OPTIMIZATION MODELS FOR TELECOMMUNICATIONS NETWORKS PLANNING AND DESIGN: CHANNEL ASSIGNMENT AND EQUIPMENT SELECTION

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Optimization Models for Telecommunications
Networks Planning and Design: Channel
Assignment and Equipment Selection

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The channel assignment problem is associated with TDM (time-division multiplexing) telecommunications networks, wherein circuits must be routed from origin to destination via discrete channels on each span traversed. Full utilization of capacity is thwarted if channels are not assigned optimally. This praxis presents computer models for solving this problem category, and was applied to the telecommunications network of the Arizona Public Service Company.

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GLOSSARY[1]

ADM. Add/drop multiplexer.

Back-to-Back Channel Bank. The interconnection between channel banks to allow dropping and inserting channels.

Bandwidth. The range of frequencies a communications channel is capable of carrying without excessive attenuation.

Bit-rate. The number of bits per second a communications system carries.

Bit Stream. A continuous string of bits transmitted serially in time.

Bridge. Circuitry used to interconnect networks with a common set of higher level protocols.

Channel. A communications path that is capable of carrying a signal.

Channel Consistency. The maintenance of the same channel assignment throughout an OD path. [2]

Circuit. A transmission path between two points in a telecommunications system.

Crossconnect. The interconnection of voice or signal paths between separate equipment units.

Data Link. A circuit capable of carrying digitized information.

DCE(Data Circuit-Terminating Equipment). Equipment designed to establish a connection to a network, condition the input and output of the DTE for transmission over the network, and terminate the connection when completed.

DCS (Digital Crossconnect System). A specialized digital switch that enables crossconnection of channels at the digital line rate.

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[1] All glossary terms were taken from The Irwin Handbook of Telecommunications unless otherwise indicated.

[2] by author.

Distortion. An unwanted change in a waveform.

DS0. A 64 Kbits/sec channel

DS1. A multiplexed 24-channel line capable of carrying voice and data signals at a total rate of 1.544 Mb/s (24 DS0 channels plus 8000 framing bits per second).

DS2. A multiplexed 4 DS1 channel line (96 DS0 channels).

DS3. A multiplexed 28 DS1 channel line (672 DS0 channels).

DSX (Digital Service Crossconnect). A physically wired crossconnect frame to enable connecting digital transmission equipment at a standard bit-rate.

DTE(Data Terminal Equipment). Any form of computer, peripheral, or terminal that can be used for originating or receiving data over a communication channel.

Fiber Optics. A medium for transferring electronic signals over a pathway of fibers made of a transparent material such as glass or plastic.

Frequency. The number of times per second that an alternating current signal changes state through one complete cycle.

Fresnel Zone. An imaginary zone that surrounds a radio or optic wave. If an obstacle is inserted into the first Fresnel zone, it results in attenuation, even if it does not penetrate into the direct path itself.

Microwave Network. A group of nodes interconnected by microwave communications circuits.[3]

Hardware. The physical components of a communications or computer system.

Hertz. The unit of frequency, in cycles per second.

Hub. A system of multiple equipment that interconnects different lines.[4]

Interface. The interconnection point between two pieces of equipment.

Link. A physical or logical circuit between two points.
LR. Line repeater.

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[3] by author.

[4] by author.

Microwave link. A communications circuit between two points operating in the microwave frequency range.[5]

Microwave. A radio frequency in the range of 1 Ghz to 300 Ghz.

Multiplexer. A device used for combining several lower speed channels into a higher speed channel.

Multiplexing. The process of combining multiple signals into a single channel.

Network Design. The process of determining quantities and architecture of circuit and equipment to achieve a cost/service balance.

Network. A group of nodes interconnected by communications channels.

Node. The switching system or computer that provides access to the network and serves as the concentration point for trunks.

OD. Origin - destination.[6]

Path. The arc or series of arcs that connect the necessary nodes to complete a connection between any two nodes. [7]

Protocol. The conventions used in a network for establishing communications compatibility between terminals and for maintaining line discipline while they are connected to the network.

Pulse. A short signal used to transmit information.

Repeater. An electronic device that reshapes pulses or adds gain or amplification to a circuit.

Route. The circuits selected by a control system to establish a path for a session.

Simulation. The process of designing a network by simulating the events and facilities that represent network load and capacity.

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[5] by author.

[6] by author.

[7] by author.

SONET. Synchronous Optical Network. A new suite of fiber optic transmission speeds that will eventually replace the present DS signal levels.

T-1 Multiplexer. An intelligent device that divides a 1.544 Mb/s facility into multiple voice and data channels.

T-1. A multiplexed 24-channel line capable of carrying voice and data signals at a total data rate of 1.522 Mb/s. Also designated DS1.

TE (Terminal Equipment). Any device meant for direct operation over a telecommunication circuit by and end user.

Telecommunications. The movement of information by electronic means.

Time Slot. A frequency range assigned to each DSO channel in a DS1 line. There are 24 time slots in each DS1.[8]

TM. Terminal multiplexer.

Topology. The architecture of a network, of the way circuits are connected to link the network nodes.

Traffic. The volume of demand on a telecommunications system.

Transmission. The process of transporting voice or data over a network or facility from one point to another.

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[8] by author.

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And above all to Jesus Christ, whom I have chosen to follow.

1. INTRODUCTION

The application of digital technology in such diverse fields as education, health, business, and government has spun out demands for videoconferencing, Internet access, telecommuting, audio, video, virtual reality, and data, all interactive and instantaneously available. Once seen as strictly for "data processing" (i.e., simple manipulation of numbers and characters), digital technology now encompasses a diverse range of elements, such as sound and images. The massive processing capabilities now available and widely accessible are generating an immense amount of information. Even with such growth, information has become an increasingly valuable asset. The timeliness and availability of information have become fundamental to its value and has dramatically raised the demands on the telecommunications infrastructure. Similarly, the transmission capabilities of this infrastructure have grown substantially through the integration of traditional transmission media, such as copper wire and coaxial cable, with microwave, satellite, and lightwave (e.g., laser and fiber-optic) technologies.

This "digital revolution" is driving the convergence of many technologies that before were considered independent and unrelated, such as sound, imaging, telecommunications and computer technology. This convergence is defining the implementation of new telecommunications networks and redefining the use of the existing networks.

The concept of telecommunications, once restricted to the idea of long distance communications, is now used more broadly and ambiguously to define not only the communications facilities between different cities, but also the facilities interconnecting several sites in the same location (i.e., the facilities of a campus-wide network)[9]. The demands being placed on this broadly defined infrastructure range from simple data transfers, as with credit-card authorizations, to massive data exchanges between and within large corporations; from the century-old telephone service to videoconferencing; from e-mail to interactive high-quality audio and video over the Internet, just to name a few. Telecommunications are expected to become the distribution and access medium for all the needs of an Information Age society. As [CIO88, p10] states,

> "Today communications systems that send voice, data, and video signals span the earth. Information is bounced off satellites and shot through cables that cross entire oceans. Computer-based systems operate in the dead of night receiving from places where it is high noon. And the organization that turns a blind side to how communications and computer technologies together are transforming the world will be outperformed and outmaneuvered by its competitors--competitors that can now come from any country on earth."[10]

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[9] James H. Green, *The Irwin handbook of telecommunication* (New York: Irwin Professional Publishing, 1992), 353-355.

[10] CIO Publishing, "Global Communications and the Computer Strategies for the 90's", *Forbes* 142, no.6, special advertising supplement (Sept. 19, 1988),139-163; quoted in John D. Spragins, Joseph L. Hammond , and Krzysztof Pawlikowski, *Telecommunications protocols and designs* (New York: Addison Wesley, 1991), 2.

1.1 Telecommunications Networks

Telecommunications networks are becoming increasingly complex. In order to better understand some of the issues that will be addressed by this praxis, the following topics will be addressed next: network components, multiplexing, the digital signal hierarchy and basic design requirements.

1.1.1 Network Components

A telecommunications network can be viewed as a set of processing nodes connected pair-wise by a series of transmission links as illustrated in Figure 1. The *nodes*, shown as circles, are associated with the equipment used to process, switch and terminate the signals, as described below. This equipment will be referred to generically as *terminal equipment*. Each transmission *link*, represented by a straight line, is associated with the medium (wire, optical fiber, radio waves) used to interconnect a given node pair.

The spanning-tree or tree-and-branch network illustrated in Figure 1is characterized by not having alternative arc paths, (i.e., to connect any node pair there is only one set of arcs that can complete the connection). However, each arc can be part of many paths connecting different node pairs. This praxis deals with a spanning-tree-type telecommunications network that utilizes microwave as a transmission link.

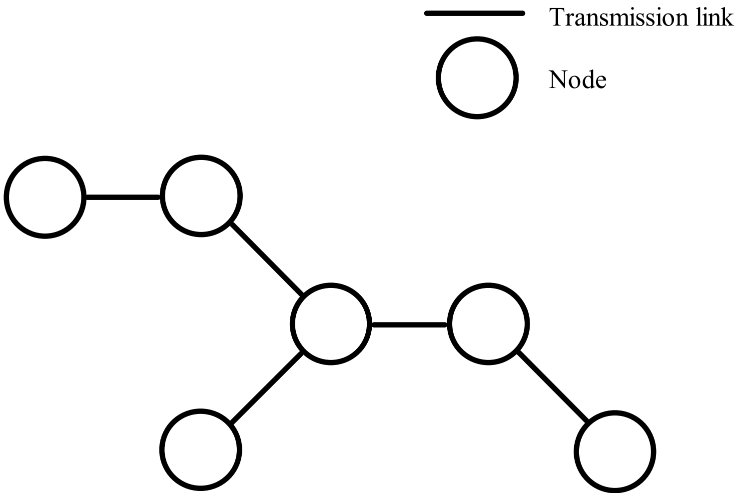

Figure 1: Network Components

The purpose of such a network is to transport the requirements of customers for two-way digital signals (i.e., *demand*) between pairs of sites (i.e., *nodes*). Although the signal flow between two nodes is usually bi-directional, as occurs with a common telephone call, in this paper it will be modeled as unidirectional, from the arbitrarily selected origin node to the destination node; these nodes will be referred to as an *OD pair* or *OD*.

In this context, the signal is defined as the basic information element that is transmitted over a link. It is binary and is represented by a series of zero and one states, or bits, corresponding to two different levels in the transmission media. All capacity and demand can ultimately be quantified in terms of *bandwidth*, or rates of data transfer, typically expressed in bits per second (bits/s). The *capacity* of a transmission link is defined as the quantity of bits per second that it is able to transport. The demand is defined as the quantity of bits per second to be transmitted between two nodes in a network. As will be explained later, these data rates have been combined into a standard structure called the digital signal hierarchy.

As the signals traverse the medium, they are impacted by the environment, subjected to various forms of degradation such as attenuation (loss of power), distortion (introduction of error) and interference (addition of noise). Therefore, these signals must be regenerated (reshaped and amplified) at proper intervals in order not to lose the information that they are carrying. This is accomplished by the processing equipment at the network nodes.

At a given node, a signal can be switched, or routed, from one transmission link to another, with the routing possibilities determined by the switching equipment's characteristics. Also, origin and destination nodes require equipment that will interface the transmission link to the customer's equipment. This node equipment is referred to as the terminal or *terminating equipment*, which is said to "terminate a signal."

1.1.2 Multiplexing

Practically all telecommunications networks use a technique called multiplexing, which combines a set of signals into a composite signal with a higher transmission rate. *Multiplexing* is basically the bundling together of these signals to form a group that is transmitted over a single medium. This group may be further bundled with others to form even larger bundles of channels to be transmitted over a single medium.

There are technical, physical and economic reasons to use multiplexing. In general, a high transmission rate results in lower cost due to economies of scale.

Therefore it is desirable to combine smaller demands into larger groups when it is advantageous to use the higher transmission rates. To achieve this, multiplexing is used.

There are three basic types of multiplexing: frequency-division multiplexing (FDM), wavelength-division multiplexing (WDM) and time-division multiplexing (TDM). In frequency-division multiplexing the individual channels are allocated a fixed bandwidth but a different frequency range, and are transmitted simultaneously over the same medium, as depicted in Figure 2. An example of FDM is radio broadcasting. Each radio station has the same frequency bandwidth but uses a different frequency range to transmit. All the radio stations are transmitting simultaneously over the same medium.

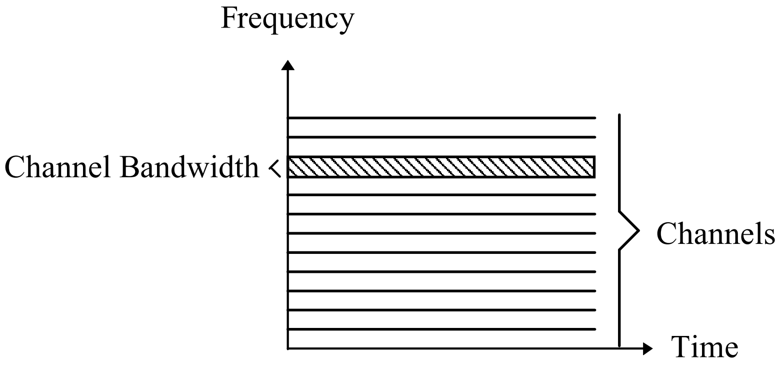

Figure 2: Frequency-Division Multiplexing

The concept behind wavelength-division multiplexing is analogous to frequency-division multiplexing, as can be seen from Figure 3. The individual services are assigned to different unique light wavelengths, or *colors* [11], and are transmitted simultaneously over the same optical medium.

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[11] Green, *Irwin handbook*, 344.

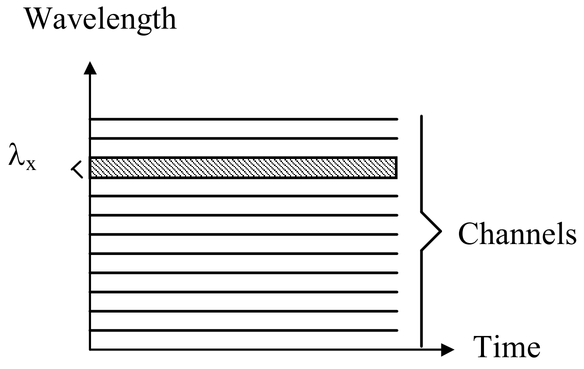

Figure 3: Wavelength-Division Multiplexing

With time-division multiplexing, the individual channels are allocated the entire available frequency bandwidth, but for a limited increment of time, called a time-slot. The channels are assigned sequentially and the process is repeated continually, as depicted in Figure 4. The time-slot is the smallest channel unit in the digital signal hierarchy. This praxis will only be considering TDM, so the terms time-slot assignment and channel assignment will be used to interchangeably.

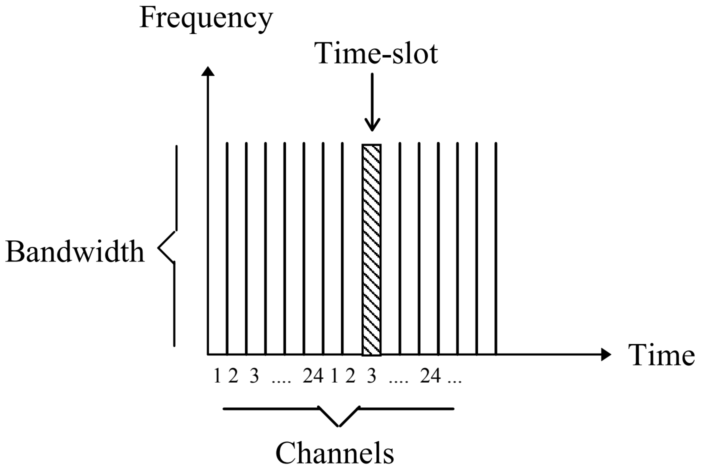

Figure 4: Time-Division Multiplexing

1.1.3 The Digital Signal Hierarchy

The Digital Signal Hierarchy shown in Table 1 defines the multiplexing structure adopted in the United States. The smallest unit is the time-slot and is capable of carrying 64 Kbits/sec; this time-slot, with a capacity of 64 Kbits/sec., is also designated a DS0 channel (Digital Signal level zero). The terms *channel*, *time-slot* and *DS0 channel* are used interchangeably in this praxis and the term *line* will refer to a *DS1 line*.

Twenty-four DS0 channels are multiplexed together to form a DS1 line. The data transmission rate is 1,544 Kbits/sec. Note that this rate is not an exact multiple of 64 Kbits/sec. This is because additional bits are needed for synchronization and alignment. The DS1 is commonly called a *T1 line*.

The T1 carrier system was developed by Bell Labs and was first installed in New York in 1962. It was a digital system and differed from the other carrier systems of the early 1960s that used frequency-division multiplexing. The T1 carrier system uses time-division multiplexing. It was designed to use the existing copper twisted-pair transmission wires in FDM carrier systems. The technology required the installation of regenerators every 6000-feet; this distance was later adopted as a standard, which allows a pulse stream of 1,544 Kbits/sec over the 6000-foot copper twisted pair. [12,13] The European digital system, which came into existence after the T1 and benefited from its experience, contains 32 time slots and is not compatible with the American system, although both coexist on the international level.[14]

As reflected in Table 1, the American Digital Signal hierarchy currently defines speeds up to a DS4 level. It should be noted that "the DS4 signal speed is too high to apply to the limited bandwidth of a digital microwave, which is currently limited to carrying three DS3 signals."[15] (A DS4 can carry six DS3 level signals.)

Table 1: Digital Signal Hierarchy

DS0 channel carries 64 Kbits/sec
DS1 can carry 24 DS0 channels (also known as a T-1 line)
DS2 can carry 4 DS1 lines (96 DS0 channels)
DS3 can carry 7 DS2 lines (28 DS1 lines, 672 DS0 channels)
DS4 can carry 6 DS3 lines (168 DS1 lines, 4032 DS0 channels)

Multiplexers are used to raise the basic bit-rates to higher levels. To indicate which DS level is being raised and to what level multiplexer classes are assigned a

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[12] Spragins, Hammond , and Pawlikowski, *Telecommunications protocols and designs* , 12-13.

[13] Green, *Irwin handbook*, 116.

[14] Tarek Saadawi, Mostafa Amar, and Ahmed El Hakeem, *Fundamentals of telecommunications networks* (New York: John Wiley & Sons, Inc., 1994), 62.

[15] Green, *Irwin handbook*, 129-130.

capital letter M followed by two hyphenated digits. For example, a M1-2 multiplexer connects four DS1 lines to a DS2 level. Similarly a M1-3 combines 28 DS1 signals into a DS3 signal bit-rate.

Higher-level multiplexing is also possible and should increase in usage as fiber optic and laser technologies continue to evolve. One set of standards that have been adopted for lightwave transmissions are defined by SONET, which "specifies standard optical signals, a synchronous frame structure for the multiplexed digital traffic, and operations procedures."[16] There is a separate "OC" (Office Channel) bandwidth hierarchy for the lightwave-based transmission technologies. The highest level in the original SONET hierarchy is capable of transmitting the equivalent of 48 DS3 lines.[17]

1.2 Designing Telecommunications Networks

According to Spragins[18] there are a number of problems that must be addressed in the design of telecommunication networks, these appear at different stages of, and with differing impact on, the design process. Included among these are:

- · Resolving incompatibilities of equipment
- · Coordination of sender and receiver
- Maximizing reliability and freedom from errors
- Optimizing performance

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[16] Saadawi, Amar, and El Hakeem, *Telecommunications networks* , 387.

[17] Green, Irwin handbook, 351-353.

[18] Spragins, Hammond , and Pawlikowski, *Telecommunications protocols and designs* , 18-24.

- Minimizing costs
- Network management

There are three aspects to the design of a telecommunications network that properly addressed, can considerably reduce these problems and contribute to the achievement of desired goals of high performance, reliability, security, flexibility, and cost-effectiveness. These aspects are: the applications to be used, the network topology, and the expected service level.

- The network's applications to be used will define the capacity requirements of the transmission links. If the application is a simple voice connection to be established between two sites, the demanded capacity will be relatively low, if it is videoconferencing, the required capacity will be much higher. The applications may require real-time connection, as with a telephone conversation, or can accommodate a delayed connection, as with electronic mail. The applications will ultimately determine other critical network design parameters such as busy-hour[19], traffic load, and average waiting time[20]. (These parameters will not be discussed since only the final demand for each site pair will be used in this paper. It must be noted that these parameters are part of the computations that result in the final demand values.)
- The network topology is the specific set of network transmission links and their characteristics that interconnect the sites. It is the result of the evaluation

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[19] Busy hour. The composite of various peak load periods selected for the purpose of designing network capacity.

[20] Waiting time. The expected delay time for the message to be serviced.

of several elements. The selection of the sites to be served can impact the decision on what types of transmission media are most appropriate and economically viable. The distance between the sites, the type of terrain, and the demand requirements determine the suitability of a particular transmission medium. The need for alternate demand transmission paths, if any, must also be considered in creating a given topology.

- The service level is the expected overall performance of the network, as defined by many technical specifications derived from the network users' needs, the physical environment and many legal and security issues.

In the problem addressed by this praxis, it is assumed that the above factors have been considered, a DS1 network topology has been specified, the DS0 OD demands are known, and the OD demand routings are either unique or specified. To be determined is a specific path on which each demand unit will travel; this requires the assignment of a DS0 channel (time-slot) on a DS1 on each arc that links the OD sites.

The generation of this assignment for a large network can be time-consuming because it is necessary not only to assign the DS0 channels to a DS1 line on each arc of the OD path, but to identify the connections between these DS0s at each site for each unit of demand for each OD path. This level of detail is necessary for the installation, operation, and maintenance of the telecommunications network. Models for generating these detailed assignments are developed in this praxis.

The most cost-effective networks are those that integrate different applications at the transmission level. Integrating terminating equipment and transmission media type into a network requires the determination of the capacity of each link and the amount of shared network equipment needed to reach a reasonable balance between costs and service level desired. The next section describes different types of terminal equipment and the characteristics that are germane to network design decisions.

1.3 Types of Terminal Equipment

While terminal equipment's behavioral characteristics vary from manufacturer to manufacturer, common characteristics permit classifications by basic functions. Below are descriptions of four basic equipment types: line repeaters, terminal multiplexers/demultiplexers, add/drop multiplexers, and digital-access-and-crossconnect systems. For simplicity, their basic functions are described in terms of the lowest levels of the digital signal hierarchy (i.e., DS0 and DS1), although variations of these types of equipment can support higher, as well as multiple, DS levels.

1.3.1 Line Repeater

A *line repeater* receives and regenerates an incoming DS1 signal before sending it to the outgoing DS1 line. The equipment maintains channel consistency; that is, the same time-slot assignments are used for each DS0 signal on incoming and outgoing lines. Since no demultiplexing occurs, a repeater simply connects a pair of links, as illustrated in Figure 5.

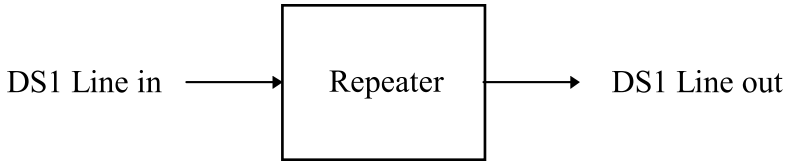

Figure 5: Repeater

1.3.2 Terminal Multiplexers/Demultiplexers

This type of terminal equipment multiplexes/demultiplexes all channels of a given line. These *terminal multiplexers* (TMs) are used at a network's *end-nodes* (nodes that are located at the extremes of the network) or at an intermediate node if splitting is necessary to drop or add channels. As illustrated in Figure 6, a TM has only one transmission link when used at an end node.

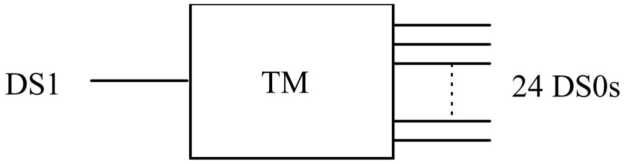

Figure 6: Terminal Multiplexer

Also, multiple TMs may be connected in various ways at a given node. A common *back-to-back configuration*, shown in Figure 7, is used at a node at which some traffic traverses the node by demultiplexing and then re-multiplexing; other, terminating DS0 channels are only demultiplexed for connection to the OD customers. The terminating OD demand is said to be added or dropped, and the traversing traffic is said to pass through this node on the through channels. This configuration performs many of the same functions as the add/drop multiplexer equipment type described next.

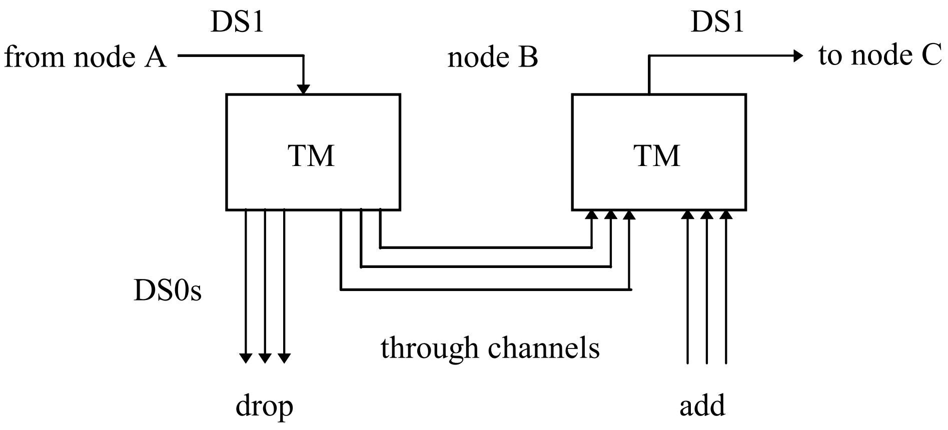

Figure 7: Two Terminal Multiplexers Used in Add/Drop Multiplexer Configuration

1.3.3 Add/Drop Multiplexer

As illustrated in Figure 8, an *add/drop multiplexer* (ADM) device demultiplexes only a certain number of DS0 channels out of the connected DS1 bit streams. It can also multiplex DS0 bit streams onto any unused channels. The channels that are not demultiplexed maintain their original channel assignment (i.e., time-slot). Some ADMs limit the number of channels that can be added or dropped. This type of multiplexer has the advantage that the channels that are passing through do not have to be demultiplexed and re-multiplexed, thus avoiding the inherent signal quality losses in this conversion.

An ADM can be used in place of two back-to-back TMs, but it may yield unused time-slots. The empty channels result when the number of dropped channels differs from the number of added channels. The number of dropped and added channels allowed varies from manufacturer to manufacturer.

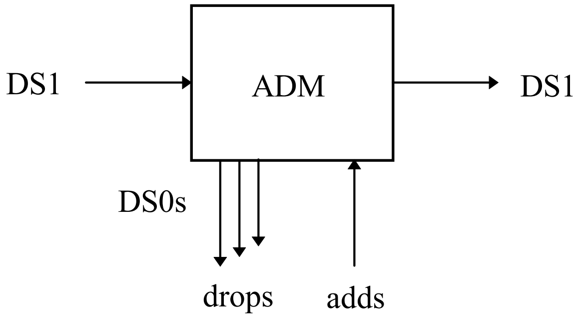

Figure 8: Add/Drop Multiplexer

1.3.4 Digital Access and Crossconnect System

A digital access and crossconnect system (DACS) is a type of electronic switch that operates like an ADM, with the added capability to change the channel assignments of traversing traffic. DACSs have several different possible configurations and are capable of switching, and multiplexing/demultiplexing, possibly at different DS levels. Figure 9 illustrates an DACS configured to operate as an ADM.

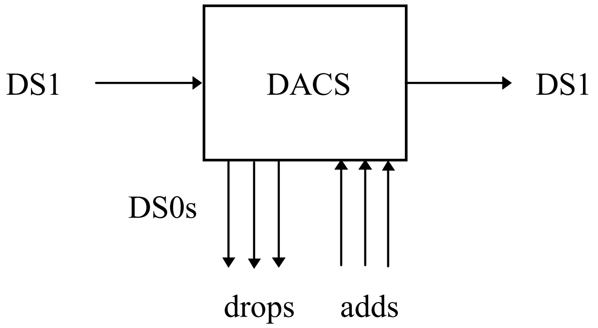

Figure 9: Digital Access and Crossconnect System Used as an Add/Drop Multiplexer

Because it can change channel assignments, a DACS can improve the utilization of network capacity, by "grooming" or rearranging signal assignments to minimize conflicts and unused channels (as in Figure 10). In busy environments, a DACS can be used as a “hub”, (see Figure 11). Several sites that need to be interconnected can utilize full DS1 transmission capacity to the DACS, where they are demultiplexed to DS0 channels, routed and re-multiplexed to the DS1 lines of the different destination sites.

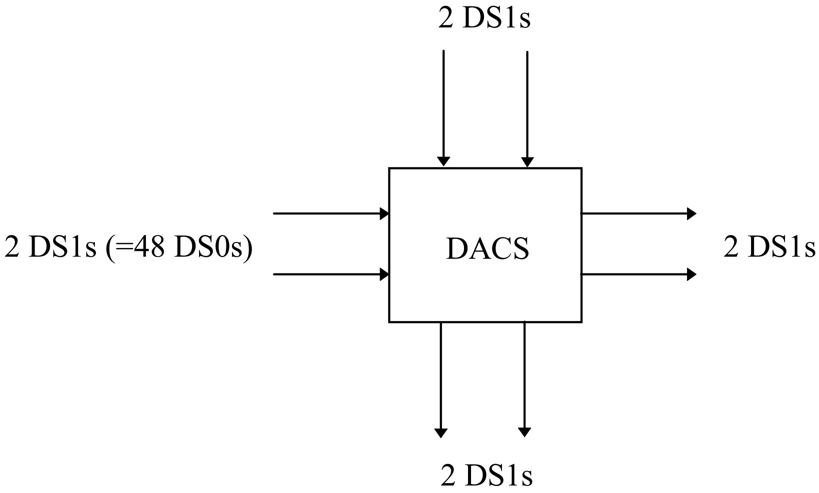

Figure 10: Digital Access Crossconnect System Used as a "Groomer"

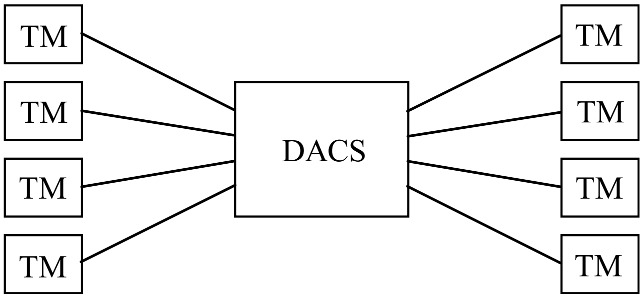

Figure 11: Digital Access Crossconnect System Operating as a Hub

The channel routing is programmable and some types of DACS can have their routing pattern changed remotely, by a central control office. This adds flexibility and a powerful resource in case of disaster recovery. It establishes a semi-permanent route for the different channels through the switch. This path remains connected until it is disconnected or changed by a programmer order or administrative action.

1.4 The Channel Consistency Issue

A key element in the development of this praxis was the concept of channel consistency and its impact on the equipment selection and channel assignment processes. Due to its importance it will be explained in detail next.

As described previously, channels are specific time-slots within the DS1 structure. Each DS0 channel is associated with one of 24 time-slots when multiplexed onto a DS1 line. The simple fact of having a certain amount of channels available on a link does not necessarily mean all can be used. The choice of the channel assignment(s) for each OD may create channel assignment conflicts between ODs over one or more common network links. Resolving this conflict requires additional processing at the node and the proper equipment (e.g., a digital access crossconnect system). The absence of this type of equipment may result in unused time-slots and consequently lower utilization of the available capacity.

Optimization of the channel assignments for a network's ODs can reduce this problem considerably, and increase the capacity utilization of the network. Having the proper equipment at each node can further improve the utilization. Optimizing the channel assignments can minimize the number of nodes where changes in channel assignment are needed, thus potentially reducing the need for the more sophisticated (and more costly) ADMs and DACSs.

Aside from costs, there are some technical reasons for minimizing the usage of terminal multiplexers/demultiplexers and DACSs. Each additional piece of equipment is an added source of potential circuit failure. The extra conversions that occur in this type of equipment are a potential source of undesirable distortion.

A simplified network model has been created to illustrate the concept of channel consistency and is shown in Figure 12. All the arcs in the model have been arbitrarily assigned a capacity of only three DS0 channels, labeled channel 1, 2 and 3. The required ODs for this model are given in

Table 2.

Table 2: Required ODs

OD	Nodes
1	N1 - N4
2	N2 - N4
3	N4 - N6
4	N3 - N5
5	N6 - N5
6	N2 - N6

From Figure 12 it can be observed that OD 1 must connect node N1 and N4. It will be arbitrarily assumed that the signal originates at node N1 and terminates at node N4. Thus the signal leaving node N1 must traverse to node N2, then to node N3 to finally reach node N4. This is trajectory will be referred to as the OD path.

The demand for each OD is one. All ODs, except OD 1, are able to traverse throughout the network, from origin to destination, with the same channel assignment. However, a conflict occurs at node N3. Between nodes N2 and N3 the only available channel for OD 1 is channel 2, but between nodes N3 and N4 the only available channel is channel 1. To eliminate this conflict it is necessary to insert, at node N3, equipment that can handle channel assignment changes, as illustrated in Figure 13.

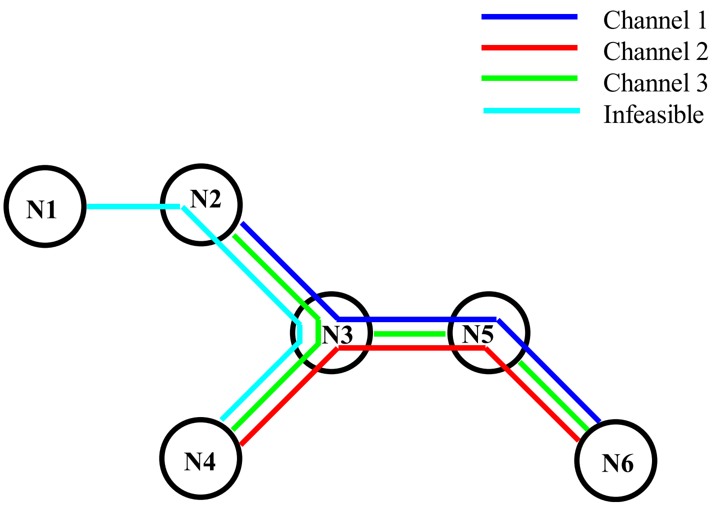

Figure 12: Infeasibility at Node N3 Due to Channel Consistency Constraints

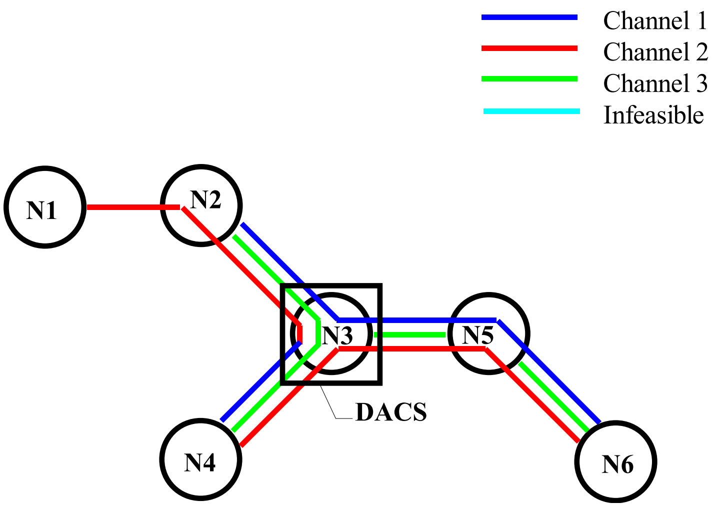

Figure 13: Feasibility Achieved Through Insertion of DACS at Node C

As stated before, channel assignment is a problem that can affect the actual usable capacity of a network depending on the type of switching equipment being used at the different nodes and the traffic demands between them. Since this praxis deals with a microwave network, there are limits to the available capacity. The expansion of a microwave network involves the complex issue of microwave frequency assignment (availability, interference protection, licensing, etc.) for new links. Having the right type of switching equipment at the right node can, in some cases, increase the overall capacity of the system. The cost of the different types of switching equipment must be considered in analyzing the network design.

1.5 Related Literature

There is a large body of literature on telecommunication network optimization, primarily addressing the issues of topology and demand. Far less literature has been published on the issues of bundling, grouping and channel assignment.

Burkard, Çela and Woeginger[21] propose a model to determine the location of the communication centers in a network and the routing pattern that minimizes the maximum intermediate traffic passing through all centers. Chari and Dutta[22] propose a model for determining transmission line capacity in networks for multiple busy-hour point-to-point circuit requirements. In a companion paper[23] grouping of circuits is addressed. The proposed grouping poses additional difficulties such as (1) all circuits in a group must follow the same route during a busy hour and (2) circuits in a group cannot be split across different lines.

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[21] Rainer Burkard, Eranda Çela, and Gerhard Woeginger, "A minimax assignment problem," *European Journal of Operational Research* 87 (1995): 670-684.

[22] Kaushal Chari and Amitava Dutta, " Design of private backbone networks - I: Time varying traffic," *European Journal of Operational Research* 67(1993): 428-442.

[23] Kaushal Chari and Amitava Dutta, " Design of private backbone networks - II: Time varying grouped traffic," *European Journal of Operational Research* 67(1993): 443-452.

Ayllón, Galán, Marín and Menéndez[24] propose a bundling and routing multiphase algorithm to determine the degree of occupation of the transmission facilities. The cost of additional multiplexers is weighed against higher utilization of the transmission facilities.

Doverspike[25] presented a multiplex bundling model and algorithm that minimizes equipment and transmission costs for a given multi-period demand forecast and demand routing. This is achieved by demultiplexing the higher rate signals into lower rate signals, combining them with lower rates from other ODs and recombining them to a higher rate, thus achieving higher utilization of the transmission facilities.

The above papers address the issues of bundling, its relationship to used capacity, and cost tradeoffs between equipment options and actual transmitted capacity. However, they do not address the issue of the low-level DS0 channel assignment that is necessary to establish the connection matrix for the equipment at the network nodes.

1.6 Praxis Overview

The goal of this praxis is to develop a series of models to address both the channel assignment optimization problem and the node terminal-equipment selection problem for a given set of demands between the nodes of a spanning tree, tree-and-branch, or any other type of telecommunications network for which the set of links for routing each demand is unique or predefined. The application of these models to a large Arizona microwave network is also given.

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[24] Fátima G. Ayllón and others, "Price-directive decomposition applied to routing in telecommunication networks," *European Journal of Operational Research* 91 (1996): 587-599.

A key design element is the maintenance of channel consistency within certain parts of the system and the generation of the associated channel-assignment list. Experimentation with different mixed integer programming models explores implementability and solvability issues. These models are applicable to spanning-tree-type telecommunications networks operating within the DS3 range (i.e. 28 DS1 lines, and that require discrete DS0 level channels assignments for some or all of the Origin-destination demands). These models can be modified to optimize networks operating within the DS4 range, if the smallest OD demands are given as full DS1 lines.

Spanning tree or tree and branch type networks with many low-demand nodes can benefit from bundling (multiplexing into higher-capacity demand units)and the resulting improved used transmission capacity. By minimizing channel assignment changes it is possible to use lower-cost equipment at the nodes while at the same time maximizing the usage of the available transmission capacity.

The proper equipment selection can minimize capital costs. An add-drop multiplexer is less expensive than two back-to-back terminal multiplexers, with the additional benefit of lower signal degradation. Repeaters are much cheaper than add-drop multiplexers, hence, if all DS0s in a DS1 line can pass through a node to another DS1 line without changing their time-slots, it is possible to achieve cost reduction as well as avoiding potential signal degradation.

The first of four models addresses a generic DS0 channel assignment for a given demand for the different ODs, assuming there are no equipment constraints at the nodes

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[25] R. D. Doverspike, "Algorithms for multiplex bundling in a telecommunications network," *Operations Research* 39, No 6 (1991): 925-944.

(i.e., no channel consistency required). The second model addresses the issue of channel consistency and minimizes the number of channel assignment changes for all demands on the network. It will identify the nodes with add/drop-only characteristics and enforce channel consistency at these nodes. At the other nodes it will assume no equipment constraints.

A third model will select the equipment type for each add/drop node (i.e., either an add/drop multiplexer or back-to-back terminal multiplexers). Enforcement of channel consistency is required to satisfy the equipment characteristics.

The final model will address equipment selection, while observing the channel assignment consistency requirements. The strategy will be to design a model that will relax the hard channel consistency constraints by allowing the addition at the nodes of new equipment, with their respective constraints and costs, when necessary to avoid unfeasibility, to permit channel switching, and to satisfy customer preferences. The model also permits the analysis of different demand problems and establish the feasibility and equipment cost of each of these problems for the given microwave network .

The resulting models can:

- Improve the used capacity of an existing network by minimizing the number of unused channels due to conflicting channel assignments;
- Determine the DS0 channel assignments for a given network, generating a complete assignment list for each node and link;
- Determine the optimal terminal equipment type for each node that meets the forecasted OD demands and customer preferences, and generate a complete

assignment list for each node of the network. Optimality in this instance will be interpreted to mean the least cost.

These models are then implemented using a mathematical modeling language and applied to the Arizona network design problem. Computational results are reported, and implications for industrial use discussed.

2. THE ARIZONA PUBLIC SERVICE COMPANY NETWORK

The models described in Chapter 1 will be applied to a telecommunications network design problem of the Arizona Public Service Company (APSC). The problem data, provided by a major equipment manufacturer, covers the southern part of the State of Arizona. The network topology was developed by network engineers, along with channel assignments and equipment selection. The process required over six man-weeks for the channel assignment portion alone, hence a computer-based solution approach would be of great assistance to the engineering group.

As shown in Figure 14, the 39-node network is a connected spanning tree of microwave links that operate primarily at the DS1 level. The configuration contains no loops, nor alternate routes, thus there is only one path between each of the 61 ODs. Table 4 shows the OD demands, expressed in the amount of DS0 and DS1 traffic for each OD pair.

The microwave links have varying capacities, designed to meet the forecasted OD demands. Also, the original topology design incorporated two selection rules, which will be maintained. The first is that if there is a node that serves as a junction between more that two arcs, then a DACS should be used. The second rule is that if there is a node with add-drop characteristics, then the lowest possible equipment cost should be considered. To avoid the higher-priced DACS equipment and use the lower-cost add-drop multiplexers or back-to-back terminal multiplexers, it is necessary to enforce channel consistency.

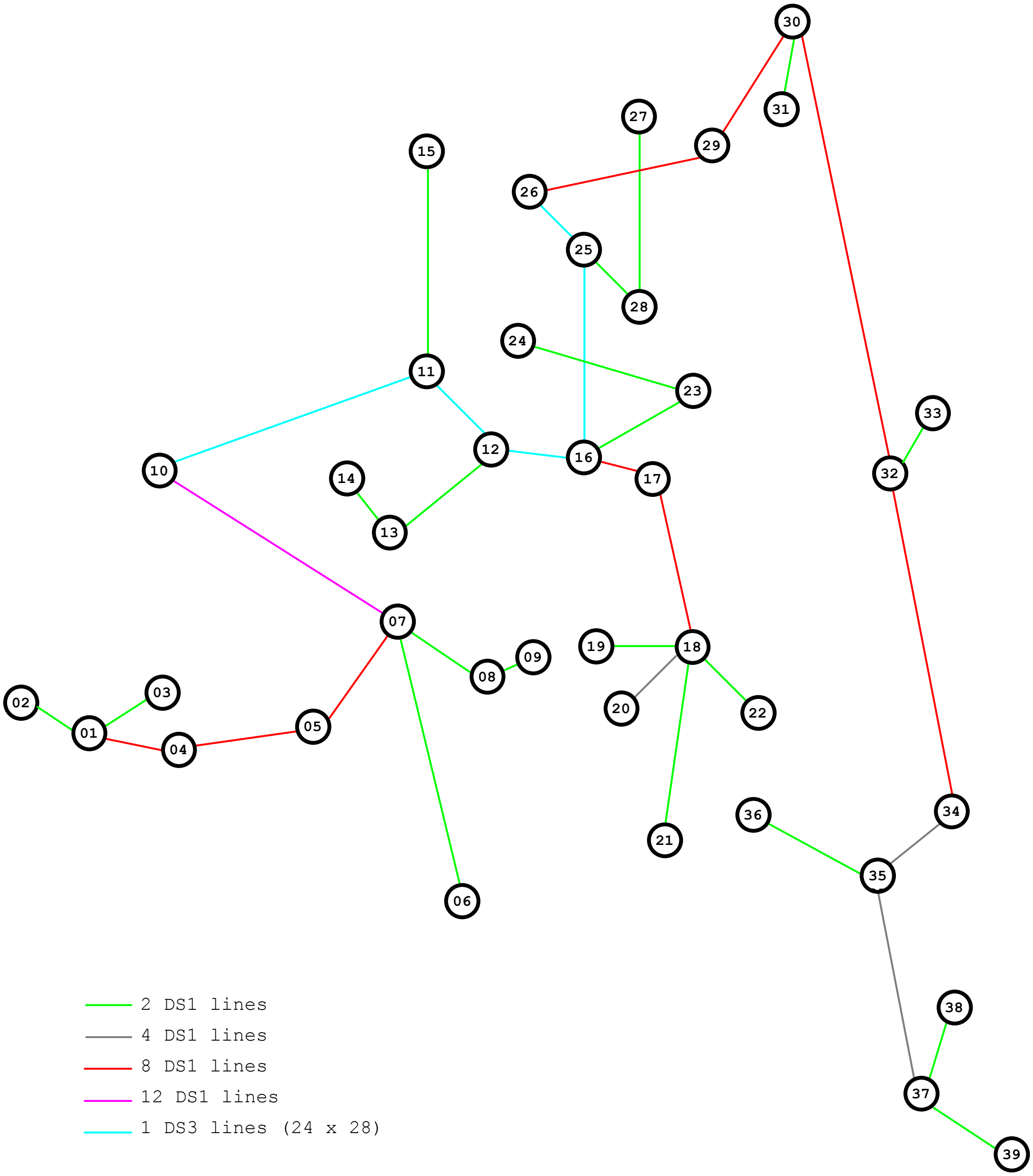

Figure 14: Microwave Point to Point Communications Map

Table 3 gives the node numbers assigned to actual site names in the Arizona Public Service Company network.

Table 3: Assigned Node Numbering to Node Names

NODE #	NODE NAME
N01	Yuma
N02	Yucca
N03	North Gila
N04	Telegraph Pass
N05	Mohawk
N06	Childs Mtn
N07	Oatman Mtn
N08	Gila Bend
N09	Gila Bend Office
N10	Palo Verde
N11	White Tanks
N12	West Phoenix
N13	WDSC
N14	Buckeye
N15	Francis Mtn
N16	PHX MWC
N17	Butte
N18	Sacaton Peak
N19	Santa Rosa
N20	Casa Grande
N21	Tat Momoli
N22	Coolidge
N23	Country Club
N24	Sunnyslope
N25	Shaw Butte
N26	DVDC
N27	Pinnacle Peak
N28	Cactus
N29	MT ORD
N30	Diamond Point
N31	Preacher Canyon
N32	Signal Peak
N33	MTN DIST
N34	San Manuel
N35	MT Lemmon
N36	Saguaro
N37	Mule Mtn
N38	Adams
N39	Douglas

NODE #	NODE NAME
N38	Adams
N14	Buckeye
N17	Butte
N28	Cactus
N20	Casa Grande
N06	Childs Mtn
N22	Coolidge
N23	Country Club
N30	Diamond Point
N39	Douglas
N26	DVDC
N15	Francis Mtn
N08	Gila Bend
N09	Gila Bend Office
N05	Mohawk
N35	MT Lemmon
N29	MT ORD
N33	MTN DIST
N37	Mule Mtn
N03	North Gila
N07	Oatman Mtn
N10	Palo Verde
N16	PHX MWC
N27	Pinnacle Peak
N31	Preacher Canyon
N18	Sacaton Peak
N36	Saguaro
N34	San Manuel
N19	Santa Rosa
N25	Shaw Butte
N32	Signal Peak
N24	Sunnyslope
N21	Tat Momoli
N04	Telegraph Pass
N13	WDSC
N12	West Phoenix
N11	White Tanks
N02	Yucca
N01	Yuma

Table 4: OD Demands

OD	Nodes		Demand		Total
Number	Origin	Destination	DS0	DS1	DS0
01	01	02	04	00	04
02	01	03	01	00	01
03	01	16	15	01	39
04	01	26	16	01	40
05	02	16	07	00	07
06	02	26	00	01	24
07	03	16	11	00	11
08	03	26	01	00	01
09	04	16	05	00	05
10	06	16	11	00	11
11	06	26	01	01	25
12	07	16	05	00	05
13	08	16	08	00	08
14	08	26	01	01	25
15	10	16	00	02	48
16	10	26	02	11	266
17	11	16	22	00	22
18	11	26	02	00	02
19	12	16	15	00	15
20	13	16	09	00	09
21	13	26	00	01	24
22	14	16	09	00	09
23	14	26	01	00	01
24	16	17	11	00	11
25	16	18	15	00	15
26	16	19	05	00	05
27	16	20	12	01	36
28	16	21	02	00	02
29	16	22	04	00	04
30	16	23	07	00	07
31	16	24	02	00	02
32	16	25	07	00	07
33	16	26	08	04	104
34	16	27	13	00	13
35	16	29	03	00	03
36	16	30	05	00	05
37	16	31	02	00	02
38	16	32	02	00	02
39	16	34	09	00	09
40	16	35	02	00	02
41	16	36	14	00	14

42	16	37	03	00	03
43	16	38	10	00	10
44	16	39	10	00	10

Table 3 - *Continued.*

OD	Nodes		Demand		Total
Number	Origin	Destination	DS0	DS1	DS0
45	17	19	01	00	01
46	17	27	02	00	02
47	17	28	03	00	03
48	19	20	03	00	03
49	19	21	02	00	02
50	19	36	01	00	01
51	20	26	12	01	36
52	20	36	03	00	03
53	21	36	01	00	01
54	23	24	05	00	05
55	24	27	01	00	01
56	25	26	01	00	01
57	26	34	01	00	01
58	26	36	00	01	24
59	26	39	01	01	25
60	27	28	03	00	03
61	27	31	04	00	04

Table 4 describes the network demand that must be accomodated. In it, a reference number is assigned to each origin-destination node pair and each OD's required demands assignments in both DS0 and DS1 levels and the equivalent total DS0s.

Channel assignment is a problem that can affect the actual usable capacity of a network depending on the type of switching equipment being used at the different nodes and the traffic demands between them. Since this is a microwave network, there are limits to the available capacity. Expansion of the network involves the complex issue of microwave frequency assignment (availability, interference protection, etc.) for new links. Having the right type of switching equipment at the right node can, in some cases, increase the overall capacity of the system. The cost of the different types of switching equipment must be considered in analyzing the network design.

2.1 Types of Microwave Links in Use and Their Capacity

There are five different types of microwave links used in the APSC network. Each type has a different line capacity, as shown in Table 5.

Table 5: Types of Microwave Links

TYPE	CAPACITY
MDR-6506-2	2 DS1s
MDR-6506-4	4 DS1s
MDR-6706-8	8 DS1s
MDR-6706-12	12 DS1s
MDR-4106E-C	1 DS3

2.2 Types and Characteristics of Available Terminal Equipment

Four types of node equipment are available for use, the selection and location of which can impact the overall performance and cost of the network. The specific characteristics of this equipment and the constraints they impose on the network are as follows.

- Line repeater. The line repeater in the APSC network interconnects the microwave links when the distances between the nodes exceed the range of the transmission equipment The repeater connects two similar lines, hence no transformations or conversions occur. Channel assignments are unchanged and channel consistency is maintained.

- Terminal multiplexer. The terminal multiplexers used in this network are of two types: DS0 to/from DS1 and DS1 to/from DS3. The former connects an incoming DS1 to 24 DS0 lines, the latter converts an incoming DS3 line to 28 DS1 lines.
- Add-drop multiplexer. The Arizona network also can use add/drop multiplexers for DS1 to/from DS0 connections. The available equipment limits the total number of adds and drops to 30 DS0s, as illustrated in Figure 15. Channel consistency is maintained on all other, pass-through channels. Note that empty DS0 channels (time-slots) result if the number of drops is different from the number of adds.

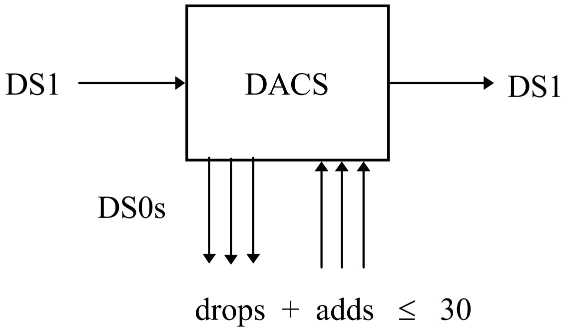

Figure 15: Add/Drop Multiplexer - Arizona Network

- Digital access crossconnect system. The DACS available for use in the network design can substitute for an ADM, but the constraints are different. First, the DACS can drop 24 or fewer DS0 channels and add 24 or fewer DS0 channels. Secondly, it can change channel assignment, thus eliminating the channel consistency constraint. When operating as a hub, the DACS can interconnect several incoming DS1 channels to several outgoing DS1 channels and, in the process, also make channel reassignments.

2.3 Assumptions

Two assumptions are made in the development of the models. It is assumed that the microwave network's basic topology will be unchanged, meaning that the microwave links will maintain their present capacity (i.e., number of lines of each type). It is also assumed that busy hour, traffic load, and waiting time parameters were considered during the development of the original design and are reflected in the OD traffic data.

3. CHANNEL ASSIGNMENT MODELS

This section begins with a brief summary of the initial efforts to solve the problem using a traditional network structure, it then proceeeds to present chosen design and modeling processes, and three mathematical formulations of the channel assignment and equipment selection problem (i.e., Models 1, 2 and 3). The logic of each model is developed and illustrated with a small example.

A simplified hypothetical physical network, shown in Figure 16, was created with the basic components and characteristics present in the Arizona network. Using this as a test case, the mathematical models were created and verified for correctness of representation, by examining different problems and progressively adding equipment constraints. By working with small models it was possible to manually validate the mathematical results. Once the model's accuracy was checked, capacity and demand was increased to determine the impact on the computational resources necessary to achieve the desired results.

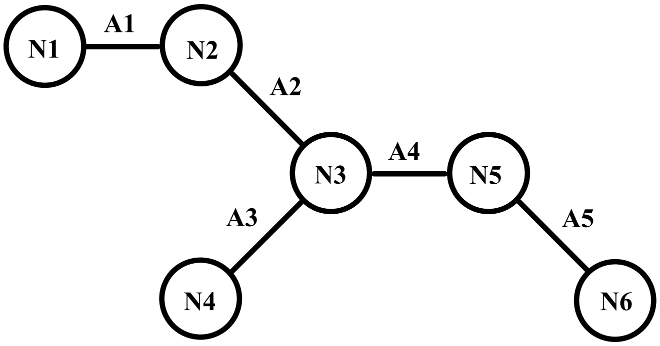

Figure 16: Hypothetical Network

The natural course was to address the problem using a network structure. This original model, using a network structure, applied to the hypothetical network with reduced data proved to be accurate, and made the required the assignments of channels and properly selected terminal equipment. However, when real world data was applied to the hypothetical network the size of the problem became too large to process on the computational resources available.

An example of how quickly the size of the model grows is illustrated by the Table 6. Here the hypothetical network was further simplified to only five nodes in line (i.e., node 4 of the hypothetical network was removed), four arcs and six ODs. Four different arc capacities and required demands were applied to this simplified network model. In the first case all arcs had a capacity of one DS1 line, and a demand of five DS0s for each OD. The second case the arc capacity was doubled (i.e., two DS1 lines) as were the demands. The third and fourth cases followed the same pattern, always doubling the arc capacity and the required demands. With the computational resources available only the first case was solved. All the three other cases were interrupted before the optimal solution was reached, due to insufficient computer memory.

Table 6: Number of DS1 Lines Versus Problem Size

Number of DS1 lines per arc	Number of rows	Number of columns	Number of non-zero elements
01	495	3,821	22,096
02	824	9,836	57,653
04	2,272	57,081	336,931
08	5,412	225,269	1,336,095

After several attempts to reduce the size of the model by constraining as much as possible the solution search space and the number of variables it was concluded that a different approach to the problem was required. The new premise was that minimization of the DS1 lines used to add and or drop DS0 channels implied in reducing the use of more costly terminal equipment such as ADMs and DACS, and that this model could be implemented as a multicommodity assignment problem. This new approach brought two immediate two benefits. The first was the reduction of the number of variables by (1) the elimination of the source and sink nodes used in the original model (i.e., in a network model it is necessary to have a source node that originates the demand and a sink node that absorbs this demand, and their respective connecting arcs), and by (2) the the substitution of the variables with seven indices by variables with only four indices. This considerably reduced the size of the problem. The second benefit was that the solution output data set allowed post-optimization manipulation to achieve alternative objectivesfurther reducing the size of the optimization process. The development of the models with this new approach is described next in this chapter.

Models 1 and 2 are the mathematical formulations which proved to be computationally viable, both in memory requirements and processing time, for a real-world environment, such as the Arizona network. It became necessary to decompose Model 3 into sub-problems to achieve computational viability for the Arizona network with the computing resources that were available.

3.1 Design Considerations

Channel assignment and equipment selection problems easily create large models. The number of variables grows geometrically with the number of nodes, links,ODs, and DS1 lines in the network. In developing the models contained herein, , two design objectives were used: minimize the problem size and simplify the data input.

The first modeling objetive was the reduction of the size of a given problem. Two different approaches to this issue were considered. One was to partitioni a network into smaller independent networks. This would require reassembling of the network after all the channel assignments were made, without generating conflicting assignments at the reassembly points.

The other approach considered was to decompose a network into two sub-problems while still maintaining the full network characteristics. This methodology was selected since it did not de-characterize the network. In the approach taken, the first sub-problem is an assignment problem that identifies those OD demands that are greater than the capacity of a DS1 line (or multiples of it), assigns these demands to DS1 lines eliminates these full DS1s from the network demand, and reduces proportionally the capacity of the arcs affected. Add-drop nodes are identified in the process. Nodes that are connected to only two arcs are referred to in this praxis as *add-drop nodes*. This does not imply that these are then only nodes that can add or drop DS0 demands in a network. It also identifies those arcs that are not connected to add-drop nodes and assigns the required channels to these arcs.

The reduction process potentially offers the designer the choice of using DACS with less number of ports at the junction nodes by the use of repeaters for the full DS1 lines passing through these nodes. This latter option reduces flexibility, but could be economically interesting depending on the specific customer requirements. It must be observed that this reduction of DACS ports is likely not be the optimal minimum. The explanation for this fact is that there is the potential, through bundling, that other DS1 lines could pass through the node without the need of channel assignment changes, further reducing the number of DACS ports necessary.

The second sub-problem processes the remaining network using only those nodes that require equipment selection and in which all OD demands are less than 24 DS0s. These OD demands with less than 24 DS0s will be referred to as *residual demands*. In this manner, the problem is simplified to only the residual OD demands at the add-drop nodes. This reduces the OD demands of the Arizona network problem by approximately two thirds. For computational speed, the reduced Arizona network was partitioned into a series of sub-problems that evaluate the add-drop nodes individually, or grouped by adjacency, generating the channel assignments and the equipment selections for each add-drop node. The grouping of adjacent add-drop nodes was necessary to avoid assignment conflict of the DS0 channels on the interconnecting arcs.

The re-construction of the network simply requires compilation of the individual assignment charts into a full network assignment chart, which can be accomplished using a spreadsheet. The models used for this low-level partitioning will be described in detail in chapter four.

The second design concern was problem specification simplcity. As a network increases in size, the input data becomes more complex and requires considerable care to avoid the introduction of errors, especially since the data are interrelated. An error in one data table can result in incomplete equation generation and erroneous results. This concern prompted an effort to reduce the input data to a minimum, and to compute all the other necessary parameters, thus increasing the likelihood of correct equation and data set generation. The reduction of data input also means a reduction in the time necessary to create new data to evaluate different problems.

The input data characterizes the microwave network topology and the problem that is to be analyzed. The microwave network *topology* is defined as the sites, the microwave links that interconnect them, and the site equipment constraints. A *problem* is defined as a set of origin-destination demands, and their associated paths through the network.

3.1.1 Data Input

The problem's data requirements have been divided into three groups: the origin-destination data, the microwave network topology data, and the equipment constraint data.

3.1.1.1 Origin-Destination Data

The demand data are entered as a table that gives the number of DS0 channels required to fulfill the demand for each origin-destination pair. Table 7 is such an origin-destination demand requirement table for Figure 16, indicating, for example, that the demand required by OD01 is six DS0s.

Table 7: OD Demand Requirements (# of DS0s)

OD LABEL	DEMAND (DS0s required)
OD01	6
OD02	18
OD03	6
OD04	6
OD05	6
OD06	4

The arc path for each origin to the respective destination is entered as a table relating each OD to all the arcs necessary to complete the connection. Table 8 is such an arc-path table designation for Figure 16, indicating by the number "1", for example, that demand OD01 requires arcs A01, A02, and A03 to complete its path.

Table 8: Arcs Needed to Complete OD Path

	ARC NUMBER				
OD	A01	A02	A03	A04	A05
OD01	1	1	1		
OD02	1	1			
OD03		1		1	1
OD04		1		1	
OD05			1	1	1

OD06					1

3.1.1.2 Network Topology Data

The capacity of each arc is entered as a table giving the number of DS1 lines available on each arc. Table 9 is such an arc-capacity table for Figure 16, indicating, for example, that arc A01 has a capacity of five DS1 lines. This data was used in one of the problems during model testing.

Table 9: Network Arc Capacity (# of DS1 lines)

ARC LABEL	ARC CAPACITY (# of DS1 lines)
A01	5
A02	5
A03	4
A04	3
A05	3

The interconnections between the arcs are entered as a table relating the arcs to the nodes that they connect called “node-arc incidence matrix” in network terminology,. Table 10 gives the arcs that connect at each node for the hypothetical network illustrated in Figure 16. These connections are indicated by the use of number “1” in the matrix.

An interesting aspect of Table 10 is that it allows for a quick fault check for data input. All end nodes have only one entry in their respective columns. All add-drop nodes have exactly two entries in their respective columns, since each arc can be connected to only two nodes.

Table 10: Arcs that Connect at Each Node

ARC	NODE					
	N01	N02	N03	N04	N05	N06
A01	1	1				
A02		1	1			
A03			1	1		
A04			1		1	
A05					1	1

3.1.1.3 Equipment Constraint Data

Since equipment characteristics vary from manufacturer to manufacturer, it is necessary to include elements into the models that allow for these differences. The ADM equipment limit is a scalar in a model that defines the maximum number of DS0 channels that can be added and dropped by an ADM at any node.

Other scalars can be used to implement customer preferences using the equipment characteristics. A possible of implementation of this type to add flexibility to a network design is presented in chapter 5 (see Model 4).

3.2 Modeling Process

This section describes the development of three models, which will be referred to as Models 1, 2 and 3 respectively. These are single-process models that generate a set of DS0 channel assignments for the complete network. Models 2 and 3 are of increasing complexity, each adding constraints to Model 1 as necessary to create a combined channel-assignment and equipment-selection model.

3.2.1 Notation and Conventions

This section defines the sets, parameters, variables, and logical conditions used in constructing Models 1, 2 and 3. The equations and logic used to generate the parameters and logical conditions are described throughout this chapter.

Sets are denoted by italicized uppercase Latin letters. The set created by removing element e from set S is given as $S - e$ and $|S|$ is the cardinality of S. Variables are denoted by bold uppercase italicized Latin letters. All parameters, scalars, constraints and logical conditions are denoted by uppercase Latin letters.

3.2.1.1 User-Defined Sets and Parameters

The are two groups of sets and parameters used in the models: user-defined and computed. The user-defined sets and parameters are the data provided bu the user that characterizes the problem.

User-defined sets:

I: set of all arcs in the network

K: set of all DS0 channels available on any given DS1 line (typically, $|K| = 24$)

J: set of all possible DS1 lines available on any given arc $i \in I$

L: set of all origin-destination demand pairs in the network

N: set of all nodes in the network

D_l: set of arcs contained in the path connecting the endpoints of OD pair $l \in L$

$NODES_n$: set of arcs that connect to a given node $n \in N$

User-defined parameters:

ADMLIMIT: maximum number of add and drops allowed by an ADM at any given node

DEMAND$_l$: quantity of DS0 channels required for a given OD $l \in L$

CAP$_i$: quantity of DS1 lines available on a given arc $i \in I$

Decision variables:

$\boldsymbol{X}_{lijk}$: 0/1 variable indicating do-not/do assign OD $l \in L$ to arc $i \in I$, DS1 line $j \in J$ and DS0 channel $k \in K$

$\boldsymbol{Y}_{lij}$: 0/1 variable indicating do-not/do assign OD $l \in L$ to arc $i \in I$ and full DS1 line $j \in J$ (e.g., some or all of DEMAND$_l$ will be carried on arc i, using all channels of line j)

$\boldsymbol{W}_{nljk}$: 0/1 variable indicating that channel consistency does-not/does exist for OD $l \in L$ on DS1 line $j \in J$, DS0 channel $k \in K$ at node $n \in AD$

$\boldsymbol{ACCESS}_{nij}$: number of DS0 channels in DS1 line $j \in J$, on arc $i \in I$ that are added and dropped at node $n \in AD$ (definitional variable)

$\boldsymbol{DS1}_{nj}$: 0/1 variable indicating whether DS1 line $j \in J$ *does-not/does* add or drop demand at node $n \in AD$

3.2.1.2 Generation of computed sets and parameters

There are two groups of computed values: those values that define sets and parameters prior to optimization and those that are generated post optimization. The first manipulates mathematically the user-defined data to define all the sets and parameters required by the model while at the same time constraining the solution search space. The latter group uses the decision variables resulting from optimization to compute the post-optimization variables and generate the channel assignment tables and equipment selection. The equipment selection logic is described as it applies to the different models. This section presents the mathematical formulation for the generation of the computed sets and parameters.

Computed sets:

*FULLO*D: set of ODs $l \in L$ that have one or more full DS1 demands

$$\text{FULLOD} = \begin{cases} 1, & \text{if } REDUDS1_l \geq 1; \\ 0, & \text{otherwise.} \end{cases}$$

AD: set of all add-drop nodes, where AD $\subset$ N

$$\text{AD} = \begin{cases} 1, & \text{if } \sum_{i \in I} NODES_n = 2; \\ 0, & \text{otherwise.} \end{cases}$$

$PASS2_{nli}$ - set of all valid node-OD-arc combinations

$$\text{PASS2}_{nl} = \begin{cases} 1, & \text{if } D_l = 1 \text{ and } NODES_n = 1; \\ 0, & \text{otherwise.} \end{cases}$$

$PASSTHRU_n$: set of OD $l \in L$ paths that pass through a given node $n \in N$

$$PASSTHRU_n = \begin{cases} 1, & \text{if} \sum_{i \in I} PASS2_{nl} \geq 2; \\ 0, & \text{otherwise.} \end{cases}$$

$DROP_n$: set of OD, that add or drop at node $n \in N$

$$\mathrm{DROP}_n = \begin{cases} 1, & \text{if} \sum_{i \in I} PASS2_{nl} = 1; \\ 0, & \text{otherwise.} \end{cases}$$

$ARCCAP_i$: set of all DS1 lines $j \in J$ available on a given arc $i \in I$; $ARCCAP_i =$

$ARCCAP2_i \cup ARCCAP3_i$

$$\mathrm{ARCCAP}_i = \begin{cases} 1, & |j| \leq \mathrm{CAP}_i; \\ 0, & \text{otherwise.} \end{cases}$$

$ARCCAP2_i$: set of residual DS1 lines $j \in J$ available on a given arc $i \in I$;

$ARCCAP2_i \subset ARCCAP_i$

$$\mathrm{ARCCAP2}_i = \begin{cases} 1, & |j| \leq \mathrm{REDUCAP}_i; \\ 0, & \text{otherwise.} \end{cases}$$

$ARCCAP3_i$: set of full DS1 lines $j \in J$ available on a given arc $i \in I$;

$ARCCAP3_i \subset ARCCAP_i$

$$\mathrm{ARCCAP3}_i = \mathrm{ARCCAP}_i - \mathrm{ARCCAP2}_i$$

$G1_l$: set of all valid $\{i,j,k\}$ combinations of arc $i \in I$, DS1 line $j \in$

$ARCCAP2_i$, and residual DS0 channel $k \in K$ for a given OD $l \in L$

$G1_{lijk} = (D_l * \text{CHANNEL}_k * \text{LINE}_j), \forall i \in ARCCAP2_i$

$G3_l$: set of all valid $\{i,j\}$ combinations of, arc $i \in I$, and full DS1 line $j \in ARCCAP3_i$ for a given OD $l \in FULLOD$

$G3_{lij} = (D_l * \text{LINE}_j)\ \forall ij \in ARCCAP3_i, \forall l \in FULLOD$

$ARCCAP4_{ni}$ - Arc capacity at node n

$ARCCAP4_{ni} = ARCCAP2_i * NODES_n$

$NODECAP_n$: set of residual DS1 lines $j \in J$ that pass through node $n \in AD$

$$NODECAP_n = \begin{cases} 1, & \text{if } \sum_i ARCCAP4_{ni} \geq 1; \\ 0, & \text{otherwise.} \end{cases}$$

Computed parameters:

REDUDS1_l: quantity of full DS1 lines required for a given OD $l \in L$

$\text{REDUDS1}_l = \text{FLOOR}(\text{DEMAND}_l / 24)$

REDUCAP_i: quantity of residual DS1 lines available on a given arc $i \in I$

$\text{REDUCAP}_i = \text{CAP}_i - (\sum_l \text{D}_l * \text{REDUDS1}_l)$

RESIDUAL_l: quantity of residual DS0 channels required a given OD $l \in L$

$\text{RESIDUAL}_l = (\text{DEMAND}_l - \text{TRUNC}(\text{DEMAND}_l / 24) * 24)$

ADMMAX: maximum number of adds <u>or</u> drops allowed by an ADM at any given node

ADMMAX = ADMLIMIT / 2

Post-optimization variables:

$\boldsymbol{DIMF}_{nij}$: 0/1 variable indicating that add-drop multiplexer requirements are-not/are met at node $n \in AD$ by arc $i \in I$, DS1 line $j \in J$

$\boldsymbol{TMF}_{nij}$: 0/1 variable indicating that the terminal multiplexer requirements are-not/are met at node $n \in AD$ by arc $i \in I$, DS1 line $j \in J$

$\boldsymbol{DIM}_{nj}$: 0/1 variable indicating that an add-drop multiplexer should-not/should be used at node $n \in AD$ for DS1 line $j \in J$

$\boldsymbol{BBTM}_{nj}$: 0/1 variable indicating that back-to-back terminal multiplexers should-not/should be used at node $n \in AD$ for DS1 line $j \in J$

$\boldsymbol{TMP}_{nj}$: 0/1 variable that a terminal multiplexer should-not/should be used at node $n \in AD$ for DS1 line $j \in J$

$\boldsymbol{TM}_{nij}$: 0/1 variable indicating that a terminal multiplexer should-not/should be used at node $n \in AD$, arc $i \in I$ for DS1 line $j \in J$

$\boldsymbol{PASSING}_{nj}$ 0/1 variable indicating that DS1 line $j \in J$ is-not/is used by a pass-through OD at node $n \in AD$

$\boldsymbol{USEDRESID}_{nijkl}$ 0/1 variable indicating that at node $n \in N$, arc $i \in I$, DS1 line $j \in J$, DS0 channel $k \in K$ is-not/is assigned to OD $l \in L$

$\boldsymbol{USEDFULL}_{nijl}$ 0/1 variable indicating that at node $n \in N$, arc $i \in I$, full DS1 line $j \in J$, is-not/is assigned to OD $l \in L$

3.2.2 Computational Testing Environment

The mathematical models in this praxis were tested on an Alpha Server 2100 Model 5/300 computer manufactured by Digital Equipment Corporation. This computer system was equipped with two 300 MHz processors and 1 Gbyte of RAM (random access memory), and running the Digital UNIX version 3.2D operating system. The modeling language used was GAMS (General Algebraic Modeling System) version 2.25 and the solver was CPLEX version 4.0.

Several optional settings were used, both in GAMS as in CPLEX. In order to reduce the volume of output from GAMS, the solution printout setting was set to OFF (OPTION SOLPRINT = OFF); and only the desired solution and post-optimization data were displayed. In order to limit the processing times to reasonable values or to make partial tests, various different time limits were used (e.g., OPTION RESLIM = 900, which limited processing time to 900 CPU seconds). The SOLUTION SUMMARY section of the GAMS output shows what limit was used. To insure that the solution was close to optimal, OPTION OPTCR = .01 was used, causing the solver to terminate processing when a feasible solution was within 1% of the best possible feasible solution.

In order to modify default parameters in CPLEX the .OPTFILE = 1 option was introduced. This called a file CPLEX.OPT that contained the optional settings for CPLEX. Only two settings were used that differ from the default values of CPLEX. The limit on the number of iterations was used in a similar fashion to the processing time limitation option. The default value is 100,000 which was used in some of the final tests (iterationlim 100000). The second non-default setting used in CPLEX was the node search strategy that was set to *depth first search strategy* (nodeselect 2). The reason for this setting will be explained in chapter four. The default values were used for all other settings, in both GAMS and CPLEX.

3.2.3 Model 1

Model 1 takes the form of a semi-assignment problem with integer side constraints, in which each OD demand is a separate commodity and there are no restrictions on channel assignment other than that only one DS0 channel can be assigned to each OD unit of demand..

The model accomplishes the following tasks:

- Separates full DS1 demand from total demand.
- Identifies add-drop nodes.
- Assigns full DS1 demand units to DS1 lines on all valid arcs for each OD.
- Assigns residual DS0 demand units to residual DS1 lines on all valid arcs for each OD.

3.2.3.1 Mathematical Formulation

Since this simply an assignment problem, minimization or maximization could be used and the same results would be obtained because the demand is an equality constraint. Minimization was chosen because the final objective was to minimize costs.

$$\text{Minimize} \sum_{l \in L} \sum_{i \in I} \sum_{j \in J} \boldsymbol{Y}_{lij} \qquad (1)$$

For each OD, the required number of residual demand units are assigned to the DS0 channels on the residual DS1 lines on each arc necessary to complete the OD path.

Equation (2) assigns one residual DS1 line-DS0 channel on each arc for each unit of residual demand for each OD.

$$\sum_{j \in ARCCAP2i \text{ and } k \in K} \boldsymbol{X}_{lijk} = \text{RESIDUAL}_l, \ \forall\ l \in \text{L, and } \forall\ i \in D_l \qquad (2)$$

The multicommodity constraint, equation (3) limits the assignment to only one unit of residual demand to each DS1-DS0 channel on each arc of the network.

$$\sum_{l \in L} \boldsymbol{X}_{lijk} \leq 1, \ \forall\ i \in I, j \in ARCCAP2_i,\ k \in K \qquad (3)$$

For each OD with one or more full DS1 demands, the required number of DS1 lines to meet these demands are assigned to the full DS1 lines on each arc necessary to complete the OD path. Equation (4) assigns one full DS1 line on each arc for each unit of full DS1 demand for each OD.

$$\sum_{j \in ARCCAP3i} \boldsymbol{Y}_{lij} = \text{REDUDS1}_l, \ \forall\ l \in FULLOD,\ i \in D_l \qquad (4)$$

The multicommodity constraint, equation (5), limits the assignment to only one unit of full DS1 demand to each DS1 line on each arc of the network.

$$\sum_{l \in FULLOD} \boldsymbol{Y}_{lij} \leq 1, \quad \forall\ i \in I, j \in ARCCAP3_i \qquad (5)$$

3.2.3.2 Computational Results

The computational results from the processing of Model 1 applied to the hypothetical network and to the Arizona network are compared in Table 11. The processing times shown are CPU seconds spent in the CPLEX optimizer. This table clearly shows the impact of size on the complexity of problem. However, the Arizona network is processed without problems.

Table 11: Computational Results for Model 1

	Hypothetical Network	Arizona Network
Number of rows	95	4,304
Number of columns	225	44,200
Number of non-zero elements	449	90,622
Iteration count	100	2,395
CPU run-time in CPLEX	0.017 sec	5.65 sec

3.2.3.3 Interesting Aspects and limitations

The speed with which the Arizona network was solved indicates potential use of Model 1 for:

- time-varying demands analysis, and nodes matrix assignment tables in networks with full crossconnect capabilities
- feasibility studies for varying demand problems on an existing network with full crossconnect capabilities

What is missing from this model , however, is the ability to ensure channel consistency. As a result, implementing the solution may require a DACS at every node chere a transiting demand is assigned to a different channel on adjacent arcs.

3.2.4 Model 2

Model 2 adds a channel consistency constraint to Model 1, thus accomplishing this additional task:Adds a channel consistency constraint to all residual DS0 demands that do not drop and/or add at a specific add-drop node.

3.2.4.1 Mathematical Formulation

Model 2 consists of expressions (1) - (5) plus the following.

$$\sum_{i \in NODESn} X_{lijk} = 2W_{nljk}, \quad \text{n} \in \text{AD}, l \in PASSTHRU_n, j \in NODECAP_n, k \in K \qquad (6)$$

These constraints ensure channel consistency by assigning the same DS1 line-DS0 channel combination to both arcs of add-drop node for each unit of residual demand that passes through the node.

3.2.4.2 Computational Results

The computational results from the application of Model 2 to the hypothetical network and to the Arizona network are displayed in Table 12. Note the increase in CPU processing time (i.e., time used running CPLEX optimization) resulting from the addition of the channel consistency constraints to Model 1. In the case of the hypothetical network, times approximately double, but in the Arizona network there was a 5,175% increase. This illustrates how network size and complexity can easily become limitations to achieving solutions to this type of problem.

Table 12: Computational Results for Model 2

	Hypothetical Network	Arizona Network
Number of rows	159	5,000
Number of columns	289	89,896
Number of non-zero elements	641	158,398
Iteration count	172	20,399
CPU run-time in CPLEX	0.033 sec	292.4 sec

3.2.5 Model 3

Model 3 adds the equipment selection logic equations and minimizes the number of DS1 lines used at each add-drop node, thus accomplishing these additional tasks:

- Minimizes the number of residual DS1 lines used at add-drop nodes to drop and/or add DS0s.
- Selects add-drop node equipment.

3.2.5.1 Additional Mathematical Formulation

The variable for minimization differs from the previous models. The decision to minimize the number of DS1 lines used to drop and/or add DS0 channels at the add-drop nodes assumes that the fewer DS1 lines needed implies in less equipment and consequential lower equipment costs.

$$\text{Minimize} \sum_{n \in AD} \sum_{j \in NODECAPn} \boldsymbol{DS1}_{nj} \tag{7}$$

The $\boldsymbol{DS1}_{nj}$ variable is used in equation (8) to identify the DS1 lines that actually add and drop DS0 channels at the node.

$$\sum_{l \in DROPn} \sum_{i \in NODESn} \sum_{k \in K} \boldsymbol{X_{lijk}} \leq 16\boldsymbol{DS1}_{nj}, \quad n \in AD, j \in NODECAP_n \tag{8}$$

The equipment selection process is a function of the number of DS0 channels added or dropped by each pair of DS1 lines at a add-drop node. The variable $\boldsymbol{ACCESS_{nij}}$ identifies the number of DS0 channels that are added and/or dropped by each DS1 line at a given node n. At most two variables for each same DS1 line number at each node are generated (e.g., if DS1 line R2 passes through a node, two variables will result, one for each arc that connects to the node). The the number of DS0 channels that are dropped or added at an add-drop node is determined by equation (9).

$$\sum_{l \in DROPn} \sum_{k \in K} \boldsymbol{X_{lijk}} = \boldsymbol{ACCESS_{nij}}, \quad n \in AD, j \in NODECAP_n, i \in NODES_n \quad (9)$$

3.2.5.2 Equipment Selection Logic

The equipment-selection decisions are made after the minimization process is concluded, that is, after the number of DS1 lines used to add or drop DS0 channels at each add-drop node is determined. The capability that GAMS offers to generate parameters based on the variables that result from the solved problem was used to implement the equipment selection logic. In this praxis these parameters are referred to as *post-optimization variables* and are all binary.

Equipment to be placed at a node is determined from the results of equation (9). Figure 17 illustrates the selection space rules at a node $n \in AD$, on line $j \in NODECAP_n$, where arcs i and $i' \in NODES_n$ connect. All post-optimization variables are contasined within these sets.

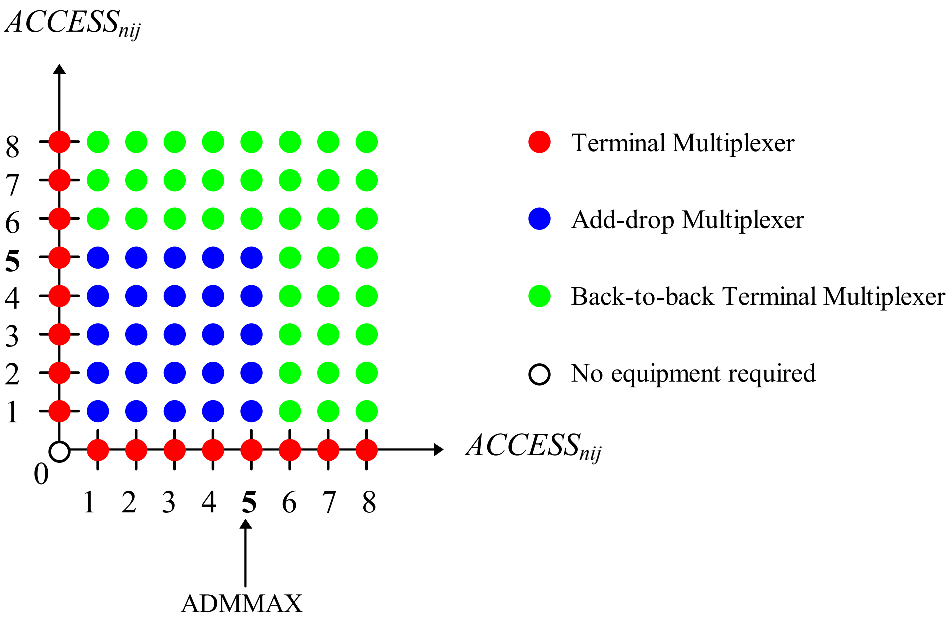

Figure 17: Equipment Selection Space

As can be observed in Figure 17, if any variable $\boldsymbol{ACCESS}_{nij}$ for a DS1 line is positive, then some type of terminal equipment must be used. If the value of variable $\boldsymbol{ACCESS}_{nij}$ is greater than parameter ADMMAX, then requirements are met for placing a terminal multiplexer the specific DS1 line. Parameter ADMMAX is equal to half the total number of add and/or drop DS0 channels allowed by the equipment which is given by parameter ADMLIMIT. The value for parameter ADMLIMIT in the hypothetical network was arbitrarily chosen to be ten, in order to maintain the same proportionality to the real equipment used in the Arizona network. Equation (10) is used to identify when terminal multiplexer requirements are met at node n, arc i, DS1 line j. Post-optimization variable $\boldsymbol{TMF}_{nij}$ is one when this requirement is met, and zero otherwise.

$$\boldsymbol{TMF}_{nij} = \begin{cases} 1, & \text{if } \boldsymbol{ACCESS}_{nij} \geq \text{ADMMAX}; \\ 0, & \text{otherwise}; \\ \text{for} & n \in AD, j \in NODECAP_n, i \in NODES_n \end{cases} \tag{10}$$

If the value of variable $\boldsymbol{ACCESS}_{nij}$ is positive but less than scalar ADMMAX, then add-drop multiplexer requirements are met for the specific DS1 line. Equation (11) is used to determine when requirements are met for placing an add-drop multiplexer at node *n*, arc *i*, DS1 line *j*. Post-optimization variable $\boldsymbol{DIMF}_{nij}$ is one when this requirement is met, and zero otherwise.

$$\boldsymbol{DIMF}_{nij} = \begin{cases} 1, & \text{if } 0 < \boldsymbol{ACCESS}_{nij} \leq \text{ADMMAX}; \\ 0, & \text{otherwise}; \\ \text{for } n \in AD, j \in NODECAP_n, i \in NODES_n \end{cases} \tag{11}$$

Table 13 shows when the post-optimization variables $\boldsymbol{DIMF}_{nij}$ and $\boldsymbol{TMF}_{nij}$ are activated as a function of the value of variable $\boldsymbol{ACCESS}_{nij}$ in order for equations (10) and (11) to be consistent.

Table 13: Activation of post-optimization variables $\boldsymbol{DIMF}_{nij}$ and $\boldsymbol{TMF}_{nij}$

Value of $\boldsymbol{ACCESS}_{nij}$	Activated parameter
0	None
1	$\boldsymbol{DIMF}_{nij}$
2	$\boldsymbol{DIMF}_{nij}$
3	$\boldsymbol{DIMF}_{nij}$
4	$\boldsymbol{DIMF}_{nij}$
5	$\boldsymbol{DIMF}_{nij}$
6	$\boldsymbol{TMF}_{nij}$
7	$\boldsymbol{TMF}_{nij}$
8	$\boldsymbol{TMF}_{nij}$

To implement the logic decision process it was also necessary to generate a parameter that identified whether the DS1 line was used by any origin-destination demands that passed through the node. The use of this parameter insured that a terminal multiplexer was not selected if the DS1 line had pass-through ODs. As defined by equation (12) post-optimization variable $\boldsymbol{PASSING}_{nj}$ is one only when DS1 line is used by one or more pass-through ODs, and zero otherwise.

$$\boldsymbol{PASSING}_{nj} = \begin{cases} 1, & \text{if } \sum_{l}\sum_{k} \boldsymbol{W}_{nljk} \geq 1; \\ 0, & \text{otherwise;} \\ \text{for } n \in AD, j \in NODECAP_n & \end{cases} \tag{12}$$

Manipulation of post-optimization variables $\boldsymbol{DIMF}_{nij}$, $\boldsymbol{TMF}_{nij}$ and $\boldsymbol{PASSING}_{nj}$ are used to generate the equipment selection logic illustrated in Table 14.

Table 14: Equipment Selection Logic

Row	***PASSINGnj***	$\sum_{i} \boldsymbol{DIMF}_{nij}$	$\sum_{i} \boldsymbol{TMF}_{nii}$	$\boldsymbol{DIM}_{nj}$	$\boldsymbol{BBTM}_{nj}$	$\boldsymbol{TMP}_{nj}$	$\boldsymbol{TM}_{nij}$
1	1	0	0	0	0	0	0
2	1	0	1	0	1	0	0
3	1	0	2	0	1	0	0
4	1	1	0	1	0	0	0
5	1	1	1	0	1	0	0
6	1	2	0	1	0	0	0
7	0	0	0	0	0	0	0
8	0	0	1	0	0	1	1
9	0	0	2	0	1	0	0
10	0	1	0	0	0	1	1
11	0	1	1	0	1	0	0
12	0	2	0	1	0	0	0

Post-optimization variable $\boldsymbol{DIM_{nj}}$ identifies an active add-drop multiplexer on DS1 line *j* at node *n*. The logic used is given in equation (13). An one indicates that an add-drop multiplexer should be placed at that point; a zero means that no ADM should be used.

$$\boldsymbol{DIM}_{nj} = \begin{cases} 1, & \text{if } \sum_i \boldsymbol{DIMF_{nij}} = 2; \\ & \text{or} \\ & \boldsymbol{PASSING_{nj}} = 1 \text{ and } \sum_i \boldsymbol{DIMF_{nij}} = 1 \text{ and } \sum_i \boldsymbol{TMF_{nij}} = 0; \\ 0, & \text{otherwise.} \end{cases} \tag{13}$$

Parameter $\boldsymbol{BBTM}_{nj}$ identifies an active back-to-back multiplexer on DS1 line *j* at node *n*. The logic used is given in equation 14. An one indicates that an back-to-back multiplexer should be placed on line j at node n; a zero means no back-to-back multiplexer should be used.

$$\boldsymbol{BBTM}_{nj} = \begin{cases} 1, & \text{if } \sum_i \boldsymbol{TMF_{nij}} = 2; \\ & \text{or} \\ & \sum_i \boldsymbol{DIMF_{nij}} = 1 \text{ and } \sum_i \boldsymbol{TMF_{nij}} = 1; \\ & \text{or} \\ & \boldsymbol{PASSING_{nj}} = 1 \text{ and } \sum_i \boldsymbol{DIMF_{nij}} = 0 \text{ and } \sum_i \boldsymbol{TMF_{nij}} = 1; \\ 0, & \text{otherwise.} \end{cases} \tag{14}$$

The logic used to identify an active terminal multiplexer on arc *i*, DS1 line *j* at node *n* requires two steps. The first step, equation (15), identifies that a terminal multiplexer is used on DS1 line *j* at node *n*. A value of one for post-optimization variable $\boldsymbol{TMP}_{nj}$ indicates that a terminal multiplexer should be used on DS1 line *j* at node *n*; a zero indicates otherwise.

$$\boldsymbol{TMP}_{nj} = \begin{cases} 1, & \text{if } \boldsymbol{PASSING_{nj}} = 0 \text{ and } \sum_i \boldsymbol{DIMF_{nij}} = 0 \text{ and } \sum_i \boldsymbol{TMF_{nij}} = 1; \\ & \text{or} \\ & \boldsymbol{PASSING_{nj}} = 0 \text{ and } \sum_i \boldsymbol{DIMF_{nij}} = 1 \text{ and } \sum_i \boldsymbol{TMF_{nij}} = 0; \\ 0, & \text{otherwise.} \end{cases} \tag{15}$$

The second step, equation (16), identifies the arc to which the terminal multiplexer is connected. A value of one for parameter $\boldsymbol{TM}_{nij}$ indicates a terminal multiplexer should be placed on arc *i*, DS1 line *j* at node *n*; a zero means that no TM is used.

$$\boldsymbol{TM_{nij}} = \begin{cases} 1, & \text{if } \boldsymbol{TMP_{nj}} = 1 \text{ and } \boldsymbol{DIMF_{nij}} = 1; \\ & \text{or} \\ & \boldsymbol{TMP_{nj}} = 1 \text{ and } \boldsymbol{TMFnij} = 1; \\ 0, & \text{otherwise.} \end{cases} \tag{16}$$

3.2.5.3 Output Parameters

To create the assignment charts which identify the channel assignments for each arc-DS1 line at each node, it is necessary to generate two parameters, one for the residual demands and one for the full DS1 demands. Parameter $USEDRESID_{nijkl}$ generates the output listing of all the DS0 channel assignments for the residual demands and is given by equation (17).

$$USEDRESID_{nijkl} = \boldsymbol{X_{lijk}} \cap NODES_n \tag{17}$$

An output listing must also be generated for the full-DS1 lines. Parameter $USEDFULL_{nijl}$ is generates all the DS1 line assignments for each node and is given by Equation (18).

$$USEDFULL_{nijl} = \boldsymbol{Y_{lij}} \cap NODES_n \tag{18}$$

3.2.5.4 Computational Results

Several different problmes were applied to Model 3. Three problems were chosen to illustrate the equipment selection process. The data for these problems is given in Table 15.

Table 15: Data Sets Applied to Model 3

Problem	**1**	**2**	**3**
Demand (DS0)			
OD01	4	8	6
OD02	12	24	18
OD03	4	8	6
OD04	4	8	6
OD05	4	8	6
OD06	4	8	4
Arc capacity (DS1)			
A01	3	6	5
A02	3	6	5
A03	3	6	4
A04	2	4	3
A05	2	4	3

Shown next are the computational results from the processing of Model 3 for different problems applied to the hypothetical network. Table 16 compares the results from the different problems. The objetive value represents the number of DS1 lines that are used to add and drop DS0 channels in the hypothetical network.

Table 16: Computational Results for Hypothetical Network

Problem	**1**	**2**	**3**
Objective value	-2	0	-3
Iteration count	326	19	679
Optimal solution	YES	YES	YES
Number of add-drop multiplexers	1	0	1
Number of back-to-back multiplexers	0	0	1
Number of terminal multiplexers (*)	1	0	1
CPU run-time in CPLEX	0.117 sec	0.017 sec	0.233 sec

(*) Terminal multiplexers for full DS1 lines for same OD not included since full DS1 OD demands use TMs at their respective end nodes when these are add-drop nodes.

3.2.5.5 Interesting Aspects

It would be possible to assume that the doubling of the demand and capacity of the hypothetical network would simply require the doubling of the equipment previously selected for each node. The results above show that this assumption is not necessarily correct. Consider problem 1 and problem 2: both demand and arc capacity were doubled for problem 2 with respect to problem 1. The assumption that doubling the demands and capacities would require the doubling the equipment proves to be wrong. The results from Table 16 show this clearly. In fact, only repeaters and terminal multiplexers for full DS1 lines are required.

The model was verified manually for the different problems and proved to be precise. It was then applied to the Arizona network as described in the following chapter.

A listing of the GAMS version of Model 3 is given in Appendix B, along with its solution of the hypothetical network for problem 1. The channel assignment charts for problem 3 of the hypothetical network are given in Table 17. The Node Channel Assignment Charts give the DS0 channel assignments for each Arc-DS1 line arriving at the specific node. The nodes connected to the same arc, DS1 are shown side by side for verification of assignment consistency.

Table 17: Full Assignment Charts for Problem 3 - Hypothetical Model 3

Assignment Chart	
Node=**N01**, Arc=**A01**, DS1=**R01**	
DS0 Channel	Origin-Destination
C01	
C02	OD02
C03	
C04	
C05	OD01
C06	OD01
C07	
C08	OD01

Assignment Chart	
Node=**N02**, Arc=**A01**, DS1=**R01**	
DS0 Channel	Origin-Destination
C01	
C02	OD02
C03	
C04	
C05	OD01
C06	OD01
C07	
C08	OD01

Assignment Chart	
Node=**N01**, Arc=**A01**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	OD02
C06	OD01
C07	OD01
C08	OD01

Assignment Chart	
Node=**N02**, Arc=**A01**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	OD02
C06	OD01
C07	OD01
C08	OD01

Assignment Chart

Node=**N02**, Arc=**A02**, DS1=**R01**

DS0 Channel	Origin-Destination
C01	
C02	OD02
C03	
C04	
C05	OD01
C06	OD01
C07	
C08	OD01

Assignment Chart

Node=**N03**, Arc=**A02**, DS1=**R01**

DS0 Channel	Origin-Destination
C01	
C02	OD02
C03	
C04	
C05	OD01
C06	OD01
C07	
C08	OD01

Assignment Chart

Node=**N02**, Arc=**A02**, DS1=**R02**

DS0 Channel	Origin-Destination
C01	OD04
C02	OD04
C03	OD03
C04	OD04
C05	OD03
C06	OD03
C07	OD03
C08	OD03

Assignment Chart

Node=**N03**, Arc=**A02**, DS1=**R02**

DS0 Channel	Origin-Destination
C01	OD04
C02	OD04
C03	OD03
C04	OD04
C05	OD03
C06	OD03
C07	OD03
C08	OD03

Assignment Chart

Node=**N02**, Arc=**A02**, DS1=**R03**

DS0 Channel	Origin-Destination
C01	OD04
C02	OD04
C03	OD04
C04	OD03
C05	OD02
C06	OD01
C07	OD01
C08	OD01

Assignment Chart

Node=**N03**, Arc=**A02**, DS1=**R03**

DS0 Channel	Origin-Destination
C01	OD04
C02	OD04
C03	OD04
C04	OD03
C05	OD02
C06	OD01
C07	OD01
C08	OD01

Assignment Chart

Node=**N03**, Arc=**A03**, DS1=**R01**

DS0 Channel	Origin-Destination
C01	OD01
C02	OD01
C03	
C04	OD01
C05	OD01
C06	OD01
C07	
C08	

Assignment Chart

Node=**N04**, Arc=**A03**, DS1=**R01**

DS0 Channel	Origin-Destination
C01	OD01
C02	OD01
C03	
C04	OD01
C05	OD01
C06	OD01
C07	
C08	

Assignment Chart

Node=**N03**, Arc=**A03**, DS1=**R02**

DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	
C06	OD05
C07	OD05
C08	OD05

Assignment Chart

Node=**N04**, Arc=**A03**, DS1=**R02**

DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	
C06	OD05
C07	OD05
C08	OD05

Assignment Chart

Node=**N03**, Arc=**A03**, DS1=**R03**

DS0 Channel	Origin-Destination
C01	OD05
C02	OD05
C03	OD05
C04	
C05	
C06	
C07	
C08	

Assignment Chart

Node=**N04**, Arc=**A03**, DS1=**R03**

DS0 Channel	Origin-Destination
C01	OD05
C02	OD05
C03	OD05
C04	
C05	
C06	
C07	
C08	

Assignment Chart	
Node=**N03**, Arc=**A03**, DS1=**R04**	
DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	
C06	
C07	OD01
C08	

Assignment Chart	
Node=**N04**, Arc=**A03**, DS1=**R04**	
DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	
C06	
C07	OD01
C08	

Assignment Chart	
Node=**N03**, Arc=**A04**, DS1=**R01**	
DS0 Channel	Origin-Destination
C01	OD05
C02	OD05
C03	OD05
C04	OD05
C05	OD05
C06	
C07	
C08	

Assignment Chart	
Node=**N05**, Arc=**A04**, DS1=**R01**	
DS0 Channel	Origin-Destination
C01	OD05
C02	OD05
C03	OD05
C04	OD05
C05	OD05
C06	
C07	
C08	

Assignment Chart	
Node=**N03**, Arc=**A04**, DS1=**R02**	
DS0 Channel	Origin-Destination
C01	
C02	OD03
C03	OD03
C04	OD03
C05	
C06	OD05
C07	OD03
C08	

Assignment Chart	
Node=**N05**, Arc=**A04**, DS1=**R02**	
DS0 Channel	Origin-Destination
C01	
C02	OD03
C03	OD03
C04	OD03
C05	
C06	OD05
C07	OD03
C08	

Assignment Chart	
Node=**N03**, Arc=**A04**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	OD04
C02	OD04
C03	OD04
C04	OD04
C05	OD04
C06	OD04
C07	OD03
C08	OD03

Assignment Chart	
Node=**N05**, Arc=**A04**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	OD04
C02	OD04
C03	OD04
C04	OD04
C05	OD04
C06	OD04
C07	OD03
C08	OD03

Assignment Chart	
Node=**N05**, Arc=**A05**, DS1=**R01**	
DS0 Channel	Origin-Destination
C01	OD05
C02	OD05
C03	OD05
C04	OD05
C05	OD05
C06	
C07	
C08	

Assignment Chart	
Node=**N06**, Arc=**A05**, DS1=**R01**	
DS0 Channel	Origin-Destination
C01	OD05
C02	OD05
C03	OD05
C04	OD05
C05	OD05
C06	
C07	
C08	

Assignment Chart	
Node=**N05**, Arc=**A05**, DS1=**R02**	
DS0 Channel	Origin-Destination
C01	
C02	OD03
C03	OD03
C04	OD03
C05	
C06	OD05
C07	OD03
C08	

Assignment Chart	
Node=**N06**, Arc=**A05**, DS1=**R02**	
DS0 Channel	Origin-Destination
C01	
C02	OD03
C03	OD03
C04	OD03
C05	
C06	OD05
C07	OD03
C08	

Assignment Chart	
Node=**N05**, Arc=**A05**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	OD06
C02	OD06
C03	OD06
C04	
C05	OD06
C06	
C07	OD03
C08	OD03

Assignment Chart	
Node=**N06**, Arc=**A05**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	OD06
C02	OD06
C03	OD06
C04	
C05	OD06
C06	
C07	OD03
C08	OD03

The output from Model 3 in GAMS can also be used to generate the OD Path Assignment Charts, given in Table 18, which permit the verification of all assignments given by origin-destination.

Table 18: OD Path Assignment Charts for Problem 3 - Hypothetical Model 3

Origin-destination	**PATH**								
	Arc	**DS1**	**DS0**	**Arc**	**DS1**	**DS0**	**Arc**	**DS1**	**DS0**
OD01	A01	R01	C05	A02	R01	C05	A03	R01	C01
OD01	A01	R01	C06	A02	R01	C06	A03	R01	C02
OD01	A01	R01	C08	A02	R01	C08	A03	R01	C04
OD01	A01	R03	C06	A02	R03	C06	A03	R01	C05
OD01	A01	R03	C07	A02	R03	C07	A03	R01	C06
OD01	A01	R03	C08	A02	R03	C08	A03	R04	C07
OD02	A01	R01	C02	A02	R01	C02			
OD02	A01	R03	C05	A02	R03	C05			
OD02	A01	R04	**All**	A02	R04	**All**			
OD02	A01	R05	**All**	A02	R05	**All**			

Origin-destination	**PATH**								
	Arc	**DS1**	**DS0**	**Arc**	**DS1**	**DS0**	**Arc**	**DS1**	**DS0**
OD03	A02	R02	C03	A04	R02	C02	A05	R02	C02
OD03	A02	R02	C05	A04	R02	C03	A05	R02	C03
OD03	A02	R02	C06	A04	R02	C04	A05	R02	C04
OD03	A02	R02	C07	A04	R02	C07	A05	R02	C07
OD03	A02	R02	C08	A04	R03	C07	A05	R03	C07
OD03	A02	R03	C04	A04	R03	C08	A05	R03	C08
OD04	A02	R02	C01	A04	R03	C01			
OD04	A02	R02	C02	A04	R03	C02			
OD04	A02	R02	C04	A04	R03	C03			
OD04	A02	R03	C01	A04	R03	C04			
OD04	A02	R03	C02	A04	R03	C05			
OD04	A02	R03	C03	A04	R03	C06			
OD05	A03	R02	C06	A04	R01	C01	A05	R01	C01
OD05	A03	R02	C07	A04	R01	C02	A05	R01	C02
OD05	A03	R02	C08	A04	R01	C03	A05	R01	C03
OD05	A03	R03	C01	A04	R01	C04	A05	R01	C04
OD05	A03	R03	C02	A04	R01	C05	A05	R01	C05
OD05	A03	R03	C03	A04	R02	C06	A05	R02	C06
OD06	A05	R03	C01						
OD06	A05	R03	C02						
OD06	A05	R03	C03						
OD06	A05	R03	C05						

Note that for OD 2 the word “**ALL**” appears in the DS0 columns, indicating that all channels in the DS1 line are used for that OD. In the specific case of OD 2, there are two full DS1 lines used. The remaining two DS0 demands are assigned to DS1 line R01, channel C02, and DS1 line R03, channel C05, on both arcs A01 and A02.

4. SOLVING THE ARIZONA NETWORK

Applying Model 3 to the Arizona network to resulted in long processing times. Figure 18 illustrates the steps of the processing steps required for Model 3. A fourth, decomposition model was developed to achieve computational speed and provide a proven optimal solution for the Arizona network. To achieve these goals, Model 3 was decomposed into two sub-models referred to as Model 3A and Model 3B. Model 3B was processed individually for each add-drop node or group of adjacent add-drop nodes. Figure 19 illustrates the steps of the multiple processing using models 3A and 3B.

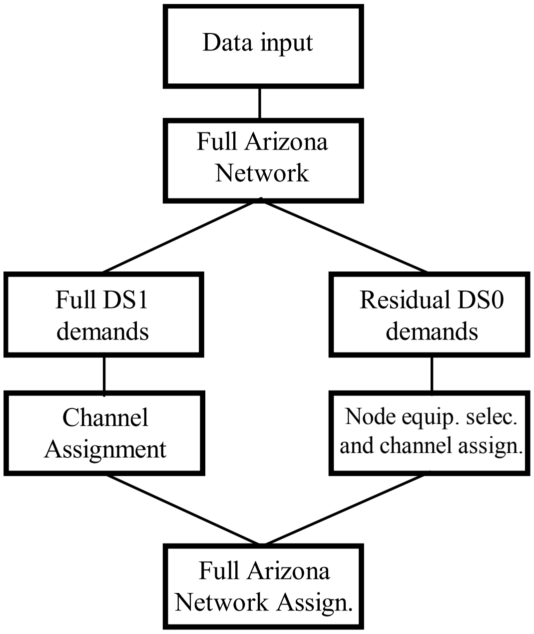

Figure 18: Model 3 Processing Steps

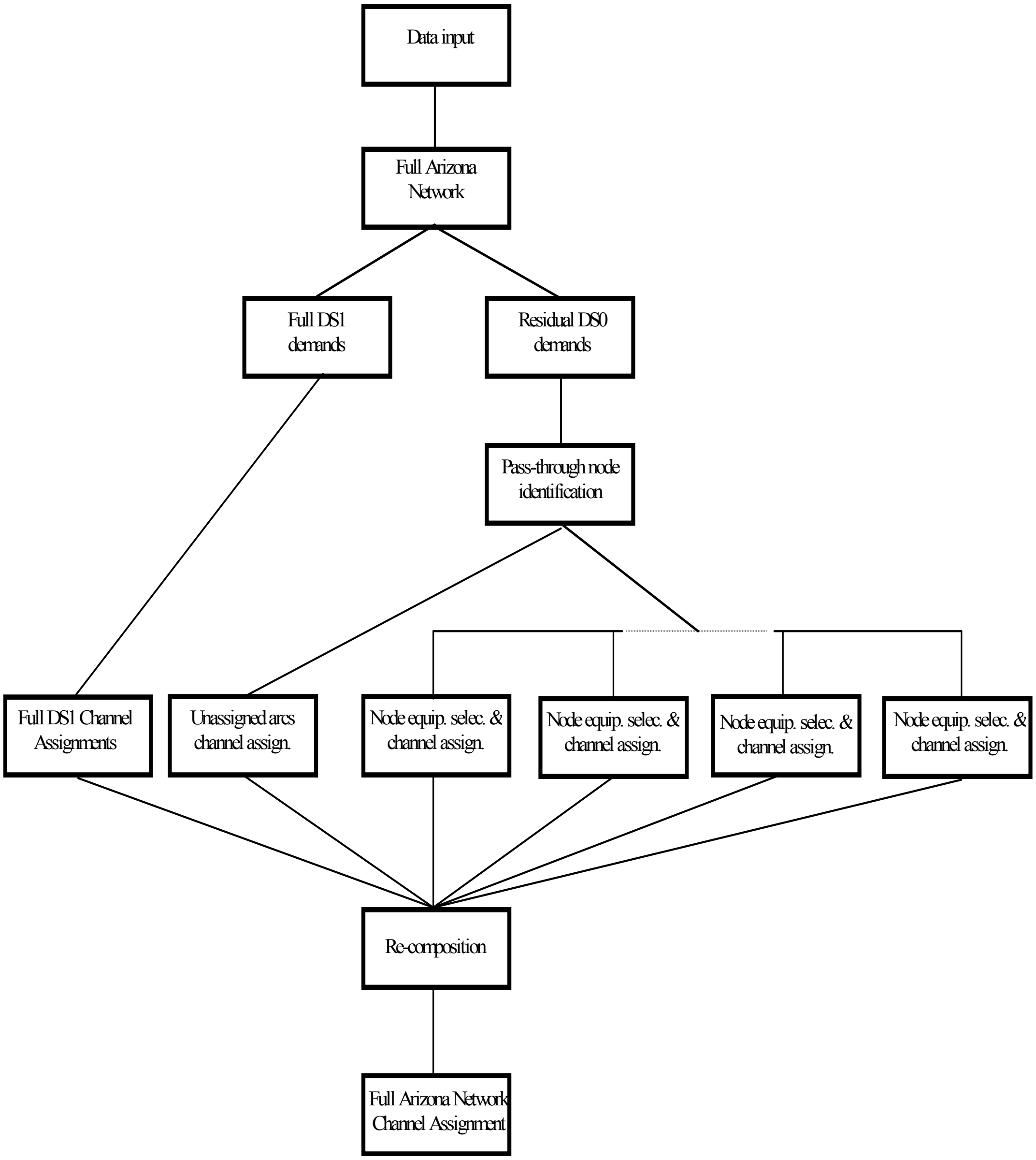

Figure 19: Decomposition Model's Processing Steps

4.1 Notation and Conventions

The following sets are defined to achieve the specific characteristics required by each model.

ADI: set of arcs that connect to add-drop nodes

$$ADI = \begin{cases} 1, & \text{if } \sum_{n \in AD} NODES_n \geq 1; \\ 0, & \text{otherwise.} \end{cases}$$

NOTADI: set of arcs that do not connect to add-drop nodes.

$$NOTADI = \begin{cases} 1, & \text{if } \sum_{n \in AD} NODES_n = 0; \\ 0, & \text{otherwise.} \end{cases}$$

Equation 1

4.2 Model 3A

Model 3A takes the form of a multicommodity assignment problem, in which each OD demand is a separate commodity and there are no restrictions on channel assignment other than that only one DS0 channel can be assigned to each OD unit of demand..

The model accomplishes the following tasks:

- Separates full DS1 demand from total demand.
- Identifies add-drop nodes.
- Assigns full DS1 demand units to DS1 lines on all valid arcs for each OD.
- Assigns residual DS0 demand units to residual DS1 lines on all arcs that do not connect to add-drop nodes and that are valid for each OD

4.2.1 Mathematical Formulation

Model 3A is identical to Model 1 except for the sets that constrain the search space for the residual demands. Set *NOTADI* limits the valid ***X*** variables to those arcs that do not connect to add-drop nodes. The ***Y*** variables are unchanged and the model remains a simple assignment problem.

$$\text{Minimize } \sum_{l}\sum_{i}\sum_{j} Ylij \tag{19}$$

For each OD, the required number of residual demand units are assigned to the DS0 channels on the residual DS1 lines on each arc that does not connect to add-drop nodes necessary to complete the OD path. Equation (20) assigns one DS1 line's residual DS0 channel on each of these arcs for each unit of residual demand for each OD.

$$\sum_{j \in ARCCAP2i \text{ and } k \in K} \boldsymbol{X}_{lijk} = \text{RESIDUAL}_l,\ \forall\ l \in \text{L, and } \forall\ i \in D_l \mid i \in NOTADI \tag{20}$$

The multicommodity constraint, equation (21) limits the assignment to only one unit of residual demand to each DS1-DS0 channel on each arc of the network.

$$\sum_{l \in L} \boldsymbol{X}_{lijk} \leq 1,\ \forall\ i \in I \mid i \in NOTADI, j \in ARCCAP2_i,\ k \in K \tag{21}$$

For each OD with one or more full DS1 demands, the required number of DS1 lines to meet these demands are assigned to the full DS1 lines on each arc necessary to complete the OD path. Equation (22) assigns one full DS1 line on each arc for each unit of full DS1 demand for each OD.

$$\sum_{j \in ARCCAP3i} \boldsymbol{Y}_{lij} = \text{REDUDS1}_l, \; \forall \; l \in FULLOD, \; i \in D_l \tag{22}$$

The multicommodity constraint, equation (23), limits the assignment to only one unit of full DS1 demand to each DS1 line on each arc of the network.

$$\sum_{l \in FULLOD} \boldsymbol{Y}_{lij} \leq 1, \quad \forall \; i \in I, j \in ARCCAP3_i \tag{23}$$

In order to process Model 3B, it is required to know which nodes are add-drop nodes or adjacent add-drop nodes. Model 3A computes set *AD* , which contains the add-drop nodes.

4.3 Model 3B

Model 3B is identical to Model 3 except for the sets that constrain the search space for the residual demands and the fact that no full-DS1 assignments are made. Set ADI limits the included ***X*** variables to those arcs that connect to add-drop nodes. The full-DS1 demands and the residual demands for arcs that do not connect to add-drop nodes are not evaluated since they are solved by Model 3A. The elements of set *AD* must be entered individually (for each add-drop node or group of adjacent add-drop nodes) during processing. Model 3B accomplishes the following tasks:

- Evaluates each add-drop node individually or in groups of adjacent nodes.
- Adds a channel consistency constraint to all residual DS0 demands that do not drop and/or add at the specific add-drop node or group of adjacent nodes.
- Assigns residual DS0 demand units to residual DS1 lines on the arcs connected to individual add-drop node or group of adjacent add-drop nodes for each relevant OD.

- Minimizes number of residual DS1 lines used at the add-drop node(s) to drop and/or add DS0s.
- Selects equipment for individual add-drop node or group of adjacent nodes.

4.3.1 Mathematical Formulation

This model minimizes the number of DS1 lines used to add and/or drop DS0 channels at the specific node or group of adjacent nodes. Channel consistency must be applied to the residual demands that pass through the node or group of adjacent nodes. The basic difference between Model 3, described in chapter 3, and Model 3B is the universe of valid variables, which are restricted in 3B to only the variables for the residual demands on arcs that connect to add-drop nodes. The objective function is shown in equation (24).

$$\text{Minimize} \sum_{n \in AD} \sum_{j \in NODECAPn} \boldsymbol{DS1}_{nj} \tag{24}$$

For each OD, the required number of residual demand units are assigned to the DS0 channels on the residual DS1 lines on each arc that is connected to add-drop nodes necessary to complete the OD path. Equation (25) assigns one residual DS1 line-DS0 channel on each of these arcs for each unit of residual demand for each OD.

$$\sum_{j \in ARCCAP2i \;\; and \;\; k \in K} \boldsymbol{X}_{lijk} = \text{RESIDUAL}_l, \ \forall \ l \in \text{L, and } \forall \ i \in D_l \mid i \in ADI \tag{25}$$

The multicommodity constraint, equation (26), limits the assignment to only one unit of residual demand to each DS1-DS0 channel on each arc that connects to an add-drop node of the network.

$$\sum_{l \in L} \boldsymbol{X}_{lijk} \leq 1, \forall\ i \in I \mid i \in ADI, j \in ARCCAP2_{i},\ k \in K \qquad (26)$$

Channel consistency is achieved by assigning the same DS1 line-DS0 channel combination to both arcs of the add-drop node for each unit of residual demand that passes through the node. Note that set *AD* is an additional constraint added to the valid search region in equation (27).

$$\sum_{i \in NODESn} \boldsymbol{X}_{lijk} = 2\boldsymbol{W}_{nljk}, \quad n \in AD, l \in PASSTHRU_{n}, j \in NODECAP_{n}, k \in K \quad (27)$$

The $\boldsymbol{DS1}_{nj}$ variable is used in equation (28) to identify the DS1 line pairs that actually add and/or drop DS0 channels at the node.

$$\sum_{l \in DROPn} \sum_{i \in NODESn} \sum_{k \in K} \boldsymbol{X}_{lijk} \leq 48\boldsymbol{DS1}_{nj}, \quad n \in AD, j \in NODECAP_{n} (28)$$

The equipment selection process is the same as in Model 3, that is, a function of the number of DS0 channels added or dropped by each pair of DS1 lines at a add-drop node. The variable $\boldsymbol{ACCESS}_{nij}$, determined by equation (29), identifies the number of DS0 channels that are added and/or dropped by each DS1 line at the node specified by set *AD*. At most two variables for each same number DS1 line at each node are generated (i.e., DS1 line R2, which passes through the node will result in two $\boldsymbol{ACCESS}_{nij}$ variables, one for each arc that connects to the node).

$$\sum_{l \in DROPn} \sum_{k \in K} \boldsymbol{X}_{lijk} = \boldsymbol{ACCESS}_{nij}, \quad n \in AD, j \in NODECAP_{n}, i \in NODES_{n} \ (29)$$

4.3.2 Equipment Selection Logic

The equipment selection logic parameters are identical to those in Model 3, and it is illustrated in Table 14 and described in chapter 3.

4.4 Model Re-Composition

The solution to the full Arizona Network required one processing of Model 3A and nine applications of Model 3B. Set AD identified the add-drop nodes for the Arizona Network and Model 3B was used to process individually each add-drop node or group of adjacent add-drop nodes. The identified add-drop nodes were: N04, N05, N08, N10, N13, N17, N23, N28, N29 and N34. Nodes N04 and N05 were processed together because they are adjacent add-drop nodes.

The assignment outputs parameters USEDRESID_{nijkl} and USEDFULL_{nijl} from Model 3A and the nine processing's of Model 3B were compiled in a spreadsheet and sorted by node, arc, DS1 line and DS0 channel to generate the arc-DS1 line-DS0 channel-OD assignment listing for each node of the complete network. In the case of the full DS1 demands only the DS1 lines were assigned. This was done in order to minimize the size of the assignment listing, since the assumption was that channel consistency was maintained at each node for these DS1 lines. Appendix B gives the compiled assignments for the full Arizona Network.

4.4.1 Computational Results

Computational time was relatively short for both Model 3A and Model 3B, once proper node selection strategy for each add-drop node was implemented. Using the default CPLEX node-selection rule, best-bound search, some of the subproblems did not solve quickly. Actually a couple of nodes were processed for over an hour without reaching the solution. The two other node selection strategies available in CPLEX are depth-first search and best-estimate search. The best solution times resulted from using the depth-first search. Each add-drop node, or group of adjacent add-drop nodes, was processed in 25 seconds or less and a proven optimal solution was found.

A summary of the computational results of the equipment selection process for all add-drop nodes of the Arizona network is given in Table 19 shown below. CPU processing times, in CPLEX, for the subproblems averaged 7.14 seconds, and the total of all times was 64.22 seconds.

Table 19: Equipment Selection Summary

NODE(S)	**N04&N05**	**N08**	**N10**	**N13**	**N17**	**N23**	**N28**	**N29**	**N34**
Objective value	1	1	1	1	1	1	1	1	1
Processing time (seconds)	14.550	0.017	3.400	0.400	23.267	0.100	0.133	5.433	16.917
Iteration count	11315	10	1244	718	10228	114	229	929	7788
Optimal solution	YES	YES	YES	YES	YES	YES	YES	YES	YES
Number of add-drop multiplexers	1	0	1	1	0	1	1	0	1
Number of back-to-back multiplexers	0	0	0	0	1	0	0	0	0
Number of terminal multiplexers (*)	0	1	0	0	0	0	0	1	0
Node & DS1 Line	N04.R02	N08.R01	N10.R06	N13.R03	N17.R05	N23.R02	N28.R01	N29.R10	N34.R03

4.4.2 Assignment Charts

The four assignment charts resulting from the processing of Node N13 are given below in Table 20 to Table 22. It is important to note that the processing of node N13 results in DS0 assignments for nodes N12 and N14, but only for the arc-DS1 lines carrying residual demands for the ODs that pass through, originate, or terminate at node N13. The blank spaces indicate unused DS0 channels.

The DS0 channel assignments for arc A13-DS1 R03, which is connected to Node N12, is given in Table 20. Node N12 is a DACS and the remaining DS0 channel assignments are generated by Model 3A and/or Model 3B processing of other add-drop nodes that connect to node N12.

Table 20: Node N12 Assignment Chart for Arc A13- DS1 R03

Assignment Chart	
Node=**N12**, Arc=**A13**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	
C02	OD20
C03	OD20
C04	OD20
C05	OD20
C06	OD20
C07	OD20
C08	OD20
C09	OD20
C10	
C11	
C12	
C13	OD20
C14	
C15	OD22
C16	OD22
C17	OD22
C18	OD23
C19	OD22
C20	OD22
C21	OD22
C22	OD22
C23	OD22
C24	OD22

Node N13 is an add-drop node. The assignment charts for node N13, Table 21, are shown side by side in order to facilitate the viewing of the added DS0 channels for OD20 and the channel consistency of the pass-through demands for OD22 and OD23.

Table 21: Node N13 Assignment Chart for Arc A13-DS1 R03 and Arc A14-DS1 R03

Assignment Chart	
Node=**N13**, Arc=**A13**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	
C02	OD20
C03	OD20
C04	OD20
C05	OD20
C06	OD20
C07	OD20
C08	OD20
C09	OD20
C10	
C11	
C12	
C13	OD20
C14	
C15	OD22
C16	OD22
C17	OD22
C18	OD23
C19	OD22
C20	OD22
C21	OD22
C22	OD22
C23	OD22
C24	OD22

Assignment Chart	
Node=**N13**, Arc=**A14**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	
C06	
C07	
C08	
C09	
C10	
C11	
C12	
C13	
C14	
C15	OD22
C16	OD22
C17	OD22
C18	OD23
C19	OD22
C20	OD22
C21	OD22
C22	OD22
C23	OD22
C24	OD22

Node N14 is an end node, thus a terminal multiplexer is automatically selected. The assignment chart for Arc A14-DS1 R03, connected to node N14, is given in Table 22.

Table 22: Node N14 Assignment Chart for Arc A14-DS1 R03

Assignment Chart	
Node=**N14**, Arc=**A14**, DS1=**R03**	
DS0 Channel	Origin-Destination
C01	
C02	
C03	
C04	
C05	
C06	
C07	
C08	
C09	
C10	
C11	
C12	
C13	
C14	
C15	OD22
C16	OD22
C17	OD22
C18	OD23
C19	OD22
C20	OD22
C21	OD22
C22	OD22
C23	OD22
C24	OD22

4.5 Conclusions

The goal of this praxis was to develop a series of models to address and optimize the channel assignment and node terminal equipment selection problem for forecasted demands between nodes in a telecommunications network. A key element was the maintenance of channel consistency within certain parts of the system. The experimentation with different mixed integer programming models resulted in the selection of Models 3A and 3B as the combination that insured implementability and solvability with a dramatic reduction of time in the channel assignment and equipment selection processes over models 1, 2, and 3. Total actual processing time was 89.618 seconds. The detailed processing time for each node or group of adjacent nodes is given in Table 23.

Table 23: Actual Processing Time for the Arizona Network

	Model 3B									Model 3A
ACTIVITY					**NODES**					
	N04&N05	**N08**	**N10**	**N13**	**N17**	**N23**	**N28**	**N29**	**N34**	**Full&Not AD**
Model Generation Time	0.367	0.017	0.667	0.067	0.367	0.050	0.067	0.950	0.383	1.283
Model Execution Time	0.983	0.633	1.317	0.700	1.000	0.700	0.700	1.583	1.017	1.917
Model Solve Time	14.550	0.017	3.400	0.400	23.267	0.100	0.133	5.433	16.917	1.783
Model Output Execution Time	0.683	0.400	0.967	0.467	0.817	0.483	0.517	1.083	0.750	2.683
Sub-total	16.583	1.067	6.351	1.634	25.451	1.333	1.417	9.049	19.067	7.666
Total Processing Time	**89.618**	**Seconds**				AD = add/drop nodes				

These times reflect CPU processing time and do not include the time spent manually inserting the node constraint in the Model 3B GAMS program. It maybepossible to automate this process. Compilation time and assignment chart generation varies with the sophistication of the report desired. The assignment output is a simple *.txt* type file that can be imported into a spreadsheet for manipulation and formatting. The spreadsheet software used in this praxis was the Microsoft Excel 5.0.

The GAMS version of Model 3A for the Arizona Network is shown in Appendix C, and the GAMS version of Model 3B for node N10 of the Arizona Network is shown in Appendix D.

5. ENHANCEMENTS, FUTURE DEVELOPMENTS, AND CONCLUSION

This chapter shows how flexibility can be added to the equipment selection process and suggests enhancements that can be made to the basic model. The potential for future developments is also discussed.

5.1 Enhancements to the Model

The basic model, Model 3, can be further expanded by implementing more user-defined parameters, increasing design control and further enhancing the ability to implement customer preferences. The minimized output of Model 3 (i.e., positive ***X*** and ***Y*** values only) can be manipulated in various ways in order to achieve differentiated equipment-selection results. This is done by modifying the equations and logic used in the generation the equipment-selection output parameters.

5.1.1 Model 4

Increase in design flexibility is a desirable goal that has been considered. Model 4 was developed to increase design flexibility of Model 3's equipment selection process (the GAMS version applied to the hypothetical network is given in Appendix E and the output for Model 4 applied to node 17 of the Arizona network is given in Appendix F). Models 3 and 4 differ only in the post-optimization processing (those statements following the SOLVE statement in the GAMS model).

Post-optimization variable $\boldsymbol{DIMF}_{nij}$ was modified to include a deviation factor, scalar DEV, in the ADMMAX calculation; this allows the number of adds or drops at a node to be greater than half of scalar ADMLIMIT. It must be noted that, when more than half of the number of allowed add-drops are used, DS0 channels are left unused on the paired DS1 line. The number of unused DS0 channels created by addas and drops is equal to the value of scalar DEV. An additional constraint is required to insure that the maximum permitted number of add/drops is not exceeded. This is achieved by adding another factor to the logic used to activate $\boldsymbol{DIM}_{nj}$ (i.e., $\sum_{i} \boldsymbol{ACCESS}_{nij} \leq \text{ADMLIMIT}$).

The value for scalar ADMLIMIT in the hypothetical network was arbitrarily chosen to be ten, in order to maintain the same proportionality of the real equipment used in the Arizona network. The effect on the equipment selection space, using a value of one for DEV, is illustrated in Figure 20. DEV can have values that vary from zero to the difference between full DS1 line capacity and scalar ADMMAX, thus enhancing design flexibility to better meet customer preferences. Specifying a value of zero for DEV results in the same equipment selection that was provided by Model 3.

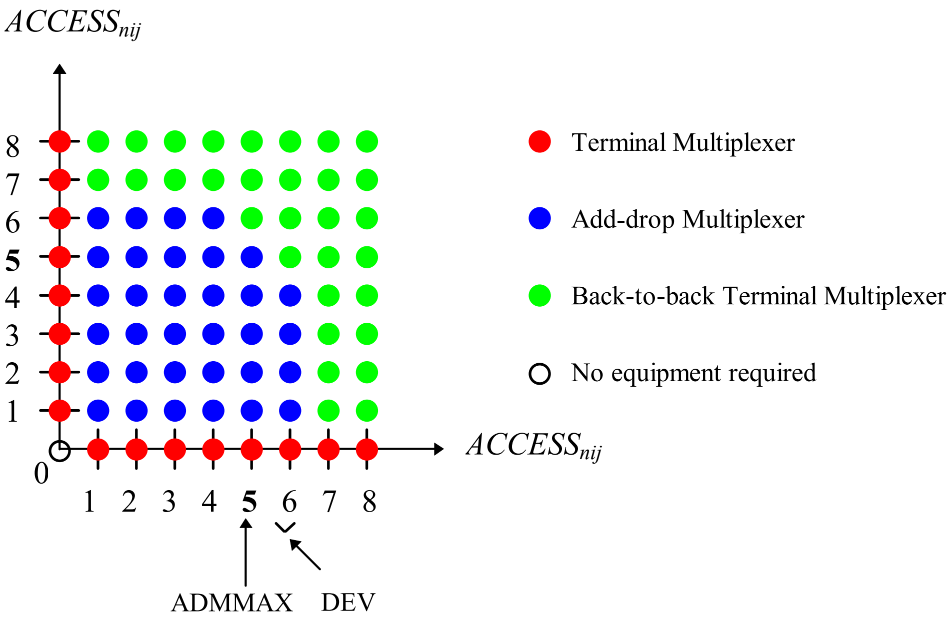

Figure 20: Expanded Flexibility Equipment Selection Space

As can be observed in Figure 20, if any variable $\boldsymbol{ACCESS}_{nij}$ for a DS1 line is positive, then some type of terminal equipment must be used. If the value of variable $\boldsymbol{ACCESS}_{nij}$ is greater than (ADMMAX + DEV), then terminal multiplexer requirements are met for the specific DS1 line, however, there is a region which requires additional logic to properly select the terminal equipment as will be described later in this chapter.

If the value of variable $\boldsymbol{ACCESS}_{nij}$ is positive and less than (ADMMAX + DEV), then add-drop multiplexer requirements are met for the specific DS1 line. Equation (49) is used to determine whether add-drop multiplexer requirements are met at node *n*, arc *i*, DS1 line *j*. Post-optimization variable $\boldsymbol{DIMF}_{nij}$ has a value of one when this requirement is met, and zero otherwise.

$$\boldsymbol{DIMF}_{nij} = \begin{cases} 1, & \text{if } 0 < \boldsymbol{ACCESS}_{nij} \leq \text{ADMMAX} + \text{DEV}; \\ 0, & \text{otherwise.} \end{cases} \tag{49}$$

Equation (50) is used to determine whether terminal multiplexer requirements are met at node *n*, arc *i*, DS1 line *j*. Post-optimization variable $\boldsymbol{TMF}_{nij}$'s value is one when this requirement is met, and zero otherwise.

$$\boldsymbol{TMF}_{nij} = \begin{cases} 1, & \text{if } \boldsymbol{ACCESS}_{nij} > \text{ADMMAX}; \\ 0, & \text{otherwise.} \end{cases} \tag{50}$$

Table 24 shows when the post-optimization variables $\boldsymbol{DIMF}_{nij}$ and $\boldsymbol{TMF}_{nij}$ are activated (i.e., parameters meet requirements for connection respectively to an ADM and a TM) as a function of the value of variable $\boldsymbol{ACCESS}_{nij}$ in order for equations (49) and (50) to be consistent. Post-optimization variables $\boldsymbol{DIMF}_{nij}$ and $\boldsymbol{TMF}_{nij}$ are binary, with one representing an activate state and zero an inactive state. It must be noted that when $\boldsymbol{ACCESS}_{nij}$ has a value of six, both post-optimization variables $\boldsymbol{DIMF}_{nij}$ and $\boldsymbol{TMF}_{nij}$ are activated (both have a value of one). This is due to the inclusion of the deviation factor, scalar DEV, with a value of one.

Table 24: Activation of Post-Optimization Variables $\boldsymbol{DIMF}_{nij}$ and $\boldsymbol{TMF}_{nij}$ for Model 4

Value of $\boldsymbol{ACCESS}_{nij}$	Activated variable
0	None
1	$\boldsymbol{DIMF}_{nij}$
2	$\boldsymbol{DIMF}_{nij}$
3	$\boldsymbol{DIMF}_{nij}$
4	$\boldsymbol{DIMF}_{nij}$
5	$\boldsymbol{DIMF}_{nij}$
6	$\boldsymbol{DIM}_{nij}$ and $\boldsymbol{TMF}_{nij}$
7	$\boldsymbol{TMF}_{nij}$
8	$\boldsymbol{TMF}_{nij}$

As in the case of Model 3, to implement the logic decision process it was necessary to generate a parameter that identified whether the DS1 line was used by any origin-destination demands that passed through the node. The use of this parameter insured that a terminal multiplexer was not selected if the DS1 line had any pass-through OD traffic. Binary post-optimization variable $\boldsymbol{PASSING}_{nj}$ is set to one when DS1 line j is used by one or more pass-through ODs, as defined by equation (51); otherwise it is zero.

$$\boldsymbol{PASSING}_{nj} = \begin{cases} 1, & \text{if } \sum_{l}\sum_{k} \boldsymbol{W}_{\boldsymbol{nljk}} \geq 1; \\ 0, & \text{otherwise.} \end{cases} \tag{51}$$

Manipulation of parameters $\boldsymbol{DIMF}_{nij}$, $\boldsymbol{TMF}_{nij}$ and $\boldsymbol{PASSING}_{nj}$ are used to generate the equipment selection logic illustrated in Table 25. This table is divided into three groups of columns (separated by the thick lines) and the rows represent all possible combinations of values for $\boldsymbol{ACCESS}_{nij}$ and $\boldsymbol{PASSING}_{nj}$.

The first group of columns, entitled “VARIABLES,” contains all possible combinations of $\boldsymbol{ACCESS}_{nij}$ (i.e., for an arc pair, each arc here given an arbitrary identifying digit “1” and “2”, at node *n* for DS1 line *j*), the sum over arcs “1” and “2” of all adds and drops of DS1 line *j* at node *n* and the corresponding states for post-optimization variables $\boldsymbol{DIMF}_{nij}$ and $\boldsymbol{TMF}_{nij}$ for arcs “1” and “2.” Aside from the number of adds and drops there is another condition that influences the equipment selection: the existence or absence of pass-through ODs on the DS1 line. The next two column groups give the resulting equipment selection respectively for parameter $\boldsymbol{PASSING}_{nj} = 1$ and $\boldsymbol{PASSING}_{nj} = 0$. Post-optimizations variables $\boldsymbol{DIM}_{nj}$ and $\boldsymbol{TMP}_{nj}$ are dependent on the state of $\boldsymbol{PASSING}_{nj}$, but post-optimization variable $\boldsymbol{BBTM}_{\boldsymbol{n}j}$ is independent. When $\boldsymbol{PASSING}_{nj} = 1$, a single terminal multiplexer cannot be used; only add-drop multiplexer or back-to-back multiplexer can be used, because there are pass-through ODs on DS1 line *j*. Post-optimization variables $\boldsymbol{DIM}_{nj}$, $\boldsymbol{BBTM}_{nj}$, and $\boldsymbol{TMP}_{nj}$ are binary states (i.e., $\boldsymbol{DIM}_{nj} = 1$ when add-drop multiplexer is selected, $\boldsymbol{BBTM}_{nj} = 1$ when back-to-back terminal multiplexers are selected, $\boldsymbol{TMP}_{nj} = 1$ when single terminal multiplexer is selected; all are zero otherwise).

The equipment selection for post-optimization variable $\boldsymbol{PASSING}_{nj}$ equal to zero and equal to one are shown side by side to facilitate the visualization of the selection logic. The black regions indicate invalid conditions for post-optimization variable $\boldsymbol{PASSING}_{nj}$ equal one. [It is not possible to have ODs passing through a node on a particular DS1 line if it is fully used to add or drop DS0 channels (i.e., eight DS0 channels, in the case of the hypothetical network, and 24 DS0 channels in the case of the Arizona network)].

In order to emphasize the equipment selection states, blank spaces are used to represent zero in columns **DIMF 1**, **DIMF 2**, **TMF 1**, **TMF 2**, **DIM**, **BBTM**, and **TMP**. Selected equipment is represented by ‘1’.

Table 25: Equipment Selection Logic - Model 4

		VARIABLES					For *PASSINGnj* = 1				For *PASSINGnj* = 0			
ACCESS 1	DIMF 1	TMF1	ACCESS 2	DIMF 2	TMF 2	Sum ACCESS	Passing	DIM	BBTM	TMP	Passing	DIM	BBTM	TMP
0			0			0	1				0			
0			1	**1**		1	1	**1**			0			**1**
0			2	**1**		2	1	**1**			0			**1**
0			3	**1**		3	1	**1**			0			**1**
0			4	**1**		4	1	**1**			0			**1**
0			5	**1**		5	1	**1**			0			**1**
0			6	**1**	**1**	6	1	**1**			0			**1**
0			7		**1**	7	1		**1**		0			**1**
0			8		**1**	8	▨	▨	▨	▨	0			**1**
1	**1**		0			1	1	**1**			0			**1**
1	**1**		1	**1**		2	1	**1**			0	**1**		
1	**1**		2	**1**		3	1	**1**			0	**1**		
1	**1**		3	**1**		4	1	**1**			0	**1**		
1	**1**		4	**1**		5	1	**1**			0	**1**		
1	**1**		5	**1**		6	1	**1**			0	**1**		
1	**1**		6	**1**	**1**	7	1	**1**			0	**1**		
1	**1**		7		**1**	8	1		**1**		0		**1**	
1	**1**		8		**1**	9	▨	▨	▨	▨	0		**1**	
2	**1**		0			2	1	**1**			0			**1**
2	**1**		1	**1**		3	1	**1**			0	**1**		
2	**1**		2	**1**		4	1	**1**			0	**1**		
2	**1**		3	**1**		5	1	**1**			0	**1**		
2	**1**		4	**1**		6	1	**1**			0	**1**		
2	**1**		5	**1**		7	1	**1**			0	**1**		
2	**1**		6	**1**	**1**	8	1	**1**			0	**1**		
2	**1**		7		**1**	9	1		**1**		0		**1**	
2	**1**		8		**1**	10	▨	▨	▨	▨	0		**1**	
3	**1**		0			3	1	**1**			0			**1**
3	**1**		1	**1**		4	1	**1**			0	**1**		
3	**1**		2	**1**		5	1	**1**			0	**1**		
3	**1**		3	**1**		6	1	**1**			0	**1**		
3	**1**		4	**1**		7	1	**1**			0	**1**		
3	**1**		5	**1**		8	1	**1**			0	**1**		
3	**1**		6	**1**	**1**	9	1	**1**			0	**1**		
3	**1**		7		**1**	10	1		**1**		0		**1**	
3	**1**		8		**1**	11	▨	▨	▨	▨	0		**1**	

Table 23 – *Continued*

		VARIABLES					For *PASSINGnj* = 1				For *PASSINGnj* = 0			
ACCESS 1	DIMF 1	TMF1	ACCESS 2	DIMF 2	TMF 2	Sum ACCESS	Passing	DIM	BBTM	TMP	Passing	DIM	BBTM	TMP
4	**1**		0			4	1	**1**			0			**1**
4	**1**		1	**1**		5	1	**1**			0	**1**		
4	**1**		2	**1**		6	1	**1**			0	**1**		
4	**1**		3	**1**		7	1	**1**			0	**1**		
4	**1**		4	**1**		8	1	**1**			0	**1**		
4	**1**		5	**1**		9	1	**1**			0	**1**		
4	**1**		6	**1**	**1**	10	1	**1**			0	**1**		
4	**1**		7		**1**	11	1		**1**		0		**1**	
4	**1**		8		**1**	12					0		**1**	
5	**1**		0			5	1	**1**			0			**1**
5	**1**		1	**1**		6	1	**1**			0	**1**		
5	**1**		2	**1**		7	1	**1**			0	**1**		
5	**1**		3	**1**		8	1	**1**			0	**1**		
5	**1**		4	**1**		9	1	**1**			0	**1**		
5	**1**		5	**1**		10	1	**1**			0	**1**		
5	**1**		6	**1**	**1**	11	1		**1**		0		**1**	
5	**1**		7		**1**	12	1		**1**		0		**1**	
5	**1**		8		**1**	13					0		**1**	
6	**1**	**1**	0			6	1	**1**			0			**1**
6	**1**	**1**	1	**1**		7	1	**1**			0	**1**		
6	**1**	**1**	2	**1**		8	1	**1**			0	**1**		
6	**1**	**1**	3	**1**		9	1	**1**			0	**1**		
6	**1**	**1**	4	**1**		10	1	**1**			0	**1**		
6	**1**	**1**	5	**1**		11	1		**1**		0		**1**	
6	**1**	**1**	6	**1**	**1**	12	1		**1**		0		**1**	
6	**1**	**1**	7		**1**	13	1		**1**		0		**1**	
6	**1**	**1**	8		**1**	14					0		**1**	
7		**1**	0			7	1		**1**		0			**1**
7		**1**	1	**1**		8	1		**1**		0		**1**	
7		**1**	2	**1**		9	1		**1**		0		**1**	
7		**1**	3	**1**		10	1		**1**		0		**1**	
7		**1**	4	**1**		11	1		**1**		0		**1**	
7		**1**	5	**1**		12	1		**1**		0		**1**	
7		**1**	6	**1**	**1**	13	1		**1**		0		**1**	
7		**1**	7		**1**	14	1		**1**		0		**1**	
7		**1**	8		**1**	15					0		**1**	
8		**1**	0			8					0			**1**
8		**1**	1	**1**		9					0		**1**	
8		**1**	2	**1**		10					0		**1**	
8		**1**	3	**1**		11					0		**1**	
8		**1**	4	**1**		12					0		**1**	
8		**1**	5	**1**		13					0		**1**	
8		**1**	6	**1**	**1**	14					0		**1**	
8		**1**	7		**1**	15					0		**1**	
8		**1**	8		**1**	16					0		**1**	

Post-optimization variable $\boldsymbol{DIM}_{nj}$ identifies an active add-drop multiplexer on DS1 line *j* at node *n*. The logic used is given in equation (52). A "1" indicates the selection of an add-drop multiplexer at node *n* for DS1 line *j*. A "0" indicates that no add-drop multiplexer should be placed at node *n* for DS1 line *j*.

$$\boldsymbol{DIM}_{nj} = \begin{cases} 1, & \text{if } \sum_i \boldsymbol{DIMF}_{\boldsymbol{nij}} = 2 \text{ and } \sum_i \boldsymbol{ACCESS}_{\boldsymbol{nij}} \le \text{ ADMLIMIT;} \\ & \text{or} \\ & \boldsymbol{PASSING}_{\boldsymbol{nj}} = 1 \text{ and } \sum_i \boldsymbol{DIMF}_{\boldsymbol{nij}} = 1 \text{ and } \sum_i \boldsymbol{TMF}_{\boldsymbol{nij}} = 0 \text{ and} \\ & \sum_i \boldsymbol{ACCESS}_{\boldsymbol{nij}} \le \text{ (ADMMAX + DEV);} \\ & \text{or} \\ & \boldsymbol{PASSING}_{\boldsymbol{nj}} = 1 \text{ and } \sum_i \boldsymbol{DIMF}_{\boldsymbol{nij}} = 1 \text{ and } \sum_i \boldsymbol{TMF}_{\boldsymbol{nij}} = 1 \text{ and} \\ & \sum_i \boldsymbol{ACCESS}_{\boldsymbol{nij}} \le \text{ (ADMMAX + DEV);} \\ 0, & \text{otherwise.} \end{cases} \tag{52}$$

Post-optimization variable $\boldsymbol{BBTM}_{nj}$ identifies an active back-to-back multiplexer on DS1 line *j* at node *n*. The logic used is given in equation (53). A "1" indicates the selection of back-to-back terminal multiplexers at node *n* for DS1 line *j*. A "0" indicates no back-to-back terminal multiplexers should be placed at node *n* for DS1 line *j*.

$$\boldsymbol{BBTM}_{nj} = \begin{cases} 1, & \text{If } \sum_i \boldsymbol{ACCESS}_{nij} \geq \text{ADMLIMIT ;} \\ & \text{or} \\ & \sum_i \boldsymbol{DIMF}_{nij} = 1 \text{ and } \sum_i \boldsymbol{TMF}_{nij} = 1 \text{ and } \sum_i \boldsymbol{ACCESS}_{nij} \leq \\ & (\text{ADMMAX} + \text{DEV}) \\ & \text{or} \\ & \boldsymbol{PASSING}_{nj} = 1 \text{ and } \sum_i \boldsymbol{DIMF}_{nij} = 0 \text{ and } \sum_i \boldsymbol{TMF}_{nij} = 1; \\ 0, & \text{otherwise.} \end{cases} \tag{53}$$

The logic used to identify an active single terminal multiplexer on arc *i*, DS1 line *j* at node *n* requires two steps. The first step, equation (54), determines that a single terminal multiplexer is used on DS1 line *j* at node *n*. Post-optimization variable $\boldsymbol{TMP}_{nj}$ = 1 indicates the selection of a single terminal multiplexers at node *n* for DS1 line *j*. A “0” indicates no single terminal multiplexers at node *n* for DS1 line *j*. Post-optimization variable $\boldsymbol{TMP}_{nj}$ does not identify on the arc to which the single terminal multiplexer is connected.

$$\boldsymbol{TMP}_{nj} = \begin{cases} 1, & \text{If } \boldsymbol{PASSING}_{\boldsymbol{nj}} = 0 \text{ and } \sum_i \boldsymbol{DIMF}_{\boldsymbol{nij}} = 1 \text{ and } \sum_i \boldsymbol{TMF}_{\boldsymbol{nij}} = 1 \text{ and} \\ & \sum_i \boldsymbol{ACCESS}_{\boldsymbol{nij}} \leq (\text{ADMMAX} + \text{DEV}); \\ & \text{or} \\ & \boldsymbol{PASSING}_{\boldsymbol{nj}} = 0 \text{ and } (\sum_i \boldsymbol{DIMF}_{\boldsymbol{nij}} + \sum_i \boldsymbol{TMF}_{\boldsymbol{nij}} = 1); \\ 0, & \text{otherwise.} \end{cases} \tag{54}$$

The second step, equation (55), identifies the arc i to which the terminal multiplexer is connected. Post-optimization variable $\boldsymbol{TM}_{nij} = 1$ indicates the selection of a single terminal multiplexer on arc i, DS1 line j at node n.

$$\boldsymbol{TM}_{nij} = \begin{cases} 1, & \text{if } \boldsymbol{TMP}_{\boldsymbol{nj}} \text{ and } \boldsymbol{DIMF}_{\boldsymbol{nij}}; \\ & \text{or} \\ & \boldsymbol{TMP}_{\boldsymbol{nj}} \text{ and } \boldsymbol{TMF}_{\boldsymbol{nij}}; \\ 0, & \text{otherwise.} \end{cases} \tag{55}$$

5.1.1.1 Example Computational Results

Problem 3 was chosen to illustrate the effect of scalar DEV on the equipment selection process on the hypothetical network. The data for problem 3 is the same as used in chapter 3. The comparison of the results obtained for this problem applied to Model 3 and Model 4 are given in Table 26.

Table 26: Comparison of Computational Results between Model 3 and Model 4

Hypothetical network - problem 3	**Model 3**	**Model 4** (DEV=1)
Objective value	-3	-3
Iteration count	679	679
Optimal solution	YES	YES
Number of add-drop multiplexers	1	2
Number of back-to-back multiplexers	1	0
Number of terminal multiplexers	1	1
Node & DS1 line requiring equipment	N05.R03	N05.R03
CPU run- time in CPLEX (seconds)	.233	.233

Model 4 was applied to node N17 of the Arizona network, since this node resulted in the selection of a back-to-back terminal multiplexer when applied to Model 3B. DEV was set to one in Model 4. A comparison of the results obtained for node N17 from Models 3B and 4 is given in Table 27.

Table 27: Comparison between Model 3B and Model 4 for Node 17 - Arizona Network

NODE 17	**Model 3B**	**Model 4** (DEV=1)
Objective value	1	1
Processing time(seconds)	23.267	23.017
Iteration count	10,228	10,228
Optimal solution	YES	YES
Number of add-drop multiplexers	0	**1**
Number of back-to-back multiplexers	**1**	0
Number of terminal multiplexers	0	0
Node & DS1 line	N17.R05	N17.R05

5.1.1.2 Analysis

The two comparison tables clearly show the effect of scalar DEV on the output of the equipment selection process. In the case of the hypothetical network, Model 3 selected a back-to-back terminal multiplexer because there were six DS0 channels dropped at node N05 by DS1 line R03, thus exceeding the value of parameter ADMMAX. By contrast, Model 4 selected an add-drop multiplexer at node N05 for DS1 line R03 even though six DS0 channels dropped. Despite the fact that the number of channels dropped exceeded ADMMAX by one, the solution was consistent with the permitted deviation given by the value of DEV. Six DS0 channels were dropped and four DS0 channels added, giving a total of ten DS0 channels, which was within the allowable equipment configuration set by ADMLIMIT.

There were similar results when Model 4 was applied to Node N17 of the Arizona network. Sixteen DS0 channels were added at node N17 on DS1 line R05, exceeding the ADMMAX value of fifteen. When DEV was introduced in Model 4 with a value of one, an add-drop multiplexer was selected because neither the number of added DS0 channels nor dropped DS0 channels were greater than sixteen and their sum was less than parameter ADMLIMIT.

Another aspect of interest is that the processing times and iteration counts were not significantly different between the two runs. This is a result of applying the equipment selection process after the optimization step.

5.2 Future Developments

The basic model can be easily modified to implement other objectives. One strategy is manipulation of the input data through parameters that constrain the solution search space to achieve specific goals. For example, an effective way to implement alternate equipment selection rules is to, after optimization, alter the output-parameter-generation logic, as demonstrated by Model 4. Implementation of decomposition techniques as used in Model 3A and Model 3B can bring into the realm of computability and solvability problems that might otherwise be intractable. Additional enhancements and alternative objectives are suggested next.

5.2.1 Minimize the Number of DS1 Lines Between Nodes

The model could be modified to minimize the number of DS1 lines between nodes required to meet a specific demand problem. Parameters controlling the node equipment type would be desirable to permit user preferences to be introduced into the evaluation process. The model would also generate the channel assignment tables for each node.

5.2.2 Minimize the Number of DS1 Lines Connected to End-Nodes

The minimization of the number of DS1 lines that connect end-nodes to DACS is easily implemented by creating a parameter to constrain the search space to only those arcs connected to end nodes. Care must be taken in specifying the search-space constraints in order not to generate redundant arcs and conflicting assignments. In the case of an end-node connected to an add-drop node the minimization of the number of DS1s is a common process (i.e., the DS1's of the same arc are being minimized).

5.2.3 Time-Varying Demand Peaks for Different Origin-Destinations

The model could be modified to evaluate problems where the main factor is varying peak demands over time for different origin-destinations. It could use the output to generate the interconnection tables to be programmed at each node for specific time periods in order to meet the forecasted demand peaks. Parameters controlling the node equipment type would be necessary since they would have to be fixed for this type of model. The results could be a higher average traffic on the network, which would imply a better usage of the existing network facilities.

5.2.4 Wavelength-division Multiplexing applications

By substituting the DS0 channels with light wavelengths and the DS1 lines with optic fibers, the models could be adapted for use in the design and wavelength assignments in optical networks. The number of different light wavelengths carried by each fiber must replace the number of DS0 channels (24) used in the present models.

5.2.5 Fully Develop a Spreadsheet Template for Interfacing GAMS Using the SSLINKP Program

Using a spreadsheet template should make the input of data more user-friendly, quicker and less prone to errors. Also, the output data can be organized to meet the customer's needs and preferences by the use of spreadsheet macros. The use of the SSLINK program to connect the spreadsheet to the GAMS model will eliminate the need of the user to do any extensive manipulations of the GAMS model other than insert the file name of desired data, which means that the user will not have to possess any extensive knowledge of the GAMS language.

5.2.6 Design of Heuristics and Specialized Algorithms to Improve the Time-Performance of the Model

Performance is an issue that concerns everyone dealing with MIP modeling. The models developed in this praxis used general-purpose optimization and decomposition techniques only, and did not propose to address the use of heuristics or special-purpose algorithms to improve performance. The development of such methods could eventually eliminate the need for decomposition or allow for extremely large problems to be evaluated in viable processing times.

5.3 Conclusion

The basic model, i.e. Model 3, is a semi-assignment problem based on the premise that minimization of the DS1 lines used to add and or drop DS0 channels is desired, and constrained by the requirement of DS0 channel consistency for pass-through ODs at the nodes for residual DS0 channels. The simple decomposition techniques applied and the careful manipulation of the input data through parameters that constrain the solution search space can reduce considerably the problem size as well as create a variety of different implementations. Also the GAMS modeling language with its parameter generation based on optimized variables, enhances the flexibility and capability of the model to be used as the basis for several different types of implementations in telecommunications networks.

APPENDIX

APPENDIX A

MODEL 3 IN GAMS AND SOLUTION OF THE HYPOTHETICAL NETWORK FOR PROBLEM 3

The version of Model 3 in GAMS and the solution of the hypothetical network, i.e. channel assignment and equipment selection, for **PROBLEM** 3 are shown below.

Gams model

```
* HMODEL63.GMS
* CHANNEL ASSIGNMENT FOR HYPOTHETICAL MODEL 3
* - IDENTIFICATION OF ADD-DROP NODES
* - DS1 PAIRING CONSTRAINTS AT ADD-DROP NODES
* - EQUIPMENT TYPE SELECTION FOR ADD-DROP NODES
* ASSUMPTIONS:
* - NODE JUNCTIONS WITH MORE THAN TWO ARCS USE DACS
* - OD PASSING THROUGH A NODE MUST MAINTAIN LINE AND CHANNEL CONSISTENCY

* PROBLEM 3

SETS
I ARCS /A01*A05/
K DS0 CHANNELS /C01 * C08/
J DS1 LINES /R01*R05/
L ORIGIN DESTINATION /OD01 * OD06/
N NODES /N01*N06/

PARAMETER ADMLIMIT MAXIMUM NUMBER OF ADD-DROPS ALLOWED BY EQUIPMENT
                                                         CHARACTERISTICS;
ADMLIMIT = 10;

PARAMETER DEMAND(L) NUMBER OF CHANNELS K REQUIRED FOR EACH OD L/
OD01   6
OD02   18
OD03   6
OD04   6
OD05   6
OD06   4/;

TABLE D(L,I) ARCS NEEDED TO COMPLETE OD PATH
       A01  A02  A03  A04  A05
OD01     1    1    1
OD02     1    1
OD03          1         1    1
OD04          1         1
OD05               1    1    1
OD06                         1;

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PARAMETER CAP(I) NUMBER OF DS1 LINES AVAILABLE ON EACH ARC/
A01  5
A02  5
A03  4
A04  3
A05  3/;

TABLE NODES(I,N) ARCS I THAT CONNECT AT EACH NODE N
     N01 N02 N03 N04 N05 N06
A01    1   1
A02        1   1
A03            1   1
A04            1       1
A05                    1   1;


*    ----   I M P O R T A N T  -  D O   N O T   A L T E R   ----
*THE EQUATIONS BELOW GENERATE ALL ADDITIONAL TABLES AND PARAMETERS.

PARAMETER ADMMAX MAXIMUM NUMBER OF ADD OR DROPS ALLOWED BY EQUIPMENT
                                                         CHARACTERISTICS;
ADMMAX = ADMLIMIT / 2;

PARAMETER REDUDS1(L) NUMBER OF FULL DS1 LINES DEMAND FOR EACH OD;
REDUDS1(L) = FLOOR(DEMAND(L)/8);

PARAMETER REDUCAP(I) RESIDUAL ARC CAPACITY;
REDUCAP(I) = CAP(I) - SUM(L, D(L,I)*REDUDS1(L));

PARAMETER RESIDUAL(L) RESIDUAL DEMAND FOR EACH OD;
RESIDUAL(L) = (DEMAND(L) -TRUNC (DEMAND(L)/ 8)* 8);

PARAMETER FULLOD(L) ODS THAT HAVE FULL DS1 LINES;
FULLOD(L)$(REDUDS1(L) GE 1) = 1;

PARAMETER AD(N) ADD-DROP NODE;
AD(N)$(SUM(I, NODES(I,N)) EQ 2) = 1;

PARAMETER ADI(I) ARCS CONNECTED TO ADD-DROP NODES;
ADI(I)$(SUM(N$AD(N), NODES(I,N)) GE 1) = 1;

PARAMETER PASS2(N,L,I) ALL VALID NODE-OD-ARC COMBINATIONS;
PASS2(N,L,I)$ (D(L,I) AND NODES(I,N)) = 1 ;

PARAMETER PASSTHRU(N,L) ODS THAT PASS THROUGH NODE;
PASSTHRU(N,L)$(SUM(I, PASS2(N,L,I)) GE 2) = 1;

PARAMETER DROP(N,L) ODS THAT ADD-DROP AT NODE;
DROP(N,L)$(SUM(I, PASS2(N,L,I)) EQ 1) = 1;

PARAMETER CHANNEL(K) MAKE ALL DS0 CHANNELS AVAILABLE;
CHANNEL(K) = 1;

PARAMETER LINE(J) MAKE ALL DS1 LINES AVAILABLE;
LINE(J) = 1;

PARAMETER ARCCAP(I,J) NUMBER OF DS1 LINES ON EACH ARC;
ARCCAP(I,J)$(ORD(J) LE CAP(I)) = 1;

PARAMETER ARCCAP2(I,J) NUMBER OF RESIDUAL DS1 LINES ON EACH ARC;
ARCCAP2(I,J)$(ORD(J) LE REDUCAP(I)) = 1;

PARAMETER ARCCAP3(I,J) NUMBER OF DESIGNATED FULL DS1 LINES ON EACH ARC;
ARCCAP3(I,J) = ARCCAP(I,J) - ARCCAP2(I,J);

PARAMETER ARCCAP4(N,I,J) ARC CAPACITY AT NODE N;
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ARCCAP4(N,I,J) = ARCCAP2(I,J) * NODES(I,N);

PARAMETER NODECAP(N,J) MAXIMUM CAPACITY AT NODE N;
NODECAP(N,J)$(SUM(I, ARCCAP4(N,I,J) GE 1)) = 1;

PARAMETER G1(L,I,J,K) ALL VALID OD ARC CHANNEL COMBINATIONS;
G1(L,I,J,K) = (D(L,I) * CHANNEL(K) * LINE(J))$ARCCAP2(I,J);

PARAMETER G3(L,I,J) ALL VALID OD ARC-FULL-DS1 COMBINATIONS;
G3(L,I,J) = (D(L,I)$FULLOD(L) * LINE(J))$ARCCAP3(I,J);

VARIABLES
X(L,I,J,K) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I, DS1
                                                  LINE J AND DS0 CHANNEL K
W(N,L,J,K) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, DS0
                                                  CHANNEL K PAIR AT NODE N
Y(L,I,J) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I AND DS1
                                                                    LINE J
ACCESS(N,I,J) NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY ARC I, DS1
                                                          LINE J AT NODE N
DS1(N,J) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, AT NODE N
                                      USED TO DROP AND OR ADD DS0 CHANNELS
Z TOTAL;
BINARY VARIABLE X,W,Y,DS1;

EQUATIONS

ARCASSIGN(L,I) ASSIGN ONLY ONE ARC-DS1-DS0 FOR EACH UNIT OF DEMAND FOR
                                                                   EACH OD
CHANASSIGN(I,J,K) ARC-DS1-DS0 CHANNEL CAN BE ASSIGNED ONLY ONCE -
                                                            MULTICOMMODITY
DS1USED(N,L,J,K) IDENTIFY ACTIVE DS1 PAIRS AT ADD-DROP NODE
ADM(N,I,J) NUMBER OF DS0 CHANNEL DROPPED AND OR ADDED ON ARC-DS1 LINE AT
                                                                    NODE N
UPLOAD(N,J) DS1 LINE USED TO ADD AND OR DROP DS0 CHANNELS AT NODE N
FULLDS1(L,I) ASSIGN ONLY ONE ARC-DS1 LINE FOR EACH FULL DS1 DEMAND FOR
                                                                 EACH OD L
DS1ASSIGN(I,J) ARC-DS1 LINE CAN BE ASSIGNED ONLY ONCE - MULTICOMMODITY
GOAL DEFINE OBJECTIVE FUNCTION;

ARCASSIGN(L,I)$D(L,I).. SUM((J,K)$G1(L,I,J,K), X(L,I,J,K)$ARCCAP2(I,J) *
                                                  D(L,I)) =E= RESIDUAL(L);

CHANASSIGN(I,J,K)$ARCCAP2(I,J).. SUM(L$G1(L,I,J,K), X(L,I,J,K)) =L= 1;

DS1USED(N,L,J,K)$(NODECAP(N,J)$(AD(N)$PASSTHRU(N,L))).. SUM((I) $(G1(L,I,
J,K) $(NODES(I,N) $(AD(N) $D(L,I)))), X(L,I,J,K)$PASSTHRU(N,L)) =E=  2 *
                                         W(N,L,J,K)$(AD(N)$PASSTHRU(N,L));

ADM(N,I,J)$(NODECAP(N,J)$(AD(N)$NODES(I,N))).. SUM((L,K)$(G1(L,I,J,K)
 $(NODES(I,N) $(AD(N) $D(L,I)))), X(L,I,J,K)$DROP(N,L)) =E= ACCESS(N,I,J)
                                                                   $AD(N);

UPLOAD(N,J)$(AD(N)$NODECAP(N,J)).. SUM((L,I,K)$(G1(L,I,J,K)$(NODES(I,N)
        $(AD(N)$D(L,I)))), X(L,I,J,K)$DROP(N,L)) =L= 16 * DS1(N,J)$AD(N);

FULLDS1(L,I)$D(L,I).. SUM(J$G3(L,I,J), Y(L,I,J) * D(L,I)) =E= REDUDS1(L);

DS1ASSIGN(I,J).. SUM(L$G3(L,I,J), Y(L,I,J)) =L= 1;

GOAL.. Z =E= - SUM((N,J)$(AD(N)$NODECAP(N,J)), DS1(N,J));

OPTION SOLPRINT = OFF;
OPTION RESLIM =900;
MODEL FAST  /ALL/;
OPTION OPTCR = .01;
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 155  FAST.OPTFILE = 1;
 156  SOLVE FAST USING MIP MAXIMIZING Z;
 157  PARAMETER USEDRESID(N,I,J,K,L) ASSIGNMENT CHART FOR RESIDUAL DS1 LINES;
        USEDRESID(N,I,J,K,L) = X.L(L,I,J,K)*NODES(I,N); OPTION USEDRESID:1:0:1;
                                                                 DISPLAY USEDRESID;
 158  PARAMETER USEDFULL(N,I,J,L) ASSIGNMENT CHART FOR FULL-DS1 LINES;
      USEDFULL(N,I,J,L) = Y.L(L,I,J)*NODES(I,N); OPTION USEDFULL:1:0:1;DISPLAY
                                                                          USEDFULL;
 159  DISPLAY AD;
 160  OPTION W:1:0:1; DISPLAY W.L;
 161  OPTION ACCESS:1:0:1; DISPLAY ACCESS.L;
 162  OPTION DS1:1:0:1; DISPLAY DS1.L;
 163  PARAMETER DIMF(N,I,J) ADD-DROP MULTIPLEXER REQUIREMENTS NOT MET-MET AT
                                                                  NODE ARC DS1 LINE;
 164  DIMF(N,I,J)$((ACCESS.L(N,I,J) LE ADMMAX) AND (ACCESS.L(N,I,J) GT 0)) = 1;
                                                    OPTION DIMF:1:0:1; DISPLAY DIMF;
 165  PARAMETER TMF(N,I,J) TERMINAL MULTIPLEXER REQUIREMENTS NOT MET-MET AT
                                                                  NODE ARC DS1 LINE;
 166  TMF(N,I,J)$(ACCESS.L(N,I,J) GE (ADMMAX + 1)) = 1; OPTION TMF:1:0:1;
                                                                        DISPLAY TMF;
 167  PARAMETER PASSING(N,J) DS1 LINE USED BY ODS THAT PASS THROUGH NODE N;
 168  PASSING(N,J)$(SUM((L,K), W.L(N,L,J,K)) GE 1) = 1; OPTION PASSING:1:0:1;
                                                                    DISPLAY PASSING;
 169  PARAMETER DIM(N,J) ACTIVE ADD-DROP MULTIPLEXER ON DS1 LINE J AT NODE N;
 170  DIM(N,J)$((SUM(I, DIMF(N,I,J)) EQ 2) OR ((PASSING(N,J) EQ 1) AND (SUM(I,
               DIMF(N,I,J)) EQ 1) AND (SUM(I, TMF(N,I,J)) EQ 0 ))) = 1; OPTION
                                                              DIM:1:0:1; DISPLAY DIM;
 171  PARAMETER BBTM(N,J) ACTIVE BACK-TO-BACK MULTIPLEXER ON DS1 LINE J AT
                                                                             NODE N;
 172  BBTM(N,J)$((SUM(I, TMF(N,I,J)) EQ 2) OR ((SUM(I, DIMF(N,I,J)) EQ 1) AND
      (SUM(I, TMF(N,I,J)) EQ 1 )) OR ((PASSING(N,J) EQ 1) AND (SUM(I, DIMF(N,I,
            J)) EQ 0) AND (SUM(I, TMF(N,I,J)) EQ 1 ))) = 1; OPTION BBTM:1:0:1;
                                                                       DISPLAY BBTM;
 173  PARAMETER TMP(N,J) ACTIVE TERMINAL MULTIPLEXER USED AT NODE N;
 174  TMP(N,J)$(((PASSING(N,J) EQ 0) AND (SUM(I, DIMF(N,I,J)) EQ 0) AND (SUM(I,
       TMF(N,I,J)) EQ 1 )) OR ((PASSING(N,J) EQ 0) AND (SUM(I, DIMF(N,I,J)) EQ
        1) AND (SUM(I, TMF(N,I,J)) EQ 0 ))) = 1; OPTION TMP:1:0:1; DISPLAY TMP;
 175  PARAMETER TM(N,I,J) ACTIVE TERMINAL MULTIPLEXER ON ARC-DS1 LINE AT NODE
                                                                                  N;
 176  TM(N,I,J) = ((TMP(N,J) * DIMF(N,I,J)) OR (TMP(N,J) * TMF(N,I,J)));
                                                         OPTION TM:1:0:1; DISPLAY TM;

COMPILATION TIME     =        0.033 SECONDS        VERID AXU-25-087

             MODEL STATISTICS

BLOCKS OF EQUATIONS       8     SINGLE EQUATIONS      263
BLOCKS OF VARIABLES       6     SINGLE VARIABLES      471
NON ZERO ELEMENTS      1217     DISCRETE VARIABLES    458
GENERATION TIME      =        0.050 SECONDS
EXECUTION TIME       =        0.067 SECONDS        VERID AXU-25-087
             S O L V E      S U M M A R Y
     MODEL   FAST                OBJECTIVE  Z
     TYPE    MIP                 DIRECTION  MAXIMIZE
     SOLVER  CPLEX               FROM LINE  156
**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE                 -3.0000
 RESOURCE USAGE, LIMIT          0.233      900.000
 ITERATION COUNT, LIMIT       679         1000
Option file:
> iterationlim 100000
> nodeselect 0
Proven optimal solution.
MIP Solution  :           -3.000000    (679 iterations, 80 nodes)
Final LP      :           -3.000000    (0 iterations)
```

```
Best integer solution possible :          -3.000000
Relative gap                   :                  0
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
----    157 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N01.A01.R01.C02.OD02 1.0
N01.A01.R01.C03.OD01 1.0
N01.A01.R01.C04.OD01 1.0
N01.A01.R01.C05.OD01 1.0
N01.A01.R01.C08.OD02 1.0
N01.A01.R03.C06.OD01 1.0
N01.A01.R03.C07.OD01 1.0
N01.A01.R03.C08.OD01 1.0
N02.A01.R01.C02.OD02 1.0
N02.A01.R01.C03.OD01 1.0
N02.A01.R01.C04.OD01 1.0
N02.A01.R01.C05.OD01 1.0
N02.A01.R01.C08.OD02 1.0
N02.A01.R03.C06.OD01 1.0
N02.A01.R03.C07.OD01 1.0
N02.A01.R03.C08.OD01 1.0
N02.A02.R01.C02.OD02 1.0
N02.A02.R01.C03.OD01 1.0
N02.A02.R01.C04.OD01 1.0
N02.A02.R01.C05.OD01 1.0
N02.A02.R01.C08.OD02 1.0
N02.A02.R02.C01.OD04 1.0
N02.A02.R02.C02.OD03 1.0
N02.A02.R02.C03.OD04 1.0
N02.A02.R02.C04.OD04 1.0
N02.A02.R02.C05.OD03 1.0
N02.A02.R02.C06.OD03 1.0
N02.A02.R02.C07.OD03 1.0
N02.A02.R02.C08.OD03 1.0
N02.A02.R03.C01.OD04 1.0
N02.A02.R03.C02.OD04 1.0
N02.A02.R03.C03.OD04 1.0
N02.A02.R03.C04.OD03 1.0
N02.A02.R03.C06.OD01 1.0
N02.A02.R03.C07.OD01 1.0
N02.A02.R03.C08.OD01 1.0
N03.A02.R01.C02.OD02 1.0
N03.A02.R01.C03.OD01 1.0
N03.A02.R01.C04.OD01 1.0
N03.A02.R01.C05.OD01 1.0
N03.A02.R01.C08.OD02 1.0
N03.A02.R02.C01.OD04 1.0
N03.A02.R02.C02.OD03 1.0
N03.A02.R02.C03.OD04 1.0
N03.A02.R02.C04.OD04 1.0
N03.A02.R02.C05.OD03 1.0
N03.A02.R02.C06.OD03 1.0
N03.A02.R02.C07.OD03 1.0
N03.A02.R02.C08.OD03 1.0
N03.A02.R03.C01.OD04 1.0
N03.A02.R03.C02.OD04 1.0
N03.A02.R03.C03.OD04 1.0
N03.A02.R03.C04.OD03 1.0
N03.A02.R03.C06.OD01 1.0
N03.A02.R03.C07.OD01 1.0
N03.A02.R03.C08.OD01 1.0
N03.A03.R01.C01.OD01 1.0
N03.A03.R01.C02.OD01 1.0
N03.A03.R01.C04.OD01 1.0
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N03.A03.R01.C05.OD01 1.0
N03.A03.R01.C06.OD01 1.0
N03.A03.R02.C06.OD05 1.0
N03.A03.R02.C07.OD05 1.0
N03.A03.R02.C08.OD05 1.0
N03.A03.R03.C01.OD05 1.0
----    157 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N03.A03.R03.C02.OD05 1.0
N03.A03.R03.C03.OD05 1.0
N03.A03.R04.C07.OD01 1.0
N03.A04.R01.C01.OD05 1.0
N03.A04.R01.C02.OD05 1.0
N03.A04.R01.C03.OD05 1.0
N03.A04.R01.C04.OD05 1.0
N03.A04.R02.C01.OD03 1.0
N03.A04.R02.C02.OD03 1.0
N03.A04.R02.C03.OD03 1.0
N03.A04.R02.C04.OD03 1.0
N03.A04.R02.C05.OD05 1.0
N03.A04.R02.C08.OD05 1.0
N03.A04.R03.C01.OD04 1.0
N03.A04.R03.C02.OD04 1.0
N03.A04.R03.C03.OD04 1.0
N03.A04.R03.C04.OD04 1.0
N03.A04.R03.C05.OD04 1.0
N03.A04.R03.C06.OD04 1.0
N03.A04.R03.C07.OD03 1.0
N03.A04.R03.C08.OD03 1.0
N04.A03.R01.C01.OD01 1.0
N04.A03.R01.C02.OD01 1.0
N04.A03.R01.C04.OD01 1.0
N04.A03.R01.C05.OD01 1.0
N04.A03.R01.C06.OD01 1.0
N04.A03.R02.C06.OD05 1.0
N04.A03.R02.C07.OD05 1.0
N04.A03.R02.C08.OD05 1.0
N04.A03.R03.C01.OD05 1.0
N04.A03.R03.C02.OD05 1.0
N04.A03.R03.C03.OD05 1.0
N04.A03.R04.C07.OD01 1.0
N05.A04.R01.C01.OD05 1.0
N05.A04.R01.C02.OD05 1.0
N05.A04.R01.C03.OD05 1.0
N05.A04.R01.C04.OD05 1.0
N05.A04.R02.C01.OD03 1.0
N05.A04.R02.C02.OD03 1.0
N05.A04.R02.C03.OD03 1.0
N05.A04.R02.C04.OD03 1.0
N05.A04.R02.C05.OD05 1.0
N05.A04.R02.C08.OD05 1.0
N05.A04.R03.C01.OD04 1.0
N05.A04.R03.C02.OD04 1.0
N05.A04.R03.C03.OD04 1.0
N05.A04.R03.C04.OD04 1.0
N05.A04.R03.C05.OD04 1.0
N05.A04.R03.C06.OD04 1.0
N05.A04.R03.C07.OD03 1.0
N05.A04.R03.C08.OD03 1.0
N05.A05.R01.C01.OD05 1.0
N05.A05.R01.C02.OD05 1.0
N05.A05.R01.C03.OD05 1.0
N05.A05.R01.C04.OD05 1.0
N05.A05.R02.C01.OD03 1.0
N05.A05.R02.C02.OD03 1.0
N05.A05.R02.C03.OD03 1.0
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N05.A05.R02.C04.OD03 1.0
N05.A05.R02.C05.OD05 1.0
N05.A05.R02.C08.OD05 1.0
N05.A05.R03.C01.OD06 1.0
N05.A05.R03.C02.OD06 1.0
N05.A05.R03.C03.OD06 1.0
N05.A05.R03.C05.OD06 1.0
----    157 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N05.A05.R03.C07.OD03 1.0
N05.A05.R03.C08.OD03 1.0
N06.A05.R01.C01.OD05 1.0
N06.A05.R01.C02.OD05 1.0
N06.A05.R01.C03.OD05 1.0
N06.A05.R01.C04.OD05 1.0
N06.A05.R02.C01.OD03 1.0
N06.A05.R02.C02.OD03 1.0
N06.A05.R02.C03.OD03 1.0
N06.A05.R02.C04.OD03 1.0
N06.A05.R02.C05.OD05 1.0
N06.A05.R02.C08.OD05 1.0
N06.A05.R03.C01.OD06 1.0
N06.A05.R03.C02.OD06 1.0
N06.A05.R03.C03.OD06 1.0
N06.A05.R03.C05.OD06 1.0
N06.A05.R03.C07.OD03 1.0
N06.A05.R03.C08.OD03 1.0


----    158 PARAMETER USEDFULL      ASSIGNMENT CHART FOR FULL-DS1 LINES

N01.A01.R04.OD02 1.0
N01.A01.R05.OD02 1.0
N02.A01.R04.OD02 1.0
N02.A01.R05.OD02 1.0
N02.A02.R04.OD02 1.0
N02.A02.R05.OD02 1.0
N03.A02.R04.OD02 1.0
N03.A02.R05.OD02 1.0


----    159 PARAMETER AD            ADD-DROP NODE

N02 1.000,    N05 1.000


----  160 VARIABLE  W.L     0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J

N02.OD01.R01.C03 1.0
N02.OD01.R01.C04 1.0
N02.OD01.R01.C05 1.0
N02.OD01.R03.C06 1.0
N02.OD01.R03.C07 1.0
N02.OD01.R03.C08 1.0
N02.OD02.R01.C02 1.0
N02.OD02.R01.C08 1.0
N05.OD03.R02.C01 1.0
N05.OD03.R02.C02 1.0
N05.OD03.R02.C03 1.0
N05.OD03.R02.C04 1.0
N05.OD03.R03.C07 1.0
N05.OD03.R03.C08 1.0
N05.OD05.R01.C01 1.0
N05.OD05.R01.C02 1.0
N05.OD05.R01.C03 1.0
N05.OD05.R01.C04 1.0
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N05.OD05.R02.C05 1.0
N05.OD05.R02.C08 1.0






----  161 VARIABLE  ACCESS.L   NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY ARC I

N02.A02.R02 8.0
N02.A02.R03 4.0
N05.A04.R03 6.0
N05.A05.R03 4.0


----    162 VARIABLE  DS1.L         LINE J AND DS0 CHANNEL K

N02.R02 1.0
N02.R03 1.0
N05.R03 1.0
----    164 PARAMETER DIMF          ADD-DROP MULTIPLEXER REQUIREMENTS NOT
                                    MET-MET AT NODE ARC DS1 LINE

N02.A02.R03 1.0
N05.A05.R03 1.0


----    166 PARAMETER TMF           TERMINAL MULTIPLEXER REQUIREMENTS NOT
                                    MET-MET AT NODE ARC DS1 LINE

N02.A02.R02 1.0
N05.A04.R03 1.0


----    168 PARAMETER PASSING       DS1 LINE USED BY ODS THAT PASS THROUGH
                                    NODE N

N02.R01 1.0
N02.R03 1.0
N05.R01 1.0
N05.R02 1.0
N05.R03 1.0


----    170 PARAMETER DIM           ACTIVE ADD-DROP MULTIPLEXER ON DS1 LINE J
                                    AT NODE N

N02.R03 1.0


----    172 PARAMETER BBTM          ACTIVE BACK-TO-BACK MULTIPLEXER ON DS1
                                    LINE J AT NODE N

N05.R03 1.0


----    174 PARAMETER TMP           ACTIVE TERMINAL MULTIPLEXER USED AT NODE N

N02.R02 1.0


----    176 PARAMETER TM            ACTIVE TERMINAL MULTIPLEXER ON ARC-DS1
                                    LINE AT NODE N

N02.A02.R02 1.0
```

```
EXECUTION TIME        =         0.033 SECONDS        VERID AXU-25-087
```

APPENDIX B

ARIZONA NETWORK FULL DS0 CHANNEL ASSIGNMENT LISTING

The assignments for the full Arizona Network listed below, have both output parameters USEDRESID_{nijkl} and USEDFULL_{nijl} already compiled together in ascending order by node, arc, DS1 line, DS0 channel and respective Origin-Destination. This data can be manipulated and formatted in a variety of ways according to the specific requirements of each situation. When the word ALL appears under the DS0 column it refers to all the DS0 channels on the arc-DS1 line since it is a full DS1 designation.

DS0 channel assignment output for the full Arizona Network

```
 Node Arc  DS1  DS0  OD                          Node Arc  DS1  DS0  OD
N01  A01  R01  C01 OD05                         N01  A03  R01  C04 OD03
N01  A01  R01  C02 OD05                         N01  A03  R01  C05 OD03
N01  A01  R01  C03 OD01                         N01  A03  R01  C06 OD03
N01  A01  R01  C04 OD05                         N01  A03  R01  C07 OD07
N01  A01  R01  C05 OD01                         N01  A03  R01  C09 OD07
N01  A01  R01  C06 OD05                         N01  A03  R01  C10 OD07
N01  A01  R01  C07 OD01                         N01  A03  R01  C13 OD05
N01  A01  R01  C10 OD01                         N01  A03  R01  C14 OD04
N01  A01  R01  C17 OD05                         N01  A03  R01  C15 OD04
N01  A01  R01  C18 OD05                         N01  A03  R01  C16 OD04
N01  A01  R01  C19 OD05                         N01  A03  R01  C18 OD04
N01  A01  R02  ALL OD06                         N01  A03  R01  C21 OD05
N01  A02  R01  C01 OD08                         N01  A03  R02  C09 OD07
N01  A02  R01  C03 OD07                         N01  A03  R02  C11 OD05
N01  A02  R01  C04 OD07                         N01  A03  R02  C12 OD05
N01  A02  R01  C06 OD07                         N01  A03  R02  C13 OD05
N01  A02  R01  C09 OD07                         N01  A03  R02  C14 OD07
N01  A02  R01  C10 OD07                         N01  A03  R02  C15 OD07
N01  A02  R01  C11 OD07                         N01  A03  R02  C17 OD07
N01  A02  R01  C16 OD07                         N01  A03  R03  C01 OD03
N01  A02  R01  C20 OD02                         N01  A03  R03  C03 OD03
N01  A02  R01  C22 OD07                         N01  A03  R03  C04 OD03
N01  A02  R02  C14 OD07                         N01  A03  R03  C05 OD03
N01  A02  R02  C15 OD07                         N01  A03  R03  C06 OD03
N01  A02  R02  C21 OD07                         N01  A03  R03  C07 OD03
N01  A03  R01  C01 OD04                         N01  A03  R03  C08 OD03
N01  A03  R01  C02 OD03                         N01  A03  R03  C09 OD03
N01  A03  R01  C03 OD03                         N01  A03  R03  C12 OD03
```

Node	**Arc**	**DS1**	**DS0**	**OD**
N01	A03	R03	C20	OD04
N01	A03	R03	C23	OD07
N01	A03	R03	C24	OD07
N01	A03	R04	C01	OD07
N01	A03	R04	C06	OD04
N01	A03	R04	C07	OD04
N01	A03	R04	C12	OD04
N01	A03	R04	C13	OD04
N01	A03	R04	C14	OD04
N01	A03	R04	C15	OD04
N01	A03	R04	C16	OD04
N01	A03	R04	C17	OD04
N01	A03	R04	C24	OD05
N01	A03	R05	C04	OD05
N01	A03	R05	C07	OD03
N01	A03	R05	C09	OD08
N01	A03	R05	C10	OD07
N01	A03	R05	C12	OD04
N01	A03	R05	C21	OD04
N01	A03	R06	ALL	OD04
N01	A03	R07	ALL	OD03
N01	A03	R08	ALL	OD06
N02	A01	R01	C01	OD05
N02	A01	R01	C02	OD05
N02	A01	R01	C03	OD01
N02	A01	R01	C04	OD05
N02	A01	R01	C05	OD01
N02	A01	R01	C06	OD05
N02	A01	R01	C07	OD01
N02	A01	R01	C10	OD01
N02	A01	R01	C17	OD05
N02	A01	R01	C18	OD05
N02	A01	R01	C19	OD05
N02	A01	R02	ALL	OD06
N03	A02	R01	C01	OD08
N03	A02	R01	C03	OD07
N03	A02	R01	C04	OD07
N03	A02	R01	C06	OD07
N03	A02	R01	C09	OD07
N03	A02	R01	C10	OD07
N03	A02	R01	C11	OD07
N03	A02	R01	C16	OD07
N03	A02	R01	C20	OD02
N03	A02	R01	C22	OD07
N03	A02	R02	C14	OD07
N03	A02	R02	C15	OD07
N03	A02	R02	C21	OD07
N04	A03	R01	C01	OD04
N04	A03	R01	C02	OD03
N04	A03	R01	C03	OD03
N04	A03	R01	C04	OD03
N04	A03	R01	C05	OD03
N04	A03	R01	C06	OD03
N04	A03	R01	C07	OD07
N04	A03	R01	C09	OD07
N04	A03	R01	C10	OD07
N04	A03	R01	C13	OD05
N04	A03	R01	C14	OD04
N04	A03	R01	C15	OD04
N04	A03	R01	C16	OD04
N04	A03	R01	C18	OD04
N04	A03	R01	C21	OD05
N04	A03	R02	C09	OD07
N04	A03	R02	C11	OD05
N04	A03	R02	C12	OD05
N04	A03	R02	C13	OD05
Node	**Arc**	**DS1**	**DS0**	**OD**
N04	A03	R02	C14	OD07
N04	A03	R02	C15	OD07
N04	A03	R02	C17	OD07
N04	A03	R03	C01	OD03
N04	A03	R03	C03	OD03
N04	A03	R03	C04	OD03
N04	A03	R03	C05	OD03
N04	A03	R03	C06	OD03
N04	A03	R03	C07	OD03
N04	A03	R03	C08	OD03
N04	A03	R03	C09	OD03
N04	A03	R03	C12	OD03
N04	A03	R03	C20	OD04
N04	A03	R03	C23	OD07
N04	A03	R03	C24	OD07
N04	A03	R04	C01	OD07
N04	A03	R04	C06	OD04
N04	A03	R04	C07	OD04
N04	A03	R04	C12	OD04
N04	A03	R04	C13	OD04
N04	A03	R04	C14	OD04
N04	A03	R04	C15	OD04
N04	A03	R04	C16	OD04
N04	A03	R04	C17	OD04
N04	A03	R04	C24	OD05
N04	A03	R05	C04	OD05
N04	A03	R05	C07	OD03
N04	A03	R05	C09	OD08
N04	A03	R05	C10	OD07
N04	A03	R05	C12	OD04
N04	A03	R05	C21	OD04
N04	A03	R06	ALL	OD04
N04	A03	R07	ALL	OD03
N04	A03	R08	ALL	OD06
N04	A04	R01	C01	OD04
N04	A04	R01	C02	OD03
N04	A04	R01	C03	OD03
N04	A04	R01	C04	OD03
N04	A04	R01	C05	OD03
N04	A04	R01	C06	OD03
N04	A04	R01	C07	OD07
N04	A04	R01	C09	OD07
N04	A04	R01	C10	OD07
N04	A04	R01	C13	OD05
N04	A04	R01	C14	OD04
N04	A04	R01	C15	OD04
N04	A04	R01	C16	OD04
N04	A04	R01	C18	OD04
N04	A04	R01	C21	OD05
N04	A04	R02	C09	OD07
N04	A04	R02	C10	OD09
N04	A04	R02	C11	OD05
N04	A04	R02	C12	OD05
N04	A04	R02	C13	OD05
N04	A04	R02	C14	OD07
N04	A04	R02	C15	OD07
N04	A04	R02	C16	OD09
N04	A04	R02	C17	OD07
N04	A04	R02	C18	OD09
N04	A04	R02	C23	OD09
N04	A04	R02	C24	OD09
N04	A04	R03	C01	OD03
N04	A04	R03	C03	OD03
N04	A04	R03	C04	OD03

Node	Arc	DS1	DS0	OD
N04	A04	R03	C05	OD03
N04	A04	R03	C06	OD03
N04	A04	R03	C07	OD03
N04	A04	R03	C08	OD03
N04	A04	R03	C09	OD03
N04	A04	R03	C12	OD03
N04	A04	R03	C20	OD04
N04	A04	R03	C23	OD07
N04	A04	R03	C24	OD07
N04	A04	R04	C01	OD07
N04	A04	R04	C06	OD04
N04	A04	R04	C07	OD04
N04	A04	R04	C12	OD04
N04	A04	R04	C13	OD04
N04	A04	R04	C14	OD04
N04	A04	R04	C15	OD04
N04	A04	R04	C16	OD04
N04	A04	R04	C17	OD04
N04	A04	R04	C24	OD05
N04	A04	R05	C04	OD05
N04	A04	R05	C07	OD03
N04	A04	R05	C09	OD08
N04	A04	R05	C10	OD07
N04	A04	R05	C12	OD04
N04	A04	R05	C21	OD04
N04	A04	R06	ALL	OD03
N04	A04	R07	ALL	OD06
N04	A04	R08	ALL	OD04
N05	A04	R01	C01	OD04
N05	A04	R01	C02	OD03
N05	A04	R01	C03	OD03
N05	A04	R01	C04	OD03
N05	A04	R01	C05	OD03
N05	A04	R01	C06	OD03
N05	A04	R01	C07	OD07
N05	A04	R01	C09	OD07
N05	A04	R01	C10	OD07
N05	A04	R01	C13	OD05
N05	A04	R01	C14	OD04
N05	A04	R01	C15	OD04
N05	A04	R01	C16	OD04
N05	A04	R01	C18	OD04
N05	A04	R01	C21	OD05
N05	A04	R02	C09	OD07
N05	A04	R02	C10	OD09
N05	A04	R02	C11	OD05
N05	A04	R02	C12	OD05
N05	A04	R02	C13	OD05
N05	A04	R02	C14	OD07
N05	A04	R02	C15	OD07
N05	A04	R02	C16	OD09
N05	A04	R02	C17	OD07
N05	A04	R02	C18	OD09
N05	A04	R02	C23	OD09
N05	A04	R02	C24	OD09
N05	A04	R03	C01	OD03
N05	A04	R03	C03	OD03
N05	A04	R03	C04	OD03
N05	A04	R03	C05	OD03
N05	A04	R03	C06	OD03
N05	A04	R03	C07	OD03
N05	A04	R03	C08	OD03
N05	A04	R03	C09	OD03
N05	A04	R03	C12	OD03
N05	A04	R03	C20	OD04
N05	A04	R03	C23	OD07
N05	A04	R03	C24	OD07
N05	A04	R04	C01	OD07
N05	A04	R04	C06	OD04
N05	A04	R04	C07	OD04
N05	A04	R04	C12	OD04
N05	A04	R04	C13	OD04
N05	A04	R04	C14	OD04
N05	A04	R04	C15	OD04
N05	A04	R04	C16	OD04
N05	A04	R04	C17	OD04
N05	A04	R04	C24	OD05
N05	A04	R05	C04	OD05
N05	A04	R05	C07	OD03
N05	A04	R05	C09	OD08
N05	A04	R05	C10	OD07
N05	A04	R05	C12	OD04
N05	A04	R05	C21	OD04
N05	A04	R06	ALL	OD03
N05	A04	R07	ALL	OD06
N05	A04	R08	ALL	OD04
N05	A05	R01	C01	OD04
N05	A05	R01	C02	OD03
N05	A05	R01	C03	OD03
N05	A05	R01	C04	OD03
N05	A05	R01	C05	OD03
N05	A05	R01	C06	OD03
N05	A05	R01	C07	OD07
N05	A05	R01	C09	OD07
N05	A05	R01	C10	OD07
N05	A05	R01	C13	OD05
N05	A05	R01	C14	OD04
N05	A05	R01	C15	OD04
N05	A05	R01	C16	OD04
N05	A05	R01	C18	OD04
N05	A05	R01	C21	OD05
N05	A05	R02	C09	OD07
N05	A05	R02	C10	OD09
N05	A05	R02	C11	OD05
N05	A05	R02	C12	OD05
N05	A05	R02	C13	OD05
N05	A05	R02	C14	OD07
N05	A05	R02	C15	OD07
N05	A05	R02	C16	OD09
N05	A05	R02	C17	OD07
N05	A05	R02	C18	OD09
N05	A05	R02	C23	OD09
N05	A05	R02	C24	OD09
N05	A05	R03	C01	OD03
N05	A05	R03	C03	OD03
N05	A05	R03	C04	OD03
N05	A05	R03	C05	OD03
N05	A05	R03	C06	OD03
N05	A05	R03	C07	OD03
N05	A05	R03	C08	OD03
N05	A05	R03	C09	OD03
N05	A05	R03	C12	OD03
N05	A05	R03	C20	OD04
N05	A05	R03	C23	OD07
N05	A05	R03	C24	OD07
N05	A05	R04	C01	OD07
N05	A05	R04	C06	OD04
N05	A05	R04	C07	OD04
N05	A05	R04	C12	OD04
N05	A05	R04	C13	OD04

N05	A05	R04	C14	OD04
N05	A05	R04	C15	OD04
N05	A05	R04	C16	OD04
N05	A05	R04	C17	OD04

Node	**Arc**	**DS1**	**DS0**	**OD**
N05	A05	R04	C24	OD05
N05	A05	R05	C04	OD05
N05	A05	R05	C07	OD03
N05	A05	R05	C09	OD08
N05	A05	R05	C10	OD07
N05	A05	R05	C12	OD04
N05	A05	R05	C21	OD04
N05	A05	R06	ALL	OD04
N05	A05	R07	ALL	OD06
N05	A05	R08	ALL	OD03
N06	A06	R01	C01	OD11
N06	A06	R01	C02	OD10
N06	A06	R01	C03	OD10
N06	A06	R01	C04	OD10
N06	A06	R01	C05	OD10
N06	A06	R01	C08	OD10
N06	A06	R01	C09	OD10
N06	A06	R01	C14	OD10
N06	A06	R01	C18	OD10
N06	A06	R01	C19	OD10
N06	A06	R01	C20	OD10
N06	A06	R01	C22	OD10
N06	A06	R02	ALL	OD11
N07	A05	R01	C01	OD04
N07	A05	R01	C02	OD03
N07	A05	R01	C03	OD03
N07	A05	R01	C04	OD03
N07	A05	R01	C05	OD03
N07	A05	R01	C06	OD03
N07	A05	R01	C07	OD07
N07	A05	R01	C09	OD07
N07	A05	R01	C10	OD07
N07	A05	R01	C13	OD05
N07	A05	R01	C14	OD04
N07	A05	R01	C15	OD04
N07	A05	R01	C16	OD04
N07	A05	R01	C18	OD04
N07	A05	R01	C21	OD05
N07	A05	R02	C09	OD07
N07	A05	R02	C10	OD09
N07	A05	R02	C11	OD05
N07	A05	R02	C12	OD05
N07	A05	R02	C13	OD05
N07	A05	R02	C14	OD07
N07	A05	R02	C15	OD07
N07	A05	R02	C16	OD09
N07	A05	R02	C17	OD07
N07	A05	R02	C18	OD09
N07	A05	R02	C23	OD09
N07	A05	R02	C24	OD09
N07	A05	R03	C01	OD03
N07	A05	R03	C03	OD03
N07	A05	R03	C04	OD03
N07	A05	R03	C05	OD03
N07	A05	R03	C06	OD03
N07	A05	R03	C07	OD03
N07	A05	R03	C08	OD03
N07	A05	R03	C09	OD03
N07	A05	R03	C12	OD03
N07	A05	R03	C20	OD04
N07	A05	R03	C23	OD07
N07	A05	R03	C24	OD07
N07	A05	R04	C01	OD07
N07	A05	R04	C06	OD04
N07	A05	R04	C07	OD04
N07	A05	R04	C12	OD04

Node	**Arc**	**DS1**	**DS0**	**OD**
N07	A05	R04	C13	OD04
N07	A05	R04	C14	OD04
N07	A05	R04	C15	OD04
N07	A05	R04	C16	OD04
N07	A05	R04	C17	OD04
N07	A05	R04	C24	OD05
N07	A05	R05	C04	OD05
N07	A05	R05	C07	OD03
N07	A05	R05	C09	OD08
N07	A05	R05	C10	OD07
N07	A05	R05	C12	OD04
N07	A05	R05	C21	OD04
N07	A05	R06	ALL	OD04
N07	A05	R07	ALL	OD06
N07	A05	R08	ALL	OD03
N07	A06	R01	C01	OD11
N07	A06	R01	C02	OD10
N07	A06	R01	C03	OD10
N07	A06	R01	C04	OD10
N07	A06	R01	C05	OD10
N07	A06	R01	C08	OD10
N07	A06	R01	C09	OD10
N07	A06	R01	C14	OD10
N07	A06	R01	C18	OD10
N07	A06	R01	C19	OD10
N07	A06	R01	C20	OD10
N07	A06	R01	C22	OD10
N07	A06	R02	ALL	OD11
N07	A07	R01	C01	OD14
N07	A07	R01	C02	OD13
N07	A07	R01	C03	OD13
N07	A07	R01	C04	OD13
N07	A07	R01	C05	OD13
N07	A07	R01	C10	OD13
N07	A07	R01	C11	OD13
N07	A07	R01	C19	OD13
N07	A07	R01	C20	OD13
N07	A07	R02	ALL	OD14
N07	A09	R01	C01	OD09
N07	A09	R01	C02	OD07
N07	A09	R01	C03	OD04
N07	A09	R01	C04	OD03
N07	A09	R01	C05	OD03
N07	A09	R01	C06	OD03
N07	A09	R01	C07	OD05
N07	A09	R01	C08	OD03
N07	A09	R01	C09	OD03
N07	A09	R01	C10	OD03
N07	A09	R01	C11	OD03
N07	A09	R01	C12	OD03
N07	A09	R01	C13	OD03
N07	A09	R01	C14	OD04
N07	A09	R01	C15	OD07
N07	A09	R01	C16	OD05
N07	A09	R01	C17	OD07
N07	A09	R01	C18	OD05
N07	A09	R01	C19	OD03
N07	A09	R01	C20	OD04
N07	A09	R01	C21	OD09
N07	A09	R01	C22	OD07

N07	A09	R01	C23	OD07
N07	A09	R02	C01	OD10
N07	A09	R02	C02	OD03
N07	A09	R02	C03	OD04
N07	A09	R02	C05	OD05
N07	A09	R02	C07	OD04

Node	**Arc**	**DS1**	**DS0**	**OD**
N07	A09	R02	C08	OD07
N07	A09	R02	C10	OD10
N07	A09	R02	C11	OD04
N07	A09	R02	C12	OD12
N07	A09	R02	C13	OD10
N07	A09	R02	C21	OD09
N07	A09	R03	C01	OD10
N07	A09	R03	C02	OD04
N07	A09	R03	C06	OD11
N07	A09	R03	C08	OD14
N07	A09	R03	C10	OD13
N07	A09	R03	C11	OD13
N07	A09	R03	C12	OD13
N07	A09	R03	C14	OD04
N07	A09	R03	C15	OD13
N07	A09	R03	C22	OD09
N07	A09	R04	C01	OD10
N07	A09	R04	C02	OD05
N07	A09	R04	C03	OD09
N07	A09	R04	C05	OD04
N07	A09	R04	C06	OD04
N07	A09	R04	C09	OD10
N07	A09	R04	C10	OD04
N07	A09	R04	C11	OD12
N07	A09	R04	C12	OD10
N07	A09	R04	C13	OD08
N07	A09	R04	C14	OD07
N07	A09	R04	C15	OD04
N07	A09	R04	C16	OD03
N07	A09	R04	C17	OD03
N07	A09	R04	C20	OD13
N07	A09	R05	C01	OD03
N07	A09	R05	C02	OD05
N07	A09	R05	C03	OD04
N07	A09	R05	C06	OD12
N07	A09	R05	C08	OD10
N07	A09	R05	C10	OD12
N07	A09	R05	C13	OD10
N07	A09	R05	C19	OD03
N07	A09	R05	C20	OD04
N07	A09	R05	C21	OD12
N07	A09	R05	C23	OD07
N07	A09	R06	C01	OD13
N07	A09	R06	C05	OD05
N07	A09	R06	C08	OD04
N07	A09	R06	C09	OD10
N07	A09	R06	C13	OD07
N07	A09	R06	C15	OD04
N07	A09	R06	C24	OD10
N07	A09	R07	C01	OD07
N07	A09	R07	C08	OD13
N07	A09	R07	C11	OD13
N07	A09	R07	C15	OD07
N07	A09	R08	ALL	OD14
N07	A09	R09	ALL	OD04
N07	A09	R10	ALL	OD11
N07	A09	R11	ALL	OD06
N07	A09	R12	ALL	OD03
N08	A07	R01	C01	OD14
N08	A07	R01	C02	OD13
N08	A07	R01	C03	OD13
N08	A07	R01	C04	OD13
N08	A07	R01	C05	OD13
N08	A07	R01	C10	OD13
N08	A07	R01	C11	OD13
N08	A07	R01	C19	OD13

Node	**Arc**	**DS1**	**DS0**	**OD**
N08	A07	R01	C20	OD13
N08	A07	R02	ALL	OD14
N10	A09	R01	C01	OD09
N10	A09	R01	C02	OD07
N10	A09	R01	C03	OD04
N10	A09	R01	C04	OD03
N10	A09	R01	C05	OD03
N10	A09	R01	C06	OD03
N10	A09	R01	C07	OD05
N10	A09	R01	C08	OD03
N10	A09	R01	C09	OD03
N10	A09	R01	C10	OD03
N10	A09	R01	C11	OD03
N10	A09	R01	C12	OD03
N10	A09	R01	C13	OD03
N10	A09	R01	C14	OD04
N10	A09	R01	C15	OD07
N10	A09	R01	C16	OD05
N10	A09	R01	C17	OD07
N10	A09	R01	C18	OD05
N10	A09	R01	C19	OD03
N10	A09	R01	C20	OD04
N10	A09	R01	C21	OD09
N10	A09	R01	C22	OD07
N10	A09	R01	C23	OD07
N10	A09	R02	C01	OD10
N10	A09	R02	C02	OD03
N10	A09	R02	C03	OD04
N10	A09	R02	C05	OD05
N10	A09	R02	C07	OD04
N10	A09	R02	C08	OD07
N10	A09	R02	C10	OD10
N10	A09	R02	C11	OD04
N10	A09	R02	C12	OD12
N10	A09	R02	C13	OD10
N10	A09	R02	C21	OD09
N10	A09	R03	C01	OD10
N10	A09	R03	C02	OD04
N10	A09	R03	C06	OD11
N10	A09	R03	C08	OD14
N10	A09	R03	C10	OD13
N10	A09	R03	C11	OD13
N10	A09	R03	C12	OD13
N10	A09	R03	C14	OD04
N10	A09	R03	C15	OD13
N10	A09	R03	C22	OD09
N10	A09	R04	C01	OD10
N10	A09	R04	C02	OD05
N10	A09	R04	C03	OD09
N10	A09	R04	C05	OD04
N10	A09	R04	C06	OD04
N10	A09	R04	C09	OD10
N10	A09	R04	C10	OD04
N10	A09	R04	C11	OD12
N10	A09	R04	C12	OD10
N10	A09	R04	C13	OD08
N10	A09	R04	C14	OD07
N10	A09	R04	C15	OD04

N10	A09	R04	C16	OD03
N10	A09	R04	C17	OD03
N10	A09	R04	C20	OD13
N10	A09	R05	C01	OD03
N10	A09	R05	C02	OD05
N10	A09	R05	C03	OD04
N10	A09	R05	C06	OD12
N10	A09	R05	C08	OD10

Node	**Arc**	**DS1**	**DS0**	**OD**
N10	A09	R05	C10	OD12
N10	A09	R05	C13	OD10
N10	A09	R05	C19	OD03
N10	A09	R05	C20	OD04
N10	A09	R05	C21	OD12
N10	A09	R05	C23	OD07
N10	A09	R06	C01	OD13
N10	A09	R06	C05	OD05
N10	A09	R06	C08	OD04
N10	A09	R06	C09	OD10
N10	A09	R06	C13	OD07
N10	A09	R06	C15	OD04
N10	A09	R06	C24	OD10
N10	A09	R07	C01	OD07
N10	A09	R07	C08	OD13
N10	A09	R07	C11	OD13
N10	A09	R07	C15	OD07
N10	A09	R08	ALL	OD14
N10	A09	R09	ALL	OD04
N10	A09	R10	ALL	OD11
N10	A09	R11	ALL	OD06
N10	A09	R12	ALL	OD03
N10	A10	R01	C01	OD09
N10	A10	R01	C02	OD07
N10	A10	R01	C03	OD04
N10	A10	R01	C04	OD03
N10	A10	R01	C05	OD03
N10	A10	R01	C06	OD03
N10	A10	R01	C07	OD05
N10	A10	R01	C08	OD03
N10	A10	R01	C09	OD03
N10	A10	R01	C10	OD03
N10	A10	R01	C11	OD03
N10	A10	R01	C12	OD03
N10	A10	R01	C13	OD03
N10	A10	R01	C14	OD04
N10	A10	R01	C15	OD07
N10	A10	R01	C16	OD05
N10	A10	R01	C17	OD07
N10	A10	R01	C18	OD05
N10	A10	R01	C19	OD03
N10	A10	R01	C20	OD04
N10	A10	R01	C21	OD09
N10	A10	R01	C22	OD07
N10	A10	R01	C23	OD07
N10	A10	R02	C01	OD10
N10	A10	R02	C02	OD03
N10	A10	R02	C03	OD04
N10	A10	R02	C05	OD05
N10	A10	R02	C07	OD04
N10	A10	R02	C08	OD07
N10	A10	R02	C10	OD10
N10	A10	R02	C11	OD04
N10	A10	R02	C12	OD12
N10	A10	R02	C13	OD10
N10	A10	R02	C21	OD09
N10	A10	R03	C01	OD10
N10	A10	R03	C02	OD04
N10	A10	R03	C06	OD11
N10	A10	R03	C08	OD14
N10	A10	R03	C10	OD13
N10	A10	R03	C11	OD13
N10	A10	R03	C12	OD13
N10	A10	R03	C14	OD04
N10	A10	R03	C15	OD13
N10	A10	R03	C22	OD09

Node	**Arc**	**DS1**	**DS0**	**OD**
N10	A10	R04	C01	OD10
N10	A10	R04	C02	OD05
N10	A10	R04	C03	OD09
N10	A10	R04	C05	OD04
N10	A10	R04	C06	OD04
N10	A10	R04	C09	OD10
N10	A10	R04	C10	OD04
N10	A10	R04	C11	OD12
N10	A10	R04	C12	OD10
N10	A10	R04	C13	OD08
N10	A10	R04	C14	OD07
N10	A10	R04	C15	OD04
N10	A10	R04	C16	OD03
N10	A10	R04	C17	OD03
N10	A10	R04	C20	OD13
N10	A10	R05	C01	OD03
N10	A10	R05	C02	OD05
N10	A10	R05	C03	OD04
N10	A10	R05	C06	OD12
N10	A10	R05	C08	OD10
N10	A10	R05	C10	OD12
N10	A10	R05	C13	OD10
N10	A10	R05	C19	OD03
N10	A10	R05	C20	OD04
N10	A10	R05	C21	OD12
N10	A10	R05	C23	OD07
N10	A10	R06	C01	OD13
N10	A10	R06	C05	OD05
N10	A10	R06	C08	OD04
N10	A10	R06	C09	OD10
N10	A10	R06	C11	OD16
N10	A10	R06	C12	OD16
N10	A10	R06	C13	OD07
N10	A10	R06	C15	OD04
N10	A10	R06	C24	OD10
N10	A10	R07	C01	OD07
N10	A10	R07	C08	OD13
N10	A10	R07	C11	OD13
N10	A10	R07	C15	OD07
N10	A10	R11	ALL	OD11
N10	A10	R12	ALL	OD16
N10	A10	R13	ALL	OD04
N10	A10	R14	ALL	OD16
N10	A10	R15	ALL	OD16
N10	A10	R16	ALL	OD16
N10	A10	R17	ALL	OD16
N10	A10	R18	ALL	OD16
N10	A10	R19	ALL	OD15
N10	A10	R20	ALL	OD15
N10	A10	R21	ALL	OD16
N10	A10	R22	ALL	OD16
N10	A10	R23	ALL	OD16
N10	A10	R24	ALL	OD03
N10	A10	R25	ALL	OD16
N10	A10	R26	ALL	OD14
N10	A10	R27	ALL	OD06

Node	Arc	DS1	DS0	OD
N10	A10	R28	ALL	OD16
N11	A10	R01	C01	OD09
N11	A10	R01	C02	OD07
N11	A10	R01	C03	OD04
N11	A10	R01	C04	OD03
N11	A10	R01	C05	OD03
N11	A10	R01	C06	OD03
N11	A10	R01	C07	OD05
N11	A10	R01	C08	OD03
N11	A10	R01	C09	OD03
N11	A10	R01	C10	OD03
N11	A10	R01	C11	OD03
N11	A10	R01	C12	OD03
N11	A10	R01	C13	OD03
N11	A10	R01	C14	OD04
N11	A10	R01	C15	OD07
N11	A10	R01	C16	OD05
N11	A10	R01	C17	OD07
N11	A10	R01	C18	OD05
N11	A10	R01	C19	OD03
N11	A10	R01	C20	OD04
N11	A10	R01	C21	OD09
N11	A10	R01	C22	OD07
N11	A10	R01	C23	OD07
N11	A10	R02	C01	OD10
N11	A10	R02	C02	OD03
N11	A10	R02	C03	OD04
N11	A10	R02	C05	OD05
N11	A10	R02	C07	OD04
N11	A10	R02	C08	OD07
N11	A10	R02	C10	OD10
N11	A10	R02	C11	OD04
N11	A10	R02	C12	OD12
N11	A10	R02	C13	OD10
N11	A10	R02	C21	OD09
N11	A10	R03	C01	OD10
N11	A10	R03	C02	OD04
N11	A10	R03	C06	OD11
N11	A10	R03	C08	OD14
N11	A10	R03	C10	OD13
N11	A10	R03	C11	OD13
N11	A10	R03	C12	OD13
N11	A10	R03	C14	OD04
N11	A10	R03	C15	OD13
N11	A10	R03	C22	OD09
N11	A10	R04	C01	OD10
N11	A10	R04	C02	OD05
N11	A10	R04	C03	OD09
N11	A10	R04	C05	OD04
N11	A10	R04	C06	OD04
N11	A10	R04	C09	OD10
N11	A10	R04	C10	OD04
N11	A10	R04	C11	OD12
N11	A10	R04	C12	OD10
N11	A10	R04	C13	OD08
N11	A10	R04	C14	OD07
N11	A10	R04	C15	OD04
N11	A10	R04	C16	OD03
N11	A10	R04	C17	OD03
N11	A10	R04	C20	OD13
N11	A10	R05	C01	OD03
N11	A10	R05	C02	OD05
N11	A10	R05	C03	OD04
N11	A10	R05	C06	OD12
N11	A10	R05	C08	OD10
N11	A10	R05	C10	OD12
N11	A10	R05	C13	OD10
N11	A10	R05	C19	OD03
N11	A10	R05	C20	OD04
N11	A10	R05	C21	OD12
N11	A10	R05	C23	OD07
N11	A10	R06	C01	OD13
N11	A10	R06	C05	OD05
N11	A10	R06	C08	OD04
N11	A10	R06	C09	OD10
N11	A10	R06	C11	OD16
N11	A10	R06	C12	OD16
N11	A10	R06	C13	OD07
N11	A10	R06	C15	OD04
N11	A10	R06	C24	OD10
N11	A10	R07	C01	OD07
N11	A10	R07	C08	OD13
N11	A10	R07	C11	OD13
N11	A10	R07	C15	OD07
N11	A10	R11	ALL	OD11
N11	A10	R12	ALL	OD16
N11	A10	R13	ALL	OD04
N11	A10	R14	ALL	OD16
N11	A10	R15	ALL	OD16
N11	A10	R16	ALL	OD16
N11	A10	R17	ALL	OD16
N11	A10	R18	ALL	OD16
N11	A10	R19	ALL	OD15
N11	A10	R20	ALL	OD15
N11	A10	R21	ALL	OD16
N11	A10	R22	ALL	OD16
N11	A10	R23	ALL	OD16
N11	A10	R24	ALL	OD03
N11	A10	R25	ALL	OD16
N11	A10	R26	ALL	OD14
N11	A10	R27	ALL	OD06
N11	A10	R28	ALL	OD16
N11	A12	R01	C01	OD05
N11	A12	R01	C02	OD12
N11	A12	R01	C03	OD04
N11	A12	R01	C05	OD17
N11	A12	R01	C06	OD17
N11	A12	R01	C07	OD17
N11	A12	R01	C08	OD17
N11	A12	R01	C10	OD10
N11	A12	R01	C16	OD03
N11	A12	R02	C01	OD04
N11	A12	R02	C06	OD17
N11	A12	R02	C07	OD13
N11	A12	R02	C08	OD13
N11	A12	R02	C11	OD17
N11	A12	R02	C12	OD04
N11	A12	R02	C14	OD07
N11	A12	R02	C15	OD07
N11	A12	R02	C17	OD10
N11	A12	R02	C18	OD10
N11	A12	R02	C19	OD07
N11	A12	R02	C20	OD17
N11	A12	R02	C21	OD12
N11	A12	R02	C22	OD13
N11	A12	R03	C02	OD10
N11	A12	R03	C05	OD04
N11	A12	R03	C11	OD16
N11	A12	R03	C12	OD17
N11	A12	R03	C14	OD09

Node	Arc	DS1	DS0	OD
N11	A12	R03	C16	OD13
N11	A12	R03	C21	OD17
N11	A12	R04	C03	OD18
N11	A12	R04	C04	OD18
N11	A12	R04	C05	OD04
N11	A12	R04	C06	OD17
N11	A12	R04	C07	OD09
N11	A12	R04	C08	OD09
N11	A12	R04	C09	OD04
N11	A12	R04	C10	OD07
N11	A12	R04	C14	OD04
N11	A12	R04	C18	OD13
N11	A12	R04	C19	OD17
N11	A12	R04	C20	OD17
N11	A12	R04	C21	OD12
N11	A12	R04	C22	OD04
N11	A12	R04	C23	OD04
N11	A12	R04	C24	OD04
N11	A12	R05	C01	OD04
N11	A12	R05	C03	OD07
N11	A12	R05	C04	OD07
N11	A12	R05	C05	OD10
N11	A12	R05	C06	OD05
N11	A12	R05	C07	OD05
N11	A12	R05	C09	OD03
N11	A12	R05	C10	OD16
N11	A12	R05	C11	OD05
N11	A12	R05	C12	OD05
N11	A12	R05	C13	OD07
N11	A12	R05	C16	OD17
N11	A12	R05	C18	OD08
N11	A12	R05	C24	OD03
N11	A12	R06	C01	OD03
N11	A12	R06	C02	OD03
N11	A12	R06	C03	OD03
N11	A12	R06	C04	OD03
N11	A12	R06	C05	OD03
N11	A12	R06	C06	OD09
N11	A12	R06	C07	OD12
N11	A12	R06	C08	OD03
N11	A12	R06	C09	OD03
N11	A12	R06	C10	OD03
N11	A12	R06	C11	OD17
N11	A12	R06	C12	OD03
N11	A12	R06	C14	OD04
N11	A12	R06	C15	OD04
N11	A12	R06	C17	OD13
N11	A12	R06	C18	OD10
N11	A12	R06	C19	OD03
N11	A12	R06	C20	OD03
N11	A12	R06	C21	OD04
N11	A12	R06	C24	OD05
N11	A12	R07	C03	OD10
N11	A12	R07	C06	OD17
N11	A12	R07	C08	OD10
N11	A12	R07	C09	OD10
N11	A12	R07	C13	OD14
N11	A12	R07	C14	OD07
N11	A12	R07	C17	OD05
N11	A12	R08	C04	OD17
N11	A12	R08	C06	OD17
N11	A12	R08	C15	OD03
N11	A12	R09	C05	OD17
N11	A12	R09	C06	OD13
N11	A12	R09	C07	OD13
N11	A12	R09	C10	OD17
N11	A12	R09	C11	OD04
N11	A12	R09	C13	OD07
N11	A12	R09	C15	OD11
N11	A12	R09	C16	OD10
N11	A12	R09	C17	OD10
N11	A12	R09	C18	OD07
N11	A12	R09	C19	OD17
N11	A12	R09	C20	OD12
N11	A12	R10	C04	OD04
N11	A12	R10	C13	OD09
N11	A12	R10	C18	OD07
N11	A12	R10	C21	OD17
N11	A12	R10	C23	OD17
N11	A12	R11	ALL	OD06
N11	A12	R12	ALL	OD16
N11	A12	R13	ALL	OD16
N11	A12	R14	ALL	OD16
N11	A12	R15	ALL	OD04
N11	A12	R16	ALL	OD16
N11	A12	R17	ALL	OD16
N11	A12	R18	ALL	OD16
N11	A12	R19	ALL	OD16
N11	A12	R20	ALL	OD16
N11	A12	R21	ALL	OD16
N11	A12	R22	ALL	OD16
N11	A12	R23	ALL	OD16
N11	A12	R24	ALL	OD15
N11	A12	R25	ALL	OD03
N11	A12	R26	ALL	OD15
N11	A12	R27	ALL	OD11
N11	A12	R28	ALL	OD14
N12	A12	R01	C01	OD05
N12	A12	R01	C02	OD12
N12	A12	R01	C03	OD04
N12	A12	R01	C05	OD17
N12	A12	R01	C06	OD17
N12	A12	R01	C07	OD17
N12	A12	R01	C08	OD17
N12	A12	R01	C10	OD10
N12	A12	R01	C16	OD03
N12	A12	R02	C01	OD04
N12	A12	R02	C06	OD17
N12	A12	R02	C07	OD13
N12	A12	R02	C08	OD13
N12	A12	R02	C11	OD17
N12	A12	R02	C12	OD04
N12	A12	R02	C14	OD07
N12	A12	R02	C15	OD07
N12	A12	R02	C17	OD10
N12	A12	R02	C18	OD10
N12	A12	R02	C19	OD07
N12	A12	R02	C20	OD17
N12	A12	R02	C21	OD12
N12	A12	R02	C22	OD13
N12	A12	R03	C02	OD10
N12	A12	R03	C05	OD04
N12	A12	R03	C11	OD16
N12	A12	R03	C12	OD17
N12	A12	R03	C14	OD09
N12	A12	R03	C16	OD13
N12	A12	R03	C21	OD17
N12	A12	R04	C03	OD18
N12	A12	R04	C04	OD18
N12	A12	R04	C05	OD04

N12	A12	R04	C06	OD17
N12	A12	R04	C07	OD09
N12	A12	R04	C08	OD09
N12	A12	R04	C09	OD04
N12	A12	R04	C10	OD07
N12	A12	R04	C14	OD04
N12	A12	R04	C18	OD13
N12	A12	R04	C19	OD17
N12	A12	R04	C20	OD17
N12	A12	R04	C21	OD12
N12	A12	R04	C22	OD04
N12	A12	R04	C23	OD04
N12	A12	R04	C24	OD04
N12	A12	R05	C01	OD04
Node	**Arc**	**DS1**	**DS0**	**OD**
N12	A12	R05	C03	OD07
N12	A12	R05	C04	OD07
N12	A12	R05	C05	OD10
N12	A12	R05	C06	OD05
N12	A12	R05	C07	OD05
N12	A12	R05	C09	OD03
N12	A12	R05	C10	OD16
N12	A12	R05	C11	OD05
N12	A12	R05	C12	OD05
N12	A12	R05	C13	OD07
N12	A12	R05	C16	OD17
N12	A12	R05	C18	OD08
N12	A12	R05	C24	OD03
N12	A12	R06	C01	OD03
N12	A12	R06	C02	OD03
N12	A12	R06	C03	OD03
N12	A12	R06	C04	OD03
N12	A12	R06	C05	OD03
N12	A12	R06	C06	OD09
N12	A12	R06	C07	OD12
N12	A12	R06	C08	OD03
N12	A12	R06	C09	OD03
N12	A12	R06	C10	OD03
N12	A12	R06	C11	OD17
N12	A12	R06	C12	OD03
N12	A12	R06	C14	OD04
N12	A12	R06	C15	OD04
N12	A12	R06	C17	OD13
N12	A12	R06	C18	OD10
N12	A12	R06	C19	OD03
N12	A12	R06	C20	OD03
N12	A12	R06	C21	OD04
N12	A12	R06	C24	OD05
N12	A12	R07	C03	OD10
N12	A12	R07	C06	OD17
N12	A12	R07	C08	OD10
N12	A12	R07	C09	OD10
N12	A12	R07	C13	OD14
N12	A12	R07	C14	OD07
N12	A12	R07	C17	OD05
N12	A12	R08	C04	OD17
N12	A12	R08	C06	OD17
N12	A12	R08	C15	OD03
N12	A12	R09	C05	OD17
N12	A12	R09	C06	OD13
N12	A12	R09	C07	OD13
N12	A12	R09	C10	OD17
N12	A12	R09	C11	OD04
N12	A12	R09	C13	OD07
N12	A12	R09	C15	OD11
N12	A12	R09	C16	OD10
N12	A12	R09	C17	OD10
N12	A12	R09	C18	OD07
N12	A12	R09	C19	OD17
N12	A12	R09	C20	OD12
N12	A12	R10	C04	OD04
N12	A12	R10	C13	OD09
N12	A12	R10	C18	OD07
N12	A12	R10	C21	OD17
N12	A12	R10	C23	OD17
N12	A12	R11	ALL	OD06
N12	A12	R12	ALL	OD16
N12	A12	R13	ALL	OD16
N12	A12	R14	ALL	OD16
N12	A12	R15	ALL	OD04
N12	A12	R16	ALL	OD16
Node	**Arc**	**DS1**	**DS0**	**OD**
N12	A12	R17	ALL	OD16
N12	A12	R18	ALL	OD16
N12	A12	R19	ALL	OD16
N12	A12	R20	ALL	OD16
N12	A12	R21	ALL	OD16
N12	A12	R22	ALL	OD16
N12	A12	R23	ALL	OD16
N12	A12	R24	ALL	OD15
N12	A12	R25	ALL	OD03
N12	A12	R26	ALL	OD15
N12	A12	R27	ALL	OD11
N12	A12	R28	ALL	OD14
N12	A13	R03	C02	OD20
N12	A13	R03	C03	OD20
N12	A13	R03	C04	OD20
N12	A13	R03	C05	OD20
N12	A13	R03	C06	OD20
N12	A13	R03	C07	OD20
N12	A13	R03	C08	OD20
N12	A13	R03	C09	OD20
N12	A13	R03	C13	OD20
N12	A13	R03	C15	OD22
N12	A13	R03	C16	OD22
N12	A13	R03	C17	OD22
N12	A13	R03	C18	OD23
N12	A13	R03	C19	OD22
N12	A13	R03	C20	OD22
N12	A13	R03	C21	OD22
N12	A13	R03	C22	OD22
N12	A13	R03	C23	OD22
N12	A13	R03	C24	OD22
N12	A13	R04	ALL	OD21
N12	A15	R01	C01	OD23
N12	A15	R01	C02	OD17
N12	A15	R01	C04	OD04
N12	A15	R01	C05	OD10
N12	A15	R01	C06	OD09
N12	A15	R01	C07	OD09
N12	A15	R01	C10	OD20
N12	A15	R01	C11	OD20
N12	A15	R01	C12	OD20
N12	A15	R01	C13	OD17
N12	A15	R01	C14	OD11
N12	A15	R01	C16	OD17
N12	A15	R01	C17	OD13
N12	A15	R01	C18	OD13
N12	A15	R01	C19	OD17
N12	A15	R01	C20	OD12
N12	A15	R01	C21	OD22
N12	A15	R01	C22	OD22

N12	A15	R01	C23	OD04
N12	A15	R01	C24	OD03
N12	A15	R02	C02	OD07
N12	A15	R02	C03	OD10
N12	A15	R02	C04	OD19
N12	A15	R02	C05	OD05
N12	A15	R02	C06	OD05
N12	A15	R02	C08	OD19
N12	A15	R02	C09	OD17
N12	A15	R02	C13	OD12
N12	A15	R02	C15	OD13
N12	A15	R02	C17	OD07
N12	A15	R02	C19	OD22
N12	A15	R02	C22	OD03
N12	A15	R02	C23	OD05
N12	A15	R03	C01	OD17
Node	**Arc**	**DS1**	**DS0**	**OD**
N12	A15	R03	C04	OD03
N12	A15	R03	C05	OD09
N12	A15	R03	C06	OD04
N12	A15	R03	C09	OD13
N12	A15	R03	C12	OD19
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N12	A15	R03	C15	OD17
N12	A15	R03	C16	OD13
N12	A15	R03	C17	OD13
N12	A15	R03	C18	OD07
N12	A15	R03	C20	OD22
N12	A15	R03	C21	OD22
N12	A15	R03	C22	OD20
N12	A15	R03	C23	OD05
N12	A15	R03	C24	OD03
N12	A15	R04	C01	OD03
N12	A15	R04	C02	OD04
N12	A15	R04	C03	OD10
N12	A15	R04	C04	OD17
N12	A15	R04	C05	OD17
N12	A15	R04	C06	OD03
N12	A15	R04	C07	OD10
N12	A15	R04	C08	OD10
N12	A15	R04	C09	OD07
N12	A15	R04	C10	OD04
N12	A15	R04	C12	OD14
N12	A15	R04	C13	OD07
N12	A15	R04	C14	OD07
N12	A15	R04	C15	OD04
N12	A15	R04	C16	OD05
N12	A15	R04	C18	OD19
N12	A15	R04	C19	OD04
N12	A15	R04	C21	OD04
N12	A15	R04	C22	OD10
N12	A15	R05	C01	OD03
N12	A15	R05	C05	OD17
N12	A15	R05	C06	OD04
N12	A15	R05	C08	OD07
N12	A15	R05	C10	OD17
N12	A15	R05	C12	OD18
N12	A15	R05	C14	OD12
N12	A15	R05	C16	OD12
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N12	A15	R05	C20	OD19
N12	A15	R05	C21	OD20
N12	A15	R05	C22	OD20
N12	A15	R05	C23	OD19
N12	A15	R05	C24	OD19
N12	A15	R06	C02	OD20
N12	A15	R06	C04	OD17
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N12	A15	R06	C06	OD03
N12	A15	R06	C09	OD22
N12	A15	R06	C10	OD04
N12	A15	R06	C11	OD17
N12	A15	R06	C12	OD07
N12	A15	R06	C13	OD07
N12	A15	R06	C14	OD04
N12	A15	R06	C15	OD10
N12	A15	R06	C16	OD10
N12	A15	R06	C17	OD04
N12	A15	R06	C19	OD12
N12	A15	R06	C20	OD22
N12	A15	R06	C21	OD19
N12	A15	R06	C22	OD17
N12	A15	R06	C23	OD03
Node	**Arc**	**DS1**	**DS0**	**OD**
N12	A15	R06	C24	OD04
N12	A15	R07	C01	OD03
N12	A15	R07	C02	OD19
N12	A15	R07	C03	OD03
N12	A15	R07	C04	OD03
N12	A15	R07	C05	OD17
N12	A15	R07	C06	OD03
N12	A15	R07	C07	OD03
N12	A15	R07	C08	OD17
N12	A15	R07	C09	OD17
N12	A15	R07	C10	OD19
N12	A15	R07	C11	OD19
N12	A15	R07	C12	OD16
N12	A15	R07	C13	OD07
N12	A15	R07	C14	OD17
N12	A15	R07	C15	OD10
N12	A15	R07	C18	OD19
N12	A15	R07	C22	OD19
N12	A15	R08	C01	OD18
N12	A15	R08	C03	OD04
N12	A15	R08	C05	OD09
N12	A15	R08	C06	OD09
N12	A15	R08	C08	OD04
N12	A15	R08	C10	OD20
N12	A15	R08	C11	OD20
N12	A15	R08	C16	OD17
N12	A15	R08	C17	OD13
N12	A15	R08	C18	OD17
N12	A15	R08	C20	OD22
N12	A15	R08	C21	OD22
N12	A15	R08	C22	OD04
N12	A15	R09	C01	OD07
N12	A15	R09	C02	OD10
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N12	A15	R09	C07	OD19
N12	A15	R09	C08	OD17
N12	A15	R09	C14	OD17
N12	A15	R09	C16	OD08
N12	A15	R09	C21	OD03
N12	A15	R09	C24	OD10
N12	A15	R10	ALL	OD06
N12	A15	R11	ALL	OD16
N12	A15	R12	ALL	OD16
N12	A15	R13	ALL	OD16
N12	A15	R14	ALL	OD15
N12	A15	R15	ALL	OD16
N12	A15	R16	ALL	OD16

Node	Arc	DS1	DS0	OD
N12	A15	R17	ALL	OD16
N12	A15	R18	ALL	OD16
N12	A15	R19	ALL	OD14
N12	A15	R20	ALL	OD04
N12	A15	R21	ALL	OD16
N12	A15	R22	ALL	OD21
N12	A15	R23	ALL	OD11
N12	A15	R24	ALL	OD16
N12	A15	R25	ALL	OD03
N12	A15	R26	ALL	OD16
N12	A15	R27	ALL	OD16
N12	A15	R28	ALL	OD15
N13	A13	R03	C02	OD20
N13	A13	R03	C03	OD20
N13	A13	R03	C04	OD20
N13	A13	R03	C05	OD20
N13	A13	R03	C06	OD20
N13	A13	R03	C07	OD20
N13	A13	R03	C08	OD20
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N13	A13	R03	C15	OD22
N13	A13	R03	C16	OD22
N13	A13	R03	C17	OD22
N13	A13	R03	C18	OD23
N13	A13	R03	C19	OD22
N13	A13	R03	C20	OD22
N13	A13	R03	C21	OD22
N13	A13	R03	C22	OD22
N13	A13	R03	C23	OD22
N13	A13	R03	C24	OD22
N13	A13	R04	ALL	OD21
N13	A14	R03	C15	OD22
N13	A14	R03	C16	OD22
N13	A14	R03	C17	OD22
N13	A14	R03	C18	OD23
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N13	A14	R03	C20	OD22
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N13	A14	R03	C24	OD22
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N14	A14	R03	C16	OD22
N14	A14	R03	C17	OD22
N14	A14	R03	C18	OD23
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N14	A14	R03	C22	OD22
N14	A14	R03	C23	OD22
N14	A14	R03	C24	OD22
N16	A15	R01	C01	OD23
N16	A15	R01	C02	OD17
N16	A15	R01	C04	OD04
N16	A15	R01	C05	OD10
N16	A15	R01	C06	OD09
N16	A15	R01	C07	OD09
N16	A15	R01	C10	OD20
N16	A15	R01	C11	OD20
N16	A15	R01	C12	OD20
N16	A15	R01	C13	OD17
N16	A15	R01	C14	OD11
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N16	A15	R01	C24	OD03
N16	A15	R02	C02	OD07
N16	A15	R02	C03	OD10
N16	A15	R02	C04	OD19
N16	A15	R02	C05	OD05
N16	A15	R02	C06	OD05
N16	A15	R02	C08	OD19
N16	A15	R02	C09	OD17
N16	A15	R02	C13	OD12
N16	A15	R02	C15	OD13
N16	A15	R02	C17	OD07
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N16	A15	R03	C15	OD17
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N16	A15	R04	C01	OD03
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N16	A15	R04	C04	OD17
N16	A15	R04	C05	OD17
N16	A15	R04	C06	OD03
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N16	A15	R04	C10	OD04
N16	A15	R04	C12	OD14
N16	A15	R04	C13	OD07
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N16	A15	R05	C05	OD17
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N16	A15	R05	C08	OD07
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N16	A15	R05	C12	OD18
N16	A15	R05	C14	OD12
N16	A15	R05	C16	OD12
N16	A15	R05	C19	OD16
N16	A15	R05	C20	OD19

Node	Arc	DS1	DS0	OD
N16	A15	R05	C21	OD20
N16	A15	R05	C22	OD20
N16	A15	R05	C23	OD19
N16	A15	R05	C24	OD19
N16	A15	R06	C02	OD20
N16	A15	R06	C04	OD17
N16	A15	R06	C05	OD13
N16	A15	R06	C06	OD03
N16	A15	R06	C09	OD22
N16	A15	R06	C10	OD04
N16	A15	R06	C11	OD17
N16	A15	R06	C12	OD07
N16	A15	R06	C13	OD07
N16	A15	R06	C14	OD04
N16	A15	R06	C15	OD10
N16	A15	R06	C16	OD10
N16	A15	R06	C17	OD04
N16	A15	R06	C19	OD12
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N16	A15	R06	C22	OD17
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N16	A15	R07	C02	OD19
N16	A15	R07	C03	OD03
N16	A15	R07	C04	OD03
N16	A15	R07	C05	OD17
N16	A15	R07	C06	OD03
N16	A15	R07	C07	OD03
N16	A15	R07	C08	OD17
N16	A15	R07	C09	OD17
N16	A15	R07	C10	OD19
N16	A15	R07	C11	OD19
N16	A15	R07	C12	OD16
N16	A15	R07	C13	OD07
N16	A15	R07	C14	OD17
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N16	A15	R08	C01	OD18
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N16	A15	R08	C05	OD09
N16	A15	R08	C06	OD09
N16	A15	R08	C08	OD04
N16	A15	R08	C10	OD20
N16	A15	R08	C11	OD20
N16	A15	R08	C16	OD17
N16	A15	R08	C17	OD13
N16	A15	R08	C18	OD17
N16	A15	R08	C20	OD22
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N16	A15	R11	ALL	OD16
N16	A15	R12	ALL	OD16
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N16	A15	R19	ALL	OD14
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N16	A15	R24	ALL	OD16
N16	A15	R25	ALL	OD03
N16	A15	R26	ALL	OD16
N16	A15	R27	ALL	OD16
N16	A15	R28	ALL	OD15
N16	A16	R01	C06	OD52
N16	A16	R02	C07	OD27
N16	A16	R02	C23	OD51
N16	A16	R03	C07	OD27
N16	A16	R03	C08	OD52
N16	A16	R03	C09	OD27
N16	A16	R03	C14	OD27
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N16	A16	R03	C17	OD25
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N16	A16	R04	C13	OD26
N16	A16	R04	C16	OD52
N16	A16	R04	C17	OD51
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N16	A16	R04	C23	OD51
N16	A16	R05	C01	OD29
N16	A16	R05	C02	OD29
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N16	A16	R05	C06	OD24
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N16	A16	R05	C08	OD47
N16	A16	R05	C09	OD24
N16	A16	R05	C10	OD51
N16	A16	R05	C11	OD47
N16	A16	R05	C12	OD24
N16	A16	R05	C13	OD24
N16	A16	R05	C14	OD24
N16	A16	R05	C15	OD24
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N16	A16	R05	C19	OD27
N16	A16	R05	C20	OD51
N16	A16	R05	C21	OD47
N16	A16	R05	C22	OD24
N16	A16	R05	C23	OD46

N16	A16	R05	C24	OD24
N16	A16	R06	C01	OD29
N16	A16	R06	C02	OD51
N16	A16	R06	C03	OD26
N16	A16	R06	C06	OD27
N16	A16	R06	C07	OD27
N16	A16	R06	C08	OD29
N16	A16	R06	C09	OD25
N16	A16	R06	C10	OD25
N16	A16	R06	C11	OD25
N16	A16	R06	C12	OD25
N16	A16	R06	C13	OD25
N16	A16	R06	C14	OD51
N16	A16	R06	C15	OD28
N16	A16	R06	C16	OD51
N16	A16	R06	C17	OD53
N16	A16	R06	C18	OD51
N16	A16	R06	C19	OD28
N16	A16	R06	C20	OD26
N16	A16	R06	C21	OD26
N16	A16	R06	C22	OD27
N16	A16	R06	C23	OD27
Node	**Arc**	**DS1**	**DS0**	**OD**
N16	A16	R06	C24	OD25
N16	A16	R07	ALL	OD27
N16	A16	R08	ALL	OD51
N16	A17	R01	C01	OD47
N16	A17	R01	C03	OD41
N16	A17	R01	C04	OD08
N16	A17	R01	C06	OD39
N16	A17	R01	C07	OD04
N16	A17	R01	C08	OD51
N16	A17	R01	C09	OD44
N16	A17	R01	C10	OD44
N16	A17	R01	C11	OD43
N16	A17	R01	C12	OD43
N16	A17	R01	C15	OD43
N16	A17	R01	C16	OD47
N16	A17	R01	C17	OD46
N16	A17	R01	C18	OD32
N16	A17	R01	C19	OD44
N16	A17	R01	C20	OD44
N16	A17	R01	C21	OD11
N16	A17	R01	C22	OD44
N16	A17	R01	C23	OD52
N16	A17	R01	C24	OD44
N16	A17	R02	C04	OD40
N16	A17	R02	C05	OD40
N16	A17	R02	C06	OD51
N16	A17	R02	C08	OD04
N16	A17	R02	C09	OD37
N16	A17	R02	C10	OD36
N16	A17	R02	C11	OD35
N16	A17	R02	C12	OD34
N16	A17	R02	C13	OD43
N16	A17	R02	C14	OD04
N16	A17	R02	C15	OD32
N16	A17	R02	C16	OD32
N16	A17	R02	C17	OD34
N16	A17	R02	C18	OD34
N16	A17	R02	C19	OD37
N16	A17	R02	C20	OD34
N16	A17	R02	C21	OD43
N16	A17	R02	C22	OD51
N16	A17	R02	C23	OD43
N16	A17	R02	C24	OD04
N16	A17	R03	C01	OD04
N16	A17	R03	C02	OD41
N16	A17	R03	C03	OD33
N16	A17	R03	C04	OD33
N16	A17	R03	C05	OD32
N16	A17	R03	C06	OD41
N16	A17	R03	C08	OD41
N16	A17	R03	C09	OD34
N16	A17	R03	C10	OD51
N16	A17	R03	C11	OD51
N16	A17	R03	C15	OD47
N16	A17	R03	C16	OD46
N16	A17	R03	C18	OD43
N16	A17	R03	C19	OD39
N16	A17	R03	C20	OD39
N16	A17	R03	C21	OD43
N16	A17	R03	C22	OD43
N16	A17	R03	C23	OD14
N16	A17	R03	C24	OD34
N16	A17	R04	C01	OD41
N16	A17	R04	C02	OD32
N16	A17	R04	C03	OD41
N16	A17	R04	C04	OD04
Node	**Arc**	**DS1**	**DS0**	**OD**
N16	A17	R04	C05	OD41
N16	A17	R04	C06	OD18
N16	A17	R04	C07	OD39
N16	A17	R04	C08	OD44
N16	A17	R04	C09	OD44
N16	A17	R04	C10	OD44
N16	A17	R04	C11	OD04
N16	A17	R04	C12	OD51
N16	A17	R04	C13	OD04
N16	A17	R04	C14	OD41
N16	A17	R04	C17	OD42
N16	A17	R04	C18	OD44
N16	A17	R04	C19	OD36
N16	A17	R04	C21	OD34
N16	A17	R04	C22	OD16
N16	A17	R04	C23	OD04
N16	A17	R04	C24	OD36
N16	A17	R05	C01	OD34
N16	A17	R05	C02	OD34
N16	A17	R05	C05	OD41
N16	A17	R05	C06	OD53
N16	A17	R05	C08	OD52
N16	A17	R05	C10	OD51
N16	A17	R05	C11	OD51
N16	A17	R05	C12	OD33
N16	A17	R05	C13	OD33
N16	A17	R05	C14	OD33
N16	A17	R05	C15	OD33
N16	A17	R05	C16	OD41
N16	A17	R05	C17	OD34
N16	A17	R05	C18	OD04
N16	A17	R05	C21	OD43
N16	A17	R05	C22	OD04
N16	A17	R05	C23	OD51
N16	A17	R05	C24	OD42
N16	A17	R06	C01	OD41
N16	A17	R06	C02	OD04
N16	A17	R06	C03	OD41
N16	A17	R06	C04	OD39
N16	A17	R06	C05	OD39
N16	A17	R06	C06	OD39
N16	A17	R06	C07	OD39

Node	Arc	DS1	DS0	OD
N16	A17	R06	C10	OD18
N16	A17	R06	C11	OD04
N16	A17	R06	C12	OD50
N16	A17	R06	C15	OD39
N16	A17	R06	C17	OD36
N16	A17	R06	C18	OD35
N16	A17	R06	C19	OD04
N16	A17	R06	C20	OD51
N16	A17	R06	C21	OD42
N16	A17	R06	C22	OD55
N16	A17	R06	C23	OD04
N16	A17	R06	C24	OD04
N16	A17	R07	C03	OD23
N16	A17	R07	C04	OD41
N16	A17	R07	C05	OD41
N16	A17	R07	C06	OD32
N16	A17	R07	C07	OD38
N16	A17	R07	C08	OD16
N16	A17	R07	C10	OD36
N16	A17	R07	C11	OD35
N16	A17	R07	C12	OD34
N16	A17	R07	C13	OD34
N16	A17	R07	C14	OD33
N16	A17	R07	C15	OD32
N16	A17	R07	C17	OD38
N16	A17	R07	C18	OD33
N16	A17	R07	C20	OD34
N16	A17	R07	C21	OD52
N16	A17	R07	C23	OD51
N16	A17	R07	C24	OD51
N16	A17	R08	ALL	OD33
N16	A17	R09	ALL	OD16
N16	A17	R10	ALL	OD16
N16	A17	R11	ALL	OD16
N16	A17	R12	ALL	OD16
N16	A17	R13	ALL	OD16
N16	A17	R14	ALL	OD16
N16	A17	R15	ALL	OD16
N16	A17	R16	ALL	OD16
N16	A17	R17	ALL	OD16
N16	A17	R18	ALL	OD14
N16	A17	R19	ALL	OD21
N16	A17	R20	ALL	OD51
N16	A17	R21	ALL	OD16
N16	A17	R22	ALL	OD33
N16	A17	R23	ALL	OD06
N16	A17	R24	ALL	OD04
N16	A17	R25	ALL	OD16
N16	A17	R26	ALL	OD11
N16	A17	R27	ALL	OD33
N16	A17	R28	ALL	OD33
N16	A18	R01	C24	OD55
N16	A18	R02	C01	OD30
N16	A18	R02	C02	OD30
N16	A18	R02	C03	OD30
N16	A18	R02	C05	OD31
N16	A18	R02	C06	OD31
N16	A18	R02	C15	OD30
N16	A18	R02	C16	OD30
N16	A18	R02	C17	OD30
N16	A18	R02	C18	OD30
N17	A16	R01	C06	OD52
N17	A16	R02	C07	OD27
N17	A16	R02	C23	OD51
N17	A16	R03	C07	OD27
N17	A16	R03	C08	OD52
N17	A16	R03	C09	OD27
N17	A16	R03	C14	OD27
N17	A16	R03	C16	OD25
N17	A16	R03	C17	OD25
N17	A16	R03	C19	OD25
N17	A16	R03	C20	OD25
N17	A16	R03	C21	OD25
N17	A16	R03	C22	OD25
N17	A16	R03	C23	OD25
N17	A16	R03	C24	OD25
N17	A16	R04	C08	OD27
N17	A16	R04	C10	OD27
N17	A16	R04	C13	OD26
N17	A16	R04	C16	OD52
N17	A16	R04	C17	OD51
N17	A16	R04	C18	OD51
N17	A16	R04	C19	OD26
N17	A16	R04	C20	OD51
N17	A16	R04	C22	OD25
N17	A16	R04	C23	OD51
N17	A16	R05	C01	OD29
N17	A16	R05	C02	OD29
N17	A16	R05	C03	OD46
N17	A16	R05	C04	OD27
N17	A16	R05	C05	OD51
N17	A16	R05	C06	OD24
N17	A16	R05	C07	OD50
N17	A16	R05	C08	OD47
N17	A16	R05	C09	OD24
N17	A16	R05	C10	OD51
N17	A16	R05	C11	OD47
N17	A16	R05	C12	OD24
N17	A16	R05	C13	OD24
N17	A16	R05	C14	OD24
N17	A16	R05	C15	OD24
N17	A16	R05	C16	OD24
N17	A16	R05	C17	OD24
N17	A16	R05	C18	OD24
N17	A16	R05	C19	OD27
N17	A16	R05	C20	OD51
N17	A16	R05	C21	OD47
N17	A16	R05	C22	OD24
N17	A16	R05	C23	OD46
N17	A16	R05	C24	OD24
N17	A16	R06	C01	OD29
N17	A16	R06	C02	OD51
N17	A16	R06	C03	OD26
N17	A16	R06	C06	OD27
N17	A16	R06	C07	OD27
N17	A16	R06	C08	OD29
N17	A16	R06	C09	OD25
N17	A16	R06	C10	OD25
N17	A16	R06	C11	OD25
N17	A16	R06	C12	OD25
N17	A16	R06	C13	OD25
N17	A16	R06	C14	OD51
N17	A16	R06	C15	OD28
N17	A16	R06	C16	OD51
N17	A16	R06	C17	OD53
N17	A16	R06	C18	OD51
N17	A16	R06	C19	OD28
N17	A16	R06	C20	OD26
N17	A16	R06	C21	OD26
N17	A16	R06	C22	OD27

Node	Arc	DS1	DS0	OD
N17	A16	R06	C23	OD27
N17	A16	R06	C24	OD25
N17	A16	R07	ALL	OD27
N17	A16	R08	ALL	OD51
N17	A20	R01	C06	OD52
N17	A20	R02	C07	OD27
N17	A20	R02	C23	OD51
N17	A20	R03	C07	OD27
N17	A20	R03	C08	OD52
N17	A20	R03	C09	OD27
N17	A20	R03	C14	OD27
N17	A20	R03	C16	OD25
N17	A20	R03	C17	OD25
N17	A20	R03	C19	OD25
N17	A20	R03	C20	OD25
N17	A20	R03	C21	OD25
N17	A20	R03	C22	OD25
N17	A20	R03	C23	OD25
N17	A20	R03	C24	OD25
N17	A20	R04	C08	OD27
N17	A20	R04	C10	OD27
N17	A20	R04	C13	OD26
N17	A20	R04	C16	OD52
N17	A20	R04	C17	OD51
N17	A20	R04	C18	OD51
N17	A20	R04	C19	OD26
N17	A20	R04	C20	OD51
N17	A20	R04	C22	OD25
N17	A20	R04	C23	OD51
N17	A20	R05	C01	OD29
N17	A20	R05	C02	OD29
N17	A20	R05	C04	OD27
N17	A20	R05	C05	OD51
N17	A20	R05	C06	OD45
N17	A20	R05	C07	OD50
N17	A20	R05	C10	OD51
N17	A20	R05	C19	OD27
N17	A20	R05	C20	OD51
N17	A20	R06	C01	OD29
N17	A20	R06	C02	OD51
N17	A20	R06	C03	OD26
N17	A20	R06	C06	OD27
N17	A20	R06	C07	OD27
N17	A20	R06	C08	OD29
N17	A20	R06	C09	OD25
N17	A20	R06	C10	OD25
N17	A20	R06	C11	OD25
N17	A20	R06	C12	OD25
N17	A20	R06	C13	OD25
N17	A20	R06	C14	OD51
N17	A20	R06	C15	OD28
N17	A20	R06	C16	OD51
N17	A20	R06	C17	OD53
N17	A20	R06	C18	OD51
N17	A20	R06	C19	OD28
N17	A20	R06	C20	OD26
N17	A20	R06	C21	OD26
N17	A20	R06	C22	OD27
N17	A20	R06	C23	OD27
N17	A20	R06	C24	OD25
N17	A20	R07	ALL	OD51
N17	A20	R08	ALL	OD27
N18	A20	R01	C06	OD52
N18	A20	R02	C07	OD27
N18	A20	R02	C23	OD51
N18	A20	R03	C07	OD27
N18	A20	R03	C08	OD52
N18	A20	R03	C09	OD27
N18	A20	R03	C14	OD27
N18	A20	R03	C16	OD25
N18	A20	R03	C17	OD25
N18	A20	R03	C19	OD25
N18	A20	R03	C20	OD25
N18	A20	R03	C21	OD25
N18	A20	R03	C22	OD25
N18	A20	R03	C23	OD25
N18	A20	R03	C24	OD25
N18	A20	R04	C08	OD27
N18	A20	R04	C10	OD27
N18	A20	R04	C13	OD26
N18	A20	R04	C16	OD52
N18	A20	R04	C17	OD51
N18	A20	R04	C18	OD51
N18	A20	R04	C19	OD26
N18	A20	R04	C20	OD51
N18	A20	R04	C22	OD25
N18	A20	R04	C23	OD51
N18	A20	R05	C01	OD29
N18	A20	R05	C02	OD29
N18	A20	R05	C04	OD27
N18	A20	R05	C05	OD51
N18	A20	R05	C06	OD45
N18	A20	R05	C07	OD50
N18	A20	R05	C10	OD51
N18	A20	R05	C19	OD27
N18	A20	R05	C20	OD51
N18	A20	R06	C01	OD29
N18	A20	R06	C02	OD51
N18	A20	R06	C03	OD26
N18	A20	R06	C06	OD27
N18	A20	R06	C07	OD27
N18	A20	R06	C08	OD29
N18	A20	R06	C09	OD25
N18	A20	R06	C10	OD25
N18	A20	R06	C11	OD25
N18	A20	R06	C12	OD25
N18	A20	R06	C13	OD25
N18	A20	R06	C14	OD51
N18	A20	R06	C15	OD28
N18	A20	R06	C16	OD51
N18	A20	R06	C17	OD53
N18	A20	R06	C18	OD51
N18	A20	R06	C19	OD28
N18	A20	R06	C20	OD26
N18	A20	R06	C21	OD26
N18	A20	R06	C22	OD27
N18	A20	R06	C23	OD27
N18	A20	R06	C24	OD25
N18	A20	R07	ALL	OD51
N18	A20	R08	ALL	OD27
N18	A21	R01	C01	OD29
N18	A21	R01	C02	OD29
N18	A21	R01	C04	OD29
N18	A21	R01	C05	OD29
N18	A22	R01	C01	OD53
N18	A22	R01	C12	OD28
N18	A22	R02	C03	OD49
N18	A22	R02	C16	OD28
N18	A22	R02	C23	OD49
N18	A23	R01	C01	OD51

Node	Arc	DS1	DS0	OD
N18	A23	R01	C02	OD27
N18	A23	R01	C03	OD52
N18	A23	R01	C04	OD48
N18	A23	R01	C05	OD27
N18	A23	R01	C06	OD27
N18	A23	R01	C07	OD51
N18	A23	R01	C08	OD52
N18	A23	R01	C09	OD27
N18	A23	R01	C10	OD51
N18	A23	R01	C11	OD51
N18	A23	R01	C12	OD48
N18	A23	R01	C13	OD52
N18	A23	R01	C14	OD51
N18	A23	R01	C15	OD48
N18	A23	R01	C16	OD51
N18	A23	R01	C17	OD27
N18	A23	R01	C18	OD27
N18	A23	R01	C20	OD27
N18	A23	R01	C21	OD51
N18	A23	R01	C23	OD27
N18	A23	R02	C01	OD51
N18	A23	R02	C02	OD27
N18	A23	R02	C05	OD27
N18	A23	R02	C06	OD51
N18	A23	R02	C07	OD51
N18	A23	R02	C10	OD27
N18	A23	R02	C11	OD27
N18	A23	R02	C14	OD51
N18	A23	R02	C23	OD51
N18	A23	R03	ALL	OD51
N18	A23	R04	ALL	OD27
N18	A24	R01	C01	OD48
N18	A24	R01	C02	OD50
N18	A24	R01	C12	OD45
N18	A24	R01	C14	OD48
N18	A24	R01	C16	OD26
N18	A24	R01	C17	OD26
N18	A24	R01	C20	OD26
N18	A24	R01	C22	OD49
N18	A24	R02	C14	OD49
N18	A24	R02	C15	OD48
N18	A24	R02	C20	OD26
N18	A24	R02	C23	OD26
N19	A24	R01	C01	OD48
N19	A24	R01	C02	OD50
N19	A24	R01	C12	OD45
N19	A24	R01	C14	OD48
N19	A24	R01	C16	OD26
N19	A24	R01	C17	OD26
N19	A24	R01	C20	OD26
N19	A24	R01	C22	OD49
N19	A24	R02	C14	OD49
N19	A24	R02	C15	OD48
N19	A24	R02	C20	OD26
N19	A24	R02	C23	OD26
N20	A23	R01	C01	OD51
N20	A23	R01	C02	OD27
N20	A23	R01	C03	OD52
N20	A23	R01	C04	OD48
N20	A23	R01	C05	OD27
N20	A23	R01	C06	OD27
N20	A23	R01	C07	OD51
N20	A23	R01	C08	OD52
N20	A23	R01	C09	OD27
N20	A23	R01	C10	OD51
N20	A23	R01	C11	OD51
N20	A23	R01	C12	OD48
N20	A23	R01	C13	OD52
N20	A23	R01	C14	OD51
N20	A23	R01	C15	OD48
N20	A23	R01	C16	OD51
N20	A23	R01	C17	OD27
N20	A23	R01	C18	OD27
N20	A23	R01	C20	OD27
N20	A23	R01	C21	OD51
N20	A23	R01	C23	OD27
N20	A23	R02	C01	OD51
N20	A23	R02	C02	OD27
N20	A23	R02	C05	OD27
N20	A23	R02	C06	OD51
N20	A23	R02	C07	OD51
N20	A23	R02	C10	OD27
N20	A23	R02	C11	OD27
N20	A23	R02	C14	OD51
N20	A23	R02	C23	OD51
N20	A23	R03	ALL	OD51
N20	A23	R04	ALL	OD27
N21	A22	R01	C01	OD53
N21	A22	R01	C12	OD28
N21	A22	R02	C03	OD49
N21	A22	R02	C16	OD28
N21	A22	R02	C23	OD49
N22	A21	R01	C01	OD29
N22	A21	R01	C02	OD29
N22	A21	R01	C04	OD29
N22	A21	R01	C05	OD29
N23	A18	R01	C24	OD55
N23	A18	R02	C01	OD30
N23	A18	R02	C02	OD30
N23	A18	R02	C03	OD30
N23	A18	R02	C05	OD31
N23	A18	R02	C06	OD31
N23	A18	R02	C15	OD30
N23	A18	R02	C16	OD30
N23	A18	R02	C17	OD30
N23	A18	R02	C18	OD30
N23	A19	R01	C24	OD55
N23	A19	R02	C01	OD54
N23	A19	R02	C02	OD54
N23	A19	R02	C03	OD54
N23	A19	R02	C04	OD54
N23	A19	R02	C05	OD31
N23	A19	R02	C06	OD31
N23	A19	R02	C24	OD54
N24	A19	R01	C24	OD55
N24	A19	R02	C01	OD54
N24	A19	R02	C02	OD54
N24	A19	R02	C03	OD54
N24	A19	R02	C04	OD54
N24	A19	R02	C05	OD31
N24	A19	R02	C06	OD31
N24	A19	R02	C24	OD54
N25	A17	R01	C01	OD47
N25	A17	R01	C03	OD41
N25	A17	R01	C04	OD08
N25	A17	R01	C06	OD39
N25	A17	R01	C07	OD04
N25	A17	R01	C08	OD51
N25	A17	R01	C09	OD44
N25	A17	R01	C10	OD44

Node	Arc	DS1	DS0	OD
N25	A17	R01	C11	OD43
N25	A17	R01	C12	OD43
N25	A17	R01	C15	OD43
N25	A17	R01	C16	OD47
N25	A17	R01	C17	OD46
N25	A17	R01	C18	OD32
N25	A17	R01	C19	OD44
N25	A17	R01	C20	OD44
N25	A17	R01	C21	OD11
N25	A17	R01	C22	OD44
N25	A17	R01	C23	OD52
N25	A17	R01	C24	OD44
N25	A17	R02	C04	OD40
N25	A17	R02	C05	OD40
N25	A17	R02	C06	OD51
N25	A17	R02	C08	OD04
N25	A17	R02	C09	OD37
N25	A17	R02	C10	OD36
N25	A17	R02	C11	OD35
N25	A17	R02	C12	OD34
N25	A17	R02	C13	OD43
N25	A17	R02	C14	OD04
N25	A17	R02	C15	OD32
N25	A17	R02	C16	OD32
N25	A17	R02	C17	OD34
N25	A17	R02	C18	OD34
N25	A17	R02	C19	OD37
N25	A17	R02	C20	OD34
N25	A17	R02	C21	OD43
N25	A17	R02	C22	OD51
Node	**Arc**	**DS1**	**DS0**	**OD**
N25	A17	R02	C23	OD43
N25	A17	R02	C24	OD04
N25	A17	R03	C01	OD04
N25	A17	R03	C02	OD41
N25	A17	R03	C03	OD33
N25	A17	R03	C04	OD33
N25	A17	R03	C05	OD32
N25	A17	R03	C06	OD41
N25	A17	R03	C08	OD41
N25	A17	R03	C09	OD34
N25	A17	R03	C10	OD51
N25	A17	R03	C11	OD51
N25	A17	R03	C15	OD47
N25	A17	R03	C16	OD46
N25	A17	R03	C18	OD43
N25	A17	R03	C19	OD39
N25	A17	R03	C20	OD39
N25	A17	R03	C21	OD43
N25	A17	R03	C22	OD43
N25	A17	R03	C23	OD14
N25	A17	R03	C24	OD34
N25	A17	R04	C01	OD41
N25	A17	R04	C02	OD32
N25	A17	R04	C03	OD41
N25	A17	R04	C04	OD04
N25	A17	R04	C05	OD41
N25	A17	R04	C06	OD18
N25	A17	R04	C07	OD39
N25	A17	R04	C08	OD44
N25	A17	R04	C09	OD44
N25	A17	R04	C10	OD44
N25	A17	R04	C11	OD04
N25	A17	R04	C12	OD51
N25	A17	R04	C13	OD04
N25	A17	R04	C14	OD41
N25	A17	R04	C17	OD42
N25	A17	R04	C18	OD44
N25	A17	R04	C19	OD36
N25	A17	R04	C21	OD34
N25	A17	R04	C22	OD16
N25	A17	R04	C23	OD04
N25	A17	R04	C24	OD36
N25	A17	R05	C01	OD34
N25	A17	R05	C02	OD34
N25	A17	R05	C05	OD41
N25	A17	R05	C06	OD53
N25	A17	R05	C08	OD52
N25	A17	R05	C10	OD51
N25	A17	R05	C11	OD51
N25	A17	R05	C12	OD33
N25	A17	R05	C13	OD33
N25	A17	R05	C14	OD33
N25	A17	R05	C15	OD33
N25	A17	R05	C16	OD41
N25	A17	R05	C17	OD34
N25	A17	R05	C18	OD04
N25	A17	R05	C21	OD43
N25	A17	R05	C22	OD04
N25	A17	R05	C23	OD51
N25	A17	R05	C24	OD42
N25	A17	R06	C01	OD41
N25	A17	R06	C02	OD04
N25	A17	R06	C03	OD41
N25	A17	R06	C04	OD39
N25	A17	R06	C05	OD39
N25	A17	R06	C06	OD39
Node	**Arc**	**DS1**	**DS0**	**OD**
N25	A17	R06	C07	OD39
N25	A17	R06	C10	OD18
N25	A17	R06	C11	OD04
N25	A17	R06	C12	OD50
N25	A17	R06	C15	OD39
N25	A17	R06	C17	OD36
N25	A17	R06	C18	OD35
N25	A17	R06	C19	OD04
N25	A17	R06	C20	OD51
N25	A17	R06	C21	OD42
N25	A17	R06	C22	OD55
N25	A17	R06	C23	OD04
N25	A17	R06	C24	OD04
N25	A17	R07	C03	OD23
N25	A17	R07	C04	OD41
N25	A17	R07	C05	OD41
N25	A17	R07	C06	OD32
N25	A17	R07	C07	OD38
N25	A17	R07	C08	OD16
N25	A17	R07	C10	OD36
N25	A17	R07	C11	OD35
N25	A17	R07	C12	OD34
N25	A17	R07	C13	OD34
N25	A17	R07	C14	OD33
N25	A17	R07	C15	OD32
N25	A17	R07	C17	OD38
N25	A17	R07	C18	OD33
N25	A17	R07	C20	OD34
N25	A17	R07	C21	OD52
N25	A17	R07	C23	OD51
N25	A17	R07	C24	OD51
N25	A17	R08	ALL	OD33
N25	A17	R09	ALL	OD16
N25	A17	R10	ALL	OD16

N25	A17	R11	ALL	OD16
N25	A17	R12	ALL	OD16
N25	A17	R13	ALL	OD16
N25	A17	R14	ALL	OD16
N25	A17	R15	ALL	OD16
N25	A17	R16	ALL	OD16
N25	A17	R17	ALL	OD16
N25	A17	R18	ALL	OD14
N25	A17	R19	ALL	OD21
N25	A17	R20	ALL	OD51
N25	A17	R21	ALL	OD16
N25	A17	R22	ALL	OD33
N25	A17	R23	ALL	OD06
N25	A17	R24	ALL	OD04
N25	A17	R25	ALL	OD16
N25	A17	R26	ALL	OD11
N25	A17	R27	ALL	OD33
N25	A17	R28	ALL	OD33
N25	A25	R01	C01	OD56
N25	A25	R01	C03	OD08
N25	A25	R01	C09	OD33
N25	A25	R01	C10	OD51
N25	A25	R01	C18	OD04
N25	A25	R01	C19	OD04
N25	A25	R01	C20	OD33
N25	A25	R01	C21	OD57
N25	A25	R01	C22	OD04
N25	A25	R01	C23	OD04
N25	A25	R01	C24	OD04
N25	A25	R02	C01	OD33
N25	A25	R02	C08	OD04
N25	A25	R02	C10	OD14

Node	**Arc**	**DS1**	**DS0**	**OD**
N25	A25	R02	C19	OD04
N25	A25	R02	C24	OD04
N25	A25	R03	C02	OD33
N25	A25	R03	C03	OD33
N25	A25	R03	C04	OD04
N25	A25	R03	C07	OD11
N25	A25	R03	C09	OD51
N25	A25	R03	C10	OD51
N25	A25	R03	C14	OD51
N25	A25	R03	C17	OD04
N25	A25	R03	C21	OD18
N25	A25	R03	C23	OD04
N25	A25	R04	C01	OD51
N25	A25	R04	C03	OD04
N25	A25	R04	C05	OD33
N25	A25	R04	C07	OD04
N25	A25	R04	C08	OD04
N25	A25	R04	C10	OD51
N25	A25	R04	C14	OD16
N25	A25	R04	C15	OD51
N25	A25	R04	C17	OD04
N25	A25	R04	C18	OD51
N25	A25	R04	C19	OD51
N25	A25	R04	C22	OD04
N25	A25	R05	C07	OD16
N25	A25	R05	C13	OD33
N25	A25	R05	C14	OD33
N25	A25	R05	C15	OD23
N25	A25	R05	C17	OD59
N25	A25	R05	C18	OD51
N25	A25	R05	C22	OD51
N25	A25	R05	C23	OD51
N25	A25	R05	C24	OD18

N25	A25	R06	ALL	OD16
N25	A25	R07	ALL	OD33
N25	A25	R08	ALL	OD06
N25	A25	R09	ALL	OD33
N25	A25	R10	ALL	OD11
N25	A25	R11	ALL	OD16
N25	A25	R12	ALL	OD16
N25	A25	R13	ALL	OD16
N25	A25	R14	ALL	OD16
N25	A25	R15	ALL	OD16
N25	A25	R16	ALL	OD16
N25	A25	R17	ALL	OD16
N25	A25	R18	ALL	OD33
N25	A25	R19	ALL	OD16
N25	A25	R20	ALL	OD59
N25	A25	R21	ALL	OD16
N25	A25	R22	ALL	OD16
N25	A25	R23	ALL	OD21
N25	A25	R24	ALL	OD51
N25	A25	R25	ALL	OD04
N25	A25	R26	ALL	OD33
N25	A25	R27	ALL	OD14
N25	A25	R28	ALL	OD58
N25	A26	R01	C01	OD46
N25	A26	R01	C02	OD34
N25	A26	R01	C03	OD34
N25	A26	R01	C04	OD34
N25	A26	R01	C05	OD34
N25	A26	R01	C06	OD34
N25	A26	R01	C07	OD34
N25	A26	R01	C08	OD34
N25	A26	R01	C09	OD61
N25	A26	R01	C10	OD34

Node	**Arc**	**DS1**	**DS0**	**OD**
N25	A26	R01	C11	OD34
N25	A26	R01	C12	OD61
N25	A26	R01	C13	OD47
N25	A26	R01	C14	OD47
N25	A26	R01	C15	OD61
N25	A26	R01	C17	OD55
N25	A26	R01	C18	OD47
N25	A26	R02	C02	OD46
N25	A26	R02	C06	OD34
N25	A26	R02	C16	OD34
N25	A26	R02	C17	OD34
N25	A26	R02	C18	OD34
N25	A26	R02	C20	OD61
N25	A28	R01	C01	OD39
N25	A28	R01	C02	OD40
N25	A28	R01	C03	OD43
N25	A28	R01	C04	OD41
N25	A28	R01	C05	OD43
N25	A28	R01	C06	OD44
N25	A28	R01	C17	OD42
N25	A28	R01	C20	OD50
N25	A28	R01	C21	OD41
N25	A28	R01	C22	OD41
N25	A28	R01	C23	OD36
N25	A28	R01	C24	OD41
N25	A28	R02	C01	OD38
N25	A28	R02	C10	OD41
N25	A28	R02	C12	OD36
N25	A28	R02	C19	OD37
N25	A28	R03	C01	OD41
N25	A28	R03	C04	OD39
N25	A28	R03	C05	OD39

N25	A28	R03	C06	OD42
N25	A28	R03	C08	OD61
N25	A28	R03	C09	OD36
N25	A28	R03	C11	OD44
N25	A28	R03	C14	OD53
N25	A28	R03	C16	OD43
N25	A28	R03	C18	OD52
N25	A28	R04	C04	OD43
N25	A28	R04	C11	OD52
N25	A28	R04	C13	OD39
N25	A28	R04	C21	OD42
N25	A28	R04	C22	OD41
N25	A28	R04	C23	OD61
N25	A28	R04	C24	OD44
N25	A28	R05	C02	OD41
N25	A28	R05	C03	OD41
N25	A28	R05	C05	OD39
N25	A28	R05	C06	OD57
N25	A28	R05	C10	OD59
N25	A28	R05	C20	OD37
N25	A28	R05	C23	OD39
N25	A28	R05	C24	OD39
N25	A28	R06	C12	OD43
N25	A28	R06	C15	OD44
N25	A28	R06	C16	OD41
N25	A28	R06	C17	OD38
N25	A28	R06	C18	OD43
N25	A28	R06	C19	OD43
N25	A28	R06	C20	OD43
N25	A28	R06	C21	OD52
N25	A28	R06	C23	OD41
N25	A28	R07	C05	OD61
N25	A28	R07	C06	OD61
N25	A28	R07	C08	OD36
Node	**Arc**	**DS1**	**DS0**	**OD**
N25	A28	R07	C09	OD44
N25	A28	R07	C10	OD39
N25	A28	R07	C16	OD44
N25	A28	R07	C17	OD44
N25	A28	R07	C18	OD44
N25	A28	R07	C23	OD43
N25	A28	R08	C01	OD44
N25	A28	R08	C03	OD39
N25	A28	R08	C11	OD40
N25	A28	R08	C16	OD43
N25	A28	R08	C20	OD41
N25	A28	R08	C21	OD41
N25	A28	R08	C22	OD36
N25	A28	R08	C23	OD41
N25	A28	R09	C06	OD44
N25	A28	R10	C01	OD35
N25	A28	R10	C02	OD35
N25	A28	R10	C07	OD35
N25	A28	R11	ALL	OD58
N25	A28	R12	ALL	OD59
N26	A25	R01	C01	OD56
N26	A25	R01	C03	OD08
N26	A25	R01	C09	OD33
N26	A25	R01	C10	OD51
N26	A25	R01	C18	OD04
N26	A25	R01	C19	OD04
N26	A25	R01	C20	OD33
N26	A25	R01	C21	OD57
N26	A25	R01	C22	OD04
N26	A25	R01	C23	OD04
N26	A25	R01	C24	OD04
N26	A25	R02	C01	OD33
N26	A25	R02	C08	OD04
N26	A25	R02	C10	OD14
N26	A25	R02	C19	OD04
N26	A25	R02	C24	OD04
N26	A25	R03	C02	OD33
N26	A25	R03	C03	OD33
N26	A25	R03	C04	OD04
N26	A25	R03	C07	OD11
N26	A25	R03	C09	OD51
N26	A25	R03	C10	OD51
N26	A25	R03	C14	OD51
N26	A25	R03	C17	OD04
N26	A25	R03	C21	OD18
N26	A25	R03	C23	OD04
N26	A25	R04	C01	OD51
N26	A25	R04	C03	OD04
N26	A25	R04	C05	OD33
N26	A25	R04	C07	OD04
N26	A25	R04	C08	OD04
N26	A25	R04	C10	OD51
N26	A25	R04	C14	OD16
N26	A25	R04	C15	OD51
N26	A25	R04	C17	OD04
N26	A25	R04	C18	OD51
N26	A25	R04	C19	OD51
N26	A25	R04	C22	OD04
N26	A25	R05	C07	OD16
N26	A25	R05	C13	OD33
N26	A25	R05	C14	OD33
N26	A25	R05	C15	OD23
N26	A25	R05	C17	OD59
N26	A25	R05	C18	OD51
N26	A25	R05	C22	OD51
N26	A25	R05	C23	OD51
Node	**Arc**	**DS1**	**DS0**	**OD**
N26	A25	R05	C24	OD18
N26	A25	R06	ALL	OD16
N26	A25	R07	ALL	OD33
N26	A25	R08	ALL	OD06
N26	A25	R09	ALL	OD33
N26	A25	R10	ALL	OD11
N26	A25	R11	ALL	OD16
N26	A25	R12	ALL	OD16
N26	A25	R13	ALL	OD16
N26	A25	R14	ALL	OD16
N26	A25	R15	ALL	OD16
N26	A25	R16	ALL	OD16
N26	A25	R17	ALL	OD16
N26	A25	R18	ALL	OD33
N26	A25	R19	ALL	OD16
N26	A25	R20	ALL	OD59
N26	A25	R21	ALL	OD16
N26	A25	R22	ALL	OD16
N26	A25	R23	ALL	OD21
N26	A25	R24	ALL	OD51
N26	A25	R25	ALL	OD04
N26	A25	R26	ALL	OD33
N26	A25	R27	ALL	OD14
N26	A25	R28	ALL	OD58
N27	A27	R01	C01	OD46
N27	A27	R01	C02	OD34
N27	A27	R01	C03	OD34
N27	A27	R01	C04	OD34
N27	A27	R01	C05	OD34
N27	A27	R01	C06	OD34

Node	Arc	DS1	DS0	OD
N27	A27	R01	C07	OD34
N27	A27	R01	C08	OD34
N27	A27	R01	C09	OD61
N27	A27	R01	C10	OD34
N27	A27	R01	C11	OD34
N27	A27	R01	C12	OD61
N27	A27	R01	C13	OD60
N27	A27	R01	C14	OD60
N27	A27	R01	C15	OD61
N27	A27	R01	C16	OD60
N27	A27	R01	C17	OD55
N27	A27	R02	C02	OD46
N27	A27	R02	C06	OD34
N27	A27	R02	C16	OD34
N27	A27	R02	C17	OD34
N27	A27	R02	C18	OD34
N27	A27	R02	C20	OD61
N28	A26	R01	C01	OD46
N28	A26	R01	C02	OD34
N28	A26	R01	C03	OD34
N28	A26	R01	C04	OD34
N28	A26	R01	C05	OD34
N28	A26	R01	C06	OD34
N28	A26	R01	C07	OD34
N28	A26	R01	C08	OD34
N28	A26	R01	C09	OD61
N28	A26	R01	C10	OD34
N28	A26	R01	C11	OD34
N28	A26	R01	C12	OD61
N28	A26	R01	C13	OD47
N28	A26	R01	C14	OD47
N28	A26	R01	C15	OD61
N28	A26	R01	C17	OD55
N28	A26	R01	C18	OD47
N28	A26	R02	C02	OD46
N28	A26	R02	C06	OD34
N28	A26	R02	C16	OD34
N28	A26	R02	C17	OD34
N28	A26	R02	C18	OD34
N28	A26	R02	C20	OD61
N28	A27	R01	C01	OD46
N28	A27	R01	C02	OD34
N28	A27	R01	C03	OD34
N28	A27	R01	C04	OD34
N28	A27	R01	C05	OD34
N28	A27	R01	C06	OD34
N28	A27	R01	C07	OD34
N28	A27	R01	C08	OD34
N28	A27	R01	C09	OD61
N28	A27	R01	C10	OD34
N28	A27	R01	C11	OD34
N28	A27	R01	C12	OD61
N28	A27	R01	C13	OD60
N28	A27	R01	C14	OD60
N28	A27	R01	C15	OD61
N28	A27	R01	C16	OD60
N28	A27	R01	C17	OD55
N28	A27	R02	C02	OD46
N28	A27	R02	C06	OD34
N28	A27	R02	C16	OD34
N28	A27	R02	C17	OD34
N28	A27	R02	C18	OD34
N28	A27	R02	C20	OD61
N29	A28	R01	C01	OD39
N29	A28	R01	C02	OD40
N29	A28	R01	C03	OD43
N29	A28	R01	C04	OD41
N29	A28	R01	C05	OD43
N29	A28	R01	C06	OD44
N29	A28	R01	C17	OD42
N29	A28	R01	C20	OD50
N29	A28	R01	C21	OD41
N29	A28	R01	C22	OD41
N29	A28	R01	C23	OD36
N29	A28	R01	C24	OD41
N29	A28	R02	C01	OD38
N29	A28	R02	C10	OD41
N29	A28	R02	C12	OD36
N29	A28	R02	C19	OD37
N29	A28	R03	C01	OD41
N29	A28	R03	C04	OD39
N29	A28	R03	C05	OD39
N29	A28	R03	C06	OD42
N29	A28	R03	C08	OD61
N29	A28	R03	C09	OD36
N29	A28	R03	C11	OD44
N29	A28	R03	C14	OD53
N29	A28	R03	C16	OD43
N29	A28	R03	C18	OD52
N29	A28	R04	C04	OD43
N29	A28	R04	C11	OD52
N29	A28	R04	C13	OD39
N29	A28	R04	C21	OD42
N29	A28	R04	C22	OD41
N29	A28	R04	C23	OD61
N29	A28	R04	C24	OD44
N29	A28	R05	C02	OD41
N29	A28	R05	C03	OD41
N29	A28	R05	C05	OD39
N29	A28	R05	C06	OD57
N29	A28	R05	C10	OD59
N29	A28	R05	C20	OD37
N29	A28	R05	C23	OD39
N29	A28	R05	C24	OD39
N29	A28	R06	C12	OD43
N29	A28	R06	C15	OD44
N29	A28	R06	C16	OD41
N29	A28	R06	C17	OD38
N29	A28	R06	C18	OD43
N29	A28	R06	C19	OD43
N29	A28	R06	C20	OD43
N29	A28	R06	C21	OD52
N29	A28	R06	C23	OD41
N29	A28	R07	C05	OD61
N29	A28	R07	C06	OD61
N29	A28	R07	C08	OD36
N29	A28	R07	C09	OD44
N29	A28	R07	C10	OD39
N29	A28	R07	C16	OD44
N29	A28	R07	C17	OD44
N29	A28	R07	C18	OD44
N29	A28	R07	C23	OD43
N29	A28	R08	C01	OD44
N29	A28	R08	C03	OD39
N29	A28	R08	C11	OD40
N29	A28	R08	C16	OD43
N29	A28	R08	C20	OD41
N29	A28	R08	C21	OD41
N29	A28	R08	C22	OD36
N29	A28	R08	C23	OD41

N29	A28	R09	C06	OD44
N29	A28	R10	C01	OD35
N29	A28	R10	C02	OD35
N29	A28	R10	C07	OD35
N29	A28	R11	ALL	OD58
N29	A28	R12	ALL	OD59
N29	A29	R01	C01	OD39
N29	A29	R01	C02	OD40
N29	A29	R01	C03	OD43
N29	A29	R01	C04	OD41
N29	A29	R01	C05	OD43
N29	A29	R01	C06	OD44
N29	A29	R01	C17	OD42
N29	A29	R01	C20	OD50
N29	A29	R01	C21	OD41
N29	A29	R01	C22	OD41
N29	A29	R01	C23	OD36
N29	A29	R01	C24	OD41
N29	A29	R02	C01	OD38
N29	A29	R02	C10	OD41
N29	A29	R02	C12	OD36
N29	A29	R02	C19	OD37
N29	A29	R03	C01	OD41
N29	A29	R03	C04	OD39
N29	A29	R03	C05	OD39
N29	A29	R03	C06	OD42
N29	A29	R03	C08	OD61
N29	A29	R03	C09	OD36
N29	A29	R03	C11	OD44
N29	A29	R03	C14	OD53
N29	A29	R03	C16	OD43
N29	A29	R03	C18	OD52
N29	A29	R04	C04	OD43
N29	A29	R04	C11	OD52
N29	A29	R04	C13	OD39
N29	A29	R04	C21	OD42
N29	A29	R04	C22	OD41
N29	A29	R04	C23	OD61
Node	**Arc**	**DS1**	**DS0**	**OD**
N29	A29	R04	C24	OD44
N29	A29	R05	C02	OD41
N29	A29	R05	C03	OD41
N29	A29	R05	C05	OD39
N29	A29	R05	C06	OD57
N29	A29	R05	C10	OD59
N29	A29	R05	C20	OD37
N29	A29	R05	C23	OD39
N29	A29	R05	C24	OD39
N29	A29	R06	C12	OD43
N29	A29	R06	C15	OD44
N29	A29	R06	C16	OD41
N29	A29	R06	C17	OD38
N29	A29	R06	C18	OD43
N29	A29	R06	C19	OD43
N29	A29	R06	C20	OD43
N29	A29	R06	C21	OD52
N29	A29	R06	C23	OD41
N29	A29	R07	C05	OD61
N29	A29	R07	C06	OD61
N29	A29	R07	C08	OD36
N29	A29	R07	C09	OD44
N29	A29	R07	C10	OD39
N29	A29	R07	C16	OD44
N29	A29	R07	C17	OD44
N29	A29	R07	C18	OD44
N29	A29	R07	C23	OD43
N29	A29	R08	C01	OD44
N29	A29	R08	C03	OD39
N29	A29	R08	C11	OD40
N29	A29	R08	C16	OD43
N29	A29	R08	C20	OD41
N29	A29	R08	C21	OD41
N29	A29	R08	C22	OD36
N29	A29	R08	C23	OD41
N29	A29	R09	C06	OD44
N29	A29	R11	ALL	OD58
N29	A29	R12	ALL	OD59
N30	A29	R01	C01	OD39
N30	A29	R01	C02	OD40
N30	A29	R01	C03	OD43
N30	A29	R01	C04	OD41
N30	A29	R01	C05	OD43
N30	A29	R01	C06	OD44
N30	A29	R01	C17	OD42
N30	A29	R01	C20	OD50
N30	A29	R01	C21	OD41
N30	A29	R01	C22	OD41
N30	A29	R01	C23	OD36
N30	A29	R01	C24	OD41
N30	A29	R02	C01	OD38
N30	A29	R02	C10	OD41
N30	A29	R02	C12	OD36
N30	A29	R02	C19	OD37
N30	A29	R03	C01	OD41
N30	A29	R03	C04	OD39
N30	A29	R03	C05	OD39
N30	A29	R03	C06	OD42
N30	A29	R03	C08	OD61
N30	A29	R03	C09	OD36
N30	A29	R03	C11	OD44
N30	A29	R03	C14	OD53
N30	A29	R03	C16	OD43
N30	A29	R03	C18	OD52
N30	A29	R04	C04	OD43
N30	A29	R04	C11	OD52
Node	**Arc**	**DS1**	**DS0**	**OD**
N30	A29	R04	C13	OD39
N30	A29	R04	C21	OD42
N30	A29	R04	C22	OD41
N30	A29	R04	C23	OD61
N30	A29	R04	C24	OD44
N30	A29	R05	C02	OD41
N30	A29	R05	C03	OD41
N30	A29	R05	C05	OD39
N30	A29	R05	C06	OD57
N30	A29	R05	C10	OD59
N30	A29	R05	C20	OD37
N30	A29	R05	C23	OD39
N30	A29	R05	C24	OD39
N30	A29	R06	C12	OD43
N30	A29	R06	C15	OD44
N30	A29	R06	C16	OD41
N30	A29	R06	C17	OD38
N30	A29	R06	C18	OD43
N30	A29	R06	C19	OD43
N30	A29	R06	C20	OD43
N30	A29	R06	C21	OD52
N30	A29	R06	C23	OD41
N30	A29	R07	C05	OD61
N30	A29	R07	C06	OD61
N30	A29	R07	C08	OD36
N30	A29	R07	C09	OD44

N30	A29	R07	C10	OD39
N30	A29	R07	C16	OD44
N30	A29	R07	C17	OD44
N30	A29	R07	C18	OD44
N30	A29	R07	C23	OD43
N30	A29	R08	C01	OD44
N30	A29	R08	C03	OD39
N30	A29	R08	C11	OD40
N30	A29	R08	C16	OD43
N30	A29	R08	C20	OD41
N30	A29	R08	C21	OD41
N30	A29	R08	C22	OD36
N30	A29	R08	C23	OD41
N30	A29	R09	C06	OD44
N30	A29	R11	ALL	OD58
N30	A29	R12	ALL	OD59
N30	A30	R01	C01	OD61
N30	A30	R01	C03	OD61
N30	A30	R01	C10	OD61
N30	A30	R02	C01	OD61
N30	A30	R02	C08	OD37
N30	A30	R02	C13	OD37
N30	A31	R01	C01	OD59
N30	A31	R01	C02	OD41
N30	A31	R01	C04	OD41
N30	A31	R01	C05	OD39
N30	A31	R01	C06	OD39
N30	A31	R01	C07	OD41
N30	A31	R01	C08	OD52
N30	A31	R01	C10	OD43
N30	A31	R01	C11	OD43
N30	A31	R01	C15	OD39
N30	A31	R01	C16	OD43
N30	A31	R01	C18	OD44
N30	A31	R01	C19	OD38
N30	A31	R01	C21	OD41
N30	A31	R01	C23	OD41
N30	A31	R01	C24	OD50
N30	A31	R02	C03	OD40
N30	A31	R02	C04	OD40

Node	**Arc**	**DS1**	**DS0**	**OD**
N30	A31	R02	C05	OD41
N30	A31	R02	C06	OD43
N30	A31	R02	C14	OD43
N30	A31	R02	C21	OD43
N30	A31	R02	C22	OD53
N30	A31	R03	C01	OD41
N30	A31	R03	C02	OD41
N30	A31	R03	C03	OD41
N30	A31	R03	C05	OD44
N30	A31	R03	C07	OD52
N30	A31	R03	C12	OD42
N30	A31	R03	C13	OD42
N30	A31	R03	C15	OD41
N30	A31	R03	C16	OD41
N30	A31	R03	C18	OD39
N30	A31	R03	C19	OD39
N30	A31	R03	C20	OD43
N30	A31	R03	C21	OD43
N30	A31	R03	C24	OD52
N30	A31	R04	C01	OD39
N30	A31	R04	C04	OD43
N30	A31	R04	C05	OD39
N30	A31	R04	C07	OD44
N30	A31	R04	C08	OD44
N30	A31	R04	C09	OD44
N30	A31	R04	C10	OD44
N30	A31	R04	C14	OD38
N30	A31	R04	C15	OD44
N30	A31	R04	C16	OD44
N30	A31	R04	C17	OD44
N30	A31	R04	C18	OD57
N30	A31	R05	C14	OD41
N30	A31	R05	C15	OD41
N30	A31	R05	C20	OD43
N30	A31	R05	C23	OD42
N30	A31	R05	C24	OD41
N30	A31	R06	C05	OD39
N30	A31	R06	C06	OD39
N30	A31	R06	C18	OD44
N30	A31	R07	ALL	OD58
N30	A31	R08	ALL	OD59
N31	A30	R01	C01	OD61
N31	A30	R01	C03	OD61
N31	A30	R01	C10	OD61
N31	A30	R02	C01	OD61
N31	A30	R02	C08	OD37
N31	A30	R02	C13	OD37
N32	A31	R01	C01	OD59
N32	A31	R01	C02	OD41
N32	A31	R01	C04	OD41
N32	A31	R01	C05	OD39
N32	A31	R01	C06	OD39
N32	A31	R01	C07	OD41
N32	A31	R01	C08	OD52
N32	A31	R01	C10	OD43
N32	A31	R01	C11	OD43
N32	A31	R01	C15	OD39
N32	A31	R01	C16	OD43
N32	A31	R01	C18	OD44
N32	A31	R01	C19	OD38
N32	A31	R01	C21	OD41
N32	A31	R01	C23	OD41
N32	A31	R01	C24	OD50
N32	A31	R02	C03	OD40
N32	A31	R02	C04	OD40
N32	A31	R02	C05	OD41

Node	**Arc**	**DS1**	**DS0**	**OD**
N32	A31	R02	C06	OD43
N32	A31	R02	C14	OD43
N32	A31	R02	C21	OD43
N32	A31	R02	C22	OD53
N32	A31	R03	C01	OD41
N32	A31	R03	C02	OD41
N32	A31	R03	C03	OD41
N32	A31	R03	C05	OD44
N32	A31	R03	C07	OD52
N32	A31	R03	C12	OD42
N32	A31	R03	C13	OD42
N32	A31	R03	C15	OD41
N32	A31	R03	C16	OD41
N32	A31	R03	C18	OD39
N32	A31	R03	C19	OD39
N32	A31	R03	C20	OD43
N32	A31	R03	C21	OD43
N32	A31	R03	C24	OD52
N32	A31	R04	C01	OD39
N32	A31	R04	C04	OD43
N32	A31	R04	C05	OD39
N32	A31	R04	C07	OD44
N32	A31	R04	C08	OD44
N32	A31	R04	C09	OD44

Node	Arc	DS1	DS0	OD
N32	A31	R04	C10	OD44
N32	A31	R04	C14	OD38
N32	A31	R04	C15	OD44
N32	A31	R04	C16	OD44
N32	A31	R04	C17	OD44
N32	A31	R04	C18	OD57
N32	A31	R05	C14	OD41
N32	A31	R05	C15	OD41
N32	A31	R05	C20	OD43
N32	A31	R05	C23	OD42
N32	A31	R05	C24	OD41
N32	A31	R06	C05	OD39
N32	A31	R06	C06	OD39
N32	A31	R06	C18	OD44
N32	A31	R07	ALL	OD58
N32	A31	R08	ALL	OD59
N32	A33	R01	C02	OD50
N32	A33	R01	C03	OD59
N32	A33	R01	C05	OD52
N32	A33	R01	C06	OD52
N32	A33	R01	C08	OD42
N32	A33	R01	C14	OD42
N32	A33	R01	C15	OD44
N32	A33	R02	C21	OD43
N32	A33	R03	C01	OD39
N32	A33	R03	C02	OD39
N32	A33	R03	C03	OD44
N32	A33	R03	C04	OD39
N32	A33	R03	C05	OD39
N32	A33	R03	C06	OD39
N32	A33	R03	C07	OD39
N32	A33	R03	C08	OD44
N32	A33	R03	C17	OD52
N32	A33	R03	C20	OD43
N32	A33	R03	C21	OD57
N32	A33	R03	C22	OD39
N32	A33	R03	C23	OD39
N32	A33	R03	C24	OD39
N32	A33	R04	C02	OD44
N32	A33	R04	C19	OD43
N32	A33	R04	C20	OD44
N32	A33	R04	C24	OD53
N32	A33	R05	C04	OD43
N32	A33	R05	C05	OD43
N32	A33	R05	C06	OD43
N32	A33	R05	C10	OD44
N32	A33	R05	C14	OD43
N32	A33	R05	C20	OD44
N32	A33	R05	C21	OD41
N32	A33	R06	C01	OD44
N32	A33	R06	C02	OD42
N32	A33	R06	C04	OD43
N32	A33	R06	C06	OD44
N32	A33	R06	C07	OD41
N32	A33	R06	C08	OD41
N32	A33	R06	C09	OD41
N32	A33	R06	C10	OD41
N32	A33	R06	C11	OD44
N32	A33	R06	C12	OD43
N32	A33	R06	C13	OD41
N32	A33	R06	C14	OD41
N32	A33	R06	C15	OD41
N32	A33	R06	C16	OD41
N32	A33	R06	C17	OD41
N32	A33	R06	C18	OD41
N32	A33	R06	C19	OD43
N32	A33	R06	C20	OD41
N32	A33	R06	C21	OD41
N32	A33	R06	C22	OD40
N32	A33	R06	C23	OD41
N32	A33	R06	C24	OD40
N32	A33	R07	ALL	OD59
N32	A33	R08	ALL	OD58
N34	A33	R01	C02	OD50
N34	A33	R01	C03	OD59
N34	A33	R01	C05	OD52
N34	A33	R01	C06	OD52
N34	A33	R01	C08	OD42
N34	A33	R01	C14	OD42
N34	A33	R01	C15	OD44
N34	A33	R02	C21	OD43
N34	A33	R03	C01	OD39
N34	A33	R03	C02	OD39
N34	A33	R03	C03	OD44
N34	A33	R03	C04	OD39
N34	A33	R03	C05	OD39
N34	A33	R03	C06	OD39
N34	A33	R03	C07	OD39
N34	A33	R03	C08	OD44
N34	A33	R03	C17	OD52
N34	A33	R03	C20	OD43
N34	A33	R03	C21	OD57
N34	A33	R03	C22	OD39
N34	A33	R03	C23	OD39
N34	A33	R03	C24	OD39
N34	A33	R04	C02	OD44
N34	A33	R04	C19	OD43
N34	A33	R04	C20	OD44
N34	A33	R04	C24	OD53
N34	A33	R05	C04	OD43
N34	A33	R05	C05	OD43
N34	A33	R05	C06	OD43
N34	A33	R05	C10	OD44
N34	A33	R05	C14	OD43
N34	A33	R05	C20	OD44
N34	A33	R05	C21	OD41
N34	A33	R06	C01	OD44
N34	A33	R06	C02	OD42
N34	A33	R06	C04	OD43
N34	A33	R06	C06	OD44
N34	A33	R06	C07	OD41
N34	A33	R06	C08	OD41
N34	A33	R06	C09	OD41
N34	A33	R06	C10	OD41
N34	A33	R06	C11	OD44
N34	A33	R06	C12	OD43
N34	A33	R06	C13	OD41
N34	A33	R06	C14	OD41
N34	A33	R06	C15	OD41
N34	A33	R06	C16	OD41
N34	A33	R06	C17	OD41
N34	A33	R06	C18	OD41
N34	A33	R06	C19	OD43
N34	A33	R06	C20	OD41
N34	A33	R06	C21	OD41
N34	A33	R06	C22	OD40
N34	A33	R06	C23	OD41
N34	A33	R06	C24	OD40
N34	A33	R07	ALL	OD59
N34	A33	R08	ALL	OD58

Node	Arc	DS1	DS0	OD
N34	A34	R01	C02	OD50
N34	A34	R01	C03	OD59
N34	A34	R01	C05	OD52
N34	A34	R01	C06	OD52
N34	A34	R01	C08	OD42
N34	A34	R01	C14	OD42
N34	A34	R01	C15	OD44
N34	A34	R02	C21	OD43
N34	A34	R03	C03	OD44
N34	A34	R03	C08	OD44
N34	A34	R03	C17	OD52
N34	A34	R03	C20	OD43
N34	A34	R04	C02	OD44
N34	A34	R04	C19	OD43
N34	A34	R04	C20	OD44
N34	A34	R04	C24	OD53
N34	A34	R05	C04	OD43
N34	A34	R05	C05	OD43
N34	A34	R05	C06	OD43
N34	A34	R05	C10	OD44
N34	A34	R05	C14	OD43
N34	A34	R05	C20	OD44
N34	A34	R05	C21	OD41
N34	A34	R06	C01	OD44
N34	A34	R06	C02	OD42
N34	A34	R06	C04	OD43
N34	A34	R06	C06	OD44
N34	A34	R06	C07	OD41
N34	A34	R06	C08	OD41
N34	A34	R06	C09	OD41
N34	A34	R06	C10	OD41
N34	A34	R06	C11	OD44
N34	A34	R06	C12	OD43
N34	A34	R06	C13	OD41
N34	A34	R06	C14	OD41
N34	A34	R06	C15	OD41
N34	A34	R06	C16	OD41
N34	A34	R06	C17	OD41
N34	A34	R06	C18	OD41
N34	A34	R06	C19	OD43
N34	A34	R06	C20	OD41
N34	A34	R06	C21	OD41
N34	A34	R06	C22	OD40
N34	A34	R06	C23	OD41
N34	A34	R06	C24	OD40
N34	A34	R07	ALL	OD58
N34	A34	R08	ALL	OD59
N35	A34	R01	C02	OD50
N35	A34	R01	C03	OD59
N35	A34	R01	C05	OD52
N35	A34	R01	C06	OD52
N35	A34	R01	C08	OD42
N35	A34	R01	C14	OD42
N35	A34	R01	C15	OD44
N35	A34	R02	C21	OD43
N35	A34	R03	C03	OD44
N35	A34	R03	C08	OD44
N35	A34	R03	C17	OD52
N35	A34	R03	C20	OD43
N35	A34	R04	C02	OD44
N35	A34	R04	C19	OD43
N35	A34	R04	C20	OD44
N35	A34	R04	C24	OD53
N35	A34	R05	C04	OD43
N35	A34	R05	C05	OD43
N35	A34	R05	C06	OD43
N35	A34	R05	C10	OD44
N35	A34	R05	C14	OD43
N35	A34	R05	C20	OD44
N35	A34	R05	C21	OD41
N35	A34	R06	C01	OD44
N35	A34	R06	C02	OD42
N35	A34	R06	C04	OD43
N35	A34	R06	C06	OD44
N35	A34	R06	C07	OD41
N35	A34	R06	C08	OD41
N35	A34	R06	C09	OD41
N35	A34	R06	C10	OD41
N35	A34	R06	C11	OD44
N35	A34	R06	C12	OD43
N35	A34	R06	C13	OD41
N35	A34	R06	C14	OD41
N35	A34	R06	C15	OD41
N35	A34	R06	C16	OD41
N35	A34	R06	C17	OD41
N35	A34	R06	C18	OD41
N35	A34	R06	C19	OD43
N35	A34	R06	C20	OD41
N35	A34	R06	C21	OD41
N35	A34	R06	C22	OD40
N35	A34	R06	C23	OD41
N35	A34	R06	C24	OD40
N35	A34	R07	ALL	OD58
N35	A34	R08	ALL	OD59
N35	A35	R01	C01	OD53
N35	A35	R01	C02	OD41
N35	A35	R01	C03	OD41
N35	A35	R01	C04	OD41
N35	A35	R01	C08	OD41
N35	A35	R01	C09	OD52
N35	A35	R01	C10	OD41
N35	A35	R01	C20	OD41
N35	A35	R01	C24	OD41
N35	A35	R02	C01	OD41
N35	A35	R02	C06	OD41
N35	A35	R02	C07	OD52
N35	A35	R02	C08	OD52
N35	A35	R02	C20	OD41
N35	A35	R02	C23	OD50
N35	A35	R03	C01	OD41
N35	A35	R03	C03	OD41
N35	A35	R03	C13	OD41
N35	A35	R03	C24	OD41
N35	A35	R04	ALL	OD58
N35	A36	R01	C01	OD44
N35	A36	R01	C04	OD59
N35	A36	R01	C07	OD43
N35	A36	R01	C08	OD44
N35	A36	R01	C15	OD44
N35	A36	R01	C19	OD44
N35	A36	R01	C20	OD44
N35	A36	R01	C21	OD44
N35	A36	R01	C22	OD42
N35	A36	R01	C23	OD42
N35	A36	R02	C01	OD44
N35	A36	R02	C04	OD42
N35	A36	R02	C06	OD44
N35	A36	R02	C09	OD43
N35	A36	R02	C10	OD43
N35	A36	R02	C17	OD43

Node	Arc	DS1	DS0	OD
N35	A36	R02	C19	OD43
N35	A36	R02	C22	OD44
N35	A36	R03	C03	OD43
N35	A36	R03	C05	OD43
N35	A36	R03	C06	OD43
N35	A36	R03	C09	OD43
N35	A36	R03	C12	OD43
N35	A36	R03	C23	OD44
N35	A36	R04	ALL	OD59
N36	A35	R01	C01	OD53
N36	A35	R01	C02	OD41
N36	A35	R01	C03	OD41
N36	A35	R01	C04	OD41
N36	A35	R01	C08	OD41
N36	A35	R01	C09	OD52
N36	A35	R01	C10	OD41
N36	A35	R01	C20	OD41
N36	A35	R01	C24	OD41
N36	A35	R02	C01	OD41
N36	A35	R02	C06	OD41
N36	A35	R02	C07	OD52
N36	A35	R02	C08	OD52
N36	A35	R02	C20	OD41
N36	A35	R02	C23	OD50
N36	A35	R03	C01	OD41
N36	A35	R03	C03	OD41
N36	A35	R03	C13	OD41
N36	A35	R03	C24	OD41
N36	A35	R04	ALL	OD58
N37	A36	R01	C01	OD44
N37	A36	R01	C04	OD59
N37	A36	R01	C07	OD43
N37	A36	R01	C08	OD44
N37	A36	R01	C15	OD44
N37	A36	R01	C19	OD44
N37	A36	R01	C20	OD44
N37	A36	R01	C21	OD44
N37	A36	R01	C22	OD42
N37	A36	R01	C23	OD42
N37	A36	R02	C01	OD44
N37	A36	R02	C04	OD42
N37	A36	R02	C06	OD44
N37	A36	R02	C09	OD43
N37	A36	R02	C10	OD43
N37	A36	R02	C17	OD43
N37	A36	R02	C19	OD43
N37	A36	R02	C22	OD44
N37	A36	R03	C03	OD43
N37	A36	R03	C05	OD43
N37	A36	R03	C06	OD43
N37	A36	R03	C09	OD43
N37	A36	R03	C12	OD43
N37	A36	R03	C23	OD44
N37	A36	R04	ALL	OD59
N37	A37	R01	C01	OD43
N37	A37	R01	C03	OD43
N37	A37	R01	C09	OD43
N37	A37	R01	C16	OD43
N37	A37	R02	C06	OD43
N37	A37	R02	C08	OD43
N37	A37	R02	C09	OD43
N37	A37	R02	C10	OD43
N37	A37	R02	C12	OD43
N37	A37	R02	C21	OD43
N37	A38	R01	C01	OD59
N37	A38	R01	C02	OD44
N37	A38	R01	C03	OD44
N37	A38	R01	C04	OD44
N37	A38	R01	C09	OD44
N37	A38	R01	C10	OD44
N37	A38	R01	C12	OD44
N37	A38	R01	C13	OD44
N37	A38	R01	C22	OD44
N37	A38	R01	C23	OD44
N37	A38	R01	C24	OD44
N37	A38	R02	ALL	OD59
N38	A37	R01	C01	OD43
N38	A37	R01	C03	OD43
N38	A37	R01	C09	OD43
N38	A37	R01	C16	OD43
N38	A37	R02	C06	OD43
N38	A37	R02	C08	OD43
N38	A37	R02	C09	OD43
N38	A37	R02	C10	OD43
N38	A37	R02	C12	OD43
N38	A37	R02	C21	OD43
N39	A38	R01	C01	OD59
N39	A38	R01	C02	OD44
N39	A38	R01	C03	OD44
N39	A38	R01	C04	OD44
N39	A38	R01	C09	OD44
N39	A38	R01	C10	OD44
N39	A38	R01	C12	OD44
N39	A38	R01	C13	OD44
N39	A38	R01	C22	OD44
N39	A38	R01	C23	OD44
N39	A38	R01	C24	OD44
N39	A38	R02	ALL	OD59

APPENDIX C

MODEL 3A IN GAMS

The version of Model 3A in GAMS used to assign full DS1 demands and residual demands to arcs that do not connect to add-drop nodes or adjacent add-drop nodes of the Arizona network.

Gams model

```
* BMALL.GMS
* CHANNEL ASSIGNMENT FOR ARIZONA NETWORK MODEL 3A
* - IDENTIFICATION OF ADD-DROP NODES
* - DS1 PAIRING CONSTRAINTS AT ADD-DROP NODES
* - EQUIPMENT TYPE SELECTION FOR ADD-DROP NODES
* ASSUMPTIONS:
* - NODE JUNCTIONS WITH MORE THAN TWO ARCS USE DACS
* - OD PASSING THROUGH A NODE MUST MAINTAIN LINE AND CHANNEL CONSISTENCY

SETS
I ARCS /A01*A38/
K DS0 CHANNELS /C01 * C24/
J DS1 LINES /R01*R28/
L ORIGIN DESTINATION /OD01 * OD61/
N NODES /N01*N39/

PARAMETER ADMLIMIT MAXIMUM NUMBER OF ADD-DROPS ALLOWED BY EQUIPMENT
CHARACTERISTICS;
ADMLIMIT = 30;

PARAMETER DEMAND(L) NUMBER OF CHANNELS K REQUIRED FOR EACH OD L/
OD01   4
OD02   1
OD03  39
OD04  40
OD05   7
OD06  24
OD07  11
OD08   1
OD09   5
OD10  11
OD11  25
OD12   5
OD13   8
OD14  25
OD15  48
OD16 266
OD17  22
```

```
OD18   2
OD19  15
OD20   9
OD21  24
OD22   9
OD23   1
OD24  11
OD25  15
OD26   5
OD27  36
OD28   2
OD29   4
OD30   7
OD31   2
OD32   7
OD33 104
OD34  13
OD35   3
OD36   5
OD37   2
OD38   2
OD39   9
OD40   2
OD41  14
OD42   3
OD43  10
OD44  10
OD45   1
OD46   2
OD47   3
OD48   3
OD49   2
OD50   1
OD51  36
OD52   3
OD53   1
OD54   5
OD55   1
OD56   1
OD57   1
OD58  24
OD59  25
OD60   3
OD61   4 /;

TABLE D(L,I) ARCS NEEDED TO COMPLETE OD PATH
       A01  A02  A03  A04  A05  A06  A07  A08  A09  A10  A11  A12  A13  A14  A15
A16  A17  A18  A19  A20  A21  A22  A23  A24  A25  A26  A27  A28  A29  A30  A31
A32  A33  A34  A35  A36  A37  A38
OD01     1
OD02          1
OD03               1    1    1                   1    1         1              1
OD04               1    1    1                   1    1         1              1
1                                       1
OD05     1         1    1    1                   1    1         1              1
OD06     1         1    1    1                   1    1         1              1
1                                       1
OD07          1    1    1    1                   1    1         1              1
OD08          1    1    1    1                   1    1         1              1
1                                       1
OD09                    1    1                   1    1         1              1
OD10                              1              1    1         1              1
OD11                              1              1    1         1              1
1                                       1
OD12                                             1    1         1              1
OD13                                   1         1    1         1              1
```

```
OD14                                   1         1    1         1              1
1                                       1
OD15                                                  1         1              1
OD16                                                  1         1              1
1                                       1
OD17                                                            1              1
OD18                                                            1              1
1                                       1
OD19                                                                           1
OD20                                                                 1         1
OD21                                                                 1         1
1                                       1
OD22                                                                 1    1    1
OD23                                                                 1    1    1
1                                       1
OD24
1
OD25
1                   1
OD26
1                   1                   1
OD27
1                   1              1
OD28
1                   1         1
OD29
1                   1    1
OD30
1
OD31
1    1
OD32
1
OD33
1                                       1
OD34
1                                            1    1
OD35
1                                                      1
OD36
1                                                      1    1
OD37
1                                                      1    1    1
OD38
1                                                      1    1         1
OD39
1                                                      1    1         1
1
OD40
1                                                      1    1         1
1    1
OD41
1                                                      1    1         1
1    1    1
OD42
1                                                      1    1         1
1    1         1
OD43
1                                                      1    1         1
1    1         1    1
OD44
1                                                      1    1         1
1    1         1         1
OD45
1                   1
```

```
OD46
1    1                                             1    1
OD47
1    1                                             1
OD48
1    1
OD49
1         1
OD50
1    1              1                   1                   1    1         1
1    1    1
OD51
1    1              1              1         1
OD52
1    1              1              1                        1    1         1
1    1    1
OD53
1    1              1         1                             1    1         1
1    1    1
OD54
1
OD55
1    1    1                                   1    1
OD56
1
OD57
1              1    1         1         1
OD58
1              1    1         1         1    1    1
OD59
1              1    1         1         1    1         1         1
OD60
1
OD61
1    1    1    1    1                            ;

PARAMETER CAP(I) NUMBER OF DS1 LINES AVAILABLE ON EACH ARC/
A01  2
A02  2
A03  8
A04  8
A05  8
A06  2
A07  2
A08  0
A09 12
A10 28
A11  0
A12 28
A13  4
A14  4
A15 28
A16  8
A17 28
A18  2
A19  2
A20  8
A21  2
A22  2
A23  4
A24  2
A25 28
A26  2
A27  2
A28 12
A29 12
```

```
A30  2
A31  8
A32  0
A33  8
A34  8
A35  4
A36  4
A37  2
A38  2 /;

TABLE NODES(I,N) ARCS I THAT CONNECT AT EACH NODE N
     N01 N02 N03 N04 N05 N06 N07 N08 N09 N10 N11 N12 N13 N14 N15 N16 N17 N18 N19
N20 N21 N22 N23 N24 N25 N26 N27 N28 N29 N30 N31 N32 N33 N34 N35 N36 N37 N38 N39
A01    1   1
A02    1       1
A03    1           1
A04                1   1
A05                    1       1
A06                        1   1
A07                            1   1
A08                                1   1
A09                            1           1
A10                                        1   1
A11                                            1               1
A12                                            1   1
A13                                                1   1
A14                                                    1   1
A15                                                1               1
A16                                                                1   1
A17                                                                1
1
A18                                                                1
1
A19
1   1
A20                                                                    1   1
A21                                                                        1
1
A22                                                                        1
1
A23                                                                        1
1
A24                                                                        1   1
A25
1   1
A26
1           1
A27
1   1
A28
1               1
A29
1   1
A30
1   1
A31
1       1
A32
1   1
A33
1       1
A34
1   1
A35
1   1
```

```
A36
1       1
A37
1   1
A38
1       1;

*    ----   I M P O R T A N T  -  D O   N O T   A L T E R  ----
*THE EQUATIONS BELOW GENERATE ALL ADDITIONAL TABLES AND PARAMETERS.

PARAMETER ADMMAX MAXIMUM NUMBER OF ADD OR DROPS ALLOWED BY EQUIPMENT
CHARACTERISTICS;
ADMMAX = ADMLIMIT / 2;

PARAMETER REDUDS1(L) NUMBER OF FULL DS1 LINES DEMAND FOR EACH OD;
REDUDS1(L) = FLOOR(DEMAND(L)/24);

PARAMETER REDUCAP(I) RESIDUAL ARC CAPACITY;
REDUCAP(I) = CAP(I) - SUM(L, D(L,I)*REDUDS1(L));

PARAMETER RESIDUAL(L) RESIDUAL DEMAND FOR EACH OD;
RESIDUAL(L) = (DEMAND(L) -TRUNC (DEMAND(L)/ 24)* 24);

PARAMETER FULLOD(L) ODS THAT HAVE FULL DS1 LINES;
FULLOD(L)$(REDUDS1(L) GE 1) = 1;

PARAMETER AD(N) ADD-DROP NODE;
AD(N)$(SUM(I, NODES(I,N)) EQ 2) = 1;

PARAMETER ADI(I) ARCS CONNECTED TO ADD-DROP NODES;
ADI(I)$(SUM(N$AD(N), NODES(I,N)) GE 1) = 1;

PARAMETER NOTADI(I) ARCS THAT DO NOT CONNECT TO ADD-DROP NODES;
NOTADI(I)$(ADI(I) EQ 0) = 1;
DISPLAY NOTADI;

PARAMETER PASS2(N,L,I) ALL VALID NODE-OD-ARC COMBINATIONS;
PASS2(N,L,I)$ (D(L,I) AND NODES(I,N)) = 1 ;

PARAMETER PASSTHRU(N,L) ODS THAT PASS THROUGH NODE;
PASSTHRU(N,L)$(SUM(I, PASS2(N,L,I)) GE 2) = 1;

PARAMETER DROP(N,L) ODS THAT ADD-DROP AT NODE;
DROP(N,L)$(SUM(I, PASS2(N,L,I)) EQ 1) = 1;

PARAMETER CHANNEL(K) MAKE ALL DS0 CHANNELS AVAILABLE;
CHANNEL(K) = 1;

PARAMETER LINE(J) MAKE ALL DS1 LINES AVAILABLE;
LINE(J) = 1;

PARAMETER ARCCAP(I,J) NUMBER OF DS1 LINES ON EACH ARC;
ARCCAP(I,J)$(ORD(J) LE CAP(I)) = 1;

PARAMETER ARCCAP2(I,J) NUMBER OF RESIDUAL DS1 LINES ON EACH ARC;
ARCCAP2(I,J)$(ORD(J) LE REDUCAP(I)) = 1;

PARAMETER ARCCAP3(I,J) NUMBER OF DESIGNATED FULL DS1 LINES ON EACH ARC;
ARCCAP3(I,J) = ARCCAP(I,J) - ARCCAP2(I,J);

PARAMETER ARCCAP4(N,I,J) ARC CAPACITY AT NODE N;
ARCCAP4(N,I,J) = ARCCAP2(I,J) * NODES(I,N);

PARAMETER NODECAP(N,J) MAXIMUM CAPACITY AT NODE N;
NODECAP(N,J)$(SUM(I, ARCCAP4(N,I,J) GE 1)) = 1;
```

```
PARAMETER G1(L,I,J,K) ALL VALID OD ARC CHANNEL COMBINATIONS;
G1(L,I,J,K) = (D(L,I) * CHANNEL(K) * LINE(J))$ARCCAP2(I,J);

PARAMETER G3(L,I,J) ALL VALID OD ARC-FULL-DS1 COMBINATIONS;
G3(L,I,J) = (D(L,I)$FULLOD(L) * LINE(J))$ARCCAP3(I,J);

VARIABLES
X(L,I,J,K) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I, DS1 LINE J
AND DS0 CHANNEL K
W(N,L,J,K) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, DS0 CHANNEL K
PAIR AT NODE N
Y(L,I,J) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I AND DS1 LINE J
ACCESS(N,I,J) NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY ARC I, DS1 LINE J AT
NODE N
DS1(N,J) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, AT NODE N USED TO
DROP AND OR ADD DS0 CHANNELS
Z TOTAL;
BINARY VARIABLE X,W,Y,DS1;

EQUATIONS

ARCASSIGN(L,I) ASSIGN ONLY ONE ARC-DS1-DS0 FOR EACH UNIT OF DEMAND FOR EACH OD
CHANASSIGN(I,J,K) ARC-DS1-DS0 CHANNEL CAN BE ASSIGNED ONLY ONCE - MULTICOMMODITY
FULLDS1(L,I) ASSIGN ONLY ONE ARC-DS1 LINE FOR EACH FULL DS1 DEMAND FOR EACH OD L
DS1ASSIGN(I,J) ARC-DS1 LINE CAN BE ASSIGNED ONLY ONCE - MULTICOMMODITY
GOAL DEFINE OBJECTIVE FUNCTION;

ARCASSIGN(L,I)$(NOTADI(I)$D(L,I)).. SUM((J,K)$G1(L,I,J,K),
X(L,I,J,K)$ARCCAP2(I,J) * D(L,I)) =E= RESIDUAL(L);

CHANASSIGN(I,J,K)$(NOTADI(I)$ARCCAP2(I,J)).. SUM(L$G1(L,I,J,K), X(L,I,J,K)) =L=
1;

FULLDS1(L,I)$D(L,I).. SUM(J$G3(L,I,J), Y(L,I,J) * D(L,I)) =E= REDUDS1(L);

DS1ASSIGN(I,J).. SUM(L$G3(L,I,J), Y(L,I,J)) =L= 1;

GOAL.. Z =E= SUM((L,I,J)$G3(L,I,J), Y(L,I,J));

OPTION SOLPRINT = OFF;
OPTION RESLIM =14400;
MODEL FAST  /ALL/;
OPTION OPTCR = .01;
FAST.OPTFILE = 1;
SOLVE FAST USING MIP MAXIMIZING Z;
PARAMETER USEDRESID(N,I,J,K,L) ASSIGNMENT CHART FOR RESIDUAL DS1 LINES;
USEDRESID(N,I,J,K,L) = X.L(L,I,J,K)*NODES(I,N); OPTION USEDRESID:1:0:1;DISPLAY
USEDRESID;
PARAMETER USEDFULL(N,I,J,L) ASSIGNMENT CHART FOR FULL-DS1 LINES;
USEDFULL(N,I,J,L) = Y.L(L,I,J) * NODES(I,N); OPTION USEDFULL:1:0:1; DISPLAY
USEDFULL;
DISPLAY AD;
```

APPENDIX D

MODEL 3B IN GAMS

The version of Model 3B in GAMS used to assign residual demands to arcs connected to add-drop nodes or adjacent add-drop nodes. The model below evaluated node N10 of the Arizona network. Each evaluation required a change in parameter AD_n for the respective add-drop nodes identified by Model 3A.

Gams model

```
* BM10.GMS
* CHANNEL ASSIGNMENT FOR ARIZONA NETWORK MODEL 3B
* - IDENTIFICATION OF ADD-DROP NODES
* - DS1 PAIRING CONSTRAINTS AT ADD-DROP NODES
* - EQUIPMENT TYPE SELECTION FOR ADD-DROP NODES
* ASSUMPTIONS:
* - NODE JUNCTIONS WITH MORE THAN TWO ARCS USE DACS
* - OD PASSING THROUGH A NODE MUST MAINTAIN LINE AND CHANNEL CONSISTENCY

SETS
I ARCS /A01*A38/
K DS0 CHANNELS /C01 * C24/
J DS1 LINES /R01*R28/
L ORIGIN DESTINATION /OD01 * OD61/
N NODES /N01*N39/

PARAMETER ADMLIMIT MAXIMUM NUMBER OF ADD-DROPS ALLOWED BY EQUIPMENT
CHARACTERISTICS;
ADMLIMIT = 30;

PARAMETER DEMAND(L) NUMBER OF CHANNELS K REQUIRED FOR EACH OD L/
OD01   4
OD02   1
OD03  39
OD04  40
OD05   7
OD06  24
OD07  11
OD08   1
OD09   5
OD10  11
OD11  25
OD12   5
OD13   8
OD14  25
```

```
OD15  48
OD16 266
OD17  22
OD18   2
OD19  15
OD20   9
OD21  24
OD22   9
OD23   1
OD24  11
OD25  15
OD26   5
OD27  36
OD28   2
OD29   4
OD30   7
OD31   2
OD32   7
OD33 104
OD34  13
OD35   3
OD36   5
OD37   2
OD38   2
OD39   9
OD40   2
OD41  14
OD42   3
OD43  10
OD44  10
OD45   1
OD46   2
OD47   3
OD48   3
OD49   2
OD50   1
OD51  36
OD52   3
OD53   1
OD54   5
OD55   1
OD56   1
OD57   1
OD58  24
OD59  25
OD60   3
OD61   4 /;

TABLE D(L,I) ARCS NEEDED TO COMPLETE OD PATH
       A01  A02  A03  A04  A05  A06  A07  A08  A09  A10  A11  A12  A13  A14  A15
A16  A17  A18  A19  A20  A21  A22  A23  A24  A25  A26  A27  A28  A29  A30  A31
A32  A33  A34  A35  A36  A37  A38
OD01     1
OD02          1
OD03               1    1    1                   1    1         1              1
OD04               1    1    1                   1    1         1              1
1                                       1
OD05     1         1    1    1                   1    1         1              1
OD06     1         1    1    1                   1    1         1              1
1                                       1
OD07          1    1    1    1                   1    1         1              1
OD08          1    1    1    1                   1    1         1              1
1                                       1
OD09                    1    1                   1    1         1              1
OD10                              1              1    1         1              1
```

```
OD11                              1              1    1         1              1
1                                       1
OD12                                             1    1         1              1
OD13                                   1         1    1         1              1
OD14                                   1         1    1         1              1
1                                       1
OD15                                                  1         1              1
OD16                                                  1         1              1
1                                       1
OD17                                                            1              1
OD18                                                            1              1
1                                       1
OD19                                                                           1
OD20                                                                     1         1
OD21                                                                     1         1
1                                       1
OD22                                                                     1    1    1
OD23                                                                     1    1    1
1                                       1
OD24
1
OD25
1                   1
OD26
1                   1                   1
OD27
1                   1              1
OD28
1                   1         1
OD29
1                   1    1
OD30
1
OD31
1    1
OD32
1
OD33
1                                       1
OD34
1                                            1    1
OD35
1                                                      1
OD36
1                                                      1    1
OD37
1                                                      1    1    1
OD38
1                                                      1    1         1
OD39
1                                                      1    1         1
1
OD40
1                                                      1    1         1
1    1
OD41
1                                                      1    1         1
1    1    1
OD42
1                                                      1    1         1
1    1         1
OD43
1                                                      1    1         1
1    1         1    1
```

```
OD44
1                                                      1    1         1
1    1         1         1
OD45
1                   1
OD46
1    1                                            1    1
OD47
1    1                                            1
OD48
1    1
OD49
1         1
OD50
1    1              1                   1                   1    1         1
1    1    1
OD51
1    1              1              1         1
OD52
1    1              1              1                        1    1         1
1    1    1
OD53
1    1              1         1                             1    1         1
1    1    1
OD54
1
OD55
1    1    1                                  1    1
OD56
1
OD57
1              1    1         1         1
OD58
1              1    1         1         1    1    1
OD59
1              1    1         1         1    1         1         1
OD60
1
OD61
1    1    1    1    1                            ;

PARAMETER CAP(I) NUMBER OF DS1 LINES AVAILABLE ON EACH ARC/
A01  2
A02  2
A03  8
A04  8
A05  8
A06  2
A07  2
A08  0
A09 12
A10 28
A11  0
A12 28
A13  4
A14  4
A15 28
A16  8
A17 28
A18  2
A19  2
A20  8
A21  2
A22  2
A23  4
A24  2
```

```
A25 28
A26  2
A27  2
A28 12
A29 12
A30  2
A31  8
A32  0
A33  8
A34  8
A35  4
A36  4
A37  2
A38  2 /;

TABLE NODES(I,N) ARCS I THAT CONNECT AT EACH NODE N
     N01 N02 N03 N04 N05 N06 N07 N08 N09 N10 N11 N12 N13 N14 N15 N16 N17 N18 N19
N20 N21 N22 N23 N24 N25 N26 N27 N28 N29 N30 N31 N32 N33 N34 N35 N36 N37 N38 N39
A01    1   1
A02    1       1
A03    1           1
A04                1   1
A05                    1       1
A06                        1   1
A07                            1   1
A08                                1   1
A09                            1           1
A10                                        1   1
A11                                            1               1
A12                                            1   1
A13                                                1   1
A14                                                    1   1
A15                                                1               1
A16                                                                1   1
A17                                                                1
1
A18                                                                1
1
A19
1   1
A20                                                                    1   1
A21                                                                        1
1
A22                                                                        1
1
A23                                                                        1
1
A24                                                                        1   1
A25
1   1
A26
1           1
A27
1   1
A28
1               1
A29
1   1
A30
1   1
A31
1       1
A32
1   1
A33
1       1
```

```
A34
1   1
A35
1   1
A36
1       1
A37
1   1
A38
1       1;

*    ----   I M P O R T A N T  -  D O   N O T   A L T E R   ----
*THE EQUATIONS BELOW GENERATE ALL ADDITIONAL TABLES AND PARAMETERS.

PARAMETER ADMMAX MAXIMUM NUMBER OF ADD OR DROPS ALLOWED BY EQUIPMENT
CHARACTERISTICS;
ADMMAX = ADMLIMIT / 2;

PARAMETER REDUDS1(L) NUMBER OF FULL DS1 LINES DEMAND FOR EACH OD;
REDUDS1(L) = FLOOR(DEMAND(L)/24);

PARAMETER REDUCAP(I) RESIDUAL ARC CAPACITY;
REDUCAP(I) = CAP(I) - SUM(L, D(L,I)*REDUDS1(L));

PARAMETER RESIDUAL(L) RESIDUAL DEMAND FOR EACH OD;
RESIDUAL(L) = (DEMAND(L) -TRUNC (DEMAND(L)/ 24)* 24);

PARAMETER FULLOD(L) ODS THAT HAVE FULL DS1 LINES;
FULLOD(L)$(REDUDS1(L) GE 1) = 1;

PARAMETER AD(N) ADD-DROP NODE;
AD(N) = 0 ;
AD("N10") = 1;

PARAMETER ADI(I) ARCS CONNECTED TO ADD-DROP NODES;
ADI(I)$(SUM(N$AD(N), NODES(I,N)) GE 1) = 1;

PARAMETER PASS2(N,L,I) ALL VALID NODE-OD-ARC COMBINATIONS;
PASS2(N,L,I)$ (D(L,I) AND NODES(I,N)) = 1 ;

PARAMETER PASSTHRU(N,L) ODS THAT PASS THROUGH NODE;
PASSTHRU(N,L)$(SUM(I, PASS2(N,L,I)) GE 2) = 1;

PARAMETER DROP(N,L) ODS THAT ADD-DROP AT NODE;
DROP(N,L)$(SUM(I, PASS2(N,L,I)) EQ 1) = 1;

PARAMETER CHANNEL(K) MAKE ALL DS0 CHANNELS AVAILABLE;
CHANNEL(K) = 1;

PARAMETER LINE(J) MAKE ALL DS1 LINES AVAILABLE;
LINE(J) = 1;

PARAMETER ARCCAP(I,J) NUMBER OF DS1 LINES ON EACH ARC;
ARCCAP(I,J)$(ORD(J) LE CAP(I)) = 1;

PARAMETER ARCCAP2(I,J) NUMBER OF RESIDUAL DS1 LINES ON EACH ARC;
ARCCAP2(I,J)$(ORD(J) LE REDUCAP(I)) = 1;

PARAMETER ARCCAP3(I,J) NUMBER OF DESIGNATED FULL DS1 LINES ON EACH ARC;
ARCCAP3(I,J) = ARCCAP(I,J) - ARCCAP2(I,J);

PARAMETER ARCCAP4(N,I,J) ARC CAPACITY AT NODE N;
ARCCAP4(N,I,J) = ARCCAP2(I,J) * NODES(I,N);

PARAMETER NODECAP(N,J) MAXIMUM CAPACITY AT NODE N;
NODECAP(N,J)$(SUM(I, ARCCAP4(N,I,J) GE 1)) = 1;
```

```
PARAMETER G1(L,I,J,K) ALL VALID OD ARC CHANNEL COMBINATIONS;
G1(L,I,J,K) = (D(L,I) * CHANNEL(K) * LINE(J))$ARCCAP2(I,J);

PARAMETER G3(L,I,J) ALL VALID OD ARC-FULL-DS1 COMBINATIONS;
G3(L,I,J) = (D(L,I)$FULLOD(L) * LINE(J))$ARCCAP3(I,J);

VARIABLES
X(L,I,J,K) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I, DS1 LINE J
AND DS0 CHANNEL K
W(N,L,J,K) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, DS0 CHANNEL K
PAIR AT NODE N
Y(L,I,J) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I AND DS1 LINE J
ACCESS(N,I,J) NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY ARC I, DS1 LINE J AT
NODE N
DS1(N,J) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, AT NODE N USED TO
DROP AND OR ADD DS0 CHANNELS
Z TOTAL;
BINARY VARIABLE X,W,Y,DS1;

EQUATIONS

ARCASSIGN(L,I) ASSIGN ONLY ONE ARC-DS1-DS0 FOR EACH UNIT OF DEMAND FOR EACH OD
CHANASSIGN(I,J,K) ARC-DS1-DS0 CHANNEL CAN BE ASSIGNED ONLY ONCE - MULTICOMMODITY
DS1USED(N,L,J,K) IDENTIFY ACTIVE DS1 PAIRS AT ADD-DROP NODE
ADM(N,I,J) NUMBER OF DS0 CHANNEL DROPPED AND OR ADDED ON ARC-DS1 LINE AT NODE N
UPLOAD(N,J) DS1 LINE USED TO ADD AND OR DROP DS0 CHANNELS AT NODE N
GOAL DEFINE OBJECTIVE FUNCTION;

ARCASSIGN(L,I)$(ADI(I)$D(L,I)).. SUM((J,K)$G1(L,I,J,K), X(L,I,J,K)$ARCCAP2(I,J)
* D(L,I)) =E= RESIDUAL(L);

CHANASSIGN(I,J,K)$(ADI(I)$ARCCAP2(I,J)).. SUM(L$G1(L,I,J,K), X(L,I,J,K)) =L= 1;

DS1USED(N,L,J,K)$(NODECAP(N,J)$(AD(N)$PASSTHRU(N,L))).. SUM((I) $(G1(L,I,J,K)
$(NODES(I,N) $(AD(N) $D(L,I)))), X(L,I,J,K)$PASSTHRU(N,L)) =E=  2 *
W(N,L,J,K)$(AD(N)$PASSTHRU(N,L));

ADM(N,I,J)$(NODECAP(N,J)$(AD(N)$NODES(I,N))).. SUM((L,K)$(G1(L,I,J,K)
$(NODES(I,N) $(AD(N) $D(L,I)))), X(L,I,J,K)$DROP(N,L)) =E= ACCESS(N,I,J)$AD(N);

UPLOAD(N,J)$(AD(N)$NODECAP(N,J))..
SUM((L,I,K)$(G1(L,I,J,K)$(NODES(I,N)$(AD(N)$D(L,I)))), X(L,I,J,K)$DROP(N,L)) =L=
48 * DS1(N,J)$AD(N);

GOAL.. Z =E= - SUM((N,J)$(AD(N)$NODECAP(N,J)), DS1(N,J));

OPTION SOLPRINT = OFF;
OPTION RESLIM =14400;
MODEL FAST  /ALL/;
OPTION OPTCR = .01;
FAST.OPTFILE = 1;
SOLVE FAST USING MIP MAXIMIZING Z;
PARAMETER USEDRESID(N,I,J,K,L) ASSIGNMENT CHART FOR RESIDUAL DS1 LINES;
USEDRESID(N,I,J,K,L) = X.L(L,I,J,K)*NODES(I,N); OPTION USEDRESID:1:0:1;DISPLAY
USEDRESID;
DISPLAY AD;
OPTION W:1:0:1; DISPLAY W.L;
OPTION ACCESS:1:0:1; DISPLAY ACCESS.L;
OPTION DS1:1:0:1; DISPLAY DS1.L;
PARAMETER DIMF(N,I,J) ADD-DROP MULTIPLEXER REQUIREMENTS NOT MET-MET AT NODE ARC
DS1 LINE;
DIMF(N,I,J)$((ACCESS.L(N,I,J) LE ADMMAX) AND (ACCESS.L(N,I,J) GT 0)) = 1;
OPTION DIMF:1:0:1; DISPLAY DIMF;
PARAMETER TMF(N,I,J) TERMINAL MULTIPLEXER REQUIREMENTS NOT MET-MET AT NODE ARC
DS1 LINE;
```

```
TMF(N,I,J)$(ACCESS.L(N,I,J) GE (ADMMAX + 1)) = 1;
OPTION TMF:1:0:1; DISPLAY TMF;
PARAMETER PASSING(N,J) DS1 LINE USED BY ODS THAT PASS THROUGH NODE N;
PASSING(N,J)$(SUM((L,K), W.L(N,L,J,K)) GE 1) = 1;
OPTION PASSING:1:0:1; DISPLAY PASSING;
PARAMETER DIM(N,J) ACTIVE ADD-DROP MULTIPLEXER ON DS1 LINE J AT NODE N;
DIM(N,J)$((SUM(I, DIMF(N,I,J)) EQ 2) OR ((PASSING(N,J) EQ 1) AND (SUM(I,
DIMF(N,I,J)) EQ 1) AND (SUM(I, TMF(N,I,J)) EQ 0 ))) = 1;
OPTION DIM:1:0:1; DISPLAY DIM;
PARAMETER BBTM(N,J) ACTIVE BACK-TO-BACK MULTIPLEXER ON DS1 LINE J AT NODE N;
BBTM(N,J)$((SUM(I, TMF(N,I,J)) EQ 2) OR ((SUM(I, DIMF(N,I,J)) EQ 1) AND (SUM(I,
TMF(N,I,J)) EQ 1 )) OR ((PASSING(N,J) EQ 1) AND (SUM(I, DIMF(N,I,J)) EQ 0) AND
(SUM(I, TMF(N,I,J)) EQ 1 ))) = 1;
OPTION BBTM:1:0:1; DISPLAY BBTM;
PARAMETER TMP(N,J) ACTIVE TERMINAL MULTIPLEXER USED AT NODE N;
TMP(N,J)$(((PASSING(N,J) EQ 0) AND (SUM(I, DIMF(N,I,J)) EQ 0) AND (SUM(I,
TMF(N,I,J)) EQ 1 )) OR ((PASSING(N,J) EQ 0) AND (SUM(I, DIMF(N,I,J)) EQ 1) AND
(SUM(I, TMF(N,I,J)) EQ 0 ))) = 1;
OPTION TMP:1:0:1; DISPLAY TMP;
PARAMETER TM(N,I,J) ACTIVE TERMINAL MULTIPLEXER ON ARC-DS1 LINE AT NODE N;
TM(N,I,J) = ((TMP(N,J) * DIMF(N,I,J)) OR (TMP(N,J) * TMF(N,I,J)));
OPTION TM:1:0:1; DISPLAY TM;
```

APPENDIX E

MODEL 4 IN GAMS AND THE SOLUTION OF THE HYPOTHETICAL NETWORK

The version of Model 4 in GAMS and the solution of the hypothetical network, i.e. channel assignment and equipment selection, for problem 3 is shown below.

Gams Model

```
* HMODEL4.GMS
* CHANNEL ASSIGNMENT FOR HYPOTHETICAL MODEL 4
* - DEVIATION ADDED TO EQUIPMENT SELECTION
* - IDENTIFICATION OF ADD-DROP NODES
* - DS1 PAIRING CONSTRAINTS AT ADD-DROP NODES
* - EQUIPMENT TYPE SELECTION FOR ADD-DROP NODES
* ASSUMPTIONS:
* - NODE JUNCTIONS WITH MORE THAN TWO ARCS USE DACS
* - OD PASSING THROUGH A NODE MUST MAINTAIN LINE AND CHANNEL CONSISTENCY

* PROBLEM 3

SETS
I ARCS /A01*A05/
K DS0 CHANNELS /C01 * C08/
J DS1 LINES /R01*R05/
L ORIGIN DESTINATION /OD01 * OD06/
N NODES /N01*N06/

PARAMETER ADMLIMIT MAXIMUM NUMBER OF ADD-DROPS ALLOWED BY EQUIPMENT
CHARACTERISTICS;
ADMLIMIT = 10;

PARAMETER DEV DEVIATION FROM EQUALITY;
DEV =1;

PARAMETER DEMAND(L) NUMBER OF CHANNELS K REQUIRED FOR EACH OD L/
OD01   6
OD02   18
OD03   6
OD04   6
OD05   6
OD06   4/;

TABLE D(L,I) ARCS NEEDED TO COMPLETE OD PATH
       A01  A02  A03  A04  A05
OD01     1    1    1
OD02     1    1
OD03          1         1    1
OD04          1         1
OD05               1    1    1
OD06                         1;


PARAMETER CAP(I) NUMBER OF DS1 LINES AVAILABLE ON EACH ARC/
A01  5
A02  5
```

```
A03  4
A04  3
A05  3/;

TABLE NODES(I,N) ARCS I THAT CONNECT AT EACH NODE N
     N01 N02 N03 N04 N05 N06
A01    1   1
A02        1   1
A03            1   1
A04            1       1
A05                    1   1;


*    ----   I M P O R T A N T  -  D O   N O T   A L T E R   ----
*THE EQUATIONS BELOW GENERATE ALL ADDITIONAL TABLES AND PARAMETERS.

PARAMETER ADMMAX MAXIMUM NUMBER OF ADD OR DROPS ALLOWED BY EQUIPMENT
CHARACTERISTICS;
ADMMAX = ADMLIMIT / 2;

PARAMETER REDUDS1(L) NUMBER OF FULL DS1 LINES DEMAND FOR EACH OD;
REDUDS1(L) = FLOOR(DEMAND(L)/8);

PARAMETER REDUCAP(I) RESIDUAL ARC CAPACITY;
REDUCAP(I) = CAP(I) - SUM(L, D(L,I)*REDUDS1(L));

PARAMETER RESIDUAL(L) RESIDUAL DEMAND FOR EACH OD;
RESIDUAL(L) = (DEMAND(L) -TRUNC (DEMAND(L)/ 8)* 8);

PARAMETER FULLOD(L) ODS THAT HAVE FULL DS1 LINES;
FULLOD(L)$(REDUDS1(L) GE 1) = 1;

PARAMETER AD(N) ADD-DROP NODE;
AD(N)$(SUM(I, NODES(I,N)) EQ 2) = 1;

PARAMETER ADI(I) ARCS CONNECTED TO ADD-DROP NODES;
ADI(I)$(SUM(N$AD(N), NODES(I,N)) GE 1) = 1;

PARAMETER PASS2(N,L,I) ALL VALID NODE-OD-ARC COMBINATIONS;
PASS2(N,L,I)$ (D(L,I) AND NODES(I,N)) = 1 ;

PARAMETER PASSTHRU(N,L) ODS THAT PASS THROUGH NODE;
PASSTHRU(N,L)$(SUM(I, PASS2(N,L,I)) GE 2) = 1;

PARAMETER DROP(N,L) ODS THAT ADD-DROP AT NODE;
DROP(N,L)$(SUM(I, PASS2(N,L,I)) EQ 1) = 1;

PARAMETER CHANNEL(K) MAKE ALL DS0 CHANNELS AVAILABLE;
CHANNEL(K) = 1;

PARAMETER LINE(J) MAKE ALL DS1 LINES AVAILABLE;
LINE(J) = 1;

PARAMETER ARCCAP(I,J) NUMBER OF DS1 LINES ON EACH ARC;
ARCCAP(I,J)$(ORD(J) LE CAP(I)) = 1;

PARAMETER ARCCAP2(I,J) NUMBER OF RESIDUAL DS1 LINES ON EACH ARC;
ARCCAP2(I,J)$(ORD(J) LE REDUCAP(I)) = 1;

PARAMETER ARCCAP3(I,J) NUMBER OF DESIGNATED FULL DS1 LINES ON EACH ARC;
ARCCAP3(I,J) = ARCCAP(I,J) - ARCCAP2(I,J);

PARAMETER ARCCAP4(N,I,J) ARC CAPACITY AT NODE N;
ARCCAP4(N,I,J) = ARCCAP2(I,J) * NODES(I,N);

PARAMETER NODECAP(N,J) MAXIMUM CAPACITY AT NODE N;
```

```
NODECAP(N,J)$(SUM(I, ARCCAP4(N,I,J) GE 1)) = 1;

PARAMETER G1(L,I,J,K) ALL VALID OD ARC CHANNEL COMBINATIONS;
G1(L,I,J,K) = (D(L,I) * CHANNEL(K) * LINE(J))$ARCCAP2(I,J);

PARAMETER G3(L,I,J) ALL VALID OD ARC-FULL-DS1 COMBINATIONS;
G3(L,I,J) = (D(L,I)$FULLOD(L) * LINE(J))$ARCCAP3(I,J);

VARIABLES
X(L,I,J,K) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I, DS1 LINE J
AND DS0 CHANNEL K
W(N,L,J,K) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, DS0 CHANNEL K
PAIR AT NODE N
Y(L,I,J) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I AND DS1 LINE J
ACCESS(N,I,J) NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY ARC I, DS1 LINE J AT
NODE N
DS1(N,J) 0-1 NOT ACTIVE-ACTIVE DS1 LINE J AT NODE N USED TO DROP AND OR ADD DS0
CHANNELS
Z TOTAL;
BINARY VARIABLE X,W,Y,DS1;

EQUATIONS

ARCASSIGN(L,I) ASSIGN ONLY ONE ARC-DS1-DS0 FOR EACH UNIT OF DEMAND FOR EACH OD
CHANASSIGN(I,J,K) ARC-DS1-DS0 CHANNEL CAN BE ASSIGNED ONLY ONCE - MULTICOMMODITY
DS1USED(N,L,J,K) IDENTIFY ACTIVE DS1 PAIRS AT ADD-DROP NODE
ADM(N,I,J) NUMBER OF DS0 CHANNEL DROPPED AND OR ADDED ON ARC-DS1 LINE AT NODE N
UPLOAD(N,J) ARC-DS1 LINES USED TO ADD AND OR DROP DS0 CHANNELS AT NODE N
FULLDS1(L,I) ASSIGN ONLY ONE ARC-DS1 LINE FOR EACH FULL DS1 DEMAND FOR EACH OD L
DS1ASSIGN(I,J) ARC-DS1 LINE CAN BE ASSIGNED ONLY ONCE - MULTICOMMODITY
GOAL DEFINE OBJECTIVE FUNCTION;

ARCASSIGN(L,I)$D(L,I).. SUM((J,K)$G1(L,I,J,K), X(L,I,J,K)$ARCCAP2(I,J) * D(L,I))
=E= RESIDUAL(L);

CHANASSIGN(I,J,K)$ARCCAP2(I,J).. SUM(L$G1(L,I,J,K), X(L,I,J,K)) =L= 1;

DS1USED(N,L,J,K)$(NODECAP(N,J)$(AD(N)$PASSTHRU(N,L))).. SUM((I) $(G1(L,I,J,K)
$(NODES(I,N) $(AD(N) $D(L,I)))), X(L,I,J,K)$PASSTHRU(N,L)) =E=  2 *
W(N,L,J,K)$(AD(N)$PASSTHRU(N,L));

ADM(N,I,J)$(NODECAP(N,J)$(AD(N)$NODES(I,N))).. SUM((L,K)$(G1(L,I,J,K)
$(NODES(I,N) $(AD(N) $D(L,I)))), X(L,I,J,K)$DROP(N,L)) =E= ACCESS(N,I,J)$AD(N);

UPLOAD(N,J)$(AD(N)$NODECAP(N,J))..
SUM((L,I,K)$(G1(L,I,J,K)$(NODES(I,N)$(AD(N)$D(L,I)))), X(L,I,J,K)$DROP(N,L)) =L=
16 * DS1(N,J)$AD(N);

FULLDS1(L,I)$D(L,I).. SUM(J$G3(L,I,J), Y(L,I,J) * D(L,I)) =E= REDUDS1(L);

DS1ASSIGN(I,J).. SUM(L$G3(L,I,J), Y(L,I,J)) =L= 1;

GOAL.. Z =E= - SUM((N,J)$(AD(N)$NODECAP(N,J)), DS1(N,J));

OPTION SOLPRINT = OFF;
OPTION RESLIM =900;
MODEL FAST  /ALL/;
OPTION OPTCR = .01;
FAST.OPTFILE = 1;
SOLVE FAST USING MIP MAXIMIZING Z;
OPTION X:1:0:1; DISPLAY X.L;
PARAMETER USEDRESID(N,I,J,K,L) ASSIGNMENT CHART FOR RESIDUAL DS1 LINES;
USEDRESID(N,I,J,K,L) = X.L(L,I,J,K)*NODES(I,N); OPTION USEDRESID:1:0:1;DISPLAY
USEDRESID;
```

```
PARAMETER USEDFULL(N,I,J,L) ASSIGNMENT CHART FOR FULL-DS1 LINES;
USEDFULL(N,I,J,L) = Y.L(L,I,J)*NODES(I,N); OPTION USEDFULL:1:0:1;DISPLAY
USEDFULL;
DISPLAY AD;
OPTION W:1:0:1; DISPLAY W.L;
OPTION ACCESS:1:0:1; DISPLAY ACCESS.L;
OPTION DS1:1:0:1; DISPLAY DS1.L;

PARAMETER DIMF(N,I,J) ADD-DROP MULTIPLEXER REQUIREMENTS NOT MET-MET AT NODE ARC
DS1 LINE;
DIMF(N,I,J)$((ACCESS.L(N,I,J) LE (ADMMAX + DEV)) AND (ACCESS.L(N,I,J) GT 0 )) =
1;
OPTION DIMF:1:0:1; DISPLAY DIMF;

PARAMETER TMF(N,I,J) TERMINAL MULTIPLEXER REQUIREMENTS NOT MET-MET AT NODE ARC
DS1 LINE;
TMF(N,I,J)$(ACCESS.L(N,I,J) GT ADMMAX) = 1;
OPTION TMF:1:0:1; DISPLAY TMF;

PARAMETER PASSING(N,J) DS1 LINE USED BY ODS THAT PASS THROUGH NODE N;
PASSING(N,J)$(SUM((L,K), W.L(N,L,J,K)) GE 1) = 1;
OPTION PASSING:1:0:1; DISPLAY PASSING;

PARAMETER DIM(N,J) ACTIVE ADD-DROP MULTIPLEXER ON DS1 LINE J AT NODE N;
DIM(N,J)$(((SUM(I, DIMF(N,I,J)) =1) AND (SUM(I, TMF(N,I,J)) EQ 0)) AND
(PASSING(N,J) EQ 1) AND (SUM(I, ACCESS.L(N,I,J)) LE (ADMMAX + DEV)) OR
((SUM(I, DIMF(N,I,J)) EQ 1) AND (SUM(I, TMF(N,I,J)) EQ 1) AND (PASSING(N,J) EQ
1) AND (SUM(I, ACCESS.L(N,I,J)) LE (ADMMAX + DEV))) OR
((SUM(I, DIMF(N,I,J)) EQ 2) AND (SUM(I, ACCESS.L(N,I,J)) LE ADMLIMIT))) = 1;
OPTION DIM:1:0:1; DISPLAY DIM;

PARAMETER BBTM(N,J) ACTIVE BACK-TO-BACK MULTIPLEXER ON DS1 LINE J AT NODE N;
BBTM(N,J)$(((SUM(I, ACCESS.L(N,I,J)) GT ADMLIMIT)) OR ((SUM(I, DIMF(N,I,J))EQ 1)
AND (SUM(I, TMF(N,I,J)) EQ 1) AND (SUM(I, ACCESS.L(N,I,J)) GT (ADMMAX + DEV)))
OR ((SUM(I, TMF(N,I,J))EQ 1) AND (SUM(I, DIMF(N,I,J)) EQ 0) AND (PASSING(N,J) EQ
1))) = 1;
OPTION BBTM:1:0:1; DISPLAY BBTM;

PARAMETER TMP(N,J) ACTIVE TERMINAL MULTIPLEXER USED AT NODE N;
TMP(N,J)$(((PASSING(N,J) EQ 0) AND (SUM(I, DIMF(N,I,J)) EQ 1) AND (SUM(I,
TMF(N,I,J)) EQ 1) AND (SUM(I, ACCESS.L(N,I,J)) LE (ADMMAX + DEV))) OR
((PASSING(N,J) EQ 0) AND ((SUM(I, DIMF(N,I,J)) + SUM(I, TMF(N,I,J))) EQ 1))) =
1;
OPTION TMP:1:0:1; DISPLAY TMP;

PARAMETER TM(N,I,J) ACTIVE TERMINAL MULTIPLEXER ON ARC-DS1 LINE AT NODE N;
TM(N,I,J) = ((TMP(N,J) * DIMF(N,I,J)) OR (TMP(N,J) * TMF(N,I,J)));
OPTION TM:1:0:1; DISPLAY TM;
```

```
       MODEL STATISTICS
BLOCKS OF EQUATIONS       8     SINGLE EQUATIONS      263
BLOCKS OF VARIABLES       6     SINGLE VARIABLES      471
NON ZERO ELEMENTS      1217     DISCRETE VARIABLES    458
GENERATION TIME      =        0.050 SECONDS
EXECUTION TIME       =        0.067 SECONDS        VERID AXU-25-087
               S O L V E      S U M M A R Y
     MODEL   FAST                OBJECTIVE  Z
     TYPE    MIP                 DIRECTION  MAXIMIZE
     SOLVER  CPLEX               FROM LINE  160
**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE               -3.0000
 RESOURCE USAGE, LIMIT          0.233      900.000
 ITERATION COUNT, LIMIT       679         1000
Option file:
```

```
> iterationlim 100000
> nodeselect 0
Proven optimal solution.
MIP Solution  :           -3.000000    (679 iterations, 80 nodes)
Final LP      :           -3.000000    (0 iterations)
Best integer solution possible :          -3.000000
Relative gap                   :                  0
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED

----  161 VARIABLE  X.L   0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I

OD01.A01.R01.C03 1.0
OD01.A01.R01.C04 1.0
OD01.A01.R01.C05 1.0
OD01.A01.R03.C06 1.0
OD01.A01.R03.C07 1.0
OD01.A01.R03.C08 1.0
OD01.A02.R01.C03 1.0
OD01.A02.R01.C04 1.0
OD01.A02.R01.C05 1.0
OD01.A02.R03.C06 1.0
OD01.A02.R03.C07 1.0
OD01.A02.R03.C08 1.0
OD01.A03.R01.C01 1.0
OD01.A03.R01.C02 1.0
OD01.A03.R01.C04 1.0
OD01.A03.R01.C05 1.0
OD01.A03.R01.C06 1.0
OD01.A03.R04.C07 1.0
OD02.A01.R01.C02 1.0
OD02.A01.R01.C08 1.0
OD02.A02.R01.C02 1.0
OD02.A02.R01.C08 1.0
OD03.A02.R02.C02 1.0
OD03.A02.R02.C05 1.0
OD03.A02.R02.C06 1.0
OD03.A02.R02.C07 1.0
OD03.A02.R02.C08 1.0
OD03.A02.R03.C04 1.0
OD03.A04.R02.C01 1.0
OD03.A04.R02.C02 1.0
OD03.A04.R02.C03 1.0
OD03.A04.R02.C04 1.0
OD03.A04.R03.C07 1.0
OD03.A04.R03.C08 1.0
OD03.A05.R02.C01 1.0
OD03.A05.R02.C02 1.0
OD03.A05.R02.C03 1.0
OD03.A05.R02.C04 1.0
OD03.A05.R03.C07 1.0
OD03.A05.R03.C08 1.0
OD04.A02.R02.C01 1.0
OD04.A02.R02.C03 1.0
OD04.A02.R02.C04 1.0
OD04.A02.R03.C01 1.0
OD04.A02.R03.C02 1.0
OD04.A02.R03.C03 1.0
OD04.A04.R03.C01 1.0
OD04.A04.R03.C02 1.0
OD04.A04.R03.C03 1.0
OD04.A04.R03.C04 1.0
OD04.A04.R03.C05 1.0
OD04.A04.R03.C06 1.0
OD05.A03.R02.C06 1.0
```

```
OD05.A03.R02.C07 1.0
OD05.A03.R02.C08 1.0
----  161 VARIABLE  X.L   0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I

OD05.A03.R03.C01 1.0
OD05.A03.R03.C02 1.0
OD05.A03.R03.C03 1.0
OD05.A04.R01.C01 1.0
OD05.A04.R01.C02 1.0
OD05.A04.R01.C03 1.0
OD05.A04.R01.C04 1.0
OD05.A04.R02.C05 1.0
OD05.A04.R02.C08 1.0
OD05.A05.R01.C01 1.0
OD05.A05.R01.C02 1.0
OD05.A05.R01.C03 1.0
OD05.A05.R01.C04 1.0
OD05.A05.R02.C05 1.0
OD05.A05.R02.C08 1.0
OD06.A05.R03.C01 1.0
OD06.A05.R03.C02 1.0
OD06.A05.R03.C03 1.0
OD06.A05.R03.C05 1.0


----    162 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N01.A01.R01.C02.OD02 1.0
N01.A01.R01.C03.OD01 1.0
N01.A01.R01.C04.OD01 1.0
N01.A01.R01.C05.OD01 1.0
N01.A01.R01.C08.OD02 1.0
N01.A01.R03.C06.OD01 1.0
N01.A01.R03.C07.OD01 1.0
N01.A01.R03.C08.OD01 1.0
N02.A01.R01.C02.OD02 1.0
N02.A01.R01.C03.OD01 1.0
N02.A01.R01.C04.OD01 1.0
N02.A01.R01.C05.OD01 1.0
N02.A01.R01.C08.OD02 1.0
N02.A01.R03.C06.OD01 1.0
N02.A01.R03.C07.OD01 1.0
N02.A01.R03.C08.OD01 1.0
N02.A02.R01.C02.OD02 1.0
N02.A02.R01.C03.OD01 1.0
N02.A02.R01.C04.OD01 1.0
N02.A02.R01.C05.OD01 1.0
N02.A02.R01.C08.OD02 1.0
N02.A02.R02.C01.OD04 1.0
N02.A02.R02.C02.OD03 1.0
N02.A02.R02.C03.OD04 1.0
N02.A02.R02.C04.OD04 1.0
N02.A02.R02.C05.OD03 1.0
N02.A02.R02.C06.OD03 1.0
N02.A02.R02.C07.OD03 1.0
N02.A02.R02.C08.OD03 1.0
N02.A02.R03.C01.OD04 1.0
N02.A02.R03.C02.OD04 1.0
N02.A02.R03.C03.OD04 1.0
N02.A02.R03.C04.OD03 1.0
N02.A02.R03.C06.OD01 1.0
N02.A02.R03.C07.OD01 1.0
N02.A02.R03.C08.OD01 1.0
N03.A02.R01.C02.OD02 1.0
N03.A02.R01.C03.OD01 1.0
N03.A02.R01.C04.OD01 1.0
```

```
N03.A02.R01.C05.OD01 1.0
N03.A02.R01.C08.OD02 1.0
N03.A02.R02.C01.OD04 1.0
----    162 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N03.A02.R02.C02.OD03 1.0
N03.A02.R02.C03.OD04 1.0
N03.A02.R02.C04.OD04 1.0
N03.A02.R02.C05.OD03 1.0
N03.A02.R02.C06.OD03 1.0
N03.A02.R02.C07.OD03 1.0
N03.A02.R02.C08.OD03 1.0
N03.A02.R03.C01.OD04 1.0
N03.A02.R03.C02.OD04 1.0
N03.A02.R03.C03.OD04 1.0
N03.A02.R03.C04.OD03 1.0
N03.A02.R03.C06.OD01 1.0
N03.A02.R03.C07.OD01 1.0
N03.A02.R03.C08.OD01 1.0
N03.A03.R01.C01.OD01 1.0
N03.A03.R01.C02.OD01 1.0
N03.A03.R01.C04.OD01 1.0
N03.A03.R01.C05.OD01 1.0
N03.A03.R01.C06.OD01 1.0
N03.A03.R02.C06.OD05 1.0
N03.A03.R02.C07.OD05 1.0
N03.A03.R02.C08.OD05 1.0
N03.A03.R03.C01.OD05 1.0
N03.A03.R03.C02.OD05 1.0
N03.A03.R03.C03.OD05 1.0
N03.A03.R04.C07.OD01 1.0
N03.A04.R01.C01.OD05 1.0
N03.A04.R01.C02.OD05 1.0
N03.A04.R01.C03.OD05 1.0
N03.A04.R01.C04.OD05 1.0
N03.A04.R02.C01.OD03 1.0
N03.A04.R02.C02.OD03 1.0
N03.A04.R02.C03.OD03 1.0
N03.A04.R02.C04.OD03 1.0
N03.A04.R02.C05.OD05 1.0
N03.A04.R02.C08.OD05 1.0
N03.A04.R03.C01.OD04 1.0
N03.A04.R03.C02.OD04 1.0
N03.A04.R03.C03.OD04 1.0
N03.A04.R03.C04.OD04 1.0
N03.A04.R03.C05.OD04 1.0
N03.A04.R03.C06.OD04 1.0
N03.A04.R03.C07.OD03 1.0
N03.A04.R03.C08.OD03 1.0
N04.A03.R01.C01.OD01 1.0
N04.A03.R01.C02.OD01 1.0
N04.A03.R01.C04.OD01 1.0
N04.A03.R01.C05.OD01 1.0
N04.A03.R01.C06.OD01 1.0
N04.A03.R02.C06.OD05 1.0
N04.A03.R02.C07.OD05 1.0
N04.A03.R02.C08.OD05 1.0
N04.A03.R03.C01.OD05 1.0
N04.A03.R03.C02.OD05 1.0
N04.A03.R03.C03.OD05 1.0
N04.A03.R04.C07.OD01 1.0
N05.A04.R01.C01.OD05 1.0
N05.A04.R01.C02.OD05 1.0
N05.A04.R01.C03.OD05 1.0
N05.A04.R01.C04.OD05 1.0
N05.A04.R02.C01.OD03 1.0
```

```
N05.A04.R02.C02.OD03 1.0
N05.A04.R02.C03.OD03 1.0
N05.A04.R02.C04.OD03 1.0
N05.A04.R02.C05.OD05 1.0
----    162 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N05.A04.R02.C08.OD05 1.0
N05.A04.R03.C01.OD04 1.0
N05.A04.R03.C02.OD04 1.0
N05.A04.R03.C03.OD04 1.0
N05.A04.R03.C04.OD04 1.0
N05.A04.R03.C05.OD04 1.0
N05.A04.R03.C06.OD04 1.0
N05.A04.R03.C07.OD03 1.0
N05.A04.R03.C08.OD03 1.0
N05.A05.R01.C01.OD05 1.0
N05.A05.R01.C02.OD05 1.0
N05.A05.R01.C03.OD05 1.0
N05.A05.R01.C04.OD05 1.0
N05.A05.R02.C01.OD03 1.0
N05.A05.R02.C02.OD03 1.0
N05.A05.R02.C03.OD03 1.0
N05.A05.R02.C04.OD03 1.0
N05.A05.R02.C05.OD05 1.0
N05.A05.R02.C08.OD05 1.0
N05.A05.R03.C01.OD06 1.0
N05.A05.R03.C02.OD06 1.0
N05.A05.R03.C03.OD06 1.0
N05.A05.R03.C05.OD06 1.0
N05.A05.R03.C07.OD03 1.0
N05.A05.R03.C08.OD03 1.0
N06.A05.R01.C01.OD05 1.0
N06.A05.R01.C02.OD05 1.0
N06.A05.R01.C03.OD05 1.0
N06.A05.R01.C04.OD05 1.0
N06.A05.R02.C01.OD03 1.0
N06.A05.R02.C02.OD03 1.0
N06.A05.R02.C03.OD03 1.0
N06.A05.R02.C04.OD03 1.0
N06.A05.R02.C05.OD05 1.0
N06.A05.R02.C08.OD05 1.0
N06.A05.R03.C01.OD06 1.0
N06.A05.R03.C02.OD06 1.0
N06.A05.R03.C03.OD06 1.0
N06.A05.R03.C05.OD06 1.0
N06.A05.R03.C07.OD03 1.0
N06.A05.R03.C08.OD03 1.0


----    163 PARAMETER USEDFULL      ASSIGNMENT CHART FOR FULL-DS1 LINES

N01.A01.R04.OD02 1.0
N01.A01.R05.OD02 1.0
N02.A01.R04.OD02 1.0
N02.A01.R05.OD02 1.0
N02.A02.R04.OD02 1.0
N02.A02.R05.OD02 1.0
N03.A02.R04.OD02 1.0
N03.A02.R05.OD02 1.0


----    164 PARAMETER AD            ADD-DROP NODE

N02 1.000,    N05 1.000
```

```
----  165 VARIABLE  W.L     0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J

N02.OD01.R01.C03 1.0
N02.OD01.R01.C04 1.0
N02.OD01.R01.C05 1.0
----  165 VARIABLE  W.L     0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J

N02.OD01.R03.C06 1.0
N02.OD01.R03.C07 1.0
N02.OD01.R03.C08 1.0
N02.OD02.R01.C02 1.0
N02.OD02.R01.C08 1.0
N05.OD03.R02.C01 1.0
N05.OD03.R02.C02 1.0
N05.OD03.R02.C03 1.0
N05.OD03.R02.C04 1.0
N05.OD03.R03.C07 1.0
N05.OD03.R03.C08 1.0
N05.OD05.R01.C01 1.0
N05.OD05.R01.C02 1.0
N05.OD05.R01.C03 1.0
N05.OD05.R01.C04 1.0
N05.OD05.R02.C05 1.0
N05.OD05.R02.C08 1.0


----  166 VARIABLE  ACCESS.L   NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY ARC I

N02.A02.R02 8.0
N02.A02.R03 4.0
N05.A04.R03 6.0
N05.A05.R03 4.0


----    167 VARIABLE  DS1.L         LINE J AND DS0 CHANNEL K

N02.R02 1.0
N02.R03 1.0
N05.R03 1.0


----    171 PARAMETER DIMF          ADD-DROP MULTIPLEXER REQUIREMENTS NOT MET-
MET AT NODE ARC DS1 LINE

N02.A02.R03 1.0
N05.A04.R03 1.0
N05.A05.R03 1.0


----    175 PARAMETER TMF           TERMINAL MULTIPLEXER REQUIREMENTS NOT MET-
MET AT NODE ARC DS1 LINE

N02.A02.R02 1.0
N05.A04.R03 1.0


----    179 PARAMETER PASSING       DS1 LINE USED BY ODS THAT PASS THROUGH NODE
N

N02.R01 1.0
N02.R03 1.0
N05.R01 1.0
N05.R02 1.0
N05.R03 1.0
```

```
----    185 PARAMETER DIM           ACTIVE ADD-DROP MULTIPLEXER ON DS1 LINE J AT
NODE N

N02.R03 1.0
N05.R03 1.0


----    189 PARAMETER BBTM          ACTIVE BACK-TO-BACK MULTIPLEXER ON DS1 LINE
J AT NODE N

                    ( ALL         0.0 )


----    194 PARAMETER TMP           ACTIVE TERMINAL MULTIPLEXER USED AT NODE N

N02.R02 1.0


----    198 PARAMETER TM            ACTIVE TERMINAL MULTIPLEXER ON ARC-DS1 LINE
AT NODE N

N02.A02.R02 1.0


EXECUTION TIME       =        0.033 SECONDS        VERID AXU-25-087
```

APPENDIX F

MODEL 4 IN GAMS FOR NODE N17 OF ARIZONA NETWORK

The version of Model 4 in GAMS used to assign residual demands to arcs connected to add-drop nodes or adjacent add-drop nodes. The model below evaluated node N17 of the Arizona network.

Gams model

```
* AMODEL4.GMS
* CHANNEL ASSIGNMENT FOR ARIZONA NETWORK MODEL 4 NODE 17
* - DEVIATION ADDED TO EQUIPMENT SELECTION
* - IDENTIFICATION OF ADD-DROP NODES
* - DS1 PAIRING CONSTRAINTS AT ADD-DROP NODES
* - EQUIPMENT TYPE SELECTION FOR ADD-DROP NODES
* ASSUMPTIONS:
* - NODE JUNCTIONS WITH MORE THAN TWO ARCS USE DACS
* - OD PASSING THROUGH A NODE MUST MAINTAIN LINE AND CHANNEL CONSISTENCY

SETS
I ARCS /A01*A38/
K DS0 CHANNELS /C01 * C24/
J DS1 LINES /R01*R28/
L ORIGIN DESTINATION /OD01 * OD61/
N NODES /N01*N39/

PARAMETER ADMLIMIT MAXIMUM NUMBER OF ADD-DROPS ALLOWED BY EQUIPMENT CHARACTERISTICS;
ADMLIMIT = 30;

PARAMETER DEV DEVIATION FROM EQUALITY;
DEV =1;

PARAMETER DEMAND(L) NUMBER OF CHANNELS K REQUIRED FOR EACH OD L/
OD01   4
OD02   1
OD03  39
OD04  40
OD05   7
OD06  24
OD07  11
OD08   1
OD09   5
OD10  11
OD11  25
OD12   5
OD13   8
```

```
38  OD14  25
39  OD15  48
40  OD16 266
41  OD17  22
42  OD18   2
43  OD19  15
44  OD20   9
45  OD21  24
46  OD22   9
47  OD23   1
48  OD24  11
49  OD25  15
50  OD26   5
51  OD27  36
52  OD28   2
53  OD29   4
54  OD30   7
55  OD31   2
56  OD32   7
57  OD33 104
58  OD34  13
59  OD35   3
60  OD36   5
61  OD37   2
62  OD38   2
63  OD39   9
64  OD40   2
65  OD41  14
66  OD42   3
67  OD43  10
68  OD44  10
69  OD45   1
70  OD46   2
71  OD47   3
72  OD48   3
73  OD49   2
74  OD50   1
75  OD51  36
76  OD52   3
77  OD53   1
78  OD54   5
79  OD55   1
80  OD56   1
81  OD57   1
82  OD58  24
83  OD59  25
84  OD60   3
85  OD61   4 /;
86
87  TABLE D(L,I) ARCS NEEDED TO COMPLETE OD PATH
88         A01  A02  A03  A04  A05  A06  A07  A08  A09  A10  A11  A12  A13
       A14  A15  A16  A17  A18  A19  A20  A21  A22  A23  A24  A25  A26  A27
                        A28  A29  A30  A31  A32  A33  A34  A35  A36  A37  A38
89  OD01     1
90  OD02          1
91  OD03               1    1    1                   1    1         1
                                                                            1
92  OD04               1    1    1                   1    1         1
                          1         1                                       1
93  OD05     1         1    1    1                   1    1         1
                                                                            1
94  OD06     1         1    1    1                   1    1         1
                          1         1                                       1
95  OD07          1    1    1    1                   1    1         1
                                                                            1
96  OD08          1    1    1    1                   1    1         1
```

```
                           1         1                                       1
 97  OD09                    1    1                   1    1         1
                                                                             1
 98  OD10                              1              1    1         1
                                                                             1
 99  OD11                              1              1    1         1
                           1         1                                       1
100  OD12                                             1    1         1
                                                                             1
101  OD13                                   1         1    1         1
                                                                             1
102  OD14                                   1         1    1         1
                           1         1                                       1
103  OD15                                                  1         1
                                                                             1
104  OD16                                                  1         1
                           1         1                                       1
105  OD17                                                            1
                                                                             1
106  OD18                                                            1
                           1         1                                       1
107  OD19
                                                                             1
108  OD20                                                                 1
                                                                             1
109  OD21                                                                 1
                           1         1                                       1
110  OD22                                                                 1
                                                                        1    1
111  OD23                                                                 1
                      1    1         1                                       1
112  OD24
                                                                             1
113  OD25
                                                         1                   1
114  OD26
                                     1                   1                   1
115  OD27
                                          1                   1              1
116  OD28
                                               1                   1         1
117  OD29
                                                    1                   1    1
118  OD30
                                                                             1
119  OD31
                                                                        1    1
120  OD32
                                                                             1
121  OD33
                                     1                                       1
122  OD34
                           1                                            1    1
123  OD35
                      1                                                      1
124  OD36
                     1                                                      1
                                                                             1
125  OD37
                     1                                                      1
                                                                        1    1
126  OD38
                     1                                                      1
                                                                   1         1
127  OD39
                     1                                                      1
```

```
                                                    1         1         1
OD40
                1                                                      1
                                               1         1         1    1
OD41
                1                                                      1
                                          1         1         1    1    1
OD42
                1                                                      1
                                     1         1         1    1         1
OD43
                1                                                      1
                                1         1         1    1         1    1
OD44
                1                                                      1
                           1         1         1    1         1         1
OD45
                                                    1                   1
OD46
                 1    1                                            1    1
OD47
                      1    1                                            1
OD48
                                                                   1    1
OD49
                                                              1         1
OD50
           1    1              1                   1                   1
                                          1         1         1    1    1
OD51
                           1    1              1              1         1
OD52
           1    1              1              1                        1
                                          1         1         1    1    1
OD53
           1    1              1         1                             1
                                          1         1         1    1    1
OD54
                                                                        1
OD55
                      1    1    1                                  1    1
OD56
                                                                        1
OD57
                                                        1              1
                                                    1         1         1
OD58
                                                        1              1
                                          1         1         1    1    1
OD59
                                                        1              1
                           1         1         1    1         1         1
OD60
                                                                        1
OD61
                                                             1    1    1
                                      1    1                            ;

PARAMETER CAP(I) NUMBER OF DS1 LINES AVAILABLE ON EACH ARC/
A01  2
A02  2
A03  8
A04  8
A05  8
A06  2
A07  2
```

```
A08  0
A09 12
A10 28
A11  0
A12 28
A13  4
A14  4
A15 28
A16  8
A17 28
A18  2
A19  2
A20  8
A21  2
A22  2
A23  4
A24  2
A25 28
A26  2
A27  2
A28 12
A29 12
A30  2
A31  8
A32  0
A33  8
A34  8
A35  4
A36  4
A37  2
A38  2 /;

TABLE NODES(I,N) ARCS I THAT CONNECT AT EACH NODE N
     N01 N02 N03 N04 N05 N06 N07 N08 N09 N10 N11 N12 N13 N14 N15 N16 N17
 N18 N19 N20 N21 N22 N23 N24 N25 N26 N27 N28 N29 N30 N31 N32 N33 N34 N35
                                                          N36 N37 N38 N39
A01    1   1
A02    1       1
A03    1           1
A04                1   1
A05                    1       1
A06                        1   1
A07                            1   1
A08                                1   1
A09                            1           1
A10                                        1   1
A11                                            1               1
A12                                            1   1
A13                                                1   1
A14                                                    1   1
A15                                                1               1
A16                                                                1   1
A17                                                                1
                                                                        1
A18                                                                1
                                                                        1
A19
                                                                    1   1
A20                                                                    1
                                                                        1
A21
                                                        1               1
A22
                                                            1           1
A23
                                                                1       1
```

```
A24
                                                                     1   1
A25
                                                                     1   1
A26
                                                             1           1
A27
                                                                     1   1
A28
                                                         1               1
A29
                                                                     1   1
A30
                                                                     1   1
A31
                                                                 1       1
A32
                                                                     1   1
A33
                                                                 1       1
A34
                                                                     1   1
A35
                                                                       1
                                                                         1
A36
                                                                       1
                                                                         1
A37

                                                                     1   1
A38

                                                                1       1;

*    ----   I M P O R T A N T  -  D O   N O T   A L T E R  ----
*THE EQUATIONS BELOW GENERATE ALL ADDITIONAL TABLES AND PARAMETERS.

PARAMETER ADMMAX MAXIMUM NUMBER OF ADD OR DROPS ALLOWED BY EQUIPMENT
CHARACTERISTICS;
ADMMAX = ADMLIMIT / 2;

PARAMETER REDUDS1(L) NUMBER OF FULL DS1 LINES DEMAND FOR EACH OD;
REDUDS1(L) = FLOOR(DEMAND(L)/24);

PARAMETER REDUCAP(I) RESIDUAL ARC CAPACITY;
REDUCAP(I) = CAP(I) - SUM(L, D(L,I)*REDUDS1(L));

PARAMETER RESIDUAL(L) RESIDUAL DEMAND FOR EACH OD;
RESIDUAL(L) = (DEMAND(L) -TRUNC (DEMAND(L)/ 24)* 24);

PARAMETER FULLOD(L) ODS THAT HAVE FULL DS1 LINES;
FULLOD(L)$(REDUDS1(L) GE 1) = 1;

PARAMETER AD(N) ADD-DROP NODE;
AD(N) = 0 ;
AD("N17") = 1;

PARAMETER ADI(I) ARCS CONNECTED TO ADD-DROP NODES;
ADI(I)$(SUM(N$AD(N), NODES(I,N)) GE 1) = 1;

PARAMETER PASS2(N,L,I) ALL VALID NODE-OD-ARC COMBINATIONS;
PASS2(N,L,I)$ (D(L,I) AND NODES(I,N)) = 1 ;

PARAMETER PASSTHRU(N,L) ODS THAT PASS THROUGH NODE;
PASSTHRU(N,L)$(SUM(I, PASS2(N,L,I)) GE 2) = 1;
```

```

PARAMETER DROP(N,L) ODS THAT ADD-DROP AT NODE;
DROP(N,L)$(SUM(I, PASS2(N,L,I)) EQ 1) = 1;

PARAMETER CHANNEL(K) MAKE ALL DS0 CHANNELS AVAILABLE;
CHANNEL(K) = 1;

PARAMETER LINE(J) MAKE ALL DS1 LINES AVAILABLE;
LINE(J) = 1;

PARAMETER ARCCAP(I,J) NUMBER OF DS1 LINES ON EACH ARC;
ARCCAP(I,J)$(ORD(J) LE CAP(I)) = 1;

PARAMETER ARCCAP2(I,J) NUMBER OF RESIDUAL DS1 LINES ON EACH ARC;
ARCCAP2(I,J)$(ORD(J) LE REDUCAP(I)) = 1;

PARAMETER ARCCAP3(I,J) NUMBER OF DESIGNATED FULL DS1 LINES ON EACH ARC;
ARCCAP3(I,J) = ARCCAP(I,J) - ARCCAP2(I,J);

PARAMETER ARCCAP4(N,I,J) ARC CAPACITY AT NODE N;
ARCCAP4(N,I,J) = ARCCAP2(I,J) * NODES(I,N);

PARAMETER NODECAP(N,J) MAXIMUM CAPACITY AT NODE N;
NODECAP(N,J)$(SUM(I, ARCCAP4(N,I,J) GE 1)) = 1;

PARAMETER G1(L,I,J,K) ALL VALID OD ARC CHANNEL COMBINATIONS;
G1(L,I,J,K) = (D(L,I) * CHANNEL(K) * LINE(J))$ARCCAP2(I,J);

PARAMETER G3(L,I,J) ALL VALID OD ARC-FULL-DS1 COMBINATIONS;
G3(L,I,J) = (D(L,I)$FULLOD(L) * LINE(J))$ARCCAP3(I,J);

VARIABLES
X(L,I,J,K) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I, DS1 LINE J AND DS0 CHANNEL K
W(N,L,J,K) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, DS0 CHANNEL K PAIR AT NODE N
Y(L,I,J) 0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I AND DS1 LINE J
ACCESS(N,I,J) NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY ARC I, DS1 LINE J AT NODE N
DS1(N,J) 0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J, AT NODE N USED TO DROP AND OR ADD DS0 CHANNELS
Z TOTAL;
BINARY VARIABLE X,W,Y,DS1;

EQUATIONS

ARCASSIGN(L,I) ASSIGN ONLY ONE ARC-DS1-DS0 FOR EACH UNIT OF DEMAND FOR EACH OD
CHANASSIGN(I,J,K) ARC-DS1-DS0 CHANNEL CAN BE ASSIGNED ONLY ONCE - MULTICOMMODITY
DS1USED(N,L,J,K) IDENTIFY ACTIVE DS1 PAIRS AT ADD-DROP NODE
ADM(N,I,J) NUMBER OF DS0 CHANNEL DROPPED AND OR ADDED ON ARC-DS1 LINE AT NODE N
UPLOAD(N,J) DS1 LINE USED TO ADD AND OR DROP DS0 CHANNELS AT NODE N
GOAL DEFINE OBJECTIVE FUNCTION;

ARCASSIGN(L,I)$(ADI(I)$D(L,I)).. SUM((J,K)$G1(L,I,J,K), X(L,I,J,K)$ARCCAP2(I,J) * D(L,I)) =E= RESIDUAL(L);

CHANASSIGN(I,J,K)$(ADI(I)$ARCCAP2(I,J)).. SUM(L$G1(L,I,J,K), X(L,I,J,K)) =L= 1;

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```
DS1USED(N,L,J,K)$(NODECAP(N,J)$(AD(N)$PASSTHRU(N,L))).. SUM((I)
$(G1(L,I,J,K) $(NODES(I,N) $(AD(N)
$D(L,I)))), X(L,I,J,K)$PASSTHRU(N,L)) =E=  2 *
W(N,L,J,K)$(AD(N)$PASSTHRU(N,L));

ADM(N,I,J)$(NODECAP(N,J)$(AD(N)$NODES(I,N))).. SUM((L,K)$(G1(L,I,J,K)
 $(NODES(I,N) $(AD(N) $D(L,I)))), X(L,I,J,K)$DROP(N,L)) =E= ACCESS(N,I,J)
$AD(N);

UPLOAD(N,J)$(AD(N)$NODECAP(N,J)).. SUM((L,I,K)$(G1(L,I,J,K)$(NODES(I,N)
        $(AD(N)$D(L,I)))), X(L,I,J,K)$DROP(N,L)) =L= 48 * DS1(N,J)$AD(N);

GOAL.. Z =E= - SUM((N,J)$(AD(N)$NODECAP(N,J)), DS1(N,J));

OPTION SOLPRINT = OFF;
OPTION RESLIM =14400;
MODEL FAST  /ALL/;
OPTION OPTCR = .01;
FAST.OPTFILE = 1;
SOLVE FAST USING MIP MAXIMIZING Z;
OPTION X:1:0:1; DISPLAY X.L;
PARAMETER USEDRESID(N,I,J,K,L) ASSIGNMENT CHART FOR RESIDUAL DS1 LINES;
  USEDRESID(N,I,J,K,L) = X.L(L,I,J,K)*NODES(I,N); OPTION USEDRESID:1:0:1;
DISPLAY USEDRESID;
DISPLAY AD;
OPTION W:1:0:1; DISPLAY W.L;
OPTION ACCESS:1:0:1; DISPLAY ACCESS.L;
OPTION DS1:1:0:1; DISPLAY DS1.L;

PARAMETER DIMF(N,I,J) ADD-DROP MULTIPLEXER REQUIREMENTS NOT MET-MET AT
NODE ARC DS1 LINE;
DIMF(N,I,J)$((ACCESS.L(N,I,J) LE (ADMMAX + DEV)) AND (ACCESS.L(N,I,J) GT 0
)) = 1;
OPTION DIMF:1:0:1; DISPLAY DIMF;

PARAMETER TMF(N,I,J) TERMINAL MULTIPLEXER REQUIREMENTS NOT MET-MET AT NODE
ARC DS1 LINE;
TMF(N,I,J)$(ACCESS.L(N,I,J) GT ADMMAX) = 1;
OPTION TMF:1:0:1; DISPLAY TMF;

PARAMETER PASSING(N,J) DS1 LINE USED BY ODS THAT PASS THROUGH NODE N;
PASSING(N,J)$(SUM((L,K), W.L(N,L,J,K)) GE 1) = 1;
OPTION PASSING:1:0:1; DISPLAY PASSING;

PARAMETER DIM(N,J) ACTIVE ADD-DROP MULTIPLEXER ON DS1 LINE J AT NODE N;
DIM(N,J)$(((SUM(I, DIMF(N,I,J)) =1) AND (SUM(I, TMF(N,I,J)) EQ 0)) AND
   (PASSING(N,J) EQ 1) AND (SUM(I, ACCESS.L(N,I,J)) LE (ADMMAX + DEV)) OR
((SUM(I, DIMF(N,I,J)) EQ 1) AND (SUM(I, TMF(N,I,J)) EQ 1) AND (PASSING(N,
            J) EQ 1) AND (SUM(I, ACCESS.L(N,I,J)) LE (ADMMAX + DEV))) OR
((SUM(I, DIMF(N,I,J)) EQ 2) AND (SUM(I, ACCESS.L(N,I,J)) LE ADMLIMIT))) =
1;
OPTION DIM:1:0:1; DISPLAY DIM;

PARAMETER BBTM(N,J) ACTIVE BACK-TO-BACK MULTIPLEXER ON DS1 LINE J AT NODE
N;
BBTM(N,J)$(((SUM(I, ACCESS.L(N,I,J)) GT ADMLIMIT)) OR ((SUM(I, DIMF(N,I,
  J))EQ 1) AND (SUM(I, TMF(N,I,J)) EQ 1) AND (SUM(I, ACCESS.L(N,I,J)) GT
  (ADMMAX + DEV))) OR ((SUM(I, TMF(N,I,J))EQ 1) AND (SUM(I, DIMF(N,I,J))
                                     EQ 0) AND (PASSING(N,J) EQ 1))) = 1;
OPTION BBTM:1:0:1; DISPLAY BBTM;

PARAMETER TMP(N,J) ACTIVE TERMINAL MULTIPLEXER USED AT NODE N;
TMP(N,J)$(((PASSING(N,J) EQ 0) AND (SUM(I, DIMF(N,I,J)) EQ 1) AND (SUM(I,
    TMF(N,I,J)) EQ 1) AND (SUM(I, ACCESS.L(N,I,J)) LE (ADMMAX + DEV))) OR
((PASSING(N,J) EQ 0) AND ((SUM(I, DIMF(N,I,J)) + SUM(I, TMF(N,I,J))) EQ
1))) = 1;
```

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 361  OPTION TMP:1:0:1; DISPLAY TMP;
 362
 363  PARAMETER TM(N,I,J) ACTIVE TERMINAL MULTIPLEXER ON ARC-DS1 LINE AT NODE N;
 364  TM(N,I,J) = ((TMP(N,J) * DIMF(N,I,J)) OR (TMP(N,J) * TMF(N,I,J)));
 365  OPTION TM:1:0:1; DISPLAY TM;
 366

COMPILATION TIME     =        0.067 SECONDS        VERID AXU-25-087


             MODEL STATISTICS
BLOCKS OF EQUATIONS       6     SINGLE EQUATIONS     1625
BLOCKS OF VARIABLES       5     SINGLE VARIABLES     4483
NON ZERO ELEMENTS     11401     DISCRETE VARIABLES   4470
GENERATION TIME      =        0.400 SECONDS
EXECUTION TIME       =        1.000 SECONDS        VERID AXU-25-087
               S O L V E      S U M M A R Y
     MODEL   FAST                OBJECTIVE  Z
     TYPE    MIP                 DIRECTION  MAXIMIZE
     SOLVER  CPLEX               FROM LINE  328
**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE               -1.0000
 RESOURCE USAGE, LIMIT          23.017    14400.000
 ITERATION COUNT, LIMIT     10228         1000
Option file:
> iterationlim 100000
> nodeselect 0
Proven optimal solution.
MIP Solution  :           -1.000000    (10228 iterations, 700 nodes)
Final LP      :           -1.000000    (0 iterations)
Best integer solution possible :          -1.000000
Relative gap                   :                 0
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED


----  329 VARIABLE  X.L   0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I

OD24.A16.R05.C06 1.0
OD24.A16.R05.C09 1.0
OD24.A16.R05.C12 1.0
OD24.A16.R05.C13 1.0
OD24.A16.R05.C14 1.0
OD24.A16.R05.C15 1.0
OD24.A16.R05.C16 1.0
OD24.A16.R05.C17 1.0
OD24.A16.R05.C18 1.0
OD24.A16.R05.C22 1.0
OD24.A16.R05.C24 1.0
OD25.A16.R03.C16 1.0
OD25.A16.R03.C17 1.0
OD25.A16.R03.C19 1.0
OD25.A16.R03.C20 1.0
OD25.A16.R03.C21 1.0
OD25.A16.R03.C22 1.0
OD25.A16.R03.C23 1.0
OD25.A16.R03.C24 1.0
OD25.A16.R04.C22 1.0
OD25.A16.R06.C09 1.0
OD25.A16.R06.C10 1.0
OD25.A16.R06.C11 1.0
OD25.A16.R06.C12 1.0
OD25.A16.R06.C13 1.0
OD25.A16.R06.C24 1.0
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OD25.A20.R03.C16 1.0
OD25.A20.R03.C17 1.0
OD25.A20.R03.C19 1.0
OD25.A20.R03.C20 1.0
OD25.A20.R03.C21 1.0
OD25.A20.R03.C22 1.0
OD25.A20.R03.C23 1.0
OD25.A20.R03.C24 1.0
----  329 VARIABLE  X.L   0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I

OD25.A20.R04.C22 1.0
OD25.A20.R06.C09 1.0
OD25.A20.R06.C10 1.0
OD25.A20.R06.C11 1.0
OD25.A20.R06.C12 1.0
OD25.A20.R06.C13 1.0
OD25.A20.R06.C24 1.0
OD26.A16.R04.C13 1.0
OD26.A16.R04.C19 1.0
OD26.A16.R06.C03 1.0
OD26.A16.R06.C20 1.0
OD26.A16.R06.C21 1.0
OD26.A20.R04.C13 1.0
OD26.A20.R04.C19 1.0
OD26.A20.R06.C03 1.0
OD26.A20.R06.C20 1.0
OD26.A20.R06.C21 1.0
OD27.A16.R02.C07 1.0
OD27.A16.R03.C07 1.0
OD27.A16.R03.C09 1.0
OD27.A16.R03.C14 1.0
OD27.A16.R04.C08 1.0
OD27.A16.R04.C10 1.0
OD27.A16.R05.C04 1.0
OD27.A16.R05.C19 1.0
OD27.A16.R06.C06 1.0
OD27.A16.R06.C07 1.0
OD27.A16.R06.C22 1.0
OD27.A16.R06.C23 1.0
OD27.A20.R02.C07 1.0
OD27.A20.R03.C07 1.0
OD27.A20.R03.C09 1.0
OD27.A20.R03.C14 1.0
OD27.A20.R04.C08 1.0
OD27.A20.R04.C10 1.0
OD27.A20.R05.C04 1.0
OD27.A20.R05.C19 1.0
OD27.A20.R06.C06 1.0
OD27.A20.R06.C07 1.0
OD27.A20.R06.C22 1.0
OD27.A20.R06.C23 1.0
OD28.A16.R06.C15 1.0
OD28.A16.R06.C19 1.0
OD28.A20.R06.C15 1.0
OD28.A20.R06.C19 1.0
OD29.A16.R05.C01 1.0
OD29.A16.R05.C02 1.0
OD29.A16.R06.C01 1.0
OD29.A16.R06.C08 1.0
OD29.A20.R05.C01 1.0
OD29.A20.R05.C02 1.0
OD29.A20.R06.C01 1.0
OD29.A20.R06.C08 1.0
OD45.A20.R05.C06 1.0
OD46.A16.R05.C03 1.0
OD46.A16.R05.C23 1.0
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OD47.A16.R05.C08 1.0
OD47.A16.R05.C11 1.0
OD47.A16.R05.C21 1.0
OD50.A16.R05.C07 1.0
OD50.A20.R05.C07 1.0
OD51.A16.R02.C23 1.0
OD51.A16.R04.C17 1.0
OD51.A16.R04.C18 1.0
OD51.A16.R04.C20 1.0
----  329 VARIABLE  X.L   0-1 VARIABLE INDICATING DO NOT-DO ASSIGN OD L TO ARC I

OD51.A16.R04.C23 1.0
OD51.A16.R05.C05 1.0
OD51.A16.R05.C10 1.0
OD51.A16.R05.C20 1.0
OD51.A16.R06.C02 1.0
OD51.A16.R06.C14 1.0
OD51.A16.R06.C16 1.0
OD51.A16.R06.C18 1.0
OD51.A20.R02.C23 1.0
OD51.A20.R04.C17 1.0
OD51.A20.R04.C18 1.0
OD51.A20.R04.C20 1.0
OD51.A20.R04.C23 1.0
OD51.A20.R05.C05 1.0
OD51.A20.R05.C10 1.0
OD51.A20.R05.C20 1.0
OD51.A20.R06.C02 1.0
OD51.A20.R06.C14 1.0
OD51.A20.R06.C16 1.0
OD51.A20.R06.C18 1.0
OD52.A16.R01.C06 1.0
OD52.A16.R03.C08 1.0
OD52.A16.R04.C16 1.0
OD52.A20.R01.C06 1.0
OD52.A20.R03.C08 1.0
OD52.A20.R04.C16 1.0
OD53.A16.R06.C17 1.0
OD53.A20.R06.C17 1.0


----    330 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N16.A16.R01.C06.OD52 1.0
N16.A16.R02.C07.OD27 1.0
N16.A16.R02.C23.OD51 1.0
N16.A16.R03.C07.OD27 1.0
N16.A16.R03.C08.OD52 1.0
N16.A16.R03.C09.OD27 1.0
N16.A16.R03.C14.OD27 1.0
N16.A16.R03.C16.OD25 1.0
N16.A16.R03.C17.OD25 1.0
N16.A16.R03.C19.OD25 1.0
N16.A16.R03.C20.OD25 1.0
N16.A16.R03.C21.OD25 1.0
N16.A16.R03.C22.OD25 1.0
N16.A16.R03.C23.OD25 1.0
N16.A16.R03.C24.OD25 1.0
N16.A16.R04.C08.OD27 1.0
N16.A16.R04.C10.OD27 1.0
N16.A16.R04.C13.OD26 1.0
N16.A16.R04.C16.OD52 1.0
N16.A16.R04.C17.OD51 1.0
N16.A16.R04.C18.OD51 1.0
N16.A16.R04.C19.OD26 1.0
N16.A16.R04.C20.OD51 1.0
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N16.A16.R04.C22.OD25 1.0
N16.A16.R04.C23.OD51 1.0
N16.A16.R05.C01.OD29 1.0
N16.A16.R05.C02.OD29 1.0
N16.A16.R05.C03.OD46 1.0
N16.A16.R05.C04.OD27 1.0
N16.A16.R05.C05.OD51 1.0
N16.A16.R05.C06.OD24 1.0
N16.A16.R05.C07.OD50 1.0
N16.A16.R05.C08.OD47 1.0
----    330 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N16.A16.R05.C09.OD24 1.0
N16.A16.R05.C10.OD51 1.0
N16.A16.R05.C11.OD47 1.0
N16.A16.R05.C12.OD24 1.0
N16.A16.R05.C13.OD24 1.0
N16.A16.R05.C14.OD24 1.0
N16.A16.R05.C15.OD24 1.0
N16.A16.R05.C16.OD24 1.0
N16.A16.R05.C17.OD24 1.0
N16.A16.R05.C18.OD24 1.0
N16.A16.R05.C19.OD27 1.0
N16.A16.R05.C20.OD51 1.0
N16.A16.R05.C21.OD47 1.0
N16.A16.R05.C22.OD24 1.0
N16.A16.R05.C23.OD46 1.0
N16.A16.R05.C24.OD24 1.0
N16.A16.R06.C01.OD29 1.0
N16.A16.R06.C02.OD51 1.0
N16.A16.R06.C03.OD26 1.0
N16.A16.R06.C06.OD27 1.0
N16.A16.R06.C07.OD27 1.0
N16.A16.R06.C08.OD29 1.0
N16.A16.R06.C09.OD25 1.0
N16.A16.R06.C10.OD25 1.0
N16.A16.R06.C11.OD25 1.0
N16.A16.R06.C12.OD25 1.0
N16.A16.R06.C13.OD25 1.0
N16.A16.R06.C14.OD51 1.0
N16.A16.R06.C15.OD28 1.0
N16.A16.R06.C16.OD51 1.0
N16.A16.R06.C17.OD53 1.0
N16.A16.R06.C18.OD51 1.0
N16.A16.R06.C19.OD28 1.0
N16.A16.R06.C20.OD26 1.0
N16.A16.R06.C21.OD26 1.0
N16.A16.R06.C22.OD27 1.0
N16.A16.R06.C23.OD27 1.0
N16.A16.R06.C24.OD25 1.0
N17.A16.R01.C06.OD52 1.0
N17.A16.R02.C07.OD27 1.0
N17.A16.R02.C23.OD51 1.0
N17.A16.R03.C07.OD27 1.0
N17.A16.R03.C08.OD52 1.0
N17.A16.R03.C09.OD27 1.0
N17.A16.R03.C14.OD27 1.0
N17.A16.R03.C16.OD25 1.0
N17.A16.R03.C17.OD25 1.0
N17.A16.R03.C19.OD25 1.0
N17.A16.R03.C20.OD25 1.0
N17.A16.R03.C21.OD25 1.0
N17.A16.R03.C22.OD25 1.0
N17.A16.R03.C23.OD25 1.0
N17.A16.R03.C24.OD25 1.0
N17.A16.R04.C08.OD27 1.0
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N17.A16.R04.C10.OD27 1.0
N17.A16.R04.C13.OD26 1.0
N17.A16.R04.C16.OD52 1.0
N17.A16.R04.C17.OD51 1.0
N17.A16.R04.C18.OD51 1.0
N17.A16.R04.C19.OD26 1.0
N17.A16.R04.C20.OD51 1.0
N17.A16.R04.C22.OD25 1.0
N17.A16.R04.C23.OD51 1.0
N17.A16.R05.C01.OD29 1.0
N17.A16.R05.C02.OD29 1.0
----    330 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N17.A16.R05.C03.OD46 1.0
N17.A16.R05.C04.OD27 1.0
N17.A16.R05.C05.OD51 1.0
N17.A16.R05.C06.OD24 1.0
N17.A16.R05.C07.OD50 1.0
N17.A16.R05.C08.OD47 1.0
N17.A16.R05.C09.OD24 1.0
N17.A16.R05.C10.OD51 1.0
N17.A16.R05.C11.OD47 1.0
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N17.A16.R05.C13.OD24 1.0
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N17.A16.R05.C16.OD24 1.0
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N17.A16.R05.C22.OD24 1.0
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N17.A16.R05.C24.OD24 1.0
N17.A16.R06.C01.OD29 1.0
N17.A16.R06.C02.OD51 1.0
N17.A16.R06.C03.OD26 1.0
N17.A16.R06.C06.OD27 1.0
N17.A16.R06.C07.OD27 1.0
N17.A16.R06.C08.OD29 1.0
N17.A16.R06.C09.OD25 1.0
N17.A16.R06.C10.OD25 1.0
N17.A16.R06.C11.OD25 1.0
N17.A16.R06.C12.OD25 1.0
N17.A16.R06.C13.OD25 1.0
N17.A16.R06.C14.OD51 1.0
N17.A16.R06.C15.OD28 1.0
N17.A16.R06.C16.OD51 1.0
N17.A16.R06.C17.OD53 1.0
N17.A16.R06.C18.OD51 1.0
N17.A16.R06.C19.OD28 1.0
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N17.A16.R06.C22.OD27 1.0
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N17.A16.R06.C24.OD25 1.0
N17.A20.R01.C06.OD52 1.0
N17.A20.R02.C07.OD27 1.0
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N17.A20.R03.C07.OD27 1.0
N17.A20.R03.C08.OD52 1.0
N17.A20.R03.C09.OD27 1.0
N17.A20.R03.C14.OD27 1.0
N17.A20.R03.C16.OD25 1.0
N17.A20.R03.C17.OD25 1.0
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N17.A20.R03.C19.OD25 1.0
N17.A20.R03.C20.OD25 1.0
N17.A20.R03.C21.OD25 1.0
N17.A20.R03.C22.OD25 1.0
N17.A20.R03.C23.OD25 1.0
N17.A20.R03.C24.OD25 1.0
N17.A20.R04.C08.OD27 1.0
N17.A20.R04.C10.OD27 1.0
N17.A20.R04.C13.OD26 1.0
N17.A20.R04.C16.OD52 1.0
N17.A20.R04.C17.OD51 1.0
N17.A20.R04.C18.OD51 1.0
----    330 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N17.A20.R04.C19.OD26 1.0
N17.A20.R04.C20.OD51 1.0
N17.A20.R04.C22.OD25 1.0
N17.A20.R04.C23.OD51 1.0
N17.A20.R05.C01.OD29 1.0
N17.A20.R05.C02.OD29 1.0
N17.A20.R05.C04.OD27 1.0
N17.A20.R05.C05.OD51 1.0
N17.A20.R05.C06.OD45 1.0
N17.A20.R05.C07.OD50 1.0
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N17.A20.R06.C01.OD29 1.0
N17.A20.R06.C02.OD51 1.0
N17.A20.R06.C03.OD26 1.0
N17.A20.R06.C06.OD27 1.0
N17.A20.R06.C07.OD27 1.0
N17.A20.R06.C08.OD29 1.0
N17.A20.R06.C09.OD25 1.0
N17.A20.R06.C10.OD25 1.0
N17.A20.R06.C11.OD25 1.0
N17.A20.R06.C12.OD25 1.0
N17.A20.R06.C13.OD25 1.0
N17.A20.R06.C14.OD51 1.0
N17.A20.R06.C15.OD28 1.0
N17.A20.R06.C16.OD51 1.0
N17.A20.R06.C17.OD53 1.0
N17.A20.R06.C18.OD51 1.0
N17.A20.R06.C19.OD28 1.0
N17.A20.R06.C20.OD26 1.0
N17.A20.R06.C21.OD26 1.0
N17.A20.R06.C22.OD27 1.0
N17.A20.R06.C23.OD27 1.0
N17.A20.R06.C24.OD25 1.0
N18.A20.R01.C06.OD52 1.0
N18.A20.R02.C07.OD27 1.0
N18.A20.R02.C23.OD51 1.0
N18.A20.R03.C07.OD27 1.0
N18.A20.R03.C08.OD52 1.0
N18.A20.R03.C09.OD27 1.0
N18.A20.R03.C14.OD27 1.0
N18.A20.R03.C16.OD25 1.0
N18.A20.R03.C17.OD25 1.0
N18.A20.R03.C19.OD25 1.0
N18.A20.R03.C20.OD25 1.0
N18.A20.R03.C21.OD25 1.0
N18.A20.R03.C22.OD25 1.0
N18.A20.R03.C23.OD25 1.0
N18.A20.R03.C24.OD25 1.0
N18.A20.R04.C08.OD27 1.0
N18.A20.R04.C10.OD27 1.0
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N18.A20.R04.C13.OD26 1.0
N18.A20.R04.C16.OD52 1.0
N18.A20.R04.C17.OD51 1.0
N18.A20.R04.C18.OD51 1.0
N18.A20.R04.C19.OD26 1.0
N18.A20.R04.C20.OD51 1.0
N18.A20.R04.C22.OD25 1.0
N18.A20.R04.C23.OD51 1.0
N18.A20.R05.C01.OD29 1.0
N18.A20.R05.C02.OD29 1.0
N18.A20.R05.C04.OD27 1.0
N18.A20.R05.C05.OD51 1.0
N18.A20.R05.C06.OD45 1.0
----    330 PARAMETER USEDRESID     ASSIGNMENT CHART FOR RESIDUAL DS1 LINES

N18.A20.R05.C07.OD50 1.0
N18.A20.R05.C10.OD51 1.0
N18.A20.R05.C19.OD27 1.0
N18.A20.R05.C20.OD51 1.0
N18.A20.R06.C01.OD29 1.0
N18.A20.R06.C02.OD51 1.0
N18.A20.R06.C03.OD26 1.0
N18.A20.R06.C06.OD27 1.0
N18.A20.R06.C07.OD27 1.0
N18.A20.R06.C08.OD29 1.0
N18.A20.R06.C09.OD25 1.0
N18.A20.R06.C10.OD25 1.0
N18.A20.R06.C11.OD25 1.0
N18.A20.R06.C12.OD25 1.0
N18.A20.R06.C13.OD25 1.0
N18.A20.R06.C14.OD51 1.0
N18.A20.R06.C15.OD28 1.0
N18.A20.R06.C16.OD51 1.0
N18.A20.R06.C17.OD53 1.0
N18.A20.R06.C18.OD51 1.0
N18.A20.R06.C19.OD28 1.0
N18.A20.R06.C20.OD26 1.0
N18.A20.R06.C21.OD26 1.0
N18.A20.R06.C22.OD27 1.0
N18.A20.R06.C23.OD27 1.0
N18.A20.R06.C24.OD25 1.0


----    331 PARAMETER AD            ADD-DROP NODE

N17 1.000


----  332 VARIABLE  W.L     0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J

N17.OD25.R03.C16 1.0
N17.OD25.R03.C17 1.0
N17.OD25.R03.C19 1.0
N17.OD25.R03.C20 1.0
N17.OD25.R03.C21 1.0
N17.OD25.R03.C22 1.0
N17.OD25.R03.C23 1.0
N17.OD25.R03.C24 1.0
N17.OD25.R04.C22 1.0
N17.OD25.R06.C09 1.0
N17.OD25.R06.C10 1.0
N17.OD25.R06.C11 1.0
N17.OD25.R06.C12 1.0
N17.OD25.R06.C13 1.0
N17.OD25.R06.C24 1.0
N17.OD26.R04.C13 1.0
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N17.OD26.R04.C19 1.0
N17.OD26.R06.C03 1.0
N17.OD26.R06.C20 1.0
N17.OD26.R06.C21 1.0
N17.OD27.R02.C07 1.0
N17.OD27.R03.C07 1.0
N17.OD27.R03.C09 1.0
N17.OD27.R03.C14 1.0
N17.OD27.R04.C08 1.0
N17.OD27.R04.C10 1.0
N17.OD27.R05.C04 1.0
N17.OD27.R05.C19 1.0
N17.OD27.R06.C06 1.0
N17.OD27.R06.C07 1.0
----  332 VARIABLE  W.L     0-1 VARIABLE INDICATING NOT ACTIVE-ACTIVE DS1 LINE J

N17.OD27.R06.C22 1.0
N17.OD27.R06.C23 1.0
N17.OD28.R06.C15 1.0
N17.OD28.R06.C19 1.0
N17.OD29.R05.C01 1.0
N17.OD29.R05.C02 1.0
N17.OD29.R06.C01 1.0
N17.OD29.R06.C08 1.0
N17.OD50.R05.C07 1.0
N17.OD51.R02.C23 1.0
N17.OD51.R04.C17 1.0
N17.OD51.R04.C18 1.0
N17.OD51.R04.C20 1.0
N17.OD51.R04.C23 1.0
N17.OD51.R05.C05 1.0
N17.OD51.R05.C10 1.0
N17.OD51.R05.C20 1.0
N17.OD51.R06.C02 1.0
N17.OD51.R06.C14 1.0
N17.OD51.R06.C16 1.0
N17.OD51.R06.C18 1.0
N17.OD52.R01.C06 1.0
N17.OD52.R03.C08 1.0
N17.OD52.R04.C16 1.0
N17.OD53.R06.C17 1.0


----    333 VARIABLE  ACCESS.L      NUMBER OF DS0 CHANNELS ADDED AND DROPPED BY
ARC I

N17.A16.R05 16.0
N17.A20.R05  1.0


----    334 VARIABLE  DS1.L         LINE J AND DS0 CHANNEL K

N17.R05 1.0


----    338 PARAMETER DIMF          ADD-DROP MULTIPLEXER REQUIREMENTS NOT MET-
MET AT NODE ARC DS1 LINE

N17.A16.R05 1.0
N17.A20.R05 1.0


----    342 PARAMETER TMF           TERMINAL MULTIPLEXER REQUIREMENTS NOT MET-
MET AT NODE ARC DS1 LINE

N17.A16.R05 1.0
```

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----    346 PARAMETER PASSING       DS1 LINE USED BY ODS THAT PASS THROUGH NODE
N

N17.R01 1.0
N17.R02 1.0
N17.R03 1.0
N17.R04 1.0
N17.R05 1.0
N17.R06 1.0



----    352 PARAMETER DIM           ACTIVE ADD-DROP MULTIPLEXER ON DS1 LINE J AT
NODE N

N17.R05 1.0


----    356 PARAMETER BBTM          ACTIVE BACK-TO-BACK MULTIPLEXER ON DS1 LINE
J AT NODE N

                    ( ALL         0.0 )



----    361 PARAMETER TMP           ACTIVE TERMINAL MULTIPLEXER USED AT NODE N

                    ( ALL         0.0 )


----    365 PARAMETER TM            ACTIVE TERMINAL MULTIPLEXER ON ARC-DS1 LINE
AT NODE N

                    ( ALL         0.0 )


EXECUTION TIME       =        0.800 SECONDS        VERID AXU-25-087
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