSIDERS THE LABOR COST AND ANY OTHER
C OVERHEADS THAT WERE INCURRED AT THE TIME OF
C INSTALLATION OF THE PLANT AS SUNK COST. ONLY
C CURRENT MATERIAL COST AFTER DEDUCTING A FIXED
C PERCENTAGE FOR THE COST OF REMOVAL IS RELEVENT
C IN MAKING ANY DECISIONS.
      SUBROUTINE EXCOST(KODE,ITYPE,CAP1,CAP2,NYEAR,DIST
     %,ISPEC,B,V)
      REAL CTF(5,9),LCCOST(6),PERSAL(9),DLCOST(8)
     $,MSUM(6),CONCOS(5,6),MHCOST,INTCPT(6,3,5),SLOPE(6,3,5)
     %,EQUIPM(6,2,4,40),SIZE(6,2,4,40),UNCOST(3),LSUM(6)
     %,VO(9),VNNEX(9)
      DIMENSION OLDCOS(3)
```

```
      INTEGER CODARC,GSIZE(5),CAP1,CAP2,LIMIT(5),PAIRS(35)
      COMMON/C/NSIZE,SIZE/G/LCINT,POLDIS
     %/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,
     %NCSIZE,LIMIT,CONCOS,MHCOST,INTCPT,SLOPE,
     %EQUIPM,POLCOS,NGAUGE,GSIZE
     %/K/CTF/D/VO,VNNEX
      COSTM=0.
      B=0.
      VM=0.
      JSPEC=MOD(ISPEC,10000)
      KSPEC=MOD(ISPEC,1000)
      JSPEC=JSPEC/1000
      DO 11 IG=1,NGAUGE
      IF(KSPEC.EQ.GSIZE(IG))GO TO 12
11    CONTINUE
12    KSPEC=IG
      DO 2222 ICAP=1,40
      IF(CAP1.EQ.SIZE(ITYPE,JSPEC,KSPEC,ICAP))GO TO 2223
2222  CONTINUE
2223  MSPEC=ICAP
      IF((ISPEC/10000).NE.1)GO TO 22
      COSTM=COSTM+LCCOST(ITYPE)*CTF(NYEAR,9)*DIST
     %/FLOAT(LCINT)
      VM=VM+COSTM*VNNEX(9)
22    IF(MOD(ITYPE,3).NE.1) GO TO 6
      DO 8 I=1,NCSIZE
      IF(LIMIT(I).LT.CAP1)GO TO 8
      J=1
      GO TO 9
8     CONTINUE
      I=NCSIZE
      J=CAP1/LIMIT(NCSIZE)
      IF(MOD(CAP1,LIMIT(NCSIZE)).NE.0)J=J+1
9     COSTM1=(CONCOS(I,J)*DIST+MHCOST)
      COSTM=COSTM+COSTM1*CTF(NYEAR,7)
      VM=VM+COSTM1*VNNEX(7)
      IF(ITYPE.EQ.4)GO TO 10
      COSTM1=(INTCPT(1,JSPEC,KSPEC)+(SLOPE(1,JSPEC,KSPEC)*
     %CAP1))*DIST+EQUIPM(1,JSPEC,KSPEC,MSPEC)
      COSTM=COSTM+COSTM1*CTF(NYEAR,6)
      VM=VM+COSTM1*VNNEX(6)
      GO TO 15
10    COSTM1=((INTCPT(4,JSPEC,KSPEC)+SLOPE(1,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(4,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,8)
      VM=VM+COSTM1*VNNEX(8)
15    COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      VL=VL*(1.+LSUM(ITYPE)/100.)
      B=0.8*COSTM
      V=0.8*VM
      RETURN
6     IF(MOD(ITYPE,3).EQ.0)GO TO 16
      NOPOLE=IFIX(DIST/POLDIS)
```

```
      IF((FLOAT(NOPOLE)*POLDIS).NE.DIST) NOPOLE=NOPOLE+1
      COSTM1=FLOAT(NOPOLE)*POLCOS*(1.+POLEQ/100.)
      COSTM=COSTM+COSTM1*CTF(NYEAR,2)
      VM=VM+COSTM1*VNNEX(2)
      IF(ITYPE.EQ.5) GO TO 18
      COSTM1=((INTCPT(2,JSPEC,KSPEC)+SLOPE(2,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(2,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,1)
      VM=VM+COSTM1*VNNEX(1)
      GO TO 19
18    COSTM1=((INTCPT(5,JSPEC,KSPEC)+SLOPE(5,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(5,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,3)
      VM=VM+COSTM1*VNNEX(3)
19    COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      B=0.8*COSTM
      V=0.8*VM
      RETURN
16    JDEP=5-MOD(ITYPE,2)
      COSTM1=(INTCPT(ITYPE,JSPEC,KSPEC)+SLOPE(ITYPE,
     %JSPEC,KSPEC)*CAP1*DIST+EQUIPM(ITYPE,JSPEC,
     %KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,JDEP)
      VM=VM+COSTM1*VNNEX(JDEP)
      GO TO 19
      END
C *******************END OF THE PROGRAM************
```

APPENDIX-E TECHNICAL INFORMATION ON CARRIER SYSTEMS

E.1 Transmission

In order to transmit information from point A to point B; the following are necessary:

a) terminal equipment consisting of a sender and a receiver,

b) a transmission medium.

The terminal can be a simple telephone set or a complex multi-channel carrier terminal.

The medium may be a pair of wires, a radio path, a coaxial cable tube etc. Disregarding the radio path, the medium can be divided into two main classes;

a) voice frequency circuits (VF)...(on cable - freq. band 300 - 3400 KHZ)

b) carrier frequency circuits...(on cable, 0 - 24KHZ)

The carrier technique is divided into two broad sub-sections.

1. Frequency Division Multiplexing (FDM) - where individual VF circuits are translated from high frequency bands and are 'stacked' or 'multiplexed' in frequency for transmission over a common medium such as a cable pair.

2. Time Division Multiplexing (TDM) - where individual circuits are "sampled" in time and the samples are

interleaved and "coded" for transmission over a common medium such as a cable pair.

'FDM' is 'analogue' in nature while TDM is 'digital' in nature.

E.1.1 Analogue Carrier (Using FDM)

Figure E.1, shows a simple three channel analogue carrier system.

Using three identical VF circuits (0 - 4KHZ), two of the signals are "modulated" to higher frequency bands and sent to the common cable pair. The combined three channels have a carrier frequency of 0 - 20 KHZ with each channel separated in frequency. If the reverse process is done at the receiving end, each channel is converted back to the original VF frequency.

The above process is termed as "amplitude modulation"; another type of carrier uses "frequency modulation".

E.1.2 Digital Carrier (Using TDM)

Digital carrier is also divided into two or more modulation schemes, of which Pulse Code Modulation (PCM) is in widespread use today.

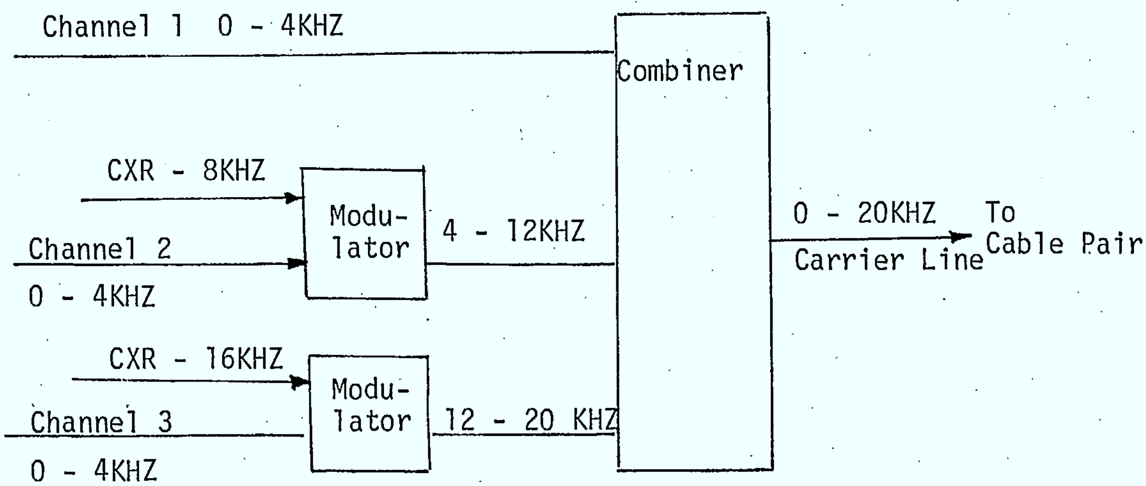

Figure E.1 Three Channel Analogue Carrier System

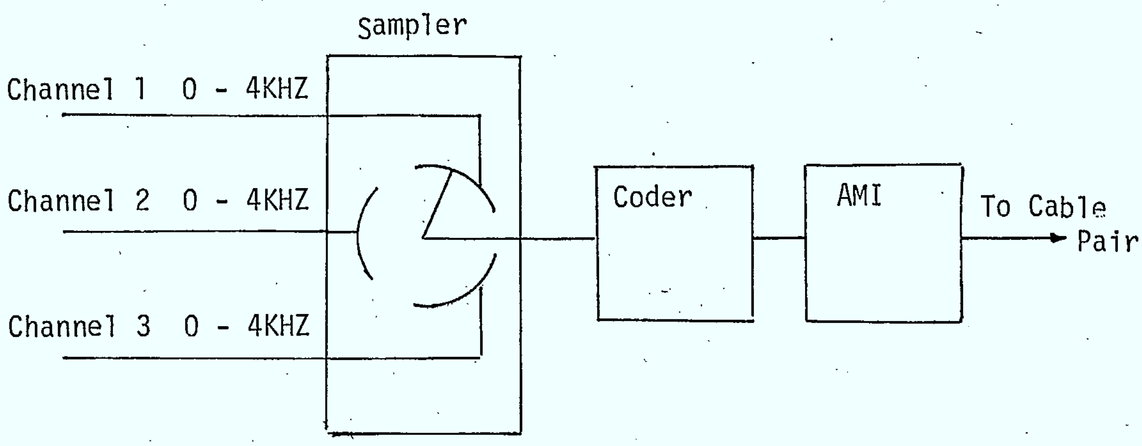

Figure E.2 Three Channel Digital Carrier System

In Figure E.2, the sampler is an electronic device which samples each VF channel individually in sequence. It produces one complete set of three samples, 8000 times per second. This sequence is now applied to the coder which assigns a unique code or sequence of binary pulses to represent the height or amplitude of the incoming signals. That is the VF information is carried in the sequence or code of the ON/OFF binary pulses, and hence the name "Pulse Code Modulation".

Before transmitting to the cable, the 'Alternate Mark Inverter' (AMI) reverses the polarity of every other pulse in order to reduce the average d.c voltage level of the binary signal to zero. This simplifies the design of the line repeater required to regenerate the signal. When the signal has travelled a long distance, it is considerably attenuated and distorted. A line repeater (not an amplifier) then regenerates or reconstructs the distorted incoming pulse signal to produce as its output perfect undistorted signal.

E.2 Subscriber Carrier System

A few of the subscriber carriers are listed in Table E.1. The number of channels indicates the number of simultaneous conversations possible over the carrier system. The pair gain indicates the advantage of the carrier system over the cable pair placement.

E.2.1 Concentrators

In the subscriber systems listed above each channel of the carrier system is dedicated to one subscriber, and 90% of the time each channel is idle and earning no revenue. Better use of the carrier system can be made possible by using concentrators. In this situation many subscribers share the available channels back to the switching center on a first come first served basis.

In Figure E.3, 32 subscribers are connected to the switching center, each being dedicated one channel. In Figure E.4, 128 subscribers are connected to the switching center. By addition of concentrator switches, 128 subscribers can use the same facilities previously required for 32 subscribers. The concentrator connects a subscriber requiring dial tone to the first free channel but of course no more than 32 subscribers can talk simultaneously. However, since each phone is used very little, the chance of call blocking is low.

Using concentration, the maximum pair gain available with the previously listed carriers is as shown in Table E.2.

E.2.2 Digital Carriers in Conjunction With Digital Switching Machines

Pair gain devices were previously considered

Table E.1 Information Relating to Some Subscriber Carriers

Manufacturer	Name	Type	No. of wire Pairs	Channels	Pair Gain
a) Anaconda	56A	Analogue	1	6	1:6
b) Superior Cont.	CM8	Analogue	1	8	1:8
c) ITT	DM 32S	Digital	2	32	1:16
d) Northern Telecom	DMS 1	Digital	4	48	1:12

Table E.2 Pair Gains for Different Carriers

System	Pair Gain
S6A	1:24 (ES-1 Concentrator)
CM8	1:24 (ES-1 Concentrator)
DM32S	1:64 (Built in Concentrator)
DMS1	1:64 (Built in Concentrator)

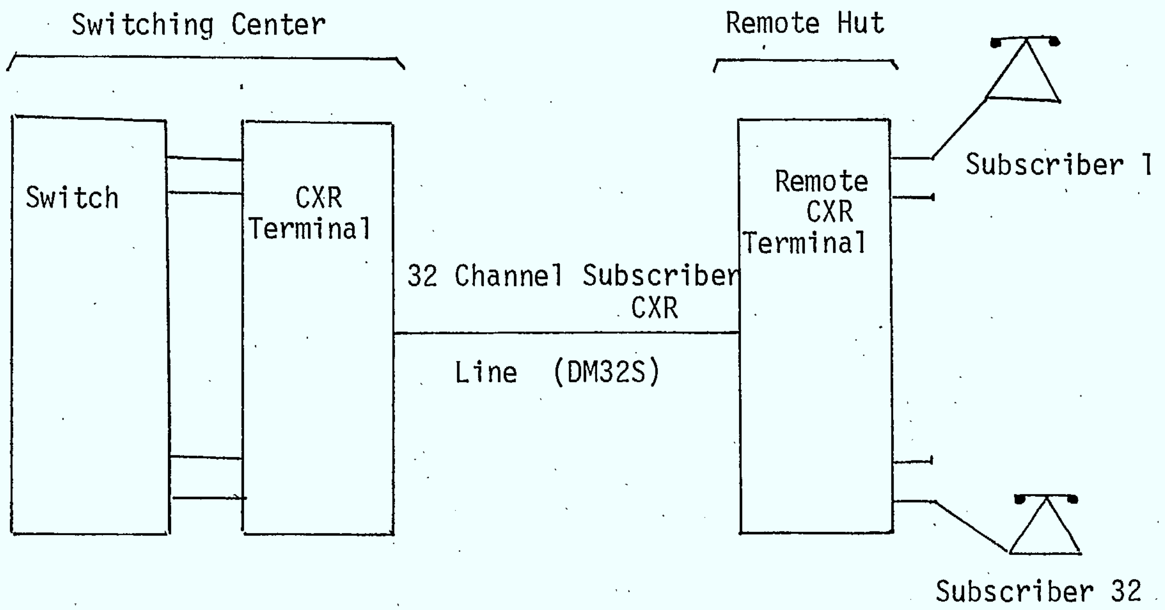

Figure E.3 Subscriber Carrier Without Concentrator

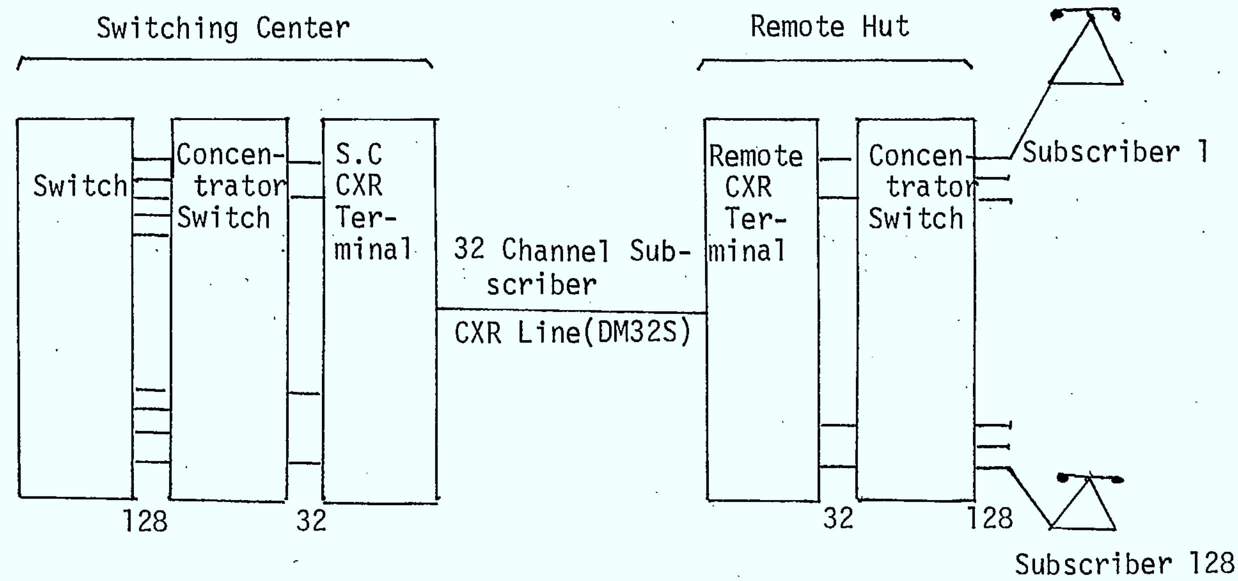

Figure E.4 Subscriber Carrier With Concentrator

(Carrier, concentrators) working on existing analogue switching machines. With the introduction of digital switching machines the office terminal (OT) of the subscriber carrier is no longer needed. The T-CXR line is directly accepted by the switch without any conversion.

APPENDIX-F THE "S" CURVE PARAMETERS

The technology curve parameters 'A' and 'k' are obtained from the envelope curve as suggested below. The carrier companies can plot the envelope curve and extrapolate it to obtain the ordinates of the curve in the future years. From these values the representative parameters of the curve can be obtained by simple linear regression of a transformed variable.

In the 'S' curve equation;

$$f(t) = f(to) - f(to)/(1+A.EXP(-kt))$$

Since f(to) is the ordinate of the curve in year 0, while normalizing this value becomes equal to 1.

Therefore,

$$f(t) = 1 - 1/(1+A.EXP(-kt))$$

if Z, a new variable is made equal to 1/(1+A* EXP(-kt)), then,

$$\ln A - k.t = \ln[(1-Z)/Z] \qquad ,Z<1$$

$$\ln[Z/(1-Z)] = k.t - \ln A$$

A linear regression of ln [Z/(1-Z)] versus t will give the intercept and the line, from which;

k = slope of the line, and

A = - EXP(intercept).