NASA CR 168236

Communications Network Design and Costing Model

Final Technical Report

by K.P. Logan, S.S. Somes, and C.A. Clark

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

A Communications Network Design and Costing (CNDC) computer model provides the capability for analyzing long-haul communications networks. The model is well-suited for market assessment studies involving the integration of developing satellite communication systems into the environment of existing service offerings of licensed domestic and specialized interstate communications common carriers. A capability is provided for analyzing long-haul trunking networks comprising a set of user-defined cities, traffic conditions, and tariff rates. Networks may consist of all terrestrial connectivity, all satellite connectivity, or a combination of terrestrial and satellite connectivity. Network solutions provide the least-cost routes between all cities, the least-cost network routing configuration, and terrestrial and satellite service cost totals. The CNDC model allows analyses involving three specific FCC-approved tariffs, which are uniquely structured and representative of most existing service connectivity and pricing philosophies. User-defined tariffs that can be variations of these three tariffs are accepted as input to the model and allow considerable flexibility in network problem specification.

The resulting model extends the domain of network analysis from traditional fixed link cost (distance-sensitive) problems to more complex problems involving combinations of distance- and traffic-sensitive tariffs. A heuristic algorithm is developed to determine minimum cost network routing solutions specifying the location of satellite access cities and their hubbing terrestrial extensions for typical customer premise services.

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Summary

The Communications Network Design and Costing (CNDC) model is capable of analyzing long-haul trunking networks for a variety of cities and traffic conditions, using strictly terrestrial connectivity, using strictly satellite connectivity, or using some combination of terrestrial and satellite connectivity. The model determines the least-cost routes between network cities based on the current FCC-approved tariffs of three specific communications carriers whose tariffs are uniquely structured and representative of tariffs associated with most licensed domestic and specialized interstate communications common carriers. The CNDC model also allows analyses involving variations of the three FCC-approved tariffs, as postulated by the model user.

The CNDC model provides a unique approach to evaluating networks having a combination of terrestrial and customer premise type satellite services (CPS). Rate structures associated with terrestrial tariffs are typically a function of distance serviced, while those associated with CPS type satellite service, such as SBS, are a function of traffic volume. Traditional approaches to network analysis rely on fixed costs over the network links. Tariffs that are sensitive to distance are handled quite readily by these traditional approaches because link costs are fixed and can be determined on the basis of the cities being serviced. There is an abundance of these types of algorithms and they vary in performance based on their implementation scheme. Generally, they are variations of two basic approaches, label setting and label correcting. Tariffs whose rates are a variable function of

traffic volume do not conform with the traditional fixed cost label correcting and setting algorithms unless the volumes over each link can be specifically defined. The CPS-type tariffs that can be incorporated into the CNDC model allow shared facility resources among neighboring cities in a hubbing or clustering fashion. Cities not having sufficient traffic volume of their own to economically justify an earth station can route traffic to a nearby earth station in some neighboring city for satellite transmission. The identification of satellite access cities and their trunking terrestrial connectivity is not clear cut, particularly when satellite service rates vary nonlinearly as a function of volume and the number of sharing cities.

The resulting CNDC model extends the domain of network analysis from fixed link cost/distance-sensitive problems to more complex problems involving combinations of distance- and volume-sensitive tariffs. Minimum cost network routing solutions specify the cost-effective locations of satellite access cities and the hubbing terrestrial extensions.

In light of the rate uncertainty surrounding the AT&T divestiture and the ever-changing rate and service offerings being provided by communications carriers, network design and costing will become an even more complex and formidable task. The CNDC model represents a valuable tool for conducting network analyses in this environment of constant change.

This final technical report of the CNDC model contains six sections. Section 1 describes the CNDC model as it fits in the ongoing studies conducted by NASA to assess the potential demand for telecommunication services. Section 2 describes the types of tariffs that can be used with the CNDC model to perform network analyses. Section 3 describes the components of network analysis problems that can be evaluated using the model, while Section 4 describes in more detail the optimization algorithms implemented in the model. Section 5 contains a description of the computer implementation of the model, including the operating environment, supporting data bases, and computer programs. Finally, Section 6 presents a detailed interpretation of the various types of output generated by the model. Any tariff changes will be included in the Addendum.

1.0 INTRODUCTION

This document represents the final technical report under National Aeronautics and Space Administration (NASA) contract NAS3-23348 and describes the development of the Communications Network Design and Costing (CNDC) computer model.

1.1 Background

This project is part of an ongoing effort by NASA to develop, demonstrate, and promote the technological implementation of cost-effective and spectrum conservative satellite communications systems. The need for spectrum conservation systems (e.g., 30/20 GHz or Ka band systems) is driven by projected demand levels in voice, data, and video services. Forecasts of demand for telecommunications services through the year 2000 have estimated growth by a factor of five over present demand levels, with the satellite transmission portion of this demand growing by an even larger factor. The demand growth is projected to surpass available C and Ku band satellite capacity around 1990. Additional capacity in these bands, as well as the development of new satellite technology such as 30/20 GHz satellite systems, is required to respond to this growing demand.

Another factor driving the need for Ka band satellite systems is the spacing requirements of orbital slots for geostationary satellites. There are a limited number of orbital slots, and congestion of the orbital arc will restrict future entry of new major communications carriers into the satellite transmission market. Although spacing requirements have been recently eased from 4 to 2 degrees (FCC 83-186 Memorandum Opinion and Order adopted April 27, 1983, released August 12, 1983.), the imminent saturation of available C and Ku band capacity will likely promote the use of higher frequency satellite systems in the 30/20 GHz spectrum. These new systems will have less restrictive orbital spacing requirements than C and Ku band systems and can help satisfy future demand levels.

NASA has directly funded several market studies to assess the potential demand for telecommunications services, particularly those applicable to 30/20 GHz satellite systems (references 17 and 18). Key factors in these studies have included network types, network size, and service prices. Based on these studies and other proof-of-concept (POC) projects, NASA has recently issued a solicitation for proposals to build and test an Advanced Communication Technology Satellite (ACTS) system that will operate in the 30/20 GHz band. Present plans call for the launch of the ACTS system in mid-1988, followed by a two-year experiment period.

1.2 Scope of Work

Model development under this project involved a twelve-month effort that resulted in a computer program and associated database useful for analyzing long-haul communication networks. The model will support market assessment studies involving future satellite services. The model's capabilities include connectivity availability analysis, cost analysis of that connectivity, and the determination of the set of least-cost routes. Project efforts also included the implementation of the model on the NASA-Lewis Research Center computer, the development of programmer and user documentation, training of selected NASA staff on model operation, and continuing maintenance of the program and its supporting databases.

1.3 Purpose

The purposes of the model development and resulting computer programs were:

To model and analyze communications trunking networks;

To model full connectivity between service nodes, using either terrestrial systems, satellite systems, or a combination of the two, for voice services offered by licensed domestic and specialized interstate communications common carriers;

To determine the trunking network traffic routing alternatives and associated user costs based on the current published tariffs of American Telephone and Telegraph (AT&T), Western Union (WU), and Satellite Business Systems (SBS), and on postulated tariffs for future terrestrial and satellite communication services;

To determine the set of least-cost routes based on the lowest tariffed cost per set of input traffic assumptions for a specified network; and

To determine the configuration providing the minimum overall cost in networks involving a combination of terrestrial and satellite services.

2.0 CNDC MODEL TARIFFS AND THEIR CONNECTIVITY

This section describes the types of tariffs that can be used with the CNDC model to perform network analyses. A description of the types of network connectivity possible is also provided.

2.1 Significance of Tariff Types

The CNDC model includes the following types of communications tariffs:

AT&T Private Line Service (FCC #260),

List of Rate Centers (FCC #264)

WU Satellite Transmission Service (FCC #261),

SBS Series A Communications Network Service (FCC #2), and

User-defined variations of the above.

The model was developed to include only the voice services relating to the above tariffs. The AT&T, WU, and SBS tariffs are contained in a prestored database that is accessed by the model's programs. The model was developed around these three tariffs because each has a unique connectivity and rate structure. Jointly, the structures of these three tariffs are representative of most tariffs offered by licensed domestic and specialized communications common carriers. The model provides the user with the capability to define variations of these three tariffs, thereby modeling a wide range of existing and postulated tariffs. The user is able to define varying rates and city connectivity based on tariff structures similar to the three prestored tariffs. User-defined tariffs can be stored in a database for later retrieval when performing network analyses. User-defined tariffs and any of the three prestored tariffs are used as input in setting up network problems.

The structures that make each of the prestored tariffs unique are described in detail in the following section.

2.2 Tariff Descriptions

The prestored tariffs in the CNDC model database include only recurring charges, and these are specified on a monthly basis. Nonrecurring charges were excluded from the model to simplify the costing procedure and to eliminate the complexity of time varying rates associated with the amortization of installation charges. The network costs associated with the model solutions are therefore exclusive of any nonrecurring tariffed service charges.

The unique structures of the AT&T, WU, and SBS tariffs make them appropriate choices for inclusion in a network design and costing model because they are each representative of a distinct class of tariff. These tariffs are described in the following paragraphs in the context of their implementation within the CNDC model.

2.2.1 AT&T Private Line Service

The prestored AT&T tariff specifies the terrestrial rates for private line voice service. The tariff is structured so that terrestrial rates for intercity service are dependent on two factors, the distance between the cities and the status of the connected cities (i.e., tariff listed or unlisted).

As part of the rate determination, mileage calculations must be performed using a formula specified in the tariff to calculate the distance between the cities or rate centers of interest. The AT&T tariff contains vertical (V) and horizontal (H) coordinates for each rate center serviced. These coordinates are used to calculate the distance between any two rate centers, R_1 and R_2, according to the following formula:

$$D_{12} = \sqrt{\frac{(V_2-V_1)^2 + (H_2-H_1)^2}{10}},$$

where

D_{12} = distance between R_1 and R_2,

V_1, H_1 = vertical and horizontal coordinates for R_1, and

V_2, H_2 = vertical and horizontal coordinates for R_2.

Tariff rates increase proportionally with distance; however, they are not strictly a function of distance. The AT&T tariff contains a specific list of high volume rate centers. These are called "listed" (or category A) cities, meaning that they are listed in the tariff. Any rate center not listed in the tariff is called an "unlisted" (or category B) city. The tariff rate is also dependent on the listed/unlisted status of the cities on each end of the communications link. With two types of city status, there are three combinations of link types that can occur:

Listed city ←——→ listed city,
Listed city ←——→ unlisted city, and
Unlisted city ←——→ unlisted city.

(See Figure 2-1). The tariff contains a separate rate schedule for each link type. Within each schedule is a graduated service pricing structure that varies strictly as a function of distance. Given any two cities to be connected by terrestrial voice service, the AT&T tariffed rate can be computed by determining the status of each city, selecting the appropriate rate schedule, calculating the intercity distance, and looking up the applicable rate in the schedule table. Tables A-1 and A-2 list examples of the AT&T listed cities and rate schedules, respectively.

2.2.2 User-Defined AT&T Type Tariffs

The CNDC model provides the user with the capability to modify the prestored AT&T tariff to create and store his own tariffs for network analysis problems. The user is able to specify his own list of category A listed cities, as well as his own rate schedules for each of the link types. However, the basic connectivity philosophy cannot be changed. This capability provides a great deal of flexibility in incorporating other types of tariffs into the CNDC model, whether real or postulated. The model is designed to easily compute the effects of rate changes on market share for competing tariffs.

2.2.3 WU Satellite Transmission Service

The prestored WU tariff specifies rates for satellite voice grade channel service. The CNDC model involves only recurring charges for month-to-month service. This tariff contains a fixed set of satellite access city pairs that define the tariff connectivity. The tariff categorizes the links defined by the satellite access city pairs on the basis of link distance. There are three rate categories specified in the tariff: short haul, medium haul, and long haul. The tariff specifies a fixed monthly channel rate for each category. The applicable rate (i.e., short, medium, or long) is charged for each individual voice circuit.

Unlike the AT&T terrestrial tariff, the WU tariff is unique in that it defines network connectivity through a specific set of satellite access city pairs that are categorized by distance. Table A-3 lists examples of WU tariff satellite access city pairs and rates by category. Figure 2-2 illustrates the types of WU satellite connectivity for the CNDC Model.

2.2.4 User-Defined WU-Type Tariffs

The CNDC model allows the user to specify his own set of satellite access city pairs, assign them to one of the three rate categories contained in the tariff structure, and set the channel rates for each category. However, the basic connectivity philosophy cannot be changed. In so doing, the user can model any type of tariff that involves fixed earth stations or network access points. While the rates of the actual WU tariff are correlated to link distance, there is no requirement on the user to conform to this convention when defining postulated tariffs.

2.2.5 SBS Series A Communications Network Service (CNS-A)

The prestored SBS CNS-A tariff defines service rates based on traffic volume over defined links as opposed to distance. The tariff does not specify satellite access cities and is based on a CPS concept. Satellite access earth stations can be placed anywhere. The earth stations, or network access centers (NAC), are sized to handle the particular traffic level of each location. SBS system hardware components are added to the NAC to support the traffic volume. Each hardware component has a monthly lease charge and the joint cost of all components within an earth station determines the monthly service rate. The CNDC model includes only the analog voice services provided under the SBS CNS-A configuration. Nonrecurring costs are not modeled. The major hardware components included in SBS CNS-A configurations are as follows:

Network Access Centers (NAC) - These provide the switching, administration, and testing functions of the communications network service. SBS CNS-A networks require a minimum of three NACs. Each NAC has an initial capacity for 372 analog voice circuits supplied through its satellite communications controller (SCC). This component is the heart of the NAC. It is a time division switch consisting of processors, memory units, and control programs. It performs essential timing, switching, control, and processing functions in association with the transmission and reception of network traffic through the NAC.

Supplemental Capacity Unit (SCU) - Each SCU added increases the capacity of the NAC by 372 analog VFs. Each NAC may have a maximum of 2 additional SCUs or a total capacity of 1116 VFs (372 + 2 X 372).

Full-time transmission unit (FTU) - This component provides 224 kbps (simplex) of satellite transponder capacity on a 24 hours per day, seven days per week basis. One FTU is required for every twenty analog voice grade circuits of transponder capacity. A minimum of one FTU is required at each CNS-A NAC configuration.

Connection arrangement unit (CAU) - This component allows the connection of customer facilities to the communications network service. There are both analog and digital type CAUs; however, the model only considers analog. A single analog CAU is required for each analog voice circuit.

Table A-4 lists examples of monthly CNS-A component lease rates. The SBS tariff also specifies a minimum CAU charge per NAC, making the use of CNS-A service attractive to primarily high volume users. Figure 2-3 illustrates the types of SBS Satellite connectivity for the CNDC Model.

The structure of the SBS tariff is unique in that service costs are embedded within monthly equipment leases, whose total cost is a function of traffic volume for the particular location. The tariff is based on a CPS concept, with network access facilities located on or near customer premises. Shared use of CNS-A type facilities is allowable under the tariff. For modeling purposes, a network involving SBS CNS-A service can consist of any set of cities, as long as there are a minimum of three NACs. Neighboring cities not having their own SBS facilities can share the resources of their closest NAC via the terrestrial connectivity provided by AT&T or some other modeled ground service in the network.

2.2.6 User-Defined SBS-Type Tariffs

The CNDC model allows the user to modify the prestored SBS tariff to define his own service. The monthly rates for each SBS component can be specified as user input, thereby allowing many variations of the tariff to be defined within the same basic structure of the prestored SBS tariff. For example, individual components can be eliminated for postulated tariffs by assigning them a rate equal to zero. In this case, that particular component would have no contribution to the cost calculations performed by the model. Although specific rates may be changed, the basic connectivity philosophy of the tariff cannot be changed.

The pricing structure of the SBS tariff has a significant effect on the complexity of the modeling procedures and the optimization of overall network costs. This is due to the nonlinear variation of SBS service costs as a function of traffic volume. This topic is discussed in detail in section 3.6.

2.3 Network Connectivities Possible Within the CNDC Model

The CNDC model provides the capability to define a given network of cities and a set of applicable tariffs regulating communications service to those cities. Specifically, the following types of network problems can be analyzed using the CNDC model:

> All terrestrial networks - involving one or more terrestrial tariffs that may include the prestored AT&T tariff and multiple user-defined variations of it (See Figure 2-1),

All satellite networks - involving the prestored WU satellite tariff and/or multiple user-defined variations of it (See Figure 2-2),

All satellite networks - involving the prestored SBS satellite tariff and/or multiple user-defined variations of it (See Figure 2-3),

Mixed terrestrial/satellite networks - involving one terrestrial tariff (either prestored AT&T or user-defined) and one satellite tariff (either prestored WU or a user-defined variation of it), (See Figure 2-4), and

Mixed terrestrial/satellite networks - involving one terrestrial tariff (either prestored AT&T or a user-defined variation of it) and one satellite tariff (either prestored SBS or a user-defined variation of it) (See Figure 2-5).

Figures 2-1 through 2-5 illustrate the different types of network connectivity that can be analyzed by the CNDC model.

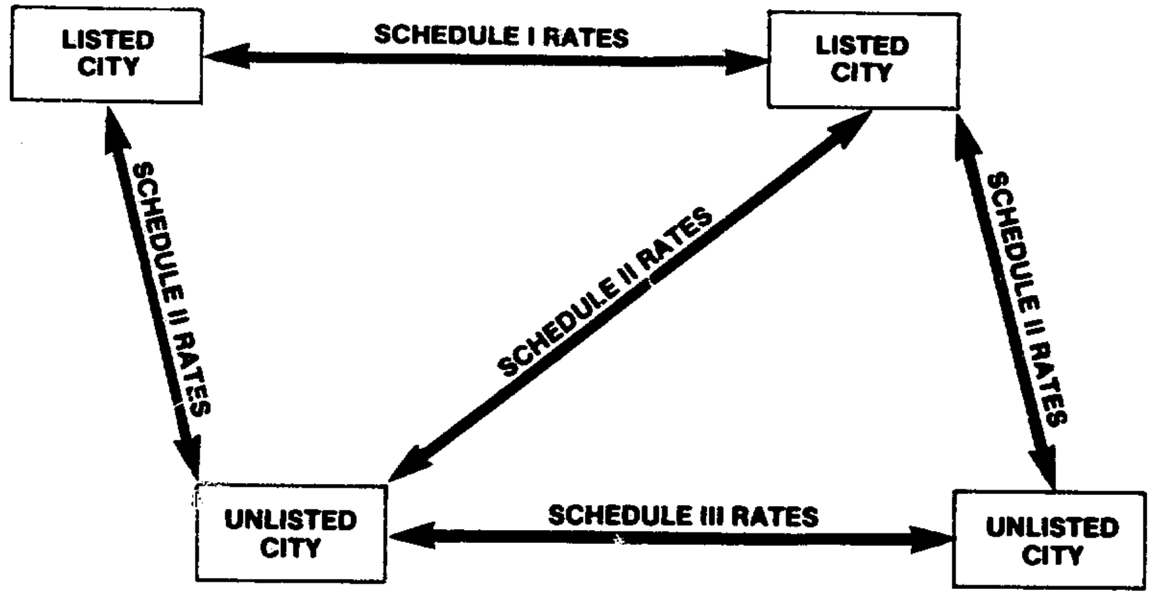

Figure 2-1. Types of Terrestrial Connectivity for CNDC Model

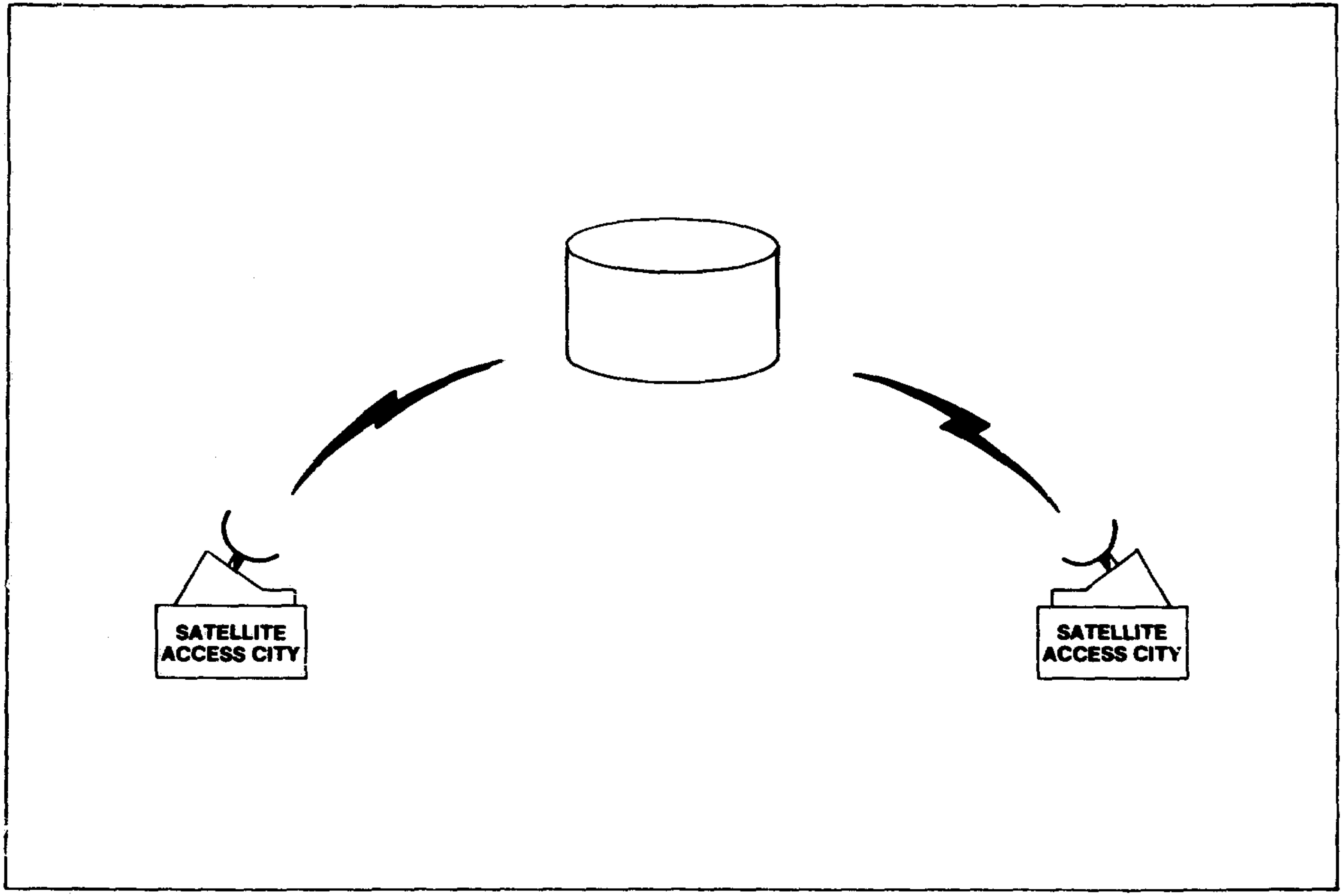

Figure 2-2. Types of WU Satellite Connectivity for CNDC Model

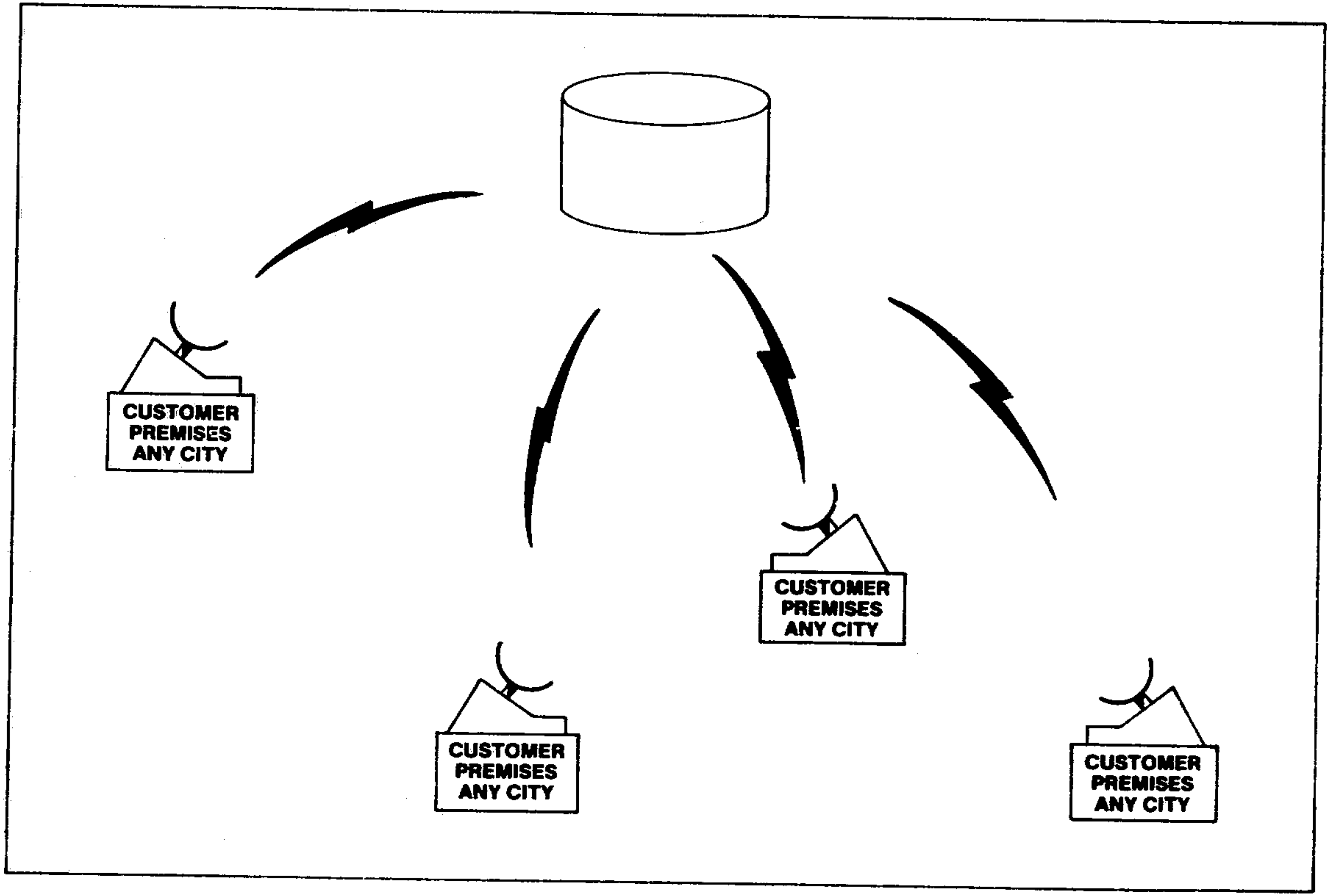

Figure 2-3. Types of SBS Satellite Connectivity for CNDC Model

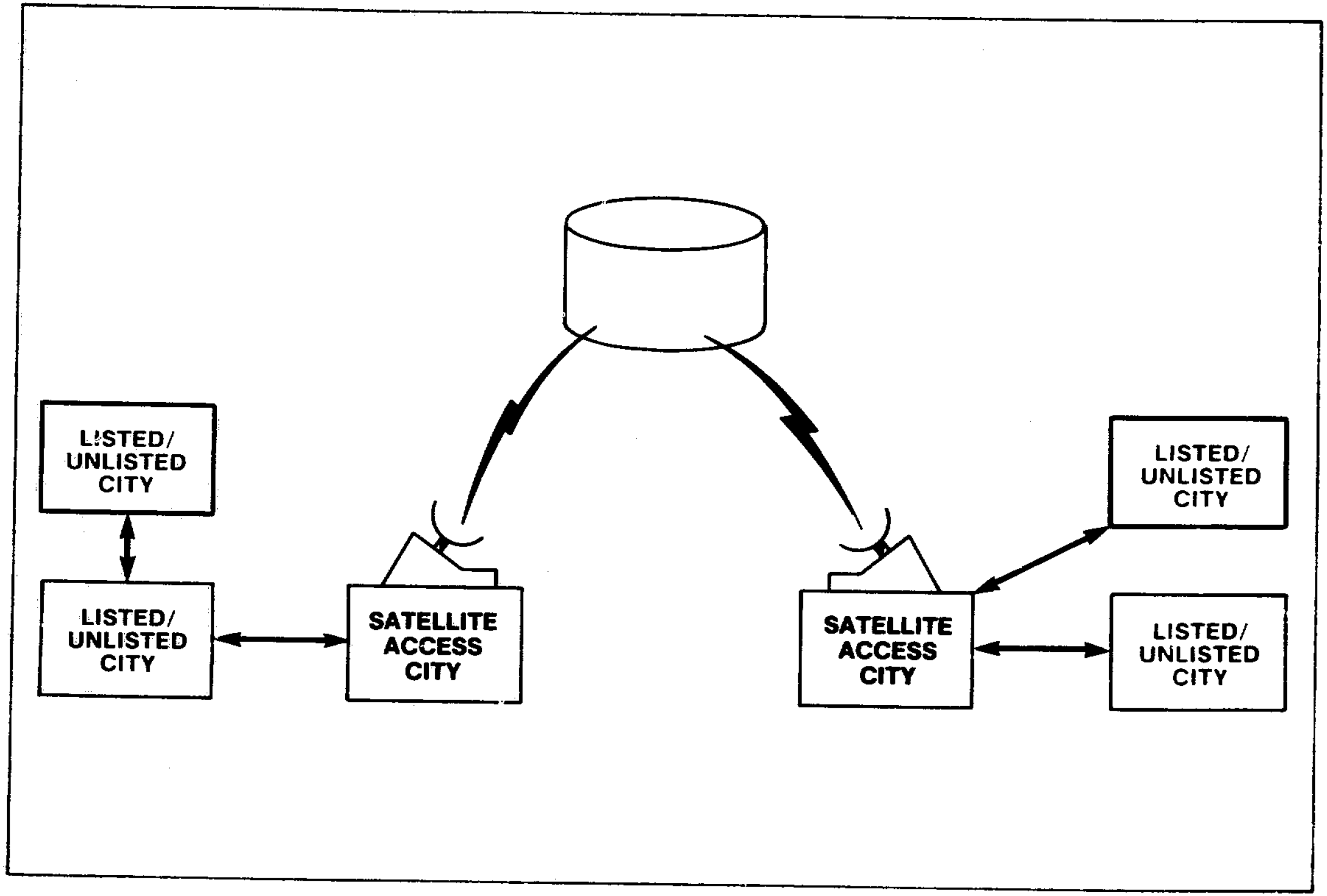

Figure 2-4. Types of Mixed Terrestrial/Satellite (WU) Connectivity for CNDC Model

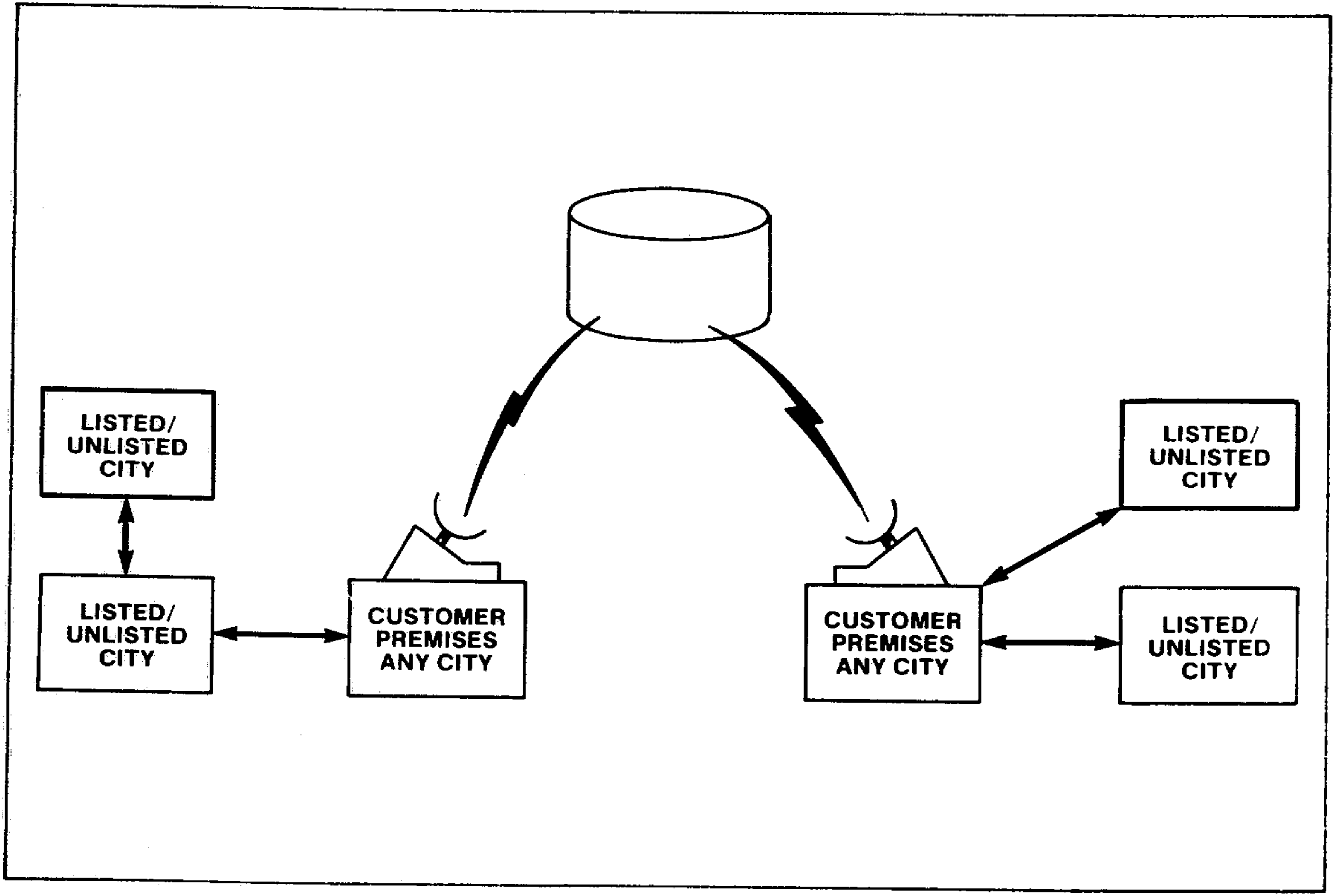

Figure 2-5. Types of Mixed Terrestrial/Satellite (SBS) Connectivity for CNDC Model

3.0 CHARACTERIZATION OF NETWORK ANALYSIS PROBLEMS

The types of network that can be evaluated using the CNDC model fall into three general classes: 1) those involving networks whose costs are a function of distance (distance-sensitive); 2) those involving networks whose costs are fixed as a function of nodal pairs (distance-insensitive); and 3) those whose costs depend on traffic volume (usage-sensitive). Distance-sensitive problems involve networks whose communication links have fixed costs associated with them, which can be computed given the locations of network cites. In this case, each voice circuit has a fixed monthly cost regardless of the network connectivity or traffic conditions. The distance-insensitive problems involve satellite networks where specific city pairs have been designed with a fixed circuit cost per month regardless of traffic condition. The final type of problem is the usage-sensitive one which has variable usage costs that are a function of the traffic volume at each network node. Within the CNDC model, the network problem takes on a unique character depending on the type of tariffs involved. The general class of each problem type that can be analyzed with the CNDC model is as follows:

All terrestrial (AT&T type) - distance-sensitive,

All satellite (WU type) - distance-insensitive,

All satellite (SBS type) - usage-sensitive (under the assumption of no facility sharing and link costs are based on originating traffic only), Mixed terrestrial/satellite (AT&T/WU) - distance-sensitive, distance insensitive, and

Mixed terrestrial/satellite (AT&T/SBS) - distance-sensitive, usage-sensitive.

Within each class of network problem are two subproblems, one dealing with a least-cost network solution, which is concerned with minimizing overall network cost, and the other dealing with least-cost route solutions for all intercity links within the network. The least-cost network solution can be shown to be the union of all least-cost routes within the network; hence, one subproblem is a subset of the other.

The distance-sensitive network problems have received much attention from researchers and mathematicians. These types of problems are amenable to solution via an abundance of well-known network algorithms. The usage-sensitive problems have not been dealt with at great length in the literature and, for this project, required the development of heuristic approaches to network optimization.

Before proceeding with the discussion of the various problem types, some familiarity with network terminology will be helpful.

3.1 Basic Network Terminology

A <u>network</u> consists of a finite set of <u>nodes</u> and a finite set of <u>links</u> connecting pairs of nodes. The network nodes are assigned numbers from 1 to N, where N is the number of nodes. The links of the network are described by ordered pairs of nodes. The first element in the ordered pair is the number of the originating node for the link, and the second element of the ordered pair indicates the node at which the link terminates. The ordered pair (i,j) denotes the link that connects node i to node j ($1 \leq [i,j] \leq N$). Values of a measure such as cost, distance, or energy level are generally assigned to links of the network. Network optimization techniques seek to maximize or minimize with respect to the measure used.

A network is said to be <u>directed</u> if the value associated with link (i,j) is in general not equal to the value associated with link (j,i). A <u>path</u> is a finite sequence of links connecting two nodes. The terminating node of each link in the path, except the last link, is the originating node of the next link in the path. For example, the set of links (x,y), (y,z), (z,w), (w,t) is a path from node x to node t. A path can be described by listing the nodes it includes. The above example is then determined by the sequence of nodes x,y,z,w,t. The path is denoted x-y-z-w-t.

Network optimization algorithms generally assume that link values are additive. This assumption is necessary for the comparison of alternative paths. The value of the link from node x to node y can be compared to the sum of the value of the links through a third node. The shortest-path connecting two nodes, then, is a path between the two nodes so that the sum of the values of the links comprising the path is a minimum. The algorithms thus assume that the addition of link values is meaningful. If link values represent distance, for example, the total distance covered in traversing a path is equal to the sum of the lengths of the links. The measure of interest must be transformed so as to be additive or otherwise expressed in a way that satisfies this assumption.

3.2 The Least-Cost Routing Problem

A network contains a collection of nodes. Select from this collection a node of interest, which will be called the root node. The least-cost route from this root node is the set of links required to connect the root to every other node in the network at the least cost.

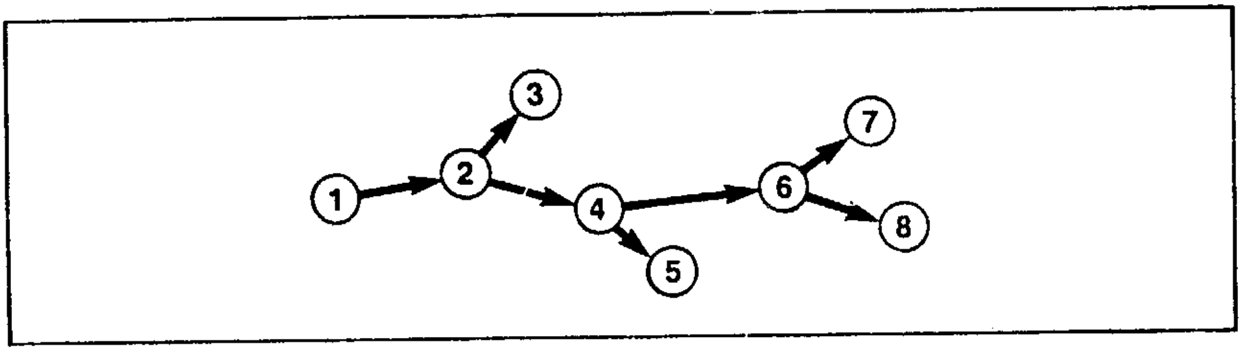

Figure 3-1. A Tree with Root at Node 1

Every node in the network has its associated least-cost route to every other node.

A least-cost route from a given node forms a structure called a tree which includes all nodes in the network. All paths in this tree are directed outward from the root and a given node in the tree can be reached from the root by only one path. Figure 3-1 is an example of a tree rooted at node 1.

Research in the area of shortest-path (least-cost) methods has resulted in the development of several efficient computer codes to solve this problem (5, 7). However, the CNDC model determines the least-cost routes as a by-product of the solution of the least-cost network problem (See section 3.3).

3.3 The Least-Cost Network Problem

The least-cost network problem involves finding the set of links that provides complete connectivity between all pairs of nodes in the network at the minimum cost. In fact, the least-cost network is the union of all the least-cost routes described in section 3.2.

The solution of the least-cost network problem implemented in the CNDC model is based on an algorithm of Floyd (12). This algorithm has been expanded to maintain additional information about the least-cost routes as the least-cost network is determined. This additional information is then used to describe the least-cost routes.

3.4 Literature Review of Network Routing Algorithms

The majority of literature reviewed dealt with the distance-sensitive class of network problems, as previously discussed.

The basic algorithms underlying virtually all of the existing computer codes are very similar; two approaches were described by Dantzig (1) and Dijkstra (2) in 1959. Both of these methods are variations of the primal simplex method (7). The implementation of the basic algorithm on a computer, however, can take many forms and can affect the efficiency of the algorithm tremendously. Over a decade, from 1968 to 1977, execution times to solve a problem using the same general algorithm, computer, and compiler became as much as 50 times faster (5,7). This improvement is due to progress in the field of "computer implementation technology" and the discovery of highly efficient ways to store and access the network data. The efficiency of a code also depends on the characteristics of the network, with certain methods gaining an advantage for specific types of problems.

The CNDC model involves the implementation of two distinct optimization algorithms, one dealing with least-cost routes and the other dealing with the least-cost network.

The first problem involves finding the least-cost route from a given origin (or root) node to all other nodes in the network. This problem has received considerable attention in the literature, and many different implementations have been documented, coded, and tested. The least-cost network problem requires the determination of the network configuration having an overall minimum cost out of all possible routing configurations. In contrast to the least-cost routing problem, this problem appears to have been solved definitively and has received far less attention. Simple and efficient algorithms have been coded and published.

Table 3-1 lists some of the factors that affect algorithm performance and the assumptions about their value in the networks analyzed by the CNDC model. These assumptions have been considered throughout the literature search.

Table 3-1 Factors Affecting the Performance of Network Optimization Algorithms

Factor	Value in CNDC Model
1. Size of network	Up to 600 nodes; up to 359,400 arcs
2. Range of link lengths	Unknown; expect it to be high
3. Density of network	Totally dense
4. Topology of network	Completely unstructured
5. Existence of negative link lengths	No negative costs
6. Computer language (some implementation techniques exploiting capabilities of assembly-language programming that are difficult or inefficient to duplicate in a higher level language)	TSS/370 FORTRAN IV
7. Importance of storage requirements versus speed	Unconstrained
8. Capacities of links	Unlimited

Several articles have been written over the past twenty years that attempt to summarize and/or compare the shortest path algorithms that the authors were aware of at the time. These overviews have been useful in comparing the available techniques (3, 4, 5, 6, 7). The earliest survey studied was by Pollack and Wiebenson in 1959 (3). Their article presents descriptions of several methods and discusses the advantages and disadvantages of each. The authors discuss methods they attribute to Minty and, later, Ford and Fulkerson, Dantzig, and Moore, among others.

A paper by Dreyfus in 1968 (4) claims the Dijkstra algorithm "outperformed all competitors." This paper also discusses the least-cost network problem and concludes that two algorithms, both requiring N*(N-1)*(N-2) additions and comparisons, "are easily proved, and programmed, and culminate a steady progression of successive improvements . . . (and hence) . . . there is good reason to believe that they are definitive." The amount of computation required by these methods was also considered by Hu (9) to compare favorably to that of other methods. One of these methods was coded as Algorithm 97 in the Communications of the ACM (12).

A 1973 comparative study was published by Gilsinn and Witzgall (5) that summarized available methods, measured their comparative efficiency, and focused attention on the importance of implementation technology. They concluded that a code developed by Dial (13), based on an algorithm of Moore (14) and published as algorithm 360 in the Communications of the ACM, was the fastest available.

A 1979 comparative analysis by Dial and others included results measuring the speed of the above-mentioned method (referred to as code S1) as well as several others. For the class of networks under investigation, in particular, a dense network with a wide range of nonnegative link lengths, Dial's improvement to his own code (referred to as code S2) appears superior. The advantage of code S2 over code S1 appears to increase with the density of the network. Several attempts were made by those authors to improve on the code, and execution times increased in each case. The conclusion was that the overhead added in attempting to avoid unnecessary processing was greater than the attendant savings.

3.5 Usage-Sensitive Network Problems

As is implied by the literature review, the solution of the general least-cost routing problem has received substantial discussion in the literature. Algorithms have been presented that are efficient and fairly straightforward. All of these algorithms require a set of known and fixed link costs for their solution. Networks involving tariffs that are distance-sensitive, such as AT&T and WU, can be analyzed quite readily with these general algorithms. For networks involving usage-sensitive tariffs, such as SBS, the link costs are a variable function of the traffic volume transmitted over the link. In general, the cost per circuit is quantity discounted and decreases as the traffic volume increases. However, the relationship between circuit cost and volume level is highly nonlinear. To determine the link costs for these types of tariffs, the exact traffic volume over the link must be known. The actual traffic over any link will depend on the number of cities that send their traffic partially over the satellite links, instead of transmitting directly on other terrestrial links. The capability to share satellite facilities among several cities is permitted by the SBS tariff and the usage costs are prorated among the users on the basis of their proportion of the total traffic volume originating at the NAC. In order to calculate the cost per circuit for SBS satellite links (or CPS tariffs in general), the total traffic volume over the link must be known. Based on this traffic level, the facility can be sized and costed. In a mixed terrestrial/SBS network, two alternatives exist for communication voice traffic: terrestrial links and satellite links.

For each city in the network, the costs of each alternative must be compared to determine the least-cost link for the distance and traffic volume under consideration. The basic problem in performing such a comparison is in fixing the satellite link costs. A method is required to determine which cities will share a single satellite facility and how much traffic will be transmitted over the satellite link. The following section provides some insight into the complexity of dealing with usage-sensitive tariffs by taking a closer look at the SBS tariff.

3.6 An Examination of the SBS Tariff Pricing Structure

The SBS tariff is different than both the AT&T and WU types in that it is usage- or volume-sensitive as opposed to distance-sensitive. Link distance has no bearing on the cost per circuit at all. The cost to connect a customer premise on the east coast to one on the west coast may be the same as that for connecting two customer premises within the same city. The actual cost per circuit is a function of the traffic requirement between nodes.

Another characteristic of the SBS tariff is that SBS network access facilities may be shared among "neighboring" cities. The traffic requirement of these neighboring cities is pooled with that of the city containing the network access facilities in determining the cost per circuit over the outgoing satellite links.

Because the SBS tariff is usage-sensitive, the number of neighboring cities sharing an SBS facility and their individual traffic requirements are important factors in determining the size of the SBS facility and in calculating the cost per circuit over the links. As a first step in developing network design and costing criteria for SBS-type networks, an SBS cost function was developed and values of circuit cost versus usage level were plotted. At this point in the tariff analysis, there was no attempt at optimization, but only to develop insight into the effect on the cost per circuit of the various rate elements. This allowed an examination of the behavior of of SBS circuit costs as traffic volume through an SBS facility increases.

The assumptions made for this analysis are summarized as follows:

Only CNS-A analog services were considered,

Seven analog voice-grade CAUs can be connected to each FTU before an additional FTU must be added*,

Minimum CAU charges were included in the cost calculations, and

The traffic level used for the cost calculations was assumed to represent simplex voice circuits originating at a NAC facility.

The actual SBS tariff rates, effective as of 1 November 1982, were used as a baseline for the analysis*. In all cases, the resulting cost per circuit represented a monthly charge, calculated on the basis of the monthly charges for each of the SBS facility components required for the traffic level specified. The baseline rates used were as follows:

---

* A recent change in the SBS tariff now allows twenty CAUs per FTU.

CNS-A NAC charge - $17,850/month;

Minimum CAU charge - $17,850/month;

SCU charge - $5,700/month;

FTU charge $2,550/month; and

Analog CAU charges -

For 1 to 150 CAUs - $95/CAU/month,

For 151 to 300 CAUs - $14,250 + $90/CAU over 150/month, and

For 300 CAUs - $27,750 + $65/CAU over 300/month.

The primary objective of this analysis was to develop a volume-sensitive function of SBS cost per circuit and examine its characteristics over some range of traffic volume using actual tariff rates.

The methodology employed in this analysis was as follows:

1. Develop a computer program to generate actual SBS cost values as a function of traffic volume and plot the calculated SBS cost per circuit versus the number of circuits, and

2. Input the actual SBS tariff rates, effective 1 November 1982, and generate the baseline (actual) SBS cost function over a range of traffic volume.

The baseline SBS cost function was initially plotted over a 0 to 10,000 voice circuit range and is shown in figure 3-2. The function is characterized as a rapidly convergent function with spikes of diminishing height as

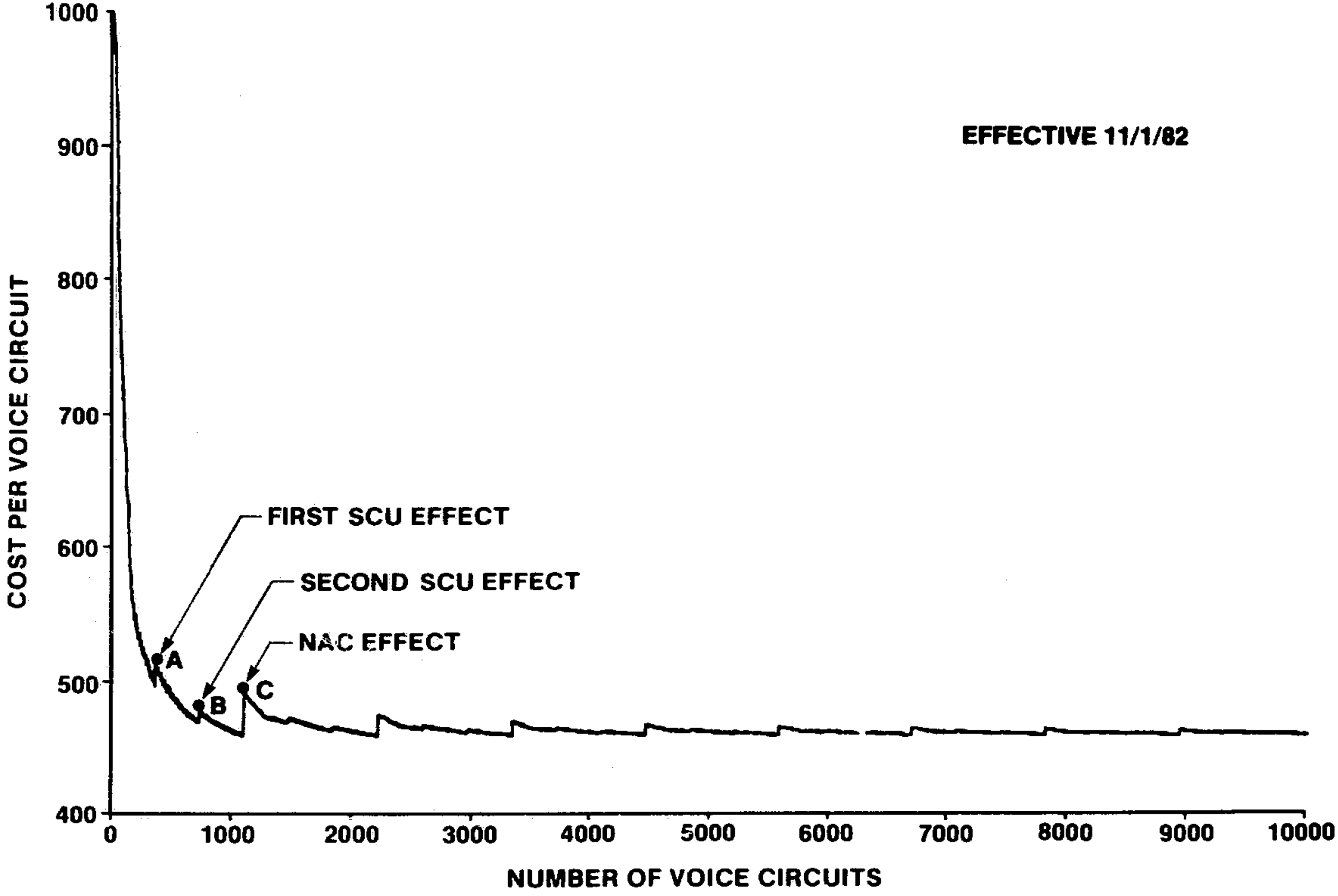

Figure 3-2. SBS Satellite Circuit Costs as a Function of Traffic Volume (0-10,000 VFs)

traffic volume increases. For low traffic levels, the cost per circuit is very high. In fact, the first circuit costs $38,250. (This cost is for one NAC structured to handle one VF.) However, the cost function rapidly decreases as volume increases. Figure 3-2 shows a sharp decrease in cost until the capacity of the initial NAC is exceeded just before point A (373 voice circuits (VFs)). Point A reflects the cost of the first supplemental capacity unit, which provides for an additional 372 VFs. Point B reflects the addition of a second and final SCU, bringing the total NAC capacity in VFs up to 1116 (3 x 372). Once this capacity is reached, an additional NAC must be placed in service; the cost effects of this are shown at point C. As the traffic volume increases, SCUs and NACs are added in the sequence (SCU, SCU, NAC) at volume increments of 372 VFs. As shown in figure 3-2, the incremental cost per circuit of this equipment diminishes as volume increases. In fact, the SBS cost curve converges to some constant value as volume increases.

It was of interest to look at an expansion of the region (0 to 500 VFs). This is shown in figure 3-3 for the baseline cost function. The sawtooth effect shows the incremental costs associated with the addition of FTUs at every 7 VFs. This incremental cost also diminishes as traffic volume increases. The incremental cost per circuit for the addition of an SCU is clearly shown at point A (373 VFs).

The conclusions drawn from this analysis are summarized as follows:

> The SBS cost function is characterized as a convergent nonlinear decreasing function, approaching some constant cost value as circuit volume increases, and

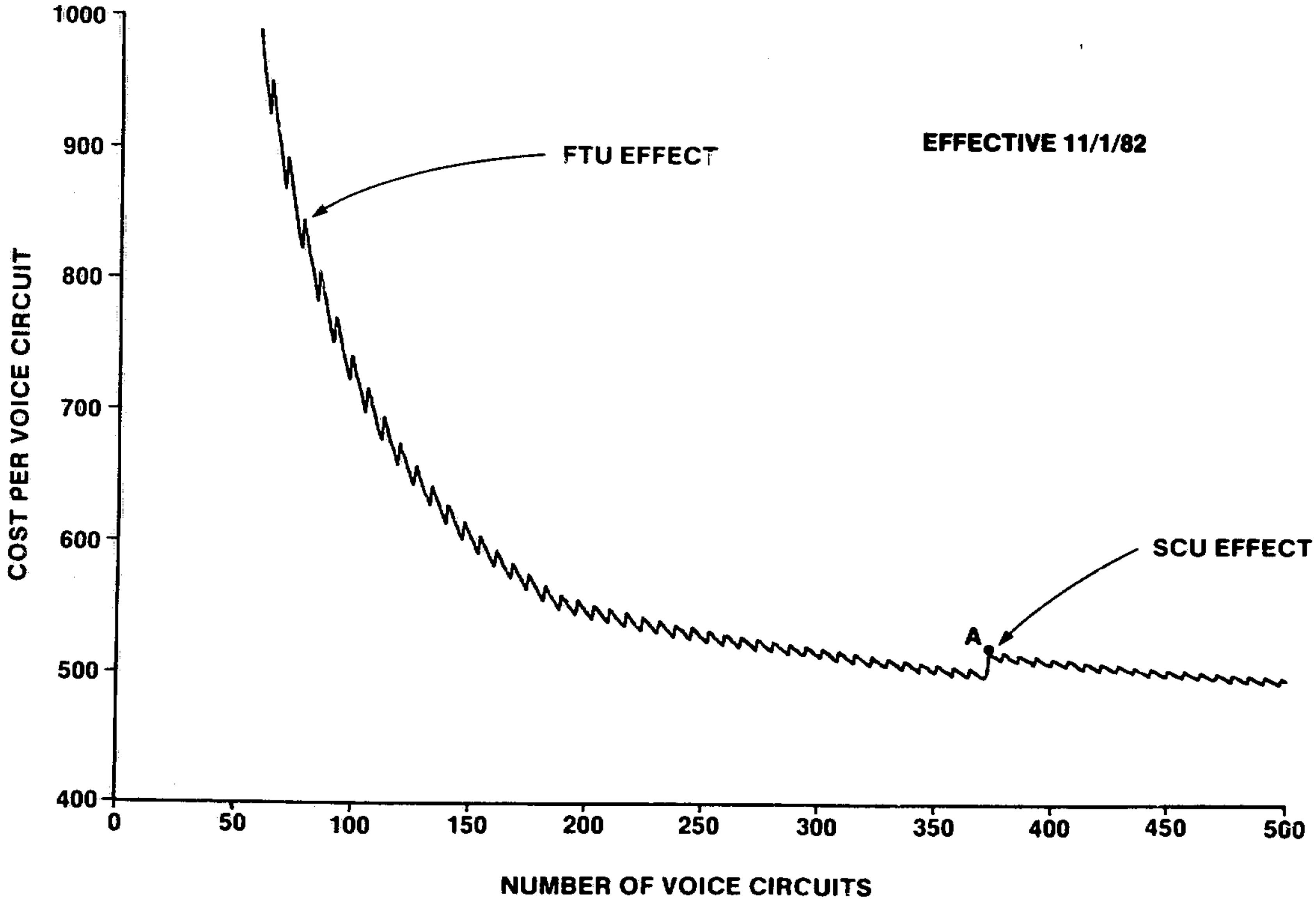

Figure 3-3. SBS Satellite Circuit Costs as a Function of Traffic Volume (0-500 VFs)

The cost function is not strictly decreasing, as there are incremental cost increases associated with the addition of FTUs, SCUs, and NACs. The effect of each of these additions diminishes as volume increases.

4.0 NETWORK OPTIMIZATION ALGORITHMS OF THE CNDC MODEL

The CNDC model provides solutions to two different network problems. The first problem deals with the least-cost routes connecting unique pairs of network nodes, exclusive of other network traffic. The second problem considers the entire network to find the set of links connecting the nodes so that overall network cost is minimized. This section discusses the optimization algorithms implemented in the CNDC model and explains the method used to provide solutions to each of the two problems.

4.1 Network Types Evaluated by the CNDC Model

There are five network types for which the CNDC model must determine the optimal routing solutions. They are characterized by the types of service offerings as follows:

1. All AT&T type terrestrial tariffs.
2. All WU-type tariffs.
3. All SBS-type tariffs.
4. Mixture of one AT&T type terrestrial tariff and one WU-type tariff.
5. Mixture of one AT&T type terrestrial tariff and one SBS-type tariff.

In network types 1 through 4, the tariff providing the least-cost service for each link is determined. For satellite-only networks (types 2 and 3), the optimal routing solution is straightforward because all satellite routes must be direct; that is, double hopping is not permitted. When the network is of type 1 or 4, there is an additional step of determining the least-cost path between each pair of nodes in the network because indirect routing is possible. The network optimization technique described in section 4.2 performs this function.

In the communications networks modeled for the CNDC program, up to 600 rate centers define the network nodes. Directed links are assumed to connect all ordered pairs of nodes. The link traffic is represented in terms of single voice circuits providing voice communications between rate centers. The criterion being optimized is cost. In order to satisfy the additivity assumption of the network algorithm, link costs must be expressed as costs per circuit. After the execution of the network algorithm, the number of voice circuits required on each link is multiplied by the cost per voice circuit on the link to determine total link costs.

The resulting cost per circuit associated with each link of the routing solution represents a minimum over all tariffs in a given run. Except for the SBS mixed problem, costs are minimized over all tariffs prior to network optimization. The network that is input to the optimization algorithm has, at most, a single, least-cost direct link between each ordered pair of nodes.

4.2 Distance-Sensitive Network Optimization Algorithm

The algorithm used by the CNDC model to find the least-cost network (and least-cost routes) is based on an algorithm of Floyd (12). The algorithm determines least-cost paths between all pairs of nodes. The algorithm also considers all network nodes for inclusion in all paths. Whenever the inclusion of a node reduces the cost of a path, the path is rerouted through that node. If no combination of links results in a lower cost than the direct link, the direct link will never be replaced in the routing solution.

The network nodes are numbered from 1 to N. The minimum cost of links between each pair of nodes are stored in an array, M^k. (The superscript denotes the state of the M array on the k^{th} iteration of the algorithm.) The element (i,j) of this array represents the cost associated with the optimal link from node i to node j. If no link exists between any pair of nodes, the corresponding cost is infinite. The computer representation of infinity can be an arbitrary large number (i.e., 9999999). The diagonal elements in the M array are all zero because there is no cost to connect a node to itself. The optimization algorithm constructs N additional M arrays where each array is determined recursively from the entries in the preceding array. The recursion equation used to determine the entry in cell (i,j) of the n^{th} array, M^n, is

$$M_{ij}^{n} = \min \left\{ M_{in}^{n-1} + M_{nj}^{n-1},\ M_{ij}^{n-1} \right\} \qquad (1)$$

where $1 \leq n \leq N$.

This equation is applied for all pairs (i,j) where neither i nor j is equal to n. It can be interpreted as testing whether routing the traffic from node i to node j via node n reduces the associated cost per circuit. If so, node n is included in the path (i,j). A second array, O^n, is constructed at each iteration to record the second node in each path.

An <u>intermediate node</u> is any node in the path except the initial or terminal node. The n^{th} array, M^n, contains the costs to connect all

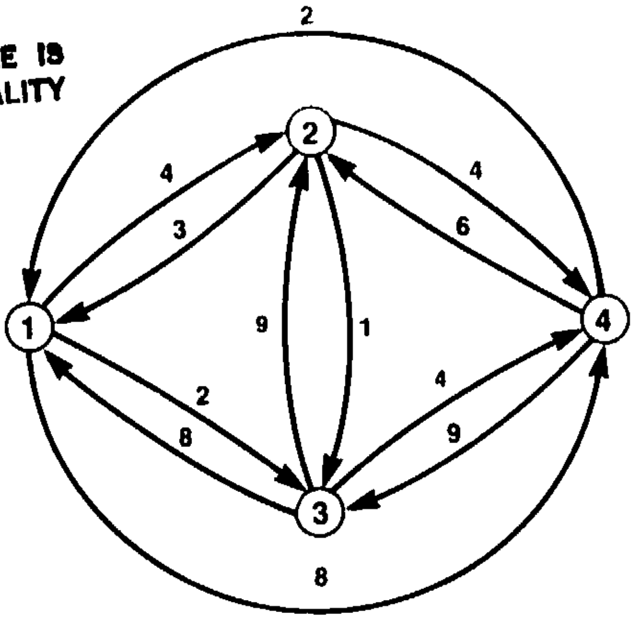

Figure 4-1. A Sample Network

M°

	1	2	3	4
1	0	4	2	8
2	3	0	1	4
3	8	9	0	4
4	2	6	9	0

0°

	1	2	3	4
1	1	2	3	4
2	1	2	3	4
3	1	2	3	4
4	1	2	3	4

Figure 4-2. Initial Arrays M° and 0° of Sample Network

pairs of nodes where only the first n nodes appear in any path. The array M^{n+1} is constructed by considering the $(n+1)^{st}$ node for inclusion in each path.

Upon termination, cell (i,j) of the final array, M^n, represents the cost associated with the least-cost path from node i to node j. At the nth iteration, node n is being considered for inclusion in the least cost path from node i to node j. If the inclusion of node n results in a cost that is less than $M^{n-1}(i,j)$ then $M^n(i,j)$ will be the lesser cost, otherwise $M^n(i,j)$ will be the same as $M^{n-1}(i,j)$. It follows, then, that at the nth iteration, the least-cost path from node i to node j includes only intermediate nodes with numbers from 1 to n and that the final cost M^n (i,j) is a minimum.

Example

Consider the four-node directed network shown in figure 4-1.

The costs of direct links are indicated by the numbers attached to the links. The network contains direct links between all pairs of nodes. The initial M and O arrays are shown in figure 4-2. Row indices correspond to the numbers of originating nodes, and column indices correspond to the numbers of terminating nodes. Cell (i,j) of the M^n array indicates the cost per circuit of traffic from node i to node j. Cell (i,j) of the O^n array indicates the second node in the path from node i to node j.

The array M^1 is constructed recursively from M° via equation (1) as follows:

	Path Selected
$M^1_{23} = \min\left\{M^\circ_{21} + M^\circ_{13}, M^\circ_{23}\right\} = \min\left\{3 + 2, 1\right\} = 1$	2-3
$M^1_{24} = \min\left\{M^\circ_{21} + M^\circ_{14}, M^\circ_{24}\right\} = \min\left\{3 + 8, 4\right\} = 4$	2-4
$M^1_{32} = \min\left\{M^\circ_{31} + M^\circ_{12}, M^\circ_{32}\right\} = \min\left\{8 + 4, 9\right\} = 9$	3-2
$M^1_{34} = \min\left\{M^\circ_{31} + M^\circ_{14}, M^\circ_{34}\right\} = \min\left\{8 + 8, 4\right\} = 4$	3-4
$M^1_{42} = \min\left\{M^\circ_{41} + M^\circ_{12}, M^\circ_{42}\right\} = \min\left\{2 + 4, 6\right\} = 6$	4-2
$M^1_{43} = \min\left\{M^\circ_{41} + M^\circ_{13}, M^\circ_{43}\right\} = \min\left\{2 + 2, 9\right\} = 4$	4-1-3

Remembering that $M^n_{ij} = 0$ for all n when i = j (these are the diagonals), we have $M^1_{11} = M^1_{22} = M^1_{33} = M^1_{44} = 0$. The remainder of the cells of the M^1 array will have the same values as the M° array because of the following relationships:

$$M^n_{in} = M^{n-1}_{in}\text{, and} \qquad (2)$$

$$M^n_{nj} = M^{n-1}_{nj}\text{.} \qquad (3)$$

This can be seen by examining the recursion equations for M^1_{14} and M^1_{41} :

$$M^1_{14} = \min\left\{M^\circ_{11} + M^\circ_{14}, M^\circ_{14}\right\} = M^\circ_{14}$$

$$M^1_{41} = \min\left\{M^\circ_{41} + M^\circ_{11}, M^\circ_{41}\right\} = M^\circ_{41}$$

Thus, for the first iteration, the entries in row and column 1 retain their previous values. The originating and terminating nodes of a path need not be considered for inclusion as intermediate nodes in the path. The arrays M^2, M^3, M^4, 0^2, 0^3, and 0^4 are calculated in a similar manner. The least-cost network defined by M^4 and 0^4 is represented in figure 4-3. Figure 4-4 contains the resulting tables.

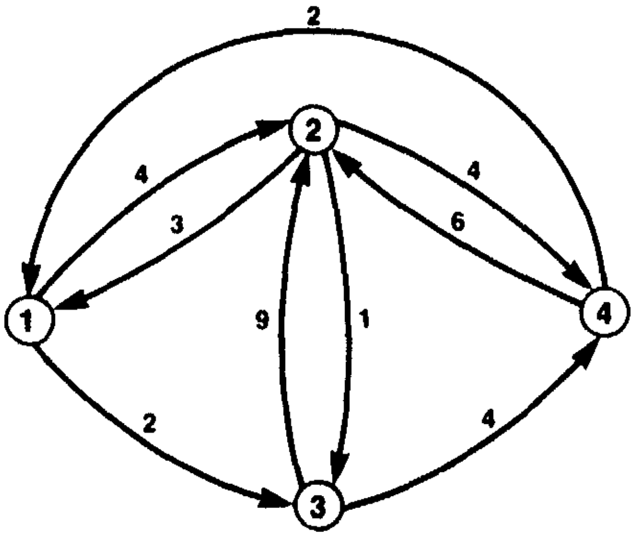

Figure 4-3. Least Cost Routes of Sample Network

The paths connecting pairs of nodes in the least-cost network are traced from the final 0 array. The second node on the path from node 1 to node 4 is node 3, since $0^4_{14} = 3$. The second node on the path from node 3 to node 4 is 4, since $0^4_{34} = 4$. The path from node 1 to node 2 to node 4 is therefore 1-3-4.

The link costs associated with the least-cost solution can be obtained directly from the final M array. Each cell (i,j) of the final M array contains the cost of the least-cost route from node i to node j. The least-cost routes connecting all nodes of the sample network and their associated costs are shown in table 4-1.

4.2.1 Costing of Least-Cost Routes

The final 0 array of the network routing solution provides a data structure that contains linked lists defining the least-cost paths between all

M^1

	1	2	3	4
1	0	4	2	8
2	3	0	1	4
3	8	9	0	4
4	2	6	4	0

O^1

	1	2	3	4
1	1	2	3	4
2	1	2	3	4
3	1	2	3	4
4	1	2	1	4

M^2

	1	2	3	4
1	0	4	2	8
2	3	0	1	4
3	8	9	0	4
4	2	6	4	0

O^2

	1	2	3	4
1	1	2	3	4
2	1	2	3	4
3	1	2	3	4
4	1	2	1	4

M^3

	1	2	3	4
1	0	4	2	6
2	3	0	1	4
3	8	9	0	4
4	2	6	4	0

O^3

	1	2	3	4
1	1	2	3	3
2	1	2	3	4
3	1	2	3	4
1	1	2	1	4

M^4

	1	2	3	4
1	0	4	2	6
2	3	0	1	4
3	6	9	0	4
4	2	6	4	0

O^4

	1	2	3	4
1	1	2	3	3
2	1	2	3	4
3	4	2	3	4
4	1	2	1	4

Figure 4-4. M^N O^N Arrays of Sample Network

Table 4-1. Sample Least-Cost Routing Solutions from the Final M Array

Network Link	Least-Cost Path	Cost
(1,2)	1-2	4
(1,3)	1-3	2
(1,4)	1-3-4	6
(2,1)	2-1	3
(2,3)	2-3	1
(2,4)	2-4	4
(3,1)	3-4-1	6
(3,2)	3-2	9
(3,4)	3-4	4
(4,1)	4-1	2
(4,2)	4-2	6
(4,3)	4-1-3	4

pairs of nodes in the network. In order to determine the total cost over a given least-cost route, the traffic between all pairs of nodes in the route must be added to the appropriate link. Consider, for example, a least-cost route from node x to node y via intermediate nodes v and w, as shown in figure 4-5.

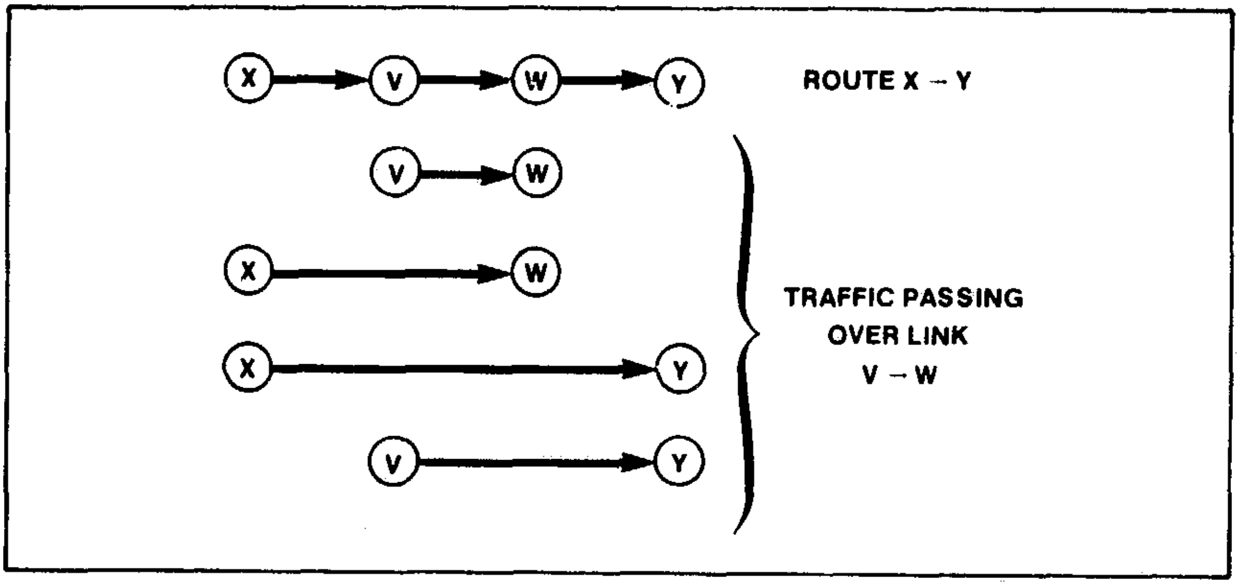

Figure 4-5. Traffic Volumes Along Least Cost Route Contributing to Link Costs

The link between node v and w must be sized to accommodate the sum of the following traffic volumes:

Traffic from node x to node y,
Traffic from node x to node w,
Traffic from node v to node w, and
Traffic from node v to node y.

The results of the network optimization algorithm are used by the CNDC model to describe each least-cost route in the network. The appropriate traffic volumes traversing each link in the route are summed. The corresponding cost per circuit is multiplied by the total traffic to calculate the total cost over the link. The costs of all intermediate links are then summed to determine the total cost of circuits on the route.

The costing procedure does not consider pass-through network traffic (i.e. traffic that either originates or terminates at nodes not on the least-cost path under consideration).

4.2.2 Costing of the Least-Cost Network

In order to cost the least-cost network, it is necessary to determine the total network traffic traversing each link in the least-cost network, including traffic originating or terminating at nodes not on the link. Consider the example shown in figure 4-6. Suppose the least-cost network for the three nodes consists of the links as shown. To determine the total traffic on each link, the model adds the traffic volume for each node pair to the total volume for each link in the path. The link totals represent the total network traffic on the links. The pairs of nodes in the least-cost network in figure 4-6 are (1,2), (1,3), (2,1), (2,3), (3,1), and (3,2).

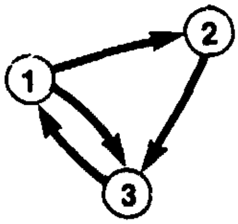

Figure 4-6. A Least Cost Network

Example: Denote the traffic column between nodes i and j by T_{ij}. Denote the total network traffic volume on link (i,j) by T(i,j). Traversing the paths connecting each pair of nodes yields the link volumes:

$T(1,2) = T_{12} + T_{32}$,

$T(1,3) = T_{13}$,

$T(2,3) = T_{21} + T_{23}$, and

$T(3,1) = T_{21} + T_{31} + T_{32}$.

The paths (1,2) and (1,3) are direct, so T_{12} is added to T(1,2) and T_{13} is added to T(1,3). The path (2,1) is via node 3, so T_{21} is only added to T(2,3) and T(3,1). The path (2,3) is direct, so T_{23} is only added to T(2,3). The path (3,1) is direct so T_{31} is added to T(3,1). The path (3,2) is via node 1, so T_{32} is added to T(3,1) and T(1,2).

The procedure outlined in the preceding example is executed by the CNDC model for the least-cost network based on the outputs of the network optimization algorithm. The link volumes thus obtained are multiplied by the minimum cost per circuit associated with each link to determine the total cost of the link. The sum of the costs for each link is the overall network cost.

4.3 Usage-Sensitive Network Optimization Algorithm

This section discusses the algorithm implemented in the CNDC model to determine the least-cost network solution for a mixed SBS/terrestrial-type network. The determination of an optimal solution is hindered by a usage-sensitive, nonlinear SBS cost function with many local extreme points, as shown in figure 4-7. A heuristic approach is developed to:

1. Iteratively partition the network such that varying levels of interpartition satellite traffic can be evaluated with respect to total network cost.

2. Select the location of NACs within each partition such that intra-partition traffic costs are minimal.

3. Determine the combination of terrestrial and satellite services yielding the least-cost routes between all network nodes.

The usage-sensitive problems capable of being analyzed by the CNDC model involve a single AT&T type terrestrial tariff and a single SBS type satellite tariff. Either of these tariffs can be the actual prestored tariff of the

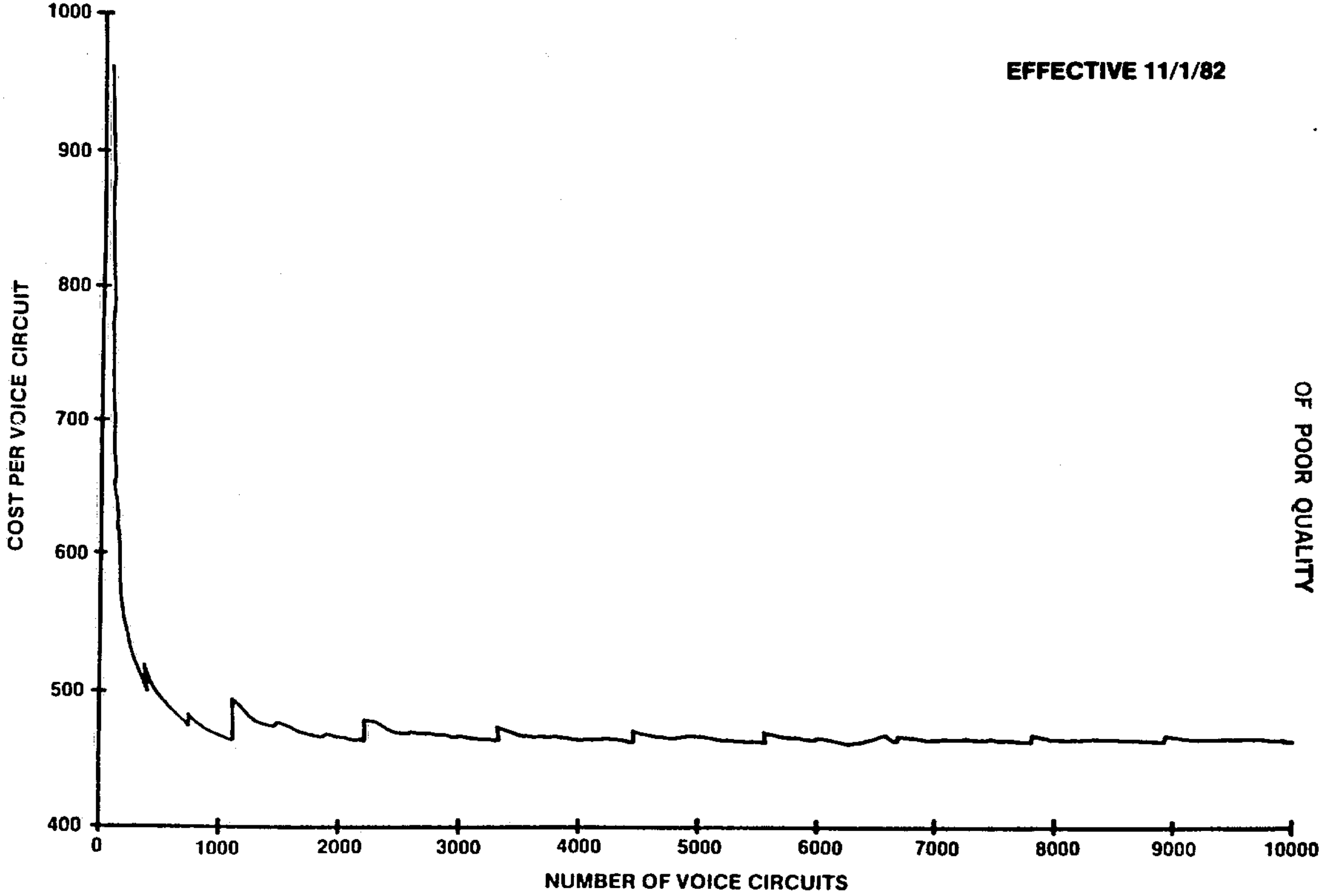

Figure 4-7. Baseline SBS Cost Function (Actual Rates)

carrier or some user-defined variation having the same pricing and connectivity structure.

4.3.1 Overview of the Usage-Sensitive Algorithm

The algorithm initially performs a least-cost routing solution using only the input terrestrial tariff and the distance-sensitive procedures discussed in section 4.2. The resulting solution is placed into computer storage for later cost comparisons. The entire network is then divided into partitions or clusters of nodes, with each partition having exactly one satellite NAC. Each partition will have two categories of traffic, intrapartition and interpartition.

Intrapartition traffic is defined as the traffic between any two cities within the same partition. The actual link between these two cities may include segments inside and/or outside of the partition. All intrapartition traffic uses terrestrial links. Interpartition traffic is defined as the traffic between any two cities that are not members of the same partition. The choice of service (satellite or terrestrial) for interpartition links is decided on the basis of cost. All interpartition traffic is routed through the NAC cities in the respective partitions if satellite service is used. By pooling satellite traffic on a partition basis, the lowest possible satellite cost per circuit can be achieved since these are volume-sensitive costs.

Initially, the algorithm assumes all interpartition traffic will use satellite service and will be routed through the partition NAC city. The total interpartition traffic level is used to determine an initial satellite cost per circuit. A determination is then made as to what portion of the initially assumed traffic volume through the NAC can cost justify the use of the satellite link versus the terrestrial alternative. The algorithm will iteratively calculate the SBS cost per circuit based on total traffic through the NAC cities. During each iteration, it will perform comparisons of satellite versus terrestrial costs for each city pair. A decision will then be made regarding which service cost is lower. The total traffic volume of those cities favoring terrestrial links will be removed from the total routed through the NAC city, and a new satellite cost per circuit will be calculated. This process is repeated until no further cities change service. At this point, a network solution is obtained. Network costs are then computed as previously described in section 4.2. The cost solution is stored in computer memory for comparison to the cost solution from the next iteration.

The algorithm performs its first iteration with only three partitions and three satellite NACs. During each iteration, the number of network partitions and satellite access cities is increased. A cost solution is generated during each iteration and total network cost is tracked. A determination is made when a minimum cost network has been obtained and the resulting solution is printed out. The solution includes the minimum cost network configuration of satellite access cities for a combined terrestrial/satellite service network.

The algorithm provides an option for the user to bypass the automatic network configuration function and to specify an input set of satellite NACs. In this case, the network is partitioned around the input set of NACs and the algorithm proceeds as previously described.

The algorithm contains four major functional modules:

Initialization,
Partitioning,
Service decisionmaking, and
Cost response tracking.

Figure 4-8 provides a flow diagram for the algorithm and depicts the relationship between these functional modules. During the initialization phase, the least-cost solution for an all-terrestrial network is calculated and the starting number of satellite network access cities is set to three (minimum for SBS CNS-A networks). The partitioning function assigns each city in the network to a partition. It also selects one city within each partition as the NAC for satellite service. All other cities within the partition will route their satellite traffic through the NAC. As the algorithm proceeds through its iterations, the number of partitions increases and, consequently, the amount of satellite traffic passing through each NAC decreases.

The service decisionmaking function performs cost comparisons regarding terrestrial versus satellite service for each link in the network. Initial assumptions are made regarding satellite traffic volume, and service changes may occur based on cost comparisons. The service decisionmaking function iteratively evaluates link costs, selects the least-cost alternate service, and recalculates satellite link costs. The process ends when no further service changes occur.

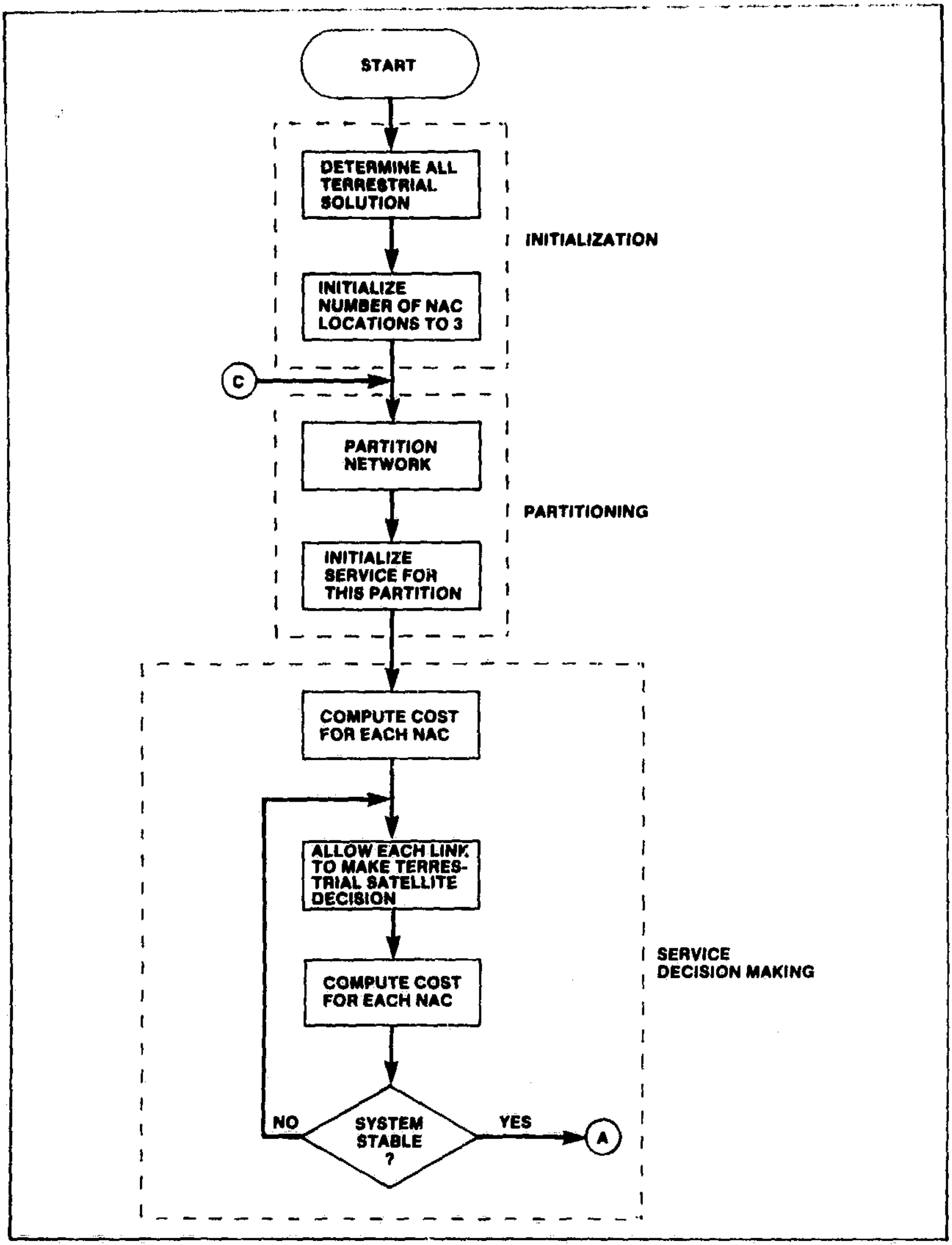

Figure 4-8a. Flow Diagram for Usage Sensitive Algorithm

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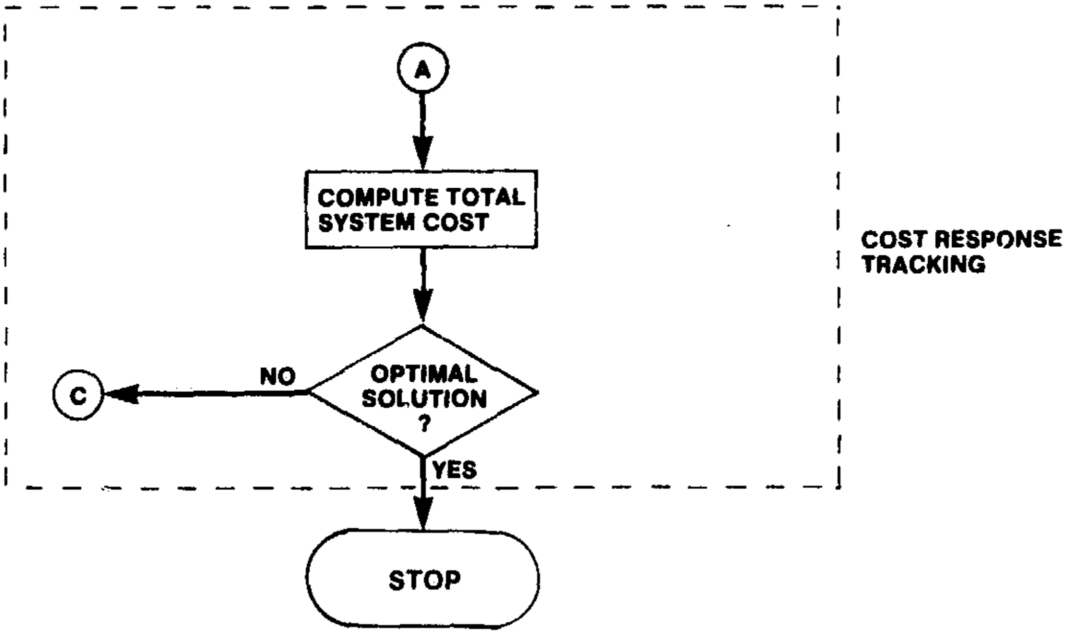


Figure 4-8b. Flow Diagram for Usage Sensitive Algorithm

The cost response tracking function maintains a history of total network cost resulting from the solution generated during each iteration (i.e., with a specific number of network partitions and NACs). The minimum cost solution is identified from the trend of cost solutions.

4.3.2 Partitioning Function

The network partitioning component of the algorithm divides the total network into nonoverlapping partitions, with the number of partitions equal to the number of NAC cities. A partition is defined as a NAC city and an associated set of non-NAC cities within the network having the following characteristics:

> For each non-NAC city within the network, its nearest (in a cost-wise sense) NAC neighbor is identified and the non-NAC city is assigned to that NAC city's partition.

Only terrestrial costs are considered because it has been assumed that all intrapartition traffic will use terrestrial services. The intent in constructing the network partitions is to configure each intrapartition network so that its traffic costs are a minimum. Because terrestrial services are being considered, there are three factors that will determine the link costs:

Distance of the link,
Listed/unlisted status of cities on the link, and
Tariff rate structure.

The minimum cost links for intrapartition traffic will be identical to those resulting from a solution of the terrestrial-only least-cost network problem. The network partitioning component of the algorithm will require this solution as an input.

The partitioning function has a goal of segmenting the network into homogeneous groupings or "natural" clusters of cities. The partitioning problem can be restated as a classification or class assignment problem, with each partition representing a separate class. The network of cities can be viewed in an abstract sense as a set of points in two-dimensional coordinate space with each point defined by its vertical and horizontal coordinates. Higher dimensions could be defined by considering the traffic distributions (originating and terminating) associated with each city; however, this was not done for the present study. The partitioning function seeks to identify specific patterns of points in this two-dimensional space (pattern space). Points in the pattern space belonging to the same class should tend to cluster according to some metric on the space. Similarly, representations of dissimilar patterns (i.e., from different classes) should lie in different regions of the space. Clustering methods can provide useful techniques for discovering regularities, structures, or patterns in complex data sets. One such technique, known as hierarchical clustering, is used in the network partitioning function.

Before discussing hierarchial clustering, it is important that the concepts of pattern similarity and pattern space metrics be understood.

The process of pattern recognition is based on measurements or features of the pattern space. The task of a pattern classifier is to assign the features to one of several possible pattern classes. Two different patterns should be assigned to the same class on the basis of their being similar and to different classes on the basis of their being dissimilar. There are several possible measures of similarity that can be completed from feature measurements. Pattern classification is dependent on both the similarity measure employed as well as on the effectiveness of the particular feature measurements for classification purposes. In a statistical sense, pattern classification attempts to minimize the within-class pattern variability, while enhancing the between-class variability. If effective features are used, pattern representations should tend to assemble into well-separated groups or clusters, with one cluster for each pattern. The pattern classification problem becomes one of partitioning the feature space into regions, with one region for each class. Good features enhance within-class pattern similarity and between-class pattern dissimilarity. The primary features employed in the partitioning scheme of the algorithm are the vertical and horizontal coordinates of each network city.

The greater the average pairwise distance between patterns of different classes, the better the separability of the two classes. The notion of interclass distance is the simplest concept of class separability that can be used to assess the discriminatory potential of pattern representations in a given space.

The distance between two points in a multidimensional space can be measured by any convenient metric. A large number of metrics have been suggested in the pattern recognition literature, each having particular advantages and disadvantages (16). One of the most commonly used metrics is the Euclidean distance measure. Given two points in a multidimensional space, denoted by the vectors X_k and X_l, the Euclidean metric, x, is defined simply as the square root of the sum of squares between the points. That is:

$$\sigma_x (X_k , X_e) = \left[\sum_{j=1}^{d} (X_{kj} - X_{lj})^2 \right]^{1/2} = \left[(X_k - X_l)^t (X_k - X_l) \right]^{1/2} \qquad (4)$$

where d = the number of features.

For the CNDC model, each city has two features (d=2). For any two cities k and l, the Euclidean distance is:

$$\sigma_x (X_k , X_l) = \left[(X_{k_1} - X_{l_1})^2 + (X_{k_2} - X_{l_2})^2 \right]^{1/2} ,$$

where

X_{k_1} = vertical coordinate of city k,
X_{k_2} = horizontal coordinate of city k,
X_{l_1} = vertical coordinate of city l, and
X_{l_2} = horizontal coordinate of city l.

The clustering algorithm attempts to partition the network of cities into homogeneous subsets or clusters by considering the similarities of cities with respect to their geographic location, using vertical and horizontal coordinates as measurement features. The use of the Euclidean distance metric supports the concept that points in the same cluster or partition should be close to each other. This is reasonable if terrestrial tails to the serving NAC city are to be minimized. By the same token, the cities of one cluster should be some distance from those of other clusters if the use of the satellite service is to be economically feasible, as will be discussed in the next section on service decisionmaking.

The clustering algorithm proceeds through several stages in which clusters are iteratively merged into other clusters until there is effectively only one cluster remaining that contains all data points. At any stage of the hierarchical clustering algorithm, the pair of the existing clusters that are most similar are merged to create a new cluster, thus reducing the number of clusters within the data set by one. For an observation data set of n points, the algorithm terminates after n-1 steps. Natural clusters of points in the data set are detected by assessing the relative changes in the value of the similarity measure at various stages of the algorithm.

At every stage of the clustering process, the hierarchical approach involves merging together the two most similar clusters. Initially, every city is considered as a separate cluster. In the next stage, the two most similar cities are combined to form one cluster. This merging process is continued in the consecutive stages of the cluster analysis, thus reducing the number of clusters at each stage by one. The clustering procedure is terminated when the number of clusters is reduced to three since the SBS tariff requires a minimum of three NAC locations in the network. Figure 4-9 depicts the clustering process.

The Euclidean distance measure is nearly identical to the airline mileage formula of the AT&T terrestrial tariff and, as such, provides no real advantage over airline mileage as a measure. Because the goal of the partitioning function is to divide the network into partitions so that the intra-partition costs will be minimal, all factors that affect terrestrial routing costs should be considered. Aside from the particular tariff used, the only other factor that affects cost is the status (listed/unlisted) of the cities at either end of each link. The clustering technique was enhanced by using terrestrial link cost as a basis of partitioning. This allowed both geographic location and city status information to be considered in the partitioning process, although location was the driving feature. During the iterative stages of the algorithm, partitions having the lowest interpartition link costs would be merged first.

A graphical representation of the hierarchical structure of the cluster yielded by the algorithm is called a dendogram. Figure 4-10 shows an example of a dendogram for a hypothetical clustering problem involving eight cities. The dendogram illustrates the cluster merging sequence as a function of distance (airline mileage). For any distance threshold, a set of clusters can be obtained that has subclusters with similarity at least equal to the threshold value. In figure 4-10, the threshold Q_T splits the data set into three clusters. In general, the threshold level should be chosen so that the intercluster distances are considerably greater than the intracluster distances.

The satellite NAC within each partition is chosen as the high traffic density node. This approach has produced reasonable results in terms of minimizing total network costs; however, the resulting solution may not be optimal. A recommended enhancement or refinement of the algorithm would involve the optimal placement of NACs within each partition. This is a type

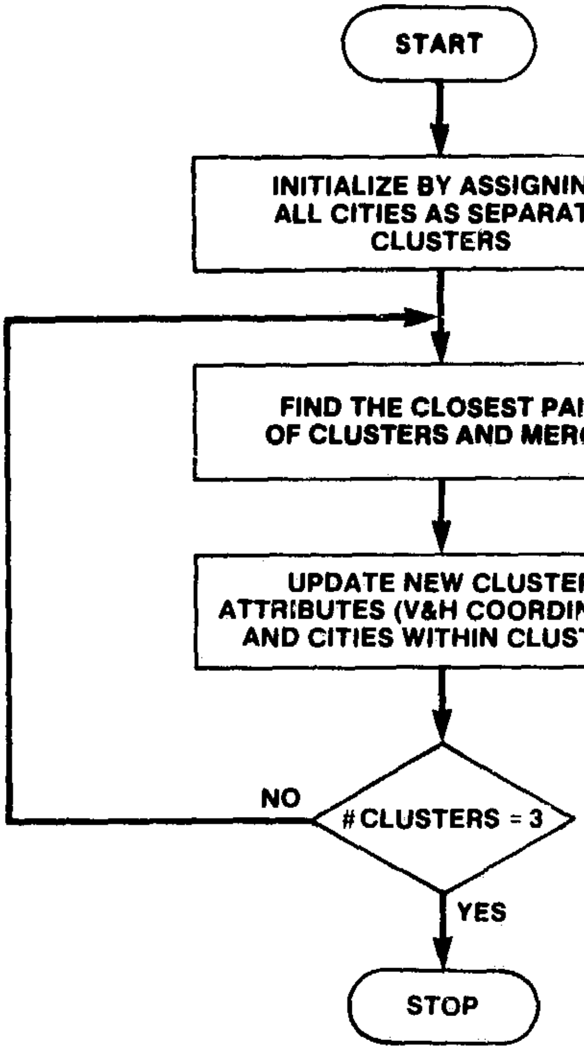


Figure 4-9. Overview of Clustering Technique

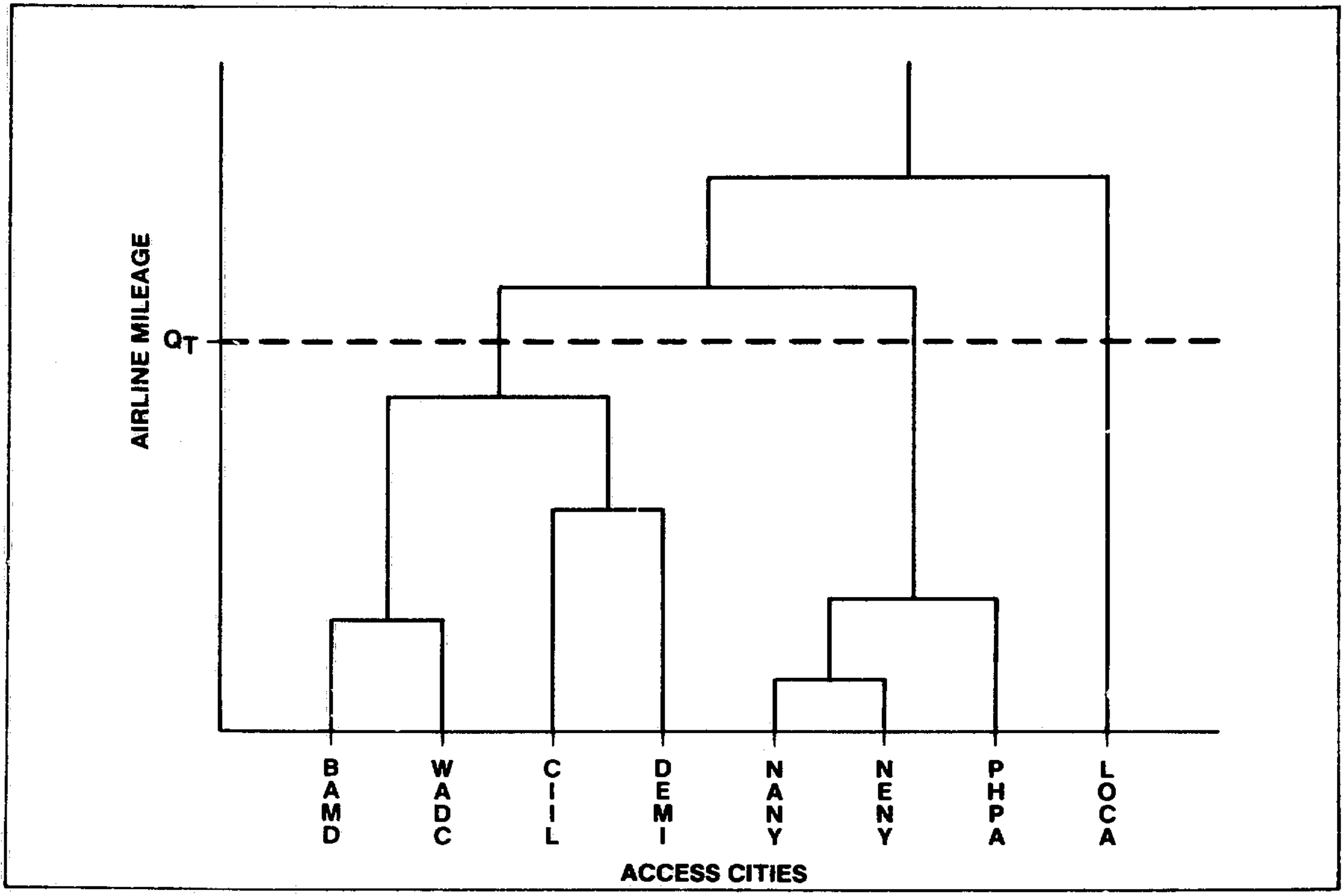


Figure 4-10. Dendogram illustrating the CNDC Model Clustering Technique

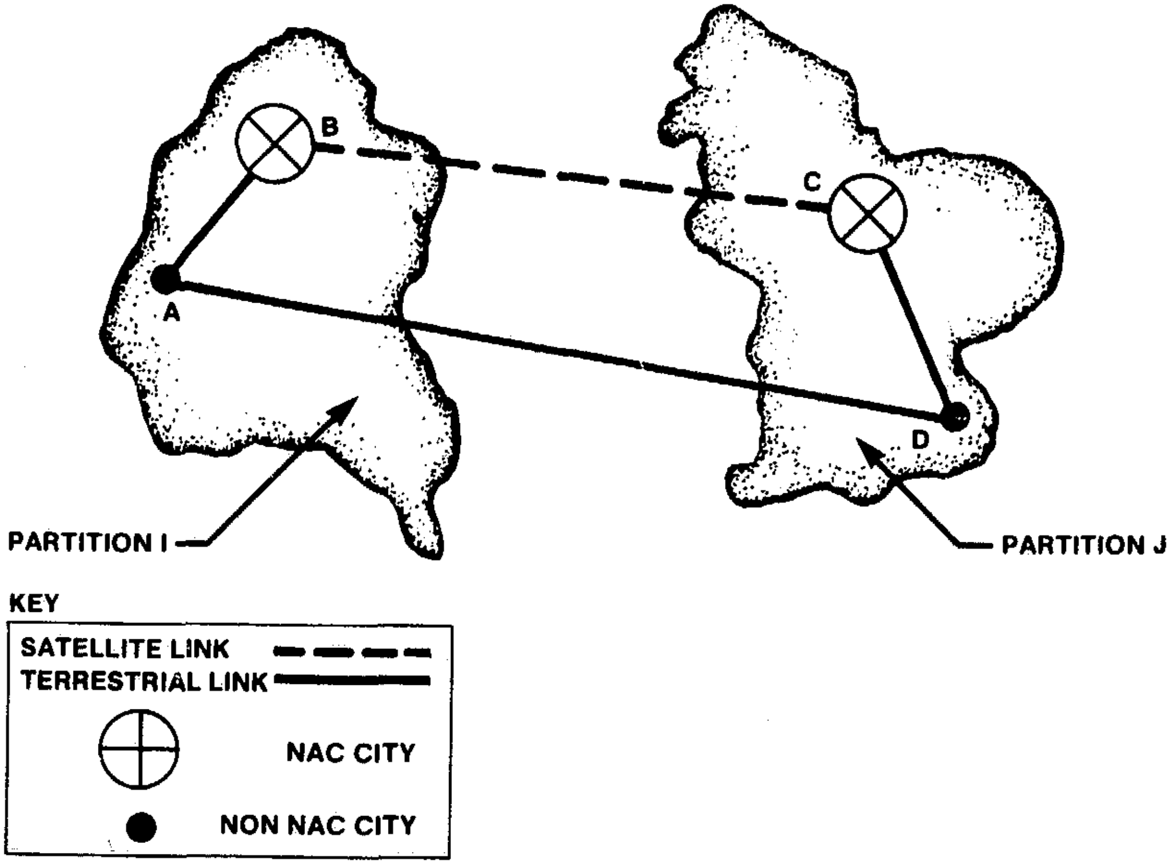
of location assignment problem for which a variety of optimization techniques exist. It is not envisioned that this refinement would produce networks of significantly lower cost.

4.3.3 Service Decisionmaking Function

The service decisionmaking component of the algorithm processes through each partition to determine the service to be used (terrestrial or satellite) for its traffic links to all other partitions. The specific decision criteria for choosing a service for any particular interpartition link will be the crossover cost associated with the link. The crossover cost is defined as that total cost per circuit associated with terrestrial services between two nodes, which will determine whether satellite or terrestrial services are employed. If the associated satellite cost per circuit between two nodes is less than the corresponding crossover cost, then satellite service will be used to link other nodes. An example is illustrated in figure 4-11. In this example of a crossover cost, the service decision for the link between city A in partition I and city D in partition J will be made. There are two alternatives to consider:

1) Via the terrestrial link AD (assumed least-cost terrestrial path), or
2) Via terrestrial link AB to satellite link BC to terrestrial link CD.

In order for the satellite alternative to be cost-effective, the following relationship must hold, where C denotes link cost:



$\text{CROSSOVER COST}_{AD} = C_{AD} - C_{AB} - C_{CD}$

Figure 4-11. Example of a Crossover Cost

$$C_{AB} + C_{BC} + C_{CD} < C_{AD}, \text{ or equivalently} \quad (5)$$

$$C_{BC} < C_{AD} - (C_{AB} + C_{CD}). \quad (6)$$

The satellite cost must be less than the difference between the least-cost terrestrial link and the sum of the tail costs in each partition (C_{AB} + C_{CD}). The expression on the right side of inequality (6) is defined as the crossover cost. Others studying similar problems have used crossover distances. They have assumed some constant satellite cost in doing so. Because we are dealing with usage-sensitive satellite tariffs with a variable cost per circuit function, cost per circuit must be used as the service decision criterion.

For any partition, the crossover costs associated with links to all other partitions can be calculated. Each partition will have its own set of crossover costs, with each crossover cost having an associated traffic volume. The set of crossover costs for any partition can be ordered from some minimum value to some maximum value. In making the service decision, there are three possibilities regarding the value of the satellite cost:

Case 1 - the satellite cost is less than the minimum crossover cost.

Case 2 - the satellite cost is greater than the maximum crossover cost.

Case 3 - the satellite cost is between the minimum and maximum crossover costs.

Figure 4-12 illustrates these three cases.

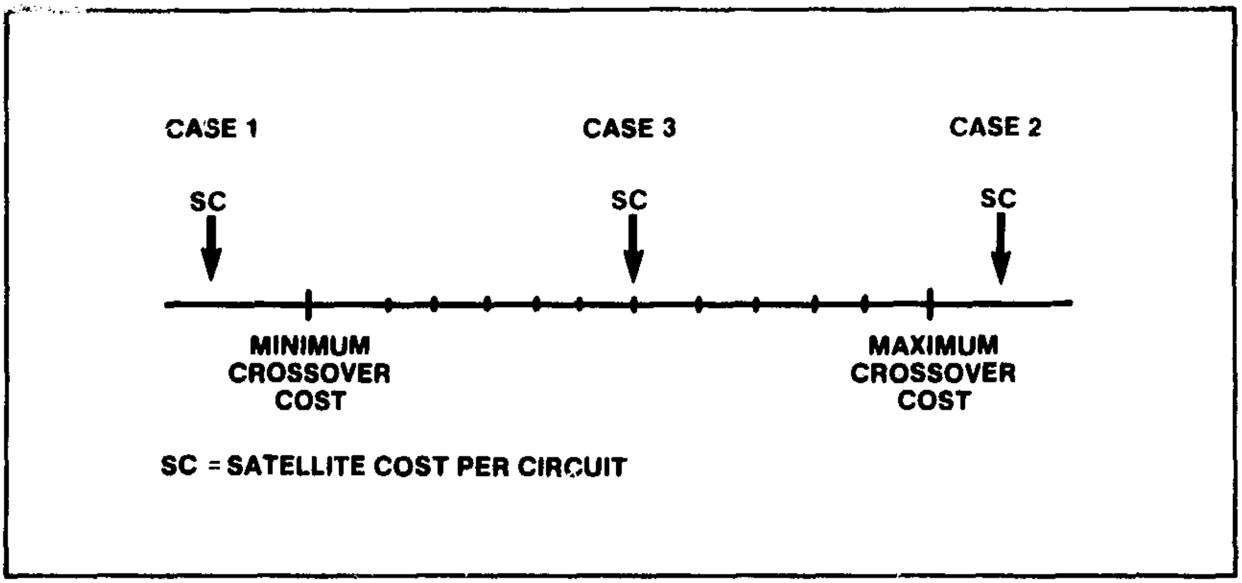


Figure 4-12. An Ordering of Crossover Costs for Any Partition

For cases 1 and 2, the decisions are clearcut. In case 1, because the cost of the satellite link is less than the costs of all competing terrestrial links, all inter-partition traffic originating in the partition under consideration will be routed via satellite. In case 2, the exact opposite is true and all traffic is routed terrestrially. Case 3 involves a situation in which satellite routes are cost-effective for some links and not for others.

Each partition has an associated set of ordered pairs of crossover costs and traffic volumes corresponding to directional links to other partitions. To calculate the satellite cost per circuit, it is initially assumed that all nodes within any partition use the satellite link for interpartition traffic. The total volume of originating interpartition traffic for all nodes within a partition is used to determine satellite cost per circuit.

This cost may produce one of the three possible cases previously discussed. If case 3 occurs, the initial satellite cost will need to be adjusted in some iterative manner to complete the service decisionmaking process.

When the initial satellite link cost (SC_0) falls somewhere between the minimum and maximum crossover costs, two groups of links result: one terrestrial and one satellite. Figure 4-13 illustrates the two groups of links.

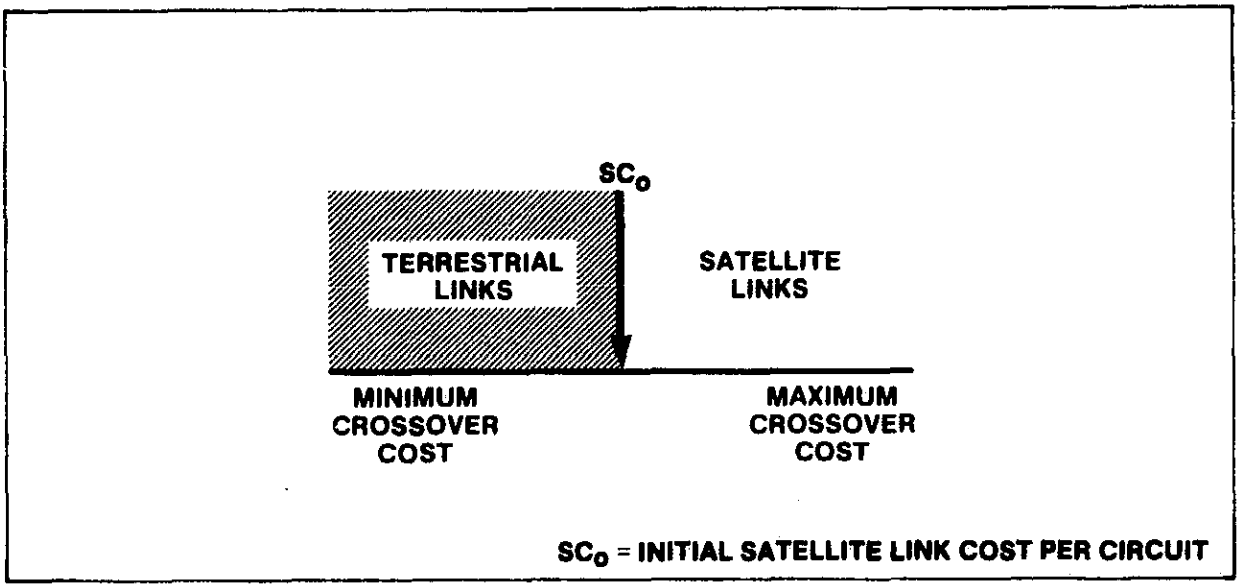


Figure 4-13. Grouping of Partition Links with Initial Satellite Cost

Because the value of SC_0 was determined on the basis of total originating traffic in the partition, the traffic associated with the links in the terrestrial group must be removed from the total originating partition traffic in order to calculate a new satellite cost (SC_1). The new cost, SC_1, will likely be higher than the previous cost and may result in terrestrial service becoming cost-effective for some prior satellite links. If this happens, the volume associated with those satellite links is removed from the satellite traffic total and a new satellite cost is again calculated. The process is repeated until either:

The new satellite cost results in no further service changes, or

The new satellite cost exceeds the maximum crossover cost, in which case all links use terrestrial service.

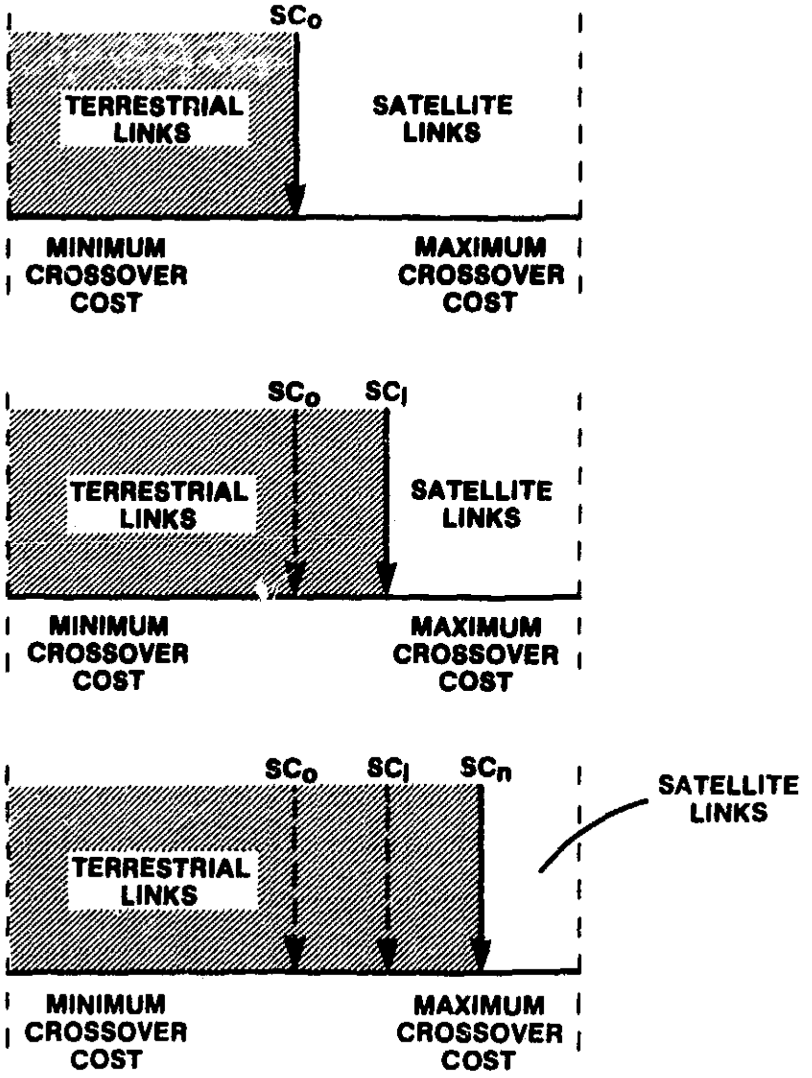
Figure 4-14 illustrates the transition of the satellite cost per circuit through the service decision stages.

Due to the behavior of the SBS cost function, it is possible for satellite circuit costs to decrease as satellite traffic is removed, particularly if traffic levels are near the spikes in the SBS cost function (i.e., the NAC has a large unused capacity). In order to avoid instability in the algorithm, an assumption is made that once links have decided upon terrestrial service, this decision is final. There is no reevaluating procedure for these links if the satellite cost comes down below the link crossover cost. This assumption is reasonable since:

SBS cost function generally decreases as volume increases;

For high-volume links, the magnitude of increases in SBS cost associated with decreases in volume will be small; and

The effect of the difference between the new satellite cost and the alternate terrestrial cost on the total network cost will be small for any one link.



SC$_0$ = initial satellite link cost per circuit

SC$_I$ = satellite link cost per circuit after first decision stage

SC$_n$ = satellite link cost per circuit after nth decision stage

Figure 4-14. Transition of Satellite Circuit Cost Through Service Decision Stages

4.3.4 Cost Response Tracking Function

The functions of the cost response tracking component of the algorithm are:

To monitor the total network cost from the various solutions as additional satellite NAC cities are included in the network,

To determine when the sequence of total network costs begins to diverge,

To terminate the algorithm, and

To identify the minimum solution in the sequence.

The network solution space ranges from an all-terrestrial network with no satellite links to an all-satellite network with no terrestrial links. Although the behavior of a total network cost function depends on the topology of the network under consideration and the tariffs used, a concave cost curve, such as that illustrated in figure 4-15, is realistic and characteristic of the SBS and AT&T tariffs. Note that the all-terrestrial case will be the least-cost network solution for a "terrestrial only" network.

The general methodology of the cost tracking component is to first store off the total network cost solution resulting from each iteration of the network partitioning and service decisionmaking components, as well as that

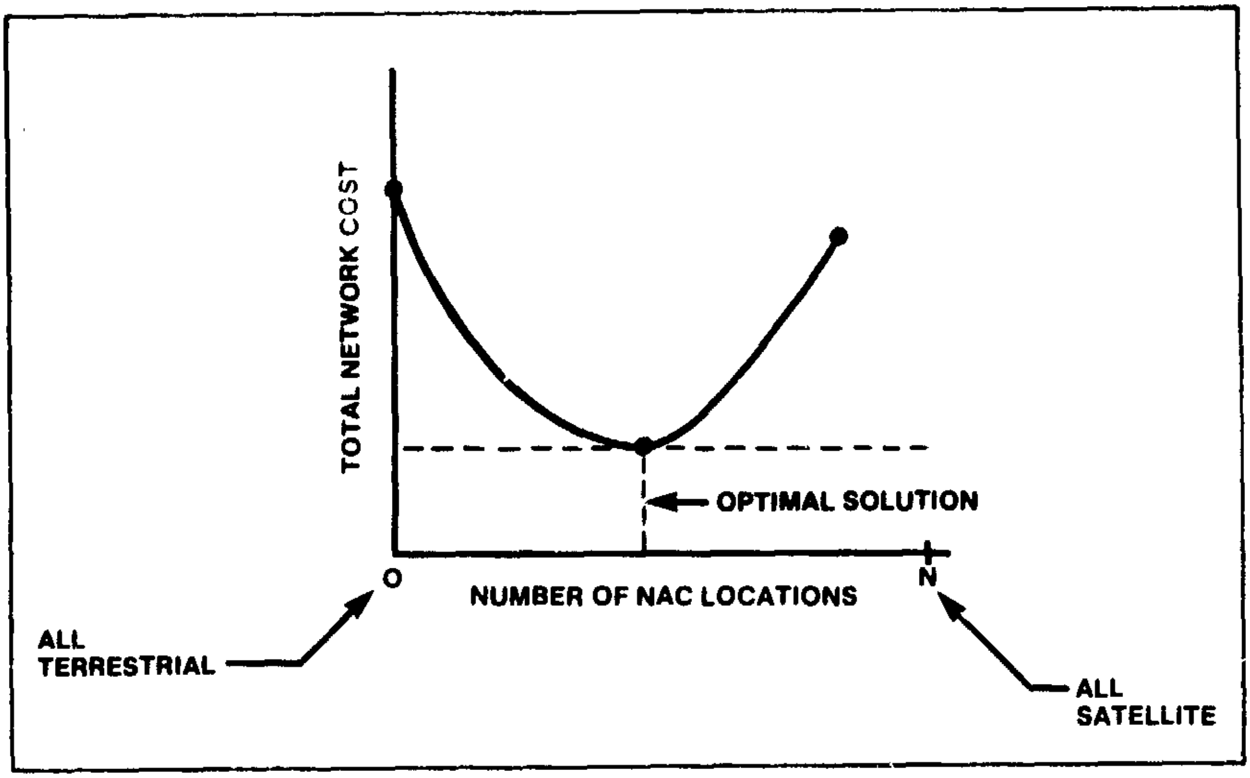


Figure 4-15. Typical Total Network Cost Function

for the all-terrestrial solution. As each new network solution is generated, it is compared to the stored file of previous solutions. The algorithm is terminated when the cost tracking component becomes "reasonably confident" that the total network cost solutions are diverging (i.e., the minimum solution has been reached). At this point, stored solutions can be examined and the minimum solution identified. The solution will correspond to a network with a specific number of NAC nodes (or partitions).

The termination scheme selected is very simple. The iterative generation of solutions will terminate when the most recent solution generated is greater than the previous minimum by a predefined factor. This factor may be adjusted to meet the user's needs as one studies the cost response behavior of the system's output.

5.0 OVERVIEW OF COMPUTER IMPLEMENTATION OF THE CNDC MODEL

5.1 Operating Environment and Program Requirements

The CNDC program was implemented on the Lewis Research Center IBM 3033AP computer system running under the TSS/370 operating system. CNDC was written in TSS/370 FORTRAN IV. The program requires computer operator involvement only if the user chooses to operate in batch mode using a card deck. However, because batch mode can be invoked from the terminal or the user may operate in interactive mode, operator involvement can be avoided.

The libraries containing the program and the elements of the database that are not defined and maintained by the user are all maintained under a single user identification. Any potential user of this model may gain access to these files from his own user identification. This access will permit him to make use of the model and database, but will not permit him to make any changes to them. Those elements of the database created and maintained by the user will be located under his user identification and are not accessible by another user. (See section 5.2 for further discussion of the database.)

The CNDC model can be executed in either of two modes: interactive or batch. In the interactive mode, the user supplies model inputs and performs database operations interactively on a terminal. When running the model in batch mode, input and control parameters are supplied from a card deck or disk file created off-line from the program.

The model allows the user to define the network analysis problem by specifying a network of cities and a set of applicable tariffs. It provides the user with the capability of specifying the types of networks to be analyzed. The user is able to build and maintain a library of network files specifying the cities included in each network as well as the voice traffic between them. The user may define his own tariffs and use them to analyze market capture given postulated rates. The user-defined network and tariffs are built by responding to questions and options presented by the program. The program presents a series of menus from which the user selects the program functions he chooses to use.

5.2 Overview of Supporting Database

The files that make up the database are of two kinds: the prestored files and the user-defined files. The model does not provide the user with direct access to any of these prestored files.

The files within the user-defined database can be referenced, created, deleted, and listed by the user within the control of the CNDC model. The files contain the descriptions of user-defined networks, user-defined tariffs, and a user-defined problem description.

5.2.1 Prestored Database

The files within the prestored database define a set of prestored nodes (Standard Metropolitan Statistical Areas (SMSAs)), the directional traffic between every pair of nodes, the AT&T, WU, and SBS tariffs, and the directories to the user-defined networks and tariffs.

The prestored AT&T tariff contains a list of the category A rate centers and the rates for series 2000/series 3000 channels between any two cities for three schedules: schedule 1 - both cities are category A rate centers; schedule 2 - only one city of the pair is a category A rate center; and schedule 3 - neither of the cities in the pair is a category A rate center. Each of the three tariff schedules is defined by a table of rates that are a function of mileage.

The prestored WU tariff contains a list of satellite access city pairs along with the tariff category (long haul, medium haul, or short haul) associated with each pair. The tariff also contains the channel charge for each of the three categories.

The prestored SBS tariff contains the SBS monthly rates for NAC, SCU, CNS-A FTUs, and CAUs.

The CNDC model allows for the definition of user tariffs based on the terrestrial and satellite prestored tariffs. The user may store up to thirteen of these tariffs so they may be used as input for computer runs. A directory is maintained by the model of the current set of user-defined tariffs. In the same way, the model allows for the definition and storing of up to twenty networks so they may also be used in future computer runs. A directory is maintained by the model of the current set of user-defined networks. These two directories are part of the prestored database.

5.2.2 User-Defined Database

The user has the capability to define tariffs and networks. These user-defined network and tariff files constitute the user-defined database. These files are built by the user through an interactive process with the model. The user must also specify his inputs to the optimization function. These inputs are placed in the execution control file, which is also built interactively through the model and maintained as part of the user-defined database.

When defining a network to be maintained as part of the user-defined database, the user must specify which, if any, of the prestored traffic nodes he wishes to include. In addition, he must specify the total traffic for the prestored nodes expressed as voice circuits. The user may also include in his network traffic and nodes not specified in the prestored network and traffic table.

A user-defined tariff is based on the existing prestored licensed common carrier and specialized common carrier tariffs, both terrestrial and satellite. A user terrestrial tariff can be defined using the AT&T terrestrial tariff as a point of departure. The user may redefine which cities are to be considered category A and may alter any of the mileage increment charges of the three schedules. A user satellite tariff can be defined using the WU satellite tariff as a point of departure. The user may define satellite access city pairs and may alter the channel charge for any of the three charge categories. A user satellite tariff can also be defined using the SBS satellite tariff as a point of departure. The user may change any of the rates specified in the tariff. However, no user defined tariff may alter the basic connectivity philosophy of the existing tariff upon which it is based.

5.3 Overview of Computer Programs

The tasks performed by the CNDC model can be divided into two major functions:

Create and maintain the database, and
Perform optimization on a defined problem set.

5.3.1 Database Management Routines

A separate stand-alone program is used to build and modify the elements of the prestored database. This program is available only to program maintenance personnel. The user-defined database is created and maintained by the INPUT module of the CNDC program. Specifically, the user has the capability to construct one or more networks for analysis, select the desired common carrier tariffs to be used, or select and define his own, and set parameters for controlling program execution. The INPUT module communicates with the user through menus and is the only CNDC module that interacts with the user.

5.3.2 Optimization Routines

Once the user has defined a problem set for modeling and created an execution control file through the INPUT module, he may initiate the optimization functions. There are five modules within CNDC to perform the optimization:

INIT - Performs all the initialization of data structures required for program execution.

COSTNG - Uses the network and tariffs specified as input to determine link costs between all nodes of the specified network for all tariffs. It then determines the service that provides the least cost for every link in the network.

NETWRK - Solves the least-cost routing and least-cost network problems for terrestrial-only or mixed terrestrial-WU satellite cases.

SBSMIX - Performs optimization for the problem that contains one terrestrial and one SBS tariff.

OUTPUT - Controls all report generation from an execution of the optimization portion of the program. The user is provided the capability to select various output reports.

5.4 Output Reports

Output is generated by the CNDC model upon completion of each individual problem within a run. Output consists of six reports or tables. By default, the program will generate all six output reports. Any of the reports can be suppressed by user request. These reports include:

Table 1. Input as Output
Table 2. Least-Cost Routes
Table 3. Least-Cost Network
Table 4. Output Network Totals
Table 5. Tariff Summary
Table 6. Traffic Table

The contents of the six output reports are described below.

Output Report 1 - Input as Output

- List of network cities
- Total traffic level for network (voice circuits)
- Listing of each tariff used

Output Report 2 - Least-Cost Route Solution

- Listing of least-cost route links
- Link summaries
  - Total airline mileage
  - Traffic volume on link (voice circuits)
  - Voice circuit facility groupings (jumbo, master, super, base)
  - Cost per circuit over link
  - Total cost of circuits over link
  - Tariff used
  - Type of service used (terrestrial or satellite)

Output Report 3 - Least-Cost Network Solution

Listing of least-cost routes

Link summaries (same as Report 2)

Output Report 4 - Network Summary

Total terrestrial circuit mileage

Total satellite circuit mileage

Total terrestrial traffic

Total satellite traffic

Total network traffic

Total terrestrial costs

Total satellite costs

Total network costs

Output Report 5 - Tariff Summary

Summary list for each tariff included in network solution

- Total circuit mileage
- Total traffic
- Percent of network traffic using tariff service
- Total network cost associated with tariff
- Percent of network cost associated with tariff service (terrestrial/satellite)

Output Report 6 - Traffic Table

Traffic volume (voice circuits) between all network city pairs

6.0 INTERPRETATION OF CNDC MODEL OUTPUT

6.1 Overview

Output is generated by the CDC model upon completion of each individual problem within a run. Output consists of six reports or tables. By default, the program will generate all six output reports. Any of the reports can be suppressed by user request. These reports include:

Table 1. Input as Output
Table 2. Least-Cost Routes
Table 3. Least-Cost Network
Table 4. Output Network Totals,
Table 5. Tariff Summary
Table 6. Traffic Table

The contents of the six output reports are described in the following sections.

6.2 Input as Output

The user has the option of having the input data set for each problem printed as the first output report. This report is printed out by default, unless the user explicitly suppresses it via execution control file inputs. Specifically, TABLE 1 contains the following types of information, which appear annotated on figure 6-1:

```
       **************************************************

                            SBSMXD

                             CASE  1

                           MIXED (SBS)

       **************************************************


*****************************************************************
**********************   TABLE 1   INPUT   **********************
*****************************************************************

                 PROBLEM  1 OF RUN SBSMXD   IS SBS MIXD ①

      NETWORK FILE NET011 CONTAINS THE FOLLOWING     9 NODES ②

        CODE                            CITY NAME
        ----              ------------------------------------
        ANCA..........ANAHEIM-SANTA ANA-GARDEN GROVE CA
        BAMD..........BALTIMORE MD
        CIIL..........CHICAGO IL
        DEMI..........DETROIT MI
        LOCA..........LOS ANGELES-LONG BEACH CA
        NANY..........NASSAU-SUFFOLK NY
        NENY..........NEW YORK NY-NJ
        PHPA..........PHILADELPHIA PA-NJ
        WADC..........WASHINGTON DC-MD

   TRAFFIC LEVEL FOR PRESTORED NODES IS   20000000 VOICE CIRCUITS ③
```

Figure 6-1. Sample Table 1 Output Report – Input as Output (Sheet 1 of 3)

```
                              TARIFFS USED
                 TARIFF TRFATT IS PRESTORED ATT TARIFF
SCHEDULE  1
 MILEAGE                              CHARGE
---------    ----------------------------------------------------------
        1    $    73.56
   2-  14    $    73.56  +  $2.59 FOR EACH MILE OVER     1 MILES
       15    $   109.82
  16-  24    $   109.82  +  $2.16 FOR EACH MILE OVER    15 MILES
       25    $   131.42
  26-  39    $   131.42  +  $1.62 FOR EACH MILE OVER    25 MILES
       40    $   155.72
  41-  59    $   155.72  +  $1.62 FOR EACH MILE OVER    40 MILES
       60    $   188.12
  61-  79    $   188.12  +  $1.62 FOR EACH MILE OVER    60 MILES
       80    $   220.52
  81-  99    $   220.52  +  $1.62 FOR EACH MILE OVER    80 MILES
      100    $   252.92
 101- 999    $   252.92  +  $0.94 FOR EACH MILE OVER   100 MILES
     1000    $  1098.92
OVER 1000    $  1098.92  +  $0.58 FOR EACH MILE OVER  1000 MILES

SCHEDULE  2
 MILEAGE                              CHARGE
---------    ----------------------------------------------------------
        1    $    75.00
   2-  14    $    75.00  +  $4.77 FOR EACH MILE OVER     1 MILES
       15    $   141.78
  16-  24    $   141.78  +  $4.47 FOR EACH MILE OVER    15 MILES
       25    $   186.48
  26-  39    $   186.48  +  $2.89 FOR EACH MILE OVER    25 MILES
       40    $   229.83
  41-  59    $   229.83  +  $1.95 FOR EACH MILE OVER    40 MILES
       60    $   268.83
  61-  79    $   268.83  +  $1.95 FOR EACH MILE OVER    60 MILES
       80    $   307.83
  81-  99    $   307.83  +  $1.95 FOR EACH MILE OVER    80 MILES
      100    $   346.83
 101- 999    $   346.83  +  $0.94 FOR EACH MILE OVER   100 MILES
     1000    $  1192.83
OVER 1000    $  1192.83  +  $0.58 FOR EACH MILE OVER  1000 MILES

SCHEDULE  3
 MILEAGE                              CHARGE
---------    ----------------------------------------------------------
        1    $    76.43
   2-  14    $    76.43  +  $6.35 FOR EACH MILE OVER     1 MILES
       15    $   165.33
```

④

Figure 6-1. Sample Table 1 Output Report – Input as Output (Sheet 2 of 3)

```
      16-  24    $  165.33  +  $5.48 FOR EACH MILE OVER   15 MILES
           25    $  220.13
      26-  39    $  220.13  +  $4.03 FOR EACH MILE OVER   25 MILES
           40    $  280.58
      41-  59    $  280.58  +  $3.03 FOR EACH MILE OVER   40 MILES
           60    $  341.18
      61-  79    $  341.18  +  $2.31 FOR EACH MILE OVER   60 MILES
           80    $  387.38
      81-  99    $  387.38  +  $1.95 FOR EACH MILE OVER   80 MILES
          100    $  426.38
     101- 999    $  426.38  +  $0.97 FOR EACH MILE OVER  100 MILES
         1000    $ 1299.38
    OVER 1000    $ 1299.38  +  $0.58 FOR EACH MILE OVER 1000 MILES
                                                                          ④
    TARIFF FILE      A CONTAINS THE FOLLOWING   9 CATEGORY A RATE CENTERS
ANCA     BAND     CIIL     DEMI     LOCA     NANY     NENY     PHPA     WADC

                    TARIFF TRFSBS IS THE PRESTORED SBS TARIFF
               THE APPROPRIATE RATES FOR THIS TARIFF ARE AS FOLLOWS

                    NAC CHARGE..................$  17850.00
                    SCU CHARGE..................$   5700.00
                    FTU CHARGE..................$   2550.00
                    MINIMUM CAU CHARGE..........$  17850.00
     NUMBER CAU                              CHARGE
    ------------------------------------------------------------------
    UP TO 150 CAU    $     95.00 FOR EACH CAU
    UP TO 300 CAU    $  14250.00 + $     90.00 FOR EACH CAU OVER  150 CAU
    OVER  300 CAU    $  27750.00 + $     65.00 FOR EACH CAU OVER  300 CAU

                    THE PROGRAM WILL SPECIFY NAC PLACEMENT ⑤
```

Figure 6-1. Sample Table ı Output Report – Input as Output (Sheet 3 of 3)

1. Indication of problem type (terrestrial-only, satellite-only, etc.),
2. Listing of network file,
3. Total traffic level for the network,
4. List of tariff files, and
5. Listing of user input NAC cities (mixed-SBS problems only).

6.3 Least-Cost Route Solution

Output TABLE 2 describes the facilities and circuits determined to supply communication services between each pair of cities in the network at the lowest tariffed cost. The traffic on each of the least-cost routes is provided in the form of link summaries. The contents of TABLE 2 for a single city pair are shown in figure 6-2. The outputs are repeated for all unique city pairs in the network. In any route which uses an SBS type tariff, the total hardware requirement associated with the origin city is itemized. The numbered annotations on figure 6-2 are described as follows:

1. Unique city pair. The field identifies the unique city pair by printing the four-character city codes of the originating and terminatng cities.
2. Least-cost route. This output field identifies the nodes in the least-cost route for the city pair. All nodes are referenced by the corresponding four-character city code.

3. Total circuit mileage. The total circuit mileage on the least-cost route is calculated by summing the airline mileages over the route. This number is the sum of the individual link airline mileages listed in the Link Summary.

4. Total cost of circuits. The total circuit cost in dollars is calculated by summing the cost of each link on the least-cost route. The number is the sum of the costs associated with the individual links listed in the Link Summary.

The remaining entries in TABLE 2 for a given city pair are included in a tabular summary that itemizes information about the individual links that comprise the least-cost route. Two link summaries are provided for each directional link between the cities. The upper link lists traffic inclusive of other network or "pass-through" traffic. The lower link lists traffic exclusive of pass-through traffic over the link.

The following information appears in both Link Summaries and is annotated on figure 6-2. NOTE: The upper link summary is inclusive of traffic between only those cities included on the least-cost route.

5. Link. The entries in the first column of a Link Summary identify the character codes of the service nodes defining each link in the least-cost route.

6. Total airline mileage. This column contains the airline mileage on each link as calculated from the vertical and horizontal coordinates of the corresponding service nodes.

7. Traffic volume. The traffic volume on each link includes all voice circuit requirements between nodes.

8. Facility size. The traffic requirement on each link is used to determine the number of base groups, super groups, master groups, and jumbo groups necessary to handle the volume on the link. A base group consists of 12 4 KHz channels, a super group consists of 60 4 KHz channels, a master group consists of 600 4 KHz channels, and a jumbo group consists of 3,600 4 KHz channels.

9. Cost per circuit. This column contains the minimum tariffed cost in dollars of a single circuit providing voice communication between the respective service nodes.

10. Total cost of circuits. This column contains the total tariffed cost in dollars for each link. The total cost is the product of the cost of an individual circuit (item 9) multiplied by the link traffic volume in voice circuits (item 7).

11. Tariff. This column contains the name associated with the tariff file yielding the lowest cost per circuit for each link.

C-2

12. Service. This field contains the word "TERRESTRIAL" or the word "SATELLITE" to reflect the type of service represented by the tariff used to supply circuits on each link.

6.4 Least-Cost Network Solution

Table 3 desribes the least-cost routes between all city pairs, indicating on each link of the routes the medium that is necessary to satisfy the traffic requirements of the entire network. The contents of TABLE 3 for a single city pair are shown in figure 6-3. The outputs are repeated for all unique city pairs in the network. In any route which uses an SBS type tariff, the total hardware requirement associated with the origin city is itemized. The annotated numbers are associated with the following descriptions:

1. Unique city pair. This field identifies the unique city pair by printing the four-character city codes of the originating and terminating cities.

2. Least-cost route. This output field identifies the nodes in the least-cost route for the city pair. All nodes are referenced by the corresponding four-character city code.

   The remaining entries in TABLE 3 for a given city pair are included in a tabular summary that itemizes information about the individual links that comprise the least-cost route.

```
TABLE 2

-------------
NANY - LOCA   ①
-------------

THE LEAST-COST ROUTE FROM NANY TO LOCA IS ②

        NANY-NENY-LOCA

THE TOTAL CIRCUIT MILEAGE FROM NANY TO LOCA IS      2463 MILES. ③

THE TOTAL COST OF CIRCUITS FROM NANY TO LOCA IS $   4327542.20  ④

                                              LINK SUMMARY
                                              ---- -------
    ⑤    |    ⑥     |      ⑦       |                 ⑧                    |     ⑨      |      ⑩        |    ⑪    |     ⑫      |
                                          FACILITY SIZE
   LINK  |  TOTAL   |    TRAFFIC    |-------------------------------------|  COST PER  |  TOTAL COST   |  TARIFF  |   SERVICE  |
         |  AIRLINE |   VOLUME ON   |  JUMBO  | MASTER | SUPER  |  BASE   |  CIRCUIT   | OF CIRCUITS   |          |            |
         |  MILEAGE | LINK (VC'S)   | GROUPS  | GROUPS | GROUPS | GROUPS  | (DOLLARS)  |  (DOLLARS)    |          |            |
--------------------------------------------------------------------------------------------------------------------------------
NANY-NENY|       20 |        21560  |       5 |      5 |      9 |       2 |$   120.62  | $  2600567.20 |TRFATT-1  | TERRESTRIAL|
NENY-LOCA|     2443 |         1867  |       0 |      3 |      1 |       1 |$   925.00  | $  1726975.00 | TRFWU    | SATELLITE  |

                                              LINK SUMMARY
                                              ---- -------
    ⑤    |    ⑥     |      ⑦       |                 ⑧                    |     ⑨      |      ⑩        |    ⑪    |     ⑫      |
   LINK  |  TOTAL   |               |              FACILITY SIZE
         |  AIRLINE |    TRAFFIC    |-------------------------------------|  COST PER  |  TOTAL COST   |  TARIFF  |   SERVICE  |
         |  MILEAGE |   VOLUME ON   |  JUMBO  | MASTER | SUPER  |  BASE   |  CIRCUIT   | OF CIRCUITS   |          |            |
         |          | LINK (VC'S)   | GROUPS  | GROUPS | GROUPS | GROUPS  | (DOLLARS)  |  (DOLLARS)    |          |            |
--------------------------------------------------------------------------------------------------------------------------------
NANY-NENY|       20 |          725  |       0 |      1 |      2 |       1 |$   120.62  | $    87449.50 |TRFATT-1  | TERRESTRIAL|
NENY-LOCA|     2443 |          725  |       0 |      1 |      2 |       1 |$   925.00  | $   670625.00 | TRFWU    | SATELLITE  |
```

Figure 6-2. Table 2 Output Report – Least Cost Routes

```
TABLE 3

-------------
NANY - LOCA  ①
-------------

THE LEAST-COST ROUTE FROM NANY TO LOCA IS ②

          NANY-NENY-LOCA

                                                   LINK SUMMARY
                                                   ---- -------
                                   ⑤
    ③     |     ④        |                                         |     ⑥          |       ⑦          |    ⑧      |      ⑨      |
          |TOTAL NETWORK |           FACILITY SIZE                 |  COST PER      |    TOTAL COST    |           |             |
   LINK   |TRAFFIC VOLUME|-----------------------------------------|  CIRCUIT       |  OF CIRCUITS     |  TARIFF   |   SERVICE   |
          |ON LINK (VC'S)| JUMBO  | MASTER  | SUPER   |  BASE      |  (DOLLARS)     |   (DOLLARS)      |           |             |
          |              | GROUPS | GROUPS  | GROUPS  |  GROUPS    |                |                  |           |             |
-------------------------------------------------------------------------------------------------------------------------------------
          |              |        |         |         |            |                |                  |           |             |
 NANY-NENY|       22674  |      6 |       1 |       7 |          5 | $     120.62   | $   2734937.88   | TRFATT-1  | TERRESTRIAL |
 NENY-LOCA|        1867  |      0 |       3 |       1 |          1 | $     925.00   | $   1726975.00   |  TRFHU    |  SATELLITE  |
          |              |        |         |         |            |                |                  |           |             |
```

Figure 6-3. Sample Table 3 Output Report – Least Cost Network

3. Link. The entries in the first column of a Link Summary identify the character codes of the service nodes defining each link in the least-cost route.

4. Traffic volume. This field contains the total volume of network traffic that traverses each link in the least-cost network expressed as a number of voice circuits. If the least-cost route connecting any pair of cities in the network includes the link, the corresponding directional traffic volume between those cities is included in the total network traffic volume in the link.

5. Facility size. The total network traffic requirement on each link is used to determine the number of base groups, super groups, master groups, and jumbo groups necessary to handle the volume on the link.

6. Cost per circuit. This column contains the minimum tariffed cost in dollars of a single circuit providing voice communication between the respective service nodes.

7. Total cost of circuits. This column contains the total tariffed cost in dollars for each link. The total cost is the product of the cost of an individual circuit (item 6) multiplied by the total network traffic volume on the link in voice circuits (item 4).

8. Tariff. This column contains the name associated with the file containing the tariff that was determined to yield the lowest cost per circuit for each link.

9. Service. This field contains the word "TERRESTRIAL" or the word "SATELLITE" to reflect the type of service represented by the tariff used to supply circuits on each link.

6.5 Network Totals

TABLE 4 summarizes least-cost routing totals for the entire least-cost network including airline mileage, number of circuits, and circuit costs. A typical output table is shown in figure 6-4. The annotated numbers are associated with the following descriptions:

1. Total circuit mileage. The total terrestrial circuit mileage, the total satellite circuit mileage, and the combined total circuit mileage are printed. The mileage between each pair of cities is included in the appropriate satellite or terrestrial mileage total depending on the service between the cities. The total terrestrial and satellite circuit mileages sum to the combined total circuit mileage.

2. Total voice circuits. The total number of terrestrial voice circuits, the total number of satellite voice circuits, and the combined total number of voice circuits are printed. The number of voice circuits determined to be required to handle the network traffic on each link of the least-cost network is added to the appropriate total depending on the service used to provide voice communication between the cities. The total number of terrestrial

and satellite voice circuits sum to the combined total.

3. Cost. The total cost of all the terrestrial circuits, satellite circuits, and combined circuits are printed. The total cost of circuits on each link is added to the appropriate total (satellite or terrestrial) depending on the service between the cities. The total cost of terrestrial and satellite circuits sum to the combined total cost of all circuits. For problems involving SBS-type tariffs, the following output is also included in TABLE 4:

4. Summary of satellite earth station equipment. A summary of all SBS earth station equipment is given, broken down into NACs, SCUs, FTUs, and CAUs.

5. Summary of optimization results. The results of each iteration of the cost optimization algorithm are printed. The program prints the total number of NACs, the total number of separate NAC locations (there may be multiple NACs at a given location), and the total system cost.

6. SBS NAC cities. Those cities that were determined to be cost-effective for NAC placement are printed out by the program.

6.6 Tariff Summary

TABLE 5 presents a summary of tariff utilization in the routing solutions. Statistics associated with each tariff are presented both as totals and as percentages of the corresponding overall network totals. A typical output table is shown in figure 6-5. The annotated numbers are associated with the following descriptions:

1. Tariff. Each tariff included in the routing solution is identified by name.

2. Total circuit mileage. The least-cost routing mileage associated with each tariff is printed. The mileage between each pair of cities is included in the appropriate tariff total depending on the tariff providing communication service between the cities. The total circuit mileages for the individual tariffs sum to the total network circuit mileage printed in TABLE 4.

3. Total voice circuits. The total number of circuits associated with each tariff is printed. The number of voice circuits between each pair of cities is included in the appropriate tariff total depending on the tariff providing communication service between the cities. The total number of voice circuits for the individual tariffs sum to the total number of voice circuits in the least-cost network as printed in TABLE 4.

```
**********************************************************************
**************    TABLE 4.   OUTPUT NETWORK TOTALS    ****************
**********************************************************************
                                                                                        ①
TOTAL TERRESTRIAL CIRCUIT MILEAGE IN THE LEAST-COST NETWORK ....................     504 MILES
TOTAL SATELLITE CIRCUIT MILEAGEIN THE LEAST-COST NETWORK .......................   75794 MILES
COMBINED TOTAL CIRCUIT MILEAGE IN THE LEAST-COST NETWORK .......................   76298 MILES
                                                                                        ②
TOTAL NUMBER OF TERRESTRIAL VOICE CIRCUITS IN THE LEAST-COST NETWORK ..........   110594 CIRCUITS
TOTAL NUMBER OF SATELLITE VOICE CIRCUITS IN THE LEAST-COST NETWORK ............    89992 CIRCUITS
COMBINED TOTAL NUMBER OF VOICE CIRCUITS IN THE LEAST-COST NETWORK .............   200586 CIRCUITS
                                                                                        ③
TOTAL COST OF TERRESTRIAL CIRCUITS IN THE LEAST-COST NETWORK ..................$     16544656.00
TOTAL COST OF SATELLITE CIRCUITS IN THE LEAST-COST NETWORK ....................$     21929632.60
COMBINED TOTAL COST OF CIRCUITS IN THE LEAST-COST NETWORK .....................$     38474288.00


                    SUMMARY OF SATELLITE EARTH STATION EQUIPMENT
                    ---------------------------------------------
                           NUMBER OF NACS..........       123
                           NUMBER OF SCUS..........       241     ④
                           NUMBER OF FTUS..........      4504
                           NUMBER OF CAUS..........     89992


IXED ALGORITHM TO SELECT NUMBER OF NACS WENT THROUGH   8 ITERATIONS   ⑤
AL SOLUTION WAS WITH   9 NAC LOCATIONS

                  TOTAL COST AT EACH NUMBER OF NAC LOCATIONS IS AS FOLLOWS
                        NUMBER OF NACS     TOTAL SYSTEM COST
                        --------------     -----------------
                               0         $      81812896.00        0 NAC LOCATIONS
                               3         $      53081152.00        3 NAC LOCATIONS
                               4         $      48783048.00        4 NAC LOCATIONS
                               5         $      44582384.00        5 NAC LOCATIONS
                               6         $      42889696.00        6 NAC LOCATIONS
                               7         $      40659968.00        7 NAC LOCATIONS
                               8         $      40027840.00        8 NAC LOCATIONS
                               9         $      38474288.00        9 NAC LOCATIONS

                        THE   9 NAC LOCATIONS ARE AS FOLLOWS
      NENY     LOCA     CIIL     DEMI     BAMD     PHPA     WADC     ANCA     NANY ⑥

**********************************************************************
```

Figure 6-4. Sample Table 4 Output Report – Network Totals

```
      ******************************************************************
      ****************   TABLE 5.  TARIFF SUMMARY   *****************
      ******************************************************************

   ①            ②             ③            ④              ⑤            ⑥             ⑦
 TARIFF   |   TOTAL     |    TOTAL    | PERCENT OF |               | PERCENT OF |               |
          |  CIRCUIT    |    VOICE    |  NETWORK   |  TOTAL COST   |  NETWORK   |    SERVICE    |
          |  MILEAGE    |  CIRCUITS   |  CIRCUITS  |               |    COST    |               |
----------------------------------------------------------------------------------------------
          |             |             |            |               |            |               |
 TRFATT   |        504  |     110594  |    0.55    |    16544656.  |    0.43    |  TERRESTRIAL  |
 TRFSBS   |      75794  |      89992  |    0.45    |    21929632.  |    0.57    |   SATELLITE   |
          |             |             |            |               |            |               |


      ******************************************************************
```

Figure 6-5. Sample Table 5 Output Report – Tariff Summary

4. Percent of network circuits. The total number of voice circuits associated with each tariff is expressed as a percentage of the total number of voice circuits in the least-cost network.

5. Total cost. The total least-cost routing circuit cost associated with each tariff is printed. The cost of voice circuits between each city pair is included in the appropriate tariff total depending on the tariff providing communication service between the cities. The total costs of voice circuits for the individual tariffs sum to the total cost of voice circuits in the least-cost network as printed in TABLE 4.

6. Percent of network cost. The total cost of voice circuits associated with each tariff is expressed as a percentage of the total cost of voice circuits in the least-cost network.

7. Service. This field contains the word "TERRESTRIAL" or the word "SATELLITE" to indicate the type of service represented by each of the tariffs included in the routing solution.

6.7 Traffic Table

Table 6 presents a summary of the directional traffic between all cities in the network being evaluated. The summary is presented in the form of a traffic table, which is a matrix format whose entries indicate the number of voice circuits between any two cities. The number of voice circuits between any city pair is calculated based on user inputs of network traffic. Figure 6-6 provides a sample of a typical traffic table.

```
                 *****************   TABLE 6   TRAFFIC TABLE   *****************
                 ******************************************************************


                                TRAFFIC TABLE

           ANCA         BAMD         CIIL         DEMI         LOCA         NANY         NENY         PHPA
------------------------------------------------------------------------------------------------------------
ANCA          0          240          519          327        16260          237          652          301
BAMD        240            0         1253         1230          751         1813         4594         3618
CIIL        519         1253            0         2674         1142         1114         2114         1334
DEMI        327         1230         2674            0          897         1067         2386         1353
LOCA      16260          751         1142          897            0          725         1142          800
NANY        237         1813         1114         1067          725            0        20835         3475
NENY        652         4594         2114         2386         1142        20835            0         8380
PHPA        301         3618         1334         1353          800         3475         8380            0
WADC        273         6204         1348         1342          787         1774         4201         3131

           WADC
---------------
ANCA        273
BAMD       6204
CIIL       1348
DEMI       1342
LOCA        787
NANY       1774
NENY       4201
PHPA       3131
WADC          0
1
1
```

Figure 6-6. Sample Table 6 - Traffic Table

Appendix A
PRESTORED TARIFFS OF THE CNDC MODEL

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 1 of 10)

RATE CENTER	CODE
Alabama	
Anniston	ANAL
Birmingham	BIAL
Decatur	DEAL
Huntsville	HUAL
Mobile	MOAL
Montgomery	MNAL
Troy	TRAL
Arizona	
Flagstaff	FLAR
Phoenix	PHAZ
Prescott	PRAR
Tucson	TUAZ
Yuma	YUAR
Arkansas	
Fayetteville	FAAR
Forrest City	FOAR
Hot Springs	HOAR
Jonesboro	JOAR
Little Rock	LIAR
Pine Bluff	PIAR
Searcy	SEAR
California	
Anaheim	ANCA
Bakersfield	BACA
Chico	CHCA
Eureka	EUCA
Fresno	FRCA
Garoena	GACA
Hayward	HACA
Long Beach (Los Angeles)	LOCA
Los Angeles	LOCA
Oakland (San Francisco)	SFCA
Redwood City	RDCA
Sacramento	SACA
Salinas	SLCA
San Bernardina (Riverside)	RICA
San Diego	SNCA
San Francisco	SFCA
San Jose	SJCA
San Luis Obispo	SUCA
Santa Monica	STCA
Santa Rosa	SRCA
Stockton	SOCA
Sunnyvale	SYCA
Ukiah	UKCA
Van Nuys	VNCA

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 2 of 10)

RATE CENTER	CODE
Colorado	
Colorado Springs	COCO
Denver	DECO
Fort Collins	FOCO
Fort Morgan	FRCO
Glenwood Springs	GLCO
Grand Junction	GACO
Greeley	CRCO
Montrose	MOCO
Pueblo	PUCO
Connecticut	
Bethany	BECT
Bloomfield	BLCT
Bridgeport	BRCT
Brookfield	BOCT
East Hartford	EACT
Groton	GRCT
Hamden	HMCT
Hartford	HACT
New Haven	NWCT
New London	NLCT
North Haven	NOCT
Orange	ORCT
Stamford	STCT
Stratford	SACT
West Hartford	WECT
West Haven	WSCT
Wethersfield	WTCT
Delaware	
Wilmington	WIDE
Destrict of Columbia	WADC
Florida	
Chipley	CHFL
Clearwater	CLFL
Cocoa (Melbourne)	MEFL
Crestview	CRFL
Daytona Beach	DAFL
Fort Lauderdale	FOFL
Fort Meyers	FRFL
Fort Pierce	FPFL
Fort Walton Beach	FTFL
Gainesville	GAFL
Jacksonville	JAFL
Key West	KEFL
Lake City	LKFL
Miami	MIFL

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 3 of 10)

RATE CENTER	CODE
Florida (Continued)	
Ocala	OCFL
Orlando	ORFL
Panama City	PAFL
Pensacola	PEFL
St. Petersburg (Tampa)	TMFL
Sarasota	SAFL
Tallahassee	TAFL
Tampa	TMFL
West Palm Beach	WEFL
Winter Garden	WIFL
Winter Haven (Lakeland)	LAFL
Georgia	
Albany	ALGA
Atlanta	ATGA
Augusta	AUGA
Brunswick	BRGA
Columbus	COGA
Conyers	CNGA
Dublin	DUGA
Fitzgerald	FIGA
Macon	MAGA
Rome	ROGA
Savannah	SAGA
Thomasville	THGA
Waycross	WAGA
Idaho	
Boise	BOID
Pocatello	POID
Twin Falls	TWID
Illinois	
Centralia	CEIL
Champaign-Urbana	CHIL
Chicago	CIIL
Collinsville	COIL
De Kalb	DKIL
Hinsdale	HIIL
Joliet	JOIL
Marion	MAIL
Mattoon	MTIL
Newark	NEIL
Northbrook	NOIL
Peoria	PEIL
Rockford	ROIL
Rock Island (Davenport)	DAIA
Springfield	SPIL
Woodstock	WOIL

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 4 of 10)

RATE CENTER	CODE
Indiana	
Bloomington	BLIN
Evansville	EVIN
Fort Wayne	FOIN
Indianapolis	ININ
Muncie	MUIN
New Albany	NEIN
South Bend	SOIN
Terre Haute	TEIN
Iowa	
Boone	BOIA
Burlington	BUIA
Cedar Rapids	CEIA
Davenport	DAIA
Dubuque	DUIA
Iowa City	IOIW
Sioux City	SINE
Waterloo	WAIA
Kansas	
Dodge City	DOKS
Hutchinson	HUKS
Kansas City	KAMO
Manhattan	MAKS
Salina	SAKS
Topeka	TOKS
Wichita	WIKS
Kentucky	
Danville	DAKY
Frankfort	FRKY
Loutsville	LOKY
Madisonville	MAKY
Paducah	PAKY
Winchester	WIKY
Louisiana	
Alexandria	ALLA
Baton Rouge	BALA
Lafayette	LALA
Lake Charles	LKLA
Monroe	MOLA
New Orleans	NELA
Shreveport	SHLA
Maine	
Augusta	AUME
Lewiston	LEME
Portland	POME

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 5 of 10)

RATE CENTER	CODE
Maryland	
Baltimore	BAMD
Washington	WADC
Massachusetts	
Boston	BOMA
Brockton	BRMA
Cambridge	CAMA
Fall River	FAMA
Framingham	FRMA
Lawrence	LAMA
Springfield	SPCT
Worchester	WOMA
Michigan	
Detroit	DEMI
Flint	FLMI
Grand Rapids	GRMI
Houghton	HOMI
Iron Mountain	IRMI
Jackson	JAMI
Kalamazoo	KAMI
Lansing	LAMI
Petoskey	PEMI
Plymouth	PLMI
Pontiac	POMI
Saginaw	SAMI
Sault Ste. Marie	SUMI
Traverse City	TRMI
Minnesota	
Duluth	DUMN
Minneapolis	MIMN
St. Cloud	STMN
St. Paul (Minneapolis)	MIMN
Virginia	VIMN
Wadena	WAMN
Willmar	WIMN
Mississippi	
Biloxi	BIMS
Columbus	COMS
Greenville	GRMS
Greenwood	GEMS
Gulfport (Biloxi)	BIMS
Hattiesburg	HAMS
Jackson	JAMS
Laurel	LAMS
McComb	MCMS
Meridian	MEMS
Tupelo	TUMS

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 6 of 10)

RATE CENTER	CODE
Missouri	
Cape Giradeau	
Joplin	JOMO
Kansas City	KAMO
St. Joseph	STMO
St. Louis	SLMO
Sikeston	SIMO
Springfield	SPMO
Montana	
Billings	BIMT
Glendive	GLMT
Helena	HEMT
Missoula	MIMT
Nebraska	
Grand Island	GRNE
Omaha	OMNE
Sidney	SDNE
Nevada	
Carson City	CANV
Las Vegas	LANV
Reno	RENV
New Hampshire	
Concord	CONH
Dover (Portsmouth)	POHN
Manchester	MANH
Nashua	NANH
New Jersey	
Atlantic City	ATNJ
Camden	CANJ
Hackensack	HANJ
Morristown	MONJ
Newark	NENJ
New Brunswick	NENJ
Trenton	TRNJ
New Mexico	
Albuquerque	ALNM
Las Cruces	LANM
Roswell	RONM
Santa Fe	SANM
New York	
Albany	ALNY
Binghamton	BINY
Buffalo	BUNY

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 7 of 10)

RATE CENTER	CODE
New York (Continued)	
Huntington	HUNY
Nassua	NANY
New York City	NENY
Potsdam	PTNY
Poughkeepsie	PONY
Rochester	RONY
Syracuse	SYNY
Troy (Albany)	ALNY
Westchester	WENY
North Carolina	
Asheville	ASNC
Charlotte	CHNC
Fayetteville	FANC
Gastonia (Charlotte)	CHNC
Greensboro	GRNC
Greenville	GENC
Laurinburg	LANC
New Bern	NENC
Raleigh	RANC
Rocky Mount	RONC
Wilmington	WINC
Winston-Salem (Greensboro)	GRNC
North Dakota	
Bismark	BIND
Casselton	CAND
Dickinson	DIND
Fargo	FAND
Grand Forks	GRND
Ohio	
Akron	AKOH
Canton	CAOH
Cincinnati	CIOH
Cleveland	CLOH
Columbus	COOH
Dayton	DAOH
Findley	FIOH
Mansfield	MAOH
Toledo	TOOH
Youngstown	YOOH
Oklahoma	
Enid	ENOK
Lawton	LAOK
Muskogee	MUOK
Oklahoma City	OKOK
Tulsa	TUOK

Table A-1. Prestored American Telephone and Telgraph Company Listed Cities as Defined in F.C.C. No. 250 (Effective July 3, 1983) (sheet 8 of 10)

RATE CENTER	CODE
Oregon	
Medford	MEOR
Pendleton	PEOR
Portland	POOR
Pennsylvania	
Allentown	ALPA
Altoona	ATPA
Harrisburg	HAPA
Philadelphia	PHPA
Pittsburg	PIPA
Pottsville	POPA
Reading	REPA
Scranton	SCPA
State College	STPD
Williamsport	WIPA
Rhode Island	
Providence	PRRI
South Carolina	
Charleston	CHSC
Columbia	COSC
Florence	FOSC
Greenville	GRSC
Orangeburg	ORSC
Spartanburg (Greenville)	GRSC
South Dakota	
Aberdeen	ABSD
Huron	HUSD
Sioux Falls	SISD
Tennessee	
Chattanooga	CHTN
Clarksville	CLTN
Jackson	JATN
Johnson City	JOTN
Kingsport (Johnson City)	JOTN
Knoxville	KNTN
Memphis	METN
Morristown	MOTN
Nashville	NATN
Texas	
Abilene	ABTX
Amarillo	AMTX
Austin	AUTX
Beaumont	BETX
Corpus Christi	COTX
Dallas	DATX

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 9 of 10)

RATE CENTER	CODE
Texas (Continued)	
El Paso	ELTX
Fort Worth (Dallas)	DATX
Freeport	FRTX
Harlingen (Brownsville)	BRTX
Houston	HOTX
Laredo	LATX
Longview	LOTX
Lubbock	LUTX
Midland	MITX
San Angelo	SATX
San Antonio	SNTX
Sweetwater	SWTX
Waco	WATX
Utah	
Logan	LOUT
Ogden (Salt Lake City)	SAUT
Provo	PRUT
Salt Lake City	SAUT
Vermont	
Burlington	BUVT
White River Junction	WHVT
Virginia	
Blacksburg	BLVA
Leesburg	LEVA
Lynchburg	LYVA
Newport News	NEVA
Norfolk	NOVA
Petersburg	PEVA
Richmond	RIVA
Roanoke	ROVA
Washington	WADC
Washington	
Billingham	BEWA
Kennewick (Richland)	RIWA
North Bend	NOWA
Seattle	SEWA
Spokane	SPWA
Yakima	YAWA
West Virginia	
Beckley	BEWV
Charleston	CHWV
Clarksburg	CLWV
Fairmont	FAWV
Huntington	HUWV
Morgantown	MOWV

Table A-1. Prestored American Telephone and Telegraph Company Listed Cities as Defined in F.C.C. No. 260 (Effective July 3, 1983) (sheet 10 of 10)

RATE CENTER	CODE
West Virginia (Continued)	
Parkensburg	PAWV
Wheeling	WHWV
Wisconsin	
Appleton	APWI
Dodgeville	DOWI
Eau Claire	EAWI
Green Bay	GRWI
La Crosse	LAWI
Madison	MAWI
Milwaukee	MIWI
Racine	RAWI
Stevens Port	STWI
Wyoming	
Casper	CAWY
Cheyanne	CHWY

Table A-2. American Telephone and Telegraph Company Rate Schedules as Defined in F.C.C. 260 (Effective March 3, 1982)

	Schedule I*		Schedule II**		Schedule III***	
Mileage Breakpoint	Basic Monthly Charge (Up to Breakpoint Mileage)	Incremental Monthly Charge Per Additional Mile	Basic Monthly Charge (Up to Breakpoint Mileage)	Incremental Monthly Charge Per Additional Mile	Basic Monthly Charge (Up to Breakpoint Mileage)	Incremental Monthly Charge Per Additional Mile
1	73.56	0.00	75.00	0.00	76.43	0.00
15	73.56	2.59	75.00	4.77	76.43	6.35
25	109.82	2.16	141.78	4.77	165.33	5.48
40	131.42	1.62	186.48	2.89	220.13	4.03
60	155.72	1.62	229.83	1.95	280.58	3.03
80	188.12	1.62	268.83	1.95	341.18	2.31
100	220.52	1.62	307.83	1.95	387.38	1.95
1000	252.92	0.94	346.83	0.94	426.38	0.97
over 1000	1098.92	0.58	1192.83	0.58	1299.38	0.58

Effective Date: March 3, 1982

*Applies between a pair of Category "A" Rate Centers (listed cities).

**Applies between a pair of rate centers where one is in Category "A" (listed cities) and the other is in Category "B" (nonlisted cities).

***Applies between a pair of Category "B" Rate Centers (nonlisted cities).

Table A-3. Prestored Western Union Telegraph Company Tariff as Defined in F.C.C. No. 261 (Effective May 11, 1982) (Sheet 1 of 4)

Category I: LONG HAUL

Los Angeles - Atlanta	(LOCA-ATGA)
Los Angeles - Baltimore	(LOCA-BAMD)
Los Angeles - Boston	(LOCA-BOMA)
Los Angeles - Buffalo	(LOCA-BUNY)
Los Angeles - Cincinnati	(LOCA-CIOH)
Los Angeles - Cleveland	(LOCA-CLOH)
Los Angeles - Columbus	(LOCA-COOH)
Los Angeles - Dayton	(LOCA-DAOH)
Los Angeles - Detroit	(LOCA-DEMI)
Los Angeles - New York	(LOCA-NENY)
Los Angeles - Philadelphia	(LOCA-PHPA)
Los Angeles - Pittsburgh	(LOCA-PIPA)
Los Angeles - Washington	(LOCA-WADC)
Los Angeles - Wilmington	(LOCA-WIDE)
San Francisco - Atlanta	(SFCA-ATGA)
San Francisco - Baltimore	(SFCA-BAMD)
San Francisco - Boston	(SFCA-BOMA)
San Francisco - Buffalo	(SFCA-BUNY)
San Francisco - Cincinnati	(SFCA-CIOH)
San Francisco - Cleveland	(SFCA-CLOH)
San Francisco - Columbus	(SFCA-COOH)
San Francisco - Dayton	(SFCA-DAOH)
San Francisco - Detroit	(SFCA-DEMI)
San Francisco - New York	(SFCA-NENY)
San Francisco - Philadelphia	(SFCA-PHPA)
San Francisco - Pittsburgh	(SFCA-PIPA)
San Francisco - Washington	(SFCA-WADC)
San Francisco - Wilmington	(SFCA-WIDE)
Seattle - Boston	(SEWA-BOMA)
Seattle - Cleveland	(SEWA-CLOH)
Seattle - Detroit	(SEWA-DEMI)
Seattle - New York	(SEWA-NENY)
Seattle - Philadelphia	(SEWA-PHPA)
Seattle - Pittsburgh	(SEWA-PIPA)
Seattle - Washington	(SEWA-WADC)

Category II: MEDIUM HAUL

Dallas/Ft Worth - Baltimore	(DATX-BAMD)
Dallas/Ft Worth - Boston	(DATX-BOMA)
Dallas/Ft Worth - Buffalo	(DATX-BUNY)
Dallas/Ft Worth - Los Angeles	(DATX-LOCA)
Dallas/Ft Worth - New York	(DATX-NENY)
Dallas/Ft Worth - Philadelphia	(DATX-PHPA)
Dallas/Ft Worth - San Francisco	(DATX-SFCA)
Dallas/Ft Worth - Washington	(DATX-WADC)

Table A-3. Prestored Western Union Telegraph Company Tariff as Defined in F.C.C. No. 261 (Effective May 11, 1982) (Sheet 2 of 4)

Category II: MEDIUM HAUL (Continued)

Houston - Baltimore	(HOTX-BAMD)
Houston - Boston	(HOTX-BOMA)
Houston - Cleveland	(HOTX-CLOH)
Houston - Columbus	(HOTX-COOH)
Houston - Dayton	(HOTX-DAOH)
Houston - Detroit	(HOTX-DEMI)
Houston - Los Angeles	(HOTX-LOCA)
Houston - New York	(HOTX-NENY)
Houston - Philadelphia	(HOTX-PHPA)
Houston - Pittsburg	(HOTX-PIPA)
Houston - San Francisco	(HOTX-SFCA)
Houston - Washington	(HOTX-WADC)
Houston - Wilmington	(HOTX-WIDE)
Kansas City - Boston	(KAMO-BOMA)
Kansas City - Los Angeles	(KAMO-LOCA)
Kansas City - New York	(KAMO-NENY)
Kansas City - San Francisco	(KAMO-SFCA)
Los Angeles - Chicago	(LOCA-CIIL)
*Los Angeles - Bridgeton, Mo	(LOCA-SLMO)
Los Angeles - Indianapolis	(LOCA-ININ)
Los Angeles - Milwaukee	(LOCA-MIWI)
Los Angeles - Minneapolis	(LOCA-MIMN)
Los Angeles - St Louis	(LOCA-SLMO)
Minneapolis - Boston	(MIMN-BOMA)
San Francisco - Chicago	(SFCA-CIIL)
San Francisco - Indianapolis	(SFCA-ININ)
San Francisco - Milwaukee	(SFCA-MIWI)
San Francisco - Minneapolis	(SFCA-MIMN)
San Francisco - St Louis	(SFCA-SLMO)
Seattle - Chicago	(SEWA-CIIL)
Seattle - Dallas/Ft Worth	(SEWA-DATX)
Seattle - Kansas City	(SEWA-KAMO)
Seattle - Milwaukee	(SEWA-MIWI)
Seattle - Minneapolis	(SEWA-MIMN)
Seattle - St Louis	(SEWA-SLMO)

Category III: SHORT HAUL

Atlanta - Baltimore	(ATGA-BAMD)
Atlanta - Boston	(ATGA-BOMA)
Atlanta - Chicago	(ATGA-CIIL)
Atlanta - Cleveland	(ATGA-CLOH)
Atlanta - Dallas/Ft Worth	(ATGA-DATX)
Atlanta - Detroit	(ATGA-DEMI)
Atlanta - Houston	(ATGA-HOTX)

*Bridgeton, Mo. will be viewed as St Louis, Mo.

Table A-3. Prestored Western Union Telegraph Company Tariff as Defined in F.C.C. No. 261 (Effective May 11, 1982) (Sheet 3 of 4)

Category III: SHORT HAUL (Continued)

Atlanta - Indianapolis	(ATGA-ININ)
Atlanta - Kansas City	(ATGA-KAMO)
Atlanta - Milwaukee	(ATGA-MIWI)
Atlanta - Minneapolis	(ATGA-MIMN)
Atlanta - Philadelphia	(ATGA-PHPA)
Atlanta - New York	(ATGA-NENY)
Atlanta - Washington	(ATGA-WADC)
Atlanta - Wilmington	(ATGA-WIDE)
Boston - Chicago	(BOMA-CIIL)
Boston - Cincinnati	(BOMA-CIOH)
Boston - Columbus	(BOMA-COOH)
Boston - Dayton	(BOMA-DAOH)
Boston - Indianapolis	(BOMA-ININ)
Boston - Milwaukee	(BOMA-MIWI)
Boston - St Louis	(BOMA-SLMO)
Chicago - Baltimore	(CIIL-BAMD)
Chicago - Dallas/Ft Worth	(CIIL-DATX)
Chicago - Houston	(CIIL-HOTX)
Chicago - New York	(CIIL-NENY)
Chicago - Philadelphia	(CIIL-PHPA)
Chicago - Washington	(CIIL-WADC)
Chicago - Wilmington	(CIIL-WIDE)
Dallas/Ft Worth - Cincinnati	(DATX-CIOH)
Dallas/Ft Worth - Cleveland	(DATX-CLOH)
Dallas/Ft Worth - Columbus	(DATX-COOH)
Dallas/Ft Worth - Dayton	(DATX-DAOH)
Dallas/Ft Worth - Detroit	(DATX-DEMI)
Dallas/Ft Worth - Indianapolis	(DATX-ININ)
Dallas/Ft Worth - Milwaukee	(DATX-MIWI)
Dallas/Ft Worth - Minneapolis	(DATX-MIMN)
Dallas/Ft Worth - Pittsburgh	(DATX-PIPA)
Dallas/Ft Worth - St Louis	(DATX-SLMO)
Houston - Cincinnati	(HOTX-CIOH)
Houston - Indianapolis	(HOTX-ININ)
Houston - Milwaukee	(HOTX-MIWI)
Houston - Minneapolis	(HOTX-MIMN)
Houston - St Louis	(HOTX-SLMO)
Milwaukee - Baltimore	(MIWI-BAMD)
Milwaukee - New York	(MIWI-NENY)
Milwaukee - Philadelphia	(MIWI-PHPA)
Milwaukee - Washington	(MIWI-WADC)
New York - Columbus	(NENY-COOH)
New York - Dayton	(NENY-DAOH)
New York - Indianapolis	(NENY-ININ)
New York - Minneapolis	(NENY-MIMN)
Philadelphia - Indianapolis	(PHPA-ININ)
Philadelphia - Kansas City	(PHPA-KAMO)

Table A-3. Prestored Western Union Telegraph Company Tariff as Defined in F.C.C. No. 261 (Effective May 11, 1982) (Sheet 4 of 4)

Category III: SHORT HAUL (Continued)

St Louis - Baltimore	(SLMO-BAMD)
St Louis - New York	(SLMO-NENY)
St Louis - Washington	(SLMO-WADC)
St Louis - Wilmington	(SLMO-WIDE)
Seattle - Los Angeles	(SEWA-LOCA)
Seattle - San Francisco	(SEWA-SFCA)
Washington - Indianapolis	(WADC-ININ)
Washington - Minneapolis	(WADC-MIMN)

Western Union Category I, II, and III Monthly Channel Charges

Category I: Long Haul - $925.00

Category II: Medium Haul - $695.00

Category III: Short Haul - $580.00

Table A-4. Prestored Satellite Business Systems Tariff as Defined in F.C.C. No. 2 (effective October 1, 1982)

	Monthly Charge
Network Access Centers (NACs - minimum of 3)	$17,850.00 each
Supplemental Capacity Units (SCUs)	$5,700.00 each
Full-Time Transmission Units (FTUs)	$2,550.00 each
Minimum connection Arrangement Unit (CAU) Charge Per NAC	$17,850.00

Incremental CAU Charges:

No. of CAUs at Each NAC	Basic Monthly Charge	Incremental Monthly Recurring Charge
0-150	$0.00	$95.00
151-300	$14,250.00	$90.00
301-up	$27,750.00	$65.00

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Addendum

1.0 SBS Tariff Change

Change one to the manual reflects a change to the Satellite Business Systems tariff as set forth in F.C.C. No. 2, effective May 1, 1983. This tariff is described below. All charges specified are monthly recurring charges.

Network Access Center (each)	NAC	$17,850.00
NAC Supplemental Capacity Units (each)	SCU	$ 5,700.00
Full Time Transmission Units	FTU	$ 2,550.00
Minimum CAU Charges		$17,850.00
Connection Arrangement Units (monthly at each NAC)	CAU	

NUMBER OF CAUs AT EACH NAC	MONTHLY RECURRING CHARGE
1 CAU - 150 CAUs	$100 per CAU
151 CAUs - 300 CAUs	$15,000.00 plus $95.00 per CAU in excess of 150
More than 300 CAUs	$29,250.00 plus $70.00 per CAU in excess of 300