MULTIMODAL TRANSPORTATION ANALYSIS PROCESS (MTAP):

A TRAVEL DEMAND FORECASTING MODEL

Prepared by:

North Central Texas Council of Governments

Transportation Department

January 1990

What Is NCTCOG?

The North Central Texas Council of Governments is a voluntary association of cities, counties, school districts, and special districts within the sixteen-county North Central Texas region — established in January 1966, to assist local governments in planning for common needs, cooperating for mutual benefit, and coordinating for sound regional development.

The Council of Governments is an organization of, by, and for local governments. Its purpose is to strengthen both the individual and collective power of local governments — and to help them recognize regional opportunities, resolve regional problems, eliminate unnecessary duplication, and make joint regional decisions — as well as to develop the means to assist in the implementation of those decisions.

North Central Texas is a sixteen-county metropolitan region centered around Dallas and Fort Worth. It has a population of 4.1 million persons and an area of 12,800 square miles. NCTCOG has 208 member governments — including 16 counties, 151 cities, 21 independent school districts, and 20 special districts.

North Central Texas Council of Governments

NCTCOG's offices are located in Arlington in the Centerpoint Two Building at 616 Six Flags Drive (approximately one-half mile south of the main entrance to Six Flags Over Texas).

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NCTCOG's Department of Transportation

Since 1974 NCTCOG has served as the Metropolitan Planning Organization (MPO) for transportation for the Dallas-Fort Worth area. NCTCOG's Department of Transportation is responsible for the regional planning process for all modes of transportation. The department provides technical support and staff assistance to the Regional Transportation Council and its technical committees, which compose the MPO policy-making structure. In addition the department provides technical assistance to the local governments of North Central Texas in planning, coordinating, and implementing transportation decisions.

The preparation of this document was financed through grants from and disseminated under the sponsorship of the Urban Mass Transportation Administration and the Federal Highway Administration (U.S. Department of Transportation). The United States Government assumes no liability for its contents or use thereof.

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Introduction

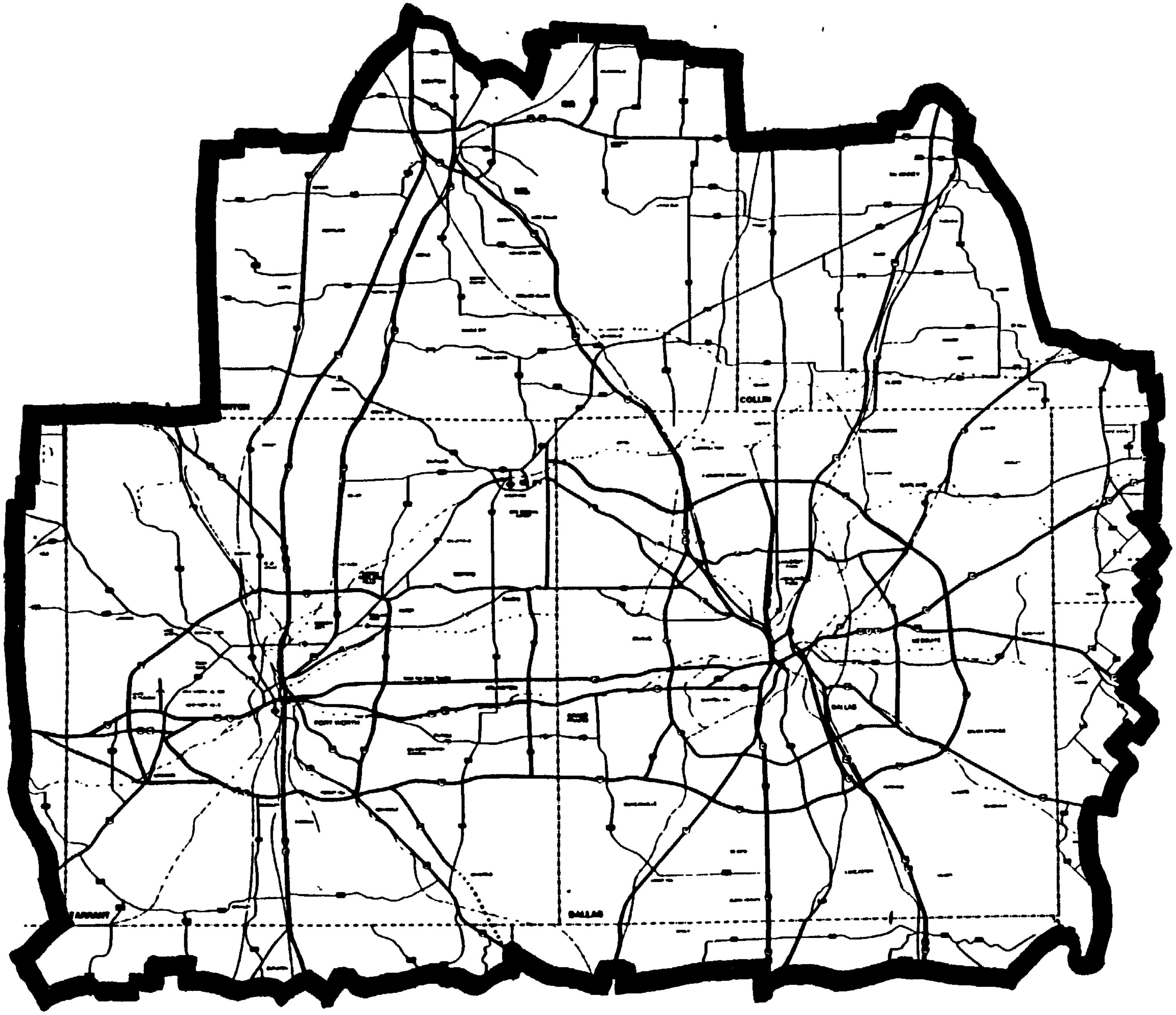
In 1986, the North Central Texas Council of Governments (NCTCOG) undertook the revision of its travel demand forecasting model. This effort was closely coordinated with the State Department of Highways and Public Transportation (SDHPT), Dallas Area Rapid Transit (DART), and the Fort Worth Transit Authority (FWTA). The outcome was a model which was developed based on travel patterns in the Dallas-Fort Worth area and used jointly by the four agencies.

The forecasting technique is based on a four-step sequential process designed to model travel behavior and predict the level of travel demand at regional, subarea, or small area levels. Similar to the traditional Urban Transportation Planning System (UTPS) software package developed by the Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA), the Multimodal Transportation Analysis Process (MTAP) consists of a large set of computer programs which is primarily used for long-range performance evaluations. The recent revision of the Model relied heavily on the results of the 1984 Home Interview[1], Workplace[2], and Transit On-Board Surveys[3] as well as the 1980 U.S. Census Journey-to-Work data. Figure 1 shows NCTCOG's Transportation Study Area in which transportation planning efforts are concentrated.

The four main components of the Model are briefly described in this section. Detailed discussions of various model components are provided within the body of the report. Throughout the text, trip purposes are defined in one of four ways: home-based work (HBW), which includes trips from home to work or work to home; home-based nonwork (HNW) trips, including all nonwork trips beginning or

FIGURE 1

TRANSPORTATION STUDY AREA



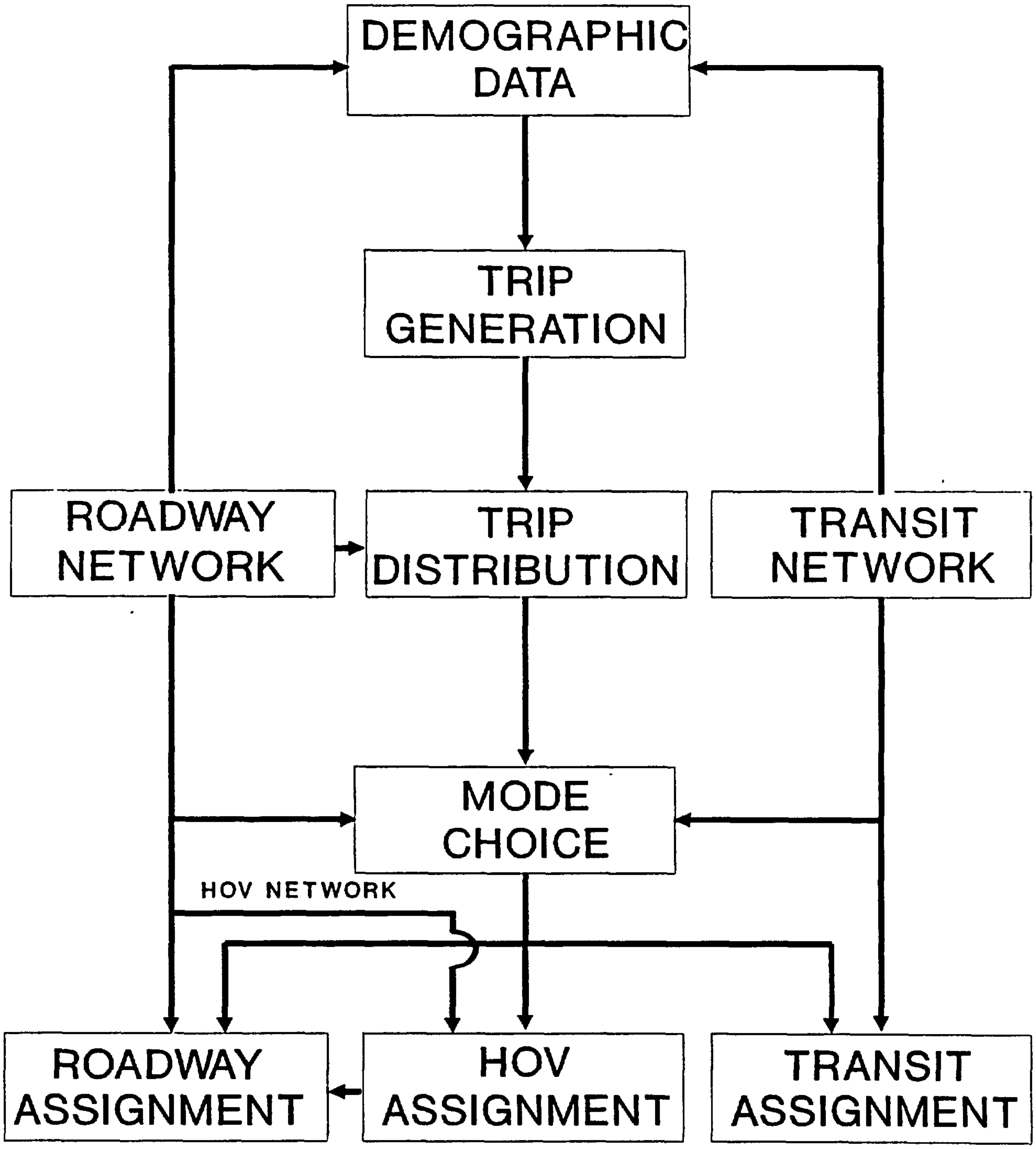
ending at home; nonhome-based (NHB) trips, which includes all trips where home is neither the origin nor the destination end; and "OTHER" trips including the external-internal, internal-external, and external-external trips as well as truck and taxi trips.

The process begins with the estimation of major socioeconomic variables for each zone (e.g., population, employment, median income, etc.).[4] The information is then fed into the Trip Generation Model which generates the number of trips sent to and from each zone. The Trip Distribution Model determines the interaction between each zone and the rest of the zones in the study area. The mode of travel is determined by the Mode Choice Model which divides the trips into transit (if applicable) and automobile trips. The automobile occupancy is also determined by this Model. The Roadway Assignment or the Route Choice Model loads the transit and roadway trips onto the respective networks. Figure 2 represents the flow of this process.

The **Trip Generation Model** converts the population and employment data into person trip ends and outputs the total number of trips produced by and attracted to each zone by trip purpose. The HBW purpose is further stratified by four income quartiles. The cross-classified production model is stratified by income quartile and household size. The allocation of a zone's households into the four income quartiles and six household-size categories is based on sets of distribution curves developed from the 1980 Census data. The cross-classified attraction model is stratified by area type, employment type (basic, retail, service), and in the case of the HBW trip purpose, income quartile. Area type designations represent the combined population and employment density of a zone.

FIGURE 2

SEQUENTIAL TRAVEL DEMAND FORECASTING PROCESS



The Trip Generation Model allows the user to directly input the increments of trips associated with special generators. These values are then added to the trips generated by the Model. Traditional travel demand forecasting models often underestimate the trips generated for special land-use categories mainly due to the discrepancy in trip rates and the relatively high employment at these facilities. At the end of the generation process, HBW trips are balanced to the estimated trip attractions. All other purposes are balanced to the estimated trip productions in that zone. Because of the uniqueness of the NHB trips, zonal productions for NHB trips are later set equal to the attractions in a given zone.

The **Trip Distribution Model** uses the person trips to and from each zone from the Trip Generation Model, plus the zone-to-zone minimum travel time information from the roadway network to estimate the number of person trips between each pair of zones for each trip purpose. All estimates of roadway travel times include a representation of the time locating a parking space, paying for parking, and walking from the car to the office. Estimates of these "terminal times" were derived from the 1984 Workplace Survey.

The Model uses a standard gravity formulation technique in the estimation of interchange trips. Second-order Bessel curves are used as the travel decay function for all trip purposes. The performance of the Bessel function was compared against the more commonly used negative exponential function and determined to perform substantially better in simulating shorter trips. For all trip purposes, iterations of the gravity model are required to ensure that the estimated number of zonal trips received equal the projected number of trip attractions generated by the Trip Generation Model. The use of an income-stratified HBW model eliminates the overestimation of low-income trip attractions to high-income employment locations. Standard gravity-based trip distribution models which do not use income levels usually suffer from this deficiency known as the "white collar/blue collar" trip orientation problem.

The choice of travel mode and automobile occupancy is determined in the **Mode Choice Model**. Using the information regarding the characteristics of the trip maker (e.g., income, auto ownership), characteristics of the roadway and transit systems (e.g., in-vehicle time, out-of-vehicle time), and the travel cost (e.g., toll, fuel, fare), the Model splits the trips among all applicable modes of travel. Based on a simple multinomial logit formulation, the Model addresses various choice sets for the HBW, HNW, and NHB trip purposes. "OTHER" trips are assumed to be vehicle trips of occupancy one and are not processed by the Mode Choice Model. The choice sets are as follows:

HBW: Drive Alone, 2 Occupant Shared Ride, 3+ Occupant Shared Ride, Walk Access to Transit, Auto Access to Transit;

HNW: Drive Alone, 2+ Occupant Shared Ride, Walk Access to Transit, Auto Access to Transit;

NHB: Drive Alone, 2+ Occupant Shared Ride, Transit.

In all three submodels, transit is treated as a generic mode rather than specifying separate modes of local bus, express bus, and rail.

The Model treats travelers with a full range of choices differently from those facing restrictions on their choice sets. The latter may be divided into three groups. The first group includes travelers whose restrictions on their choice set arise from personal characteristics. The inability to afford an automobile restricts the traveler to the walk-accessed transit mode or the ridesharing option. The second group is the automobile-captive travellers whose choices are restricted to driving alone or ridesharing. This group is mainly composed of individuals whose occupation requires the use of a car such as salesmen, self-employed individuals, or managers with access to company cars. The third group contains individuals who reside significantly outside transit service areas, again restricted to drive-alone or ridesharing options. The reason for a concern with captives resides within the nature of the Mode Choice Model which is based on theories of choice among alternative modes of travel. Forcing the Model to choose illogical alternatives may bias the coefficients to "explain" such choices.

The Roadway Assignment Model uses an incremental capacity-restrained procedure to load the vehicle trips onto the roadway network. A generalized-cost path-building technique is embedded within the Model. The best path between two zones is the one which minimizes the total impedance along the route. The calculation of impedance is based on travel time, distance (fuel cost), and tolls and their associated weights. As traffic is loaded onto the links, speed is reduced according to a volume-delay relationship. Link impedance is then updated accordingly. The Model can perform daily and peak-hour mixed-flow assignments as well as projections for peak-period HOV usage. All-or-nothing assignments may also be performed to identify the demand in a given corridor or to check for errors in network coding.

The Transit Assignment procedure used in loading the transit trips onto the transit network is a considerably different process than the Roadway Assignment. No capacity-restrained path-building models are involved. Transit trips are loaded onto the four paths defined by the path-builder in order to ensure smoother results.

The underlying principle around which the MTAP Model was built is a system of detailed data sets called the Transportation Information System (TIS). These data sets are constantly maintained for the whole region at the finest level of detail available. The process is designed to select from the comprehensive data sets an appropriate subset of data. The study area will have the best detail available while the other areas have only primary systems. The focusing technique preserves the activity of the whole region and provides a manageable and computationally efficient problem size.

TRANSPORTATION INFORMATION SYSTEM (TIS)

The Transportation Information System (TIS) is a set of data files used for regional transportation planning. These files are used by the Multimodal Transportation Analysis Process (MTAP) for detailed traffic and transit studies and as a regional inventory of transportation and demographic information. The data is organized around historical and anticipated roadway improvements. The data is maintained for the region at the level of detail required for small area studies. The files are constantly updated to include new information and changing plans.

There are five data files associated with the TIS:

- Major Thoroughfare Node File (MTN)
- Major Thoroughfare Link File (MTL)
- Street Name File (STRNAM)
- Traffic Count File (CNT)
- Zonal Activity File (ZAF)

The Major Thoroughfare Node (MTN) file contains network nodes for a particular roadway network and the data associated with each node. This data includes the node's X and Y coordinates using the Texas State Plane Coordinate System, the traffic survey zone it is contained within, its load and collapse flags, the number of links attached to it, its dime map number, and the names of the cross streets that define the node. Separate files are maintained for different years and different roadway alternatives.

The Major Thoroughfare Link (MTL) file is the basic link data set for a particular roadway network. Each link has the following attributes: network node numbers defining the beginning and end of each link, traffic direction (one-way or two-way), functional classification, divided/undivided roadway code, number of intervening controls along the link, type of traffic control at each end of the link, jurisdiction number, link length, number of operational lanes in the peak period, number of operational lanes in the off-peak period, speed limit, traffic survey zone, city code, and dime map number.

In addition to the above information, each link is assigned an eight-digit link name. The first four digits uniquely identify and distinguish the coded roadways and are known as the "family" series of the link name (e.g., Coit Street family series). The second four digits define the position of the link within the family. The combination of these two parts results in a unique link identification over time. This variable also provides a cross reference between the link, the street name, and the count files. The MTL file can be cross referenced with the MTN file as well through the network node variables.

A close companion to the MTL is the street name file. It contains the alphanumeric street names associated with each roadway link. It is primarily used for report writing and plotting, allowing the user to relate street and cross street names with each link in the MTL or other link files.

The final link-oriented data set is the count file.[5] The file contains the link name, the most recent 24-hour traffic count for each link, up to two previous counts for the link, the date each count was taken, the source of the count, and whether it is raw or adjusted. The street and city names associated with each link are also posted on the file. The count file is used in the validation of highway assignments and in estimating annual vehicle miles of travel in the region. It also serves as a major information data base for local governments.

The fifth TIS file is the Zonal Activity File (ZAF). It contains the demographic data used in the modeling process. The data is organized by Traffic Survey Zone (TSZ) which is the smallest zone size available. There are currently 5,691 TSZs in the Transportation Study Area. The data on the ZAF file includes: the full zonal hierarchy for each TSZ (see section on Zone Structure); coordinates of the zone centroid; median household income; number of households; population; basic, retail, and service employment; and total area of the zone.

ZONE STRUCTURE

The zone structure for a study is generated by the subarea focusing program called FOCUS. The focusing process centers around a hierarchy of geographic subdivisions called zones. Each level of the hierarchy contains the full set of regional demographic data. The largest size zone system is called jurisdictions (JUR). There are currently 47 jurisdictions in the Dallas-Fort Worth Transportation Study Area. Each jurisdiction is subdivided into Transportation Analysis Districts (TAD), which in turn are subdivided into Regional Analysis Areas (RAA). There are 236 TADs and 605 RAAs in the Dallas-Fort Worth region. Each RAA is subdivided into Local Analysis Districts (LAD), which in turn are subdivided into Traffic Survey Zones (TSZ). There are 2,215 LADs and 5,691 TSZs. After a set of zones are selected from the hierarchy system, the areas are renumbered and thereafter called TAP zones.

In selecting TAP zones, the user specifies the coordinate ranges of rectangular areas and the zone level to be selected. Zone level codes are defined as: 1 = JUR, 2 = TAD, 3 = RAA, 4 = LAD, 5 = TSZ. As many as 50 rectangles can be used to define the area of interest. In the likely situation that two or more rectangles define the same area, the level code of the last rectangle will prevail. Typically, a subarea is defined with a large rectangle at the jurisdiction level followed by progressively smaller rectangles defining the TAD, RAA, LAD, and TSZ boundaries. The result is a focused zone structure that increases in zone size away from the area of interest. Zone structures can vary significantly, depending on the purpose of the study. For subarea analysis, every attempt is made to keep the smallest zone size (TSZ) within the area of interest. Another common practice at NCTCOG is to define the zone structure for regional analysis such that each TAP zone in the study area contains approximately the same level of population and employment activities in the forecast year.

In designing a zone structure for a given study, the user must keep the following points in mind:

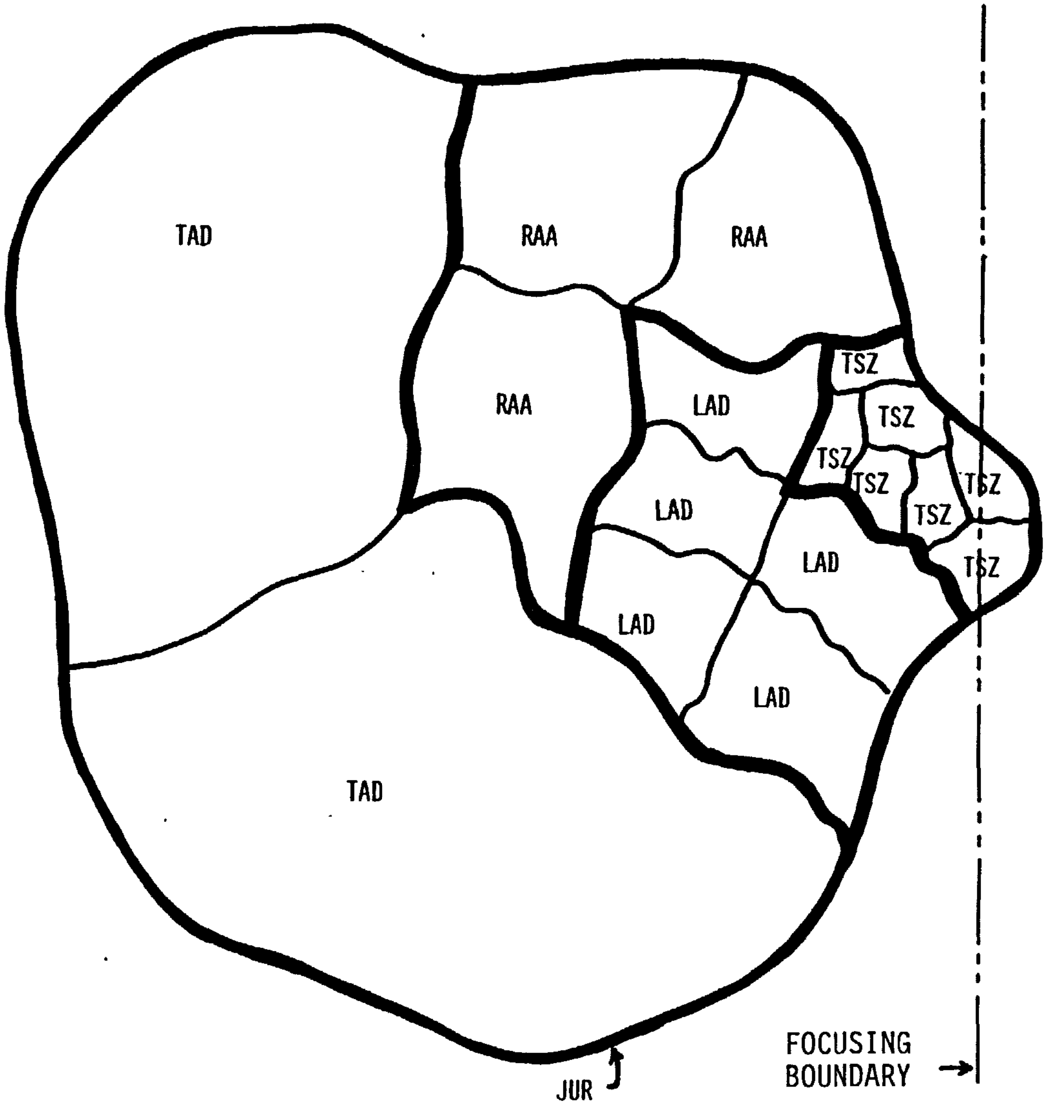
First, because of the hierarchical nature of the zone system, the selection of a single TSZ-level rectangle containing the centroid of one TSZ of a jurisdiction will lead to the inclusion of all of the remaining TSZs within that LAD. Consequently, all of the remaining LADs within that RAA will be included; all of the remaining RAAs within that TAD will be included; and all of the remaining TADs within that jurisdiction will be included. Figure 3 shows the result of this zone selection.

Second, there is an option in FOCUS to truncate the regional data set. In this situation, all zones outside of the largest rectangle are deleted from the subarea. If this method is used, external-external and internal-external trips must be manually generated at external stations defined by the user.

Finally, because TAP zone centroids are calculated as the center of activity of a zone, it is generally advisable to use the option of borrowing a previously defined zone structure when creating alternate networks or demographic data sets. As demographic activity changes in an alternative, so will the location of TAP zone centroids. This technique is computationally more efficient and avoids the potential problems associated with computed centroids within a fixed rectangular system.

FIGURE 3

ZONE FOCUSING EXAMPLE



In addition to the selection of a zone structure, FOCUS will create a TSZ-to-TAP zone equivalency table. This table associates each TSZ with the TAP zone it is contained within. Because the TSZ structure is generally constant, it is possible to use the equivalency tables of two TAP studies and generate the corresponding equivalency table between different TAP zone structures. This becomes useful when mode share and auto occupancy results are to be borrowed from a previous study.

TRIP GENERATION

The Trip Generation Model converts population and employment data to person trip ends. The end results are trip productions and attractions for each TSZ in the region, stratified by seven trip purposes:

- Home-Based Work - Low Income (HBW1)
- Home-Based Work - Low-Median Income (HBW2)
- Home-Based Work - High-Median Income (HBW3)
- Home-Based Work - High Income (HBW4)
- Home-Based Nonwork (HNW)
- Nonhome-Based (NHB)
- Other (OTH) (including internal-external, external-internal, external-external, truck, and taxi trips)

The cross-classification Trip Generation Model begins its process by aggregating Traffic Survey Zone (TSZ) data from the Zonal Activity File (ZAF) into Regional Analysis Areas (RAA). This is based on the assumption that all TSZs in an RAA have some average socioeconomic characteristics equal to the average for the RAA in which they are found. The data includes median household income, household size, employment income, and area type.

The Production Model

Trip production rates are defined as the number of person trips per household and are stratified by income quartile and household size. The estimation of trip productions requires simply the application of trip rates to the number of households in a zone, stratified by income and household size.

Tables 1-4 show the trip production rates used in the Generation Model. Notice that "OTHER" trip rates are not stratified by household size and income quartile. The number of OTHER trip productions are more closely associated with a zone's area type and employment mix. These variables are discussed in greater detail in later sections of this report. All of the trip production rates were developed from the 1984 Home Interview Survey.

Household Income Distribution

In Trip Generation, each zone's households are divided among the four income quartiles, based on a set of curves developed from the 1980 Census data (Figure 4). The curves use the ratio of the zonal median income to the regional median income as the independent variable and predict the fraction of households in the zone that fall in each income quartile. For example, if the zonal median income is $15,000 and the regional median is $30,000, the ratio is 0.5. For a ratio of 0.5, the curves show an income distribution of 54, 28, 11, and 7 percent for low, low-median, median-high, and high quartiles respectively. The regional distribution of income is then compared with the quartile definition. After application of this step to all zones, the Model then checks that the regional total number of households in each quartile is 25 percent. Using an iterative proportional fix procedure, it normalizes the distributions for each zone, if necessary, to achieve the regional distribution.

Household Size Distribution

A distribution of six household size categories is independently made in a similar manner (Figure 5). Household size distributions are not balanced to 1980 observed data. This assumes that household size varies over time.

TABLE 1

HOME-BASED WORK TRIP PRODUCTIONS
(Person Trips per Household)

Income Quartile	Household Size					
	1	2	3	4	5	6
1	1.000	1.700	1.800	1.846	2.500	2.875
2	1.204	1.970	2.423	2.864	2.667	3.300
3	1.552	2.267	2.812	2.824	3.696	3.846
4	1.600	2.800	2.848	3.198	3.439	5.286

TABLE 2

HOME-BASED NONWORK TRIP PRODUCTIONS
(Person Trips per Household)

Income Quartile	Household Size					
	1	2	3	4	5	6+
1	2.185	3.167	3.524	4.500	4.833	6.875
2	1.620	2.791	4.028	5.682	8.000	7.700
3	1.724	2.740	4.205	6.500	8.478	8.385
4	2.455	3.145	4.527	6.840	8.927	14.143

TABLE 3

NONHOME-BASED TRIP PRODUCTIONS
(Person Trips per Household)

Income Quartile	Household Size					
	1	2	3	4	5	6+
1	1.300	1.600	1.714	2.000	1.500	0.750
2	1.611	1.657	2.014	2.500	2.208	1.800
3	1.690	2.093	2.188	2.989	3.522	2.077
4	3.364	3.275	2.866	2.821	3.463	3.357

TABLE 4

OTHER TRIP PRODUCTIONS
(Person Trips per Employee)

Employment Type	Area Type				
	1	2	3	4	5
Basic	0.264	0.298	0.395	0.488	1.007
Retail	0.395	0.632	0.791	0.969	1.318
Service	0.264	0.290	0.380	0.527	0.796
Households	0.375	0.375	0.375	0.375	0.375

FIGURE 4

HOUSEHOLD INCOME DISTRIBUTION

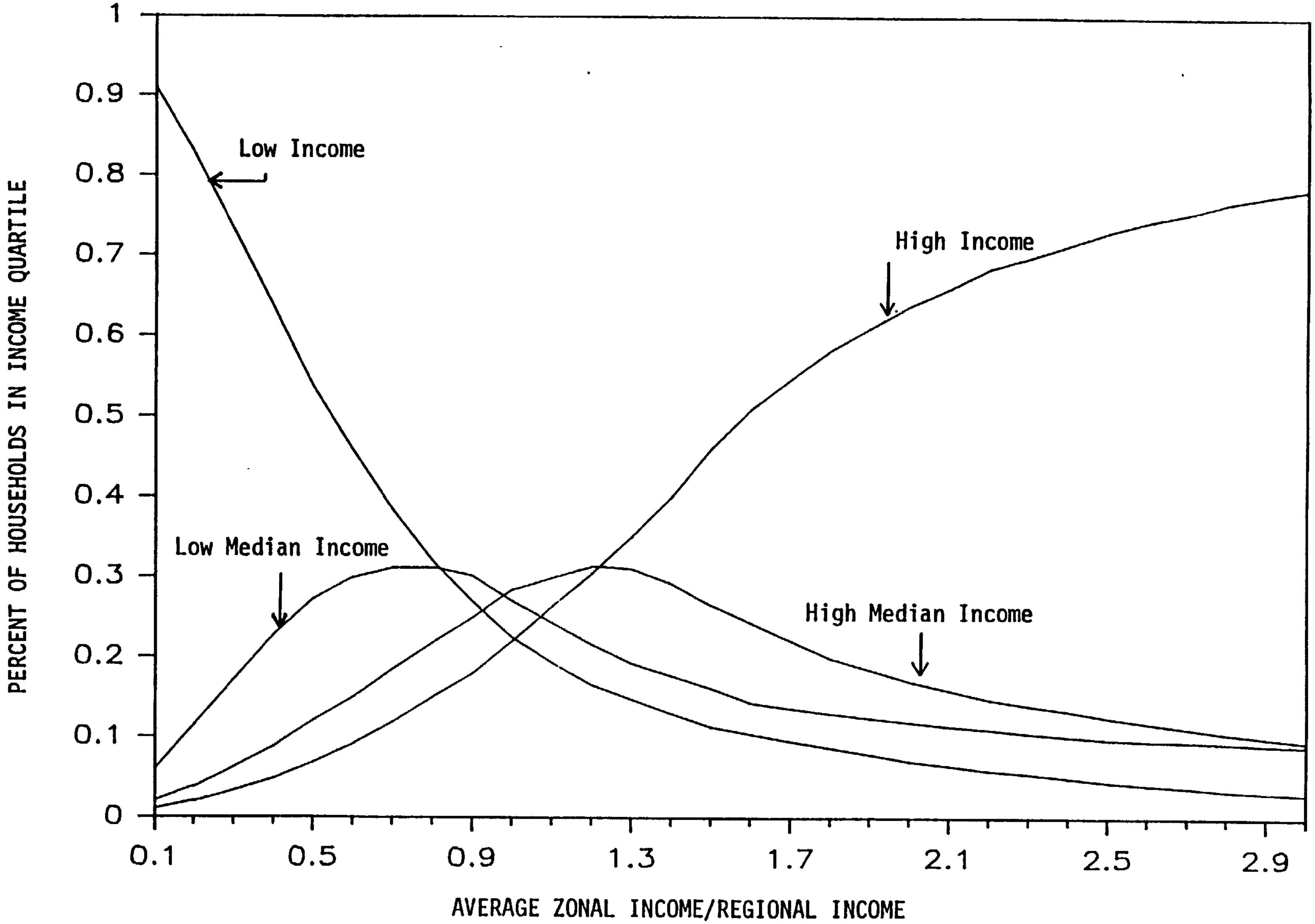
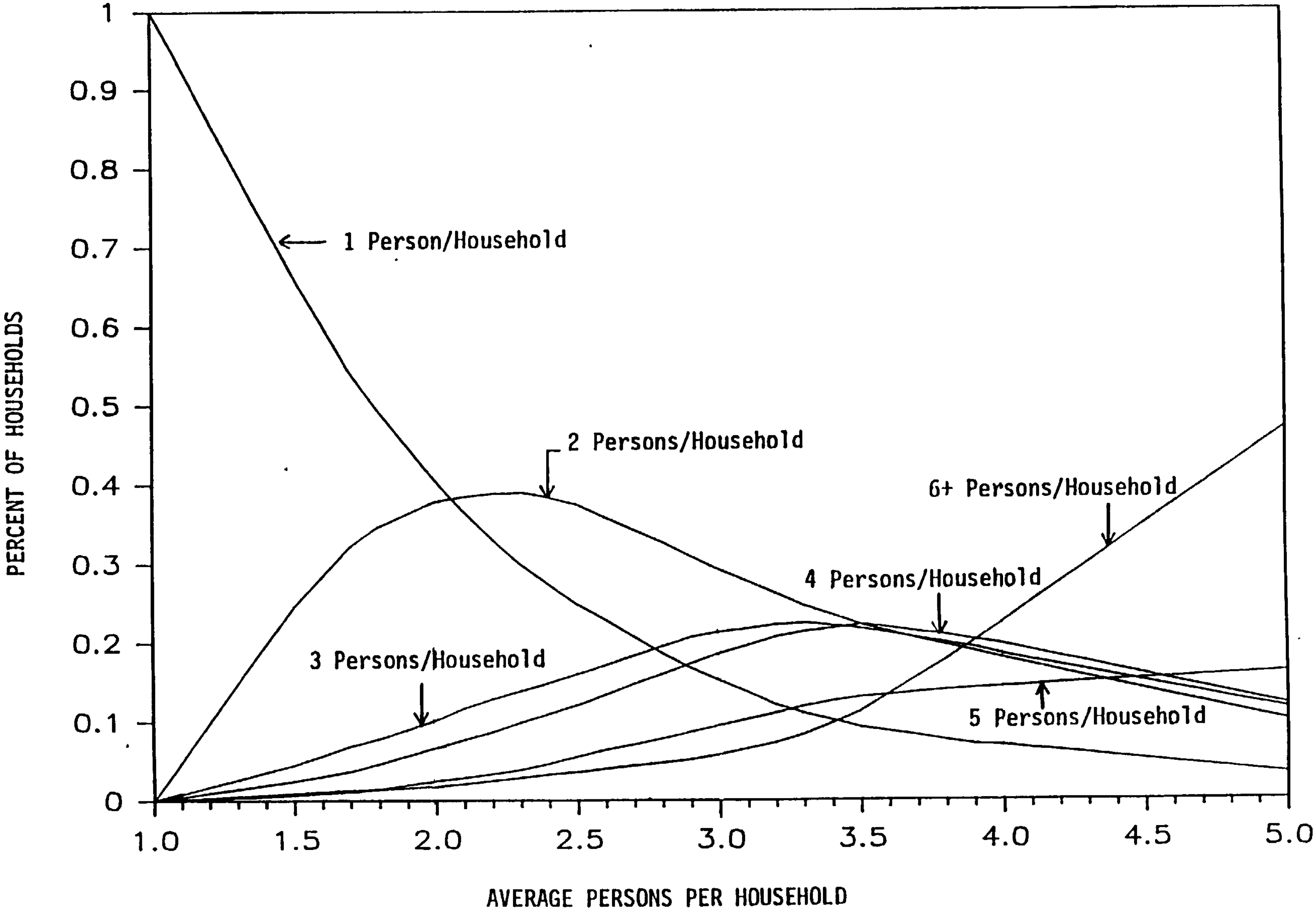


FIGURE 5

HOUSEHOLD SIZE DISTRIBUTION



Once these individual distributions have been established, a joint distribution of household size and income quartile is created. The 1980 Census curves shown in Table 5 are used as a starting point in an iterative process which adjusts this distribution to satisfy the marginal distributions estimated for each zone.

All of the above distributions are established at the RAA level and then applied to each TSZ within an RAA to determine the exact number of households in each cell of the joint income household size distribution.

The Attraction Model

Trip attractions are defined as the number of person trips per employee and are stratified by area type, employment type, and in the case of the HBW trip purpose, income quartile. Once area types have been calculated and the zonal distribution of household income of the employee has been established, person trip attractions are calculated using the rates shown in Tables 6-9. Households are also included as an attractor. The trip attraction rates were developed from the 1984 Workplace Survey. Special generators and external station trips are supplied to the Trip Generation Model by the user.

TABLE 5

1980 CENSUS DISTRIBUTION OF INCOME AND HOUSEHOLD SIZE (%)

Household Size	Income Quartile				Total
	1	2	3	4	
1	12.48	6.77	2.58	1.17	23.0
2	6.64	8.17	8.33	7.86	31.0
3	2.66	4.28	5.41	5.65	18.0
4	1.58	3.24	5.02	6.16	16.0
5	0.84	1.43	2.23	2.50	7.0
6+	0.80	1.11	1.43	1.66	5.0
Total	25.0	25.0	25.0	25.0	100.0

TABLE 6

HOME-BASED WORK TRIP ATTRACTIONS
(Person Trips per Employee)

Basic Employment

Income Quartile	Area Type 1	2	3	4	5
1	1.677	1.384	1.413	1.312	1.389
2	1.695	1.454	1.300	1.277	1.464
3	1.545	1.421	1.300	1.260	1.530
4	1.378	1.296	1.300	1.388	1.521

Retail Employment

Income Quartile	Area Type 1	2	3	4	5
1	1.500	1.486	1.643	1.400	1.455
2	1.500	1.363	1.400	1.400	1.400
3	1.467	1.435	1.736	1.634	1.400
4	1.500	1.300	1.344	1.358	1.286

Service Employment

Income Quartile	Area Type 1	2	3	4	5
1	1.732	1.296	1.424	1.402	1.422
2	1.700	1.322	1.430	1.295	1.338
3	1.700	1.341	1.365	1.456	1.566
4	1.704	1.258	1.265	1.323	1.244

TABLE 7

HOME-BASED NONWORK TRIP ATTRACTIONS
(Person Trips Per Employee)

Employment Type	Area Type				
	1	2	3	4	5
Basic	0.453	0.442	0.300	0.200	0.139
Retail	0.811	1.144	8.796	8.060	6.164
Service	1.574	1.005	1.000	1.059	1.812
Households	0.442	0.500	0.511	0.627	0.682

TABLE 8

NONHOME-BASED TRIP ATTRACTIONS
(Person Trips Per Employee)

Employment Type	Area Type				
	1	2	3	4	5
Basic	0.500	0.655	0.858	0.589	0.500
Retail	1.100	1.462	4.272	3.717	2.978
Service	0.600	0.877	1.167	1.243	1.095
Households	0.100	0.104	0.216	0.261	0.235

TABLE 9

OTHER TRIP ATTRACTIONS
(Person Trips Per Employee)

Employment Type	Area Type				
	1	2	3	4	5
Basic	0.208	0.235	0.312	0.385	0.795
Retail	0.312	0.499	0.624	0.765	1.040
Service	0.208	0.229	0.300	0.416	0.628
Households	0.299	0.299	0.299	0.299	0.299

Area Types

Area types are zonal attributes calculated from the activity density of each Regional Analysis Area (RAA).

Activity density is defined as:

$$ADEN_i = (POP_i + (B * EMP_i))/AREA_i$$

where:

$ADEN_i$ = activity density of zone i

POP_i = population in zone i

EMP_i = total employment in zone i

$AREA_i$ = total area of zone i in acres

B = 1.603 (regional population to employment ratio for the 1984 calibration year, stays constant for forecast years)

Area types are then established from the ranges in activity density cited below:

Area Type	Density Range
1. Central Business District	> 125/acre
2. Outer Business Districts	30-125/acre
3. Urban Residential	7.5-30/acre
4. Suburban Residential	1.8-7.5/acre
5. Rural	< 1.8/acre

Within this general guideline, in some cases, judgments are applied to override the area types implied by the activity density. An important judgment is that no additional zones beyond those that today constitute the Dallas and Fort Worth CBDs will qualify for the CBD area type within the current forecasting horizon. This constraint reflects the assumption that no other area will develop with an environment that is similar in function to the current CBDs, particularly in the activities associated with and supported by walking within the CBD. The results of the activity-density estimates are also reviewed to detect isolated zones within otherwise homogeneous areas and overrides the assignment of area types where appropriate.

Zonal Employment Income

The Trip Attraction Model requires estimation of the distribution of household income among employees at their workplace. This unusual requirement occurs because application of the income-stratified HBW trip distribution process uses attractions stratified by income quartile.

NCTCOG estimates the income distribution of employees in a zone on the basis of the income level of households located in and around the zone:

$$\text{PCTEMP1} = 0.11500 + 0.04486 * \text{HH670\_1} + 0.03502 * \text{HE75\_1}$$

$$\text{PCTEMP2} = 0.15892 + 0.07858 * \text{HH670\_2}$$

$$\text{PCTEMP3} = 0.17000 + 0.05969 * \text{HH670\_3}$$

$$\text{PCTEMP4} = 0.41000 + 0.06893 * \text{HH670\_4} - 0.00629 * \text{HE50}$$

where:

PCTEMP_i = percent employment of income quartile "i" employees in a zone

HH670_i = ratio of income quartile "i" households within 6.70 miles to total number of households within 6.70 miles

HE75_i = ratio of income quartile "i" households within .75 mile to total employment within .75 mile

HE50 = ratio of all households within .50 mile to total employment within .50 mile

Special Generators and External Stations

Special generator and external station trips are directly added to the Generation Model by the user. Six categories of special generators are currently used in the Model:

- Regional Shopping Malls
- Universities and Colleges
- Hospitals
- Commercial Airports
- Regional Recreation Facilities
- Military Installations

The Model applies the general trip attraction rates to the employment from these generators, and the user adds the extra increment of trips associated with the particular type of special generator. The incremental trips are calculated from the difference between the general trip rate for a particular employment type and the special generator trip rate as determined from the Regional Travel Survey of at least one special generator of each type. Special generators used in the "regional model" are listed in Table 10. Additional categories of special generators (e.g., high schools) or additional generators under the above categories may be used in more detailed subarea study applications.

External station data is also added to the "OTHER" trip purpose. The data is provided by SDHPT and is split between productions and attractions based on the percentage of through-trips and the amount of special generator attractions in the region.

TABLE 10

REGIONAL SPECIAL GENERATORS

Generator	Location (TSZ)
Retail Malls:	
North Park	886
Prestonwood	531
Collin Creek	6359
Galleria	549
Redbird	3894
Town East	2829
Richardson Square	728
Six Flags	9058
Seminary South	6078
Ridgemar	7542
Northeast	8129
Valley View	550
Irving Mall	126
The Parks	7944
Vista Ridge	9642
Universities and Colleges:	
Southern Methodist University	1888
Texas Christian University	6016
University of North Texas	6665
University of Texas at Arlington	9125
University of Texas at Dallas	9275
Brookhaven College	232
Eastfield College	2778
Richland College	745
Tarrant County Junior College (N.E.)	8230
Tarrant County Junior College (S.)	7740
Hospitals:	
Baylor Medical Center	2353
Dallas Veteran Administration	4158
Harris Methodist Hospital	5897
Parkland Memorial	1786
Presbyterian Hospital	890
St. Paul Medical Center	1763
Recreation Facilities:	
Six Flags over Texas	9034
Airports:	
D/FW	8361 8366 8369 8367 8378 8365
Love Field	1700
Meacham Field	5055
Military Bases:	
Carswell	5117
Naval Air Station	3422

Trip Balancing

Regional trip productions and attractions are balanced for each trip purpose. This step is required because there is no guarantee that the estimated regional production and attraction totals will be equal. NCTCOG controls HBW trips by income quartile to the estimated trip attractions, and all other trips purposes are balanced to the estimated number of trip productions.

NHB trips then go through one additional step in which the trip productions of each zone are set equal to the attractions in that zone. This two-step balancing process for NHB trips is necessary because the trip production model, applied to households in their home zones, cannot locate the nonhome-based trip ends in their appropriate zones. This balancing step therefore allocates the NHB trip productions in direct proportion to NHB attractions which are associated with nonhome activities in each zone.

ROADWAY NETWORK PREPARATION

As discussed earlier, the Major Thoroughfare Node (MTN) and Link (MTL) files are an integral part of the Transportation Information System. Together they form the basic roadway network on which the model is based. MTL is created and edited through a program called MTLEDIT. Links can be added, modified, or deleted. The program performs a number of logic checks to detect errors in the data set.

MTLEDIT also creates and edits the street name (STRNAM) file. Additions, modifications, and deletions can be made through the program. The MTL and STRNAM files can be modified at the same time or independently.

The MTN file is created and updated through the program MTNEDIT. The program operates much like MTLEDIT. Node records can be added, modified, or deleted, and basic logic checks are performed on the data. Because the MTN file is an input to the MTLEDIT program, any node modifications should be made before updating the MTL file.

The network node and link data sets are further built upon by the programs NODEPREP and LINKPREP. NODEPREP compares the TSZs on the node (MTN) file with a zonal file to ensure each node has been assigned a valid TSZ. LINKPREP posts free speeds, estimated loaded speeds, capacities, and area types on each record. It also compares the link (MTL) file with the zonal file to assure that the A and B nodes of a link have been assigned a valid TSZ.

Functional Classification

Each link in the roadway network is assigned a classification code determining its capacity and speed. They are as follows:

0 - Zone Centroid Connectors (approach links)
1 - Freeways
2 - Principal Arterials
3 - Minor Arterials
4 - Collectors
5 - Local Streets
6 - Ramps
7 - Frontage Roads
8 - High Occupancy Vehicle Lanes

Free Speed (Uncongested Speed)

Free speed is calculated using the speed limit, area type, functional class, number of intervening controls, and the end node traffic control coded for each link. In general, the functional class and area type determine the delay associated with various traffic controls (e.g., signals, stop signs, yield signs). Traffic control delay is added to the travel time derived from the speed limit, and the speed associated with the new travel time is then posted as the link's free speed. The basic calculation occurs in the MTAP program LINKPREP and is as follows:

For each link:

$$\text{Free Speed} = \frac{\text{Length}}{\frac{\text{Length}}{\text{Speed Limit}} + \text{Delay}}$$

There are two components to the delay calculation:

1) Intervening Control Delay - When applicable, the number of intervening controls, each assumed to be a stop sign, is coded for arterial and frontage road links. Thereafter, six seconds of deceleration and six seconds of acceleration delay is assumed for each stop. These intervening controls represent delay experienced at the intersection of arterial links with local streets not coded in our network.

   Intervening Control Delay = Number of Stops * (12 seconds)

2) (End-node) Intersection Control Delay - There are six different end-node control options available as shown in Table 11.

TABLE 11

END-NODE CONTROL OPTION

Type of Control	Delay (seconds)
No Control	0
Two-Way Stop	22
Four-Way Stop	14
Traffic Signal	(See Table 12)
Expressway On-Ramp or Yield	0
Expressway Off-Ramp	0

TABLE 12

TRAFFIC SIGNAL DELAY
(Seconds)

Area Type	Functional Classification 1	2	3	4	5	6	7
1	0	12	12	15	15	12	15
2	0	11	12	14	14	11	14
3	0	9	10	12	12	9	12
4	0	8	9	11	11	8	11
5	0	7	8	9	9	7	9

The delay due to intervening controls and the delay due to the end-node control are added together to obtain the total delay (DELAY) used in the calculation of free speed.

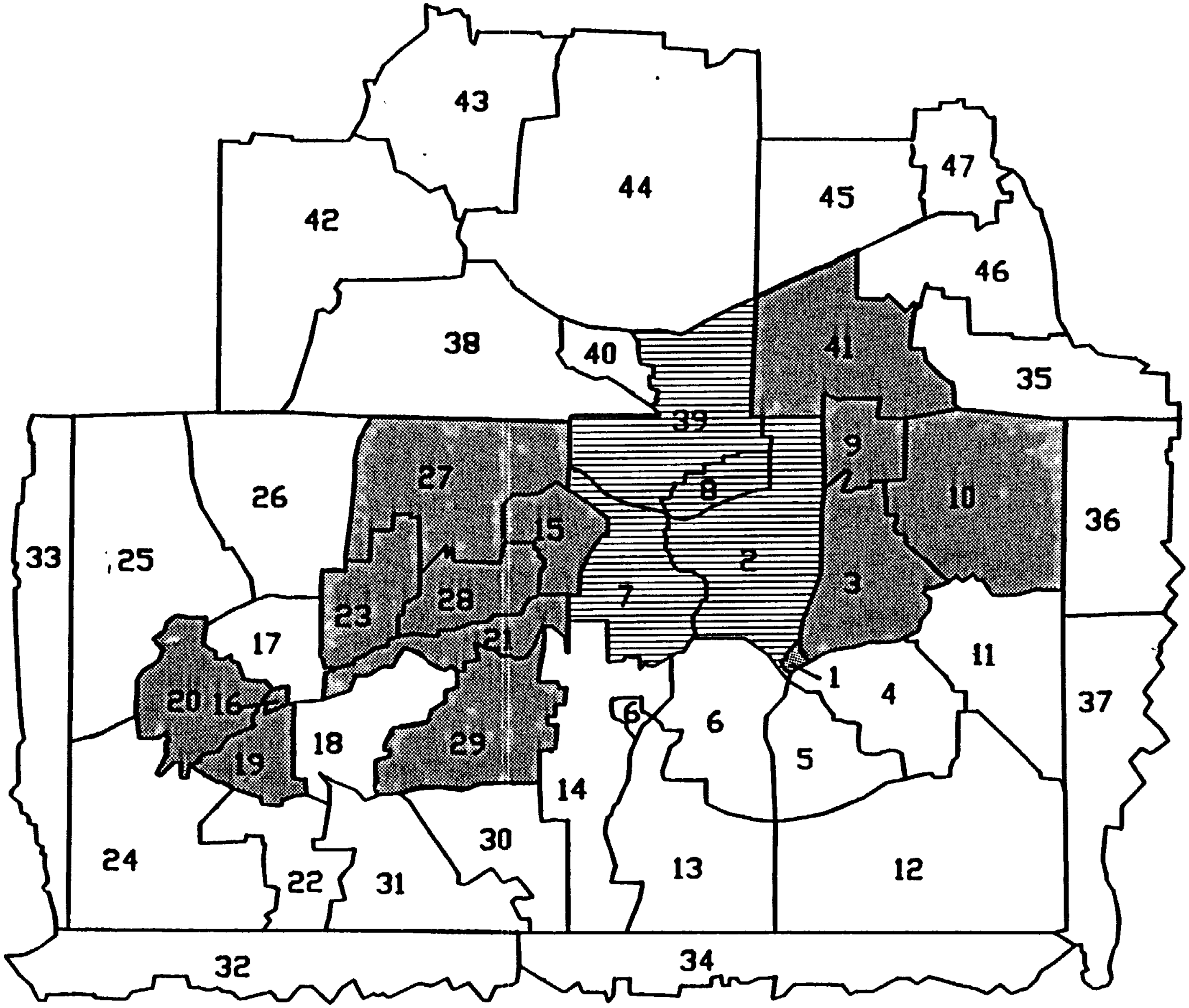
Estimated Loaded Speed (Congested Speed)

Estimated loaded speeds (ELS) are used in building minimum travel time paths for use in Trip Distribution. Estimated loaded speeds are calculated by multiplying the free speed on a link by an ELS factor. These ELS factors are based on speed data obtained from the most recent traffic forecasts, so that they represent a relatively accurate picture of congested conditions throughout the roadway network.

ELS factors vary by functional class, the number of lanes on a roadway, the location of the roadway in the Transportation Study Area (TSA), and the time of day (peak or off-peak period). Figure 6 is a map showing the three districts that have been defined to specify the location of links within the TSA. These districts were developed to distinguish between the congested and the uncongested areas in the region. Table 13 contains peak period ELS factors for 1986, and Table 14 lists the 1986 off-peak period ELS factors. Tables 15 and 16

<u>FIGURE 6</u>

DISTRICTS USED IN ESTIMATING LOADED SPEEDS



District 1 ▤ $0.5 \leq \frac{\text{Loaded Speed}}{\text{Free Speed}} < 0.8$ (DIST1 = 2, 7, 8, 39)

District 2 ▩ $0.8 \leq \frac{\text{Loaded Speed}}{\text{Free Speed}} < 0.9$ (DIST2 = 1, 3, 9, 10, 15, 16, 19-21, 23, 27-29, 41)

District 3 ☐ $0.9 \leq \frac{\text{Loaded Speed}}{\text{Free Speed}} < 1.0$ (DIST3 = 4-6, 11-14, 17, 18, 22, 24, 26, 30-38, 40, 42-47)

TABLE 13

ESTIMATED LOADED SPEED FACTORS
PEAK PERIOD
YEAR 1986

District 1

	Functional Class						
Number of Lanes	1	2	3	4	5	6	7
1	0.65	0.40	0.52	0.60	0.60	0.60	0.60
2	0.65	0.40	0.52	0.70	0.70	0.70	0.65
3	0.69	0.50	0.76	0.83	0.83	0.80	0.70
4	0.71	0.60	0.77	0.83	0.83	0.88	0.72
5	0.73	0.65	0.82	0.85	0.85	0.92	0.74
6	0.75	0.70	0.82	0.88	0.88	0.92	0.76

District 2

	Functional Class						
Number of Lanes	1	2	3	4	5	6	7
1	0.60	0.50	0.60	0.70	0.70	0.60	0.65
2	0.62	0.50	0.63	0.75	0.75	0.70	0.70
3	0.64	0.59	0.65	0.85	0.85	0.80	0.75
4	0.72	0.69	0.70	0.90	0.90	0.90	0.80
5	0.73	0.75	0.75	0.93	0.93	0.95	0.83
6	0.75	0.76	0.76	0.93	0.93	0.96	0.85

District 3

	Functional Class						
Number of Lanes	1	2	3	4	5	6	7
1	0.90	0.68	0.75	0.85	0.85	0.70	0.75
2	0.92	0.71	0.80	0.87	0.87	0.80	0.80
3	0.93	0.74	0.85	0.90	0.90	0.90	0.85
4	0.93	0.75	0.89	0.92	0.92	0.92	0.90
5	0.95	0.80	0.90	0.94	0.94	0.95	0.95
6	0.95	0.84	0.90	0.95	0.95	1.00	1.00

TABLE 14

ESTIMATED LOADED SPEED FACTORS
OFF-PEAK PERIOD
YEAR 1986

District 1

	Functional Class						
Number of Lanes	1	2	3	4	5	6	7
1	0.83	0.78	0.80	0.80	0.80	0.85	0.80
2	0.88	0.83	0.85	0.85	0.85	0.90	0.83
3	0.88	0.83	0.91	0.90	0.90	0.93	0.86
4	0.88	0.88	0.93	0.92	0.92	0.95	0.90
5	0.92	0.88	0.95	0.94	0.94	0.98	0.95
6	0.92	0.89	0.98	0.96	0.96	0.98	0.98

District 2

	Functional Class						
Number of Lanes	1	2	3	4	5	6	7
1	0.90	0.85	0.85	0.90	0.90	0.85	0.80
2	0.90	0.86	0.90	0.93	0.93	0.90	0.83
3	0.92	0.87	0.93	0.96	0.96	0.95	0.86
4	0.93	0.90	0.94	0.96	0.96	0.99	0.90
5	0.95	0.93	0.96	0.97	0.97	1.00	0.95
6	0.95	0.93	0.98	0.97	0.97	1.00	0.98

District 3

	Functional Class						
Number of Lanes	1	2	3	4	5	6	7
1	0.94	0.86	0.90	0.91	0.91	0.90	0.90
2	0.96	0.90	0.95	0.93	0.93	0.93	0.92
3	0.96	0.91	0.96	0.95	0.95	0.95	0.95
4	0.96	0.91	0.97	0.97	0.97	0.98	0.98
5	0.98	0.93	0.98	0.99	0.99	1.00	1.00
6	0.98	0.93	0.99	0.99	0.99	1.00	1.00

TABLE 15

ESTIMATED LOADED SPEED FACTORS
PEAK PERIOD
YEAR 2010

District 1

Functional Class

Number of Lanes	1	2	3	4	5	6	7
1	0.63	0.40	0.50	0.53	0.53	0.50	0.50
2	0.63	0.44	0.50	0.55	0.55	0.60	0.55
3	0.64	0.47	0.63	0.74	0.74	0.70	0.60
4	0.66	0.55	0.70	0.78	0.78	0.80	0.63
5	0.68	0.65	0.75	0.82	0.82	0.90	0.66
6	0.70	0.70	0.80	0.85	0.85	0.90	0.70

District 2

Functional Class

Number of Lanes	1	2	3	4	5	6	7
1	0.58	0.40	0.50	0.60	0.60	0.55	0.55
2	0.62	0.45	0.54	0.65	0.65	0.65	0.60
3	0.66	0.50	0.62	0.70	0.70	0.75	0.65
4	0.70	0.60	0.64	0.75	0.75	0.80	0.70
5	0.73	0.70	0.68	0.80	0.80	0.85	0.75
6	0.75	0.75	0.72	0.85	0.85	0.90	0.80

District 3

Functional Class

Number of Lanes	1	2	3	4	5	6	7
1	0.86	0.55	0.65	0.65	0.65	0.60	0.60
2	0.88	0.60	0.70	0.75	0.75	0.70	0.70
3	0.89	0.65	0.74	0.85	0.85	0.80	0.80
4	0.91	0.69	0.78	0.87	0.87	0.85	0.85
5	0.93	0.73	0.82	0.89	0.89	0.90	0.90
6	0.94	0.75	0.85	0.90	0.90	0.95	0.95

TABLE 16

ESTIMATED LOADED SPEED FACTORS
OFF-PEAK PERIOD
YEAR 2010

District 1

Functional Class

Number of Lanes	1	2	3	4	5	6	7
1	0.80	0.75	0.75	0.75	0.75	0.80	0.70
2	0.83	0.78	0.80	0.77	0.77	0.85	0.75
3	0.85	0.80	0.85	0.80	0.80	0.90	0.80
4	0.88	0.83	0.88	0.83	0.83	0.92	0.85
5	0.90	0.86	0.92	0.86	0.86	0.95	0.90
6	0.92	0.89	0.95	0.90	0.90	0.97	0.95

District 2

Functional Class

Number of Lanes	1	2	3	4	5	6	7
1	0.86	0.80	0.75	0.80	0.80	0.80	0.79
2	0.87	0.81	0.80	0.85	0.85	0.85	0.82
3	0.88	0.82	0.85	0.87	0.87	0.90	0.85
4	0.89	0.85	0.90	0.89	0.89	0.92	0.88
5	0.91	0.88	0.93	0.92	0.92	0.95	0.91
6	0.94	0.90	0.95	0.95	0.95	0.98	0.95

District 3

Functional Class

Number of Lanes	1	2	3	4	5	6	7
1	0.93	0.85	0.85	0.85	0.85	0.85	0.85
2	0.95	0.87	0.87	0.89	0.89	0.90	0.87
3	0.95	0.88	0.90	0.92	0.92	0.93	0.89
4	0.96	0.89	0.92	0.94	0.94	0.97	0.92
5	0.97	0.91	0.94	0.96	0.96	0.98	0.95
6	0.97	0.92	0.95	0.98	0.98	0.99	0.98

show the corresponding information for the year 2010. The year of the network that is being analyzed is specified in LINKPREP, and the appropriate ELS factors are interpolated between 1986 and 2010.

Hourly Capacity

LINKPREP also posts directional hourly capacities on each link. These capacities are stratified by area type, functional class, and whether a roadway is divided or undivided. Tables 17 and 18 show the lane capacities currently used in the Model. One-way links are assigned the appropriate capacity from Table 17. For two-way links, the divided/undivided flag is used to determine if the capacity is taken from Table 17 or Table 18.

TABLE 17

HOURLY SERVICE VOLUME PER LANE*
(Divided or One-Way Roads)

		Functional Class						
		Freeway	Principal Arterial	Minor Arterial	Collector	Local	Ramp	Frontage Road
AREA TYPE	CBD	1,800	550	550	450	450	1,100	550
	Fringe	1,850	600	600	475	475	1,200	600
	Urban Residential	1,875	650	625	500	500	1,250	625
	Suburban Residential	1,950	725	700	550	550	1,400	700
	Rural	2,000	800	750	575	575	1,500	750

* Service Volumes at Level of Service E (The Model requires level of service E service volumes. However, continued use of level of service C service volumes for planning purposes is suggested. Level of service C can be obtained by taking 80 percent of the above level of service E service volumes.)

- If Volume/Service Volume Ratio is <= 0.8 then Level of Service = A, B, or C
- If Volume/Service Volume Ratio is 0.8 < x <= 0.9 then Level of Service = D
- If Volume/Service Volume Ratio is 0.9 < x <= 1.0 then Level of Service = E
- If Volume/Service Volume Ratio is > 1.0 then Level of Service = F

TABLE 18

HOURLY SERVICE VOLUME PER LANE*
(Undivided Roads)

		Functional Class						
		Freeway	Principal Arterial	Minor Arterial	Collector	Local	Ramp	Frontage Road
AREA TYPE	CBD	N/A	500	500	400	400	1,100	500
	Fringe	N/A	550	550	425	425	1,200	550
	Urban Residential	N/A	600	575	450	450	1,250	575
	Suburban Residential	N/A	675	625	500	500	1,400	625
	Rural	N/A	725	675	525	525	1,500	675

N/A - Not Applicable

* Service Volumes at Level of Service E (The Model requires level of service E service volumes. However, continued use of level of service C service volumes for planning purposes is suggested. Level of service C can be obtained by taking 80 percent of the above level of service E service volumes.)

- If Volume/Service Volume Ratio is <= 0.8 then Level of Service = A, B, or C
- If Volume/Service Volume Ratio is 0.8 < x <= 0.9 then Level of Service = D
- If Volume/Service Volume Ratio is 0.9 < x <= 1.0 then Level of Service = E
- If Volume/Service Volume Ratio is > 1.0 then Level of Service = F

ROADWAY NETWORK SELECTION

Network selection is based on a set of rectangular areas and level codes in a manner analogous to zone selection using the "FOCUS" software. The same rules regarding the selection sequence and hierarchy apply. Links do, however, have two sets of coordinates to consider. A link is included if either of its end nodes falls within an equal or higher level code rectangle. Link level codes are therefore cumulative. A summary of level codes used in the network selection process is provided in Table 19.

It is advisable to match the link level with the zone level whenever possible. If the network does not match the zone structure, significant loading problems can occur. Too much network will tend to overload some streets and show no traffic on others. This is basically the inability of the assignment program to load logical paths to the approach links of large zones and simultaneously distribute the trips among the roadway miles contained within the zone. Though links are not prohibited from bisecting zones, it is relatively important that the number of links which do bisect zones be kept to a minimum.

The problem of too many zones for the network is the opposite of that discussed above. The zone approach links will tend to be unreasonably long or cross other zones because of relatively few access points to the network. Therefore, generation of a balanced network system and zone structure is of utmost importance.

In addition to the level code and coordinate ranges, link selection cards provide two optional network modification procedures. The first option is

TABLE 19

NETWORK FOCUSING SELECTION CRITERIA

Functional Class	Level Code				
	1	2	3	4	5
Freeways	X	X	X	X	X
Principal Arterials		X	X	X	X
Minor Arterials			X	X	X
Collectors				X	X
Locals					X
Ramps	X	X	X	X	X
Frontage Roads		X	X	X	X
HOV Lanes	X	X	X	X	X

network collapsing. Because of the focusing process, it is both possible and necessary to code a detailed network, particularly with regard to freeways. In order to have the detailed frontage road, ramp, and turning movement restrictions of a freeway system for a detailed subarea study, the full regional network is literally coded. Since the freeway system is the lowest level network, a large number of links will be kept for areas well outside of the subarea. The collapse option permits the FOCUS program to convert the detailed freeway coding into two-way, universal access links. In other words, freeways are converted from limited access facilities to common intersection facilities.

Network collapsing is based on network node numbering conventions and collapsible node flags. A freeway interchange is coded around one collapsible node. As the interchange is collapsed, all of the ramps, short sections, and bridges are deleted because they become links with the common node at both ends. The one-way frontage roads and main lanes are converted to one two-way link between collapsed interchanges.

Another option allows the addition of mid-block nodes on arterial links. This process greatly increases the number of nodes and links in the selected network and as such should only be used in small areas where detailed thoroughfare loadings are required. The advantage of mid-block nodes is that approach links can be moved away from the intersections (i.e., corner loading to mid-block loading). A smoother assignment may result.

There are two cautions regarding mid-block nodes that must be stated. The first is that the network node number scheme is not transferable from one network to another. The mid-block process splits arterial links of significant length within the specified area into two equal halves. A new network node location is calculated and location data generated. Because the new node number is a function of the link file sort, there is no way to guarantee that the same node would be generated for a different network. This is particularly critical when dealing with approach links, which will be discussed later.

The second consideration arises if collapse and mid-block options are used in the same network. The mid-block procedure searches the node file for vacant positions starting from the first position. It is possible for a mid-block node to be selected from a collapsible node sequence and thus cause some potential confusion. The problem can generally be avoided if collapsible node sequences are coded with a higher node number and a buffer area is provided between the mid-block and collapse rectangles such that no links have one node in the mid-block area and the other node in the collapse area.

As mentioned previously in our discussion of the zone structures and the focusing procedure, an option in the software allows the truncation of the regional data set. In this case, all zones and the network outside of the largest rectangle are deleted from the subarea. If this method is used, external stations and cordon links must be defined and manually added by the user to accommodate the external-external, external-internal, and internal-external trips.

ROADWAY APPROACH LINKS

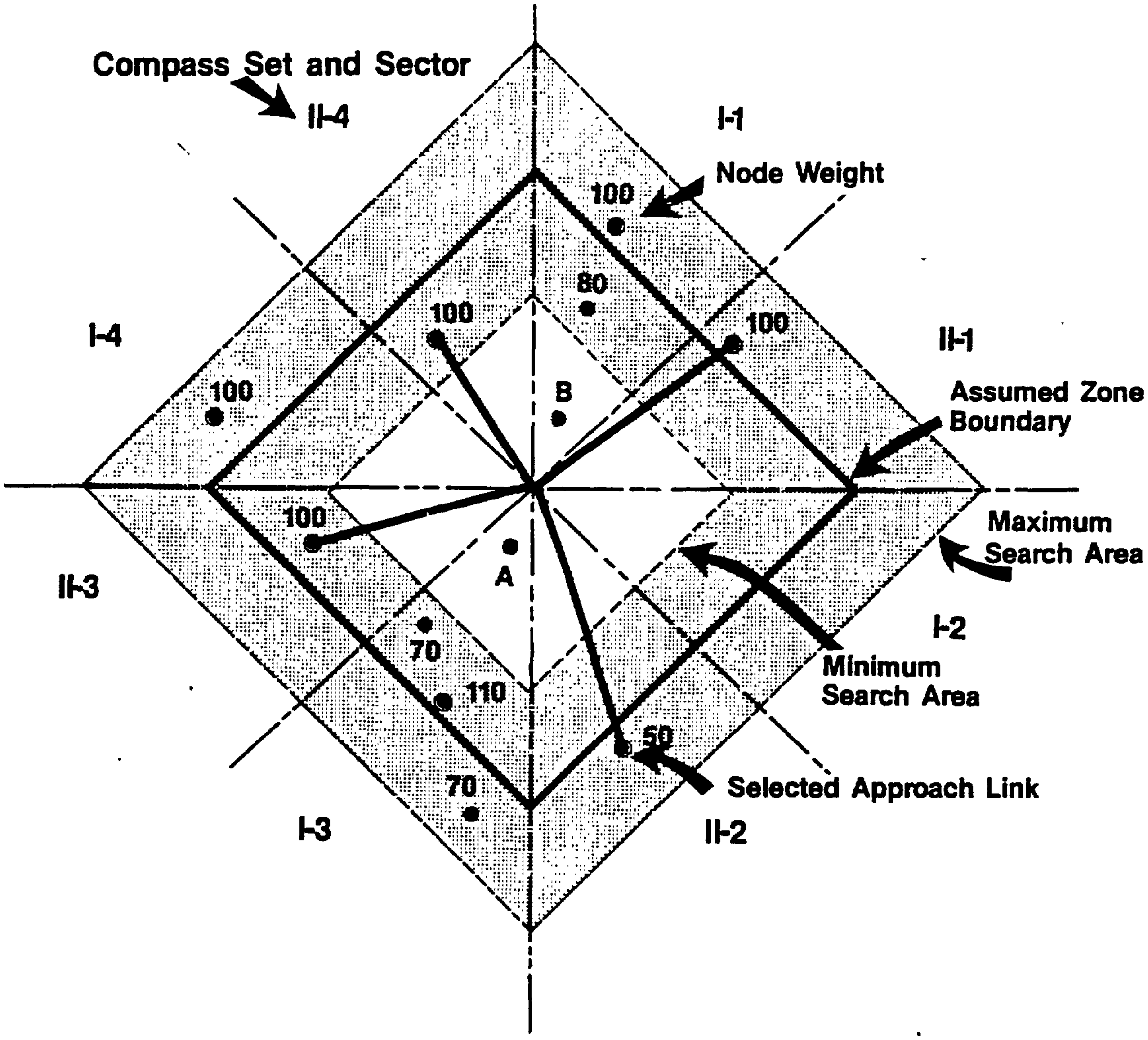
One of the important functions of FOCUS is to connect a selected network to a selected zone structure with approach links. Each node is assigned a load flag to permit or prohibit approach link connection. The program adds prohibitions to all nodes associated with freeways and ramps but permits loading at collapsed nodes. It also prohibits loading to intersections of links where mid-block nodes have been generated. Beyond that, the user controls approach link generation by varying the weights assigned to each node.

The basic principle behind approach link generation is to maximize the weights of the approach link set for each zone. The zone is assumed to be a diamond-shaped area equal to the area of the zone. The best set of approach links is assumed to be located near the perimeter of the diamond. A diamond is used because approach link lengths are measured as the right-angle distance between the zone centroid and the node. This assumes a grid system of local streets with a north-south, east-west orientation will be required to travel from the centroid of the zone to the network (see Figure 7).

There are five parameters that control approach link selection. The first two control the maximum distance beyond or inside the diamond perimeter from which potential nodes will be considered. These parameters vary by zone level code. The next two parameters determine the base weight of each node. One varies by the number of links attached to that node, and the other varies by the minimum functional classification code of those links attached to the node. The final parameter sets the weight added to or subtracted from the base weight as a function of the distance the node is away from the diamond perimeter. The distance weight also varies by zone level code.

FIGURE 7

Approach Link Selection Methodology



<u>Note:</u> ● =Best Node in the Sector
A & B are Closest and Second Closest Nodes Respectively
Compass Set II Was Selected Because the Sum of Best Nodes in its Four Sectors (350 Units) is Greater than Set I (310 Units).

In addition to the node weighting procedure, a set of approach links is chosen to ensure an even distribution around the centroid. The maximum weight node is kept for each of two sets of points of the compass (i.e., North-Northeast, East-Southeast, South-Southwest, West-Northwest, or the opposite). The number of points (possible approach links) in each set is specified by the user. Two is the recommended number. Also, the closest and second closest nodes to the centroid are located. The number of approach links requested is selected in order of highest weight from one of the two compass sets. The choice of which set to use is based on the maximum cumulative weight of each set of nodes. If sufficient nodes to satisfy the request cannot be found from the compass set, the closest and second closest nodes are used. The closest and second closest nodes are also used for external station connections because the area of these zones is very small. Approach links are created from the node and zone data and added to the link file.

Because approach links are critical to the assignment process, great care is taken to review the computer-generated links for reasonableness. Other factors such as physical barriers, irregularly shaped zones, and development patterns within the zones must be considered. FOCUS permits the user to copy the final approach links from a previous application rather than generate new ones. This is done by matching network node numbers from the first run with the second run. If a match cannot be made, the link is deleted.

Utilizing this passing option can significantly reduce or in some cases eliminate the review process on a given alternative. In addition, as approach links have an important role in model validation, it is important that links not change substantially over time or between alternatives. Every attempt should be made to retain the approach links from the assignment validation, except in cases where a new network has been added or where demographic activity has changed significantly.

As suggested earlier, attempting to copy approach links attached to mid-block nodes to another network will produce significant connectivity problems. The result will be unacceptable and therefore should not be attempted.

The results of network focusing should be reviewed before proceeding with the rest of the process. It is the practice at NCTCOG to generate a computer plot of the network and approach links to assist in the review.

ROADWAY PATH-BUILDING

Roadway minimum travel time paths are developed using the program TREBLD. These paths represent the best path from each origin zone to all nodes in the network, including all destination zones. The node string for this path can optionally be stored for future path-tracing applications. Normally, however, the zone-to-zone summary of these paths is more useful. Paths are built by the "bush" method. That is, all links leaving the node of interest are processed before the next best node is considered. For example, when the path is initiated, all approach links from the zone of interest are processed. The travel time of each link is the index of the cumulative impedance array in which the node numbers are stored. The node with the next best (i.e., minimum travel time) impedance is considered next. All of the links leaving this node are then processed. If a link tries to process a node which had previously been included, a test is made to determine which link represents the best path. If the new link is the best path, the old node is removed from the cumulative impedance array and replaced by the new node. In this way, all nodes are processed according to the order in which they are included in the minimum cumulative impedance array.

TREBLD is capable of building paths based on travel time, travel distance, travel cost, or a combination of all three. The three input parameters that guide the creation of the paths are:

Value of Time (VTIME) - represents value of time ($/hour),
Value of Distance (VDIST) - represents fuel cost ($/mile), and

Value of Cost (VCOST) - represents the consumer price index adjustment factor to convert the toll data into calibration year (1984) dollars, if it is not already.

Paths are built based on cumulative minimum travel time. Therefore, the impedance is in minutes, the VTIME parameter is set to one, and the others are given zero values. If the user wishes to build paths based on generalized costs, the VTIME, VDIST, and VCOST parameters should be set appropriately, depending on the model calibration year and the year of analysis. The Traffic Assignment Model uses generalized cost and contains appropriate values of the parameters. This method should not be used in conjunction with the Trip Distribution Model (ALDGRAV) as the specified parameters were not calibrated for this type of use.

Due to the lack of intrazonal network and consequently intrazonal paths, 75 percent of the length of the approach link of the best path to the nearest neighbor zone is used as the average intrazonal trip length. Using the approach link speed, the average intrazonal travel time is calculated for each zone. Approach link speeds vary by area type and time-of-day and are summarized in Table 20.

Path-building is one of the most costly parts of the MTAP process. The program as a test option to allow the user to build minimum paths from certain selected zones of interest (ZOI). Once the user has carefully checked the roadway network and approach links, several ZOI tests should be run prior to submitting the complete network for path-building. Another test option is to save several path node strings, to allow the user to trace paths for reasonability.

TABLE 20

ROADWAY APPROACH LINK SPEEDS

Area Type	Speed (mph)	
	Off-Peak	Peak
1	15	11
2	23	13
3	27	17
4	33	21
5	39	23

TRIP DISTRIBUTION

The Trip Distribution process uses the person trips to and from each zone produced by the Trip Generation Model, plus the zone-to-zone travel time from the minimum time paths from the roadway network to estimate the number of person trips between each pair of zones for each of the seven trip purposes. Separate models exist for each trip purpose; the structure remains the same, but the parameters differ slightly across the trip purposes.

The Gravity Model (ALDGRAV)

The NCTCOG gravity model is an adaptation of the Access and Land Development (ALD) model originally developed by Schneider[6].

The formulation of the NCTCOG gravity model is identical to the standard gravity model:

$$T_{ij} = P_i \frac{F(t_{ij})A_j}{\sum_z F(t_{iz})A_z}$$

where:

T_{ij} = the number of trips produced by zone i and attracted to zone j

P_i = the total number of trip productions for zone i

F() = the decay function; represents the rate at which a zone's attractiveness declines with increasing travel disutility

t_{ij} = the minimum zone-to-zone travel time, including terminal times

A_j = the number of attractions for zone j

z = the total number of zones in the system

ALDGRAV departs from the typical formulation in that it uses the Bessel function as the decay function. The performance of the Bessel function was compared against the more commonly used negative exponential function. It was found that the Bessel function was better able to simulate short trips. The Bessel function is defined as:

$$F(t_{ij}) = \frac{K_2\ (2\sqrt{Bt_{ij}})}{4Bt_{ij}}$$

where:

K_2 = the modified Bessel function of the second order

t_{ij} = the minimum zone-to-zone travel time

B = the Bessel parameter

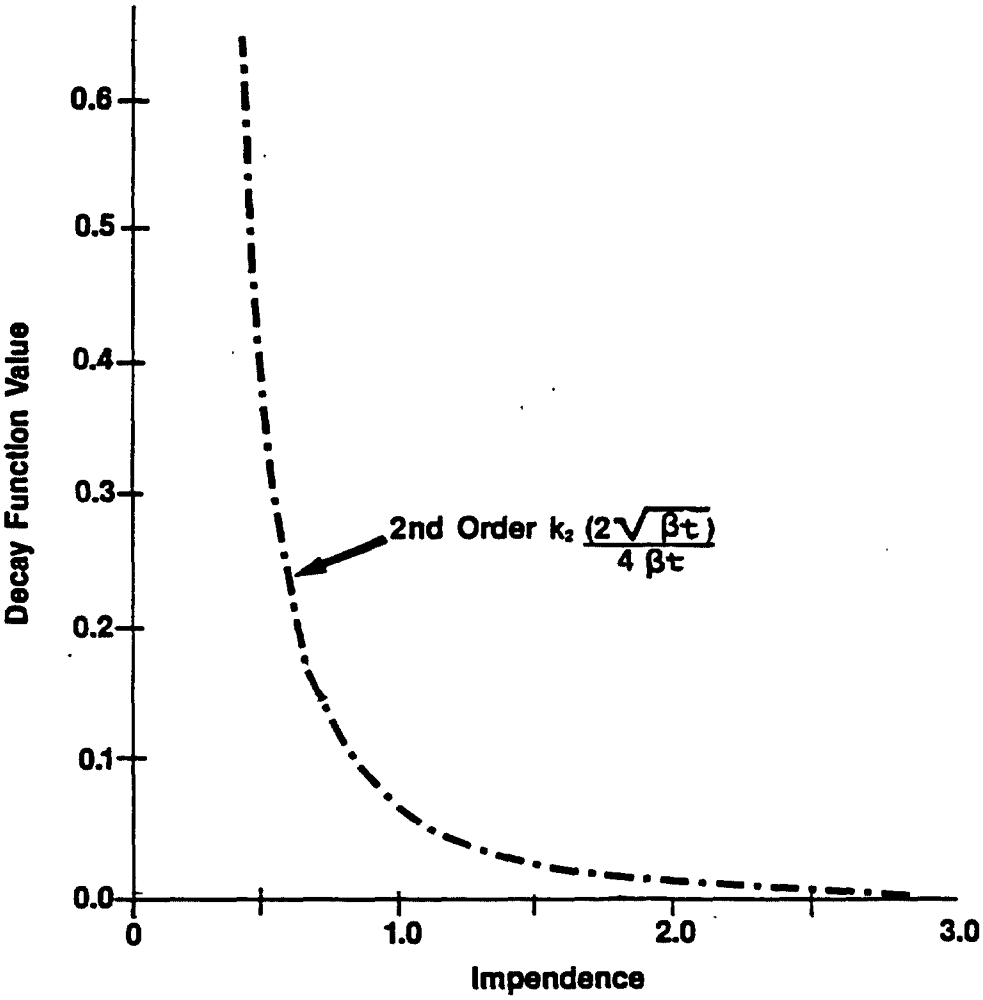
The order of the Bessel function can be used to control the variance of distribution. A second order function, however, is used for all trip purposes in MTAP. Figure 8 shows the general shape and formulation of the Bessel function.

The "B" parameter for each trip purpose was calibrated using trip length and orientation data from the 1984 Home Interview and Workplace Surveys:

Trip Purpose	Calibrated Bessel Parameter (B)
HBW1	0.001625
HBW2	0.001013
HBW3	0.000711
HBW4	0.000585
HNW	0.004993
NHB	0.001682
OTH	0.002858

FIGURE 8

SECOND-ORDER BESSEL FUNCTIONS



These parameters are held constant across any zone structure and for any forecast year. Figures 9 and 10 show the shape of purpose-specific Bessel curves using the above calibrated parameters.

For all trip purposes, the gravity model is iterated to ensure that the estimated number of trips received by each zone equals the projected number of trip attractions from the trip attraction model. Satisfaction of this constraint is guaranteed for trip productions, since the gravity model simply allocates the total number of productions to attractions in other zones. There is no guarantee, however, that the sum of all trips received by a zone will equal the expected number of attractions. Each iteration of the model therefore artificially increases the attractiveness of zones in which the trips are less than the number of trip attractions and decreases the attractiveness of zones in which trips are overstated. Iterations continue until the program reaches the maximum number of iterations permitted by the user. The number of iterations for each trip purpose is shown in Table 21:

TABLE 21

NUMBER OF ITERATIONS BY TRIP PURPOSE

Trip Purpose	Number of Iterations
HBW1	10
HBW2	10
HBW3	7
HBW4	7
HNW	10
NHB	7
OTHER	8

FIGURE 9

TRIP DISTRIBUTION BESSEL CURVE
HBW1 - HBW4

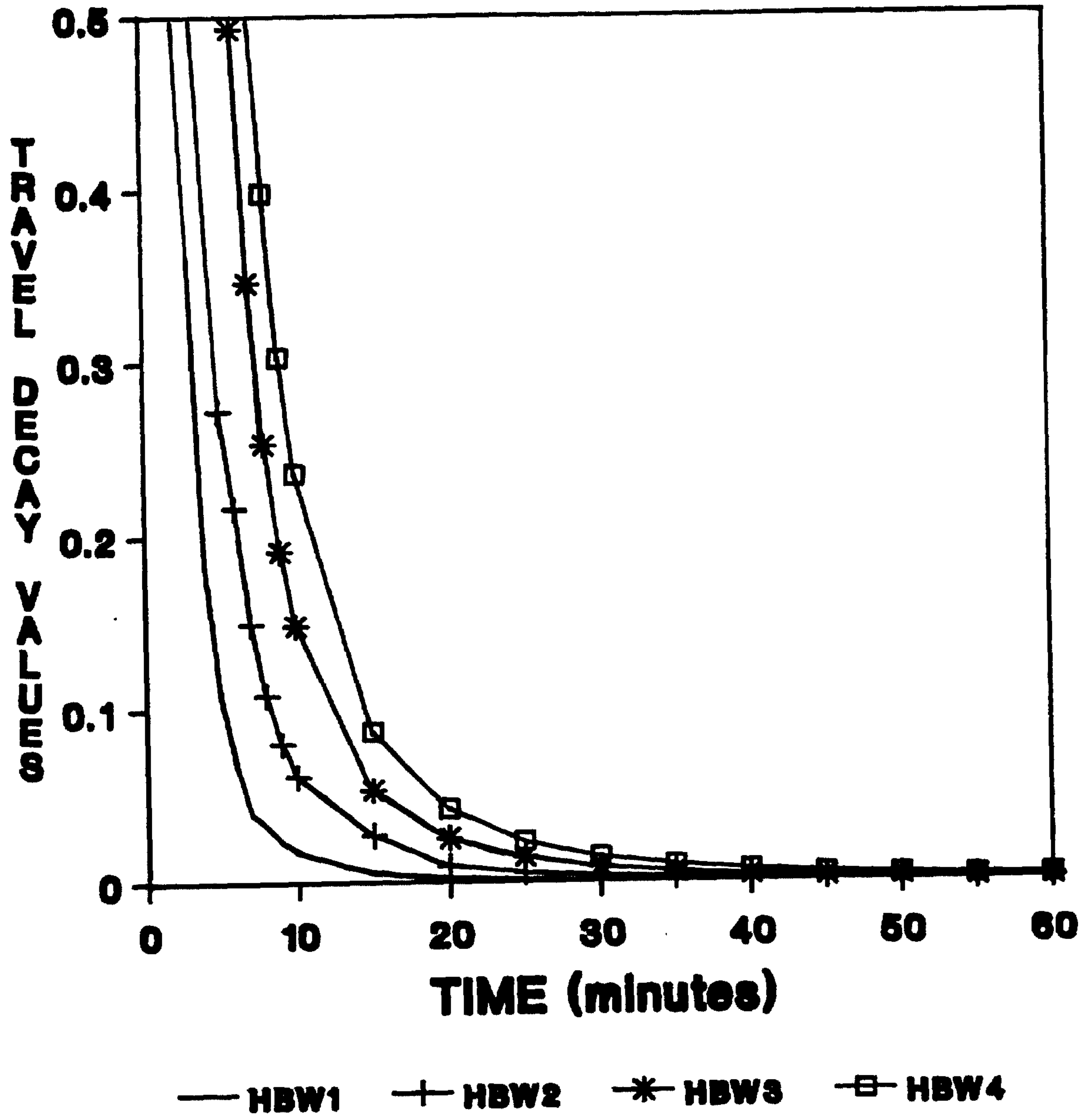
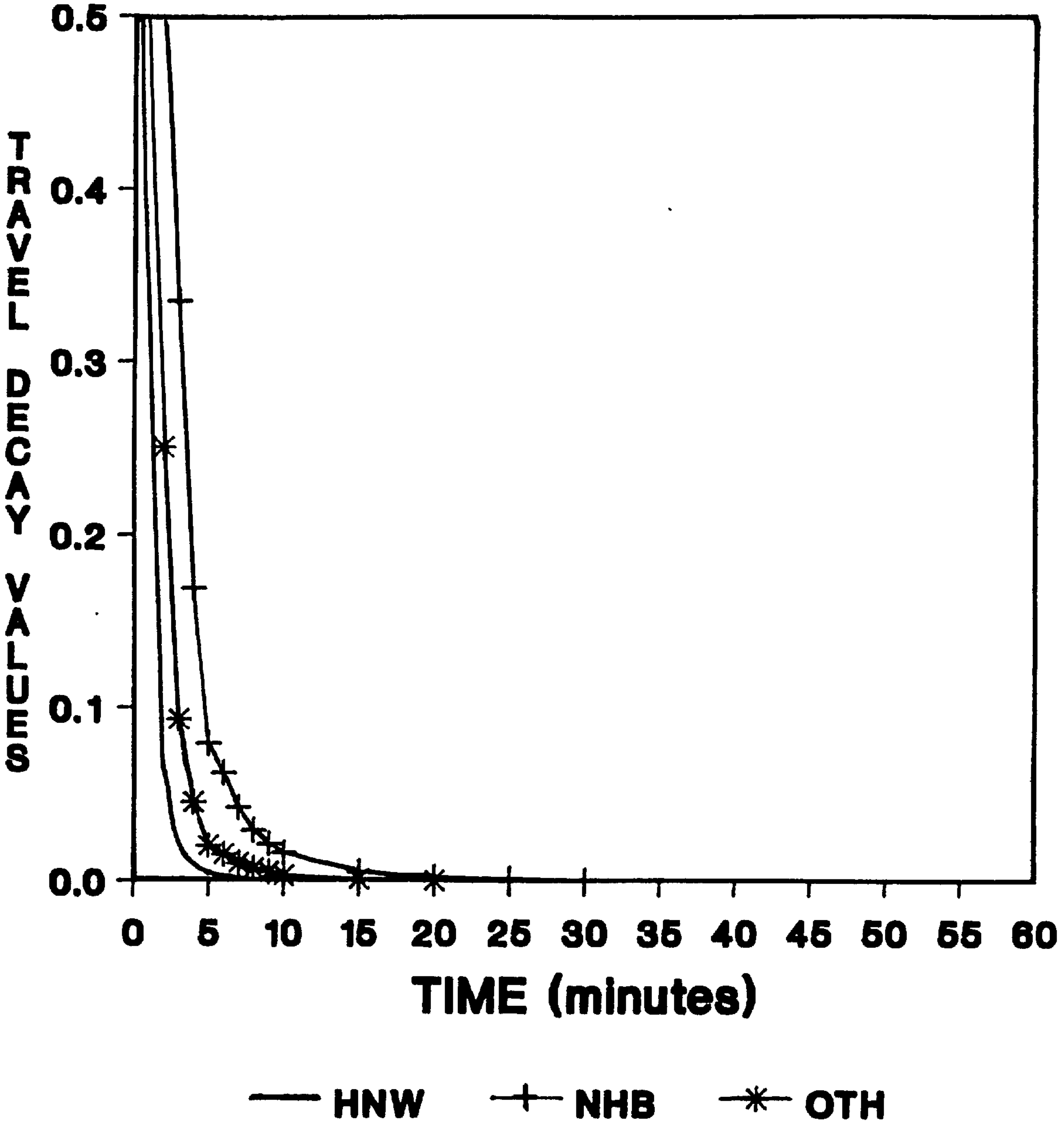


FIGURE 10

TRIP DISTRIBUTION BESSEL CURVE HNW, NHB, OTH



In order to reflect terminal activities, terminal times or fixed-end penalties for the origin and the destination of each trip are added to the minimum interchange travel time. It is this total zone-to-zone travel time that is then input to the Bessel function for use in the gravity model.

Terminal Times (Fixed-End Penalties)

All estimates of roadway travel times include a representation of the time locating a parking space, paying for parking, and walking from the car to a destination. Estimates of these times were derived from the 1984 Workplace Survey. This Survey obtained specific information from each employee on the individual components of terminal time at the workplace. The terminal time look-up table stratifies the average terminal time by trip purpose, area type, and nature of the trip end. Table 22 summarizes these values.

TABLE 22

ROADWAY TERMINAL TIMES (IN MINUTES)
FOR HBW, HNW, AND NHB
TRIP PURPOSES

Area Type	Production	Attraction
1	2.0	9.0
2	1.3	5.0
3	1.2	2.4
4	1.0	2.0
5	1.0	1.0

In order to adapt to the uniqueness of "OTHER" trip purpose use, the flatter portion of the Bessel curve is used by setting the production and attraction terminal times to 5.0 minutes across all area types. Maximum values of production and attraction fixed-end penalties are assigned to the external stations in order to reflect out-of-region travel time and prohibit the adjacent external-external movements. This is done by setting the terminal time for the smallest zone size category in Area Type 5 to 99.0 minutes. Terminal times are assumed to remain constant for all future forecast years.

Intrazonal Trips

Intrazonal and interzonal trips are processed separately in the Distribution Model. The Model disregards the intrazonal travel time estimate obtained from the path-building process and calculates a more precise value for each zone. A zone is divided into 13 concentric squares, and the average distance from the center of the zone to the perimeter of each square is determined. The outer square is equal to the area of the zone. For each distance that is greater than a specified user input minimum walk distance, a cost-per-mile value is applied to convert the distance to travel time. Before the application of the Bessel function, the origin and destination terminal times are added to these travel time values. The resulting Bessel function values for each distance greater than the minimum walk distance for a specific zone are summed up and used as the intrazonal weight for that zone. The cost-per-mile values vary by time-of-day and area type and represent the inverse of the approach link speeds used in the peak and off-peak period networks. These values are shown in Table 23.

TABLE 23

COST-PER-MILE VALUES
(Minutes * 100/Mile)

Area Type	Peak	Off-Peak
1	545	400
2	462	261
3	353	222
4	286	182
5	261	154

Terminal time and cost-per-mile values may vary by area type as well as zone size. The following five zone size ranges are currently available in the Model:

1 - 0 to 0.25 sq. mi.
2 - 0.26 to 1.00 sq. mi.
3 - 1.01 to 4.00 sq. mi.
4 - 4.01 to 16.00 sq. mi.
5 - 16.00 sq. mi. and greater

However, in the 1984 calibration of ALDGRAV, it was not necessary to utilize the zone size ranges to obtain an appropriate distribution of trips. The Model has been tested with focused subarea zone structures as well and performed acceptably with the terminal times and cost-per-mile values held constant for all zone sizes, except as indicated earlier for the OTHER trip purpose.

TRANSIT NETWORK PREPARATION

The transit network is organized around a system of modes and lines. The modes serve the function of distinguishing among various qualities or types of service. Transit mode codes used to define speed and stop density factors, dwell times, and mode-specific parameters are as follows:

1 - Walk Access Link
2 - Auto Access Link
3 - Walk Network in CBD and Parking lot links
4 - Local Feeder Bus in Fort Worth
5 - Local Feeder Bus in Dallas
6 - (Unused)
7 - Express Bus
8 - Rail

The transit network is coded over the roadway links for those modes and lines which share the right-of-way with automobiles (e.g., buses). Special links are added for modes operating on an exclusive right-of-way (e.g., rail). The transit supply-side simulation program (TNET) processes each transit line in order to approximate the actual operating characteristics on each link of the line.

Transit Speed

The choice between the use of free speeds or the estimated loaded speeds (ELS) from the background roadway network is made depending upon the "way type" code of the link segment. This is the nonstop speed of the transit system. These speeds are further reduced if stops are made to serve passengers. Way type codes invoking the use of the appropriate speed are as follows:

Way type = 1 (Mixed-Flow Traffic; use ELS)
2 (Reserved, Contraflow, or HOV Lanes; use free speeds)
3 (Exclusive Guideway; use free speeds)

Stop Delay

A line operating in the mixed-flow lanes is only subject to the traffic congestion delay. Therefore, a "closed-door" transit line operating nonstop between its origin and destination points experiences no additional delay due to stops. However, every stop along the way increases the total in-vehicle travel time. Stop delay time represents the number of seconds of delay associated with each stop due to deceleration, dwell time, and acceleration. The total delay is then added to the initial travel time under the nonstop condition. A reduced in-service speed is then calculated using the final travel time.

Thus, line delay is calculated as follows:

$$\text{Delay} = (\text{number of stops}) * \left\{ (\text{dwell time per stop}) + \left(\begin{array}{c} \text{acceleration/deceleration} \\ \text{time per stop} \end{array} \right) \right\}$$

The number of stops per link is estimated by the application of a stop-density factor to the link length. Stop density factors, defined as the number of stops per mile, and stratified by time-of-day, area type, and line haul mode are summarized in Table 24.

TABLE 24

STOP DENSITY FACTORS
(Stops per Mile)

Peak

Area Type	Mode 4	5	7	8
1	8	6	6	2
2	5	4	2	1
3	4	3	2	1
4	3	2	1	1
5	2	2	1	1

Off-Peak

Area Type	Mode 4	5	7	8
1	8	6	6	2
2	5	4	2	1
3	4	3	2	1
4	3	2	1	1
5	2	2	1	1

Dwell times defined as passenger loading and unloading time are tabulated by time-of-day, area type, and line haul mode as shown in Table 25.

TABLE 25

DWELL TIME PER STOP (Seconds)

Peak

Area Type	Mode 4	5	7	8
1	17	17	20	20
2	12	12	12	20
3	10	10	12	20
4	10	10	20	20
5	10	10	20	20

Off-Peak

Area Type	Mode 4	5	7	8
1	15	15	20	20
2	10	10	12	20
3	8	8	12	20
4	8	8	20	20
5	8	8	20	20

Acceleration and deceleration rates vary by technology codes as shown in Table 26.

TABLE 26

ACCELERATION/DECELERATION RATES (Miles/Hour/Second)

	Technology				
	1	2	3	4	5
ACC	250	250	310	330	300
DEC	250	250	310	330	300

where:

Technology Code 1 = Diesel Bus
2 = Gasoline Bus
3 = Light Rail Transit Electrical
4 = Heavy Rail Transit--Electrical
5 = Heavy Rail Transit--Diesel

The current practice at NCTCOG is to code rail's final speeds, obtained from transit agencies, directly on the special rail links therefore bypassing the calculation of stop delays for this mode.

Layover and Headways

Layover can be coded as a percent of the travel time or as a minimum time. Additional layover may be associated with poorly matched headways and travel times. The final layover is the time between the trip end time and the return trip start time for a particular vehicle. Layover parameters can be coded on the line records or by mode. A 10 percent layover assumption is used in coding the two-way local and express routes (modes 4, 5, and 7). All one-way express lines are coded with a layover of 1 percent.

Headways can be coded as the actual or the minimum and maximum values. If actual headways are requested, no attempt is made to optimize vehicle utilization or minimize layover. If the minimum and maximum method is chosen, the line travel time plus the minimum layover is divided by the maximum headway. The number of vehicles required to service the line is this division rounded to the next highest half vehicle for two-way lines or whole vehicle for one-way lines. The optimal headway is simply the travel time plus the minimum layover divided by the number of vehicles. If this headway is less than the minimum headway, the final headway is set equal to the minimum headway, and the appropriate layover is added to the travel time.

TRANSIT ACCESS LINKS

NCTCOG has developed software that automatically generates walk- and auto-access links for transit networks. The automation of this process is important because the Mode Choice Model considers transit to be an option up to very large maximum distances for transit access. Transit networks use maximum access distances of 2.5 miles for walk links and 15.0 miles for auto-access links to transit. These distances represent the point at which the probability of transit use approaches zero. More discussion on this issue is included in the Mode Choice section of this report. These large maximum distances lead to a very large number of access links that would require an unacceptably large effort to code manually. Development of the program involved several iterations in which preliminary versions were used with test network. Systematic deficiencies in the generated links were identified, and the program was updated to include additional rules and/or user-supplied parameters to better replicate manual adjustments.

This process has resulted in a program that considers a wide variety of influences on the selection of access links and that replicates manual coding results to a very large degree. Application of the program reduces the necessary manual coding effort to the removal of walk-access links that cross physical barriers (e.g., rivers) and a general review of the remaining links.

Connection Criteria

The overall goal for the criteria built into the automatic access coder was to replicate to the extent possible the rules used in manual coding of access links. Some of these rules were well established and were included in the earliest versions of the program. Others were more subtly embedded in the judgment of the coding staff and emerged only through the reviews of the links generated by early versions of the program. The final criteria embedded in the program include the following considerations:

a) To ensure adequate connection of each zone to all transit modes, the program does entirely separate analyses of walk-access to local and express services. The program generates for each zone one set of walk-access links to nodes served by local bus routes and a separate set to nodes served by express buses and rail lines. Thus, the program can reach beyond nearby "local" nodes to connect the zone to more distant "express" nodes or rail stations that are within the maximum walk-access distance.

b) The program attempts to provide a wide dispersion of access links in terms of direction from the zone centroid. It avoids the generation of links connected to nodes that are near to each other, unless one of the nodes is "local" and the other is "express."

c) To avoid software revisions to other programs used for transit network processing and to avoid unnecessary time and cost in processing superfluous access links, the program generates a maximum of four walk-to-local links, four walk-to-express links, and four drive-access links.

d) A high priority for connection with a walk-access link is any stop node at which transit lines intersect. This priority arises because a single connection to an intersection node makes walk access possible to more than one transit line, reducing the need for transfers and generally increasing the accessibility of the network.

e) Similarly, the program gives priority to rail stations for connection with walk access links. This priority reduces the chances that travelers from a zone have to use an unrealistically short bus trip to reach the rail station, when a slightly longer walk would bring them directly to the station.

Together with the user-specified parameters, these considerations make possible the automatic generation of access links that closely reflect the judgment of the user.

Search Logic

For each zone in the region, the program uses two separate phases to generate (or pass) access links for a transit network. The first phase identifies a set of candidate nodes that qualify for connection with access links. The second phase then selects the optimum set of these nodes and generates the links.

For each zone in the region, the program first identifies three sets of candidate nodes: walk-to-local, walk-to-express, and drive access. Each set contains up to eight nodes, one in each of the octants of a coordinate system constructed with origin at the zone centroid.

For walk access, the program scans the entire list of transit nodes in the network and evaluates each stop node as a possible candidate for generation of a walk-access link. The program computes the straight-line distance between the zone centroid and the node and determines the octant in which the node lies. If the distance is less than the maximum walk distance, the program determines whether the node is the best candidate found thus far in the octant using three classes of priorities:

1) Rail stations have the highest priority. The program selects the nearest rail station node in an octant, even if other stop nodes are nearer the centroid, so long as the station is within the maximum threshold distance for rail station priority. The program always treats rail stations as express nodes.

2) Intersection nodes have the next highest priority. The program selects the nearest intersection node, even if other stop nodes are nearer the centroid, so long as the intersection node is within the maximum threshold distance for intersections and there is no rail station available in the octant. The program may treat intersection nodes as either local or express, depending on the services available at the node.

3) All other nodes have the third priority. The program selects the nearest stop node, in the absence of rail and intersection nodes. These nodes may also be either local or express, depending on the service available at the node.

The program finds the most desirable candidate node in each octant by evaluating all stop nodes in the network. For drive access, it similarly evaluates all valid drive-access nodes in the region, first checking that the area type of the zone permits drive access.

In the second and final phase, the program evaluates the set of candidate nodes and selects the subset of nodes that provides best access from the zone. It is important to recognize that this evaluation considers all of the nodes in the set together, not just each node by itself. Therefore, a network revision that provides service to a node may revise the entire set of access links for the zone, rather than simply generating a single additional access link.

For all three sets of candidate nodes, the program uses three steps to select the final nodes for connection.

1) The program assigns a score to the node in each octant depending on its relative proximity to the zone centroid compared to the nodes in adjacent octants. If the node is nearer the centroid than the nodes in either adjacent octant, the program assigns the node a score of two. If the node is closer than the node in one adjacent octant, the program assigns a score of one. If the node is not closer than the node in either adjacent octant, the program assigns a zero. The program then tentatively marks all nodes with scores of zero for deletion from the candidate nodes.

2) The program then scans the remaining nodes, selecting the most attractive and (for walk access only) tentatively marking for deletion the nodes in its two adjacent octants. This selection again uses the three priority groups, choosing rail stations first in order of increasing distance, then intersection nodes in order of increasing distance, and then all other nodes again in order of increasing distance. It continues this scan until all nodes have either been selected or deleted. For drive access, the program does not delete nodes in octants adjacent to selected nodes, provided that the selected node lies beyond a specified threshold distance from the zone. This feature permits the generation of drive-access links in adjacent octants from zones outside of the immediate transit service area. Access in these peripheral areas generally lies in one direction

(towards the CBD), and the no-adjacent-connector rule tends to limit the generation of otherwise reasonable links.

3) Finally, the program then makes a final scan of the tentatively deleted nodes to identify any "gaps" in the selected nodes that can be in-filled. A gap occurs where there are three (or more) adjacent octants without selected nodes. If a node exists in the center octant in this gap, the program adds this node to the set of selected nodes.

The program calculates the length for walk access links as a straight-line distance between the zone centroid and the transit boarding node. The straight-line calculation of walking distances tends to better represent the rather extensive underground pedestrian walkway system located in downtown Dallas. The orthogonal distance is used for auto access links. Auto access link speeds are the same as those used in the roadway network; they vary by area type and time-of-day as shown in Table 27. A speed of 3.0 mph is assumed for walk access links.

TABLE 27

DRIVE ACCESS LINK SPEEDS (MPH) BY TIME OF DAY

Area Type	Peak	Off-Peak
1	11.0	15.0
2	13.0	23.0
3	17.0	27.0
4	21.0	33.0
5	23.0	39.0

TRANSIT PATH-BUILDING

The transit path-building program (TSKIM) employs a unique algorithm to generate multiple transit paths for each zone-to-zone interchange. The program is capable of generating up to seven alternate paths. The current practice at NCTCOG is to build a total of four paths for each interchange (by mode of access and time of day). The best path is the minimum impedance path which is used by the Mode Choice Model. The collection of the four paths used in the transit assignment procedure guarantees smoother assignment among various lines.

General Characteristics

The minimum impedance path is generated in a manner similar to that employed by the program UPATH in the Urban Transportation Planning System (UTPS). Tables 28 and 29 present the weights placed on the various components of transit travel to generate reasonable paths. These parameters were validated by checking, for a sample of interchanges, the paths generated by the program versus the paths reported by travelers in the 1984 On-Board Survey.

Transit paths are built in two steps. The preprocessor (TPATH) converts the two-way link file into a one-way file used in path-building procedures. The creation of one-way transit links is more complicated than highway links because of the transfer considerations used in transit path-building. In the highway paths, the choice of the next link is virtually independent of the previous link. In the transit path, the choice of the next link is dependent on the mode of the previous leg. The purpose of TPATH is to convert the two-way links of a transit line into unique and independent one-way legs. A leg is a potential boarding and alighting pair. The path-building program can

TABLE 28

TRANSIT PATH-BUILDING IMPEDANCE COEFFICIENTS PEAK PERIOD

	Walk Access	Drive Access	CBD Walk	Ft Worth Local	Dallas Local	All Express	Rail
Value of Time (1)	10.00	4.00	10.00	4.00	4.00	4.00	4.00
Value of Cost (2)	0.00	0.00	0.00	1.30	1.30	1.30	1.30
Value of Wait Time (1)	0.00	0.00	0.00	8.00	8.00	8.00	8.00
Value of Transfers (3)	0.00	0.00	0.00	0.33	0.33	0.33	0.33

TABLE 29

TRANSIT PATH-BUILDING IMPEDANCE COEFFICIENTS OFF-PEAK PERIOD

	Walk Access	Drive Access	CBD Walk	Ft Worth Local	Dallas Local	All Express	Rail
Value of Time (1)	10.00	4.00	10.00	4.00	4.00	4.00	4.00
Value of Cost (2)	0.00	0.00	0.00	2.70	2.70	2.70	2.70
Value of Wait Time (1)	0.00	0.00	0.00	8.00	8.00	8.00	8.00
Value of Transfers (3)	0.00	0.00	0.00	0.68	0.68	0.68	0.68

Units:
1 - $/Hour
2 - $/$
3 - $/Transfer

therefore assume that using a leg will require some type of transfer activity at the first node and the end node.

The first step in leg-building is to determine which stop nodes provide the potential for a transfer. Transfer nodes must have three legs, the end of a line, or an approach link attached to them. After the transfer nodes are found, all logical combinations of links between transfer nodes of one line are generated. The length, travel time, and frequency of service of each leg is stored. TPATH also determines the fare district of each end of the leg. The file is then sorted by node numbers and mode in preparation for TSKIM.

The link processing in TSKIM must first combine common legs from various lines into a single link. The interchange is combined by mode in order to avoid transfer impedance confusion later in the process. The level of service and frequency of each line serving the interchange is summed. The average travel time and distance is used to approximate the combined alternative. The result is a composite leg for each mode alternative between the two points. It should be noted that this technique does not require that the individual lines serving the interchange use the same route. The assumption is that a person waiting to board a particular mode will board the first line that serves that destination in question regardless of the route it takes. This technique, at best, approximates the complex decision-making process of transit patrons.

The program then finds three alternative paths with a set of heuristic rules that define the possible deviations from the best path. To find the first and second alternative paths (if they exist), the program traces back from the destination zone along the best path, looking for a "deviation node." A deviation node occurs where there is an alternative way back to the origin zone that is not the best path and that has no more than two legs—one transit leg and one access leg (the centroid connector). The first deviation node encountered (if any) becomes the basis for the first alternative path, and the second deviation node (again, if any) is the basis for the second alternative path. These rules lead to first and second alternative paths that use the same transit lines as the best path for most of the trip but depart from the best path in the specific access links that they use. To find the third alternative path, the program first eliminates from consideration the centroid connector at the destination zone that was part of the best path. It then scans the nodes linked to the destination zone by the remaining connectors to find the node with the minimum impedance back to the origin zone. These rules force a path that differs from the best path at least in terms of egress characteristics. In application, the third alternative path often uses entirely different transit lines compared to the best path and therefore represents a different line-haul alternative as well.

The path-builder generates zone-to-zone impedance files that include the individual (unweighted) components of travel time, distance, and cost for the best path plus the (weighted) total impedance for all four paths. Therefore, the characteristics of the best path are available for use in the Mode Choice Model; the total impedances are used in a path choice model to allocate estimated transit trips across the four available transit paths.

NCTCOG builds one set of walk-access paths and one set of drive-access paths in both the peak and off-peak periods. As a result, up to eight transit paths represent the transit options that exist for each zone-to-zone interchange in the region. A path choice model, included in the program that applies the Mode Choice Model, allocates the forecast transit trips (by access mode) across the available paths.

Wait Time

The value of wait time is calculated from the combined headway of the leg based on the random arrival theory. The value used for the first wait time is the minimum of half the headway, ten minutes plus one-sixth of the headway, or 15 minutes.

First Wait Time = Min [1/2 headway, 10 min + 1/6 headway, 15 min]

The cap of 15 minutes for the first wait time is based on the assumption that transit patrons are aware of the bus arrival schedule and do not arrive at the bus stop sooner than 15 minutes prior to the scheduled boarding time. The cap protects the user against the assignment of an unreasonable wait time for buses with low frequency of operation or the "trippers" by assuming half of their headways as the riders' wait time. No upper limit is assumed for the transfer wait time since riders have no control over their arrival time and the headway of the bus to which they intend to transfer. Therefore:

Transfer Wait time = 1/2 headway

Timed-transfer centers may be modelled by assigning a maximum wait time value at designated "pulse" nodes. The cap is applied to the transfer wait time only; first boarders' wait time remains a function of the headway of the line haul mode.

Fare Structures

The value of cost parameter is applied as a function of the fare structure. TPATH defines the fare districts. TSKIM defines the fare structure and the fare. Various fare structure techniques are available in TSKIM. It is generally necessary to combine several techniques in order to simulate most fare policies.

A zone-based fare structure with the same fare charged for all modes within a given district is the simplest and most common structure used in simulation runs. In this case, a district-to-district fare matrix needs to be defined with the appropriate fare values. The program assesses the fare for a particular zone-to-zone transit trip based on the fare districts of the origin and the final destination of that trip regardless of the intermediate stops and transfers. A flat fare structure may be simulated by defining the entire service area as one district with the intradistrict fare equivalent to the system's flat fare.

Transfer fares may be modeled using the mode-to-mode "transfer matrix" for each district. Transfers are usually uniform across all fare districts.

In modeling a mode-specific fare structure, in addition to the use of the origin-destination fare matrix, a "surcharge" should also be applied to the modes requiring higher fares. The surcharge should be coded in the "link fare" matrix and be applied to the first boarders (walk or drive modes) to the line haul modes (modes 4, 5, 7, and 8).

Alternate fare collection techniques include a distance-based fare and a minimum fare. The distance-based fare is charged based on the destination district, mode, and length of each link. The total fare is, therefore, the sum of the link fares. The minimum fare is charged based on the destination district, mode, and cumulative fare. If the fare between the origin and destination is less than the minimum, the fare and corresponding impedance is increased to the minimum. Many distance-based fare policies include a minimum charge for short trips. The combination of these two techniques allows for this policy.

Search Logic

In a manner analogous to the highway path-builder (TREBLD), TSKIM processes each leg leaving the minimum cumulative impedance node before it examines the next node. Using the "bush" method with transit legs will produce a large set of pending nodes much more quickly than highway links. The total path can be described with only three to five transit legs. Even though a particular origin will examine numerous unnecessary links to the same node, some of these links may be the best link for a different origin and therefore cannot be eliminated from the file.

TSKIM is designed to permit multiple path options. The user can specify up to seven paths constructed from second or third best node sequences. The paths are subsets defined by access and egress alternatives. The first path is the best path. The second through fourth paths are constructed from the set of second best nodes. The order of inclusion can be defined as:

1) The first alternate node closest to the destination which is or whose next leg is an approach link

2) The next alternate node after the first mentioned above which is or whose next leg is an approach link

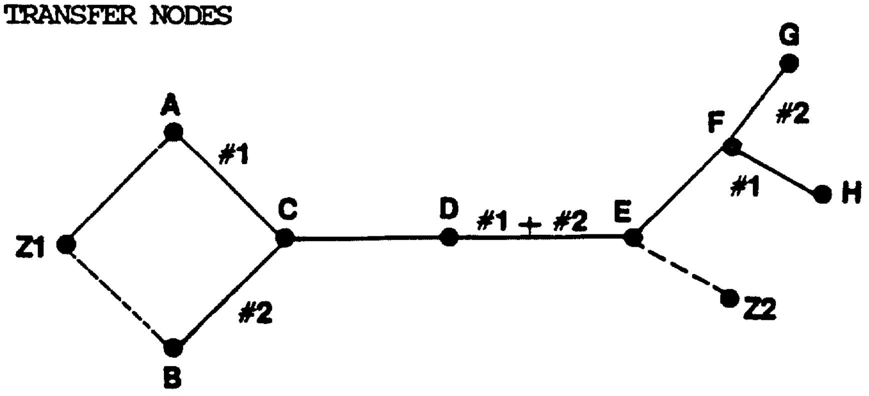
3) The first alternate approach link to the destination

The first two alternates approximate a distribution of access links, and the third alternate is an egress option. Paths five through seven use the same inclusion technique with the third best node sequence.

After the best and alternate paths are constructed, the path summary files and reports are generated. The node and mode string representing the best path is stored for path-loading. The second and third best alternate branching nodes are saved as needed. From these three arrays, up to seven paths can be reconstructed during path-loading. The zone-to-zone summary files are also generated. Mode split requires, at a minimum, the impedance and access codes for each path requested. Access codes include the access mode and link number, the first transit mode, and the last transit mode. Mode Split also needs a skim of the in-vehicle travel time, distance, cost, out-of-vehicle travel time, principle mode (i.e., the mode with the greatest cumulative contribution to distance), and number of transfers. This data is available only for the best path. They are assumed transferable to all other paths. The impedance accounts for the variations in these parameters and is therefore slightly more accurate for submode splits. It is also possible for the impedance of an alternate path to be less than the "best" path because of the transfer consideration mentioned above. The multiple-path technique can, therefore, help minimize transfer bias in path selection.

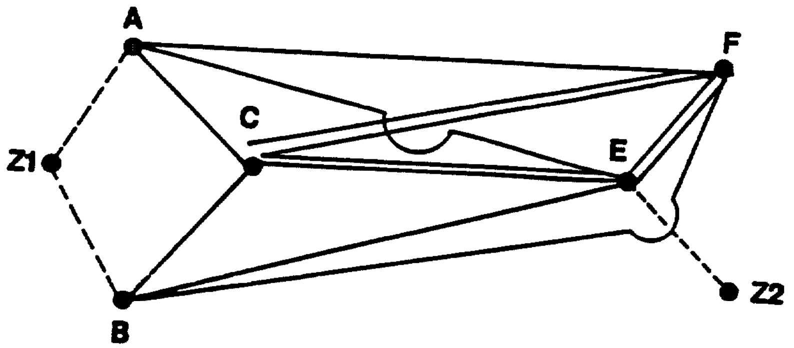
The remainder of this section will attempt to diagram simple examples of transit path-building. Each step in the process will be presented independently.

STEP 1: TRANSFER NODES



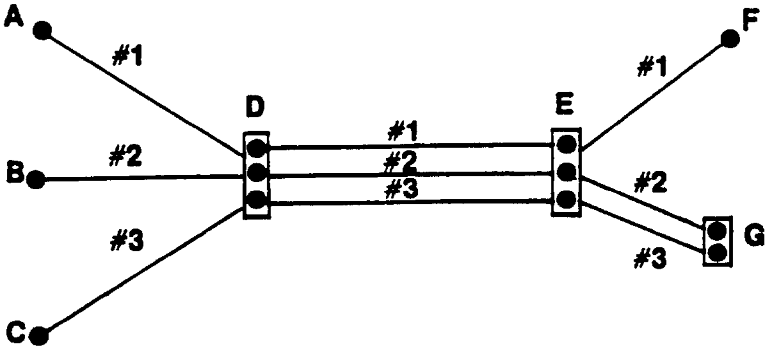
This diagram represents two transit lines and two zones. The transfer nodes are A, B, C, E, and F. A, B, and E are included because they connect with approach links. C and F are branching points.

STEP 2: LEG CONSTRUCTION



After the nontransfer nodes are removed, the STEP 1 example is converted into unique legs as shown in the diagram above.

STEP 3: LEG COLLAPSING



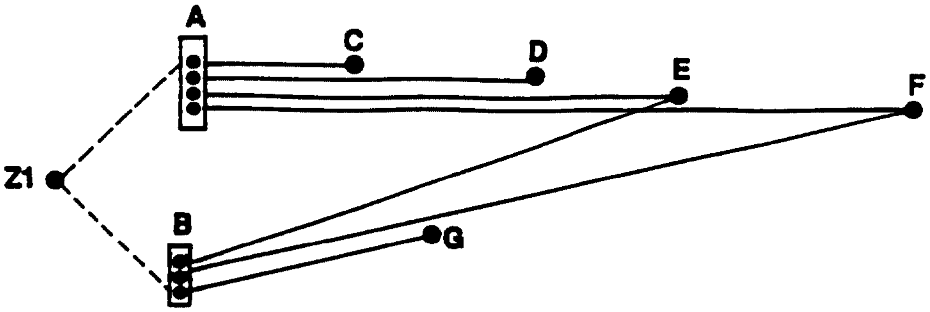
The above network will be used to demonstrate various collapsing situations:

1) If lines 1, 2, and 3 are all of the same mode, leg D-E would have the combined frequency of lines 1, 2, and 3, and legs E-G and D-G would have the combined frequency of lines 2 and 3. All other legs would remain the same.

2) If line 3 is of a different mode than lines 1 and 2, two legs between D-E, E-G, and D-G would be kept. One of the legs between D-E would be the combined frequency and mode of lines 1 and 2. The other would be the frequency and mode of line 3.

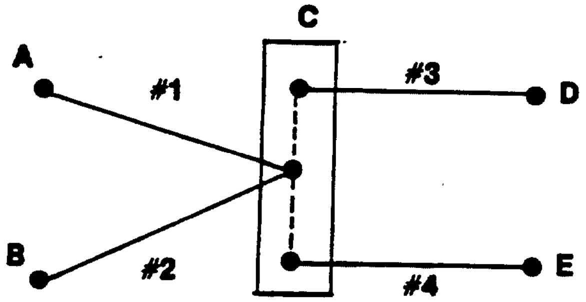
3) If line 3 did not pass through or stop at node E but all lines were the same mode, leg D-E would be the combined frequency of lines 1 and 2, and leg D-G would be the combined frequency of lines 2 and 3. All other legs would remain the same.

STEP 4: BEST PATH-BUILDING



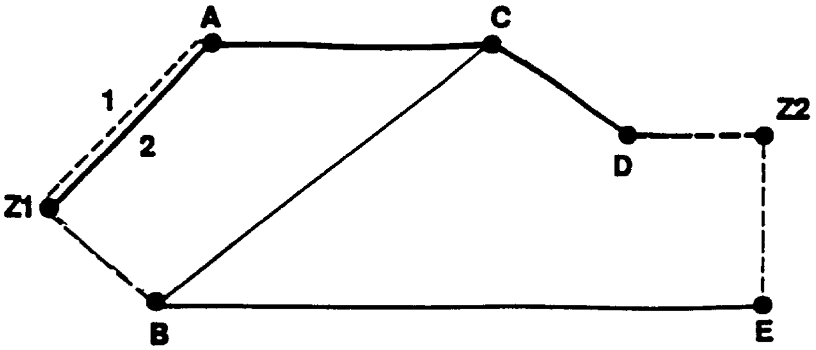
The two approach links Z1-A and Z1-B would be processed first. If Z1-A had the lower impedance, the links from node A to nodes C, D, E, and F would be processed. If the impedance to B was still the next lowest cumulative impedance, the links from B to G, E, and F would be considered. Since E and F were included when node A was processed, an impedance comparison would be made between path Z1-A-E and Z1-B-E and Z1-A-F and Z1-B-F. The best of each path would be preserved in the minimum cumulative impedance array. Because the previous link for both path options is an approach link, the second best path would be saved for alternate path-tracing.

STEP 5: TRANSFER CONSIDERATION



In the above example, lines 1 and 2 are potential paths to node C, and lines 3 and 4 are potential paths leaving node C. Suppose line 1 was the minimum impedance path to node C. When node C is ready to be processed, the transfer impedance from line 1 to lines 3 and 4 are added to the link impedance of each leg. This plus the cumulative impedance to reach node C is the impedance required to reach node D or E, respectively. If the transfer impedance between the modes of line 1 and line 3 is very large while the transfer impedance between the modes of line 2 and line 3 is small, potential path bias may occur. In other words, if the difference between the cumulative impedance required to reach mode C by way of A or B is less than the difference in the transfer impedance of path A-C-D versus B-C-D, the best path to D will not be the absolute minimum cumulative impedance path.

STEP 6: ALTERNATE PATH CONSTRUCTION



In the network above, the best path is the drive approach link (mode 2) path Z1-A-C-D-Z2. The first alternate path diverts at the last node with an alternate path whose leg or previous leg is an approach link. In this example, the second path is Z1-B-C-D-Z2 because B-C is the last alternate path. Notice that Z2-E is classified as an egress option and therefore not considered in the access alternative analysis. The third path would be the walk approach link (mode 1) path Z1-A-C-D-Z2 because this is the second to last alternate path whose leg or previous leg is an approach link. The fourth path is the egress option Z1-B-E-Z2.

MODE CHOICE

The Mode Choice Model applies the multinomial logit structure with a market segmentation strategy that portrays various travel markets in significantly more detail than is usually done. This approach departs from usual practice in the explicit treatment of travelers with limited choice sets, in the size of the walk- and auto-access markets around the transit system, and in the assumption that auto access competes with walk access within the walk-access market.

Because of the unique features of the Mode Choice Model, it is useful to organize its description in terms of seven characteristics: Model's mathematical structure, trip purposes and choice sets, limitations on choice sets for individual travelers, analysis of transit access, treatment of HOV lanes, stratification by income group, and analysis of alternative transit paths.

Multinomial Logit Structure

The multinomial logit formulation is, by a wide margin, the most commonly used model form for operational mode choice models in the United States. The multinomial logit model is formulated as shown below:

$$P_{g,i} = \frac{\exp[U_{g,i}(x_{g,i})]}{\sum_{m} \exp\,[U_{g,m}(x_{g,m})]}$$

where:

$P_{g,i}$	is the probability of a traveler from group g choosing mode i,
$x_{g,i}$	are the attributes of mode i that describe its attractiveness to group g,
$\sum_{m}$	indicates the summation of utilities over all available alternatives.
$U_{g,m}(x_{g,m})$	is the utility, or attractiveness, of mode m for travelers in group g, and

Typically, the utility function for each alternative takes the form

$$U_{g,m}(x_{g,m}) = a_m + b_m \mathrm{LOS}_m + c_{g,m} \mathrm{SEC}_{g,m} + d_m \mathrm{TRIP}$$

where:

a_m	is a constant specific to mode m that captures the overall effect of any significant variables that are missing from the expression (comfort, utility, safety, and so forth),
b_m	is a vector of coefficients describing the importance of each LOS_m variable,
LOS_m	is a set of variables describing the levels-of-service provided by mode m,
$c_{g,m}$	is a vector of coefficients describing the importance of each $\mathrm{SEC}_{g,m}$ characteristic of group g with respect to mode m,
$\mathrm{SEC}_{g,m}$	is a set of variables describing the socioeconomic characteristics of group g with respect to mode,
d_m	is a vector of coefficients describing the importance of each TRIP characteristic with respect to mode m, and
TRIP	is a set of variables describing characteristics of the trip (CBD-orientation, for example).

Trip Purposes and Choice Sets

Figure 11 presents the structure of the Mode Choice Model for each of the three trip purposes. The HBW model includes the greatest detail in the depiction of the alternative modes. It considers discrete occupancy levels as alternatives in order to permit analysis of alternative occupancy requirements for HOV lanes. It also considers walk- and auto-access to transit to be distinct alternatives in order to provide a better representation of the trade-offs between access modes, clearer analysis of passenger facilities at transit stations, and recognition of capacity constraints at stations.

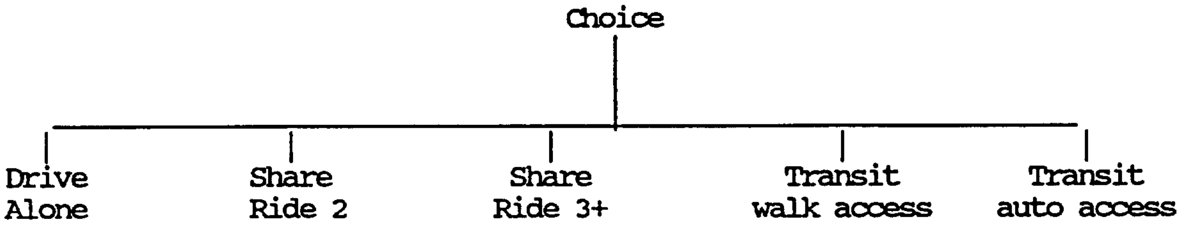
The inclusion of several alternatives that might be considered "submodes" raised concerns during the calibration phase on the validity of the structure. These concerns were that the individual occupancy levels and the transit-access options might violate the "independence of irrelevant alternatives" (IIA) property of the multinomial logit model. This property assumes that each of the alternatives in the choice set is equally competitive with the others—that their are no groups of alternatives that share characteristics. Tests for these violations during model calibration identified no instances in which the calibrated coefficients in the models were affected by any violation of the IIA assumption.

The HNW model is similar to the HBW structure but aggregates the ridesharing options into a single alternative. This simplification presumes that the important market for HOV lanes is work travel and that few nonwork travelers will choose an occupancy level based on the presence of an HOV lane. The continued representation of both transit-access modes reflects a review of the On-Board Survey data that indicated a substantial number of auto-access transit trips for HNW trips.

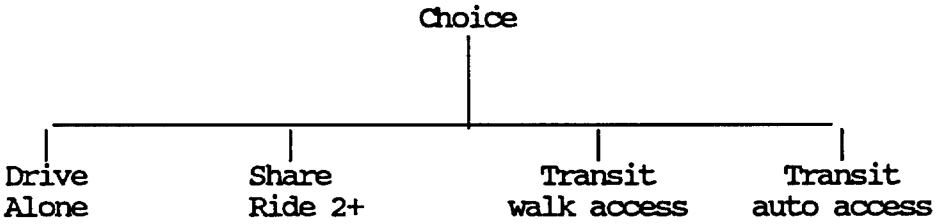
FIGURE 11

STRUCTURES OF PURPOSE-SPECIFIC
MODE CHOICE MODELS

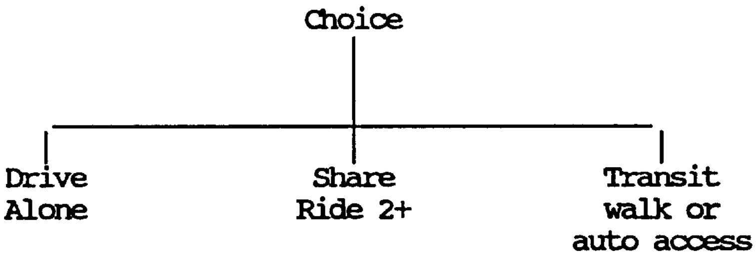
Home-Based Work



Home-Based Nonwork



Nonhome-Based



Finally, the NHB model considers the simplest set of modal alternatives, aggregating the ridesharing and transit-access options. This specification reflects the limited number of NHB transit trips in the On-Board Survey for NHB purposes.

Limitations on Choice Sets (Captivity)

While Figure 10 identifies the modal alternatives that are generally available to a traveler for each trip purpose, it says nothing of the variations in the choice set that might occur for individual travelers. Three types of limitations are possible. First, the individual may be making a trip for which transit service simply does not exist (situational captives). This case, which received intense scrutiny in the course of the analysis, is the focus of discussion in the next section. Second, the traveler may not have the means to use one or more of the modes; persons without access to a car are unable to drive alone (economic captives). Finally, various constraints may require the traveler to use a particular subset of the modes. Persons who need a car at their workplace, for example, likely will not use transit and may not rideshare (functional captives).

To screen for such limitations on choice sets, the calibration work on the Mode Choice Model included a review of tabulations of mode shares for a wide variety of subgroups in the survey data. Two groups emerged from this analysis with clear limitations on their choice sets. First, travelers from households without cars make virtually no trips by driving alone or driving to transit. Second, travelers in the "managers and self-employed" occupation group never use either transit mode. Consequently, the calibration effort excluded travelers in both groups from the calibration data and used only those travelers with full choice sets to estimate coefficients. The subsequent model validation work focused much attention on the ability of the resulting models to predict choices for travelers with limited choice sets. The validation work demonstrated clearly that the models developed for "choosers" adequately estimate the mode shares of persons with limited choice sets.

In application, the Mode Choice Model first estimates the fraction of person trips for each zone-to-zone pair that have limited choice sets. The Model uses lookup tables derived from the survey data. Table 30 summarizes the lookup tables for the managers/self-employed group, while Table 31 presents the table for zero-car households. For these two groups, the Mode Choice Model estimates mode shares among the alternatives available to the group, rather than among all of the alternatives.

Transit Access

Calibration of the Mode Choice Model proceeded with a calibration file that assumed all trips to have available both walk and auto access to the transit system. This assumption required that access coding in the 1984 calibration network provide walk- and auto-access links from all zones to the transit system, even if the zones were 30 or more miles from the nearest transit line. The calibration work used this approach for two reasons. First, the distributions of access distances in the On-Board Survey have very long "tails," with travelers' both walking and driving distances that are much longer than the mean distance for each mode. Second, and more importantly, the Home Interview Survey included very few trips that had both origin and destination within a short walking distance of transit. A tight definition of walking distance would have eliminated the transit alternatives for the large

TABLE 30

MANAGERS/SELF-EMPLOYED CAPTIVITY RATES
PERCENT TRIPS BY: TRIP PURPOSE, INCOME, AND AREA TYPE AT WORKPLACE

Home-Based-Work

Area Type at Workplace	Income Quartile			
	1	2	3	4
1. Central Business District	0	0	12	11
2. Outer Business District	3	9	14	12
3. Urban Residential	1	15	12	20
4. Suburban Residential	6	15	17	19
5. Rural	9	19	20	33

Home-Based Nonwork

Area Type at Workplace	Income Quartile			
	1	2	3	4
1. Central Business District	0	0	17	0
2. Outer Business District	0	19	7	8
3. Urban Residential	1	7	6	7
4. Suburban Residential	3	6	6	6
5. Rural	0	3	6	9

TABLE 31

ZERO-CAR HOUSEHOLD CAPTIVITY RATES
PERCENT TRIPS BY: TRIP PURPOSE, INCOME QUARTILE, AND TRANSIT AVAILABILITY

Home-Based Work

Transit Availability	Income Quartile			
	1	2	3	4
Transit serves trips within 0.3 mile radius on the production end	48	0	0	0
Transit serves trips within 0.3 - 0.5 mile radius on the production end	1	0	0	0
Transit serves trips within 0.5 - 2.5 miles radius on the production end	7	0	0	0

Home-Based Nonwork

Transit Availability	Income Quartile			
	1	2	3	4
Transit serves trips within 0.3 mile radius on the production end	21	0	0	0
Transit serves trips within 0.3 - 0.5 mile radius on the production end	1	0	0	0
Transit serves trips within 0.5 - 2.5 miles radius on the production end	5	0	0	0

majority of observations from the Home Interview Survey. This loss would have resulted in a calibration file drawing almost all observations with transit options from the On-Board Transit Survey. Since the calibration file would have included few auto travelers who had a transit option available, it became uncertain that such a file would provide sufficient data on modal trade-offs to support the calibration work. These observations suggested clearly that the maximum distances should be set much longer than typically found in transit networks.

In application, transit networks use maximum access distances of 2.5 miles for walk links to and from transit and 15.0 miles for auto-access trips to transit. These distances represent the point at which the probability of transit use, estimated by the Mode Choice Model, approaches zero. Consequently, while the coding convention for application is more restricted (and much easier to implement) than that used in calibration, the practical implications of this restriction are negligible.

Transit Coverage: Market Segmentation of Zones

To avoid the aggregation error inherent in the use of a nonlinear model over a large walk-to-transit area in each zone, a preprocessor to the Mode Choice program first segments each zone into three walk markets. The preprocessor defines these markets as aggregations of TSZs used to describe population, employment, and trip ends. There are, on average, eight TSZs in each of the region's 800 zones. The preprocessor defines the three walk markets within each zone by grouping the TSZs in the zone according to their walk distance from transit service.

The Mode Choice Model consider a walk-access market that ranges up to 2.5 miles from transit. The survey data used in calibration of the models included the specific TSZs of both the origin and destination of each trip. Because the trip ends were associated with specific TSZs rather than the larger TAP zones, it was possible in calibration to portray walk-access and walk-egress distance with more precision than is usually possible with zone-level impedances.

The 2.5-mile maximum walk distance presents some difficulties in application, however. Chief among these is the concern that the use of zone-level walk distances will create aggregation errors in the forecasts. Aggregation errors occur when nonlinear models are calibrated with disaggregate data but then applied in forecasting with aggregate data. Since the Mode Choice Model uses the nonlinear multinomial logit formulation, it would be risky to apply the Model with aggregate walk-access and walk-egress markets of up to 2.5 miles across.

To avoid these risks, a preprocessor program is used in conjunction with the Mode Choice Model to partition the walk-access market within each TAP zone in a way that minimizes the effects of aggregation error. The strategy used by the program is to group the TSZs within each zone into a maximum of three walk-access partitions so that the TSZs within each partition have walk distances that are as similar as possible. The Mode Choice Model then evaluates separately the mode shares of trips produced by and attracted to each of the walk-access partitions, using the walk times specific to each of the partitions. This strategy ensures that the Mode Choice Model is applied to walk-access and walk-egress markets that are as homogeneous as possible. The increased homogeneity of the markets, in turn, minimizes the degree to which the average walk-access time for each market might badly overstate or understate the actual walk times for any trip within the markets.

Criteria for Aggregation of TSZs in the Walk Market

The best measure of the homogeneity of TSZ groupings for this application is the sum, across all groups, of the variance around the mean walk-access distance within each group. The variance within a group is, by definition:

$$\text{Variance}_g = \frac{\sum_{t=1}^{N} (D_t - D_{avg})^2}{N-1}.$$

where:

D_t is the walk distance from the TSZ centroid to the stop node,

D_{avg} is the average zonal walk distance to the stop node, and

N is the number of TSZs in the zone.

If all of the TSZs within the group have nearly the same walk distance to the transit stop, then the variance for the group will be very small. If a similar degree of homogeneity exists for all of the groups within the zone, then the sum of the variances across the zone will also be small.

For example, one possible grouping scheme in a zone with ten TSZs would be to place the four TSZs nearest the transit stop node into the first partition, the three next closest TSZs into the second partition, and the last three (most distant) TSZs into the third. The variance for the first partition would be computed with the equation above, using the distance from each of the four TSZ centroids to the transit stop node and the average of these four distances. The variance for each of the other two partitions would be computed similarly. The sum of the variances computed for each of the three groups would then represent the degree of homogeneity of this particular grouping scheme for the TAP zone. To identify the best grouping possible, it is necessary only to evaluate the total variance for all possible groupings of the ten TSZs. The best grouping is the one that has the lowest total variance.

Because the program describes the walk-accessibility of trip ends to the transit network, each alternative transit network requires three separate applications of the program—one for the trip ends associated with each trip purpose. Within each application, the program uses four steps to create a file that describes the walk accessibility for each zone to transit.

Step 1. For each zone, the program first determines whether the zone has more trip productions or more trip attractions. This permits the determination of groupings within each zone in a way that recognizes the primary character of the zone. The program determines groupings for zones that are primarily residential areas on the basis of the trip productions in each TSZ, while it determines groupings in employment and commercial areas on the basis of trip attractions.

Step 2. The program then selects the first stop node to which the zone is connected with a walk access link in the transit network. For each TSZ in the zone, it computes the straight-line distance between the TSZ centroid and the stop node. Depending on this distance, the program then classifies the TSZ into one of 11 distance intervals. The first ten of these intervals represent 0.25-mile increments in walk distance, ranging between zero and the maximum 2.5-mile walk distance. The eleventh interval represents areas of the zone that are beyond walking distance to the transit stop node. When this step is completed, the program has allocated each TSZ in the zone to one of the 11 intervals.

Step 3. In the third step, the program compresses the 11 walk intervals into the four partitions—three representing walk-access of increasing distances and the fourth representing portions of the zone beyond the maximum 2.5-mile walk-access distance. To compress the ten intervals within walking distance, the program constructs all possible groupings of the ten intervals and computes the variance for each. In many zones, this problem is quite simple. If all TSZs in the zone fall into three or fewer intervals, then each interval becomes a walk-access partition. As the number of intervals with TSZs grows, however, the problem requires longer to solve. The maximum size of this problem occurs when each walk-access interval has at least one TSZ. In this case, there are 36 alternative groupings of the ten intervals into three partitions. It is useful to represent each grouping as a three-digit number, with the digits indicating the number of intervals grouped into the first, second, and third partitions, respectively.

Possible groupings when TSZs are found in all ten intervals:

811
721 712
631 622 613
541 532 523 514
451 442 433 424 415
361 352 343 334 325 316
271 262 253 244 235 226 217
181 172 163 154 145 136 127 118

The problem requires fewer computations as the number of intervals with TSZs becomes smaller. For example, when six intervals have TSZs, there are only ten possible groupings.

Possible groupings when TSZs are found in six intervals:

```
411
321  312
231  222  213
141  132  123  114
```

The program repeats Steps 2 and 3 for each transit stop node to which the zone is connected with a walk-access link.

Step 4. Finally, the program computes the aggregate characteristics of the households, employment, and trip ends across the TSZs in each walk-access partition. It writes an output file that includes one record for each zone. On each record, the program writes: zone number, terminal times, parking cost, area type, and transit stop nodes to which the zone is connected.

For each stop node, it stores: average walk distance to each partition; average autos per household, for each partition; average autos per person, for each partition; flag indicating high incidence of zero-car households; trip productions by income group, for each partition; and number of attractions, for each partition.

For zones that are not walk-connected to the transit network, the program writes zonal totals into the fields normally used to represent access to the first stop node and flags the zone as not-walk-connected.

Beyond the general appeal in this procedure's ability to reduce problems caused by aggregation bias, the procedure largely overcomes a long-standing problem with representation of walk access in zones with rail stations. The conventional approach to coding walk access involves manually-developed estimates of the share of each zone's trip ends that are within walking distance of transit. This convention has difficulties in zones with rail stations, however. Most rail stations are served by significant numbers of feeder bus lines--particularly those stations in the larger zones found in suburban areas. Consequently, most or all of the trip ends within the surrounding zones have walk-access to some transit service. For many trip ends, however, this walk access is to a feeder bus, not the rail station itself. The difficulty arises because the minimum impedance path often, perhaps usually, uses the direct walk connection to the station. The resulting path represents the service available only to those trip ends within walking distance of the station itself and omits the additional time and fare associated with the feeder bus access that must be used by most of the trip ends in the zone. The access coding and path-building therefore overstate the overall quality of transit service available to trips to and from the zone.

The recommended procedure largely solves this problem. When the best path involves direct walk access to the station, the three walk-access markets around the station accurately portray the distribution of walk-access distances to the station. The Mode Choice Model can therefore evaluate accurately the higher transit shares likely in areas immediately adjacent to the station, and the decline in transit share that occurs as the walk distance becomes larger.

High Occupancy Vehicle (HOV) Lane Impacts

To permit analysis of HOV lane impacts on ridesharing, the Mode Choice Model is capable of reading two sets of highway impedances. One set represents the highway travel times available to travelers in the mixed-flow traffic, while the second recognizes the reduced travel times available to travelers with occupancies that qualify for the HOV lanes. The Mode Choice Model assigns the appropriate travel time to each occupancy alternative and computes mode shares that recognize the impact of HOV time savings. Further, the attributes of the occupancy levels that qualify for the HOV lanes include a variable that represents the improved reliability of travel time on the HOV lane. The coefficient on this variable takes a value that is transferred from the Shirley Highway HOV models in suburban Washington, D.C. The reliability variable plays an important role in the Shirley Highway models in explaining the share of work trips that use the HOV lanes. Without this variable, it appears that mode choice models will underestimate significantly the likely volumes on HOVs on reserved facilities.

The borrowed coefficient does not reflect D.C.-specific carpooling characteristics and incentives (such as high parking costs, federal government carpool/vanpool programs, etc.), as these variables have their own coefficients in the Shirley Highway model. This coefficient measures only the travel time savings and nothing else; thus, it may safely be imported.

Income Stratification

As discussed previously, the Trip Distribution Model uses a set of income-stratified gravity models to estimate a separate work trip table for each of four income groups. This approach provides substantially more information to the Mode Choice Model than is normally available. The advantage of the income-stratified work-trip distribution is that it recognizes the linkages between households and jobs that are found in the same income strata. The further advantage in the mode choice analysis is that the stratified trip tables provide a specific estimate of the travel patterns of low-income workers. Since virtually all zero-car households are found in the lowest income stratum (at least in most cities outside of New York), this permits the Mode Choice Model to predict the incidence of trips from carless households with greater accuracy.

Model Calibration

Calibration of a Mode Choice Model involves the development of estimated values for the coefficients or weights of the utility equations. Calibration requires data on a sufficient number of travelers that includes descriptions of the modal alternatives available to the traveler, the choice actually made by the traveler, and relevant characteristics of the traveler and the traveler's household. For the Mode Choice Model, the 1984 Home Interview and On-Board Transit Surveys together provided more than 9,000 valid, complete observations on auto and transit trips made in the Dallas-Fort Worth area. The highway and transit networks provided the necessary descriptions of all auto and transit alternatives for travel between the origin and destination of each trip. Since the number of observations available exceeded the number needed for calibration, the calibration file is a random sample of trips drawn within a quota set for each alternative. The sampling strategy was to pull, at random, 400 observations of travelers using each mode. For modes with fewer than 400 trips in the Surveys (3+ occupant autos for work travel, for example), the calibration file includes all of the available observations.

Since the calibration files represent nonrandom samples from the population, the resulting mode-specific constants are biased estimates. A simple adjustment corrects for this bias:

$$a_m^u = a_m^o + \ln \frac{\text{P-share}_m}{\text{S-share}_m}$$

where:

a_m^u is the adjusted, unbiased estimate of the constant,

a_m^o is the biased estimate from calibration with nonrandom data,

$P\text{-share}_m$ is the share of trips on mode m in the population, and

$S\text{-share}_m$ is the share of trips on mode m in the nonrandom sample.

Calibration Strategy

The calibration effort used the mainframe computer program QUAIL to estimate the model coefficients. QUAIL is a widely used program developed by researchers at the University of California at Berkeley. It provides a variety of data-manipulation functions and evaluation statistics. It also accurately handles cases for which only a restricted choice set is available to the traveler.

The calibration effort included the estimation of nearly 100 different model specifications. The overall strategy was to begin with simple specifications that included relatively few variables, and then add both detail and additional variables in well-defined steps. Several tests applied to each additional variable helped to determine the usefulness of the variable in the Model. These tests included:

- Inspection of the sign of the variable's coefficient - Incorrect signs were sufficient cause for deletion of the variable from the Model.
- Tests on the significance of the coefficient estimate - Computed t-scores less than 2.0 led to deletion of the variable unless it played a unique role in the Model. No variables with coefficient t-scores of less than 1.6 (90 percent confidence level) appear in the Model; only two of the coefficients have t-scores less than 1.96 (95 percent confidence).

- Likelihood index tests - These tests use the statistic

  $X^2 = 2\ [LL(m2) - LL(m1)]$,

  where:

  X^2 is a chi-square distributed variable,

  $LL(m)$ is the log-likelihood value at convergence for model m, and

  m2 is a model that adds one or more variables to the specification in model m1.

  The added variables are statistically useful in the Model if the statistic has a value that is larger than the critical value taken from a chi-squared table for the desired confidence level, with the degrees of freedom equal to the number of added coefficients in model m2 compared to model m1. All variables in the Models passed this test.

- Tests for IIA violations - Since the significant implications of IIA violations are biases in the coefficient estimates in the Model, a direct test for IIA problems is the deletion of one or more of the alternatives suspected of IIA violations and reestimation of the model coefficients. Where none of the coefficients exhibits a significant change between the two Models, there is likely to be no significant violation of the IIA assumption. None of the tests for IIA problems in the Models indicated any violation.

Model Coefficients

Tables 32 through 34 present the coefficient estimates for each of the three components of the Mode Choice Model. The Model includes coefficients on four types of variables. The first type includes all variables that describe the transportation system such as times and costs. The coded transportation networks provide most of these variables, with the exception of highway

TABLE 32

Home-Based Work Mode Choice Model
Coefficients and Constants

Variable Description	Drive Alone (Occ. = 1)	Share Ride 2 (Occ. = 2)	Share Ride 3+ (Avg. Occ.= 3.1)	Transit/ Walk Access	Transit/ Auto Access
In-Vehicle Time	-0.02967	-0.02967	-0.02967	-0.02967	-0.02967
Terminal Time	-0.05524	-0.05524	-0.05524	-	-
Access/Egress Time	-	-	-	-0.05524	-0.05524
First Wait Time <=7 min.	-	-	-	-0.05492	-0.05492
First Wait Time >7 min.	-	-	-	-0.02873	-0.02873
Transfer Wait Time	-	-	-	-0.05909	-0.05909
HOV Time Savings per Mile	-	0.13000	0.13000	-	-
Auto Access Deterrent (Auto access time - Transit IVT for nonCBD zones)	-	-	-	-	-0.66040
Fuel Cost/Occupancy	-0.00465	-0.00465	-0.00465	-	-
Fare and Park-&-Ride Fee	-	-	-	-0.00465	-0.00465
Parking Cost/Occupancy	-0.01162	-0.01162	-0.01162	-	-
Dallas CBD - Attraction	-	-0.25890	-0.36268	3.51612	3.23425
Ft. Worth CBD - Attraction	-	0.49175	0.35434	2.66916	1.87084
Income Quartile	-	-	-	-0.10000	-0.10000
Autos/Person	-	-1.25600	-1.25600	-0.72180	-
Autos/Household	-	-	-	-0.86600	-0.52970
Mode-Specific Constants:					
Choosers	0.00000	-0.69356	-1.70519	0.35815	-3.36142
Zero-Car Households	-	-2.07312	-2.26187	3.11799	-
Managers/Self-Employed	0.00000	-1.02428	-1.49155	-	-

Note: Times are in minutes and costs are in cents (1984 Dollars)

TABLE 33

HOME-BASED NONWORK MODE CHOICE MODEL COEFFICIENTS AND CONSTANTS

Variable Description	Drive Alone (Occ. = 1)	Share Ride (Avg. Occ.=2.2)	Transit/ Walk Access	Transit/ Auto Access
In-Vehicle Time	-0.00368	-0.00368	-0.00368	-0.00370
Terminal Time	-0.00736	-0.00736	-	-
Access/Egress Time	-	-	-0.00736	-0.00736
First Wait Time	-	-	-0.01472	-0.01472
Transfer Wait Time	-	-	-0.01472	-0.01472
Fuel Cost/Occupancy	-0.00230	-0.00230	-	-
Fare and Park & Ride Fee	-	-	-0.00230	-0.00230
Parking Cost/Occupancy	-0.00585	-0.00585	-	-
Dallas CBD - Attraction	-	-1.83840	1.66726	0.95850
Ft Worth CBD - Attraction	-	-1.02043	1.35411	0.42254
Rural Attraction	-	0.65920	-	-
Income Quartile	-	-	-0.88450	-0.88450
Autos/Person	-	-0.95360	-0.67800	-
Autos/Household	-	-	-0.26940	-0.26940
Household Size	-	0.25420	0.41890	0.48250
Mode-Specific Constants:				
Choosers	0.00000	0.37545	-2.23464	-4.88123
Zero-Car Households	-	2.75683	3.49634	-
Managers/Self-Employed	-	0.45923	-	-

Note: Times are in minutes and costs are in cents (1984 Dollars)

TABLE 34

NONHOME-BASED MODE CHOICE MODEL
COEFFICIENTS AND CONSTANTS

Variable Description	Drive Alone (Occupancy = 1)	Share Ride (Avg. Occ.= 2.2)	Transit/ Walk & Auto
In-Vehicle Time	-0.01216	-0.01216	-0.01216
Terminal Time	-0.02432	-0.02432	-
Access/Egress Time	-	-	-0.02432
First Wait Time	-	-	-0.08512
Transfer Wait Time	-	-	-0.08512
Fuel Cost/Occupancy	-0.00435	-0.00435	-
Fare and Park & Ride Fee	-	-	-0.00435
Parking Cost/Occupancy	-0.00702	-0.00702	-
Dallas CBD - Production	-	-0.97141	1.30188
Dallas CBD - Attraction	-	-1.83518	0.34943
Ft Worth CBD - Production	-	-0.54975	0.49193
Ft Worth CBD - Attraction	-	-0.59156	0.92062
Employment Density	-	-0.00004	-
Mode-Specific Constants:			
All Groups	0.00000	-2.28567	-2.24233

Note: Times are in minutes and costs are in cents (1984 Dollars)

terminal time and parking costs that are characteristics of zones rather than of the networks. The second type of variable is a location-specific indicator. These variables capture otherwise unmeasurable effects of travel to or from certain types of areas. The Dallas CBD has the most important location-specific effects on the mode choices on the attraction-end of trips, while the Fort Worth CBD has less pronounced effects. The third type of variable includes socioeconomic characteristics of the traveler's household. Autos-per-person in the household is generally the most important socioeconomic variable that influences mode choice. The last class of variables permits estimation of three sets of mode-specific constants: one set each for travelers with no restrictions on their choice sets, one for zero-car households, and one for managers/self-employed persons.

Validation and Prediction Testing

The rigorous validation phase of the model development effort included two very different kinds of tests and examined the forecasting ability of the Models in three different years (1980, 1984, 1986) and four sources of data:

- data from the 1984 Home Interview and On-Board Surveys in disaggregate format--that is, preserved in individual trip record format;
- trip tables developed from the 1984 Surveys, stratified by trip purpose and choice set limitations;
- 1980 UTPP data for the Dallas-Fort Worth region; and
- 1986 highway and transit count data.

The important distinction among these sources is their level of aggregation. The first source is entirely disaggregated; it preserves the individual trip records from the Surveys for grouping into any stratification of trip lengths, geographic orientation, or household characteristics. The remaining sources are aggregate data that permit testing of the overall performance of the Models, applied in the same manner in which they produce forecasts of future travel conditions.

Tests of Estimated Mode Shares

The first data source permitted disaggregate tests on the performance of the Models. These tests stratified the data into specific classes of travelers and trips and tested the ability of the Models to predict the mode choice behavior within each group. These tests led to the addition of several variables to the Model--the production-end CBD-indicators in the NHB model and the rural area-type indicator in the HNW model. These variables obtained statistically insignificant coefficients in model estimation but clearly play an important role in forecasting mode shares for certain trips. With these minor adjustments, the Models performed very well within all of the geographic and socioeconomic subgroups identified for the tests.

The remaining three data sources supported testing of the full implementation of the Mode Choice Model to replicate observed, aggregate travel by mode. The 1984 data was most important in these tests, since it included trip tables for all trip purposes and for all groups of travelers. Prediction tests with this data source permitted the adjustment of the mode-specific constants so that the Mode Choice Model accurately represented 1984 travel conditions. These adjustments compensate for the effects of sampling error in the selection of the subsamples for model calibration and for any aggregation error associated with application of the Models with zonal data (rather than household-specific data from the survey records).

This validation step adjusted the constants with a procedure similar to that employed in compensating for the nonrandom sample effects in calibration. It again made iterative adjustments computed with the following equation described on page 104.

$$a_m^n = a_m^o + \ln \frac{P - \text{share}_m}{S - \text{share}_m}$$

After validation against the 1984 trip tables, the 1980 UTPP provided the basis for further validation of estimated zone-to-zone transit shares for HBW trips. Together, the validation tests in three separate years provided a good test of all of the demand models, not only Mode Choice, since there were major changes in the region over this six-year period in both the state of the region's economy and the levels of transit service. In all three years, the model set predicted overall transit vehicle miles of travel within 2 percent and total transit ridership within 5 percent, in a setting where both totals changed by more than 30 percent.

Aggregate Elasticities

A final set of tests on the Mode Choice Model was the comparison of its aggregate elasticities against compilations of elasticities from national sources. These tests relied on repeated application of the Model, in which each application considered a constant regionwide change in one service variable at a time. The resulting change in transit ridership then provided the basis for computing the aggregate elasticity. These calculations computed the arc elasticity for the change because it is more indicative of the true aggregate sensitivities in the Models than is the point elasticity measure.

The arc elasticity is:

$$\text{Elasticity} = \frac{\log Q2 - \log Q1}{\log P2 - \log P1}$$

where: Q1 & Q2 = demand (before and after)

P1 & P2 = service (before and after)

The tests examined the direct elasticity of transit with respect to changes in three transit service variables and the cross elasticity of transit with respect to changes in three highway service variables:

Service Variable	% Change
Transit	
Transit IVT	-15%
Headway	-15%
Fare	-30%
Highway	
Highway IVT	-30%
Fuel Cost	+45%
CBD Parking Cost	+45%

It is possible to compute two sets of aggregate elasticities from the Mode Choice Model: one set for all travelers and the other for travelers who have a full set of modal options available. Comparison of the two sets of elasticities highlights the effects of the identification of the two groups of travelers with limited choice sets: people from zero-car households who cannot drive alone or drive to transit and people that are managers or are self-employed and do not take transit.

Table 35 summarizes the computed aggregate elasticities from the Models for both all travelers and "choosers" only. Table 36 shows the consistency in the overall elasticities with compiled average elasticities taken from two references.

TABLE 35

MODE CHOICE MODEL: DIRECT AND CROSS ELASTICITIES OF DEMAND FOR VARIOUS SYSTEM VARIABLES

Service Variable	HBW Choosers	HBW All	HNW Choosers	HNW All	NHB All	Average All
Transit IVT	-0.27	-0.24	-0.06	-0.05	-0.13	-0.20
Headway (Wait time)	-0.13	-0.13	-0.18	-0.17	-0.72	-0.23
Fare	-0.18	-0.16	-0.15	-0.13	-0.40	-0.20
Highway IVT	0.26	0.23	0.04	0.03	0.11	0.18
Fuel Cost	0.09	0.07	0.07	0.06	0.08	0.07
CBD Parking Cost	0.38	0.39	0.51	0.38	0.35	0.38

TABLE 36

COMPARISON OF DIRECT AND CROSS ELASTICITIES OF TRANSIT DEMAND FOR LOS VARIABLES

Variable	NCTCOG	Source 1*	Source 2**
I. CBD Parking Cost			
- Average	0.38	N/A	N/A
- Work Trips	0.39	0.33	N/A
- Nonwork Trips	0.37	0.18	N/A
II. Transit Fare			
- Average	-0.20	-0.28	-0.28
- Large City (G.T. 1 mil.)	-0.20	-0.24	-0.22
- Rapid Rail	N/A	-0.17	N/A
- Peak	-0.19	-0.17	N/A
- Off-Peak	-0.22	-0.40	N/A
- Work Trips	-0.16	-0.10	N/A
III. Transit In-Vehicle Time			
- Average	-0.20	N/A	N/A
- Peak	-0.21	-0.29	N/A
- Off-Peak	-0.18	N/A	N/A
IV. Wait Time			
- Average	-0.23	N/A	-0.22
- Peak	-0.22	-0.20	N/A
- Off-Peak	-0.25	N/A	N/A
V. Roadway In-Vehicle Time			
- Average	0.18	N/A	N/A
- Work Trips	0.23	N/A	N/A
- Nonwork Trips	0.07	N/A	N/A
VI. Auto Fuel Cost			
- Average	0.07	N/A	N/A
- Work Trips	0.07	0.21	N/A
- Nonwork Trips	0.06	0.12	N/A

* Ecosometrics, Inc., Patronage Impacts of Changes in Transit Fares and Services, US DOT/UMTA, September 1980.

** Barton-Aschman Associates, R.H. Pratt and Company, Traveler Response to Transportation System Change, US DOT, July 1981.

ROADWAY ASSIGNMENT

The capacity-restrained Roadway Assignment Model (ASSIGN) uses an incremental procedure with variable link updating criteria in assigning traffic onto the roadway network. A path-building technique similar to the one used in the roadway path-building model (TREBLD) is included in this procedure. A one-way link file using the off-peak number of lanes is used in the calculation of impedance based on travel time, distance, and cost parameters:

Impedance = (a * Time) + (b * Length) + (c * Cost)

where:

Time = travel time in hours

Length = trip length in miles

Cost = toll in cents

a = value of time ($/hour)

b = fuel cost ($/mile)

c = consumer price index converting cost data to 1984 constant dollars

The values for a, b, and c vary by year and are shown in Table 37.

TABLE 37

ROADWAY ASSIGNMENT IMPEDANCE COEFFICIENTS

	Value of Time ($/hour) a	Fuel Cost ($/mile) b	CPI ($/$) c
1980	6.00	0.10	1.30
1984	6.00	0.07	1.00
1986	6.00	0.04	0.95
2000	6.00	0.05	0.70
2010	6.00	0.06	0.50

The initial impedance for assignment is based on free or uncongested speeds. It is the common practice at NCTCOG to increase the speeds on freeways, frontage roads, and principal arterials by 10 percent. This is in recognition of tendencies of the average motorist to exceed the maximum allowable speed.

As traffic is loaded onto the links, the speed is reduced according to a volume-delay relationship. The link impedance is then updated accordingly. If the trip table is to be loaded on top of a previous assignment, the volume-delay equation is applied to the previous volumes, and the initial impedance is calculated to include this traffic. The Model can perform daily as well as both morning and afternoon peak-hour assignments.

Volume-Delay Equation

Two volume-delay equations used for high- and low-capacity facilities are defined both in the daily and the peak-hour Roadway Assignment Models. The distinction is made based on the capacity of the link. High-capacity facilities (usually freeways) are defined as those exceeding 3,400 vehicles per hour (one way).

The delay impedance assigned to each link is calculated from the following volume-delay equation:

$$\underset{\text{(minutes/mile)}}{\text{Delay}} = \text{Min}\left\{ A * \exp\left[B * \frac{\text{Hourly Volume}}{\text{Hourly Capacity}} \right], C \right\}$$

Daily volumes are converted to hourly units using a peak-hour conversion factor. Factors of 0.10 and 0.12 are generally used for high- and low-capacity facilities, respectively. The conversion factors used in the peak-hour assignment are set to 1.00 since the entire peak-hour trip table is to be assigned.

A, B, and C parameters vary by capacity type and time-of-day (daily vs. peak hour) and are calibrated to produce observed traffic volumes under various traffic conditions. Table 38 lists these parameters for high- and low-capacity facilities.

TABLE 38

DAILY VOLUME-DELAY EQUATION PARAMETERS

High-Capacity Facilities	Low-Capacity Facilities
A = 0.015 B = 5.30 C = 60.00	A = 0.05 B = 3.00 C = 10.00

Peak-Hour Assignment

Besides using a different volume-delay equation (see Table 39), the peak-hour assignment process also requires the use of a peak-hour trip table. Peak-hour distribution factors by time-of-day (morning vs. afternoon), trip purpose (HBW, HNW, NHB, OTHER), and trip orientation (production vs. attraction end) are applied to daily trip tables before the application of the Assignment Model. Distribution of peak-hour vehicle trips by purpose is obtained from the 1984 Home Interview Survey and is summarized in Table 40.

TABLE 39

PEAK-HOUR VOLUME-DELAY PARAMETERS

High-Capacity Facilities	Low-Capacity Facilities
A = 0.015 B = 7.00 C = 60.00	A = 0.05 B = 4.50 C = 10.00

TABLE 40

DISTRIBUTION OF PEAK-HOUR VEHICLE TRIPS BY PURPOSE

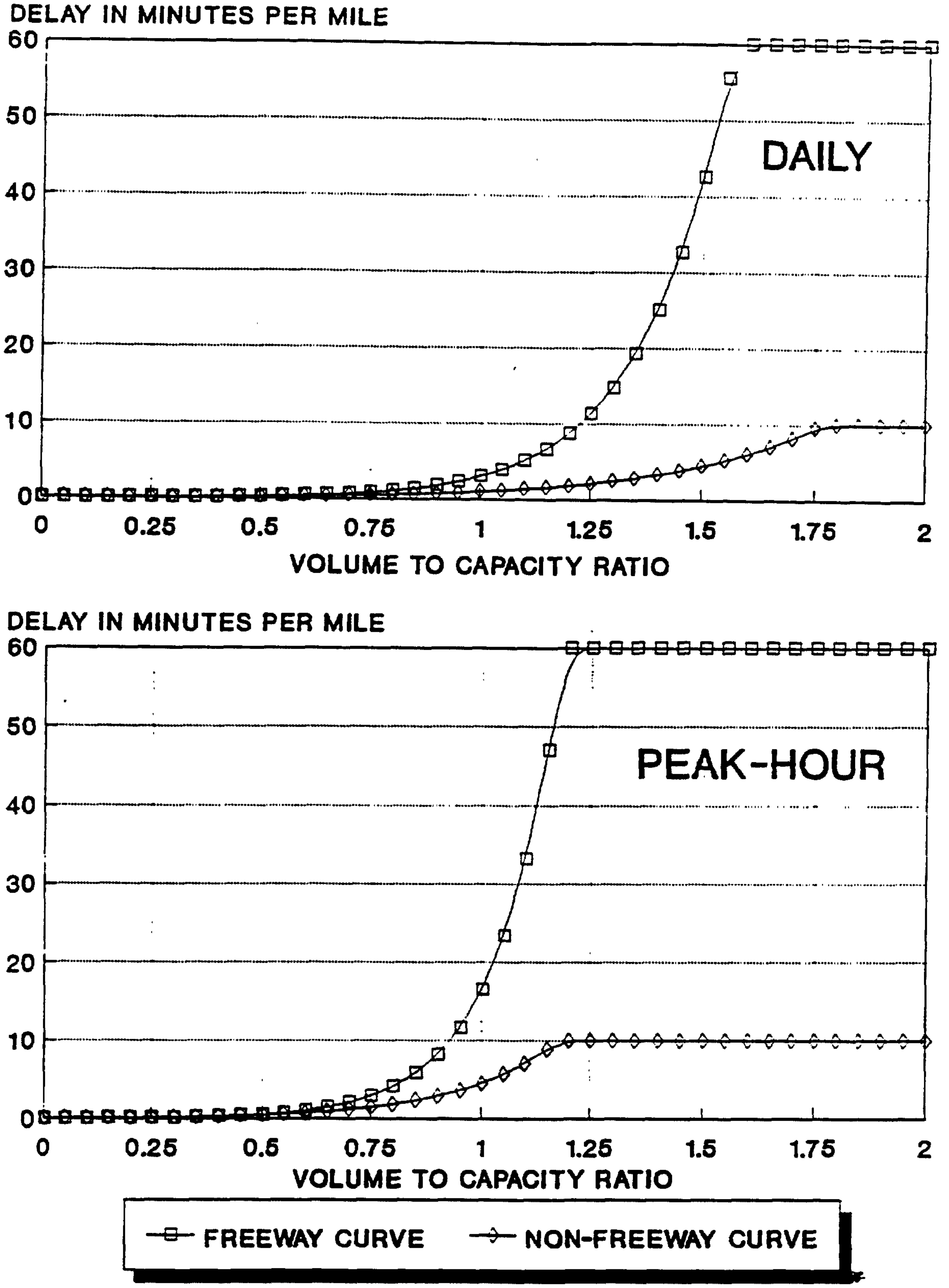
	(HBW) Home-Based Work Trips	(HNW) Home-Based Nonwork Trips	(NHB) Nonhome-Based Trips	(OTH) Other Trips
a.m. Peak-Hour				
Productions	18.00%	5.10%	0.74%	5.29%
Attractions	0.23%	0.69%	0.74%	0.71%
p.m. Peak-Hour				
Productions	0.45%	3.90%	3.78%	3.74%
Attractions	13.49%	4.43%	3.78%	4.26%

The volume-delay equation curves are shown in Figure 12 for daily and peak-hour assignment options. The curves begin with zero delay at low volume-to-capacity ratios. There is little difference between the two volume-delay curves (freeway vs. nonfreeway) for volume-to-capacity ratios of less than 0.7. The "A" parameter primarily influences the lower portion of the curve.

FIGURE 12

VOLUME DELAY CURVES

for DAILY and PEAK-HOUR ASSIGNMENT MODELS



However, as the volume-to-capacity ratios exceed 0.7, the delay rises exponentially to the maximum allowable delay. The "B" parameters determine the magnitude of the exponential increase in the curves. It is in this area where the differences between the facility types becomes significant. The maximum allowable delay of the volume-delay curves are governed by the "C" parameters. The C parameter represents the slowest possible speeds of 1 mph for freeways and 6 mph for nonfreeways. The C parameter prevents a link speed from going to zero and blocking paths under congested conditions. Another way to view the effects of congestion are shown in Figure 13. The speed-congestion curves display the decrease in link speed corresponding to increasing congestion. The initial speeds of 60 mph for freeway facilities and 30 mph for nonfreeway facilities were chosen only for display purposes.

Assignment Procedure

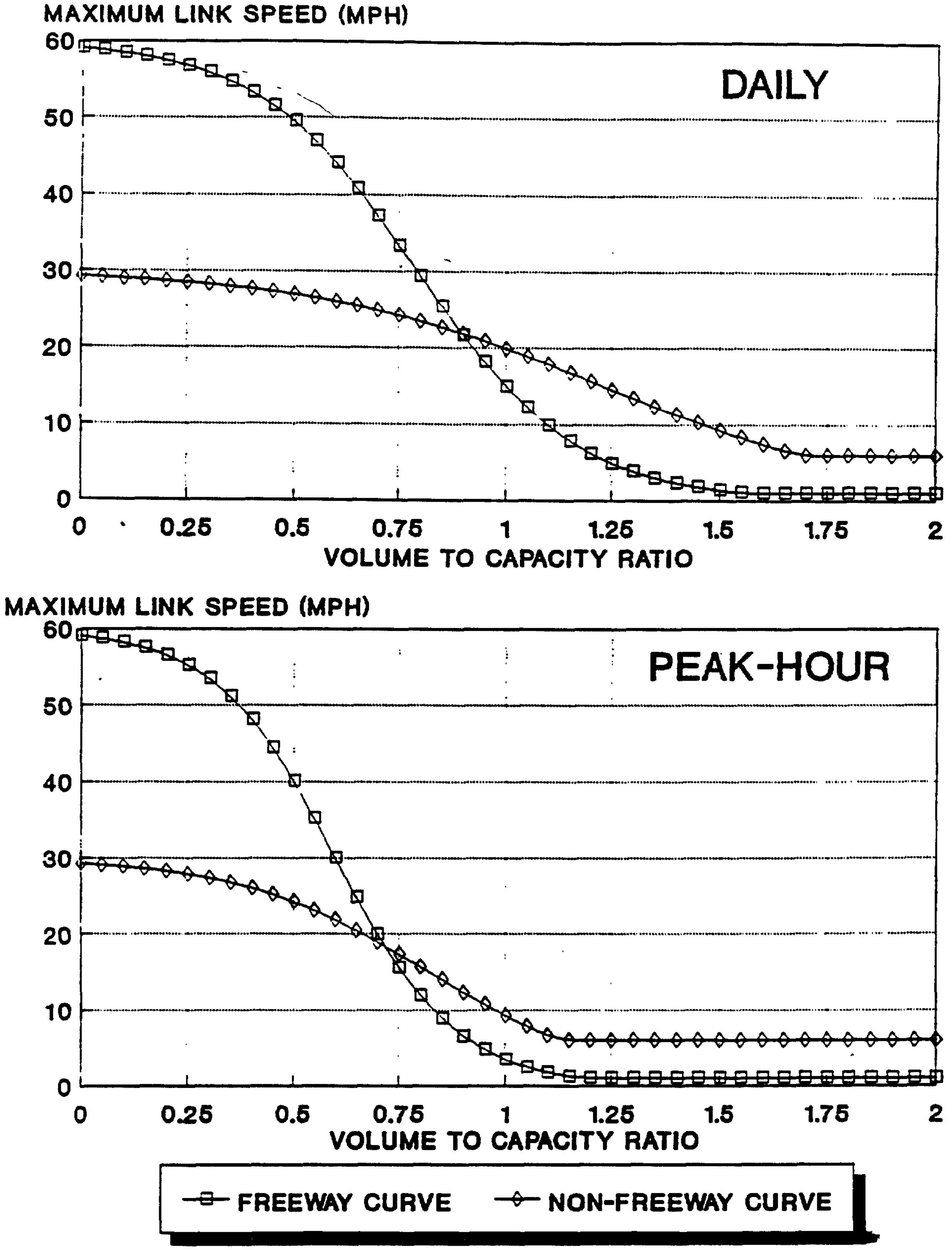
The program reads an origin zone, builds minimum impedance paths from that zone to all other zones, and assigns a portion of the interchange trips to each link along the path. As has been noted, the link impedance associated with path-building in ASSIGN is different than that of the path-builder. Minimum time paths are used in the Distribution Model while the Assignment Model minimizes a "generalized cost" function of time, distance, and tolls in building its paths. As a result, the paths used in Assignment are not the same as those used in Trip Distribution.

In order to improve the loading, several parameters are used to control the process. The first set of parameters controls the number of trips which will be loaded from a zone at one time. The user can specify the maximum number of iterations and the number of trips to be loaded in a given iteration. These

FIGURE 13

SPEED/CONGESTION CURVES

for DAILY and PEAK-HOUR ASSIGNMENT MODELS



values are currently set at three iterations and 10,000 trips per iteration, respectively.

If the total number of trips leaving a zone is greater than the number per iteration, the trips are divided by the number per iteration and rounded to the next highest integer less than or equal to the maximum number of iterations. The trips on each interchange are divided into equal parts corresponding to the resulting number of iterations. One part is loaded, and the remainder is stored for later use. After all zones have been partially loaded once, the trips stored in the temporary file are processed in the order they were stored. The trips remaining after the second pass are stored for a third pass. The process continues until the maximum number of iterations is reached or all of the trips are assigned. It should be noted that origins with more trips than the maximum number of iterations times the trips per iteration will be loaded in groups larger than the specified trips per iteration. In other words, the maximum number of iterations will override the trips per iteration when conflicts arise.

The effect of the above technique is to load smaller increments of larger trip interchanges in an attempt to avoid the impacts of loading a large number of trips with an all-or-nothing path. The technique gives all zones an opportunity to assign some trips before critical links are overloaded. The only way this will happen is if the link impedances are also updated in a timely way.

The program has three parameters which control link updating. The first two are the upper and lower bounds of the total number of trips that will be loaded before updating the link impedance. Total number of trips loaded before updating link impedances for congested and uncongested networks are presently defined as 20,000 and 100,000 trips, respectively. The other parameter is the critical volume-to-capacity ratio which defines congestion (set at 0.8). The total trips loaded from each zone are cumulated. If the next zone to be loaded would push the total over the upper bound, the link impedances are updated before that zone is processed. As the speeds are being calculated, the volume-to-capacity ratio is tested against the critical congestion parameter. If the value is greater than or equal to the parameter, the capacity of that link is added to the total. The total capacity in congested conditions is divided by the total capacity of all links. This ratio is the proportion of the capacity in congested conditions. It is multiplied times the difference in the upper and lower bound to give the number of trips the upper bound will be reduced by for the next set of loadings. In other words, as the network becomes more congested, the trips assigned between each successive link updating decrease from the upper bound toward the lower bound.

When all parameters are considered, the incremental loading in each iteration and the total number of trips loaded between updates can provide adequate control over the all-or-nothing path-building process to achieve the optimal accuracy for any given application. The trade-off is obviously in computer cost, because path-building is the most expensive operation in any modeling process. For each zone of each iteration, a full set of paths must be built. In addition, if the updating criteria are so tight that the increment of a particular zone is greater than the updating total, the program will build as many full sets of paths on updated networks as is required to load that one zone in increments less than the updating criteria. It is feasible to construct a full set of paths from one origin several times within each iteration. There are situations where this would be desirable, particularly when a large zone structure is loaded to a detailed network, but the cost of processing a large number of zones at this level of detail may be prohibitive.

The user should think of the parameters as controlling the number of paths to be assigned. Since the number of approach links do not change, a reasonable trade-off should be made between the actual number of zones selected for the study and the number of paths required in assignment to produce the desired result. Experience suggests that the zone structure should be detailed enough to provide adequate assignment results when twice as many paths as zones are loaded. Three iterations with upper bound updating criteria equal to approximately ten times the trips per increment seem to produce adequate results.

Post-Processing

After the assignment step, the post-processing program NETSUM is run. NETSUM converts the one-way file into a two-way file and calculates the average final speed using a similar delay equation to that used in the Assignment Model. The A, B, and C parameters vary slightly in NETSUM compared to those used in the volume-delay equation of the Roadway Assignment Model. Those used in NETSUM (Table 41) are based on traditional volume speed curves, while the assignment parameters are modified to validate the estimated traffic volumes against the actual traffic counts.

TABLE 41

VOLUME-DELAY PARAMETERS USED IN NETSUM

	High-Capacity Facilities	Low-Capacity Facilities
A	0.015	0.05
B	4.0	4.0
C	5.0	10.0

NETSUM uses an observed time-of-day distribution for peak period, off-peak period, and nighttime volumes by functional class and area type. Speeds for each of these periods are calculated. The weighted average daily speed or optionally the peak-period speed and volume are posted on each link.

Optionally, NETSUM can also move vehicle miles of travel from approach links to network links. The approach link lengths are reduced by two-thirds or to the minimum specified by the user (currently set at 0.4 miles), whichever is greater. The length removed times the volume is the vehicle miles of travel to be redistributed on the network links in the zones associated with either end of the approach link. Vehicle miles are distributed among the network links according to the center line miles of capacity on links in a particular zone. Freeways and ramps are excluded from the capacity calculation. The process will not alter small zones but will share the vehicle miles with arterials in large zones. The before and after summary reports of average speed, distance, and volume by area type and functional class will show how and where the volumes have been modified. The modified volumes and speeds are posted on an additional two-way link file for further processing.

HOV Assignment

As discussed previously, carpooling demand is estimated in the home-based work Mode Choice Model. Although carpools are formed even in the absence of HOV facilities, they provide, as incentives, travel time savings to promote additional carpooling activities.

In the absence of HOV lanes, all vehicle trips, regardless of occupancy, are assigned onto the mixed-flow roadway network using the capacity constraint assignment model. With HOV lanes in place, a two-step assignment technique is employed.

First, using the all-or-nothing assignment option, trips likely to use HOV facilities are loaded onto the network. Depending on the minimum occupancy requirement for the use of HOV facilities, 78 percent of work trips with two or more occupants, or 84 percent of work trips with an occupancy of three or more persons are selected for assignment to the HOV network. These figures are obtained from the 1984 Home Interview Survey and reflect the peak-period distribution of work trips by occupancy. Nonwork trips are not loaded onto the HOV network since they are, for the most part, off-peak trips with shorter trip lengths. Such trips are not likely to take an HOV facility which operates during the peak period only and has an average ramp spacing of three miles. Peak-period final speeds are posted on the mixed-flow portion of the roadway network to represent the congestion experienced by HOV users in reaching those facilities. Thereafter, maximum allowable speeds are used on HOV lanes.

The second step involves the assignment of the remainder of the vehicle trips to the roadway network using the capacity-restrained assignment technique. HOV lanes are removed from the network prior to this exercise. Volumes are added to the preloaded volumes from the HOV assignment step where applicable.

The procedure was validated to Dallas-Fort Worth's observed 2+ and 3+ carpooling data for 1986. A final reasonability check of the HOV model was made by comparing the results to the observed volumes of the Katy HOV facility in Houston.

TRANSIT ASSIGNMENT

Loading the transit trip table onto the transit network is a considerably different process than Roadway Assignment. To begin with, no capacity constraint or path-building models are involved. Transit trips are loaded onto the four paths defined by the transit path-builder for smoother results.

Four separate assignments of 24-hour transit trips to the appropriate transit paths are performed for each run:

- HBW walk-access transit trips onto peak-period walk paths
- HBW drive-access transit trips onto peak-period drive paths
- Nonwork (HNW & NHB) walk-access transit trips onto off-peak period walk paths
- Nonwork drive-access transit trips onto off-peak period drive paths

Time-of-Day Processor

After transit trip assignment, the time-of-day post-processing technique computes total peak and off-peak volumes on each link by reallocating the loadings according to the observed regionwide distribution of transit trips by purpose and access mode. For peak trips, the procedure first checks whether the transit link exists in the off-peak. If it does, the procedure allocates a portion of the HBW transit trips to the off-peak. Similarly, for nonwork trips, the procedure checks for the link in the peak network and allocates a portion of the nonwork volume to the peak if the link exists. The allocation factors area summarized in Table 42.

TABLE 42

DISTRIBUTION OF TRANSIT TRIPS BY TIME-OF-DAY
(HBW, HNW, NHB)

	Walk Access		Auto Access	
	Peak	Off-Peak	Peak	Off-Peak
HBW	71.75%	28.25%	87.72%	12.28%
HNW	49.25%	50.75%	60.66%	39.34%
NHB	54.44%	45.56%	74.12%	25.88%

Combining the HNW and NHB trip purposes into one single "nonwork" category yields the following distribution applied to 24-hour assigned trips (Table 43):

TABLE 43

DISTRIBUTION OF TRANSIT TRIPS BY TIME-OF-DAY
(Work vs. Nonwork)

	Walk Access		Auto Access	
	Peak	Off-Peak	Peak	Off-Peak
Work	71.75%	28.25%	87.72%	12.28%
Nonwork	51.42%	48.58%	69.82%	30.18%

These factors assume a five-hour peak period (6:30 a.m. - 9 a.m. and 4 p.m. - 6:30 p.m.).

The advantage of this procedure is that it ensures that all transit trips are loaded onto the transit network. An alternative approach would be to split transit trips by time-of-day before assignment. However, that approach may reallocate trips to a time period in which the corresponding transit link does not exist. Many peak-period work trips, for example, use express buses that do not operate in the off-peak. The above procedure avoids this difficulty by checking the already-loaded networks to determine the possibility of reallocation of trips between periods and reallocating only where it is possible.

FOOTNOTES

[1] Final Report: Regional Travel Surveys, Volume 1, Home Interview Surveys, Barton-Aschman Associates, Inc. for North Central Texas Council of Governments, 1984.

[2] Final Report: Regional Travel Surveys, Volume 1, Work Place Surveys, Barton-Aschman Associates, Inc. for North Central Texas Council of Governments, 1984.

[3] Final Report: On-Board Transit Survey, Booz-Allen & Hamilton, Inc. for North Central Texas Council of Governments, 1984.

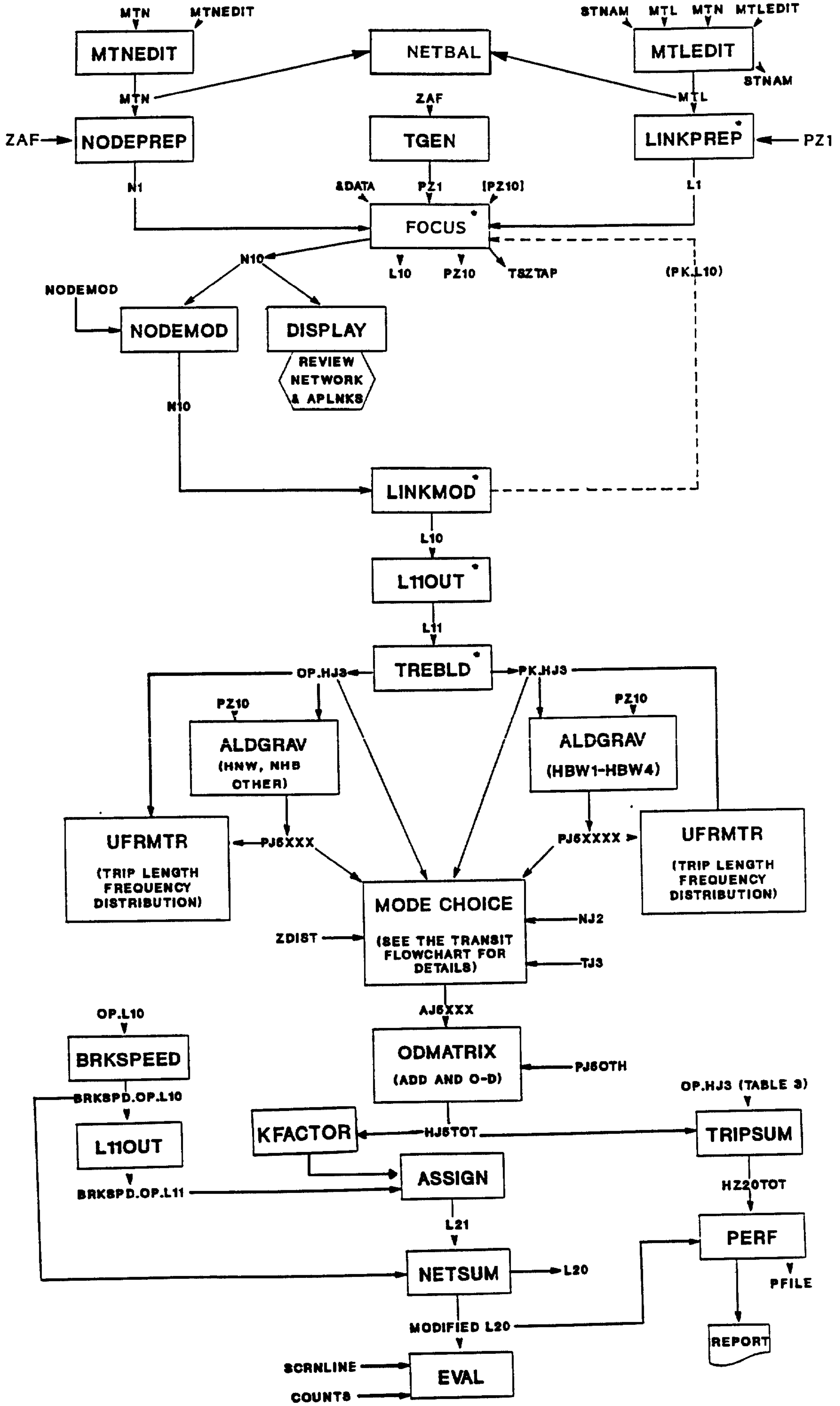
[4] "An Overview of Demographic Forecasting in Dallas-Fort Worth," North Central Texas Council of Governments, April 1987.

[5] Final Report: Traffic Counting Procedures and Information Systems, North Central Texas Council of Governments, November 1989.

[6] Morton Schneider, "Access and Land Development," Highway Research Board Special Report 97, Washington D.C.: Highway Research Board, 1968.

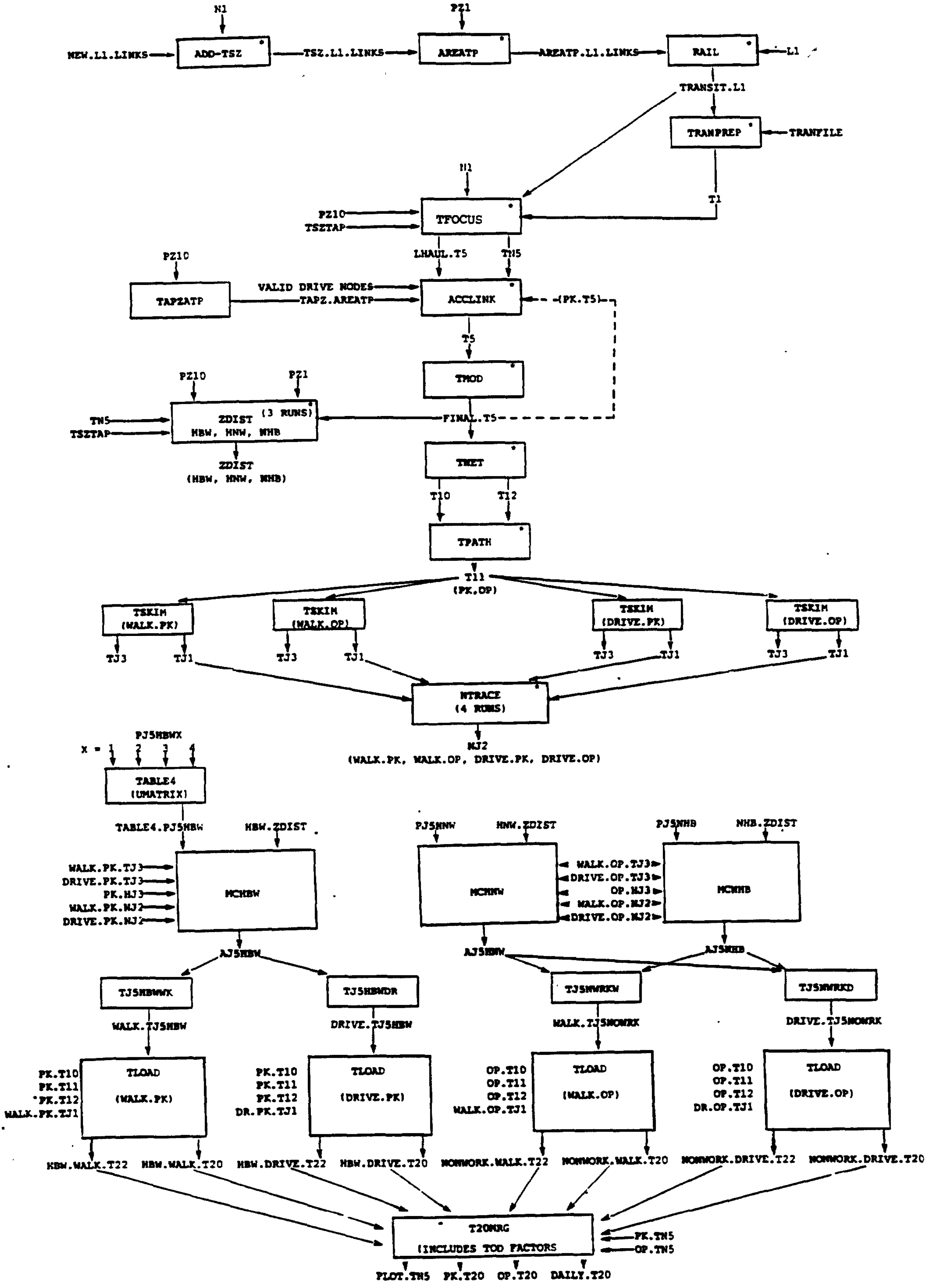
APPENDIX A

MULTIMODAL TRANSPORTATION ANALYSIS PROCESS (MTAP)



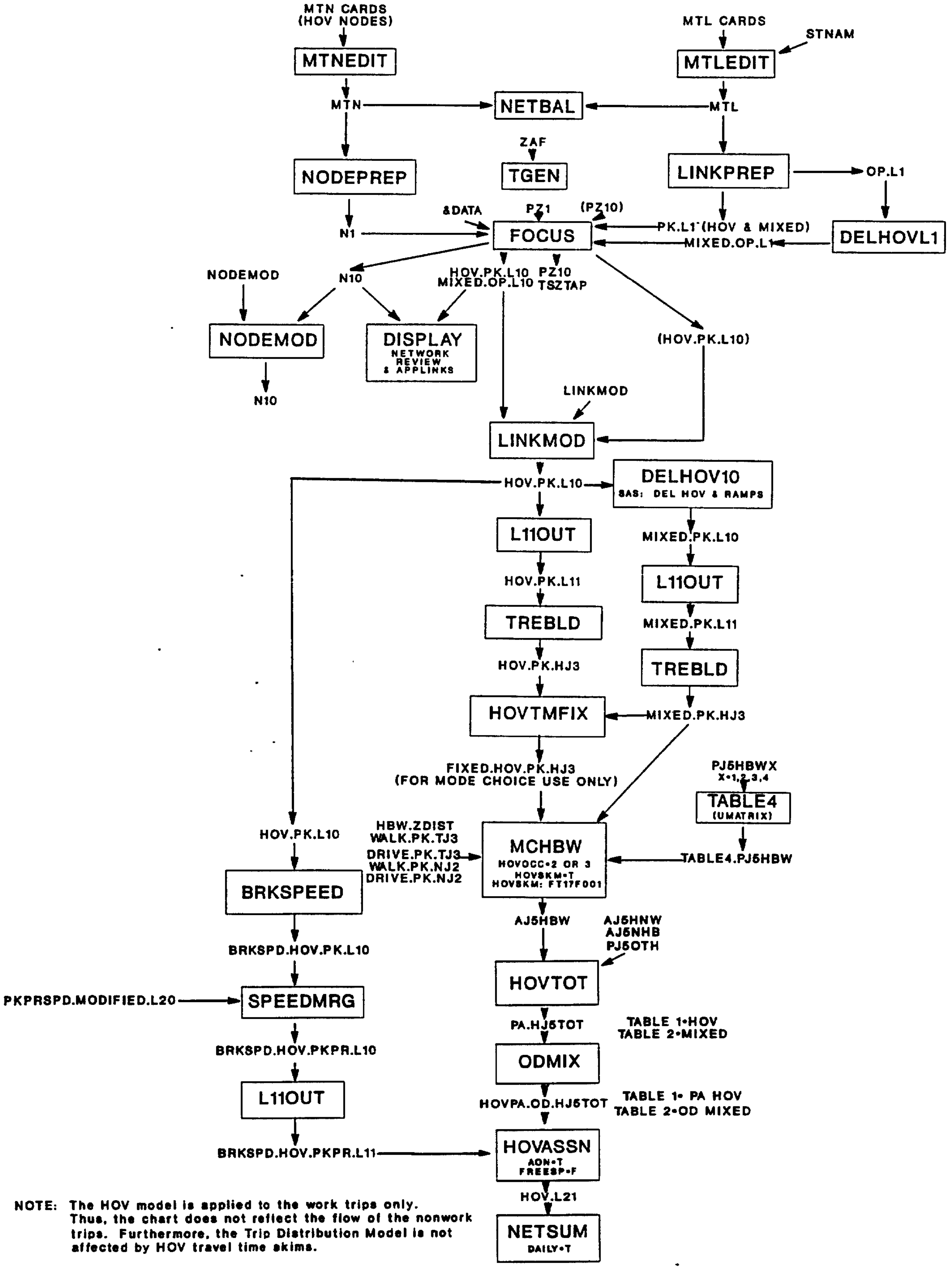
• PEAK & OFF-PEAK RUNS REQUIRED:
Use the peak network for HBW runs and the off-peak network for HNW and NHB runs as well as the daily assignment.

MULTIMODAL TRANSPORTATION ANALYSIS PROCESS:
THE TRANSIT MODEL



* PEAK & OFF-PEAK RUNS REQUIRED;
Use the peak network for HBW runs and the
off-peak network for HNW and NHB.

MULTIMODAL TRANSPORTATION ANALYSIS PROCESS:
THE HOV MODEL



NOTE: The HOV model is applied to the work trips only. Thus, the chart does not reflect the flow of the nonwork trips. Furthermore, the Trip Distribution Model is not affected by HOV travel time skims.