

HAI Model

Release 5.3

Model Description

HAI Consulting, Inc.

1355 S. Boulder Rd #184
Louisville, Colorado 80027

January 21, 2004

The HAI Model, R5.3 and its documentation is © 2004 by HAI Consulting, Inc.,
AT&T Corp., and MCI.
All rights reserved.

TABLE OF CONTENTS

1.	Overview of HM 5.3 for Verizon Washington	1
2.	Summary of the History of the HAI Model.....	4
3.	Components of the Local Exchange Network	5
3.1.	Loop Description.....	5
3.1.1.	Serving Area.....	5
3.1.2.	General Loop Description.....	6
3.1.3.	Local Loop Components.....	6
3.2.	Switching and Interoffice Network Description.....	8
3.2.1.	Wire Centers	8
3.2.2.	End Office Switches.....	9
3.2.3.	Tandem Switches	9
3.2.4.	Interoffice Transmission Facilities.....	10
3.2.5.	Signal Transfer Points	11
3.2.6.	Service Switching Points and Signaling Links	11
3.2.7.	Service Control Points	11
4.	HM 5.3 Model Organization, Structure and Logic.....	12
4.1.	Overview of HM 5.3 Organization	12
4.2.	Input Data	13
4.3.	Workfiles.....	13
4.4.	User Interface	14

4.5.	Distribution Module.....	14
4.6.	Feeder Module.....	15
4.7.	Switching and Interoffice Module	16
4.8.	Expense Modules.....	16
5.	Input Data	18
5.1.	Wire Center List.....	18
5.2.	Customer Location And Line Count Data.....	18
5.3.	Customer Location Clustering.....	20
5.3.1.	General Process.....	20
5.3.2.	Clustering Criteria	21
5.3.3.	Clustering Algorithm.....	22
5.4.	PointCode Translation Processes	23
6.	Input Data Files.....	25
6.1.	Demographic and Geological Parameters	25
6.2.	Wire Center Locations and Interoffice Distances.....	26
6.3.	ARMIS Data.....	26
6.4.	User Inputs	27
7.	Outside Plant Engineering	28
7.1.	Outside Plant Structures	29
7.2.	Terrain and Its Impact on Placement Costs.....	30
7.3.	Structure Sharing	31
7.4.	Line Density Considerations	31

7.5.	Economic Adjustment of Structure Fractions	32
8.	Distribution Module.....	34
8.1.	Treatment of Main Clusters.....	34
8.2.	Treatment of Outlier Clusters	36
8.3.	Customer Drop Arrangement.....	36
8.4.	Normalization of Distribution Distances	37
8.5.	Determination of Feeder Technology	38
8.6.	“Steering” Feeder Routes.....	38
8.7.	Calculation of SAI and DLC Investments	39
8.8.	Treatment of All-Fiber Loops	40
8.9.	Calculation of Distribution Investments	41
9.	Feeder Module.....	43
9.1.	Overview.....	43
9.2.	Feeder Architecture Assumed by the Model.....	43
9.3.	Determination of Feeder Investments	44
9.3.1.	Calculating Main Feeder and Subfeeder Distances.....	44
9.3.2.	Copper and Fiber Subfeeder Cable Sizing	47
9.3.3.	Main Feeder Segment Sizing.....	48
9.3.4.	Structure Investments.....	48
9.3.5.	Assignment of Main Feeder Investments	48
9.4.	Feeder Calculations Associated with all-Fiber Loops	48
10.	Switching and Interoffice Module	51

10.1.	Overview.....	51
10.2.	Description of Inputs and Assumptions	51
10.3.	Explanation of Calculations	52
10.3.1.	End Office Switching Investments	52
10.3.2.	Transport Investments	54
10.3.3.	Tandem Switch Investments	59
10.3.4.	Signaling Network Investments	59
10.3.5.	Operator Systems Investments	60
11.	Expense Modules	61
11.1.	Overview.....	61
11.2.	Capital Carrying Costs	62
11.3.	Operating Expenses	64
11.3.1.	Network-Related Expenses	65
11.3.2.	Non-Network Related Expenses	66
11.4.	Expense Module Output	67
11.4.1.	UNE Outputs (Unit Cost Sheet).....	67
11.4.2.	Grouping Wire Center Results	69
11.4.3.	Company-Specific Rate Sheet.....	70
12.	Summary	72

LIST OF APPENDICES

- A. History of the Hatfield/HAI Model HM 5.3**
- B. General Rules Governing the Creation of the HM 5.3 Distance Files**

1. Overview of HM 5.3 for Verizon Washington

The HAI Model, Release 5.3 (“HM 5.3”, or “the Model”) has been developed by HAI Consulting, Inc. (“HAI”) of Louisville, Colorado, at the request of AT&T Corporation and MCI. The purpose of the Model is to provide a single integrated approach for estimating the recurring forward-looking economic costs of:

- a) Basic local telephone service;
- b) Unbundled network elements (“UNEs”); and
- c) Carrier access to, and interconnection with, the local exchange network.

All three sets of costs are calculated based on forward-looking economic cost principles,¹ and use a consistent set of assumptions, procedures and input data.

The HM 5.3 uses the definition of basic local telephone service adopted by the Federal-State Joint Board on Universal Service (“Joint Board”) for universal service funding purposes.² The Joint Board includes the following functional elements as required components of universal service:

- single-line, single-party access to the first point of switching in a local exchange network;
- usage within a local exchange area, including access to interexchange service;
- touch tone capability;
- access to 911 services, operator services, directory assistance, and telecommunications relay service for the hearing-impaired.

This definition of universal service excludes many other local exchange company (“LEC”) services, such as toll calling, custom calling and CLASSSM features, private line services and white pages directory listings. However, the HM 5.3 sizes the modeled network to reflect the existence of these services as well as all UNEs. In the case of switching features such as

¹ The model applies Total Service Long Run Incremental Cost (“TSLRIC”) principles to calculate the cost of basic local service and carrier access to the basic local network. The model applies analogous Total Element Long Run Incremental Cost, or TELRIC, principles to calculate the cost of unbundled network elements and interconnection. TELRIC is a methodology developed by the Federal Communications Commission (“FCC”) that closely corresponds to TSLRIC; *see, Implementation of the Local Competition Provisions in the Telecommunications Act of 1996*, CC Docket No. 96-98, Interconnection between Local Exchange Carriers and Commercial Mobile Radio Service Providers, CC Docket No. 95-185, First Report and Order, 11 FCC Rcd 15499 (1996) (“Local Competition Order”), para 672.

² Federal-State Joint Board on Universal Service, CC Docket No. 96-45, Recommended Decision, November 8, 1996, (“Recommended Decision”) paras. 45-53, 65-70.

CLASS, the costs of those features are included in the basic price of switches assumed by the model, so the cost of the local switching UNE includes those features as well. Model users may specify which UNEs, and what volumes of those UNEs, are included in the calculation of universal service support requirements.

HM 5.3 calculates the costs of the following UNEs used in connection with voice (often referred to in the industry's jargon as Plain Old Telephone Service, or "POTS")³ and voiceband data services:

- Network Interface Device ("NID")
- Loop Distribution
- Loop Concentrator/Multiplexer
- Loop Feeder
- End Office Switching, including the cost of features supported by end office switch software
- Common Transport
- Dedicated Transport
- Direct Transport
- Tandem Switching
- Signaling Links
- Signal Transfer Point ("STP")
- Service Control Point ("SCP")
- Operator Systems
- Public Telephones

The model is capable of estimating the cost of other non-POTS UNEs as well. Depending on the jurisdiction involved, these have included for instance Integrated Services Digital Network ("ISDN"), ADSL, DS-1, DS-3 loops, multiplexing and cross-connect functions associated with dedicated circuits, dark fiber, and entrance facilities. DS-1 and DS-3 loop costs are produced as standard outputs to the model; other UNE costs are calculated in a UNE rate sheet that is structured according to the particular jurisdiction, company, and/or proceeding in which the model is being used. In sizing the amounts of copper and fiber cables in the loop, and in assigning joint and common costs to multiple UNEs, the model also

³ It is important in reading this document to remember the distinction between a service like POTS and a UNE associated with the loop and other network components of that service. For instance, loops used to provide POTS service have a certain set of transmission properties that make them suitable for carrying voice and, it was discovered many years ago, data transmitted in analog (non-digital) form using a modem at each end of the connection. A CLEC that purchases a "POTS loop" UNE is not purchasing the POTS service; rather, it is purchasing a loop that possesses the defined set of voice transmission properties. Such loops are often referred to in industry jargon as "voicegrade" loops, and data transmitted over them using modems or other devices is often referred to as "voiceband data." Similarly, a DS-3 digital service provides a circuit capable of carrying a digital signal at 44.736 Megabits per second. Such a circuit typically consists of two DS-3 links, or "loops" between a wire center and a customer premises at each end of the circuit, and an interoffice circuit connecting the two wire centers serving the premises, if different. The DS-3 loop UNE should not be confused with the entire DS-3 service the ILEC offers. Whenever this document refers to a "POTS loop" or a "DS-3" loop, it is using the term to refer to the UNE loop with the characteristics associated with the service, not to the service itself.

takes into account other high capacity loops in addition to DS-3, even though it does not explicitly present the cost results for UNEs associated with those services. The ability of the model to account for and calculate the UNEs associated with services other than POTS is predicated on the availability of data that specifies the locations of customers for those services. The model is capable of running without such data, but will then account for, and produce the UNE costs of, only UNEs related to services for which data are available.

The Model also estimates the per-minute cost of providing local network interconnection and interLATA access. These are estimated for connection points at end office and tandem switches.

The Model constructs a “bottom up” estimate of costs based upon detailed data describing demand quantities and locations, wire center locations, companies’ operational costs reported to regulatory authorities, and a substantial number of user-adjustable inputs. The Model’s demand data, particularly data describing customer locations, line demand, and traffic volumes, serve as the starting point. Customer locations are determined through geocoding, augmented as necessary by a surrogate location process for those customers whose geocoded locations are not known. A clustering algorithm is used to develop groupings of customer locations that have a realistic correlation to efficient distribution areas. The Local Exchange Routing Guide (“LERG”) licensed from Telcordia Technologies, Inc., is used to identify and locate incumbent local exchange carrier (“ILEC”) wire centers. HM 5.3 costs a local exchange network that is engineered to have sufficient capacity to meet all existing demand, both retail and wholesale, to the extent the associated demand data are available, and to maintain a high level of service quality.

The Model’s user-adjustable inputs include a large variety of information, including for instance, the prices of various network components, with their associated installation and placement costs, various capital cost parameters, forward-looking adjustments to operations costs, and many other affecting the costs of providing local service, such as the amount of sharing of outside plant structures with other utilities. These data are used to populate detailed input tables describing, for example, the cost per foot of various sizes of copper and fiber cable, cost per line of switching, cost of debt and equity, and depreciation lives for each specific network component.

Using these data, the Model calculates required network investments by detailed plant category. Next, it calculates the capital carrying cost of these investments. It then adds operations expenses, including both network-related expenses and various non-network expenses, such as corporate overhead. Once all these costs are aggregated, the model computes the total monthly cost of universal service, the cost of the UNEs identified previously, stated on both a total cost and an appropriate per-unit basis; and the cost of carrier access to, and interconnection with, the local exchange network. Costs can be displayed on a study area, density zone,⁴ wire center, or wire center “zone” basis.

⁴ Density refers to the number of subscriber access lines per square mile; a density “zone” is a range of densities.

The model uses the latest available customer location data provided by the company being studied. It also uses data on Census Block Groups, road locations, and housing occupancy rates based on the 2000 Census.

This document describes the structure and operation of the HM 5.3, including a discussion of various inputs to the Model. Section 2 summarizes the history of the model, which is presented in more detail in Appendix A to this description. Section 3 provides a general overview of the local network being modeled. Section 4 briefly reviews the structure of the Model and its data. Section 5 focuses on the method by which customer locations are determined and clustered. Section 6 provides a detailed description of the various input data files that are used by the model. Section 7 discusses outside plant engineering principles and considerations that are incorporated into the model. Sections 8-11 are each devoted to one of the four modules that make up the model, describing the assumptions, algorithms, and calculations of the modules. These sections deal respectively, with Distribution Plant (Section 8), Feeder Plant (Section 9), Switching and Interoffice Plant (Section 10), and the calculation of USF, network interconnection, and UNE costs (Section 11). Section 12 summarizes the document.

Appendix A provides a history of the Hatfield/HAI Model. Appendix B describes the calculation of interoffice network distances in the model. Also accompanying this Model Description is the HM 5.3 Inputs Portfolio (“HIP”), which identifies user inputs and explains the basis for the values assigned to those inputs, and the HM 5.3 User Guide, which explains how to install and run the Model on a suitably-equipped personal computer.

2. Summary of the History of the HAI Model

The history of the HAI Model is described in Appendix A of this model description. Briefly, the HAI Model was originally developed in 1994 to estimate the TSLRIC of basic local telephone service as part of an examination of the cost of universal service. It has evolved through many releases since that time. This evolution has occurred in response to ongoing intensive internal reviews of the Model, scrutiny of prior versions of the Model by regulators and other often-hostile parties, new regulatory requirements, and dramatic new developments in modeling techniques and data sources. Each subsequent release has provided enhancements to the prior release.

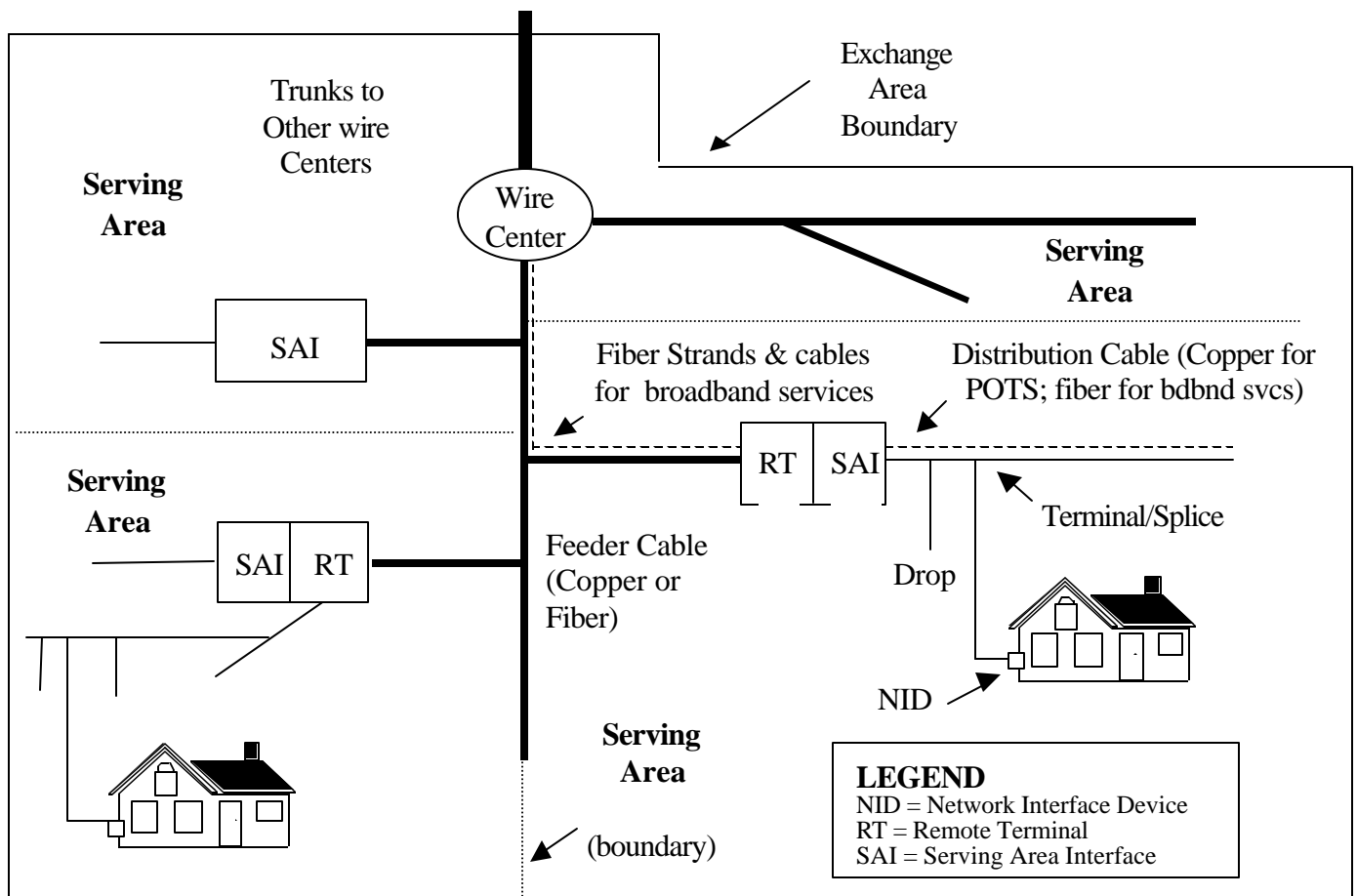
Several releases of the model were submitted to the FCC in the course of its examination of UNE and Universal Service costs, and thus are available nationwide with a database applicable to all carriers. The last such national release was Release 5.0a, submitted to the FCC on January 28, 1998. Versions subsequent to that one have been submitted in a number of individual state proceedings, with databases specific to the states and companies at issue in the proceeding. HM 5.3 was originally developed for use in estimating UNE costs for Verizon California in Application 01-02-024 et al, and has since been submitted in several proceedings. The version of HM 5.3 described in this document has a few additional capabilities and features beyond those of the original version.

3. Components of the Local Exchange Network

This section describes the network configuration and components modeled in HM 5.3. Figures 1, 2 and 3 depict the relationships among the loop, switching, interoffice, and signaling network components.

3.1. Loop Description

Figure 1 depicts the loop investment model utilized in HM 5.3. Section 3.1.1 defines the serving area. Section 3.1.2 provides a general description of the loop, shown in Figure 1. Section 3.1.3 describes the loop components in more detail.



Adapted from *Engineering and Operations in the Bell System*, 2nd Edition, 1983

Figure 1 Loop Components

3.1.1. Serving Area

The total area served by a wire center is organized into one or more serving areas, each of which contains a portion of the area and lines served by the wire center. The serving areas are delineated by dotted lines in the above figure. In HM 5.3, the serving areas equate to main customer clusters and their associated outlier clusters, as discussed in Section 7.

3.1.2. General Loop Description

One end of the feeder portion of the loop terminates within the central office building, or “wire center.” Copper cable feeder facilities terminate on the “vertical” side of the main distributing frame (“MDF”) in the wire center, and fiber optic feeder cables serving integrated digital loop carrier (“IDLC”) systems terminate on a fiber distribution frame in the wire center. The feeder plant may include additional fiber cables, or strands within existing cables, to support all-fiber loops such as DS-3 and SONET dedicated circuits.

The other end of the feeder extends to an appropriate termination point in the serving area. Copper feeder cables terminate on one or more SAIs in each serving area, where they are cross-connected to copper distribution cables. Fiber feeder cables extend to a DLC RT in the serving area, where signals associated with voicegrade loops are demultiplexed and converted to analog (non-digital) electrical signals. Individual voicegrade signals from the DLC are cross-connected to copper pairs in distribution cables at an adjacent SAI. If there are fiber-based services located in the serving area, fiber cables are cross-connected to distribution fiber cables in a patch panel in the RT or SAI.

Copper distribution cable, and, as appropriate, fiber cables, extend from the SAI along routes passing individual customer premises. At appropriate points, the copper cables pass through block terminals typically serving several housing units. In the terminal, individual copper pairs in the distribution cable are connected to “drops” that extend from the terminal to the customers premises. The drop terminates at a network interface device, or NID, at the customer’s premises. Strands from fiber cables are spliced into fiber “drop cable,” which enters the building where broadband customers are located; these strands are then spliced into fiber “pigtails” that connect the signals to the premises terminal equipment.

Feeder, distribution, and drop cables are supported by “structures”: underground conduit, poles, or trenches for buried cable and underground conduit. Underground cable is distinguished from buried cable in that underground cable is placed in conduit, while buried cable comes into direct contact with soil.⁵ In urban areas, aerial distribution cable may also be attached directly to the outside of buildings, in what is called a “block cable” arrangement or, in high-rise buildings, may consist of interior cable usually located in vertical “risers” that extend from floor to floor. The Model treats such riser cable and its associated costs as being part of the distribution network.⁶

3.1.3. Local Loop Components

⁵ Although the conduit supporting underground cable is always placed in a trench, buried cable may either be placed in a trench or be directly plowed into the earth.

⁶ To the extent that riser cable is separately tariffed or otherwise excluded from the loop UNE, the per-foot cost of riser cable can be set to \$0 to avoid double-counting costs.

1) *Network Interface Device*

The NID is the demarcation point between the local carrier's network and the customer's inside cabling. This device terminates the drop wire and is an access point that may be used to isolate trouble between the carrier's network and the customer's premises wiring. The NID also contains protection against externally-induced hazardous voltages, such as those associated with lightning strikes and contact between telephone and power lines. In a multi-tenant building, the protection is located at the point at which the distribution cable enters the building.

2) *Drop*

A copper drop cable, typically containing several wire pairs, extends from the NID at the customer's premises to the block terminal at the distribution cable that runs along the street or the lot line. The drop can be aerial or buried; generally, it is aerial if the distribution cable is aerial, and buried if the distribution cable is buried or underground. In the case of fiber-based services and elements, a fiber optic cable connects the fiber distribution cable to the fiber optic terminal equipment on the premises.

3) *Block Terminal*

A "block terminal" is the interface between the copper drop and copper distribution cable. When aerial distribution cable is used, the block terminal is attached to a pole on or close to the subscriber's property. A pedestal contains the block terminal when distribution cable is buried. In the case of fiber-based loops, the fiber distribution cable is spliced to allow fiber strands to be connected to the fiber drop cable.

4) *Distribution Cable*

Copper distribution cable runs between the block terminals and an SAI located in the serving area. Limitations on the capacity of an SAI and/or the distribution design used in a particular serving area may require multiple SAIs. Fiber optic distribution cable is cross connected to the feeder fiber optics cable at a patch panel in the RT or SAI. Distribution structure components may consist of poles, trenches and conduit.⁷

5) *Conduit and Feeder Facilities*

Feeder facilities constitute the transmission system between the SAI and the wire center. For narrowband services, these facilities may consist of either pairs of copper wire or a DLC system that uses optical fiber cables as the transmission medium. In a DLC system, the RT converts analog signals for individual lines into a digital format and multiplexes them into a composite digital bit stream for transmission over the feeder facilities. DS-3 and other fiber-based loops use fiber optic cables exclusively.

⁷ Because underground distribution exists only in the highest density zones where runs are relatively short, and because in such zones underground structure is commonly shared with feeder, distribution facilities typically do not include manholes.

The fiber strands carrying the broadband signal and those carrying POTS signals may be in the same fiber cable.

Feeder structure components include poles, trenches and conduit. Manholes for copper feeder or pullboxes for fiber feeder are also normally installed in conjunction with underground feeder cable. Manhole spacing is a function of population density and the type of feeder cable used. Pullboxes that are installed for underground fiber cable are normally farther apart than manholes used with copper cables, because the lightness and flexibility of fiber cable permits it to be pulled over longer distances than copper cable.

In many cases, feeder routes are in common with either distribution routes, interoffice routes, or both. In such cases, the feeder route normally extensively shares structures with distribution and/or interoffice cable. The ILECs typically share structure with other utilities, *e.g.*, electric utilities, competitive local exchange carriers (“CLECs”), interexchange carriers (“IXCs”) and cable television (“CATV”) operators, because it is economical to do so. Manholes may be shared with low-voltage facilities. The amount of sharing of structure and manholes may differ in different density zones and between feeder and distribution cables.

3.2. Switching and Interoffice Network Description

This section provides a general description of the network components comprising the wire center and interoffice facilities. Figures 2 and 3 illustrate the relationships among the components described below.

3.2.1. Wire Centers

The wire center is a location from which feeder routes extend towards customer premises and from which interoffice circuits or “trunks” emanate toward other wire centers. A wire center normally contains at least one end office switch for POTS traffic and may also contain a tandem switch, an STP, an operator tandem, a packet switch for broadband services, or some combination of these facilities. Wire center physical facilities include a building, power and air conditioning systems, rooms housing different switches, transmission equipment, distributing frames and entrance vaults for interoffice and loop feeder cables.

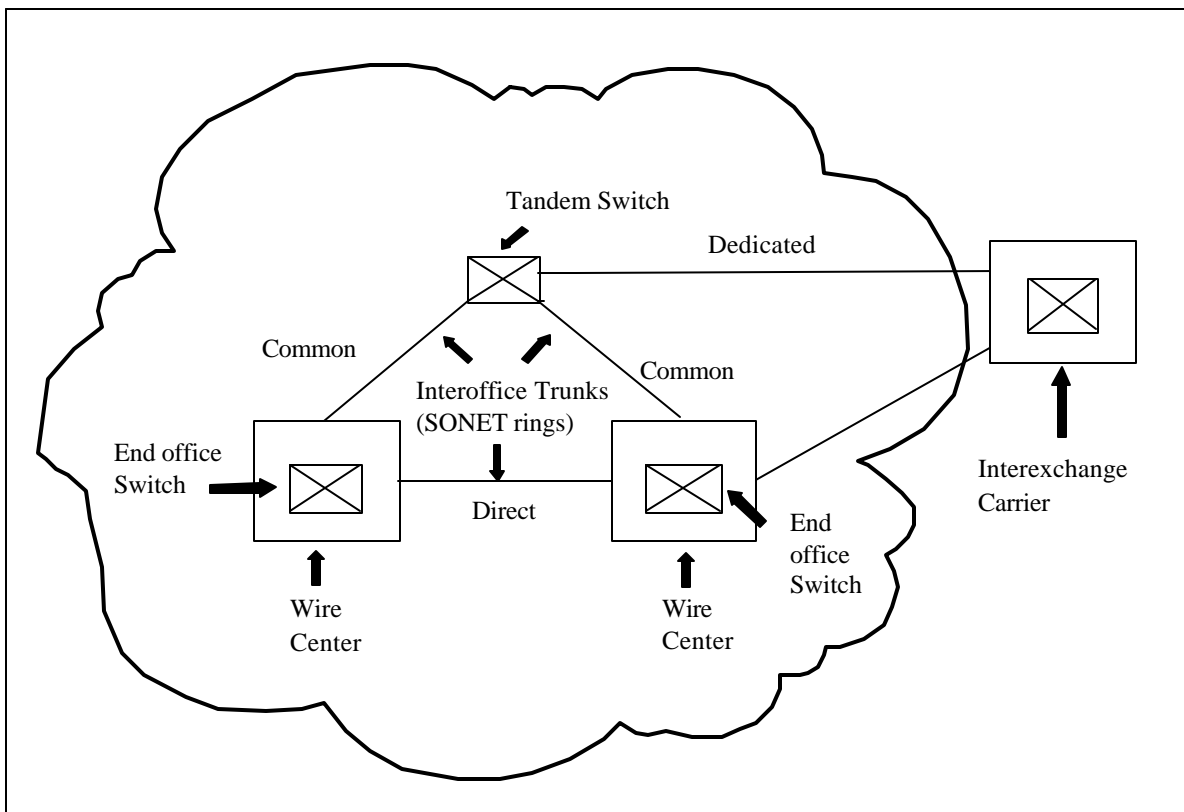


Figure 2 Interoffice Network

3.2.2. End Office Switches

The POTS end office switch provides dial tone to the switched access lines it serves. It also provides on-demand connections to other end offices via direct trunks, to tandem switches via common trunks, to IXC points of presence (“POPs”) via dedicated trunks, and to operator tandems via operator trunks.

3.2.3. Tandem Switches

Tandem switches interconnect end office switches via common trunks, and may also provide connections to IXC Points of Presence (“POPs”) via dedicated trunks. Common trunks also provide alternatives to direct routes for traffic between end offices. Tandem switching functions often are performed by switches that also perform end office functions. Tandems normally are located in wire centers that also house end office switches.

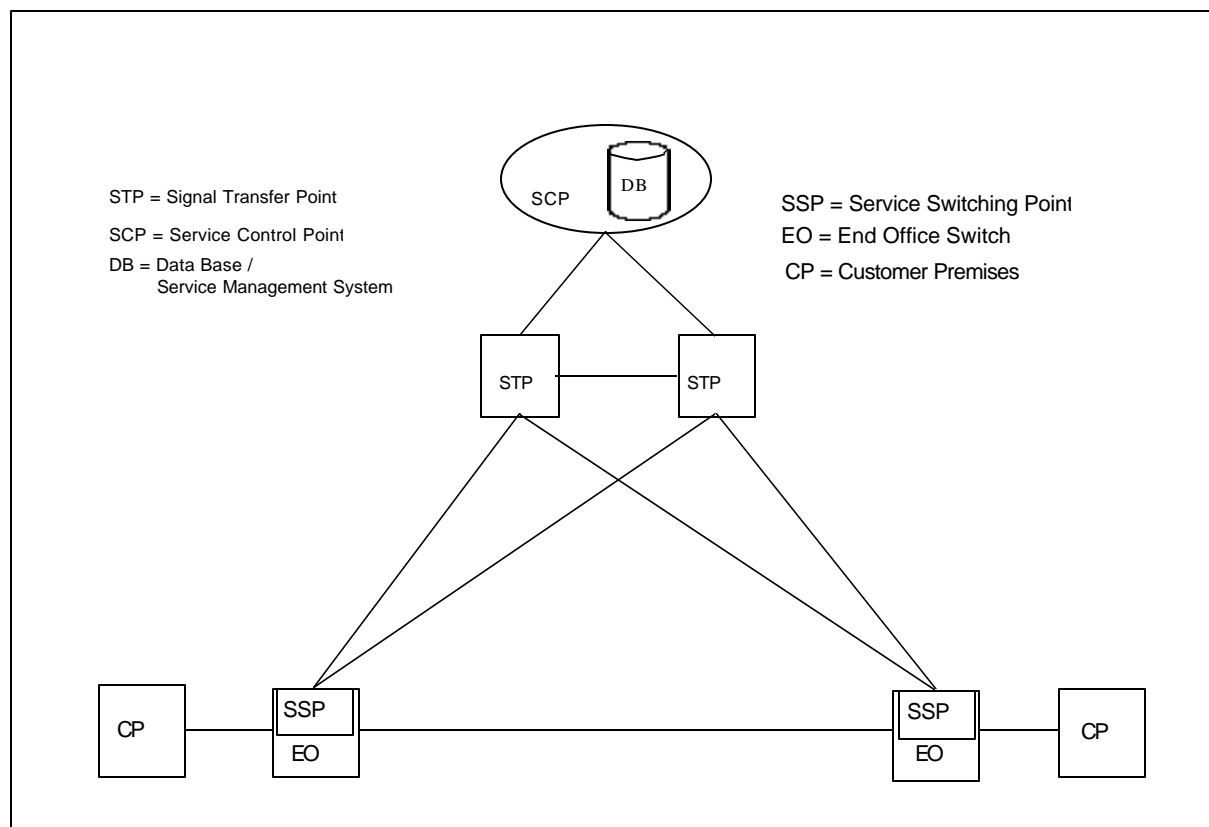


Figure 3 Interoffice Signaling Network Components

3.2.4. Interoffice Transmission Facilities

Interoffice transmission facilities carry the circuits that connect wire centers to each other and to tandem switches. Such circuits may carry POTS traffic, non-switched traffic between two points, or, increasingly, packet-switched traffic associated with various data services.⁸ In the case of trunks carrying switched traffic to/from another network provider (*e.g.*, competing local exchange carrier, interexchange carrier, or wireless provider), the trunks may be shared between carriers, or dedicated to a particular carrier. The signaling links in a Signaling System 7 (“SS7”) signaling network are also normally carried over these interoffice facilities, in DS-1 signals dedicated to carrying signaling circuits.

Interoffice transmission facilities are predominantly optical fiber systems that, in a forward-looking network, carry signals in SONET format. Both economic and service reliability considerations increasingly prescribe the use of a fiber optic ring configuration to link switches, except for switches that serve few lines or that are too remote from other switches, where ring costs might be prohibitive. In this case, the small switches are typically connected to a nearby wire center housing another end office switch that is on a ring, or the

⁸ Voice traffic may also be packet-switched.

tandem on which the small switch homes, via point-to-point links that are increasingly provided on a route-diverse (that is, redundant) basis for the sake of improved reliability. Use of rings and redundant point-to-point links in this fashion provides an extremely reliable connection between any two switches, and the potential for substantial cost savings relative to the ubiquitous deployment of traditional point-to-point facilities interconnecting all switches.

3.2.5. Signal Transfer Points

STPs route signaling messages between switching and control entities in a SS7 network. Signaling links connect STPs and Service Switching Points (“SSPs”). STPs are equipped in mated pairs, with at least one pair in each Local Access and Transport Area (“LATA”).

3.2.6. Service Switching Points and Signaling Links

SSPs are SS7-compatible end office or tandem switches. They communicate with each other and with SCPs through signaling links, which are 56 kbps (DS-0) dedicated circuits connecting SSPs with the mated STP pair serving the LATA. The DS-0 links are normally carried on the same interoffice transport facilities that carry switched traffic and non-switched circuits; typically, these DS-0 links are part of one or more DS-1 trunks dedicated to carrying signaling circuits.

3.2.7. Service Control Points

SCPs are databases residing in an SS7 network that contain various types of information, such as IXC identification or routing instructions for 800 numbers in regional 800 databases, or customer line information in Line Information Databases (“LIDB”).

4. HM 5.3 Model Organization, Structure and Logic

4.1. Overview of HM 5.3 Organization

Figure 4 shows the relationships among the various modules contained within HM 5.3. An overview of each component of the Model follows.

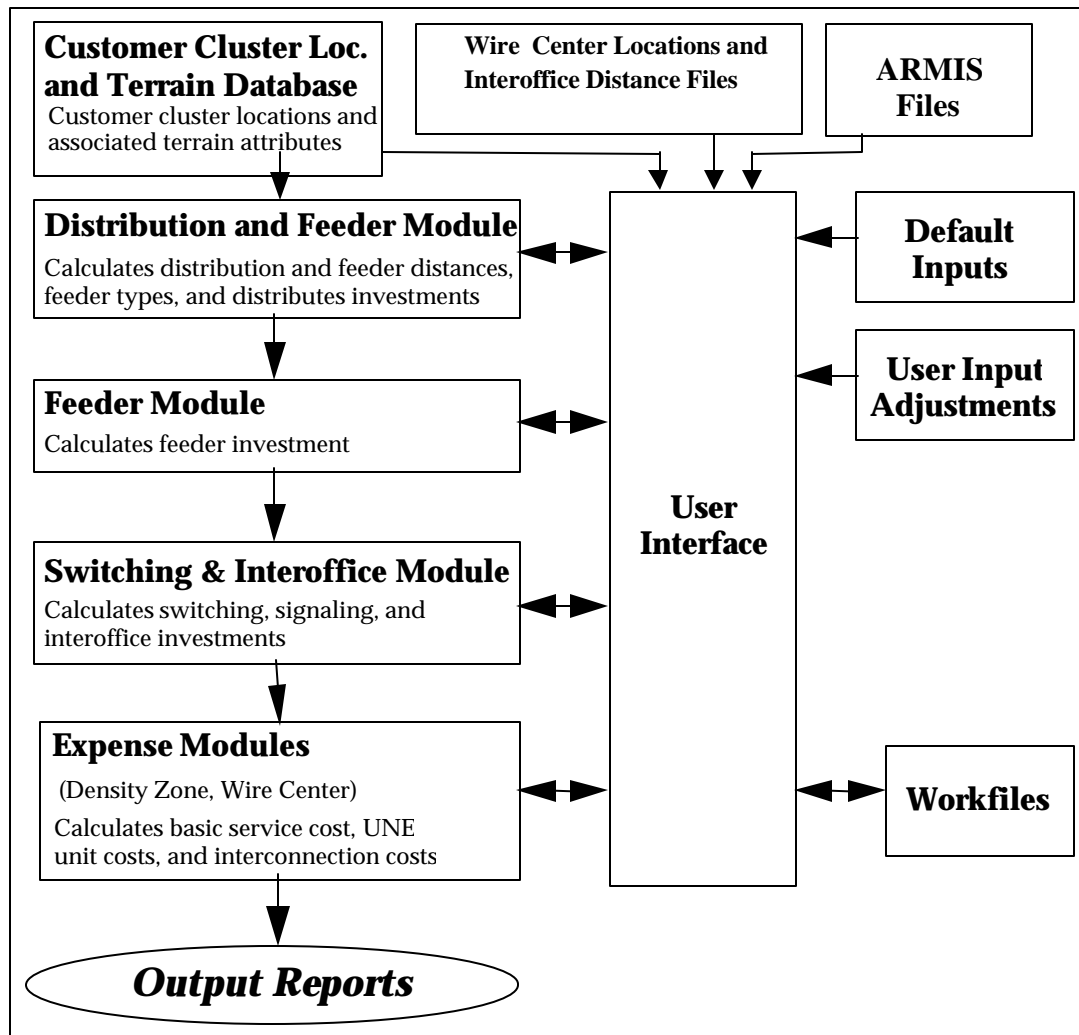


Figure 4 HM 5.3 Organization Flow Chart

4.2. Input Data

Inputs to HM 5.3 include detailed data describing the following items.

- Demographic, geographic and geological characteristics of the area served by the company being studied.⁹ These data records are specific to individual “clusters” of customer locations (*i.e.*, “main” clusters and their subtending “outlier” clusters). They include information on the number of customer locations and loops in a cluster for each kind of service for which data are available, the geometric configuration of the cluster’s boundaries, the wire center that serves the cluster and the cluster’s location relative to this wire center and to other nearby clusters, and the type of terrain that characterizes the cluster. The character and development of these data are described in greater detail in Section 5.
- Wire center locations, and interoffice distances between the incumbent’s end offices, tandems, and STPs are used to determine the route miles required for interoffice transmission and signaling facilities. These data are largely developed from Telcordia Technologies’ LERG and National Exchange Carrier Association (“NECA”) Tariff 4.
- The type of POTS switch – host, remote, or standalone – in each wire center, and, in the case of remote switches, the host switch with which each is associated.
- 2002 (or later year) Automated Record Management Information System (“ARMIS”) data reported to the FCC by the incumbent. These data provide information about current demand levels that the incumbent must serve, investments in various categories of plant, and associated expenses.
- Numerous user-adjustable inputs that allow users to set carrier- or locale-specific parameters, and perform sensitivity analyses. These inputs have preset default values based on the engineering experience and judgment of HAI personnel, as well as the judgments of independent subject matter expert consultants to HAI and the model co-sponsors.

4.3. Workfiles

A “workfile” is created from the input data files and calculating modules when the model is run for the first time on a given machine. As a complete run of the HM 5.3 progresses, intermediate outputs from HM 5.3’s constituent modules are stored in the run’s workfile. Once the run is complete, its workfile may be examined. The principal final results of the Model’s analysis is presented in the Expense Module spreadsheets that are generated when the Model is run; however, a great deal of additional information may be obtained from the run’s workfile. One example is average loop length, by cluster and by wire center.

⁹ We hereafter refer to the company being studied as the “incumbent,” since the model has primarily been used to estimate costs associated with the dominant telephone company in an area.

Additionally, the user may perform separate analyses on the LEC study area by directing the Model to create a new workfile for a subsequent run.

4.4. User Interface

The Model includes a user interface program that facilitates Model operation, including extraction of data from the input files, providing dialog boxes for users to manipulate Model inputs, executing the Excel workbooks that constitute the Model, saving intermediate results, and managing the flow of intermediate results between different modules.

The user interface program also performs certain simple aggregation and summarization calculations. This greatly shortens execution times and allows users examining the Model's Excel workbooks to focus on the Model's fundamental engineering logic.

4.5. Distribution Module

The Distribution Module addresses the portion of the network extending from SAIs to the customers' premises. The module determines the lengths, sizes, and types of distribution cable, the associated structures (poles, trenching, and conduit), the number of terminals, splices, drops, and NIDs required to provide service to the specified numbers and types of customers, and the number and type of SAIs and DLC terminals required. The module also calculates certain distances required by the Feeder Module, and, according to those calculations, determines whether the model should serve the POTS customers in a given distribution area using feeder transmission facilities consisting of copper wire pairs, or using DLC running over optical fiber cable.¹⁰ Because one of the several criteria used by the model to decide that DLC over fiber is the appropriate choice is that the feeder distance exceeds a user-adjustable maximum copper feeder distance, the user can force the model to use all fiber feeder by setting this maximum distance to zero.

The model defines two kinds of clusters, depending on the number of POTS lines and broadband services located in the cluster. If there are 20 or more POTS lines and/or one or more fiber-based services in a cluster, it is designated as a main cluster. Otherwise, it is designated as an outlier cluster. Main clusters are served by their own sub-feeder off a main feeder route as described in Section 7. Outlier clusters are associated with a main cluster, from which feeder cable extends to the outlier location.

If copper feeder is chosen to serve a main cluster, it extends from the wire center to an SAI located at the "centroid"¹¹ of the main cluster. Distribution cables then extend from the SAI to all customer premises in the cluster. If fiber feeder is chosen, it extends from the wire center to the centroid of the main cluster. From this point, one of two configurations is used to serve the customer locations within the main cluster. If the distance from the center of the cluster to the farthest customer location in the main cluster is less than the user-adjustable

¹⁰ The criteria for selecting fiber feeder cable is described in greater detail in Section 6.3.6.

¹¹ The cluster centroid is the mid-point of the line connecting the two points in the cluster that are furthest apart.

maximum copper distance,¹² a single DLC RT is located at the cluster centroid, and copper distribution cable extends from this DLC RT to all customer premises in the main cluster. If the distance to the farthest location in the main cluster exceeds the maximum copper distance, then fiber connecting cable extends vertically and/or horizontally from the centroid to two or more DLC RTs, each of which serves a portion of the main cluster and is located to ensure the longest remaining distance is less than the maximum copper distance. From these multiple DLC RTs, distribution cables extend to the customer premises in the portion of the main cluster they are responsible for serving. Customers for DS-3 and higher-speed services located in a cluster are always served by fiber feeder, regardless of how the loops in the cluster that are not all-fiber are served, and by fiber distribution cables that are spliced to the fiber feeder in the DLC or SAI and extends to such customers' premises. It will be convenient henceforth to refer to services, as well as the UNE loops associated with them, that are delivered to customer premises over copper distribution cables as "copper-based" services, and services that are delivered to customer premises over fiber distribution cables as "fiber-based."

The HM 5.3 Distribution Module serves each outlier cluster from the outliers' associated main cluster using either fiber optic cable or copper cable carrying analog signals. As discussed in Section 8, copper cables are only used under very limited circumstances; otherwise, the Model selects DLC on fiber. In either case, once the outlier cluster is reached, copper distribution cables are used to serve the customers located in the outlier cluster, while fiber/DLC systems extend to further outliers as necessary. Any cluster that serves one or more customers of fiber-based services automatically is designated to be a main cluster whether the number of POTS lines is greater than 20 or not.

After the module has determined the quantities of all components of distribution plant, it calculates the investment associated with these components, including distribution and drop cable, structures, NIDs, terminals and splices, SAIs, and DLC terminals, using as inputs the user-adjustable unit prices of each component. The numbers and types of components engineered can be examined in the intermediate outputs of the Distribution Module as recorded in the workfile.

4.6. Feeder Module

The Feeder Module configures the portion of the network that extends from the wire center to the SAIs. Based on information it receives from the Distribution Module, it determines the size and type of cables required to reach the SAIs located in each serving area, along with supporting structures (poles, trenching, conduit, manholes, and pullboxes for fiber optic cable). The Feeder Module then calculates the investment associated with these elements, using as inputs the unit prices of each such element. It passes these investments to the

¹² In the context of voicegrade circuits, the maximum distance refers here to the distance over which analog signals can be transmitted while maintaining reasonable voice quality. DS-1 and other data services that transmit signals in digital form may also utilize copper cables up to bit rates as high as 1.544 Mbps, subject to different distance limitations and the use of appropriate digital terminal equipment at the two ends of the analog link.

Expense Modules. The numbers and types of network elements required can be examined in the intermediate outputs of the Feeder Module as recorded in the workfile.

4.7. Switching and Interoffice Module

The Switching and Interoffice Module computes investments for end office switching, tandem switching, signaling, and interoffice transmission facilities. The user can designate which specific wire center locations house host, remote, and stand-alone switches for POTS, respectively, as well as specify inputs for the per-line investments associated with each type of switch. In doing so, the user can accept the existing host-remote relationships specified in the LERG and included in the HM 5.3 database, specify a set of modifications to those pre-defined relationships, or enter a set of relationships from scratch. The last two options are done through the user interface mechanism for entering host-remote relationships. Rather than differentiating between host, remote, and stand-alone switches, the user can alternatively specify that each wire center is to be served by an “amalgamated” switch. This choice is made through the user interface. HM 5.3 will calculate switching investments taking into account the switch arrangements that the user designates.

The switching module determines the required line, traffic, and call processing capacity of switches based on line totals by POTS customer type across all serving areas belonging to the wire center, and based on ARMIS-derived traffic and calling volume inputs. It also determines the required capacity and distances of interoffice transmission facilities, using the traffic data and the interoffice distances that are input to the Module. In doing so, it uses wire center locations and interoffice distances to determine an efficient mix of interoffice SONET fiber rings and redundant point-to-point fiber links. Rings are separately provided for linking host switches to their associated remotes, if the host/remote/standalone switch specification option is selected; for linking “gateway” switches to the switches that home on them; and for linking host switches to each other, to stand-alone switches and to the tandem switches on which they home.¹³ The numbers and types of elements involved can be examined in the intermediate outputs of the Switching and Interoffice Module as recorded in the workfile.

4.8. Expense Modules

There are two versions of the HM 5.3’s Expense Module – one for each of the levels of granularity at which the user can elect to have cost results displayed: by line density range (which also displays total study area costs), and by wire center. The wire center version also allows the user to roll up wire center results into groups, or “zones” of wire centers according to criteria defined by the user.

¹³ At the user’s option, small standalone wire centers serving fewer lines than a user-adjustable threshold (default value: one line) may be excluded from being placed on rings, and instead linked directly to its serving tandem using point-to-point links. In this case, the model attempts to physically route these point-to-point circuits through a nearby large wire center, and then over the fiber rings it has otherwise engineered for interconnecting larger offices and tandems.

Each version of the expense module calculates the monthly costs for unbundled network elements, universal service, and carrier access and network interconnection. These costs include the capital carrying costs associated with the investments, the costs of operating the network, and a fair share of the corporate overhead costs. Capital carrying costs include depreciation, return on the debt and equity investment required to build the network, income taxes on equity return, and other taxes. Network-related expenses include maintenance and network operations. Non-network related expenses include customer operations expenses, general support expenses, other taxes and variable overhead expenses. Further detail about network investments and costs is available from the workfile associated with a Model run.

The Distribution, Feeder, and Switching and Interoffice Modules provide network investments by specific plant category to the Expense Modules. The Expense Modules use ARMIS data, user inputs, and other sources to derive information on network operating and maintenance expense relationships.

HM 5.3 includes the capability of adding a company-specific worksheet that calculates costs for UNEs that are unique to the company or jurisdiction in question. This worksheet acquires the data it requires from the other outputs of the Expense Module, and from ARMIS data and user inputs.

5. Input Data

5.1. Wire Center List

The source of the wire center information used in the model is Telcordia Technologies' LERG database from 2002. The wire center data are taken from the incumbent's portion of the LERG. The wire centers that actually end up in the model are determined by the wire center data provided to the Model's sponsors by the incumbent.

Multiple occurrences of 8-character CLLIs may occur in the LERG due to placements of several switches at a single wire-center location. HM 5.3 engineers multiple switches in a wire center if demand requires more than one switch on a forward-looking basis; therefore, to avoid double-counting between Model-generated switches and switches in the input wire-center list, duplicate occurrences of 8-character CLLIs are removed from the Model's wire-center list.

5.2. Customer Location And Line Count Data

The cluster database in HM 5.3 is based on customer location and line count data obtained from the incumbent, usually as the result of discovery requests served on the incumbent by the model's sponsors. In earlier versions of the model, before such data were available, customer location data were determined from U.S. Census Bureau data, commercially-available residential and business databases, or both.

The ultimate goal of processing the incumbent's customer data is to create a database that contains the geocoded location of each of the incumbent's customers, the numbers of each type of lines served at that location, and the incumbent's wire center that provides service to each location (hereafter, the "serving wire center.") This information is then input to the customer clustering process described in Section 5.3. The process by which this database is created is highly dependent on the types and structures of data provided by the incumbents. It typically involves an extensive, multi-phase dialog between the incumbent and the Model's sponsors; again, the nature of that dialog is highly dependent on the type and quality of data provided. As a result, only the general highlights of the process are described here.

In the first step of the process, the incumbents' customer records are turned into a set of customer addresses, with each of which are associated the numbers and types of lines and the serving wire center. Incumbents typically provide multiple files containing the customer records. Different files may contain records of switched POTS lines, non-switched lines and circuits, and/or special cases such as ADSL lines. The files often contain overlapping entries, and it is necessary to determine from the incumbent how to recognize redundant records so they are included only once in the final database. In addition, the records may refer not to loops, but to interoffice circuits, in which case the interoffice circuits must be deleted from the files. In some cases, the files come with rules-based or other instructions as to how to read and interpret the records to extract the desired information. The processing of

the incumbent's records to arrive at the customer address database often requires several months of dialog and effort.

In the second step of the process, the customer address database is turned over to TNS Telecoms Inc. ("TNS") to geocode the customer addresses. Geocoding is the process of assigning a longitude and latitude to each address. TNS uses the software application Centrus Desktop from QMSoft (now SAGENT), in association with enhanced "TIGER" files from GDT that electronically codes road locations. The geocoding process has several levels of precision. The most precise geocode occurs when a longitude and latitude are created based on the street address. If this is not possible, the geocoding process generates a surrogate longitude and latitude location that places the customer within the boundary of the wire center that serves the customer according to the incumbent's data. TNS determines such surrogate locations by distributing the non-geocoded locations uniformly along the roads falling within the corresponding wire center boundary. In each case – whether an address is successfully geocoded or assigned a surrogate location – the end result of the process is to associate a precise longitude and latitude with each address, along with the numbers and types of lines at the address and the serving wire center information.

In the final step of the process, the geocoded customer locations are matched to the wire center boundary files provided by the incumbent to ensure that the customer locations fall within the boundaries of the serving wire center designated by the incumbent. Typically, this leads to the identification of anomalous situations for a few percent of the customer locations in which customer locations do not fall within the boundaries of the serving wire center that the incumbent has designated. In a large majority of cases, the locations are outside but still close to (within a few hundred feet) the boundaries. In such cases, the locations are assumed to still legitimately belong to the designated service wire center. In a small percentage of cases, however, the locations fall far outside the serving wire center boundaries. One legitimate reason for this to occur is that the location may be served by a foreign exchange line.¹⁴ Another might be that the incumbent is providing switching for another telephone company located in an adjacent area. A third, particularly applicable to recently-added wire centers, is that the wire center boundaries are missing or wrong in the incumbent's boundary file data. Whatever the explanation, the resolution of these anomalies often involves additional dialog between the Model sponsors and the incumbent. Ultimately, the locations in question are resolved by either altering the wire center boundaries, if appropriate, by assigning the customer locations to a different serving wire center, or in a few cases by discarding the location because it is not within the incumbent's serving area.

When all is said and done, this process leads to a high percentage of the customer locations, with associated line types and numbers and serving wire centers, appearing in the customer location database that is input to the clustering process described in the next section.

¹⁴ Foreign exchange service allows a customer to appear to be located in a wire center other than the wire center serving the area where the customer is located. The service consists of a local loop to the serving wire center combined with a dedicated circuit to the wire center where the customer wants to appear. For instance, a resort located some distance from a large city may want to allow callers in the city to reach the resort with a local, rather than toll or long distance, call. Some incumbents' data specifically identify the serving wire center associated with foreign exchange lines, in which case the geocoding process finds the customer is located within the boundaries of that wire center.

5.3. Customer Location Clustering

5.3.1. General Process

The clustering process uses the geocoded customer location information (including surrogates customer locations) described above, and groups these locations (by wire center) into logical serving areas (clusters) that are relied upon to make the outside plant calculations in the model. This clustering process begins with two general steps. First, each of the incumbent's specific service types are grouped into one of several, more generic, service categories that are used in the model design. Second, these service categories are used to develop the clusters used in the model.

The process of associating each service type with a service category required an interactive process between the Model's sponsors and the incumbent. Typically, the various service types are grouped into one of the following 12 service categories:

1. Switched Residential
2. Switched Business
3. Public
4. ISDN
5. ADSL (High Frequency Portion of the Loop)
6. ADSL Dedicated
7. Individual NonSwitched
8. NonSwitched DS-1
9. Switched DS-1
10. High-Capacity Optical
11. DS-3 Optical
12. Not A Loop

Each cluster represents a distribution area that can be efficiently served, consistent with outside plant guidelines. The model explicitly models controlled environmental vaults ("CEVs") capable of accommodating up to 8,064 lines. Designing CEV common equipment with a fill factor of 80% (allowing for 25% growth) results in a design limitation of 6,451 lines per cluster. Because the clustering process is designed to limit the number of lines so as not to exceed this limit, each serviced category requires a different factor because each service requires different DLC equipment (which in turn requires a different amount of space in the DLC common equipment channel bank assembly). In addition, some of the service

categories, such as DS-3 and high capacity optical services, do not use the DLC common equipment at all. Thus, each service type is given a clustering assignment that indicates how much, if any, SAI/DLC capacity is utilized.

These clustering assignments are then used to convert each service count into a line count that is used solely for the purpose of sizing the clusters for use in the model. Once the clustering process has completed, the clustering process passes through service counts for use in the model's outside plant algorithms.

5.3.2. Clustering Criteria

The input development process next identifies all customer locations within a wire center's boundaries that are close enough together to be efficiently engineered as a single telephone plant serving area. This process is called clustering. While there are many available off-the-shelf clustering algorithms, an efficient determination of clusters of customer locations that are consistent with telephone engineering practices requires that certain engineering restrictions be imposed during the clustering process, and not afterward. Customer locations must meet the following criteria to be considered members of a particular cluster:

- No point in a cluster may be more than 17,000 feet distant (based on right angle routing) from the cluster's centroid.
- No cluster or non-degenerate area may initially exceed an equivalent POTS line card capacity of 6,451 lines in size.¹⁵
- No point in a cluster may be farther than two miles from its nearest neighbor in the cluster.
- Any individual customer location with more than 536 lines is classified as a stand-alone cluster.

In performing the clustering process, loops provided exclusively over fiber-optic cable are taken into account and placed in the right clusters, but they are not counted against the maximum number of lines served since they do not consume line cards in the DLC. Other than the wire center boundary restriction, these criteria do not include any arbitrary geographic restrictions, such as clusters being restricted to lie within a single Census Block Group, Census Block, or latitude/longitude grid cell. Thus, clusters developed pursuant to this process are likely to be the most closely representative of actual telephone distribution areas as determined by outside plant engineers. Note, however, that the last of these restrictions – no point in a cluster may be farther than two miles from its nearest neighbor –

¹⁵ The 6,451 POTS line limit is consistent with the largest DLC of 8,065 slots at 80% occupancy. The clustering process takes account of the line card requirement of each kind of loop provisioned over copper distribution cable. For instance, each DS-1 service takes up line card capacity equivalent to four POTS lines; four-wire digital data services take up the line card capacity equivalent of two POTS lines. But if single customer locations, such as a large office or apartment building, by themselves exceed 6,451 lines, clusters are not split. As necessary, the Model will place multiple DLC RTs/SAIs to serve such "oversized" clusters.

is not an absolute engineering limitation. It is used to ensure that customer locations that are separated by the given distance are not required to be clustered together. It is possible that efficient engineering of telephone distribution plant would suggest that a different, possibly larger value be chosen.

5.3.3. Clustering Algorithm

The process used by the TNS clustering algorithm is as follows.

- a) First, to provide a uniform geographic unit for clustering operations, all customer location geocodes associated with a particular wire center are “rasterized” into 150 foot cells that overlay the geographic rectangle covering the wire center’s service area.¹⁶
- b) The algorithm then inspects all neighboring cells (*e.g.*, all cells that have their center within a 150 foot radius of the center of the initial cell) to see if any are populated with customer locations. If one of these neighboring raster cells is populated, the algorithm first checks to see whether clustering that cell (and its immediately surrounding neighbors) with the initial cell would violate any of the clustering restrictions (*i.e.*, create a cluster that has points more than 17,000 feet from the cluster centroid, create a cluster of more than 6,451 POTS-equivalent lines, or include a point more than two miles from its nearest neighbor).¹⁷ If none of these conditions would be violated, the adjoining cell plus its immediate neighbors will be added to the initial cell’s cluster.
- c) This process continues on to the next unclustered populated cell and performs the analysis described in step (b), above. This repeats until no more unclustered cells exist.
- d) The process then restarts at step (b), but uses a 300-foot search for populated neighboring cells.
- e) This continual enlargement of the search for neighboring populated cells continues on until no more cells can be added to the cluster without violating one or more of the engineering requirements. At this point, the algorithm is complete.

¹⁶ Rasterization at this level is a process whereby all customer locations that are within the 150 foot square cell are counted as being placed at the center of the cell. Rasterization to 150 foot square cells ensures that the mathematical clustering process can proceed efficiently, and that nonmeaningful distinctions in customer location are ignored. Increasing the raster to 300 or 500 feet would speed up the clustering process dramatically, and still provide a very acceptable level of precision in cluster formation. Note, too, that the TNS calculation of 150 foot raster cells is fixed and does not depend on the local latitude of the cell. Thus, raster cells do not enlarge as one moves south toward the equator.

¹⁷ Because the rasterization into 150 foot square cells may cause customer locations that actually are in the farthest corner of a cell to be considered at the cell’s center, the clustering algorithm will check to ensure that no cells added to a cluster exceed 16,700 ($16,700 = 17,000 - 2*150$) feet from the cluster’s centroid.

Clusters that contain twenty or more line equivalents or at least one all-fiber loop are classified as “main” clusters. Clusters that contain 19 or fewer line equivalents and have no all-fiber loops are called “outlier” clusters. Outlier clusters may be linked to their “home” main cluster via “chains” that string together other outlier clusters that home on the same main cluster. The process of determining the routing of the chain is as follows.

- a) The clustering algorithm first calculates the distance between each cluster and every other cluster in the wire center service area.
- b) The algorithm then determines the shortest distance between any two clusters, and associates these two clusters.
- c) Next, the algorithm determines the next shortest distance between any two clusters or cluster chains, and associates these.
- d) This process continues until all outliers are chained to a main cluster.

In addition to creating chains to associate outlier clusters to a main cluster, the clustering algorithm determines the minimum rectangle covering, or “bounding,” the convex hull of each cluster, and calculates the height and width of this rectangle. The cluster area appearing in the cluster database is the area of the original cluster before “rectangularization.”¹⁸

When this process is completed, the main cluster and its associated outliers are considered to constitute one serving area.

The description of the HM 5.3 Distribution Module in Section 8 provides greater detail on the Model’s engineering of outside plant to serve main and outlier clusters.

5.4. PointCode Translation Processes

PointCode™ is a Microsoft Access database process that translates between coordinate systems, computes distances and assigns additional characteristics to cluster records. Among the activities executed by PointCode are the following:

- Converts the latitude and longitude coordinates for cluster centroids to the V&H coordinates used in the LERG to locate wire centers;
- Calculates radial distances between main clusters and their serving wire center;
- Calculates radial distances between outlier clusters and main clusters, and main clusters to wire center;
- Computes omega angles between main feeders and the clusters they serve and computes alpha angles between clusters and their subfeeders (see Figure 8, p. 46) ;

¹⁸ Except where the height and or width, or both, equaled zero, in which case the area equals the new product of height times width

- Calculates rectilinear (right angle) distances between main clusters and their serving wire center, and between outlier clusters and main clusters;
- Ensures that modeled distribution rectangles have an aspect ratio and area that reflects a minimum dimension equal to twice the default drop length for that cluster's density range; and
- Assigns terrain, housing unit profile, and line density zone characteristics to the cluster based on the characteristics of the dominant CBG.

6. *Input Data Files*

6.1. *Demographic and Geological Parameters*

Demographic parameters are obtained from a database developed by TNS. Section 5, above, explains in detail how these data are developed. The data file resulting from these processes is identified by its state and telephone company (study area). Each customer location cluster (both main and outlier) identified in the wire center service areas of the LEC modeled appears as a separate record in the database. Each of these cluster records contains the following information:

- Identity of the LEC and wire center serving the cluster;
- Location information about the cluster relative to its wire center, the predominant CBG in which it falls, its nearest neighboring cluster, and associated distances;
- Area and dimensional measurements of the cluster and its line density;
- Terrain and geological parameters;
- Number of telephone lines by type;
- Number of households and number and type of housing units;
- Number of business firms and employees;
- Number of voice-grade analog and DS-0 digital non-switched lines;
- Number of ISDN lines;
- Number of dedicated and frequency-shared ADSL lines;
- Number of switched and non-switched DS-1 lines;
- Number of DS-3;
- Number of high-capacity optical services;
- Information about the fraction of a wire center's total POTS lines that are represented by this cluster, the average loop distribution distance of its subtending outlier clusters and total number of outlier lines;
- The “right-angle” strand distance for each main cluster representing the amount of cable theoretically required to connect all locations associated with a main cluster and the outlier clusters associated with it.¹⁹

The complete list of data fields in the Cluster Input data table is as follows:

¹⁹ That is, the path between two points extends up (or down) parallel to one axis of a coordinate system, and rightward (or leftward) parallel to an axis at right angles to the first axis. In this way, the route forms the two legs of a right triangle whose hypotenuse is the straight line connecting the two points.

Cluster Input Data Table		
State	Density Lines/SQ Mile	HU-50+
CLLI	Rock Depth	Mobile
Company	Rock Hard	Other
Neca_ID	Surf Text	Firms
Group	Water Depth	Employees
CBG	Total Lines	FracWCLine
Cluster Group	Total Bus Lines	AvgLoopDist
Overall Quad	Total Res Lines	TotOutLine
Overall Omega	Special Lines	Total Strand Distance
Overall Alpha	Public Lines	Non-Switched Lines ²⁰
Radial Dist Feet	Single Line Business	Non-Switched DS-1 Lines
Cluster or Outlier Indicator	Households	Switched DS-1 Lines
Outlier Quad	1-HU detach	High Cap Optical Lines
Outlier Omega	1-HU attach	DS-3 Optical Lines
Outlier Alpha	HU-2	ISDN Lines
Outlier Radial Distance	HU-4	ADSL Shared Lines
Total Area	HU-5-9	ADSL Dedicated Lines
Aspect Ratio	HU-10-19	Strand distance for fiber-based services ²¹
Company State	HU-20-49	

6.2. Wire Center Locations and Interoffice Distances

Calculations to determine total route-miles of interoffice facilities require as inputs wire center location information for the ring distance program to configure its SONET rings and compute effective interoffice distances, as described below in Section 10.3.2. These data are calculated from the LERG. The LERG includes the V&H coordinates of each switching entity, and the nature of the entity, *e.g.*, end office, tandem, STP, multiple use. Appendix B provides an outline of the process used to develop these distance measures.

6.3. ARMIS Data

These data are obtained from the 2002 (or later) ARMIS 43-03, -04, and -08 Operating Data Reports. ARMIS data are submitted to the FCC annually by all Tier 1 LECs.²² The following elements of these data are extracted.

²⁰ Voice-grade analog or DS-0 digital non-switched circuits.

²¹ The strand distance for fiber based services has not been calculated in some jurisdictions.

²² See, Reporting Requirements for Certain Class A and Tier 1 Telephone Companies (Parts 31, 43, 67 and 69 of the FCC's Rules), CC Docket No. 86-182, 2 FCC Rcd 5770 (1987) (*ARMIS Order*), modified on recon., 3

- The number of residential access lines, including all residential switched access lines – both flat rate (1FR) and measured rate (1MR) service.
- The number of business access lines, including analog single business lines, analog multi-line business lines and digital business lines; these totals include flat-rate business (1FB) and measured rate business (1MB) single lines, PBX trunks, Centrex lines, hotel/motel, long distance trunks and multi-line semi-public lines.²³
- Analog and digital special access lines, including dedicated lines connecting end users' premises to an IXC POP, but not including intraLATA private lines.
- Public access lines, which include lines associated with coin (public and semi-public) phones, but exclude customer-owned pay telephone lines.²⁴
- The number of local call attempts as well as intraLATA toll, intrastate interLATA access, and interstate interLATA messages.
- The number of local, intrastate, and interstate dial equipment minutes (DEM).²⁵

6.4. User Inputs

There are over 2,100 user-definable values in HM 5.3. These range from the price of network components to the percentage of joint-use end offices and tandem offices to capital structure. HAI has supplied default values for each of these variables based on publicly-available information, where possible, augmented by data obtained through discovery from the company being studied, the opinions of subject matter experts in various areas of network technology, operations and economics, and the collective judgment of the HAI Model developers. Users can vary these default parameters to reflect unusual local conditions and perform sensitivity analyses. The HM 5.3 Inputs Portfolio (“HM 5.3 HIP”) that accompanies this description also contains a complete description of each user-definable input, as well as the supporting information upon which the default input values are based.

FCC Rcd, 6375 (1988). As noted earlier, Tier 1 LECs are those with more than \$100 million in annual revenues from regulated services – over fifty carriers qualify as Tier 1 carriers.

²³ *Ibid.* at 1-2.

²⁴ *Id.* at 2.

²⁵ The local vs intrastate split of ARMIS reported combined intrastate DEMs is determined using data drawn from NECA reporting of DEMs from prior year.

7. Outside Plant Engineering

The Distribution and Feeder Modules are the main modules controlling the engineering of outside plant. While the remainder of this Section, as well as Section 8, respectively, discuss the unique aspects of these modules, this section describes several features and assumptions common to both modules.

Figure 6 shows the basic outside plant serving configuration used by HM 5.3.

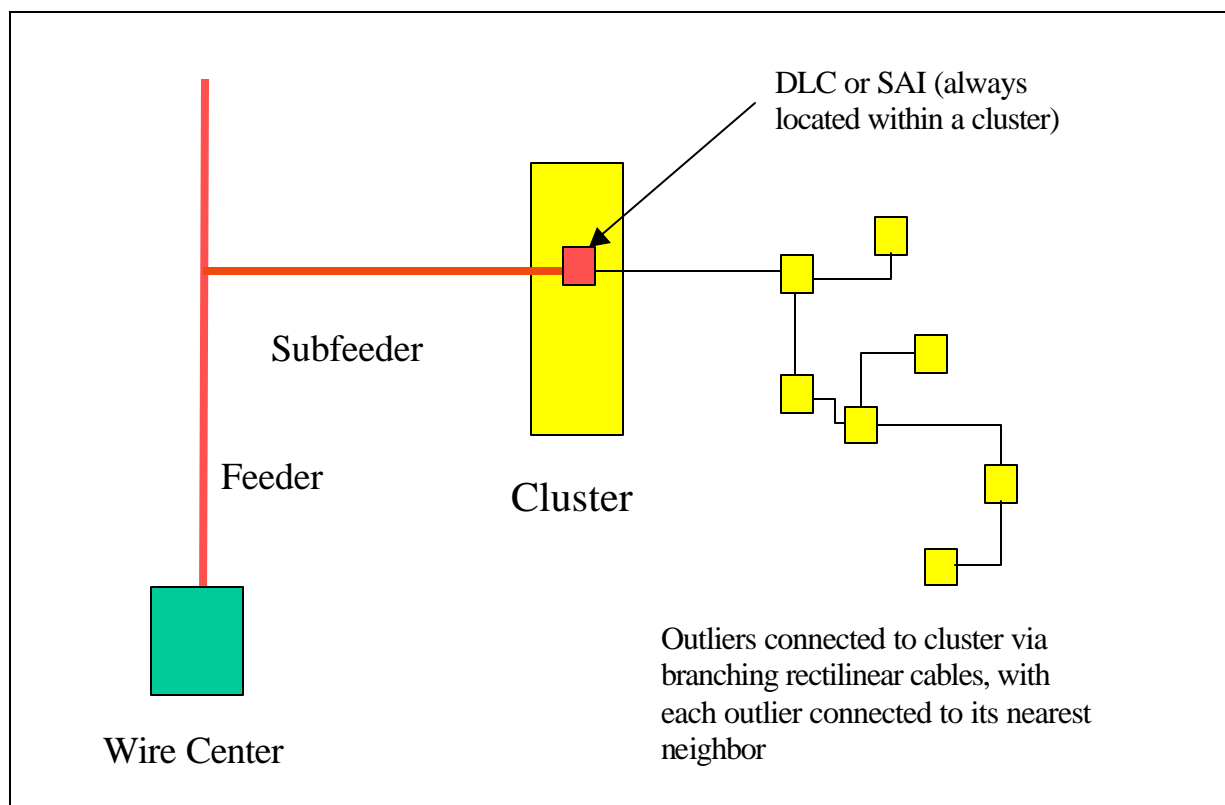


Figure 6 Loop Outside Plant Configuration

The Model assumes a main cluster and its associated outlier clusters constitute a serving area. Main feeder cable (typically shared with other main clusters on the same route) and subfeeder cable extend from the wire center to the centroid of the main cluster. If the main and subfeeder cable are copper, the subfeeder cable terminates in an SAI. If the feeder and subfeeder are fiber, the subfeeder either terminates at a single DLC RT and adjacent SAI located at the centroid of the main cluster, or extends via fiber “connecting cables” from the centroid to two or more DLC RTs and adjacent SAIs located within the cluster so as to ensure no copper distribution cable length exceeds the user-adjustable maximum copper distance. The choice between copper and fiber main feeder and subfeeder for POTS and other narrowband services is made according to the criteria discussed in Section 8.6, below. DS-3 and other high-capacity all-fiber services are always served by fiber feeder.

Copper distribution cables for POTS and other services and elements below the DS-3 level²⁶ extend from the SAI(s) to the customer locations within the main cluster in a backbone and branch fashion. The data process used to locate customers and identify population clusters also determines the “aspect ratio” of the overlying rectangle that defines the boundary of a main cluster, and is used in determining the location of the fiber DLC RTs and layout of the backbone and branch distribution arrangement for services and elements below the DS-3 level. Fiber cables to support all-fiber services and elements such as DS-3 loops extend only as far as the customer locations to which these high-capacity services are provided.

From the centroid of a main cluster, either fiber or copper cables extend to each outlier cluster that is served from that main cluster, with each outlier cluster connected to its nearest neighbor (either the main cluster or another outlier cluster) via a right-angle route in a “daisy chain” fashion. Section 8 discusses the criteria for selecting between fiber and copper connecting cable. In either case, copper distribution cables run from the SAI or DLC in the outlier cluster to the customer locations as they do in main clusters. The Model assumes a moderate amount of structure sharing between the connecting and distribution cables within the outlier cluster because of the partial coincidence of their routes that typically exists.

7.1. Outside Plant Structures

Outside plant structure refers to the set of facilities that support, house, guide, or otherwise protect distribution and feeder cable. There are three types of structure: aerial, buried and underground.

1) Aerial Structure

Aerial structure typically consists of poles.²⁷ Pole investment is a function of the material and labor costs of placing a pole. A user-adjustable input allows the customization of the labor component of pole investment to local conditions. HM 5.3 computes the total investment in aerial distribution and feeder structure associated with a cluster by evaluating relevant parameters, including the distance between poles, the investment in the pole itself, the total cable sheath mileage, and the fraction of aerial structure along the route.

The Model assumes forty-foot Class 4 poles. The spacing between poles for aerial cable is fixed within a given density range but may vary between density ranges. The number of poles on a given route is calculated as:

$$1 + (\text{route distance/pole spacing}), \text{ rounded up.}$$

2) Buried Structure

²⁶ Some incumbents offer some DS-1 services on fiber optic cable. These are classified as all-fiber loops during the customer location process described previously.

²⁷ In the two highest density zones, aerial cable is assumed to consist of a user adjustable mix of intrabuilding riser cable, “block cable” attached to buildings, and cable strung from poles.

Buried structure consists of trenches and related protection against water and other intrusions. HM 5.3 uses separate inputs for aerial, buried, and underground cable which, for instance, in the case of buried cable accounts for the additional cost for protective sheathing and waterproof filling of buried cable. There are separate costs, specified on a per-foot basis, for copper and fiber cable, and for each cable size assumed by the model. The total investment in buried structure is a function of total route mileage, the fraction of buried structure, and the density-range-specific cost of trenching.

3) *Underground Structure*

Underground structure consists of conduits, manholes, and pullboxes. Manholes are used in conjunction with copper cable routes; pullboxes are used on routes that are served exclusively by fiber cable. The total investment in a manhole varies by density zone and includes materials, frame and cover, excavation, backfill, and site delivery. Investment in fiber pullboxes is a function of materials and labor. Underground cables are housed in conduit facilities that extend between manholes or pullboxes. The total investment in underground structure is a function of total route mileage, the fraction of underground structure, investment in conduit manholes, and pullboxes, and the cost of trenching needed to hold the conduit.

In each line density range, there may be a mixture of aerial, buried and underground structure. For example, in downtown urban areas, it is frequently necessary to install cable in underground conduit systems, while rural areas may consist almost exclusively of aerial or direct-buried plant. Suburban areas may have a more balanced mixture of all three structure types. Also, as described more completely in Section 7.5, below, the HM 5.3 permits certain amounts of substitution between buried and aerial structure based on abnormal local cost conditions.

Users can adjust the mix of aerial, underground and buried cable assumed within the Model. These settings may be specified by density zone for fiber feeder, copper feeder, and distribution cables.

7.2. *Terrain and Its Impact on Placement Costs*

HM 5.3 incorporates the effects of geological factors on required structure investment. Terrain factors considered by the Model include bedrock depth, rock hardness, surface soil type, and water depth. Each cluster is assumed to have the terrain characteristics of the CBG in which it predominantly falls.²⁸

²⁸ Main clusters and their subtending subclusters are not restricted to fall entirely within a single CBG. Such a restriction would impose an artificial limitation on the “natural” serving areas being identified by the Model. As a result, the predominant CBG must be used to determine the terrain characteristics. If appropriately digitally-encoded terrain data become available, a more precise determination of the terrain characteristics of serving areas crossing several CBGs could be made.

If the rock depth in a serving area is less than a user-definable rock depth threshold, a rock placement multiplier increases structure investment in poles, conduit placement, and trenching, because it is more difficult to place these structures in rock than in soil.²⁹ The Model causes the rock placement multiplier to vary with rock depth; the entire multiplier applies if the rock depth is zero, and the value tapers linearly to unity at the user-defined placement depth.

Certain kinds of surface textures may increase the cost of structure. When these are encountered, the Model extracts a multiplier from a lookup table in the distribution module inputs worksheet, and applies it to the structure investment as determined by the density zone. If both difficult soil conditions and rocky conditions are encountered, the Model will multiply the structure investment by the sum of the rock placement and surface texture multipliers minus one.³⁰

Water table depth does not have a significant effect on trenching costs, but may affect the cost of placing manholes. The Model increases manhole placement costs by a user-adjustable amount (default value of 20%) of the nominal placement cost whenever the water table depth is less than a user-adjustable minimum depth whose default value is five feet.

Labor costs for placement may be adjusted for regional variation by the application of a user-entered labor adjustment factor.

7.3. Structure Sharing

Outside plant structures are generally shared by LECs, CATV operators, electric utilities, and others, including CLECs and IXC. To the extent that several utilities may place cables in common trenches, or on common poles, it is appropriate to share the costs of these structure items among those users. Furthermore, manholes may be shared by all low voltage utilities as well. HM 5.3 assumes sharing of structure costs among the various utilities that occupy the structure. Although assumptions concerning the degree of sharing are user-adjustable; the default values used in the Model reflect best forward-looking, economic practices for the various utilities involved.

Feeder and distribution cables often share routes, as do feeder and interoffice transport routes, allowing for the sharing of structure between these different categories of plant. The model estimates a user-adjustable amount of each kind of sharing. In addition, it estimates a user-adjustable amount of structure sharing between copper-based and fiber-based services.

7.4. Line Density Considerations

²⁹ The Model default maximum values for geological factors are as follows: rock depth threshold causing increased trenching cost, 24 inches; hard rock placement multiplier, 3.5; and soft rock placement multiplier, 2.0.

³⁰ Section 6.2.5, below, indicates how the Model automatically will adjust the fractions of buried and aerial structure to reflect economic choices based on abnormal local cost conditions for these structure types.

A number of parameters, such as the mixture of underground, buried, and aerial plant, and the amount of sharing of structure costs with other utilities, are dependent on line density. Line density refers to the number of lines per square mile; high density corresponds to urban areas, while rural areas have low density.

A properly-crafted cost model should reflect such dependencies. The model defines nine ranges of density, referred to as density “zones.” Density-dependent parameters are specified separately in each of the defined density zones. The model associates a density, and thus a density zone, with each cluster based on the CBG into which the cluster falls. Based on this association, the model uses the appropriate density zone value for each input parameter it uses in its calculations.

While entire serving areas are associated with a given density zone for purposes of accumulating density zone results, HM 5.3 makes a separate density zone determination for the main cluster and the outlier clusters, based on the CBG to which each predominately belongs, when it is selecting which density-zone-dependent factors to use in a calculation.

The line densities used by the model are shown in the following table:

Density Ranges (lines/sq. mile)
0 - 5
5 - 100
100 - 200
200 - 650
650 - 850
850 - 2550
2550 - 5000
5000 – 10,000
10,000 +

7.5. Economic Adjustment of Structure Fractions

At the user’s option, the Distribution and Feeder modules automatically adjust buried and aerial structure fractions to account for the plant placement costs occasioned by local soil and bedrock conditions. In addition to nominal buried and aerial fractions, the user may specify an “at risk” portion of the buried cable fraction that unfavorable cost conditions can cause to be shifted to aerial. The Model calculates the local relative costs of buried and aerial structure -- including both the additional placement costs arising from local terrain conditions as well as the life-cycle maintenance and capital carrying costs of the different structure

types.³¹ This local relative life-cycle cost of buried versus aerial structure is then ratioed to the national norm for relative buried to aerial life-cycle cost. The Model then adjusts the aerial fraction up or down (and buried fraction in inverse fashion) from its national default value up to the full amount of “at risk” structure, depending on the degree of difference in local versus national norm life-cycle costs.

A logistic curve is used to specify the sensitivity of structure choice to differences in relative cost. The “s-curve” shape of the logistic function suggests that initial divergences of local relative structure costs from “normal” relative structure costs cause more structure to be shifted across types than do further increases in this divergence. The user-adjustable default fraction of buried structure that is “at risk” to be converted to aerial structure based on adverse local life-cycle costs is set at a default value of 75 percent.

³¹ This calculation of the relative life-cycle costs of plant placed on various different structures is computed as follows. First, per-foot materials investment costs are calculated, and added to the per-foot investment cost of the particular structure type – adjusted for the assumed amounts of inter-utility structure sharing that apply to the particular structure type. Second, annual charge factors are developed for capital carrying costs and maintenance costs. These factors are developed within the “LCFactors” and “CCCFactor” sheets of the Distribution Module using the same methodologies described in Sections 11.2 (for capital carrying costs) and 11.3.1 (for network maintenance costs) documenting the HM 5.3 Expense Modules. Finally, the plant net investment cost is multiplied by the sum of the annual capital carrying cost and maintenance cost factors, to yield the relevant annual life-cycle per-foot cost of the particular type of plant.

8. Distribution Module

Sections 8.1 through 8.7 describe how the model deals with services below the DS-3 level provided over copper distribution lines.³² Section 8.8 discusses the treatment of DS-3 and other high-capacity services that are delivered to customers over fiber cable. Section 8.9 discusses the calculation of distribution investments.

8.1. Treatment of Main Clusters

The Distribution Module lays distribution plant directly over the rectangular areas where customer clusters are located. This plant extends from the SAI location (or locations) to the customer premises in the cluster. The basic distribution configuration employed for the main clusters is a “grid” topology, in which tapering backbone cables run from the SAI(s), while branch cables extend perpendicular to the backbone cables past the individual subscriber locations. The backbone cables extend to within a lot depth of the “north and south” cluster boundaries, and the branch cables run to within a lot width of the east and west cluster boundaries.

Main clusters with total areas less than 0.0004 square miles (100 feet on a side) are assumed to consist of high-rise buildings and accorded special treatment appropriate for such buildings. Clusters with such small areas are created by TNS during the PointCode process when there are more than 536 lines located at a single address. For fewer lines at a single address, that address is normally joined with other nearby locations to create a cluster treated as a conventional cluster. It is important to emphasize that locations near a “high-rise” are not joined to or put into the high rise building, but remain part of normal clusters covering the surrounding area.

When the Model has identified a high rise building in this fashion, it assumes the distribution cable required to serve the main cluster consists of riser cable inside the high rise building, and that the SAI required for service is located in the basement of such a building. The number of floors in the high rise buildings is estimated by dividing the occupied building space by the area of the main cluster, reduced to account for streets and sidewalks.³³ The occupied building space in square feet is calculated as follows:

$$\text{occupied space} = 1,500 * \# \text{ households} + 200 * \# \text{ employees.}$$

The number of floors is capped at 50. In a jurisdiction where inside cabling of buildings is not part of the telephone company’s regulated offering, such cabling should not be treated as

³² These include POTS, non-switched analog voice-grade and digital DS-0 lines, ISDN, DS-1, and non-shared ADSL. For simplicity, the collective term “copper-based” is used for all these loops that are delivered to the customer on copper, noting carefully that they are carried on fiber cables in the case where a cluster is served by DLC.

³³ The reduction in main cluster area for urban streets and sidewalks, expressed as a fraction, is user-adjustable with a default value of 0.2.

part of the loop. In the Model, the cost of riser cable is zeroed out to accomplish this end. Obviously, in that case the number of floors and amount of high-rise cable calculated by the Model is irrelevant.

For clusters not defined as containing high-rises, the Model computes the plot size per customer location by dividing the effective area of the main cluster by the number of customer locations in the main cluster, as stated above. The Model assumes that each customer plot is twice as deep as its frontage. However, a refinement to this calculation is required to account for the fact that many households occupy dwelling units that cannot be characterized as single family detached homes. Likewise, structures occupied by business establishments may range from small single-tenant stores on small lots to large, multi-floor buildings (high-rise buildings are treated separately). A residence and a business methodology are adopted to represent more realistically the actual situations that may occur.

For residences, the census database supplied by TNS identifies the number of households located in various types of buildings. The Model assumes that the space occupied by residences other than single-family detached units is half that of detached homes, and accordingly reduces the number of customer locations in calculating the effective plot size of detached homes. This reduction represents more adequately the space (including the actual living quarters, shared facilities, parking lots, and other area around buildings) that households in multi-dwelling units occupy relative to a detached single-family home. The reduction in effective customer locations is made before calculating the lot size in the manner described above. The intent is to calculate the effective lot size that detached homes would have in the main cluster and lay out the distribution cables accordingly. The Model assumes the grid pattern of cables continues throughout the areas where multi-tenant units are located; thus, there is no additional efficiency associated with serving such premises.

The assumed reduction in effective households is conservative because the Model assumes multi-tenant units displace one-half of a regular-sized lot. Thus, the Model will conservatively underestimate the effective lot size of detached homes because it is counting too high a number of equivalent customer locations. This underestimate of effective lot size will in turn conservatively overestimate the amount of distribution plant that is placed compared to the amount that actually is necessary to serve this area.

In all cases, the Module performs a test to ensure that the longest combined backbone and branch cable run does not exceed the user-adjustable maximum copper distance. If the maximum distance would otherwise be exceeded, the Model will force the cluster to be served by DLC on fiber, and extend the fiber subfeeder “connecting cables” from the centroid of the cluster to two or more DLC RTs (and adjacent SAIs) positioned to reduce the length of backbone cable, branch cable, or both to ensure the maximum distance is not exceeded. The number of RT/SAI locations is determined by separately checking that the backbone and branch cable lengths do not exceed a fraction of the maximum distance calculated from the aspect ratio of the cluster shape, and splitting the cluster area in either or both dimensions to create sub-areas.

8.2. Treatment of Outlier Clusters

Outlier clusters, each consisting of one or more customer locations, are served by the nearest main cluster. A main cluster and its associated outlier clusters together constitute a serving area. Clusters are always designated as main clusters if 1) they serve 20 or more copper-based loops; or 2) they contain one or more DS-3 or other all-fiber loops.

Outliers are connected to the main cluster by either fiber or copper road cables extending from the centroid of the main cluster to the centroid of the outlier. A given outlier may be directly connected to the main cluster, in which case it is labeled a “first order” outlier, or it may be connected to another outlier that, in turn, is connected directly to the main cluster or another outlier. Such connections are depicted in Figure 6. Outliers that are not directly connected to the main cluster are considered to be “higher order” outliers.

Fiber feeder is extended to any main cluster that has at least one outlier cluster. The road cables connecting the main cluster to the first-order outlier extend from the point at which the fiber feeder terminates in the main cluster. If the right-angle route distance from the main cluster to the farthest customer location in a first-order outlier is less than the maximum copper distance, the road cable carries an ordinary analog voice signal, and is called “subscriber road cable.” If the farthest customer in a first-order outlier is more than the default distance from the main cluster, or an outlier is a higher order outlier, the connecting cable is called fiber road cable. A fiber road cable terminates in a DLC in the outlier cluster. In either case, distribution cables carrying analog signals extend the remainder of the way to the customer locations within the outlier.

8.3. Customer Drop Arrangement

No matter whether a customer is located in a main cluster or outlier cluster, the distribution arrangement at the customer’s premises is similar. At a point close to the customer’s location, a splice and block terminal are installed to connect either an aerial or buried drop cable containing several wire pairs from the distribution cable to the NID located on the wall of the premises.

HM 5.3 computes a weighted average drop investment in each density zone on both a per-drop and per-pair basis. The Model uses the detailed household type and business line information contained in the demographic database to compute the total drop investment in each serving area. The total drop investment is applied to the sum of all households in single family attached and detached dwellings, mobile homes and “other” dwelling types, all two- and four-household dwellings, and all single-line businesses. The per-pair drop investment applies to the remaining business lines, the adjusted private line total, and public lines, as well as to all households in multi-unit buildings containing five or more households.

Note that HM 5.3 accounts for the fact that drop structure (*e.g.*, trenching) is likely to be shared where multiple-household dwellings such as duplexes and four-plexes are being served. The Distribution Module computes drop investment by assigning the total drop material and structure investment to each single-line business line and to each detached household. For single-family attached dwellings, duplexes, four-plexes, and other multiple-

dwelling-unit buildings, it assigns the drop material investment to each line and the drop structure investment to each occupied building. The Model estimates the number of buildings of each type by consulting an input table showing nationwide occupancy rates by building type and by density zone.

8.4. Normalization of Distribution Distances

At the discretion of the user, the distances associated with the distribution network for a given main cluster -- the connecting cable, if any, between the main feeder termination and DLC RTs in the main cluster, the distribution backbone and branch cables in main clusters, the road cables connecting outlier clusters to main clusters, and the distribution cable within the outlier clusters -- can be adjusted so the sum of their distances, referred to as the distribution route distance (“DRD”), is normalized to a function of the strand distance.³⁴ It is appropriate to include all the components identified in the preceding sentence in the normalization process because the strand distance calculation done by TNS for a main cluster includes all the points that represent customer locations in both the main cluster and all outliers that home on it. The normalization, if done, is based on the following logic and methodology.

There may be reasons why the strand distance associated with a given cluster in the HM 5.3 database is systematically over-estimated or under-estimated. An example of such a systematic bias might include the conservative over-estimation of customer dispersion, and thus strand distance, due to the use of surrogate locations. Thus, there is a user-adjustable strand distance multiplier that can be specified on a per-density-zone basis to eliminate such systematic biases; however, the default adjustment parameter in each density zone is unity so no correction is made unless the user specifies a different value.

If the DRD normalization is turned on, the Model modifies the DRD on a cluster-by-cluster basis as follows. First, it calculates the modified strand distance for a cluster using the specified strand distance multiplier for the density zone in which the cluster falls. Second, it calculates a DRD adjustment factor as the ratio of the modified strand distance to the DRD for the cluster. Finally, it applies this DRD adjustment factor to every component of the distribution plant identified above as being a contributor to the DRD.

If the user does not invoke the normalization option, the Model nevertheless ensures that the DRD in each cluster is large enough to reach the corners of the cluster rectangle that may be occupied by customers, using right-angle routing. For a cluster with two customer locations, this minimum distance is the sum of the height and width of the rectangle less two drop lengths for the cluster’s density zone, under the assumption that customers are located at diagonally opposite corners of the rectangle. For a cluster with three customer locations, the minimum distance is the sum of the height and 1.5 times the width, assuming customers are

³⁴ The strand distance is an independent measure of the amount of route mileage required to connect all the points that represent customer location to each other, appropriately adjusted to eliminate drops, since the DRD does not include drops. The strand distance is based on graph theory, where it would be referred to as a Minimum Spanning Tree (“MST”) of the points that represent the customer locations; however, the strand distance calculation assumes “right angle” routing, rather than straight-line routing, between points.

located at three corners of the rectangle. Finally, for a cluster with four or more customer locations, the minimum distance is the sum of the height and twice the width of the rectangle, assuming customers are located at all four corners of the rectangle.

8.5. Determination of Feeder Technology

Because it must calculate all of the outside plant distances to determine the kind of road cable required, the Distribution Module also determines whether copper or fiber feeder and subfeeder are utilized for a given serving area. If fiber feeder and subfeeder are used, these extend from the wire center to the main cluster centroid. The subfeeder terminates at one or more DLC RTs and adjacent SAIs -- located to ensure that the remaining distribution cable lengths do not exceed the user-adjustable maximum copper distance. In all cases, copper distribution cable is used to link SAIs to customer premises. The Model selects fiber feeder if any of the following conditions are met.

- a) The total feeder and subfeeder distance from the wire center to the main cluster centroid is greater than the user-adjustable Copper Feeder Max Distance value, whose default value is 12,000 ft.
- b) A life-cycle cost analysis of fiber versus copper feeder on the route shows that fiber is more economical.³⁵
- c) The longest distribution cable run from the wire center to the farthest corner of a main cluster is greater than the maximum copper distance.
- d) There is at least one outlier cluster connected to the main cluster.

8.6. “Steering” Feeder Routes

In HM 5.3, the user may elect to have the Feeder Module “steer” feeder routes toward the preponderance of main clusters within a quadrant. The Model computes an angular offset from the cardinal default values of 0°, 90°, 180° or 270° by weighting each main cluster’s angular offset coordinate by its radial distance from the wire center location, and then determining the weighted average angular displacement. When feeder cable is steered in this fashion, the Feeder Module also applies a route-to-airline (“R/A”) distance multiplier. The value of this multiplier may be specified by the user within an allowed range of R/A values. Subfeeder cables branch perpendicularly off the main feeder route toward main clusters. This branching is perpendicular both when feeder routes go in the cardinal compass point directions, as well as when the feeder is steered at an angular offset from these cardinal directions. Alternatively, the user may elect to leave feeder route steering to its default “off” value and have the Module calculate feeder distances using right angle routing in the four cardinal compass directions.

³⁵ The life-cycle costs of fiber and copper feeder are computed using the same methodology, as described earlier, to calculate the life-cycle costs of outside plant placements on different structure types.

8.7. Calculation of SAI and DLC Investments

The SAI in each serving area provides an interface between the feeder and distribution facilities. Each SAI consists of a cabinet, including suitable physical mounting, and a simple passive copper cross-connect. In the case of fiber feeder, there is an adjacent DLC remote terminal. SAI investment is determined by the number of distribution and feeder pairs required to be served. The Model equips multiple SAIs if the pair requirement exceeds the maximum SAI capacity.

Urban areas normally have feeder cable running directly into the basement of large buildings, rather than interfacing at an SAI outside the building. In such cases, the SAI, located in the building, is less expensive than the outdoor SAI. HM 5.3 thus differentiates between outdoor and indoor SAIs, the former being the normal case, and the latter being used when a serving area is identified as a high-rise building.

The Distribution Module sizes and calculates the investment in the SAIs required in each serving area based on the number of distribution and feeder pairs required to serve both the main and outlier clusters and the urban/non-urban characteristic of the serving area. The model assumes the installed SAI investment is a function of the number of distribution and feeder pairs served by the SAI. The Model equips each serving area with one or more SAIs. The number required is determined by comparing the total “in” and “out” lines demand to 7,200, which is the maximum number of pairs that can be supported by a single SAI.

When fiber feeder is used to serve a cluster, the model matches the required POTS capacity (taking a DLC fill factor into account) to a table of 15 line-size ranges. These ranges are based on the sizes and relative economics (as a function of line size) of four commercially-available DLC systems, ranging from a 24-line system to a system serving up to a 8,064 lines whose remote terminal is enclosed in a controlled environment vault. Inputs to the Model specify the 15 ranges of line size, and for each, the following quantities:

- Common equipment investment, including site preparation and power;
- Number of feeder fibers required to serve that DLC system;
- POTS lines per POTS line card, and the investment per card;
- POTS extended range threshold and total line card investment when above that threshold;³⁶
- Coin lines per coin line card, and the investment per card;
- DS-1 lines per DS-1 line card, and the investment per card; and
- ISDN lines per ISDN line card, and the investment per card.

³⁶ Above the extended range threshold, a different, more costly, line card is required to provide an acceptable signal level at customers' premises.

The Model also allows the user to input a percentage of DLC that are universal DLC rather than integrated DLC. The former typically have a higher cost associated with them. The Distribution Module performs all calculations involving DLC investment.

HM 5.3 now allows the user to specify a serving area configuration in which there are multiple distribution areas within the serving area, each of which is served by its own SAI. The user invokes this option by specifying the largest SAI the model is allowed to assume. This will cause the model to split the serving area into enough distribution areas to meet this limit. The model adds the necessary connecting cable from the centroid of the cluster to the center of each distribution area, and includes the SAIs at the middle of those distribution areas, rather than a single SAI location at the centroid of the cluster.

8.8. Treatment of All-Fiber Loops

HM 5.3 includes the ability to account for, and model the costs of, DS-3 and other high-capacity services provided over fiber to the premises. The Model's ability to perform these calculations is conditioned on the availability of incumbent's data that specifies the numbers and locations of such services in sufficient detail to obtain the count of each such service or element in each cluster.

For each cluster, the model determines if one or more all-fiber services are located in the cluster. If so, the model extends fiber through the DLC or SAI located at the cluster's centroid, providing sufficient additional patch panel capacity at the DLC/SAI for splicing the feeder fiber cable to distribution fiber cable(s). The model divides the total count of all-fiber services by a user-adjustable number of services per route (default value of 4) to arrive at estimates of the number of distribution fiber routes required and the number of services on each route. Fiber cables are sized by multiplying the services per route by a user-adjustable number of fiber strands per service, whose default value is 4. The Model assumes each fiber route has a length measured from the DLC/SAI location equal to $\frac{1}{4}$ the maximum possible loop length calculated for the cluster.

HM 5.3 includes the ability to alternatively use a DS-3 strand distance to normalize the distribution fiber used to provide DS-3 services. The DS-3 strand distance is not always included in the cluster database used by the model, in which case the process described in the previous paragraph is utilized.

These steps provide sufficient information to calculate the fiber cable investment. The Model further provides for structure sharing between the fiber-based and copper-based services. This is done by comparing the total fiber route distance to the total POTS distribution route distance in the cluster (capped at 1.0), and applying a user-adjustable fiber structure sharing factor. The default value of the latter is set at 50%, meaning that fiber-based and copper-based services equally share on a per-sheath basis the structure costs of their common route distance. For instance, if the fiber route distance in a given cluster is 30% of the POTS route distance, and the fiber structure sharing fraction is set to 50%, the fiber services are assigned $50\% * 30\%$, or 15%, of the total distribution structure costs for that cluster.

The model also has a fiber terminal cost input. This cost covers the cost of the extra patch panel capacity in the DLC/SAI, if any, and the following equipment at the premises end of the distribution fiber:

- A four-fiber entrance cable 100 feet long;
- A splice of the distribution fiber cable to the entrance cable;
- A splice within the premises that transforms the outside plant cable to a pigtail cable that provides individual connectorized fibers that can be plugged into the optical multiplexer;
- Two duplex fiber pigtails on the premises;
- The optical multiplexer and electronics that provides the service interface to the customer's equipment; and
- The coaxial cable for connecting the circuit termination to the customer's equipment.

There is no need for electrical over-voltage protection, because the HAI Model assumes the use of all-dielectric fiber cable with no metallic strength members (Kevlar strength members are used in such forward-looking cable designs).

Several different types of broadband services at the DS-3 level or above (or services designated as "DS-1 on fiber") may exist in a given cluster. The model calculates the investment separately for each type of broadband service. Thus, the network components that are common to all such services – the fiber distribution cable, and the amount of structure costs assigned to broadband services in total – is distributed proportionally to the number of strands of each type of service. It is important this be done correctly because while all broadband services are taken into account in sizing the distribution (and, later, the feeder) part of the network for broadband services, only the DS-3 UNE costs are explicitly included in the output of the Expense Module. Once the costs of components shared between broadband services are calculated, the cost of the components unique to each instance of a service – namely, those components listed that are included in the fiber terminal cost for a service – are then added on a service by service basis.

8.9. Calculation of Distribution Investments

After determining the amounts and sizes of all the distribution components described above, the Model estimates the investment in distribution copper and fiber cable, supporting structures, terminals and splices, drops, NIDs, SAIs, and DLC equipment. In addition to the cost inputs for these network components, the Model requires a number of additional data elements, which are provided to it through adjustable user inputs. These include cable sizing factors, the amount of structure sharing with other utilities, the relative mix of aerial, buried, and underground facilities, the unit material and installation costs of the various network components, the demographic factors identified in Section 6.1 above, and factors relating to difficult terrain characteristics that may increase installation costs.

Two sets of distribution input parameters bear special attention. The first is the set of POTS cable sizing factors. Sizing factors are intended to provide reserve capacity above and beyond the lines requirement determined by the Model. If, for instance, a given cable segment must serve 90 lines and the sizing factor set by the Model is 0.75, then the target cable size determined by the Model is $90/0.75$, or 120 pairs. However, cables are available only in discrete sizes. The Model selects the cable size at or most closely above the minimum size calculated. In this example, this corresponds to a 200 pair cable. Thus, the achieved fill is $90/200$, or 0.45. Generally, the average achieved distribution fill is significantly less than is indicated by the raw cable sizing factors. The Model outputs display this average actually-achieved fill both at the SAI and at the MDF.

Second, as discussed earlier, the Model assumes that forward-looking practices of efficient telephone companies and other utilities will involve substantial structure sharing with other utilities. The levels of structure sharing assumed in HM 5.3 are stated as the percentage of total structure costs assigned to the telephone company. The amount of structure sharing depends both on the type of structure -- poles and trenching -- and the density zone. In underground installations, the Model assumes, conservatively, that there is no sharing of the conduit itself, only excavation and restoration costs required to place the conduit.

9. Feeder Module

9.1. Overview

The Distribution Module produces as inputs to the Feeder Module the main feeder and subfeeder cable distances for each serving area. The Feeder Module uses these inputs to calculate the investment in feeder plant. Sections 9.2 and 9.3 deals with the feeder calculations related to copper-based services. Section 9.2 in particular describes the feeder architecture assumed by the Model. Section 9.3 describes how the Model develops the investment in feeder facilities. Section 9.4 discusses the addition of DS-3 and other broadband services both with respect to the impacts they have on the feeder configuration and the way in which broadband feeder investments are calculated.

9.2. Feeder Architecture Assumed by the Model

As seen earlier in Figure 1, feeder cable begins at the wire center and ends at the SAI located at the centroid of the main cluster each serving area. Figure 7 displays the basic main feeder and subfeeder architecture assumed in the Model.³⁷ Note that since a given main cluster can be surrounded by outlier clusters and/or areas with no population, there may be gaps between the main clusters, as shown in the drawing. In areas of dense population, they are, however, likely to be contiguous.

As many as four main feeder routes may terminate at each wire center. Each feeder route serves one quadrant of the wire center's service area, and quadrant boundaries form angles of $\pm 45^\circ$ with the main feeder routes.³⁸ Each main cluster is served by the main feeder route associated with the quadrant containing the centroid of the main cluster. To reach each cluster, a subfeeder branches from the main feeder at right angles and extends to an SAI within the cluster. As described in Section 8.7 of the Distribution Module, each of the four main feeders may, at the user's option, be "steered" towards the preponderance of main cluster locations within the quadrant in question, and a route-to-air multiplier applied to the "steered" feeder route distance.

The main feeder cable sizes for both fiber and copper facilities are a function of the total number of lines in each serving area, and the feeder sizing factor for those serving areas. Feeder cable sizes range from 100 to 4200 pair cable for copper, and from 12 to 216 strands for fiber. Multiple cables are installed along feeder routes when the maximum size of a

³⁷ As discussed previously, subfeeder may be linked at the main cluster centroid to connecting cables that run to two or more DLC RTs located at other points within the main cluster. Such connecting cables are also classified as feeder cable by the model, since telephone companies classify all cable on the wire center side of the DLC RT as feeder cable.

³⁸ Because HM 5.3 uses V&H coordinates to locate clusters and wire centers, feeder routes are assumed to emanate from the wire center along the V&H axes. These axes are rotated slightly clockwise relative to latitude and longitude axes.

single cable is exceeded. Main feeder routes taper as they pass the splice points at which subfeeder branches off to connect to the individual serving areas. Thus, the main feeder cable sizes generally decrease in increments as the distance from the wire center increases.

Both copper and fiber feeder cable may appear on a single main feeder route to provide connections to different serving areas. If they do, they share most structure, including poles, manholes and trenching. Copper and fiber cables are not assumed to share conduit when they follow the same route, however.

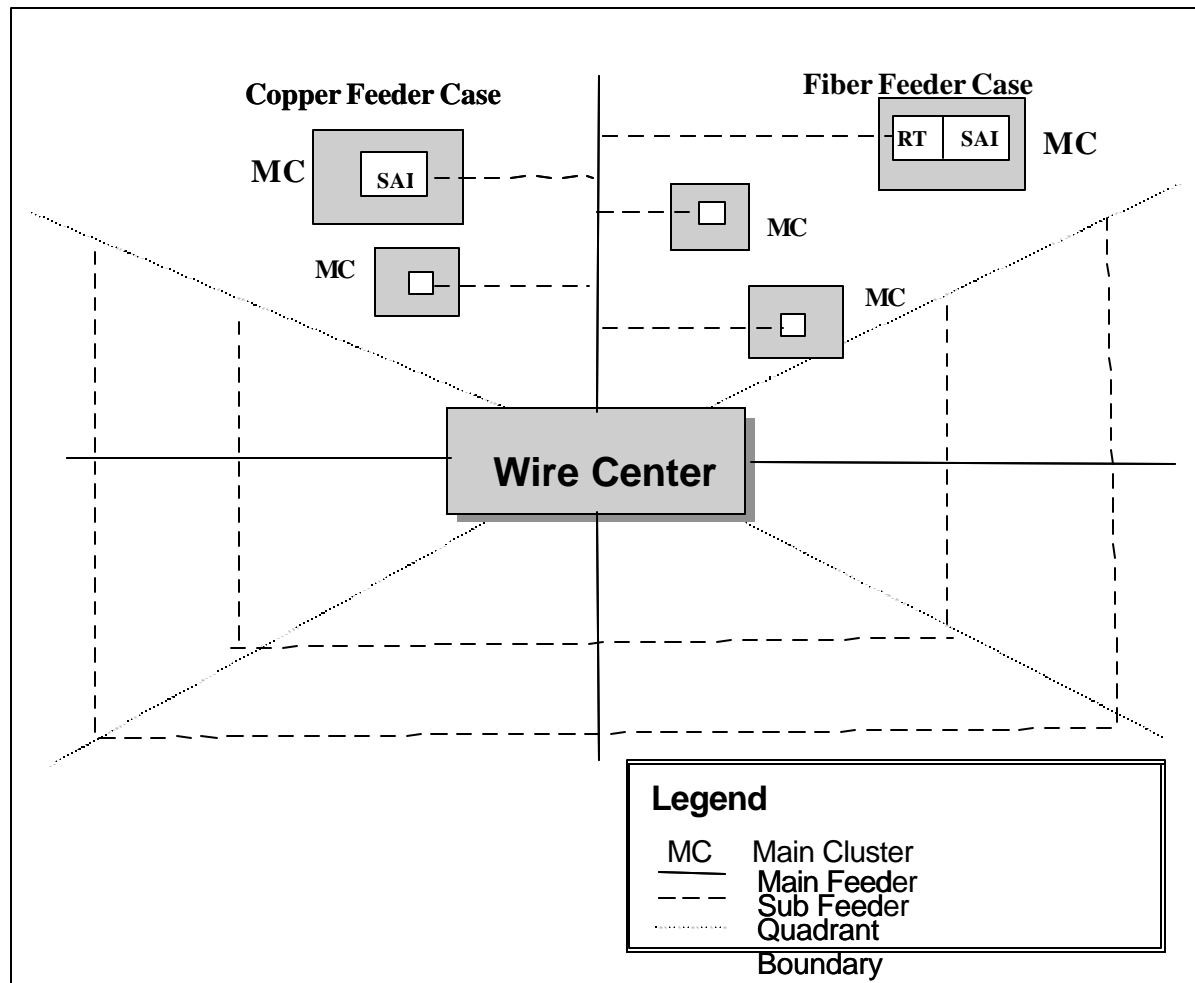


Figure 7 Feeder Architecture

9.3. Determination of Feeder Investments

9.3.1. Calculating Main Feeder and Subfeeder Distances

As was shown in Figure 7, main feeder routes extend from the wire center in as many as four directions.³⁹ Subfeeder cables branch from the main feeder at right angles, giving rise to the familiar tree topology of feeder routes. The points at which subfeeders branch off the main feeder delineate main feeder segments, which are the portions of main feeder cable between two branch points.⁴⁰

The centers (centroids) of the main clusters may fall in any of the four feeder route quadrants. As shown in Figure 8, a set of parameters, including the quadrant, airline (radial) distance and angles (omega and alpha), locate the main cluster with respect to the serving wire center. With this information, HM 5.3 applies straightforward trigonometric calculations to compute main feeder and subfeeder distances.⁴¹ The Model computes sufficient subfeeder cable to connect the main feeder route to the centroid of each main cluster. Copper subfeeder cable always terminates at an SAI at the centroid of the main cluster. If the Model calls for fiber feeder, the subfeeder terminates at an RT at the centroid, adjacent to an SAI.

³⁹ If no cluster centroids fall within a given quadrant of a wire center, no feeder route will be provided in that quadrant.

⁴⁰ Splicing is required where the main feeder branches into subfeeder. The cost of splicing, including material, equipment, and labor, is included with the cost of the cable assumed in the model.

⁴¹ In rural areas where a feeder route may serve only one or two main clusters, this rectilinear routing assumption is extremely conservative relative to the efficiencies that could be realized using a steered feeder routing.

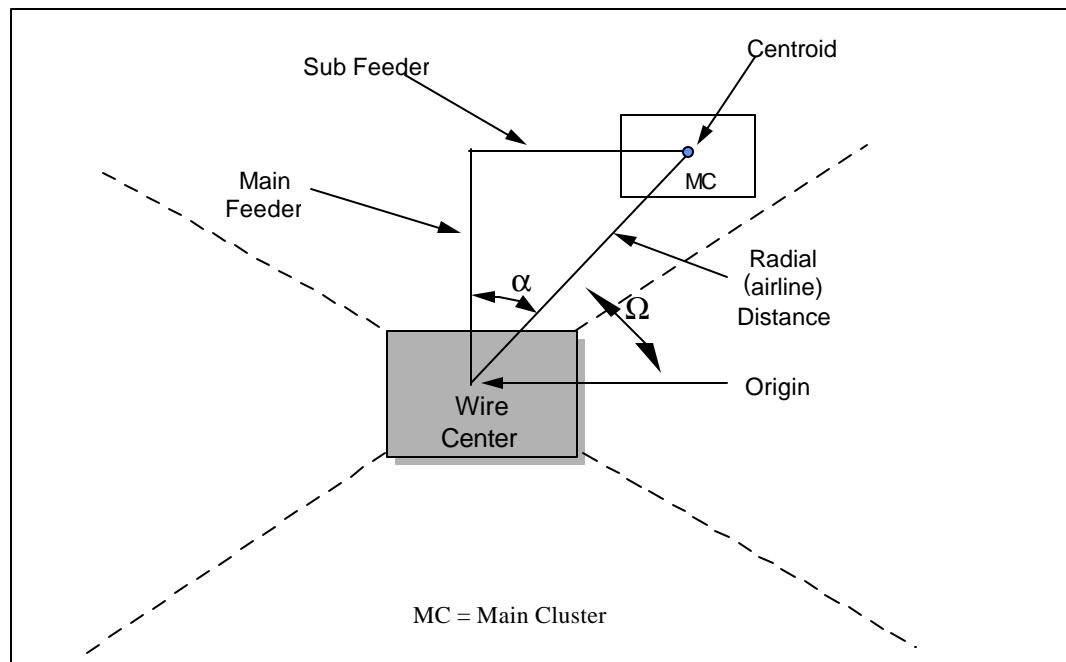


Figure 8 Determination of Cluster Locations and Distances

The criteria by which the Model decides if a main cluster is served by copper or fiber feeder cable have been discussed in the Distribution Module description, since this decision is made there.

Figure 9 demonstrates that multiple serving areas share capacity on certain segments of the main feeder route. Segments located closer to the wire center require more capacity than segments near the periphery. HM 5.3 addresses this need by tapering the main feeder facilities as the distance from the wire center increases. Thus, it must determine the various “segment distances,” shown as S-1, S-2, ..., in Figure 9, so it can size the cable in each segment. The segment distances along a main route are calculated in two steps. First, the main clusters are sorted so they appear in the order of increasing distance along the main route. Segment distances are then calculated as the difference between the main feeder distances of adjacent main clusters.

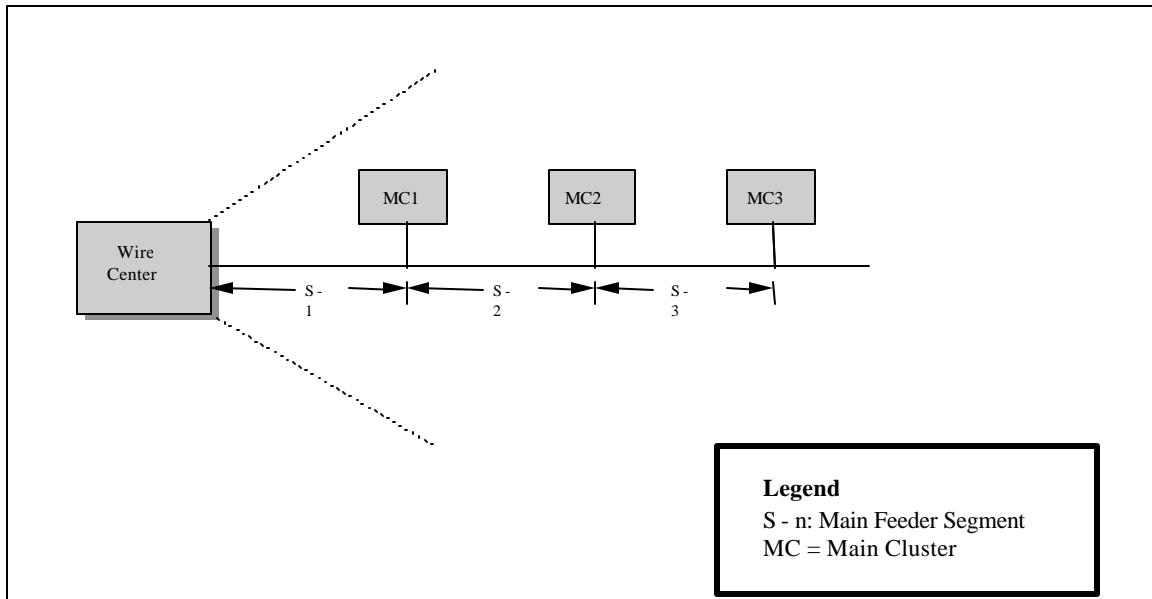


Figure 9 Main Feeder Segmentation

9.3.2. Copper and Fiber Subfeeder Cable Sizing

Sizing copper subfeeder cable for individual serving areas is a function of two parameters: the total number of lines within the serving area and the copper feeder sizing factor. To select the appropriate cable size, the required line capacity is computed by dividing the total number of lines in the serving area by the sizing factor. The Model then chooses the smallest cable size that meets or exceeds this quotient. For instance, if the number of lines is 200 and the sizing factor is 0.80, the next cable size larger than $200/0.80$ is selected. Since $200/0.80$ equals 250, the 400 pair cable is selected. As with distribution cable, this may lower substantially the average effective fill compared to the input value entered. The number of pairs resulting from this calculation for a given cluster is maintained all the way back to the wire center, even if the cable subsequently passes through an area with a higher sizing factor that might otherwise allow fewer pairs. In this way, the model ensures the number of pairs required to serve a given cluster does not vary along a cable route. Multiple cables are used in cases where the maximum cable size is surpassed.

The number of optical fibers needed to serve a given serving area is calculated by multiplying the number of DLC RTs in that serving area by the number of strands per RT, which is a user-adjustable quantity with a default value of four.⁴² In the subfeeder to a particular serving area, the Model chooses the smallest optical fiber cable size that meets or exceeds the required number of strands, with a minimum cable size of twelve fiber strands. In the main feeder, the fiber cable on each segment is sized to meet the aggregate demand of serving areas beyond that segment, taking the user-adjustable fiber strand fill factor into account.

⁴² Because a DLC terminal requires a minimum of two fibers, one for each direction of transmission, the HM 5.3 default of four fibers provides complete redundancy.

9.3.3. Main Feeder Segment Sizing

Each segment in the main feeder is sized to meet the requirements of all the serving areas located past the segment. For example, in Figure 9, segment 1 is sized with adequate capacity for serving areas 1, 2, and 3. Segment 3 will be sized with less capacity than segment 1 since it serves only serving area 3. Thus, the individual cable requirements for serving areas at and beyond the end of a particular main feeder segment are aggregated to determine the required cable size for that main feeder segment. When the maximum cable size is exceeded on a given segment, multiple cables are installed.

9.3.4. Structure Investments

The fraction of aerial, buried and underground plant may be set separately for all density ranges and for each feeder cable type, copper or optical fiber. Based on these fractions, the distances involved, and the cost of various structure components, the Feeder Module calculates the investment in feeder structure.

In addition to the sharing of structure between telephone companies and other utilities, there are two other forms of structure sharing relevant to feeder plant. First, with the exception of conduit, structure is shared between copper and fiber feeder cables along main feeder routes. Second, structure is shared between feeder and interoffice facilities. A detailed discussion of the latter type of sharing is presented in the interoffice section of this document.

9.3.5. Assignment of Main Feeder Investments

All the feeder facility investments are computed on a per-serving area basis. To do this, it is necessary to assign the appropriate amount of investment in each segment of the main feeder route to the individual serving areas that are served by that segment. The portion of a main feeder segment investment assigned to a serving area whose lines are carried on that segment is computed using the ratio of lines in that serving area to total number of lines in all serving areas carried on that main feeder segment. This is done separately for the copper and fiber feeder that may coexist on a given route.

9.4. Feeder Calculations Associated with all-Fiber Loops

Sections 9.2 and 9.3 have focused on the provision of copper-based services. HM 5.3 also includes DS-3 and other higher-capacity broadband services and elements. The same architecture described in Section 9.1 is assumed for these services.

Some or all of the clusters served off a main feeder route likely have one or more broadband services located in them. For each individual broadband service in a cluster, the Model provides a user-adjustable number of additional fiber strands required to support that service. The default setting for the number of strands per service is four. For instance, in Figure 9, if there are two broadband services in MC2, then eight ($2 * \text{default value of } 4$) strands of fiber are provided in the subfeeder serving MC2 as well as in segments s-1 and s-2.

Different scenarios must be considered by the Model, dealing with both subfeeder and main feeder cables. First, consider the subfeeder that serves a particular cluster. If the POTS lines in that cluster are served by copper, then a fiber cable (or multiple cables) must be added to that subfeeder. In this case, the entire investment in the cable is attributed to broadband services. The fiber subfeeder extends from the branching point with the main feeder cable to the middle of the cluster, where the splicing to distribution fiber cables is assumed to occur. On the other hand, if the POTS lines in the cluster are served by fiber, then the existing fiber subfeeder cable is resized to support the additional strand requirements for broadband services. The investment in the fiber sub-feeder is split between POTS and broadband services proportionally to the number of strands needed for POTS and for all the broadband services, respectively.

The main feeder route is treated in essentially the same fashion on a segment-by-segment basis, keeping in mind that the strands serving a broadband service in a given cluster must be provided in every segment between the cluster and the wire center, just as both the copper pairs and fiber strands required for POTS in a given segment must be provided in every segment back to the wire center. If a given segment requires only copper cable to meet the POTS demand supported by that segment,⁴³ then a fiber cable sized to serve the total broadband requirement on that segment is added to the segment. The investment in that cable is attributed entirely to the broadband services it is carrying. If, on the other hand, the segment already has a fiber cable (or cables) serving POTS lines in clusters at and/or beyond the end of that segment, the existing fiber cable is resized to meet the additional requirement (which, of course, could lead to additional fiber cables if the total strand requirement exceeded the capacity of the existing cable(s)). In this case, the total investment in fiber cable on that segment is split between POTS and broadband services proportionally to the number of strands each requires, and then further attributed to individual broadband service types supported on the segment.

After the process of adding/resizing fiber cables occurs, and the Model knows 1) the number of copper and fiber cables on each segment of the main feeder and on each subfeeder and 2) the number of fiber strands within the fiber cables on each subfeeder and main feeder segment that serve POTS and individual broadband services, it first assigns structure to copper and fiber cables proportionally to the number of sheaths (cables) of each. For instance, if a given main feeder segment requires two copper cables and one fiber cable, it assigns $2/3$ of the structure costs to copper and $1/3$ to fiber. It then further assigns all of the copper structure investment to POTS, while dividing the fiber structure investment between POTS and broadband services according to the relative strands required of each. Continuing with the same example, if there were three strands required for POTS for every two required for broadband (*i.e.*, the relative proportions are $3/5$ and $2/5$, respectively), then $3/5$ of the $1/3$ structure investment assigned to fiber would be further assigned to POTS, while the remaining $2/5$ of the $1/3$ structure investment would be further assigned to broadband. In this example, then, POTS and broadband would pay for the following fractions of the structure investment in question:

⁴³ That is, POTS lines in the cluster at the end of the segment and all segments further out along the feeder route.

- POTS: $1 * 2/3 + 3/5 * 1/3 = 13/15$
- Broadband: $2/5 * 1/3 = 2/15$.

But the model also includes a user-adjustable broadband allocator that can be used to increase or decrease the proportion assigned to broadband. It is multiplied by the amount of structure cost allocated to broadband to arrive at a revised broadband allocation, and the difference is added to or subtracted from the POTS allocation. In the above example, if the allocator were changed from its default value of 100% to 50%, then the amount of structure investment assigned to fiber would be $50% * 2/15 = 1/15$, and the extra $1/15$ would be added to the POTS assignment to give $14/15$ total.

Once the assignment of structure costs to broadband for a given segment is known, that amount is divided among different kinds of broadband services according to the relative proportion of strands on the segment that support each service. Similarly, once the assignment of structure costs to POTS for a given segment is known, that amount is divided among the different kinds of services we have lumped in the POTS category for this discussion (*i.e.*, telephone service, non-switched voice-grade analog and DS-0 data circuits, ISDN, DS-1, ADSL) according to the relative amounts of DLC line card capacity they consume. For instance, since a DS-1 service consumes four times the line card capacity of a telephone line, four times as much structure investment is assigned to each DS-1 service as to each telephone line. This assignment scheme recognizes that consumption of remote terminal capacity is the relevant cost driver since it causes more or less fiber strands to be required.

10. Switching and Interoffice Module

10.1. Overview

This Module produces network investment estimates in the following categories:

- a) *Switching and wire center investment* -- This category includes investment in local and tandem switches, along with associated investments in wire center facilities, including buildings, land, power systems and distributing frames.
- b) *Signaling network investment* -- This includes investment in STPs, SCPs and signaling links.
- c) *Transport investment* -- This category consists of investment in transmission systems supporting local interoffice (common and direct) trunks, intraLATA toll trunks (common and direct) and access trunks (common and dedicated).
- d) *Operator Systems investment* -- This includes investments in operator systems positions and operator tandems.

10.2. Description of Inputs and Assumptions

For the Switching and Interoffice Module to compute required switching and transmission investments, it requires as inputs total switched line counts for each wire center, distances between switches, and traffic “peakedness” assumptions, as well as inputs describing the distribution of total POTS traffic among local intraoffice, local interoffice, intraLATA toll, interexchange access and operator services. This module takes as data inputs minutes and calling volumes from ARMIS, overall switched line counts obtained from the TNS database for the serving areas belonging to that wire center, and wire center locations and interoffice distances from the distance file for the calculation of transmission facilities investments.⁴⁴ It also requires many user-adjustable input assumptions pertaining, for instance, to the percent of traffic requiring operator assistance, the percent of traffic that is inter-switch as opposed to intra-switch, and the like.

Many of the calculations in the Switching and Interoffice module rely on traffic assumptions suggested in Telcordia Technologies documents.⁴⁵ These inputs, which the user may alter, assume 1.3 busy hour call attempts (“BHCA”) per residential line and 3.5 BHCA per business line. Total busy hour usage is then determined based on published DEM information. Other inputs, which may be changed by the user, specify the fraction of traffic

⁴⁴ HM 5.3 includes a set of interoffice distance calculations produced from wire center location information from Telcordia Technologies’ LERG and from the National Exchange Carrier Association Tariff 4.

⁴⁵ Telcordia Technologies, *LSSGR: Traffic Capacity and Environment*, GR-517-CORE, Issue 1, December 1998.

that is interoffice, the fraction of traffic that flows to operator services, the local fraction of overall traffic, as well as breakouts between direct-routed and tandem-routed local, intraLATA toll, and access traffic. In HM 5.3, these can be specified separately for different switch sizes to capture, for instance, a different breakdown of intra-switch and inter-switch traffic between rural, suburban and urban areas.

10.3. Explanation of Calculations

The following sections describe the calculations used to generate investments associated with switching, wire centers, interoffice transport, signaling and operator systems functions.

10.3.1. End Office Switching Investments

The Module places at least one end office switch in each wire center. It sizes the switches placed in the wire center by adding up all the switched lines in the clusters served by the wire center, applying a user-adjustable administrative line fill factor, and then comparing the resulting line total to the maximum allowable switch line size. The maximum switch line size parameter is user-adjustable; its default setting is 120,000 lines plus trunks.⁴⁶ The Model will equip the wire center with a single switch if the number of ports (lines and trunks) served by the wire center is less than this figure. Otherwise, it equips the wire center with two or more switches of equal size to meet this size limitation. For instance, if a wire center must serve, 130,000 ports, the Model will compute the investment required for two 65,000-port switches.⁴⁷

The wire center module performs two additional capacity checks. First, it compares the BHCA produced by the mix of lines served by each switch with a user-adjustable processor capacity (default set at a maximum of up to 1,000,000 BHCA, depending on the size of the switch) to determine whether the switch is line-limited or processor real-time-limited. In making this calculation, the per-line BHCA input is multiplied by a user-adjustable processor feature loading multiplier. The default value of the feature loading multiplier varies between 1.2 and 2.0, depending on business line penetration,⁴⁸ to reflect additional processing loads caused by features.

Second, the module compares the offered traffic, expressed as BHCCS, with a user-adjustable traffic capacity limit (default set at a maximum of up to 2,400,000 BHCCS, depending on the size of the switch). To make this comparison, the per-line traffic estimate calculated from the reported DEMs is multiplied by a user-adjustable holding time multiplier, which can be separately set for business and residence customers. Default values of the business and residential holding time multipliers are unity. They can be increased above that value to reflect the incidence of calls that have longer than normal holding times, and thus increase the traffic load on the switch. An example could be heavy Internet dial-up access

⁴⁶ This is a conservatively low estimate of the maximum line capacity of current local switches.

⁴⁷ If multiple switches are required in the wire center, they are sized equally to allow for maximum growth on each switch.

⁴⁸ The multiplier is set at 1.2 up to a business penetration (*i.e.*, % business lines) threshold set by the user, then increases linearly to 2.0 at 100% business penetration.

via the voice network. If either of these processor or traffic capacity tests leads to the corresponding limit being exceeded, the Model will compute the investment required for additional switches, each serving an equal number of total lines.

HM 5.3 allows the user to select between one of two methods for engineering and costing end office switching systems. In one, the Model identifies and treats the switching systems as being explicit combinations of hosts, remotes and stand-alone switching, assigning a switch type to each CLLI used by the model. In the other, the Model assumes a blended portfolio of switch technologies, and does not associate particular CLLIs with particular switch types. Since the blended configuration is assumed in the default mode, it is described first.

The blended portfolio is appropriate when accurate data on the separate purchase prices of host, remote and standalone switches of varying capacities are not available to the user, when the user lacks information on which wire center should contain which of these switch types, and/or when a simplified calculation of the interoffice network is desired. In this mode, the total investment in a switch is described by the function $A + B * L$, where L is the line capacity of the switch, and A and B are user-adjustable input values. This function averages the investment function per-line investments over a portfolio of host, remote, and standalone end office switches. The end office switches are placed on interoffice SONET rings, as described in the next section, with no consideration given to the separate types of switches involved, focusing instead, on a forward-looking optimization interoffice ring structure.

In the host/remote/standalone mode, the investment in each type of switch is also described by the functional form $A + B * L$, where L is the number of lines and A and B are user-adjustable constants specified separately for each type of switch. Also, recognizing that these switches come in various size ranges, the user may specify define up to four switch size ranges, and specify different constants for each switch type in each size range.

The database accompanying the model contains the LERG designations of host, remote, and standalone switches. The user may change these assignments through the user interface. Using the LERG or user-adjusted designations, the Model places the hosts and their subtending remotes on SONET rings separate from the interoffice rings discussed in the next section. Host switches may therefore be involved in two of the ring formations processes described in the next subsection – one that forms local host/remote rings, and the other that forms larger interoffice rings connecting hosts, stand-alone switches and tandem switches

The Model sizes the host-remote rings to accommodate host-remote umbilical trunk and control link requirements. It then computes investment in SONET add/drop multiplexers (“ADMs”) and digital cross connect systems (“DCSs”) for the host/remote ring and calculates the average ADM and DCS investment per line for all lines in the system. The host interoffice calculations also are adjusted to account for the increased trunk and signaling capacity requirements imposed by the remotes served by the host. Once the Model computes investments for each switch in a given host/remote system, it calculates the average investment per line for all of the lines in that system.

The model also equips wire centers with ATM switches of sufficient capacity to carry all the traffic associated with the number of ADSL lines in the customer location database. This is not done to produce an ATM switching UNE, but to ensure the network being sized by the model is accounting for all the demand for switched services of all types identified in the customer location database.

Wire center investments required to support end office and tandem switches are based on assumptions regarding the room size required to house a switch (for end offices, this size varies according to the line sizes of the switch), construction costs, lot sizes, land acquisition costs and investment in power systems and distributing frames. However, some or all of these costs may be included in the switch investments that appear in various data sources. In particular, the switch cost parameters adopted by the FCC in its universal service deliberations include the main distribution frame and power costs, as well as telco switch installation costs. The user should ensure that the Model is not double-counting investments in this case, once in the switch investment itself and once in the wire center calculations, by setting appropriate wire center and/or switch installation parameters to zero.

The Model computes required wire center investments separately for each switch. For wire centers housing multiple end office switches, the wire center investment calculation adds switch rooms to house each additional switch.

10.3.2. Transport Investments

The traffic and routing inputs listed previously, along with the total mix of access lines served by each switch, form the basis for the Model's transport calculations. The Model determines the overall breakdown of traffic per subscriber according to the given traffic assumptions and computes the numbers of trunks required to carry this traffic. These calculations are based on the fractions of total traffic assumed for interoffice, local direct routing, local tandem routing, intraLATA direct and tandem routing, and access dedicated and tandem routing. These traffic fractions are applied to the total traffic generated in each wire center according to the mix of business and residential lines and appropriate per-line offered load assumptions. The Model computes the interoffice total offered load per wire center for various classes of trunks – *e.g.*, local direct-routed trunks. It then compares the offered load for a trunk class to a traffic engineering threshold. If the offered load exceeds the threshold, the computed number of trunks is just the quotient of the total offered load divided by the user-specified maximum trunk occupancy (default = 27.5 hundred call seconds ["CCS", from centum call seconds). If the traffic load is less than the threshold, the Model obtains the correct number of trunks using Erlang B assumptions and 1% blocking from a lookup table.

The traffic engineering threshold value is determined from the user-specified maximum occupancy value through another table lookup, which determines the number of trunks that will carry the specified maximum occupancy at 1% blocking. The threshold value is the product of the input maximum occupancy and the corresponding number of trunks. The user may enter maximum occupancies between 17.5 and 30 CCS.

To the trunk requirements for each wire center are added the known requirements for non-switched circuits, excluding dedicated circuits between an ILEC switch and the switches of IXC's, CLECs, and other non-ILEC carriers. These are excluded because they have already been accounted for in determining the number of trunks required to carry switched traffic. The number of non-switched circuits is determined from the non-switched loops by type included in the customer location database. Since some dedicated circuits originate and terminate in the same wire center, and thus do not require capacity in the interoffice network, the count of non-switched loops is multiplied by a user-adjustable fraction to remove those circuits from the amount of interoffice demand.

The Model assumes that, with some exceptions, all interoffice facilities take the form of a set of interconnected SONET four-fiber bi-directional line switched rings, with as many logical or coincident rings associated with each physical ring as are necessary to provide the required circuit capacity of that ring. The physical rings are interconnected within wire centers common to the two rings being interconnected. The ring calculations use a program written in Visual Basic for Applications ("VBA") and the wire center locations specified as V&H coordinates to configure a set of rings constituting the interoffice network and to compute the associated interoffice distances.

For BOC and ICOs with their own tandem switches, the interoffice ring network may consist of two ring classes: tandem/host/stand-alone and host/remote. If the user invokes the feature that allows hosts and remotes to be specified, host/remote rings are used to interconnect remote switches to their serving host. Tandem/host/standalone rings interconnect hosts and standalone wire centers to their serving tandem.

For each ILEC that does not operate its own tandem switches, the HM 5.3 distance file designates a set of gateway wire centers for that ILEC.⁴⁹ Each gateway serves as the homing point for a set of wire centers associated with this ILEC. The purpose of a gateway switch is to avoid the need for multiple links from a set of proximate switches to a distant tandem switch. The Model forms gateway rings to connect each gateway wire center with the wire centers that home on it.

The distance file assigns each gateway wire center to the tandem switch of another company.⁵⁰ The Model computes additional investment for the facilities that connect the gateway to its assigned serving tandem. Gateways may be connected to their serving tandem either through a direct, redundant path, or through a bridging wire center (bridging wire centers belong to the same operating company as the assigned serving tandem). In the latter case, the Model computes the investment required for the construction of facilities between the gateway and the bridging wire center, and an effective investment corresponding to the cost of leased facilities between the bridging wire center and the actual serving tandem.

⁴⁹ Gateway wire centers may also be selected for ILECs that *do* operate their own tandems when doing so serves to reduce overall transport distances.

⁵⁰ The input development process assigns these gateways to the nearest tandem, irrespective of tandem ownership.

In HM 5.3, there are thus three different classes of rings: host/remote, tandem/host/stand-alone, and gateway/homing. The methodology that the Model uses to determine the rings is the same for all classes of rings, with hosts serving as the homing point in the network of hosts/remotes, tandems serving as the homing point in the network of tandems, hosts, and stand-alone wire centers, and gateways serving as the homing point in the network of gateways and their subtending wire centers. The following discussion of forming tandem/host/stand-alone rings is applicable to all classes or rings, unless otherwise noted.

To compute the set of tandem/host/stand-alone rings, the HM begins with a case where all wire centers are directly connected to their serving tandem via redundant paths. Each wire center is then examined to determine whether it is more advantageous to leave the wire center directly connected to the tandem or incorporate it into a ring. To make this determination, the HM compares the investment associated with directly connecting the wire center to the tandem with the investment associated with placing the wire center on a ring. For direct connections, the investment is a function of the distance from the wire center to the tandem. When determining the investment that is required to add a wire center to a ring, the distance between interconnected wire centers and the additional cost of multiplexing are considered. If the investment on the ring is less than the investment associated with directly connecting to the tandem, the office will be placed on the ring.

The Model incorporates an optimizing algorithm to ensure that it constructs rings efficiently. The savings that are generated by placing a wire center on a ring are computed as the difference between on-ring and directly connected investment. The HM places the offices that produce the greatest savings on the ring first. When no more savings are possible, the process of creating rings is complete.

In the process of computing ring configurations, the greatest saving often is realized by allowing a set of wire centers to form their own stand-alone ring that does not include the serving tandem as a node. The algorithm requires the tandem to be placed on at least one ring, but not necessarily all rings. But since all wire centers must have a communications path to their serving tandem, the Model then connects stand-alone rings to the tandem through a series of ring interconnections. The interconnection between two rings is assumed to take place in a wire center common to the two rings. The wire centers are chosen to minimize the cost of ring interconnection. Two redundant connections are provided for each such ring interconnection.

While a given physical ring may serve up to 16 wire centers, and thus require a considerable total capacity, the Model does not provide every wire center on a ring with equipment (add-drop multiplexers, digital cross connects, and multiplexers) capacity equal to the total capacity requirement of all wire centers on the ring. Instead, the Model determines the amount of equipment required to serve the traffic capacity of each wire center. It then provides not only that amount of equipment, but an additional amount equal in capacity to the total capacity requirement of all wire centers on the ring. This additional equipment is assumed to be housed at a “hubbing” point on the ring. In this way, the model in effect envisions there are a number of logical rings carried on a given physical ring, each of which

serves a subset of the wire centers on the ring, and which are cross-connected at the hubbing point using the extra equipment the model has provided.

Because the model does not have all the information required to determine “communities of interest” on the ring, the resulting equipment capacity is conservatively high because the model is unable to take advantage of the potential reuse of circuits on different segments of the ring that typically happens during the configuration of circuits on a ring. Instead, each circuit is assumed to traverse the complete ring in both directions. On the other hand, operating in this fashion, the model avoids equipping wire centers with far more terminal equipment capacity than they require to carry the traffic to/from that wire center. This is particularly important in the case of small (capacity-wise) wire centers served by a high-capacity ring.

Because physical rings are interconnected, traffic between wire centers on two rings may “transit” one or more additional rings. Thus, the calculated capacity of a ring, based on the traffic originating/terminating in wire centers on the ring, must be increased to reflect the requirement that the ring also be able to handle transiting traffic. The actual amount of such transiting traffic on a ring depends strongly on (1) the position of that ring in the overall configuration of rings serving a given area; and (2) the amount of traffic generated (or terminated) by wire centers on a given ring that is destined for wire centers on another ring, and therefore “leaks” out of the originating ring. The Model increases the capacity of each ring to handle transiting traffic based on a user-adjustable “transiting factor,” whose default value is 0.4. This factor represents the percentage of additional ring capacity consumed by transiting traffic. Thus, the Model increases the calculated ring capacity requirement by $(1 + \text{transiting factor})$.

There are two user-adjustable parameters that govern the creation of rings. First, it is possible to set the maximum number of wire centers that may share the same physical ring. The default number is 16. Once this limit has been reached, no additional wire centers will be absorbed by the maximally sized ring – even if doing so would produce a network with a smaller total investment. The second, which applies only to host/stand-alone/tandem rings, is a threshold value dictating the minimum number of switched plus special lines a wire center must serve to be eligible to be placed on a ring. Wire centers that serve less than this threshold total line count will either: 1) directly connect to the tandem; or 2) connect to the nearest stand-alone or host wire center that is on a ring. The option that yields the shortest spur distance is selected. In either case, redundant facilities are provided. The current value of the threshold is unity, meaning that in default mode, the Model considers all switches to be ring candidates.

At the highest level in the ring network, the HM must provide a path for tandem to tandem traffic for tandems that are located in the same LATA. This is accomplished through the use of inter-ring-system connectors.⁵¹ The inter-ring-system connectors facilitate a fully interconnected mesh of all the ring systems that exist within a LATA. Ring systems may be connected to other ring systems either through direct tandem-to-tandem paths, or through any

⁵¹ A ring system is defined as the set of nodes, connectors, spurs, and ring connectors associated with a particular tandem.

of the on-ring nodes served by those tandems. Inter-ring-system connectors are always provided in pairs for redundancy and will, in most cases, terminate at unique nodes within each of the ring systems. The nodes and paths selected are those that produce the shortest two paths between ring systems. To ensure tandem switches are sized to handle inter-tandem traffic, there is a user-adjustable parameter (default value 0.10) that is expressed as a multiplier of the number of tandem trunks calculated from traffic volumes. Its effect is to increase the calculated capacity of the tandem switches.

In the case of gateway rings, the Model compares the investment associated with a given ring with the investment that would be required if each wire center on the ring were instead directly connected (or connected through a bridging office) to the designated serving tandem. It then selects the alternative that yields the least investment.

The output of the ring-calculating process is a list of the computed host/remote, gateway/homing, and tandem/host/stand-alone ring configurations. The following information is reported in the workfile “ring_io” worksheet for each set of rings: 1) the set of wire centers that comprise the ring, including the “central” wire center (host, gateway, or tandem, depending on the type of ring); 2) the number of logical rings that comprise a single physical ring, based on the total required capacity of the physical ring; 3) the identification of each wire center and the nodes (other wire centers) to which it connects; 4) the distance between each wire center and the nodes to which it connects; 5) a list of the wire centers served by spurs and their associated spur distance; 6) a list of the wire centers where ring interconnection takes place; and 7) a list of the wire centers that serve as inter-ring-system connector nodes, and the distances associated with the ring connectors. In addition to the ring distance associated with each wire center, several ring parameters are aggregated for the study area as a whole. These include: 1) the total number of ring interconnections; 2) the total number of inter-ring-system connectors; 4) the total inter-ring-system connector distance; and 5) the total number of rings that include the tandem as a node. The Model equips each ring connector with the maximum rate SONET equipment (OC-48) in current common use by the LECs. Spur terminals operate at OC-3, a sufficient capacity given the 5,000 line threshold for the smaller wire centers being placed on a spur.

Once all of this information has been computed, the Model calculates the required investment in 1) cable and structure, and 2) ring terminal equipment located in the wire centers that are connected to the rings. The Model determines the total interoffice distances, considering rings, connectors, and point-to-point links for small offices. It calculates the costs of installed cable and structure based on user-definable inputs for cable costs, structure costs and configurations (*e.g.*, pullbox spacing), the mix of different structure types, and the amount of structure sharing between interoffice and feeder plant. To account for this structure sharing, the Model determines the smaller of the investment in feeder and the investment in interoffice facilities, and applies the user-specified sharing percentage to the smaller value to calculate the amount of shared structure investment. The Model then subtracts this amount of investment from both the interoffice and feeder investment, and reassigns it back to feeder and interoffice according to the relative amounts of remaining investment in feeder versus interoffice. It does this separately for underground, buried, and aerial structure.

The Model calculates the terminal cost required in each wire center on a ring based on the computed capacity of the ring and various user inputs for the cost of terminal equipment of the required capacity. HM 5.3 avoids excess investment in small wire centers residing on high-capacity (multiple OC-48) rings. For example, a 200-line wire center residing on a 16-node ring with many large wire centers will be equipped with the terminal equipment that is appropriate to meet its capacity requirements. The Model provides for sufficient cross-connect capacity on the ring to ensure these offices can still communicate with the other offices on the ring.

Interexchange access facilities require additional treatment. Because interexchange carrier POPs are typically not located on LEC fiber rings, dedicated entrance facilities must be provided. The Model assumes the cost of entrance facilities operating at various bit rates to be the same as the cost of loops of the corresponding bit rate.

10.3.3. Tandem Switch Investments

Tandem and operator tandem switching investments are computed according to assumptions contained in an AT&T cost study.⁵² The investment calculation assigns a price for switch “common equipment,” switching matrix and control structure, and adds to these amounts the investment in trunk interfaces. The numbers of trunks and their related investments are derived from the transport calculations described above.

The Model scales the investment in tandem switch common equipment according to the total number of tandem trunks computed for the study area. By doing so, it avoids equipping maximum-capacity tandems whenever a LATA is served by multiple tandems. The calculations also recognize that a significant fraction of tandems are “Class 4/5” offices that serve both tandem and end office functions. The amount of sharing assumed is user-adjustable, with a default value of 40%. Tandem wire center calculations assume the maximum switch room size, and further assume the tandem will reside in a wire center that contains at least one end office switch.

10.3.4. Signaling Network Investments

The Module computes signaling link investment for “A” links between STPs and end offices, tandems, and SCPs; “C links” between the STPs in a mated pair; and “D link” segments connecting the STPs of different carrier's networks. All links are assumed to be DS-0n links carried in DS-1 circuits dedicated to signaling traffic over the interoffice rings discussed previously.

The Model always equips at least two signaling links per switch and computes required SS7 message traffic according to the call type and traffic assumptions described earlier to determine whether additional A-links are necessary to handle the message traffic. User inputs define the number and length of ISDN User Part (“ISUP”) messages required to set up

⁵² AT&T, “An Updated Study of AT&T’s Competitors’ Capacity to Absorb Rapid Demand Growth,” filed with the FCC in CC Docket No. 79-252, April 24, 1995, and its predecessor, “A Study of AT&T’s Competitors’ Capacity to Absorb Rapid Demand Growth,” June 20, 1990. (“AT&T Capacity Cost Study”).

interoffice calls. Default values are six messages per interoffice call attempt, with twenty-five octets per message.

Other inputs define the number and length of Transaction Capabilities Application Part (“TCAP”) messages required for database lookups, along with the percentage of calls requiring TCAP message generation. Default values, obtained from the AT&T Capacity Cost Study, are two messages per transaction, at 100 octets per message, and 10% of all calls requiring TCAP generation. If the message traffic from a given switch exceeds the link capacity (also user-adjustable and set at 56 kbps and 40% occupancy as default values), the Model will add links to carry the computed message load. The total link investment calculation includes all the links required by a given switch.

STP capacity is expressed as the total number of signaling links each STP in a mated pair can terminate (default value is 720 with an 80% fill factor). The maximum investment per STP pair is set at \$5 million, and may be changed by the user. This default value derives from the AT&T Capacity Cost Study. The minimum investment is \$224,000; this value derives from a BellSouth *ex parte* presentation to the FCC in the USF Inputs proceeding.⁵³ Both default values may be changed by the user. The STP calculation scales this investment based on the number of links the Model requires to be engineered for the study area.

SCP investment is expressed in terms of dollars of investment per transaction per second. The transaction calculation is based on the fraction of calls requiring TCAP message generation. The total TCAP message rate in each LATA is then used to determine the total SCP investment. The default SCP investment is \$2,444 per transaction per second, based on the BellSouth *ex parte* presentation to the FCC.

10.3.5. Operator Systems Investments

Operator tandem and trunk requirements are based on the operator traffic fraction inserted by the user into the Model and on the overall user-adjustable maximum trunk occupancy value (default of 27.5 CCS) discussed above. Operator tandem investment assumptions are the same as for local tandems.

Operator positions are assumed to be based on current workstation technology. The default operator position investment is \$6,400. The Model includes assumptions for maximum operator “occupancy” expressed in CCS. The default assumption is that each position supports 32 CCS of traffic in the busy hour. Also, because many operator services traditionally handled by human operators may now be served by announcement sets and voice response systems, the Model includes a “human intervention” factor that reflects the fraction of calls that require human operator assistance. The default factor is 10, which is believed to be a conservative estimate. (A factor of 10 implies that one out of ten calls will require human intervention).

⁵³ *Ex parte* letter from Whit Jordan, Vice President of Federal Regulatory for BellSouth to the FCC in CC Dockets 96-45 and 97-160, dated August 7, 1998.

11. Expense Modules

11.1. Overview

HM 5.3 contains two Expense Modules in order to allow the user to display results by line density range and by wire center. In the Wire Center Expense Module, the capability exists to flexibly aggregate wire center cost results into various wire center groupings or “zones.” Each of the Expense Modules receive from the other modules all the network investments, by type of network component necessary to provide UNEs (including the new UNEs considered by HM 5.3: non-switched voice-grade and DS-0, switched and non-switched DS-1, ISDN, and DS-3), basic universal service and network interconnection and carrier access in each study area. The Expense Modules estimate the capital carrying costs associated with the investments as well as the costs of operating this network. Capital carrying costs include depreciation, return on the debt and equity investment required to build the network and a gross-up to pay for the income taxes imposed on equity returns. Network-related operating expenses include maintenance and network operations. Non-network-related operating expenses include customer operations expenses, general support expenses, other taxes, uncollectibles and variable overhead expenses. Figure 10 depicts the flow of calculations performed by the expense modules. The modules require a number of user inputs.

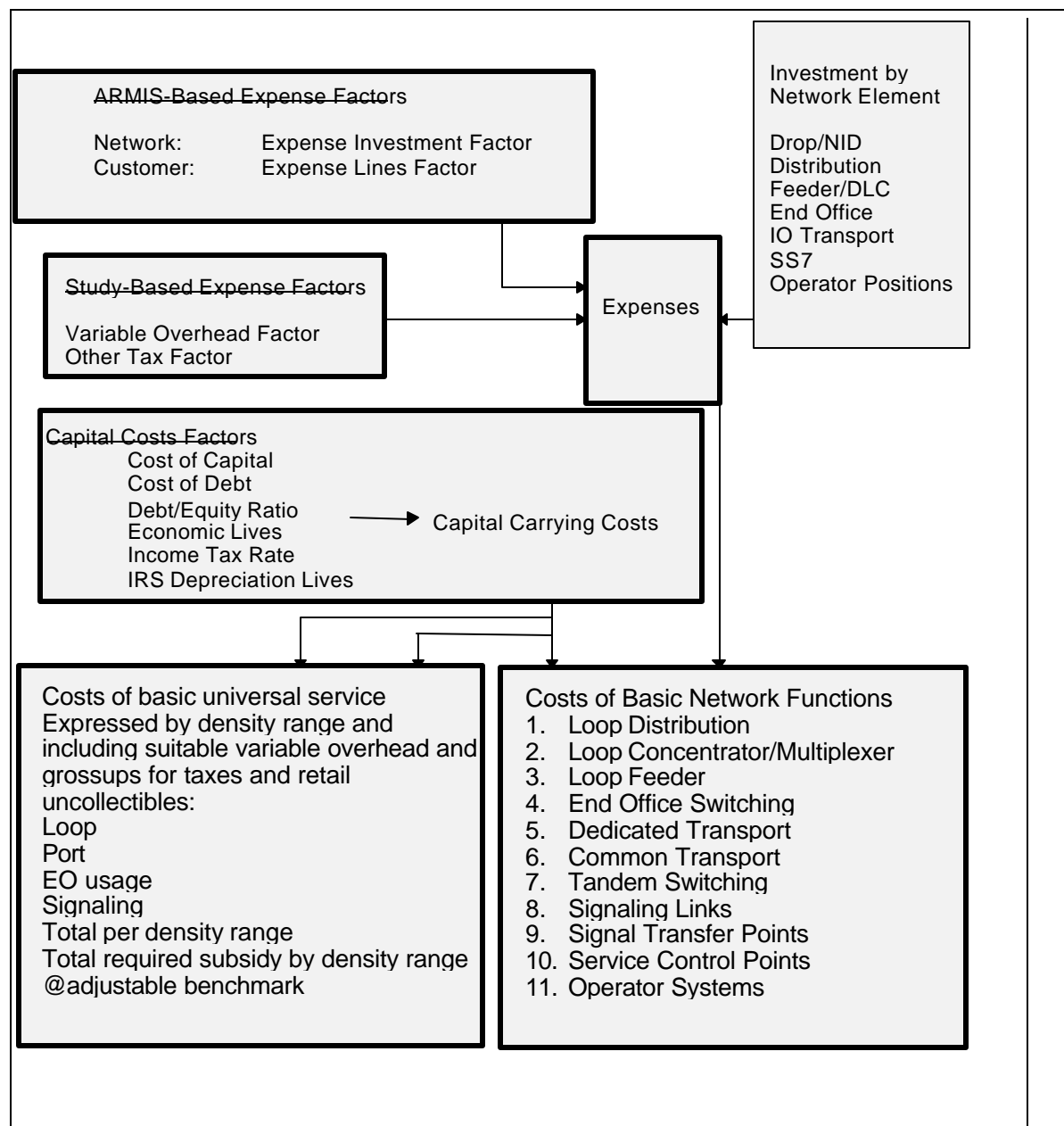


Figure 10 Expense Module Flows

11.2. Capital Carrying Costs

Estimating forward-looking capital carrying costs is relatively straightforward. The FCC and state regulators have developed standard practices that are based on sound economics to perform this function. The Model calculates annual capital cost for each UNE component based on:

- a) Plant investment for that component from the relevant investment modules,
- b) The return to the net asset;

- c) An income tax gross-up on the equity component of the return; and
- d) The expected service life adjusted for net salvage value (depreciation) of the component.

Each of these elements of the capital carrying cost estimate is discussed below.

The weighted average cost of capital (return) is built up from several user-adjustable components. These include the return on equity, the cost of debt, and the debt percentage. The equity component of the return is subject to federal, state and local income tax. As a consequence, it is necessary to increase the pre-tax return dollars, so that the after-tax return is equal to the assumed cost of capital. The effective income tax rate specific to the company being studied is a user-adjustable input to the Model.

The Model now accounts for the effect of the accelerated depreciation rates allowed by the IRS for income tax computation purposes. IRS accelerated depreciation has the effect of reducing the present value of tax payments by deferring them to later years, which in turn reduces the levelized overall cost of capital. The IRSDeprec worksheet in the Expense Module is a table of IRS Modified Accelerated Cost Recovery System (“MACRS”) depreciation schedules for each of seven tax categories of plant. These were applied to the appropriate Model investments for purposes of calculating the appropriate tax depreciation.⁵⁴

The Model now allows regulatory depreciation to be calculated using either straight-line/square life or the Equal Life Group (“ELG”) depreciation method used by the FCC. ELG, which is implemented with bell-shaped standard survival curves, is the default option.⁵⁵ Annual return on average net investment, plus tax gross-up and depreciation expenses are calculated yearly for each of the 23 categories of equipment used in the Model. Values for economic life and net salvage value for each of the 23 equipment categories are user adjustable inputs to the Model, and are specific to the jurisdiction and company in question. They are typically set to the values determined by the three-way meetings (FCC, State Commission, ILEC).

Return is earned only on net capital. Because depreciation results in a declining value of plant in each year, the return amount declines over the service life of the plant. To ensure that a meaningful long-run capital carrying cost is calculated, the return amount is levelized over the assumed life of the investment using net present value factors. An annual capital carrying charge factor is developed for each plant category in the KCCFactor worksheet in the Expense Module. The Model calculates a separate capital carrying charge factor for each

⁵⁴ Because the HAI expense module assumes that the entire network is in place at time 0, the MACRS depreciation schedules had to be adjusted to conform to this convention. This was done by using Table A-2 from IRS Pub 946 “3-, 5-, 7-, 10-, 15-, and 20-Year Property Mid-Quarter Convention Placed in Service in First Quarter.” Depreciation rates from the last period (which represent a half quarter of depreciation) were added to the first period, and the last period was removed. For 31.5-year property, an adjusted version of Table A-7 was used.

⁵⁵ The CGSCurves worksheet in the expense module applies the bell-shaped standard survival curves to investments.

combination of regulatory depreciation method (square life/ELG) and tax depreciation method (straight line/accelerated).

Given the ability to use alternative regulatory and tax depreciation methods, the user now has several options. Square life regulatory depreciation of assets can be selected along with straight line or IRS accelerated depreciation for income tax purposes. Alternatively, ELG regulatory depreciation can be selected with either straight line or IRS accelerated depreciation for income tax purposes. The KF worksheet in the expense module collects all of the capital carrying cost information from the other development sheets and shows the effect of using these alternative methods. As noted above, ELG regulatory depreciation and IRS accelerated depreciation for tax purposes are the default options.

11.3. Operating Expenses

Estimating ILEC operating costs is more difficult than estimating capital costs. Few publicly available forward-looking cost studies are available from the ILECs. Consequently, many of the operating cost estimates developed here must rely on relationships to and within historical ILEC cost information as a point of departure for estimating forward-looking operating costs. While certain of these costs are closely linked to the number of lines provided by the ILEC, other categories of operating expenses are related more closely to the levels of their related investments. For this reason, the Expense Module develops factors for numerous expense categories and applies these factors both against investment levels and demand quantities (as appropriate) generated by previous modules.

The HM 5.3 expense modules include a USOA Detail worksheet that breaks out the HM 5.3 investments and expense results by Part 32 account for comparison with embedded ARMIS data. There is also an Expense Assignment worksheet that allows the user to vary the proportion of total expenses that are assigned to loop network elements (*i.e.*, NID, distribution, concentration and feeder) based on relative number of lines versus based on the relative amount of direct expenses (direct expenses include maintenance expenses and capital carrying costs for specific network elements).

The operating expenses can be divided into two categories – network related and non-network related. Network-related expenses include the cost of operating and maintaining the network, while non-network expenses include customer operations and variable overhead.

The cost categories contained in the FCC's USOA are used as the point of departure for estimating the operating expenses associated with providing UNEs, basic universal service and carrier access and interconnection. The major expense categories in the USOA are Plant Specific Operations Expense, Plant Non-Specific Operations Expense, Customer Operations Expense and Corporate Operations Expense. The first two are network-related, the latter two are not.

Tier 1 ILECs report historical expense information for each of these major categories through the FCC's ARMIS program. Other ILECs typically report equivalent information in a "Form M" report they file with their state commissions. The ARMIS data used in the Expense Module include investment and operating expenses and revenues for a given local carrier and

state. As noted above, forward-looking expense information for these categories is not publicly available from the ILECs. A variety of approaches are used to estimate the forward-looking expenses.

11.3.1. Network-Related Expenses

The two major categories under which network-related expenses are reported by the ILECs are plant-specific operations expenses and non plant-specific operations expenses. The plant-specific expenses are primarily maintenance expenses. Certain expenses, particularly those for network maintenance, are functions of their associated capital investments. If the user takes no action to the contrary, the Expense Module estimates the ratios of expense to investment (“E to I” ratios) from historic expense ratios calculated from balance sheet and expense account information reported in each carrier’s ARMIS report. However, as discussed in the next paragraph, the user can override this nominal calculation by entering alternative values in the “Actuals” worksheet of the Expense Modules. These expense ratios are applied to the investments developed by the Distribution, Feeder, and Switching and Interoffice Modules to derive associated operating expense amounts. The ARMIS information used to perform these functions is contained in the “ARMIS Inputs” worksheet, and the expense factors are computed in the “Actuals” worksheet of the Expense Module.

Both the wire center expense module and the density zone expense module will accept user-defined expense ratios for plant-related investment categories. The modules calculate the ARMIS-based expense ratios in column F of the “Actuals” worksheet; however, if the user enters a value in column H,⁵⁶ that value will be used by the Model in all expense calculations related to the investment category for which a value was entered. If the user does not enter a value in column H for any plant category, the ARMIS-based calculated factor will be used.

Other expenses, such as network operations, vary more directly with the number of UNEs provisioned by the ILEC rather than its capital investment. Thus, expenses for these elements are calculated in proportion to the number of UNEs supported.

The Expense Module estimates direct network-related expenses for all of the UNEs. These operating expenses are added to the annual capital carrying cost to determine the total expenses associated with each UNE. Each network-related expense is described below:

- a) *Network Support* – This category includes the expenses associated with motor vehicles, aircraft, special purpose vehicles, garage and other work equipment. These costs are part of the General Support category of costs, and are calculated as described in Section 11.3.2.
- b) *Central Office Switching* – This includes end office and tandem switching as well as equipment expenses.

⁵⁶ In the case of aerial, underground, and buried cable, the user must set factors separately for fiber and copper cable in Columns I and J, respectively. The model will use the appropriate column as it calculates expenses for each kind of cable.

- c) *Central Office Transmission* – This includes circuit equipment expenses applied to transport investment.
- d) *Cable and Wire* – This category includes expenses associated with poles, aerial cable, underground/buried cable and conduit systems. This expense varies directly with capital investment. . In HM 5.3, users can manually input separate copper and fiber expense factors in place of the default cable maintenance factor.
- e) *Network Operations* – The Network Operations category includes power, provisioning, engineering and network administration expenses.

The Expense Module computes a forward-looking amount of Network Operations expenses assigned to each category of service it costs as follows. First, the module calculates the ratio of ARMIS network operations costs to the total plant in service (“TPIS”) reported in ARMIS. This ratio is then multiplied by the investment calculated for each UNE to determine a preliminary amount of network operations expense for that UNE. The resulting preliminary network operations expense for each UNE is then multiplied by a user-adjustable efficiency factor to arrive at the final network operations expense to be assigned to the UNE. The efficiency factor can be set to a value that reflects expected gains in network operations efficiency. There have been significant reductions in per-line network operations over the past several years, presumably due to the fact that the set of activities classified as network operations has been and continues to be particularly subject to the beneficial effects of new operations technology and other productivity factors. The efficiency factor is currently set to 1.0 in the Model.

Once the total network operations expense assigned to a given service category is determined, the total expense is assigned equally to each instance of that service by dividing the total amount by the number of instances of the service in question. For instance, if there are 15 million POTS lines, and the above process results in an annual network operations expense assigned to POTS of \$270 million, then the model assigns \$18 per year ($\$270/15$) to each POTS line. This process is carried out for each category of service for which the Model develops costs.

11.3.2. Non-Network Related Expenses

The Expense Module assigns non-network related expenses to each density range or wire center (depending on the unit of analysis chosen) based on the proportion of direct expenses (network expenses and capital carrying costs) for that unit of analysis to total expenses in each category. Each of these expenses is described below:

- a) *Variable Support* – The Model, as a long run cost model, recognizes that, in addition to the minuscule amount of true fixed or common overhead, there are General and Administrative (“G&A”) expenses that vary with the size of the firm.⁵⁷ For example, if an ILEC did not provide loops, it would be a much smaller company, and would

⁵⁷ At least one ILEC economist has acknowledged this cost structure for long-run overhead costs. See, Aron, Debra J., “Proper Recovery of Incremental Overheads For Local Number Portability,” Ameritech Petition for Expedited Reconsideration and Clarification, CC Docket No. 95-116, July 29, 1998.

therefore have lower G&A costs. Also large firms have greater variable support expenses than smaller firms. Therefore, the Model includes a forward-looking estimate of G&A or “variable support” costs (including common, fixed overhead) in the TSLRIC estimates for each network element. These variable support expenses may be described as “economic overhead” associated with production of the modeled network elements and services. The overhead factor is a user-adjustable input to the Model.

- b) *General Support Equipment* – The module calculates investments for furniture, office equipment, general purpose computers, buildings, motor vehicles, garage work equipment, and other work equipment. The Model uses actual company investments reported in ARMIS to determine the ratio of investments in the above categories to total investment. The ratio is then multiplied by the network investment estimated by the Model to produce the investment in general support equipment. The recurring costs – capital carrying costs and operating expenses – of these items are then calculated from the investments in the same fashion as the recurring costs for other network components. A portion of general support costs is assigned to customer operations and corporate operations according to the proportion of operating expense in these categories to total operating expense reported in the ARMIS data. The remainder of costs is then classified as network support and assigned directly to UNEs based on their relative direct costs.
- c) *Uncollectible Revenues* – Revenues are used to calculate the uncollectibles factor. This factor is a ratio of uncollectibles expense to adjusted net revenue. The Module computes both retail and wholesale uncollectibles factors, with the retail factor applied to basic local telephone service monthly costs and the wholesale factor used in the calculation of UNE costs.

In HM 5.3, users are alternatively able to enter per-line expenses for non-network-related expenses, as well as for network operations, rather than applying them as described above.

11.4. Expense Module Output

The Density Zone and Wire Center expense modules display results in a series of reports which depict detailed investments and expenses for each UNE for each density zone and wire center, summarized investments and expenses for all UNEs, unit costs by UNE and total annual and monthly network costs. In addition, the UNEs are used to estimate interexchange access costs in the Density Zone module. The two modules also calculate the cost of basic local service and universal service support across density zones and wire centers, respectively.

11.4.1. UNE Outputs (Unit Cost Sheet)

The HAI Model produces cost estimates for Unbundled Network Elements that are the building blocks for all network services. The POTS UNEs are described below.

-
- a) *Network Interface Device* – This is the equipment used to terminate a line at a subscriber’s premise. It contains connector blocks and over-voltage protection.
 - b) *Loop Distribution* – The individual communications channel to the customer premises originating at the SAI and terminating at the customer’s premises. In the HAI Model, this UNE also includes the investments in NID, drop and terminal/splice.
 - c) *Loop Concentrator/Multiplexer* – The DLC remote terminal at which individual subscriber traffic is multiplexed and connected to loop distribution for termination at the customer’s premises. The HAI Model includes DLC equipment and SAI investment in this UNE.
 - d) *Loop Feeder* – The facilities on which subscriber traffic is carried from the line side of the end office switch to the Loop Concentration facility. The UNE includes copper feeder and fiber feeder cable, plus associated structure investments (poles, conduit, etc.)
 - e) *End Office Switching* – The facility connecting lines to lines or lines to trunks. The end office represents the first point of switching. As modeled in the HAI Model, this UNE includes the end office switching machine investments and associated wire center costs, including distributing frames, power and land and building investments.
 - f) *Operator Systems* – The systems that process and record special toll calls, public telephone toll calls and other types of calls requiring operator assistance, as well as Directory Assistance. The investments identified in the HAI Model for the Operator Systems UNE include the operator position equipment, operator tandem (including required subscriber databases), wire center and operator trunks.
 - g) *Common Transport* – A switched trunk between two switching systems on which traffic is commingled to include LEC traffic as well as traffic to and from multiple IXCs. These trunks connect end offices to tandem switches. Results are provided on a per-minute basis for the central office terminating equipment associated with the UNE, and a per-minute per mile basis for the transmission medium.
 - h) *Dedicated Transport* – The full-period, bandwidth-specific interoffice transmission path between LEC wire centers and an IXC POP (or other off-network location). It provides the ability to send individual and/or multiplexed switched and special services circuits between switches. Results are provided on a per-minute basis and per-channel basis for the central office terminating equipment associated with the UNE, and on a per-minute and per-channel basis per mile for the transmission medium.
 - i) *Direct Transport* – A switched trunk between two LEC end offices. Results are provided on a per-minute basis for the central office terminating equipment associated with the UNE, and on a per-minute per-mile basis for the transmission medium.

- j) *Tandem Switching* – The facility that provides the function of connecting trunks to trunks for the purpose of completing inter-switch calls. Similar types of investments as are included in the End Office Switching UNE are also reflected in the Tandem Switching UNE.
- k) *Signaling Links* – Transmission facilities in a signaling network that carry all out-of-band signaling traffic between end office and tandem switches and STPs, between STPs, and between STPs and SCPs. Signaling link investment is developed by the HAI Model and assigned to this UNE.
- l) *Signal Transfer Point* – This facility provides the function of routing TCAP and ISUP messages between network nodes (end offices, tandems and SCPs). The Model estimates STP investment and assigns it to this UNE.
- m) *Service Control Point* – The node in the signaling network to which requests for service handling information (*e.g.*, translations for local number portability) are directed and processed. The SCP contains service logic and customer specific information required to process individual requests. Estimated SCP investment is assigned to this UNE.

HM 5.3 also estimates and can report, if appropriate for the jurisdiction in question, monthly costs associated with the following additional loop types:

- a) Various non-switched voice-grade analog and DS-0 digital;
- b) Switched and non-switched DS-1;
- c) ISDN;
- d) DS-3; and
- e) ADSL.

The model also reports sub-loop costs for DS-1 and DS-3 loops.

11.4.2. Grouping Wire Center Results

The wire center expense module has the capability to aggregate wire center cost results into various wire center groups or “zones”. The WCWeights worksheet is used to gather cost results from the Investment Inputs worksheet and to calculate line weighting factors for each wire center. A numeric category designation for each wire center may also be manually entered. If the user enters a value between 1 and 10 in column B of the WC Weights worksheet, that value will be used to form a category of all wire centers having the same designation. If the user does not enter a value, the module will use a table of cost breakpoints defined in the Zone Summary worksheet to group wire centers into categories. The user may define any set of values for the cost breakpoints; the referenced cost is the loop cost, including NID, distribution, SAI, and feeder. The module will then use the defined breakpoints to form categories of wire centers based on monthly loop cost. The results of the

aggregation as well as the number of lines in each category are shown in the Zone Summary worksheet.

11.4.3. Company-Specific Rate Sheet

For a given jurisdiction, a UNE rate sheet specific to the jurisdiction and company being studied can be added to the Density Zone expense module. This sheet can be used to estimate UNE rates in addition to those identified in Section 11.4.1. Some of the UNE rates produced in proceedings where HM 5.3 has been utilized so far include:

- a) Four-wire loops;
- b) Coin (public phone) lines;
- c) Multiplexing:
 - DS-0 to DS-1
 - DS-1 to DS-3
 - DS1 to OC-3
 - DS-3 to OC-3
 - EC-1 to OC-3
 - DS-3 to OC-12
 - EC-1 and STS-1 to OC-12
- g) Switching
 - DID port
 - ISDN BRI and PRI ports
 - DS-1 port
- h) Entrance facilities
 - Voice Grade
 - DS-1
 - DS-3
- i) Miscellaneous UNEs
 - Dark Fiber
 - Interoffice, per mile
 - Loop, per mile
 - Sub-Loop Feeder, per mile
 - Cross Connection
 - IOF to CO
 - Feeder to CO
 - At RT

To the extent that certain UNEs are deaveraged by wire center zone, outputs of both the density zone and wire center expense modules are required. Those calculations are normally done outside the model, obtaining results from the two modules as appropriate, rather than attempting to link the density zone and wire center expense module outputs.

12. Summary

In its Release 5.3 formulation, the HAI Model reliably and consistently estimates the forward-looking economic cost of unbundled local exchange network elements, as well as carrier access and interconnection and the forward-looking economic cost of basic local telephone service for universal service funding purposes. It uses the most accurate and granular data on actual customer locations available today, and it overlays its loop distribution network on these actual customer locations.

Because all of these calculations are performed in adherence to TELRIC/TSLRIC principles, HAI Model cost estimates provide the most accurate basis for the efficient pricing of unbundled network elements carrier access and interconnection and the calculation of efficient universal service funding requirements.

Like its predecessors, the HM 5.3 methodology is open to public scrutiny. To the extent possible, it uses public source data for its inputs. When documented public source data is lacking, these default input values represent the developers' best judgments of efficient, forward-looking engineering and economic practices. In addition, because these inputs are adjustable users of HM 5.3 can use the Model's automated interface to model directly and simply any desired alternative.

Appendix A

History of the Hatfield/HAI Model

Appendix B

General Rules Governing the Creation of the HM 5.3 Distance Files