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 6.2.5, below, the HM 5.0 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 copper distribution cables. Appendix B includes detailed lists of the Hatfield Model structure default values for aerial, buried and underground plant.

6.2.2. Terrain and Its Impact on Placement Costs

HM 5.0 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 serving area is assumed to have the terrain characteristics of the CBG in which it predominately falls.[37]

If the rock depth in a serving area is less than a user-definable rock depth threshold, a rocky placement multiplier increases structure investment in poles, conduit placement, and trenching, because it is more difficult to bury cable in rock than in soil.[38] If bedrock does not exist within the placement depth, then the surface soil texture is examined to determine if soil can be plowed, or if more expensive placement techniques must be used.

[37] 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.

[38] The Hatfield 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.

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.[39]

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.

6.2.3. Structure Sharing

Outside plant structures are generally shared by LECs, CATV operators, electric utilities, and others including competitive access providers ("CAPs") and IXCs. 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 these users. Furthermore, manholes may be shared by all low voltage utilities as well. The Hatfield model 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 Hatfield Model reflect best forward-looking, economic practices for the various utilities involved.

6.2.4. Lines Density Considerations

A number of parameters, such as the fill factors for distribution and feeder copper cable and the mixture of underground, buried, and aerial plant, are dependent on line density of the serving area. The line density is defined as the total number of subscriber access lines per square mile. While entire serving areas are associated with a given density zone for purposes of accumulating density zone results, HM 5.0 makes a separate density zone calculation for the main cluster and the outlier clusters when it is determining which density-zone-dependent factors to use in a calculation. In HM 5.0, as in HM 4.0, line density is broken down into nine different density ranges.

[39] 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.

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

6.2.5. Economic Adjustment of Structure Fractions

The HM 5.0 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. The user specifies nominal buried and aerial fractions, along with an "at risk" portion of the buried cable fraction that unfavorable cost conditions can cause to be shifted to aerial. The model calculates the relative costs of each type of 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. The model then adjusts the aerial fraction up or down (and buried fraction in inverse fashion) from its nominal default value by up to the full amount of "at risk" structure, depending on the degree of difference in the 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.

6.3. Distribution Module

6.3.1. Treatment of Main Clusters

HM 5.0 lays distribution plant directly over the identified locations of customer clusters. The basic distribution configuration employed by HM 5.0 for the main clusters is a "grid" topology, in which tapering backbone cables run in one direction, while branch cables emanating from the backbone run in the other direction. In HM 5.0, the backbone cable is assume to run north and south, while the branch cables run east and west. The backbone cables terminate one lot depth inside the north and south boundaries of the rectangle. The branch cables run to within one lot width of the east and west sides of the rectangle.

Main clusters with total areas less than 0.03 square miles and line densities greater than 30,000 lines per square mile are identified as consisting of high-rise buildings, and accorded special treatment appropriate for high rises.

This high-rise test identifies cases in which a serving area is very small, but its line density is so high as to be incompatible with any explanation other than vertical "stacking" of the customer locations. In such cases, the model 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.[40] The occupied building space in square feet is calculated as follows:

occupied space = 1,500 * # households + 200 * # employees.

For "regular" serving areas that do not meet the high-rise test, 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 PNR identifies the number of households located in various types of buildings. HM 5.0 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

[40] 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.

consequently 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 causes more lots to be assumed, and more distribution plant to be placed, than actually is necessary to serve this area.

Businesses are treated in a similar fashion, except that a check is made to ensure that business locations occupy at least enough area to account for 200 sq. ft per employee (the PNR database estimates both the number of businesses and number of employees in each serving area).

6.3.2. Treatment of Outlier Clusters

Outlier clusters, each consisting of one or more customer locations, are served in HM 5.0 by the nearest main cluster. A main cluster and its subtending outlier clusters together constitute a serving area.

Outliers are connected to the main cluster by 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 which in turn is connected directly to the main cluster or another outlier. Such connections are depicted in Figure 5. 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 to the first order outliers 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 a user-adjustable distance parameter whose default value is 18,000 feet, the road cable carries an ordinary analog voice signal, and is called "subscriber road cable." If the farthest customer in an outlier is more than the default distance from the main cluster, or the outlier is a higher order outlier, the cable carries a digital T1 format signal to a remote T1 terminal at the centroid of the outlier, and is served by "T1 road cable." From the T1 RT, copper cables carrying analog signals extend the remainder of the way to the customer locations within the outlier.

A T1 road cable contains copper pairs, and supports T1 signals used to provide digital connections between the fiber DLC remote terminals located at the centroid of the main cluster and subsidiary remote T1 terminals located at the centroid of each outlier cluster. The model assumes conventional T1 transmission with a user-adjustable 32 dB repeater spacing.

In HM 5.0, the cables serving subscribers from the remote terminals are assumed to be different than those that carry the T1 signals to the remote terminals. The total investment calculated for the T1 system includes the cost of the T1 interfaces in the main cluster's DLC remote terminal.

6.3.3. 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 a drop cable containing several wire pairs from the distribution cable to an aerial or buried drop to the NID located on the wall of the premises.

6.3.4. Investment Cap to Reflect Potential Wireless Technologies

As requested in the FCC's FNPRM, the HM 5.0 permits the specification of a user-adjustable cap on the model's relevant wireline investments to reflect potentially more economical wireless distribution technologies.[41] In the HM 5.0, this cap, if invoked by the user, is implemented by placing a ceiling on the per-line investments computed in the Distribution module (i.e., NID, drop, terminal and splice, distribution cable and structure, SAI, and DLC RT) that would be replaced by the wireless system.[42]

The optional cap calculation considers the cost of two different wireless systems: a "point-point" system serving customers on a one-one basis, and a "broadcast" system serving a number of customers from a shared base station. The point-point cost is assumed to be a fixed amount per line served; the broadcast system cost is structured as a fixed base station cost serving up to a given maximum number of customers, with the cost of the base station distributed among the number of customers that use it, plus a per-line cost of the radio terminal equipment at each customers' premises. Generally, the broadcast system is more expensive than the point-point system for a few lines in a serving area, but less expensive if the system is loaded to a substantial portion of its maximum capacity. The Model compares the cost of the two wireless systems to each other for a given serving area, then compares the cost of the lower-cost system to the wireline cost. If the most economical wireless system's cost is lower, the Model zeroes out the cost of the wireline distribution components for that serving area, and substitutes the cost of the wireless distribution system, while retaining the feeder portion of the wireline network.

6.3.5. 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, terminating at a DLC RT and adjacent SAI. Copper distribution cable is used beyond that point. The decision whether to use fiber feeder depends on whether any of the following conditions are met.

[41] It is unclear whether such systems exist, whether their costs can be modeled accurately across all demographic and terrain situations, and whether these systems can meet the FCC's criteria for supported universal service.

[42] It is assumed that the cost of the remote terminal electronics for the fiber feeder facilities serving the wireless radio sites would be included in the wireless system cost.

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 is 9,000 ft.

b) A life-cycle cost analysis of fiber versus copper feeder on the route shows that fiber is more economical.

c) The longest distribution cable run from the wire center to the farthest corner of a main cluster is greater than a user-input threshold distance called the Local RT (per cluster) Thresholds - Maximum Total Distance, whose default value is 18,000 ft.

d) There is at least one outlier cluster subtending the main cluster.

e) The wireless investment cap is invoked and leads to the conclusion that one of the two wireless systems is the least-cost solution for the serving area.[43],

6.3.6. "Steering" Feeder Routes

In HM 5.0, 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 "turn off" feeder route steering and have the Module calculate feeder distances using "right angle routing" in the four cardinal compass point directions -- as employed in HM 4.0.

6.3.7. Calculation of Distribution Investments

The model uses the customer location and cluster data, including cluster sizes and locations, number of lines, and lines density; and applies these demographic and architectural considerations to determine the total distribution distances involved. It then estimates the investment in distribution cable, supporting structures, terminals and splices, drops, NIDs, and SAIs.

In calculating these investments, the model requires a number of 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

[43] When wireless is used, it is assumed that a minimum of four fibers must be used to connect the radio sites to the wire center.

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 difficult terrain characteristics that may increase installation costs.

Appendix B defines each user input and the default value(s) for that input as set by the model developers. The set of inputs pertinent to the distribution calculations are inputs B1 through B45, B58 through B69, and B180 (structure sharing), and B197 through B201 in Appendix B.

Three sets of the input parameters bear special attention. The first is the set of cable sizing factors appearing as item B18 in Appendix B. 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 75 lines and the sizing factor set by the model is 0.50, then the target cable size determined by the model is 75/0.5, or 150. However, cables are available only in discrete sizes, as shown in Item B9 in Appendix B. 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 75/200, or 0.375. Generally, the average achieved distribution fill is significantly less than is indicated by the raw cable sizing factors shown in Item B18. The Model outputs display this average actually achieved fill both at the SAI and at the MDF.

Second, as discussed earlier, the Hatfield Model assumes that forward-looking practices of efficient telephone companies and other utilities will involve substantial structure sharing. The default levels of structure sharing assumed in HM 5.0, stated as the percentage of total structure costs assigned to the telephone company, are shown in Item B180 of Appendix B. In HM 5.0, the amount of structure sharing depends both on the type of structure -- poles and trenching -- and the density zone. HM 5.0 assumes, conservatively, that there is no sharing of conduit in underground installations.

Finally, HM 5.0 offers an optional cap on distribution investment as discussed, above. This cap, enabled by Parameter B41, compares the total per-line wireline distribution costs for all distribution components to the cost of two types of wireless systems. One system's per-line cost is expressed by B42; the other system's cost is parameterized by a base station cost, B43, maximum customers served by a base station, B45, and per-line radio system equipment cost, B44.

6.3.8. 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 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 of the building. In such cases, the

SAI, located in the building, is significantly less expensive than the outdoor SAI. This type of interface consists of a plywood backboard and inexpensive "punch-down blocks," rather than the heavy steel weatherproof outside terminals found in less urban areas. HM 5.0 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 and the urban/non-urban characteristic of the serving area. The pertinent input parameter for the SAI is identified as B38 in Appendix B. It is the installed investment in an SAI, stated as 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.

A given serving area may be served by either fiber feeder or copper feeder. When fiber feeder is used, one of two types of DLC equipment is selected. The first is designated "TR-303 DLC."[44] The second is designated "Low Density" DLC (which is also TR-303 compliant). The choice between these two types is determined for each serving area. If the number of lines is below a threshold value, "low density" DLC is used; above that threshold, TR-303 DLC is assumed. The threshold is user-adjustable, with a default value of 480 lines.

The investment in DLC equipment, when it is used, is calculated in the Distribution Module. The parameters involved in this calculation are identified as Items B49 through B60 in Appendix B. For either type of DLC system, low density or TR-303, the investment is calculated based on user-adjustable amounts for site and powering (B58), for common equipment (B61), and for channel units (B62). Other inputs in the range of B59-B69 specify, for example, the number of fiber strands per RT, the maximum initial lines that can be served by the DLC, the number, size and additional common equipment requirement of additional line increments, and the capacity and cost of plug-in cards for POTS and coin service.

6.3.9. Calculation of Drop Investments

HM 5.0 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

[44] TR-303 (now GR-303; the term "TR-303" refers to earlier documents but is still commonly used in the industry) is a Bellcore requirements document dealing with interfacing a DLC system with an end office switch.

line total, and public lines, as well as to all households in multi-unit buildings containing five or more households.

6.4. Feeder Module

6.4.1. 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.

As seen earlier in Figure 1, feeder cable begins at the wire center and ends at the SAI located within each serving area. Figure 6 displays the basic feeder architecture assumed in the model. A key difference between HM 5.0 compared to HM 4.0, is that in HM 5.0 the unit of population served by a given feeder and subfeeder cable combination is the main cluster and its subtending outlier clusters, rather than a CBG. 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.

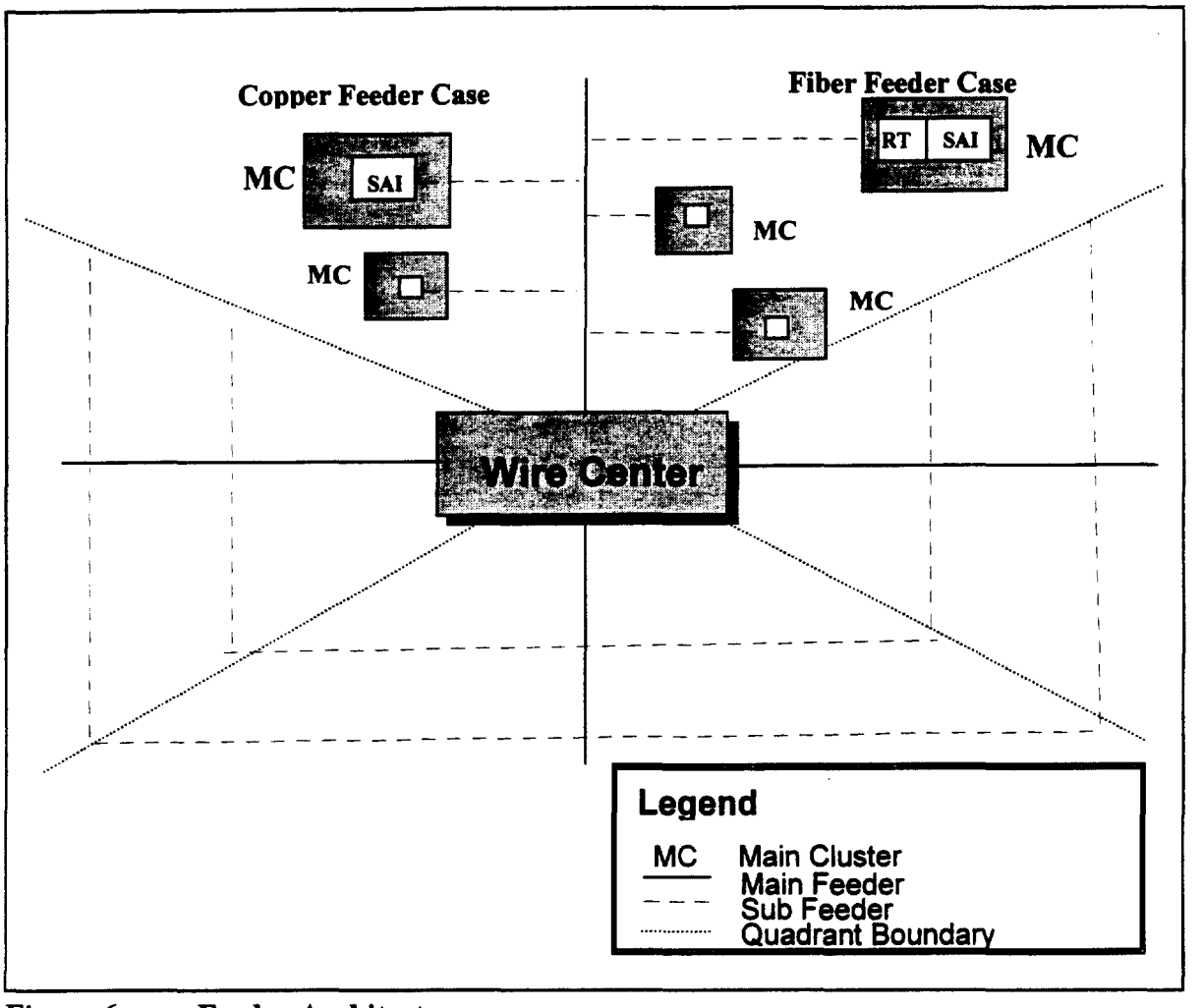

Figure 6 Feeder Architecture

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 ±45° with the main feeder routes.[45] 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 6.3.6 on 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

[45] Because HM 5.0 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.

size of a 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 assumed not, however, to share conduit when they do follow the same route.

6.4.2. Development of Feeder Investments

6.4.2.1. Calculating Main Feeder and Subfeeder Distances

As was shown in Figure 6, main feeder routes extend from the wire center in as many as four directions.[46] 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.[47]

The centers (centroids) of the main clusters may fall in any of the four feeder route quadrants. As shown in Figure 7, 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 5.0 applies straightforward trigonometric calculations to compute main feeder and subfeeder distances.[48] The model computes sufficient subfeeder cable to connect the main feeder route to the centroid of each main cluster. Copper feeder 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.

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

[47] 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.

[48] 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.

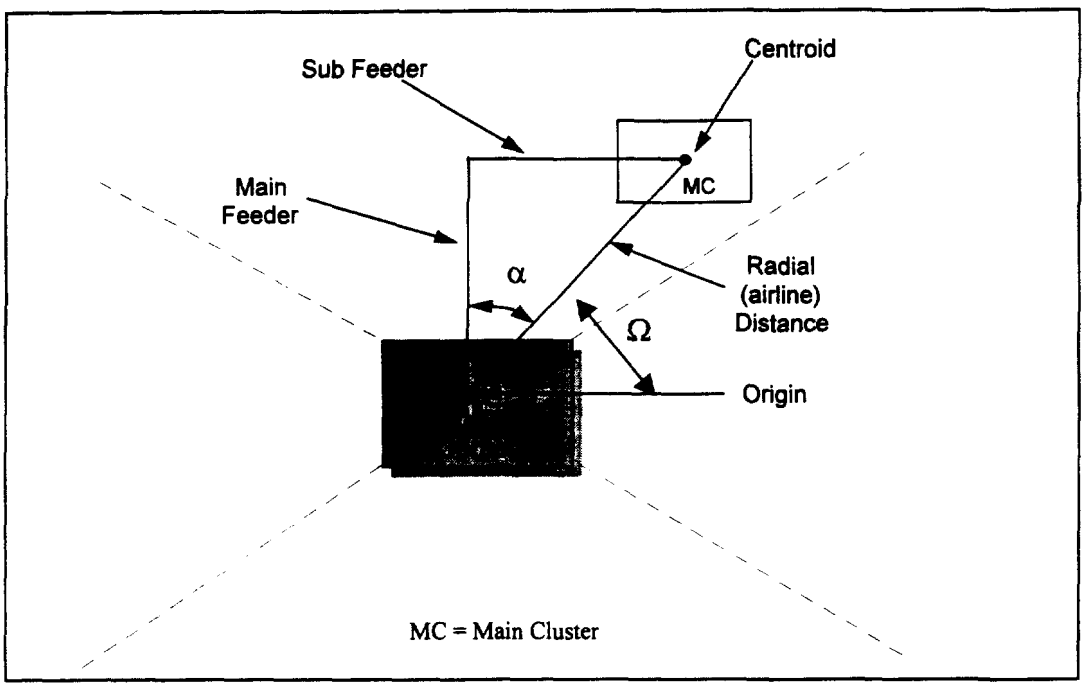

Figure 7 Determination of Cluster Locations and Distances

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 8 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 5.0 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 8, 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.

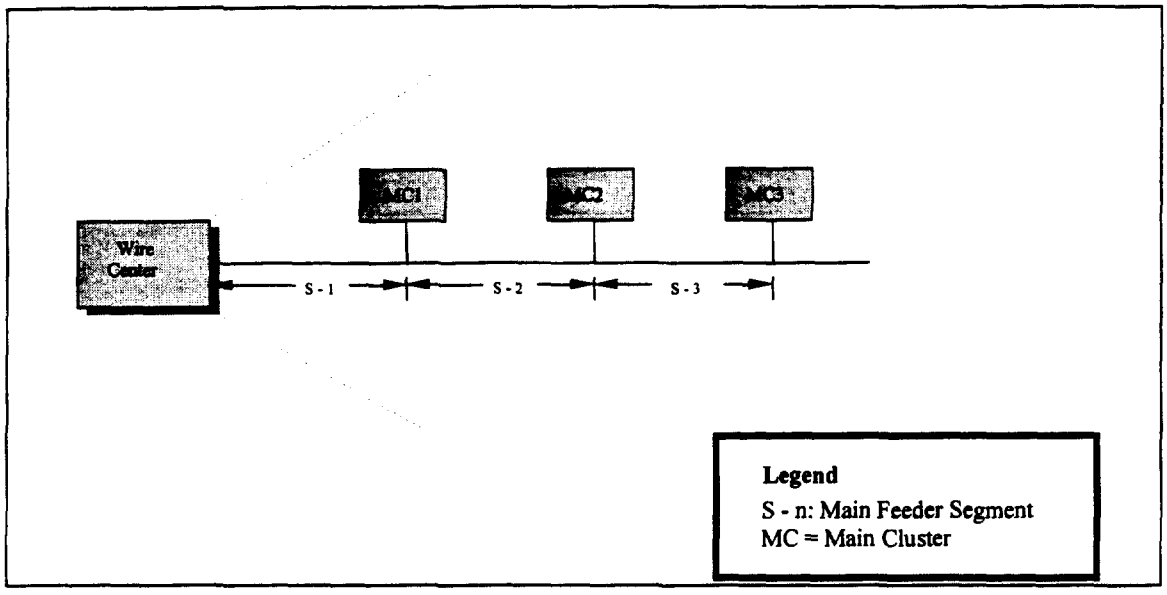

Figure 8 Main Feeder Segmentation

6.4.2.2. 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. 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. The strands per RT is a user-adjustable quantity, with a default value of four.[49] 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 a user-adjustable fiber strand fill factor into account.

6.4.2.3. Main Feeder Segment Sizing

[49] Because a DLC terminal requires a minimum of two fibers, one for each direction of transmission, the HM 5.0 default of four fibers provides complete redundancy.

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 8, 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.

6.4.2.4. 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.

6.4.2.5. Allocation 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.

6.4.2.6. Relevant Input Parameters

The set of user inputs and default values used in feeder calculations appear as inputs B46-B57 and B70-B71, described in Appendix B. The Feeder Module also calculates terrain impacts using inputs B20-B23. It allows the user to enable feeder steering and to set the route/air ratio using B26 and B27, respectively, and specifies excavation and restoration costs (jointly with distribution) using B197 through B201.

6.5. Switching and Interoffice Module

6.5.1. 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.

6.5.2. Description of Inputs and Assumptions

For the Switching and Interoffice Module to compute required switching and transmission investments, it requires as inputs total line counts for each wire center, distances between switches, and traffic peakedness assumptions, as well as inputs describing the distribution of total traffic among local intraoffice, local interoffice, intraLATA toll, interexchange access and operator services. This module takes as data inputs minutes and call attempts data from ARMIS, overall line counts obtained from the PNR 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.[50] It also requires many user-adjustable input assumptions. The set of user inputs and default values described in Appendix B and used in various phases of the module include:

- B74-B85 and B176-B177, for end office switching;
- B86-B91, for the wire center in which the end office switches and tandems are housed.
- B107-B130, for interoffice transmission terminals, media and structures;
- B143-B149, for tandem switching;
- B150-B163, for interoffice signaling; and
- B164-B167, for operator services and public telephone.

In addition, various traffic parameters are provided by inputs B92-B106, and miscellaneous parameters, such as the percent of traffic that requires operator assistance, percent that is interoffice, and percent that is routed directly between end offices, are provided by B131-B142. Finally, there is a set of inputs representing surrogate per-line investment in various switching and signaling equipment components by small

[50] HM 5.0 includes a set of interoffice distance calculations produced from wire center location information from Bellcore's Local Exchange Routing Guide (LERG) and from NECA Tariff 4.

independent telephone companies ("ICOs"), appearing as B168-B175. These are used in lieu of the results that would be calculated by the model for small ICOs with less than fifty wire centers, and better reflect these ICOs' typical practice of purchasing usage of such components from larger LECs.

Many of the calculations in the Switching and Interoffice module rely on traffic assumptions suggested in Bellcore documents.[51] 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 Dial Equipment Minutes ("DEM") information. Other inputs, which may be changed by the user, specify the fraction of traffic 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.

6.5.3. 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.

6.5.3.1. 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 CBGs 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 80,000 lines plus trunks. 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 no greater than a user-adjustable maximum size – that defaults to 80,000. If a wire center must serve, say, 90,000 ports, the model will compute the investment required for two 45,000-port switches.[52]

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 600,000 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

[51] Bell Communications Research, *LATA Switching Systems Generic Requirements, Section 17: Traffic Capacity and Environment*, TR-TSY-000517, Issue 3, March 1989.

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

varies between 1.2 and 2.0, depending on business line penetration,[53] 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 1,800,000 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 1. 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. A example could be heavy Internet access 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 5.0 is capable of engineering and costing end office switching systems comprised of explicit combinations of host, remote and standalone switches. But, because accurate data on the purchase prices of a portfolio of host, remote and standalone switches of varying capacities may not be available to the user, the HM 5.0 Switching and Interoffice Module defaults to computing end office switching investments using input values that average per-line investments over an efficient portfolio of host, remote, and standalone end office switches. Thus, the model's calculated end office switching investments and corresponding costs subsume either explicitly specified switch technologies on a wire center by wire center basis, or a blended overall efficient mixture of host, remote, and standalone switches within the modeled network.

If the user selects the explicit host, remote, standalone option, the user must specify for each wire center whether the housed switches are hosts or remotes, as well as assign correspondences between hosts and remotes. The model will designate all remaining wire centers as housing standalone switches. The model then places the hosts and their subtending remotes on SONET rings separate from the interoffice rings discussed below. Host switches may therefore appear on two rings -- their local host/remote ring, and (if the host directly serves more than the user-specified small office line limit) a larger interoffice ring interconnecting end offices and tandem locations.

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 connects ("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.

[53] 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.

End office switching investment calculations obtain common equipment and per-line investments for all three switch types from a user-adjustable investment table, which contains end office investment entries for both large and small LECs. Once the model computes investments for each switch in a host/remote system, it calculates the average investment per line for all of the lines in the system.

In more detail, the costing process is as follows. When the host-remote option is selected, switching curves that correspond to host, remote and standalone switches are used to determine the appropriate switching investment. These new switching curves incorporate a fixed plus variable investment per line for each switch type. It is recognized that there are large and small host and standalone switch technologies, and that remotes are available in multiple line sizes. Remote switches cause incremental variable investments primarily associated with the umbilical trunk ports necessary to carry traffic originating and terminating on the remote lines to the host switch. The user adjustable fixed and variable investments for host, standalone and remote switches have been scaled accordingly. In accordance with the FCC's Public Notice guidelines, the cost of an entire switching system consisting of a host and its associated remotes, is allocated evenly over all lines served by the host-remote configuration.

In default mode, the model assumes a blended configuration of switch technologies. The switching cost curves for this blended configuration were developed using typical per-line prices paid by BOCs, GTE and other independents as reported in the Northern Business Information ("NBI") publication, "U.S. Central Office Equipment Market: 1995 Database."[54] In addition, public line and switch data from the ARMIS 43-07 and responses to the USF NOI data request from 1994 are also employed.

The module uses a large telephone company switching investment curve that is based on the RBOC and GTE average switching costs per line reported in the NBI study. These two switching cost points were paired with the average sizes of current RBOC and GTE switches derived from 1995 ARMIS 43-07 line and switch data. A third cost point for large switches of 80,000 ports was developed from other industry sources. A logarithmic curve was then fit to these data using least-squares regression. As demonstrated in Figure 9, this functional form fits the data very closely.

The 1993 USF NOI (Universal Service Fund Notice of Inquiry) data was used to estimate an average line size for small LEC switches. A 1995 average line size was estimated by assuming the ICOs have experienced growth in average lines per switch between 1993 and 1995 similar to that experienced by GTE. The value on the large LEC curve corresponding to this 1995 small LEC average line size was compared to the ICO per line value from the NBI report. This produced a 1.7 factor which was applied to the constant term in the logarithmic functional form to produce a curve of identical shape, but shifted upward by $173 per line compared to the large LEC curve. The "slope" multiplier

[54] Northern Business Information study: U.S. Central Office Equipment Market -- 1995, McGraw-Hill, New York , 1996

(default of -14.922 in Figure 9) and the constant term (default of 242.73 in Figure 9 for large LECs and default of 416.11 for small ICOs) are user adjustable.

The per-line investment figures from the NBI study are for the entire end office switch, including trunk ports. The investment figures are then reduced by $16 per line to remove trunk port investment based on NBI's implicit line to trunk ratio of 6:1. The actual number of trunks per wire center is calculated in the transport calculation, and the port investments for these trunks are then added back into the switching investments. Figure 9 shows the switching investment curves for large LECs resulting from this methodology.

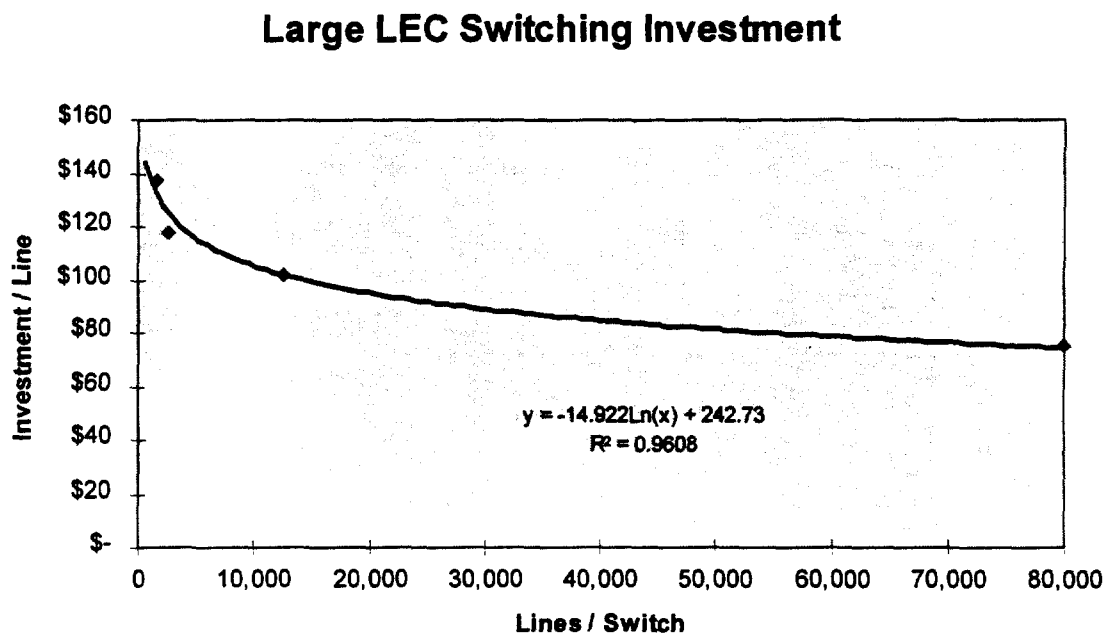

Figure 9 Blended Switch Investment Curve

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.

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.

6.5.3.2. 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 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 CCS). 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.

HM 5.0 assumes that, with some exceptions, all interoffice facilities take the form of a set of interconnected Synchronous Optical Network (SONET) fiber rings. It uses a program written in Visual Basic for Applications (VBA) and the wire center locations specified as V&H coordinates to compute a set of rings comprising the interoffice network. These ring calculations apply to all operating companies that have at least one tandem.

The interoffice network of rings consists of two ring classes: host/remote and tandem/host/standalone. 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. The methodology that the Model uses to determine the rings is the same for both classes of rings, with hosts serving as the homing point in the network of hosts, remotes and tandems serving as the homing point in the network of tandems, hosts, and standalone wire centers. Any discussion in the following section is applicable to both the host/remote and tandem/host/standalone classes unless otherwise noted.

The interoffice distance calculations in HM 5.0 are considerably more sophisticated than earlier versions of the Hatfield Model.[55] To compute the set of interoffice 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

[55] See Appendix D for a fuller description of these calculations.

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 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. Although this approach does not guarantee an optimal solution in terms of interoffice facility investment, it does strive for efficient ring paths.

When computing rings, the greatest savings often is realized by allowing a set of wire centers to form their own standalone 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 since all wire centers must have a communications path to their serving tandem, standalone rings are connected to the tandem through a series of ring connectors that provide paths either between rings, or between a standalone ring and the tandem. The location of each ring connector is determined by identifying the smallest distance from each node on the standalone ring to either the tandem itself, or to any other ring that has tandem connectivity. All ring connector distances and connector terminal costs are doubled to reflect the installation of redundant facilities.

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 ring – see parameter B142 in Appendix B. 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 user-adjustable parameter, which applies only to host/standalone/tandem rings, is a threshold value dictating the minimum number of switched plus special lines a wire center may serve and still be eligible to be on a ring. This threshold corresponds to Parameter B139 in Appendix B; its default value is 5000.

Wire centers that serve fewer than this threshold total line count will either: 1) directly connect to the tandem; or 2) connect to the nearest standalone 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.

At the highest level in the ring network, the HM must provide a path for tandem to tandem traffic. This is accomplished through the use of inter-ring-system connectors.[56] 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 of the on-ring nodes served

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

by those tandems. Inter-ring-system connectors always follow route-diverse paths 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.

The result of the ring-calculating process is a list of the computed host/remote and tandem/host/standalone ring configurations. These ring configurations are broken out by each tandem or host, and the wire centers they serve through the ring network. 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; 2) the identification of each wire center and the nodes (other wire centers) to which it connects; 3) the distance between each wire center and the nodes to which it connects; 4) a list of the wire centers served by spurs and their associated spur distance; 5) a list of the wire centers that serve as inter-ring-system connector nodes and their associated inter-ring-system connector distance; and 6) a list of the wire center pairs that serve as ring connectors and the their associated ring connector distances. In addition to the ring distance associated with each wire center, several ring parameters are aggregated by company. These include: 1) the total number of ring connectors; 2) the total ring connector distance; 3) 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 5000 line threshold for the smaller wire centers being placed on a spur.

Once the model determines the total interoffice distances, considering rings, connectors, and point-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 investment in feeder versus interoffice. It does this separately for underground, buried, and aerial structure.

Interexchange access facilities require additional treatment. Because interexchange carrier POPs are typically not located on LEC fiber rings, dedicated entrance facilities must be engineered. It is not possible to compute the route miles between wire centers (or tandems) and IXC POPs to size the lengths of these entrance facilities, because in general the locations of IXC POPs are not publicly available. Therefore, the number of POPs per tandem, and the average entrance facility distance, are user-adjustable, with default values of 5 and 0.5 miles, respectively.

6.5.3.3. Tandem Switch Investments

Tandem and operator tandem switching investments are computed according to assumptions contained in an AT&T cost study.[57] 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 module 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.

6.5.3.4. Signaling Network Investments

The Module computes signaling link investment for STP to end office to or tandem "A links," "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 carried on the interoffice rings.

The model always equips at least two signaling links per switch. It also computes required SS7 message traffic according to the call type and traffic assumptions described earlier. User inputs define the number and length of ISDN User Part ("ISUP") messages required to set up interoffice calls. Default values are six messages per interoffice call attempt to set up, 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 distance 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. These default values derive from the AT&T Capacity Cost Study. The STP calculation scales this investment based on the number of links the model requires to be engineered for the study area.

[57] 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").

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 $20,000 per transaction per second, based on a number reported in the AT&T Capacity Cost Study.

6.5.3.5. 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 maximum trunk occupancy value 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).

6.6. Expense Modules

6.6.1. Overview

HM 5.0 contains three Expense Modules in order to allow the user to display results by line density range, by wire center, or by CBG.[58] Each of the Expense Modules receive from the other modules all the network investments, by type of network component necessary to provide UNEs, 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.

The Expense modules require a number of user inputs. These inputs, and their corresponding default values, appear as inputs B178-B196 in Appendix B.

[58] Although the HM 5.0 engineers no plant based on CBG granularity, the results of its engineering to individual clusters may be rolled up to display cost results at the CBG level.