Appendix 9.4

Travel Model Validation

HOUSTON-GALVESTON AREA COUNCIL

REGIONAL TRAVEL MODELS

1995 Model Validation and Documentation Report

February 2004

1.0 Introduction

The Houston-Galveston Regional Travel Models are cooperatively developed and maintained by the Houston-Galveston Area Council (H-GAC), the Texas Department of Transportation (TxDOT) and the Metropolitan Transit Authority (METRO). This report documents the validation of the existing Houston-Galveston Regional Travel Models to the Base Year 1995. Documentation of steps previously completed by H-GAC, TxDOT and METRO are documented in the following reports:

- ***Development, Update and Calibration of 1985 Travel Models for the Houston Galveston Region***
- ***Estimation, Calibration, and Validation of the Houston Mode Choice Model - Technical Report***
- **1990 Houston Long-Range Patronage Forecasting Model Validation-Draft Technical Memorandum: Model Validation Methodology and Results**
- ***IH-10 Katy Freeway Major Investment Study: Service and Travel Forecasting Methodology, Version 3.0***

These reports describe existing model development based on five travel surveys: (1) the 1984 H-GAC Household Travel Survey, (2) the 1985 METRO On-board Transit Survey, (3) METRO's 1990 On-board Transit Survey, (4) a 1995 H-GAC Household Travel Survey and (5) a 1995 METRO On-Board Transit Survey. The existing trip generation model is based on surveyed 1984 household trip rates, derived from the 1984 Household Survey. The regional mode choice model is a nested logit model developed for incorporation into METRO's 1985 Houston Long-Range Patronage Forecasting Model, based on 1985 travel survey information. The mode choice model was later calibrated and validated for 1990 network conditions, based on the 1990 on-board rider survey and HOV traffic counts.

The regional travel models were applied in a unique version of the traditional four-step process of trip generation, trip distribution, mode choice, and assignment. H-GAC develops person trip tables by purpose (i.e. trip generation and trip distribution) and provides them to METRO who then performs mode choice analysis and estimates transit patronage. METRO then provides H-GAC with the transit patronage estimates. H-GAC then develops highway vehicle trip tables using the same person trip tables input to mode choice and the transit patronage estimates and using the vehicle trip tables, estimating highway usage.

As part of TxDOT's I-10 West (Katy) Major Investment Study travel forecasting effort, the mode choice model was enhanced and fully integrated into the model stream as applied by H-GAC. The end result was, in terms of application, a process that is the traditional "four-step" process of model application. It is this process that has been revalidated to the year 1995.

1.2 Report Structure

Chapter 2 of the report discusses the development of demographic estimates for the Base Year 1995. Included in this section is also a discussion and depiction of the zone system used in the H-GAC modeling efforts. Chapter 3 outlines preparation of the database, including the estimation of the 1995 target value used in the mode choice model calibration. The development of both highway and transit networks is also discussed in Chapter 3. This is followed, in Chapter 4, with a discussion of basic travel forecasting procedures employed in the 1995 validatio, including choice model formulation, its development and validation. The 1995 highway assignment validation results are also summarized in Chapter 4. Chapter 5 discusses the development of an HPMS adjustment factor used in applications of travel model forecasts for air quality conformity and SIP development.

2.0 Land Use and Demographic Forecasting Procedures

The eight-county Houston-Galveston-Brazoria Consolidated Metropolitan Statistical Area (CMSA) has been federally designated as the Transportation Management Area (TMA) for the Houston-Galveston region. The Houston-Galveston TMA extends over an area of 7,809 square miles. Land Use and Demographic forecasts for the TMA are developed by H-GAC.

2.1 Zone System Definition

Under 1990 (census related) geography, H-GAC has designated 3,000 detailed traffic analysis zones (TAZs) in the Houston-Galveston TMA. This includes 2,634 internal zones and 46 external stations. The internal zones are entirely within the TMA and the external stations are used to capture external-external and external-local trips into and through the TMA.

2.2 1995 Base Year Demographic Estimates

Estimates of 1995 household were derived from two data sources at different levels of detail. For the most populous part of the eight-county region, parcel level estimates of the number of households were acquired from a third-party data source. For the remainder of the region, estimates of households at the TAZ-level were provided by the Planning Office of the Texas Department of Transportation (TxDOT) – Houston District. A combination of TxDOT and Texas State Data Center county-level population totals were used as county-level control totals of the TAZ-level household population and households.

In order to provide the model validation effort, a proprietary data source containing information on household size and income was obtained and used to develop two simple household size and household income submodels. Given a zonal average household size and zonal average household income, these models would estimate the proportion of households by five size groups and income quintiles.

The U. S. Bureau of Economic Analysis was used by H-GAC to establish 1995 county-level control totals for employment estimates. The BEA employment estimates are widely used by the data community for analysis and modeling because it provides a methodologically and historically consistent database.

The 1995 county level employment estimates are allocated to the census tract and TAZ levels by the H-GAC. The primary data source for this allocation was data purchased from the American Business Information (ABI) for 1995 for all counties in the region.

The ABI database provides a record for each employer in the region by location. Each record is geocoded to the TAZ level and census tract level. The ABI data purchased for 1995 provided employment estimates for each record expressed in ranges rather than specific values.

H-GAC performed substantial data cleaning and refinement of the ABI data. The secondary data sources were used to convert the ABI ranges to specific employment estimates for employers of 250 employees and above. The secondary data sources included: Dunn and Bradstreet (D&B), Houston 1000, ES-202, Texas Education Agency (TEA), Houston Police Department (HPD), Texas Department of Corrections (TDC) and some targeted telephone surveys. Employment estimates were prepared for the remaining employers of fewer than 250 employees. The records for employers of fewer than 500 employees were subsequently scaled so that the record-level estimates by county match the BEA-based county-level control totals. The resulting employer-level employment estimates are then aggregated to the TAZ level for use in the travel modeling.

2.3 1990 Demographic Estimates

Population estimates for the base year, 1990, were derived from 1990 U.S. Census data (PL-4 and STF1 block level data tapes). A 1990 census tract population and household data series in 1980 geography was developed from these sources for use in earlier H-GAC 1990 model validation and METRO's 1990 model calibration and validation. By aggregating the 1990 block level data to 1980 census tract boundaries, subtle changes from 1980 to 1990 in the physical boundaries of the tracts were captured, providing a more accurate equivalency file and distribution of 1990 population in a 1980 geography format. Recently, H-GAC has redefined the 1990 population estimates based on 1990 geography.

County-level employment data are based on the U.S. Bureau of Economic Analysis (BEA) series (CA27) for wage and salary employment by place of work. Distribution of the BEA employment data at the sub-county level was based on an establishment-level database developed by H-GAC for earlier forecasting and estimation work. This database was enhanced by additional site-level data from the Texas Education Agency and other public agencies. H-GAC converted the database from 1980 to 1990 census geography using address standardization and matching software.

A regional land-use database was compiled from the 1990 City of Houston Metrocom land-use database (for Harris County) and 1989 Texas Department of Transportation (TxDOT) District 12 land-use files for the other seven counties in the TMA. These data were augmented with remote sensing and satellite images, providing information on the unincorporated areas of Harris County outside of Houston's database reporting boundaries.

2.4 Comparison of 1990 and 1995 Demographic Estimates by County

Table 2.1 summarizes the household changes between 1990 and 1995. Regionwide households increased 11.16 percent, from 1.34 million to 1.49 million in 1990 and 1995, respectively. Household growth by county ranged from a low of 6.4 percent (Brazoria) to a high of 29.44 percent (Waller). Table 2.2 summarizes the household population by county (which excludes group quarters such as prisons).

Table 2.1
County Households for 1990 and 1995

County	1990 Households	1995 Households	Percent Change
Brazoria	64,226	68,337	6.40
Chambers	6,906	7,710	11.64
Fort Bend	70,419	87,477	24.22
Galveston	81,305	89,143	9.64
Harris	1,026,449	1,120,751	9.19
Liberty	18,467	21,760	17.83
Montgomery	63,591	81,556	28.25
Waller	6,974	9,027	29.44
Total	1,338,337	1,487,756	11.16

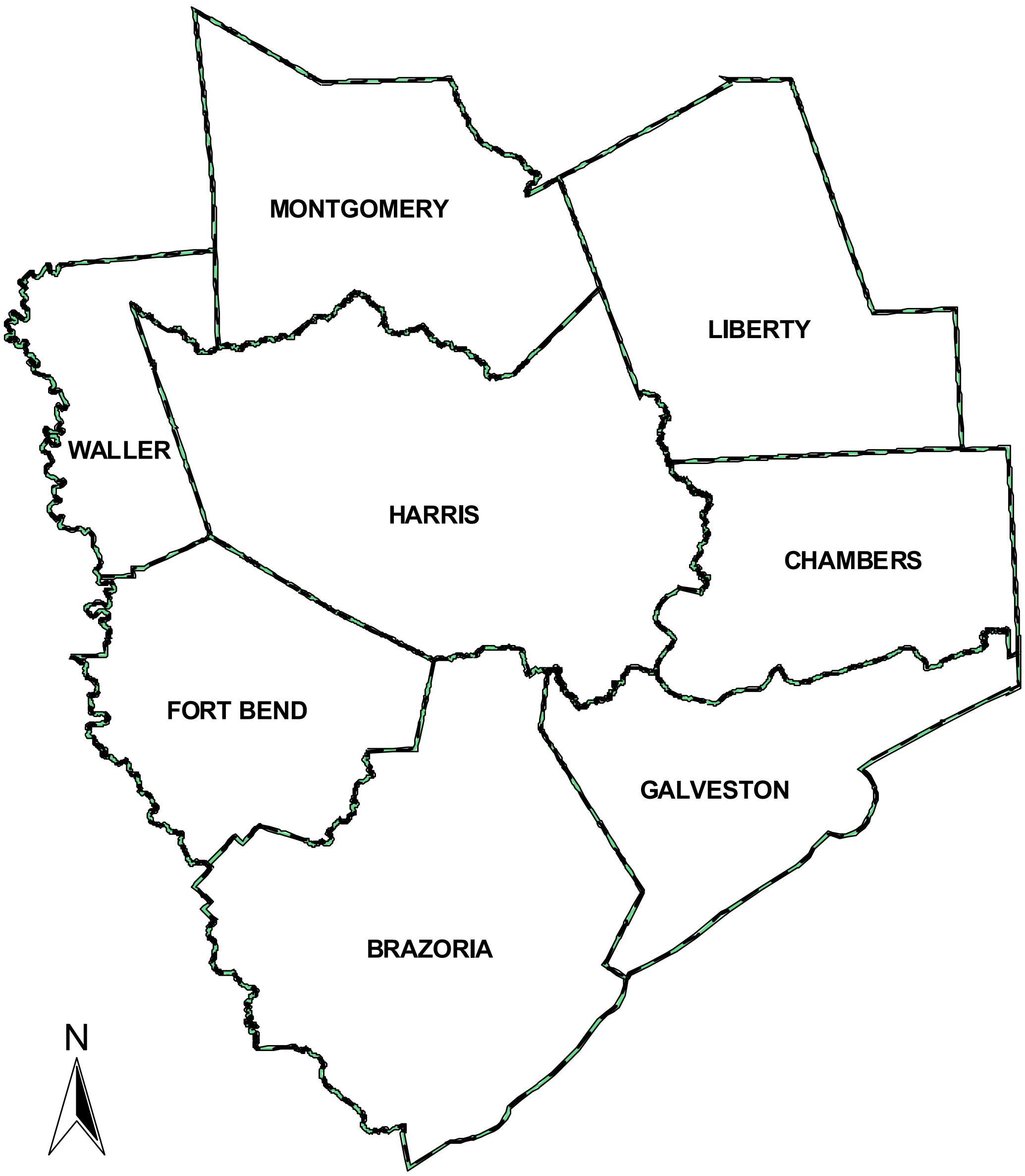
Source*: *Trip Generation Data for 1990 and 1995 prepared by H-GAC

Table 2.2
County Household Population for 1990 and 1995

County	1990 Population	1995 Population	Percent Change
Brazoria	183,584	194,966	6.22
Chambers	19,942	22,256	11.60
Fort Bend	221,107	276,051	24.85
Galveston	214,494	235,696	9.88
Harris	2,790,031	3,049,197	9.29
Liberty	51,596	60,977	18.18
Montgomery	180,687	230,918	27.80
Waller	19,154	24,927	30.14
Total	3,680,559	4,094,988	11.26

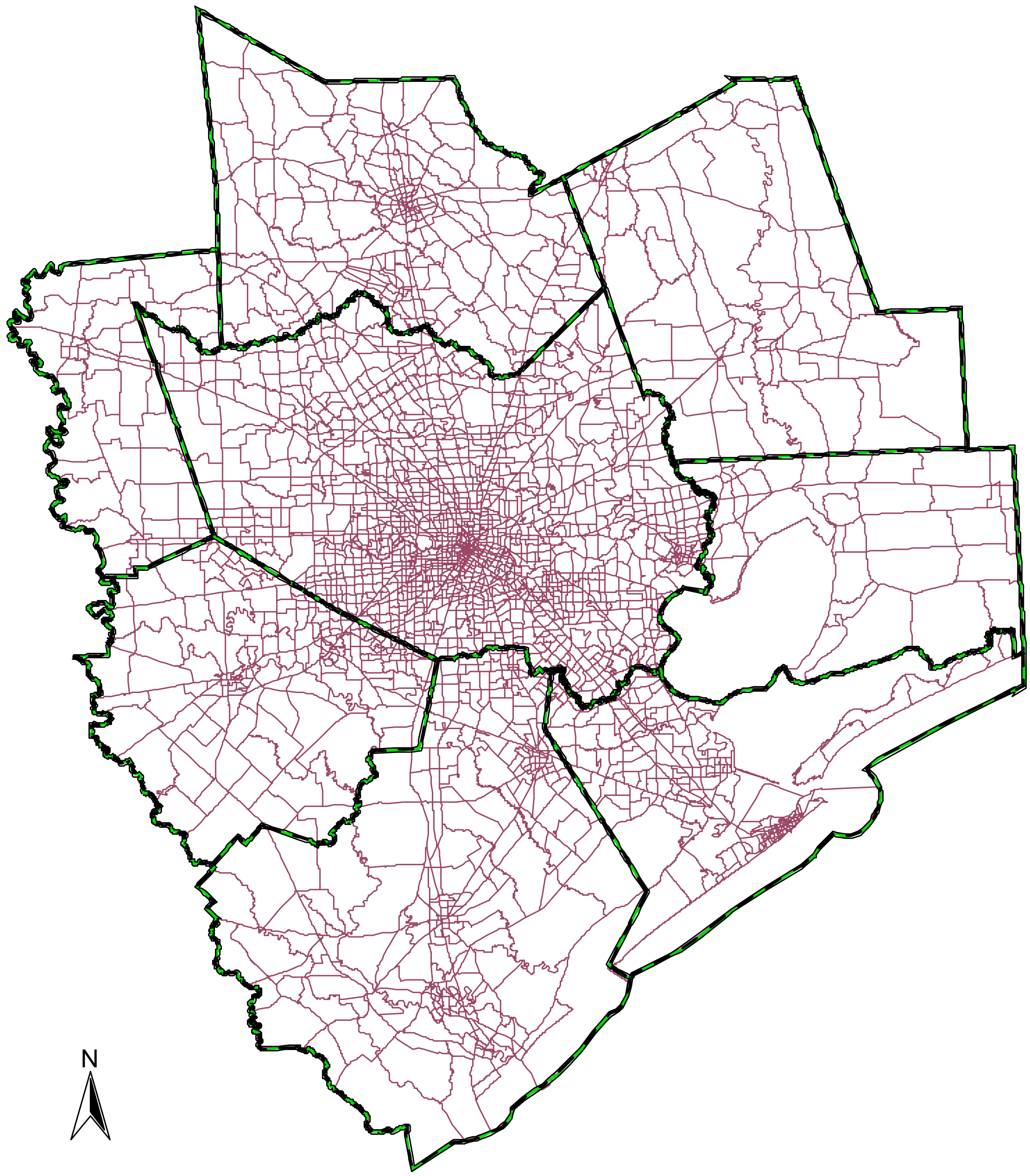
Source*: *Trip Generation Data for 1990 and 1995 prepared by H-GAC

Figure 2.1
Houston-Galveston-Brazoria Consolidated Metropolitan Statistical Area (Eight Counties)



Source: H-GAC

Figure 2.2
H-GAC Zone Structure



Source: H-GAC

Employment for the eight county region increased comparably with population growth, 12.7 percent overall (Table 2.3). Harris and Montgomery counties represent the range of percentage changes in employment (i.e., from 9.7 percent to 64.2 percent). Harris County gained nearly 150,000 employees (a 9.7 percent increase).

Table 2.3
County Employment for 1990 and 1995

County	1990 Employment	1995 Employment	Percent Change
Brazoria	62,897	74,327	18.17
Chambers	6,004	7,505	25.00
Fort Bend	50,224	72,804	44.96
Galveston	80,198	92,566	15.42
Harris	1,537,962	1,687,630	9.73
Liberty	14,301	15,744	10.09
Montgomery	42,802	70276	64.19
Waller	7,688	9577	24.57
Total	1,802,076	2,030,429	12.67

Source: H-GAC Trip Generation Input Data for 1990 and 1995

2.4 Growth in Activity Centers Between 1990 and 1995

Table 2.4 summarizes the household estimates for the four major activity centers. The Houston CBD showed only a modest increases in household for 1995. The Texas Medical Center estimates are slightly lower than the 1990 estimates. Both Greenway Plaza and the Galleria had growth rates significantly higher that the 9.75 percent growth in Harris County.

Table 2.4
Major Activity Center Households for 1990 and 1995

Major Activity Center	1990 Households	1995 Households	Percent Change
CBD	365	389	6.6
Texas Medical Center	874	853	-2.4
Greenway Plaza	5,220	6,098	16.8
Uptown/Galleria	6,113	8,423	37.8

Source: *Trip Generation Data for 1990 and 1995 prepared by H-GAC Data Services Department*

Table 2.5 summarizes the employment estimates for the four major activity centers. The Galleria shows the largest change in employment estimates at 31,779 (or 53.8 percent). The 1990 to 1995 percentage differences in the employment estimates for the Texas Medical Center and the Greenway Plaza were more than 20 percent or nearly double the 12.6 percentage change for the eight-county region. The Houston CBD employment estimates for 1995 were only 3,248 higher than the 1990 estimates (i.e., a 2.5 percent change).

Table 2.5
Major Activity Center Employment for 1990 and 1995

Major Activity Center	1990 Employment	1995 Employment	Percent Change
CBD	131,980	135,228	2.5
Texas Medical Center	57,996	70,374	21.3
Greenway Plaza	36,753	45,020	22.5
Uptown/Galleria	59,035	90,814	53.8

Source: Trip Generation Data for 1990 and 1995 prepared by H-GAC Data Services Department

2.5 Parking Costs

Parking costs have been shown to have a significant effect on transit ridership levels and must be treated carefully. This variable is defined as an estimate of the actual (or average) out-of-pocket cost paid on a daily basis per vehicle. Table 2.6 summarizes the estimated parking costs used at the four major activity centers, including the Houston CBD, Greenway Plaza, Texas Medical Center, and Uptown/Galleria, as well as selected additional zones with significant employment density.

Table 2.6
Parking Costs for Activity Centers

Activity Center	Range of Costs	Average Cost
Houston CBD	$0.66-$4.42	$2.84
Greenway Plaza	$0.22-$1.30	$0.64
Texas Medical Center	$0.47-$2.06	$1.44
Uptown/Galleria	$0.07-$0.17	$0.09

Source: Houston METRO

3.0 Data Preparation and Transportation Network Development

Calibration and validation of the regional model was dependent on observed travel behavior and transit ridership patterns, as measured by the 1984 and 1994 Household Travel Surveys and the 1995 On-Board Transit Survey.

3.1 1984 Household Travel Survey

A survey of approximately 1,500 households was performed in the fall of 1984 to establish trip generation rates for motorized person trips. The sample households were stratified based upon household size and vehicle availability. Households were asked to inventory travel for an entire day for all persons 5 years an older. Appendix A presents copies of the 1984 Household Survey forms.

3.2 1994 Household Travel Survey

In 1994, H-GAC conducted a household travel survey for the Houston Metropolitan Area. The survey obtained general household and person data, as well as specific activity-based trip information. Complete survey responses were obtained from 2,394 households, which generated in excess of 23,000 individual trip records. For purposes of this model validation effort, the survey data was used to compute calibration target values for the base year, which explicitly reflected the presence of both high-occupancy vehicle (HOV) lanes on key roadway facilities within the region (i.e., Katy, Northwest, and North Freeways), as well as the two toll road facilities – the Hardy and Sam Houston (Beltway 8).

Two travel diary questions of particular value to this study were questions #16 and #17:

- **Did you use a toll road? (yes or no)**
- **Did you use an HOV or carpool lane? (yes or no)**

It was hoped that from the response to these two questions, that a trip purpose and demographic (i.e., income) profile of toll road and HOV lane users could be developed and translated into purpose-specific calibration target values. Only 106 respondents reported utilization of the toll road, while 30 reported use of a HOV lane. The absolute magnitude of these records, precludes any serious statistical analysis focused on their distribution by trip purpose and income level, however, they were ultimately used as a *starting point* for computation of the calibration target values (section 3.4). From a relative magnitude point of view, the number of responses in both the toll road and HOV lane categories are not unexpected given the likely true proportion of their presence in the universe of all trip making; the same would be true of transit trips. This tabulation

served to illustrate the potential future need to collect a choice-based sample for toll road and HOV users if any substantive statistical use of the data is intended (i.e., mode choice model estimation).

3.3 1995 On-Board Rider Survey

The primary purpose of the 1995 On-Board Rider Survey was to provide estimates of transit trips stratified by purpose, access mode, and a socio-economic indicator[1]. This primary travel data source was needed to update the mode choice model for the Houston-Galveston TMA. It was used in concert with the preliminary tabulations from the 1994 Home-Interview survey to calibrate and validate the model to account for changes in the transit system, as well as the addition of high-occupancy vehicle (HOV) and toll road facilities in Houston since 1990.

Data on the number of transit trips by transit mode, access/egress mode, and trip purpose were collected in the on-board survey. These observations were expanded to provide estimates of the actual number of trips. Daily transit trips by mode and purpose are shown in Table 3.1. Home-based work trips totaled 113,058 (58 percent), while the home-based other purpose accounted for 55,372 (29 percent) trips, and 25,557 (13 percent) trips were non-home-based. The walk-to-bus access mode accounted for the majority of transit trips – 160,897 (83 percent). Trips accessed via the park-and-ride mode totaled 27,044 (14 percent) while kiss-and-ride trips amounted to 6,046 (3 percent). Linked transit trips totaled 193,987.

Table 3.1
Summary of 1995 Transit Trips by Mode of Access and Trip Purpose

Purpose	Mode	Linked Trips
Home-Based Work	Walk-to-Local Bus	77,429
	Walk-to-Commuter Bus	1,788
	Walk-to-Express Bus	4,918
	Park-and-Ride	24,997
	Kiss-and-Ride	3,927
Home-Based Other	Walk-to-Bus	52,959
	Park-and-Ride	972
	Kiss-and-Ride	1,441
Non-Home-Based	Walk-to-Bus	23,804
	Park-and-Ride	1,076
	Kiss-and-Ride	678

[1] Income is used as the primary indicator of wealth within the mode choice model, as auto availability is not estimated for future year condtions.

3.4 Mode Choice Calibration Target Values

Three sources of data were used to compute a revised set of calibration target values for 1995 that were derived from the latest available data and were consistent with the structure of the enhanced mode choice model[2] – (1) the 1995 person trip matrices, (2) tabulations from the 1995 On-Board transit rider survey, and (3) tabulations and summaries from the 1994/95 Home-Interview survey. The inclusion of a toll/non-toll nest for each auto mode represented in the model required an expanded set of target values for model calibration.

3.5 Estimation of Highway Supply Characteristics

Highway supply characteristics that are required by the travel forecasting procedures include estimation of the highway level of service (LOS)(i.e., travel speed or time), parking costs, auto terminal times and auto operating costs.

The 1995 base year highway network includes key operational features for approximately 5,400 center-line miles of roadways in the Houston-Galveston TMA, and consists of nearly 20,000 roadway links (excluding centroid connectors). Each link's physical and operating characteristics are described in a link data record. The source of much of the data described in the base year network is the *Houston-Galveston Regional Transportation Study Roadway Inventory*, published by the Texas Transportation Institute in June 1995. These data were supplemented by field surveys when necessary. Access to the highway network is provided by connecting links, referred to as centroid connectors, which link internal TAZ centroids to nodes (points) in the highway network. These centroid connectors represent access to collectors, arterials and other roadway facilities via local streets. The physical and operational characteristics represented with centroid connectors reflect zone size, proximity to the regional highway network and the travel characteristics of local roadway facilities, which have the function of providing access to land uses within zones.

Data on physical attributes of the network, including roadway length, number of lanes and median access type (divided or undivided), as well as operational characteristics, such as average weekday traffic count and direction (one-way/two-way), were taken from the Roadway Inventory. Link data items, such as facility type classification, 24-hour speed, and 24-hour capacity, are derived either from the above information or from a vehicle trip assignment. Highway link facility types include 20 different classifications. These are listed in Table 3.4, along with the link type codes for transit and HOV access.

[2] The enhanced nested logit mode choice model is depicted in Figure 4.2.

Table 3.3
Mode Choice Model Calibration Target Values

							Home-Based Work Trip Purpose
		Income Group					
Mode	Path	1	2	3	4	5	Total
Drive Alone	Non-Toll	175325	275972	371067	461923	511134	1795422
	Toll	4417	7510	10881	16558	20515	59881
2-Person Auto	Non-Toll	52804	64199	77915	84811	74671	354400
	Toll	1884	2354	2937	2886	2979	13040
3-Person Auto	Non-Toll	11102	13597	12844	13405	8684	59632
	Toll	524	729	834	1187	981	4256
4+ Person Auto	Non-Toll	8753	9982	7813	7332	5710	39591
	Toll	591	768	743	881	832	3817
Local Bus	Walk	34929	23745	12597	4493	1110	76875
Commuter Bus	Walk	577	222	469	190	311	1769
Express Bus	Walk	1583	1189	1290	876	562	5501
Park-and-Ride	Drive	761	2596	6367	6988	7810	24522
Kiss-and-Ride	Drive	1101	941	894	661	299	3996
Total		294349	403804	506654	602196	635603	2442608
							Home-Based Non-Work Trip Purpose
Drive Alone	Non-Toll	507166	637647	705536	830659	925759	3606767
	Toll	852	2410	4564	7870	11656	27352
2-Person Auto	Non-Toll	207941	246411	272640	312658	339739	1379390
	Toll	145	344	719	1135	1567	3909
3-Person Auto	Non-Toll	124653	130667	141098	149069	148213	693699
	Toll	153	403	769	1238	1644	4207
4+ Person Auto	Non-Toll	109337	122338	128340	138565	141457	640037
	Toll	158	489	957	1563	2096	5263
Local Bus	Walk	30385	11760	5777	1867	320	50108
Commuter Bus	Walk	30	11	27	2	3	73
Express Bus	Walk	895	388	201	45	28	1558
Park-and-Ride	Drive	485	91	217	85	37	914
Kiss-and-Ride	Drive	804	261	94	91	17	1267
Total		983003	1153219	1260940	1444845	1572537	6414544
							Non-Home Based Trip Purpose
Drive Alone	Non-Toll	3009748					3009748

	Toll	39265		39265
2-Person Auto	Non-Toll	654412		654412
	Toll	2783		2783
3-Person Auto	Non-Toll	265865		265865
	Toll	2628		2628
4+ Person Auto	Non-Toll	286572		286572
	Toll	2133		2133
Local Bus	Walk	22888		22888
Commuter Bus	Walk	84		84
Express Bus	Walk	844		844
Park-and-Ride	Drive	1096		1096
Kiss-and-Ride	Drive	638		638
Total		4288957		4288957

3.5.1 Link Capacity

Capacity and speed are the two most critical inputs into the highway network. Capacity values accorded to all roadway links represent Level of Service (LOS) E or maximum capacity based on the Highway Capacity Manual.

The following formula provided the basis for calculation of 24-hour link capacities:

$$C_{24} = \frac{(PHPD + PHNP)}{K}$$

Where:
C_{24} **= average daily traffic, or 24-hour capacity**
PHPD **= capacity in the peak direction during the peak hour**
PHNP **= capacity in the non-peak direction during the peak hour**
K **= design hourly volume as a percent of ADT**

The peak hour/peak direction and peak hour/non-peak direction capacities are then calculated as a function of the hourly saturation flow rate:

$$PHPD = \frac{CS \times \frac{G}{C} \times \frac{V}{C} \times PHF \times U \times \frac{L}{2}}{1 + \left(P_t - (E_t - 1)\right)} + LTVP$$

Where:
CS **= saturation flow rate (2,150 vehicles/hour/lane for freeways, 1,800 for arterials)**
G/C **= percent of green time at signalized intersections (100 percent for freeways)**
V/C **= ratio of volume in the peak 15 minutes to capacity**
PHF **= peak hour factor (V (volume) in highest hour / 4 $\times$ V in the peak 15 minutes)**
U **= lane utilization factor**
L **= number of lanes**
P_t **= percent of trucks**
E_t **= truck equivalency factor**
LTVP **= left turn volume in the peak hour and peak direction**

Table 3.5
Link Type Classification Codes

Code	Description
1	Radial freeways without frontage roads
2	Radial freeways with frontage roads
3	Circumferential freeways without frontage roads
4	Circumferential freeways with frontage roads
5	Radial tollways without frontage roads
6	Radial tollways with frontage roads
7	Circumferential tollways without frontage roads
8	Circumferential tollways with frontage roads
9	Principal arterials with some grade separations
10	Principal arterials – divided
11	Principal arterials – undivided
12	Other arterials – divided
13	Other arterials – undivided
14	One-way pairs
15	One-way facilities
16	Major Collectors
17	Minor Collectors
18	Ferries
19	Saturated arterials
20	HOV/transitways
21	HOV ramps – bus only
22	Transfers from park-and-ride to transit stop
23	Transfers from local bus to commuter/express bus
24	Transfers from walk access node to transit stop
25	Drive-access connectors
26	Bus only: from street to transit center
27	HOV-only slip ramps
28	Transfer from pseudo-PNR to transit stop
29	HOV terminal ramps
30	Rail
00	Centroid connectors

Application of peak hour directionality factors to estimates of peak hour/peak direction volumes provides peak hour/non-peak directional volumes:

$$PHNP = PHPD \times \frac{1 - D}{D}$$

Where:
D **= percent of peak hour traffic in the peak direction.**

3.5.2 Automobile Travel Times

Link speed is used in trip distribution and as the input speed for the initial iteration in traffic assignment. The values of these link characteristics were carefully developed and closely reviewed during the speed model calibration process. Two speed values are developed for all roadway links: a 24-hour speed and a peak hour speed.

The 24-hour link speed reflects an average daily speed for a given roadway facility type within a given area. Reasonable speed values were determined by testing values through comparisons to travel time contours developed from the 1985 Regional Travel Time and Speed Survey developed by TxDOT.

The Texas Transportation Institute developed highway speed estimation procedures for H-GAC on which automobile travel times are based. Procedures adapted from the *Highway Capacity Manual* (HCM) methodology allow for computation of congested highway link speeds. However, the procedures differ somewhat between how freeway and non-freeway link speeds are estimated. Congested freeway speed is a function of free-flow speed (a function of speed limit and area type), speed at capacity (LOS E), and the volume-to-capacity (v/c) ratio for v/c ratios up to 1.0. For v/c ratios greater than 1.0, which represents saturated (LOS F) conditions, speed is estimated using a variant of the BPR function, with a multiplicative factor of 0.15 and v/c raised to the fourth power.

Procedures outlined in the HCM are used to estimate congested speeds on arterial or collector links. Congested arterial/collector link speed is a function of free-flow speed (a function of speed limit and area type), average intersection delay, signal spacing (segment), and the ratio of segment running time per mile to free-flow-speed running time per mile, where v/c ratios are 1.0 or less. For saturated (LOS F) conditions with v/c ratios greater than 1.0, speed is estimated using a variant of the BPR function, with a multiplicative factor of 0.15 and v/c raised to the second power.

Peak hour speeds are derived from a peak hour equilibrium assignment. Since capacities used during the equilibrium assignment represent LOS E, the resulting link's v/c ratio can then be applied to the speed model to develop a peak hour speed. In other words, the traffic assignment results are post-processed to compute a reliable speed based on the assigned v/c ratio.

After link speeds and capacities have been developed, they are compiled into a look-up table used for all roadway facility types, except HOV / transitways. The look-up table (Table 3.5) provides classifications of speed and capacity by facility type and number of lanes. The table is not used for centroid connectors.

Table 3.5

Speed and Capacity Look-Up Table

		Area Type 1		Area Type 2		Area Type 3		Area Type 4		Area Type 5	
FT	Lanes	Capacity	Speed	Capacity	Speed	Capacity	Speed	Capacity	Speed	Capacity	Speed
1	4	89,000	40	100,500	45	90,500	50	76,000	55	57,500	60
1	5	111,250	40	125,500	45	112,000	50	84,250	55	61,500	60
1	6	134,500	40	151,000	45	135,500	50	114,000	55	86,500	60
1	8	179,500	40	201,500	45	180,500	50	152,000	55	115,000	60
1	9	200,250	40	226,000	45	201,500	50	190,000	55	110,750	60
1	10	224,500	40	252,000	45	226,000	50	227,500	55	144,000	60
1	12	269,000	40	302,000	45	271,000	50				
1	14	314,000	40	352,500	45	316,500	50				
1	16	359,000	40	403,000	45	361,500	50				
2	4	105,500	40	116,500	45	106,500	50	92,000	55	73,500	60
2	5	125,750	40	142,500	45	128,000	50	99,250	55	72,500	60
2	6	150,500	40	167,000	45	151,500	50	130,000	55	102,500	60
2	8	195,500	40	217,500	45	196,500	50	168,000	55	131,000	60
2	10	240,500	40	268,000	45	242,000	50	206,000	55	160,000	60
2	12	285,000	40	318,000	45	287,000	50	243,500			
2	14	330,000	40	368,500	45	332,000	50				
2	16	375,000	40	419,000	45	377,500	50		55		
3	4	85,000	40	100,500	45	94,500	50	83,000	55	68,000	60
3	6	120,500	40	151,000	45	141,500	50	124,000	55	102,000	60
3	8	160,500	40	201,500	45	189,000	50	165,500	55	136,000	60
3	10	200,500	40	252,000	45	236,000	50	207,000	55	170,000	60
3	12	241,000	40	302,000	45	283,500	50				
3	14	281,000	40	352,500	45	330,500	50				
3	16	321,000	40	403,000	45	377,500	50				
4	4	101,000	40	116,500	45	110,500	50	99,000	55	84,000	60
4	6	136,500	40	167,000	45	157,500	50	140,000	55	118,000	60
4	8	176,500	40	217,500	45	205,000	50	181,500	55	152,000	60
4	9	193,750	40	231,500	45	216,250	50	180,500	55	129,750	60
4	10	216,500	40	268,000	45	252,000	50	223,000	55	186,000	60
4	12	257,000	40	318,000	45	299,500	50				
4	14	297,000	40	368,500	45	346,500	50				
4	16	337,000	40	419,000	45	393,500	50				
5	4	57,000	45	52,000	50	48,000	55	41,000	60	34,000	60
5	6	86,000	45	78,000	50	71,000	55	61,000	60	51,000	60
5	8	114,000	45	104,000	50	95,000	55	82,000	60	68,000	60
5	10	143,000	45	130,000	50	119,000	55	102,000	60	84,000	60
5	12	171,000	45	156,000	50	143,000	55				
5	14	200,000	45	182,000	50	166,000	55				
5	16	229,000	45	208,000	50	190,000	55				
		Area Type 1		Area Type 2		Area Type 3		Area Type 4		Area Type 5	
FT	Lanes	Capacity	Speed	Capacity	Speed	Capacity	Speed	Capacity	Speed	Capacity	Speed
6	4	71,500	45	69,000	50	64,000	55	56,000	60	45,000	60
6	6	100,500	45	95,000	50	87,000	55	76,000	60	62,000	60
6	8	128,500	45	121,000	50	111,000	55	97,000	60	79,000	60
6	10	157,500	45	147,000	50	135,000	55	117,000	60	95,000	60

6	12	185,500	45	173,000	50	159,000	55				
6	14	214,500	45	199,000	50	182,000	55				
6	16	243,500	45	225,000	50	216,000	55				
7	4	60,000	45	57,000	50	54,000	55	48,000	60	45,000	60
7	6	90,000	45	85,000	50	81,000	55	73,000	60	67,000	60
7	8	119,000	45	113,000	50	108,000	55	97,000	60	90,000	60
7	10	149,000	45	142,000	50	135,000	55	121,000	60	112,000	60
7	12	179,000	45	170,000	50	162,000	55				
7	14	209,000	45	199,000	50	189,000	55				
7	16	239,000	45	227,000	50	216,000	55				
8	4	74,500	45	74,000	50	70,000	55	63,000	60	56,000	60
8	6	104,500	45	102,000	50	97,000	55	88,000	60	78,000	60
8	8	133,500	45	130,000	50	124,000	55	112,000	60	101,000	60
8	10	163,500	45	159,000	50	151,000	55	136,000	60	123,000	60
8	12	193,500	45	187,000	50	178,000	55				
8	14	223,500	45	216,000	50	205,000	55				
8	16	253,500	45	244,000	50	232,000	55				
9	2	19,600	35	23,000	35	22,400	42	20,800	45	17,400	55
9	4	38,000	35	44,800	35	43,600	42	40,500	45	33,900	55
9	6	55,500	35	65,400	35	63,600	42	59,100	45	49,500	55
9	8	74,000	35	87,300	35	84,800	42	78,800	45	66,000	55
10	2	15,000	17	16,700	30	16,200	34	14,400	39	11,700	51
10	3	22,150	17	24,700	30	23,850	34	21,050	39	17,150	51
10	4	29,300	17	32,400	30	31,500	34	28,000	39	22,800	51
10	5	36,050	17	40,100	30	38,750	34	34,150	39	27,900	51
10	6	42,700	17	47,300	30	46,000	34	40,800	39	33,200	51
10	7	49,900	17	55,550	30	53,650	34	47,300	39	38,600	51
10	8	56,900	17	63,100	30	61,300	34	54,400	39	44,300	51
11	2	13,200	17	15,400	30	14,900	34	13,300	38	10,800	50
11	3	20,000	17	22,250	30	21,800	34	19,450	38	15,850	50
11	4	25,300	17	29,600	30	28,700	34	25,500	38	20,800	50
11	5	32,150	17	35,850	30	35,050	34	31,300	38	25,550	50
11	6	36,600	17	42,700	30	41,500	34	36,900	38	30,000	50
11	8	50,100	17	55,900	30	54,600	34	48,700	38	39,800	50
11	9	48,200	17	56,300	30	54,700	34	48,600	38	39,600	50
12	2	13,500	17	16,200	30	14,600	34	12,500	37	10,500	49
12	3	19,450	17	23,850	30	21,200	34	18,450	37	14,550	49
12	4	26,300	17	31,500	30	28,400	34	24,400	37	20,500	49
12	5	31,650	17	38,700	30	34,450	34	30,000	37	23,600	49
12	6	38,400	17	45,900	30	41,500	34	35,600	37	29,900	49
12	8	51,200	17	61,300	30	55,300	34	47,400	37	39,000	49
		Area Type 1		Area Type 2		Area Type 3		Area Type 4		Area Type 5	
FT	Lanes	Capacity	Speed	Capacity	Speed	Capacity	Speed	Capacity	Speed	Capacity	Speed
13	1	6,150	17	7,550	29	6,700	33	5,850	36	4,750	48
13	2	12,500	17	15,100	29	13,600	33	11,700	36	10,200	48
13	3	18,000	17	22,050	29	19,600	33	17,100	36	13,900	48
13	4	24,100	17	29,000	29	26,200	33	22,500	36	19,500	48

13	5	28,950	17	35,450	29	31,550	33	27,500	36	28,200	48
13	6	34,700	17	41,900	29	37,900	33	32,500	36	26,500	48
13	7	39,650	17	48,550	29	43,250	33	37,650	36	30,700	48
13	8	45,100	17	55,200	29	49,200	33	42,800	36	34,900	48
14	4	29,500	17	34,600	33	32,800	37	29,000	40	23,900	52
14	5	36,250	17	42,150	33	40,250	37	35,100	40	29,200	52
14	6	43,300	17	50,700	33	48,000	37	42,400	40	35,000	52
14	7	49,550	17	57,650	33	55,000	37	48,000	40	39,900	52
14	8	56,300	17	66,000	33	62,500	37	55,200	40	45,500	52
14	9	63,050	17	73,300	33	70,000	37	61,050	40	50,750	52
14	10	70,400	17	82,500	33	78,100	37	69,000	40	56,900	52
14	11	77,100	17	89,550	33	85,550	37	74,600	40	62,050	52
14	12	84,500	17	99,000	33	93,700	37	82,800	40	68,300	52
14	13	91,100	17	105,850	33	101,100	37	88,200	40	73,350	52
14	14	98,600	17	115,500	33	109,300	37	96,600	40	79,700	52
14	16	112,600	17	132,000	33	124,900	37	110,400	40	91,100	52
15	2	14,800	17	17,300	33	16,400	37	14,500	40	11,900	52
15	3	21,600	17	25,400	33	24,000	37	21,200	40	17,500	52
15	4	28,200	17	33,000	33	31,200	37	27,600	40	22,800	52
15	5	35,200	17	41,300	33	39,000	37	34,500	40	28,500	52
15	6	42,200	17	49,500	33	46,800	37	41,400	40	34,100	52
15	7	49,300	17	57,800	33	54,700	37	48,300	40	39,800	52
15	8	56,300	17	66,000	33	62,500	37	55,200	40	45,500	52
16	2	12,500	17	14,600	29	13,200	33	11,400	36	8,800	45
16	4	24,100	17	28,200	29	25,500	33	21,800	36	16,900	45
16	6	34,700	17	40,600	29	36,800	33	31,600	36	24,400	45
16	8	45,800	17	53,600	29	48,400	33	41,600	36	32,100	45
17	2	8,700	15	10,400	24	10,200	25	8,900	26	7,400	41
17	3	12,450	15	14,700	24	14,400	25	9,450	26	5,150	41
17	4	16,200	15	19,300	24	18,900	25	16,600	26	13,700	41
17	6	24,100	15	28,300	24	27,800	25	24,400	26	20,200	41
17	7	29,000	15	33,700	24	33,100	25	20,950	26	11,500	41
17	8	33,900	15	39,800	24	39,100	25	34,400	26	28,300	41
18	2	7,000	15	7,000	15	7,000	15	7,000	15	7,000	15
19	2	19,000	17	21,600	30	21,200	34	20,800	39	15,300	51
19	3	28,250	17	31,800	30	31,150	34	30,600	39	22,100	51
19	4	37,800	17	43,000	30	42,200	34	41,400	39	30,600	51
19	5	46,850	17	52,700	30	51,700	34	50,700	39	36,600	51
19	6	56,400	17	64,200	30	63,000	34	61,800	39	45,600	51
19	7	65,250	17	73,400	30	72,000	34	70,650	39	51,000	51
19	8	74,800	17	85,100	30	83,500	34	81,900	39	60,500	51
19	9	83,850	17	94,350	30	92,500	34	90,850	39	65,600	51

In application, travel times are built in EMME/2 by tracing the paths, while using the default parameters for auto path building, which are:

- Number of iterations = 15
- Stopping criterion for relative gap = 0.50 percent
- Stopping criterion for normalized gap = 0.50 minutes

3.5.3 Auto Network Centroid Connectors

Speeds on centroid connectors are derived as a function of link length and zonal area type to reflect diversity in zone size, network density and local street operational speeds. As an example, centroid connectors of less than one-tenth mile within the Houston CBD are assigned a speed of ten miles per hour, which is considered the lowest practical facility speed that would not unduly penalize travel in that area.

CBD centroid connector speed is increased based on link length (for links less than one-tenth mile) as follows:

Travel Time (minutes) = (6.0 * link distance)
Travel Speed = 60 / (Travel Time / link distance)

For CBD centroid connectors longer than 0.10 miles, the speed is calculated as follows:

Travel Time (minutes) = (0.6 + 4 * (link distance - 0.1))
Travel Speed = 60 / (Travel Time / link distance)

As the area changes from CBD to urban to suburban, etc., centroid connector speeds increase more rapidly with increasing distance. This is based on the premise that as area type changes from denser areas (CBD) to less dense areas (suburban), zone sizes will increase accordingly. Thus, each of the other four area types have a unique set of equations for determining centroid connector speeds:

Area Type 2 - Urban

when link distance = 0.10 miles or less:
Travel Time (minutes) = (4.0 * link distance)
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.10 miles and <= 0.25 miles:
Travel Time (minutes) = (0.4 + 3 * (link distance - 0.1))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.25 miles:
Travel Time (minutes) = (0.85 + 2.4 * (link distance - 0.25))
Travel Speed = 60 / (Travel Time / link distance)

Area Type 3 - Suburban

when link distance = 0.10 miles or less:
Travel Time (minutes) = (4.0 * link distance)
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.10 miles and <= 0.25 miles:
Travel Time (minutes) = (0.4 + 3 * (link distance - 0.1))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.25 miles and <= 0.50 miles:
Travel Time (minutes) = (0.85 + 2.4 * (link distance - 0.25))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.50 miles:
Travel Time (minutes) = (1.45 + 2.0 * (link distance - 0.5))
Travel Speed = 60 / (Travel Time / link distance)

Area Type 4 - Fringe Suburban

when link distance = 0.10 miles or less:
Travel Time (minutes) = (3.5 * link distance)
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.10 miles and <= 0.25 miles:
Travel Time (minutes) = (0.35 + 2.7 * (link distance - 0.1))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.25 miles and <= 0.50 miles:
Travel Time (minutes) = (0.755 + 2.2 * (link distance - 0.25))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.50 miles and <= 0.75 miles:
Travel Time (minutes) = (1.305 + 1.8570 * (link distance - 0.5))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.75 miles:
Travel Time (minutes) = (1.76925 + 1.714 * (link distance - 0.75))
Travel Speed = 60 / (Travel Time / link distance)

Area Type 5 - Rural

when link distance = 0.10 miles or less:
Travel Time (minutes) = (3.0 * link distance)
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.10 miles and <= 0.25 miles:
Travel Time (minutes) = (0.30 + 2.4 * (link distance - 0.1))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.25 miles and <= 0.50 miles:
Travel Time (minutes) = (0.66 + 2.0 * (link distance - 0.25))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.50 miles and <= 0.75 miles:
Travel Time (minutes) = (0.96 + 1.714 * (link distance - 0.5))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 0.75 miles and <= 1.0 mile:
Travel Time (minutes) = (1.3885 + 1.5 * (link distance - 0.75))
Travel Speed = 60 / (Travel Time / link distance)

when link distance > 1.0 mile and <= 1.5 miles:
Travel Time (minutes) = (1.7035 + 1.333 * (link distance - 1.0))
Travel Speed = 60 / (Travel Time / link distance)

For rural zones exceeding 1.5 miles, link speeds are calculated as follows:

Travel Time (minutes) = (2.37 + 1.2* (link distance - 1.5))
Travel Speed = 60 / (Travel Time / link distance)

Thus, an urban zone may have a link distance of 1.0 mile yielding a speed of 22.6 miles per hour, while a suburban zone of 1.0 mile has a speed of 41.4 miles per hour. A representative table of centroid connector speeds for a distance of one mile would appear as follows:

Table 3.6
Centroid Connector Speeds

Area Type	Distance (miles)	Speed (mph)
CBD	1.0	14.3
Urban	1.0	22.6
Suburban	1.0	24.5
Fringe Suburban	1.0	27.3
Rural	1.0	32.6

Source: H-GAC

3.5.4 HOV Facilities

In 1995 there were four freeways which include one-lane reversible HOV lanes:

- Katy Freeway
- North Freeway
- Gulf Freeway
- Northwest Freeway

Unique HOV/transit only links were added to the highway network to represent each of the HOV facilities including actual connector links (note link type 27 in Table 3.4).

3.5.5 Toll Road Facilities

In the 1995, network toll roads are coded comparably to any freeway link. The actual toll imposed on a vehicle is stored in a user-specified link field and accumulated into a separate toll matrix during the assignment process. Separate toll plaza links are included in the network specifically for this purpose. There are two freeways currently designated as toll roads:

- Hardy Toll Road
- Sam Houston Tollway

There is an additional network link representing the Houston Ship Channel Bridge, which also charges a toll.

3.5.6 Auto Modes

In EMME/2, all network links contain one or more single letter identifiers for each mode allowed to traverse that link. In order to remain consistent with the choice structure of the mode choice model and facilitate use of the multi-class assignment within EMME/2, the following six codes were used in the base or roadway network:

- I SOV non-toll
- m SOV toll
- h 2-person non-toll
- I 2-person toll
- j 3+ person non-toll
- n 3+ person toll

3.5.7 Additional Highway Characteristics

Highway terminal time represents the time required to walk from a selected parking space to the ultimate destination of a trip. Historically, terminal time has been determined synthetically by relating the density of employment to the magnitude of the value – the greater the employment density, the higher the value of terminal time. This underlying concept is supported by the fact that as employment density increases, parking supply typically decreases, costs influenced by demand increase, and trip makers begin to

"trade-off" walking distance with the availability and price of parking. Currently, terminal times vary from six minutes in the CBD to a low of two minutes in residential areas.

Auto operating costs are an estimate of the out-of-pocket cost paid to operate a private vehicle on a per-mile basis. Cost components included in this variable are based on fuel cost and fuel economy plus tire, oil and general maintenance costs. Fixed elements of cost, such as depreciation and insurance costs, are not considered out-of-pocket costs. Historically, tire, oil, and maintenance costs maintain consistency with general inflationary increases in costs. However, fuel costs have displayed patterns quite divergent from these general cost increases. Most future year estimates of fuel costs (by the Department of Energy or Argonne National Laboratories) display a distinct pattern of increasing costs coupled with similar increases in fuel economy. Therefore, it is prudent to assume that projected increases in fuel cost will be largely offset by similar increases in fuel economy, resulting in *no* real increase in the auto operating cost value for 2020 (1990 operating cost is 13.01 cents per miles).

3.6 Estimation of Transit Supply Characteristics

A reflection of the level-of-service experienced by a potential transit user is constructed through development of a computerized network representation of the system of routes and service levels. This computer-coded transit network must be an accurate representation of the individual bus routes, fixed guideway lines, headways, and travel times that define that service. Consistency in representation methods across all alternatives is essential to ensure that differences in travel times between those alternatives are accurate portrayals of service level differences, and not simply differences in coding conventions.

Reflection of the choice of "path" or route(s) selected between TAZs within the network is an equally important consideration in properly determining transit supply characteristics. The algorithm which applies the "path-building" step of the process must examine all the possible ways in which a transit user could travel on one or more transit lines between each pair of TAZ's. This algorithm selects the path that involves the minimum inconvenience in terms of in-vehicle time, waiting, transferring and accessing the service.

3.6.1 Transit Routes and Coded Lines

A route in the transit system is typically a set or series of services that operate generally in the same area and over the same streets, but which may offer variations in service origination or termination. The path-building algorithm, however, must be aware of the specific service level options available to each TAZ zone pair, which, therefore, necessitates the representation of each of the variations within a route by means of a separately coded line. Similarly, not all routes or subroutes operate during the course of the entire day. Express and commuter routes, in particular, generally operate only during the morning and afternoon peak periods. In order to properly reflect these differences, separate peak and base networks are constructed for use in the travel forecasting process.

A trade-off exists between the precision of representation of individual route variations actually operated and the transit service levels perceived by transit users. This trade-off stems from the manner in which the path-building algorithm measures the frequency of

service between boarding and alighting locations. The algorithm recognizes that several lines operating in the same pattern offer a combined frequency of service that is the summation of the frequencies on each individual line. In contrast to other modeling software packages where this recognition occurs only when the lines follow *exactly* the same routing, EMME/2 allows combined service computation for coded transit network lines that comprise variations in routing or termini.

3.6.2 Headway Calculation

Specification of service frequency for each coded line is an extremely important aspect of the overall network coding process. As outlined above, service is differentiated both by delineation of individual lines (within routes) and also by time period (peak and base). The determination or calculation of a headway value for each line within a time period is related directly to the actual number of bus trips operated.

In the case of the base or off-peak period, the headway is simply the number of hours in the midday period divided by the total number of trips provided on that line during midday.

Unlike base period service, which tends to be fairly evenly distributed over the entire period, peak service may vary substantially within the peak period. Express lines, for example, may provide relatively few bus trips over the entire period, but may concentrate these trips within a relatively small time interval. Assuming that these trips are appropriately targeted to the specific demand for peak period service, the perceived headway by riders (who will become familiar with the scheduling of the service) will be significantly better than the value implied by using a computation method identical to that for base period service. Therefore, peak headway calculations must be based on the peak hour of service offered in the peak period, with an appropriate peak hour headway calculated therefrom. Table 3.7 summarizes the coded peak and base period headways for each of the lines coded in the 1995 transit network.

This approach to coding produces headway values appropriate for the ridership forecasting process, but typically overestimates peak resource requirements: vehicles, vehicle-hours and vehicle-miles. A separate analysis of resource requirements is conducted in a post-processing environment to resolve this inconsistency.

3.6.3 Transit Travel Times

Travel times are based on automobile travel times, type of transit service (local, limited, express, etc.), and bus location by sector. The running time of the transit lines over all the network links in each line is calculated using a series of travel time functions (TTF) based on these parameters. Each TTF is referenced with a designated number. Three basic types of TTFs are included in the model:

I. Simple assumed speed
II. Auto speed multiplied by an auto-to-transit time factor
III. Congested speed estimation using BPR function, based on free-flow transit speed compared to minimum transit speed.

Type I TTFs are coded with an assumed speed, which is constant across all links. Type II TTFs apply a multiplicative factor to auto time to relate transit link travel time to the corresponding auto travel time. Type III TTFs estimate congested-speed travel time based on free-flow transit travel time and the v/c ratio of the link. The general form of Type III TTFs is the BPR function:

$$t_c = t_{ff} \times \left(1 + \alpha \times \left(\frac{v}{c}\right)^4\right)$$

Where t_{ff} is free-flow transit travel time and α is a multiplicative factor. For all but two TTFs, α is 0.10. For those two TTFs representing nonstop bus operations outside the CBD, α is 0.15. Congested-speed travel time is capped against a maximum time associated with a given minimum transit speed and the resulting time is compared to a minimum time representing auto time on the same link. All three TTFs are used during the peak period, while only Types I and II are used during the off-peak period.

A summary of the peak travel time functions are presented in Table 3.8.

Table 3.7
1995 Transit Line Coded Headways

Route	Name	Peak Headway	Base Headway
		(minutes)	(minutes)
1	Hospital	15	15
2a	Bellaire-Mission Ben	20	60
2b	Bellaire-Westchase	20	30
2c	Bellaire-7600 Turn B	20	60
3	Langley LTD./West Gr	15	30
4a	Beechnut/Jensen Via	60	120
4b	Beechnut-CBD	30	50
4b	Beechnut/Jensen Nost	15	50
5a	Kashmere Gardens/Sou	30	50
5b	Kashmere Gardens/GSH	30	50
8a	W. Bellfort-CBD	25	35
8b	N.Main/S.Main-Willow	25	35
11	Nance/Almeda	35	50
13	Plaza Del oro Circ	18	35
15a	Hiram Clark Transit	22	48
15b	Hiram-Orem/Fulton	22	48
16	Memorial	30	--
17	Tanglewood/Gulfton	15	24
18	Kirby Lake 610-West	25	25
20a	Canal/Long Point-Mem	28	30
20b	Canal/Long Point-Neu	28	--
20c	CBD-Long Point-Memor	30	--
23a	Crosstimbers-xtown	28	28
25a	Rich N.Line W.Chase	24	30

25b	Rich N.Line Sharptwn	24	30
26a	Outer Loop-Clockwise	15	26
27a	Outer Loop-Counter	15	26
30a	Galena Port-CullenVF	60	--
30b	Clinton-Cullen FWY	30	60
30c	Denver Harbor-Cullen	30	60
33a	P.Oak Xtown Ridgmont	30	60
33b	Post Oak-W. Fuqua	15	60
34a	Montrose Xtown	25	25
35a	Fairview-2000/Leelan	30	50
36a	Kempwood-9800 CBD vi	60	60
36b	Kempwood-Carverdale	60	60
36c	Kempwood-9800/Lawnda	75	--
36d	Kempwood-Carverdale/	30	--
36e	Lawndale/gulf-CBD	30	--
37a	El Sol Xtown	35	35
40a	Pecore NW.Mall-Richy	30	60
40b	Pecore AHTC-Howard	30	60
40c	Howard-AHTC Via FWY	99	--
40d	Richey-CBD	60	--
41a	Gulf Medows Circ	30	60
42a	Holmn Xtwn-Dnvr Hbr	30	30
42b	Holman-EWTC	30	30
43a	TSU/UH Shuttle	15	20
44a	Acr Home-Compaq	25	60
44b	Stallings-CBD	20	60
45a	Tedwell Xtown	30	50
46a	Gessener Xtown	15	30
47a	Hillcroft Xtown	20	30
48a	Navig-Gulfgate/W. Da	60	110
48b	Navig-Plsntvil/W. Da	30	60
49a	Chimney Rock Xtown	30	45
50a	Heights CBD-FWY	35	--
50b	Heights Rosl-Airport	40	80
50c	Heights Hollister-Do	50	120
50e	Heights 4200-Airport	20	120
50f	Heights 4200-Dock	90	40
52a	Hirsch/Scott-8000	45	45
52b	Hirsch/Scott	20	22
52c	Scott-CBD via FWY	30	--
53a	Westheimer Briar For	18	50
53b	Westheimer-W. Oaks	18	50
54a	Hollyvale Circ	30	45
56a	Airline Greens FWY	10	15
57a	JFK LTD	25	50
58a	Hammerly-CBD FWY	30	--
58b	Hammerly-NWTC	20	60
60a	Hardy/S.MacGregor	30	60
63a	San Felipe LTD	60	--
63b	San Felipe LTD via P	60	--
64a	Lincoln City Circ	30	30
65a	Dairy Ash-Blue Bell	40	50

65b	Dairy Ash-Sweetwater	40	50
65c	D.A. FWY-Blue Bell	90	--
65d	D.A. FWY-Sweetwater	90	--
65e	D.A. FWY-CBD	80	--
65f	D.A. Local-CBD	25	--
68a	Brays Bayou W. belt	20	60
68b	Brays Bayou Meado	15	60
70a	University	45	--
70b	University/Memorial	60	60
72a	Westview	20	30
73a	Bellfort Xtown P.Oak	30	60
73b	Bellfort Xtown TMC	10	20
74a	Carver RD Circ	30	30
77a	Wayside-MLK	22	60
77b	Homestead-MLK	22	60
77c	MLK-CBD	25	--
78a	Alabama Irvin 9800	35	40
78b	Irvin 9800-CBD	25	--
79a	West Little York LTD	30	30
80a	Lyons Dowling	20	30
82a	Westheimer-Woodlake	30	45
82b	Westheimer-Sharptown	10	22
83a	Lee Road Circ	30	50
85a	InwoodForest-CBD	24	60
85b	InwoodForest-CBD	24	--
85c	Tidwell-CBD	24	60
86a	FM 1960 Circ-NHCC	30	60
86b	FM 1960-Greenspoint	30	60
87a	Yellowstone Circulat	15	17
88a	Broadway Exp	22	--
89a	South Park Circulato	30	30
93a	NWTC-GWY Shuttle	15	--
97a	Settegate Shuttle	40	40
98a	Briargate	30	60
102a	IAH-CBD Express	30	60
102b	Greens-CBD	40	--
119a	Willcrest Exp TWY	40	--
119c	Wilcrest Ex TWY NWTC	40	--
131a	Memo Gess Exp TWY	20	50
131b	Memo W.Belt Exp TWY	8	--
132a	Harwin Exp Mission	15	45
132b	Harwin Exp Mission	30	--
132c	Harwin Exp Cook RD	30	--
137a	Northshore Exp	10	10
143a	143 S.Belt Exp	25	50
163a	Foundren-Airport	20	60
163b	Foundren-MC P&R	20	60
201a	N.Sheph P&R-Cull CTR	15	--
201c	N.Sheph P&R-Hous CTR	25	--
202a	Kuyk P&R Houstn Ctr	22	--
202c	Kuyk P&R Cullen Ctr	8	--
202d	Kuyk P&R Cullen Ctr	20	--

202e	Kuyk P&R-GWY-P.Oak	20	--
202f	Spng&Kuy P&R Culn Ct	--	35
204a	Spring P&R	14	--
204b	Spring P&R	12	--
205a	Kingwood P&R	5	--
205b	Kingwood P&R-P.Oak	25	--
206a	Eastex P&R	20	--
206b	Eastex P&R	12	--
210a	Katy-West Belt P&R	15	--
210b	Katy-West Belt P&R	15	--
212a	Seton Lake Via TC	23	--
212b	Seton Lake P&R	6	--
214a	N.West Station P&R	12	--
214b	N.West Station P&R	10	--
214c	N.W Station P&R NW	15	--
216a	W.Little York-Pine	20	--
216b	W.Little York-Pine	20	--
221a	Mason P&R	15	--
221b	Mason P&R	30	--
221c	Katy-Mason P&R	30	--
228a	Addicks P&R	8	--
228b	Addicks P&R	10	--
236a	Maxey Rd P&R	30	--
236b	Maxey Rd P&R	30	--
245a	Edgebrook-CBD P&R	20	--
245b	Edgebrook-CBD P&R	12	--
245c	Edgebrook-CBD EWTC	15	--
246a	Bay Area P&R	7	--
246b	Bay Area P&R	20	--
246c	Bay Area P&R EWTC	30	--
246d	Combined 245/246 P&R	--	50
261a	West Loop P&R	20	--
261b	West Loop P&R	12	--
262a	Alief-W.Wood P&R	5	--
262b	Alief-W.Wood Houst C	30	--
265a	W.Belfort P&R	25	--
265b	W.Bellfort P&R	25	--
270a	Missouri City P&R	15	--
270b	Missouri City P&R	30	--
291a	N.Sheph P&R-TMC	20	--
292b	W.Wood-TMC P&R	10	--
295a	Mason-Addicks-NWTC	15	--
310a	Texas Special BLUE	--	6
311a	Texas Special RED	--	6
312a	Texas Special WHITE	--	6
313a	Texas Special Silver	5	5
320a	TMC Gold	3	15
321a	TMC Blue	5	15
322a	TMC Green	15	--
326a	TC Flyer West	15	15
327a	TC Flyer East	15	15

Source: Houston Metro

Table 3.8
Peak Transit Travel Time Functions

TTF	Type	Operation	Location	Type I Assumed Speed	Type II Auto-to-Transit Time Factor	Type III Free-flow Transit Speed	Type III Minimum Transit Speed
10	III	All Stop	Inside CBD			9	5
11	II		Transit Mall		1.0		
12	III		Inside 610 Loop			18	10
13	III		Outside 610 Loop			20	12
20	III	Limited Stop	Inside CBD			10	6
21	II		Transit Mall		1.0		
22	III		Inside 610 Loop			22	13
23	III		Outside 610 Loop			30	14
30	III	Non Stop	Inside CBD			12	7
31	II		Transit Mall		1.0		
32	III		Inside 610 Loop			40	n/a
33	III		Outside 610 Loop			45	n/a
8	I		Transit Ramp	12			
9	I		Transitway	53			

Source: 1990 Houston Long-Range Patronage Forecasting Model Validation

3.6.4 Transit Path Building

Path building between each pair of zones relies on the coded representation of the transit network, as outlined above, and a set of "weights" used to value each time component of the trip – walking, waiting, in-vehicle and transferring. To the greatest extent possible, these weights should be reasonably similar to the "weight" derived from the mode choice model relationships.

The set of path building weights below was the final set of values used in the 1990 validated model (all times are in minutes):

- **Boarding time: 1.0**
- **Boarding time weight (drive access): 1.0**
- **Boarding time weight (walk access): 10.0**
- **Waiting time factor: 0.5**
- **Waiting time weight: 2.0**
- **Auxiliary transit time weight: 1.5**

3.6.5 Transit Modes

In EMME/2, all network links contain a single letter identifier for each mode allowed to traverse the link. Auxiliary transit modes are defined as walk and auto access modes; these modes represent access to, from and between transit lines, and constitute a portion of a transit trip. The following transit modes were used:

- **b: local bus**
- **c: commuter bus**

- **x: express bus**
- **r: rail**

The auxiliary transit modes are:

- **d: walk access to transit**
- **e: walk egress to transit**
- **t: transfer between transit lines**
- **p: auto access to transit (park-and-ride lots)**
- **k: auto access to transit (kiss-and-ride lots)**
- **q: auto access to transit (informal park-and-ride lots)**
- **w: sidewalk**

4.0 Travel Forecasting Procedures

4.1 Introduction

This chapter presents the underlying theory and basis for the structure, formulation and application of each model component. Also described is the series of steps that were followed to enhance and implement the revised regional mode choice model set, as well as the calibration and validation procedures performed to verify the accuracy and acceptability of the complete model set.

Two key sets of data are input to the model: demographic, socioeconomic and land-use information; and the multimodal transportation network level-of-service (LOS) data. In the first stage of the modeling process, trip generation, estimates are developed for eight trip purposes:

- Home-based work person trips (HBW)
- Home-based school person trips (HBSCH)
- Home-based shopping person trips (HBSHP)
- Home-based other person trips (HBO)
- Non-home-based person trips (NHB)
- Truck and taxi vehicle trips (TRTX)
- External-local vehicle trips (EXTL)
- External-through vehicle trips (EXTHR)

4.2 Trip Generation

Trip generation is performed with a trip production model and a trip attraction model for each trip purpose. These models use the zonal demographic data to estimate the overall magnitude of trip making – the total number of trip ends (trip productions and trip attractions) – for each of the 2,666 detailed traffic analysis zones.

4.2.1 Trip Production

The H-GAC trip production models use cross-classification trip production rates developed from the H-GAC 1985 Travel Survey data. These rates were developed from a set of three-way cross classification models using household size, household income, and vehicle availability which were subsequently combined to yield a two-way cross classification model of household size by household income. Individual cell values in the two-way cross classification table were derived by computing the weighted average of the three-way rates using regional distributions of households by vehicle availability for the two-way cells as the weights. The dependent variable is trips per household. The objective of the cross-classification model is to develop a set of relationships that can be used to identify all of the household characteristics generating statistically different trip rates and, simultaneously, to minimize the number of individual cells in the matrix. Using disaggregate data reduces the number of errors due to zonal averaging and the cross-classification methodology. It also allows for the nonlinearity of the model with respect to the independent variables.

The trip production model determines the relationship between trips generated per household and household income in combination with household size. Thus, trip production rates are stratified by household income and household size for each trip purpose.

Two enhancements have recently been incorporated to the 1990 trip generation model:

- the use of income quintiles
- a non-resident trip purpose

Earlier 1990 model validation efforts were based on five distinct income ranges; the current 1990 model incorporates revised 1985 household survey trip rates for income quintiles. These revised rates are shown by trip purpose in Tables 4.1-4.6.

Due to the high concentration of hotels, motels and seasonal housing in the Galveston Island area, a non-resident trip purpose was developed to address the model's historical under-reporting of assigned volumes in the area. Based on area specific monthly hotel/motel occupancy rates an average rate was applied against the number of units in the Galveston Island area to estimate occupied rooms; this estimate of rooms was multiplied by a NHB trip rate to determine the number of non-resident hotel/motel NHB trips. Likewise, an occupancy rate for seasonal housing factored by a NHB trip rate yielded seasonal housing non-resident NHB trips.

Table 4.1
Home-Based Work Person Trip Rates

Household Size	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
1	0.518	0.676	1.262	1.463	1.511
2	0.937	1.052	1.606	1.810	1.910
3	1.171	1.682	1.843	2.058	2.226
4	1.297	2.070	2.126	2.336	2.661
5+	1.308	2.100	2.177	2.376	2.749

Source: H-GAC

Table 4.2
Home-Based School (1) Person Trip Rates

Household Size	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
1	0.000	0.285	0.851	1.509	2.391
2	0.000	0.289	1.008	1.795	2.814
3	0.000	0.210	1.026	2.035	3.127
4	0.000	0.115	0.955	2.296	3.398
5+	0.000	0.090	0.930	2.350	3.460

Source: H-GAC

Table 4.3
Home-Based School (2) Person Trip Rates

Household Size	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
1	0.111	0.012	0.042	0.082	0.125
2	0.031	0.017	0.053	0.095	0.153
3	0.052	0.010	0.060	0.114	0.168
4	0.111	0.003	0.053	0.127	0.187
5+	0.000	0.000	0.050	0.130	0.190

Source: H-GAC

Table 4.4
Home-Based Shopping Person Trip Rates

Household Size	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
1	0.680	0.838	0.898	0.945	1.110
2	0.540	0.999	1.096	1.181	1.329
3	0.536	1.040	1.168	1.272	1.442
4	0.530	1.123	1.425	1.557	1.748
5+	0.530	1.180	1.510	1.650	1.850

Source: H-GAC

Table 4.5
Home-Based Other Person Trip Rates

Household Size	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
1	0.956	1.789	2.134	2.456	2.983
2	1.117	2.012	2.432	2.875	3.578
3	1.200	2.002	2.627	3.103	3.989
4	1.206	1.927	3.013	3.949	4.652
5+	1.220	1.890	3.120	4.240	4.850

Source: H-GAC

Table 4.6
Non-Home-Based Person Trip Rates

Household Size	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
1	1.136	1.675	1.939	2.098	2.299
2	1.622	2.304	2.478	2.752	2.938
3	1.851	2.697	3.080	3.469	3.773
4	2.125	3.059	3.788	4.284	4.769
5+	2.150	3.110	3.910	4.420	4.950

Source: H-GAC

4.2.2 Trip Attraction

Since the disaggregate household survey data collected provide information primarily relevant to trip production, aggregate techniques were used to calibrate trip attraction models, with aggregations large enough to ensure statistical stability. Regression analysis is performed at the district level to predict trip attractions and the equations developed are modified to apply at the zonal level for some trip purposes (HBW, HBSHP, NHB, TRTX). For other trip purposes (HBSCH, HBO), the models can only be applied at the district level. Separate zonal-level allocation models are provided to estimate zonal-level trips from district totals.

The primary strategy for the trip attraction model is to determine the relationship between district-level trip attractions and the land-use variables using linear regression. These relationships are basically standard, between work attractions and employment, and between shopping attractions and retail employment. The following are the trip attraction models by purpose:

Home-Based Work Person Trips

HBW Attractions = 1.24 (Total Zonal Employment)

Home-Based School (1) Person Trips
(Grades 12 and under)

HBSCH(1) District Attractions = 1.332 (District HH’s with 2+ Persons)

Zonal Allocation Model = 11.66 (Zonal Educational Employment for Grades 12 and under)

Home-Based School (2) Person Trips
(Colleges and Universities)

HBSCH(2) Zonal Attractions = 0.744 (Enrollment)

Home-Based Shop Person Trips

CBD Model

HBSHP Zonal Attractions = 0.299 (Zonal Retail Employment)

Non-CBD Model

HBSHP District Attractions = 0.714 (District HH's) + 1.278 (District Retail Employment)

Zonal Allocation Model = 3.517 (Zonal Retail Employment)

Home-Based Other Person Trips

HBO District Attractions = 1.959 (District HH's) + 0.3 (District Industrial Emp.) + 0.637 (Other District Emp.*)

Zonal Allocation Model = 0.74 (Zonal HH's) + 0.3 (Zonal Industrial Emp.) + 2.172 (Other Zonal Emp.*)

* Excludes Medical Employment in Major Medical Centers

Non-Home-Based Person Trips

CBD Model

NHB Zonal Attractions = 0.524 (Zonal HH's) + 2.593 (Zonal Retail Emp.) + 0.212 (Zonal Office Emp.) + 0.212 (Zonal Industrial Emp.) + 2.454 (Other Zonal Emp.*)

Non-CBD Model

NHB Zonal Attractions = 0.74 (Zonal HH's) + 3.659 (Zonal Retail Emp.) + 0.30 (Zonal Office Emp.) + 0.30 (Zonal Industrial Emp.) + 3.464 (Other Zonal Emp.*)

- Excludes Medical Employment in Major Medical Centers

4.2.3 Trip Generation Results

Table 4.7 summarizes the trip generation estimates by trip purpose. The 11 percent increase in person trips is consistent with the 11 percent increase in regional households from 1990 to 1995. The number of truck trips is based on employment estimates and households. The 14 percent increase is consistent with the regional increase in employment and households.

Table 4.7
Regional Trip Estimates by Purpose

Purpose	1990 Trips	1995 Trips	Percent Change
Home-Based Work Person Trips	2,198,932	2,442,596	11.1
Home-Based School Person Trips	1,313,498	1,458,527	11.0
Home-Based Shopping Person Trips	1,469,996	1,626,779	10.7
Home-Based Other Person Trips	3,334,568	3,695,346	10.8
Non-Home-Based Person Trips	3,789,295	4,203,243	10.9
Truck and Taxi Vehicle Trips	645,318	739,650	14.6
External-Local Vehicle Trips	184,890	222,375	20.2

Source: H-GAC Model Application Results

4.3 Trip Distribution

The trip distribution models are applied at the detailed TAZ level. These models link or connect trip ends estimated in the trip generation model, determining trip interchanges between each pair of zones. In addition to estimates of the magnitude of activity in each TAZ, the models consider the effects of impedance and accessibility on destination choice. The trip distribution models receive direct feedback from trip assignment, a lower model component.

4.3.1 Person Trip Table Development

The Disaggregate Trip Distribution Model, or Atomistic Model, is used for trip distribution modeling in the Houston-Galveston TMA. This model is used to produce six trip tables for the HBW, HBSCH, HBSHP, HBO, NHB, and TRTX purposes. A modified version of the Atomistic model is used to produce external-local vehicle trip tables, while the external-through trip tables are provided by TxDOT. The underlying assumption in the Atomistic model is that trips occur between small parcels of land (atoms) rather than the defined zone structure; thus, by dividing existing zones into atoms, a more realistic interchange of intrazonal trips and short (less than five minutes) trips among adjacent zones is defined. In application, a gravity model analogy determines the number of trip interchanges between atoms and subsequently sums the trips to derive both intrazonal trips and zonal interchange volumes. The basic atomistic model formulation is:

$$T_{ij} = \frac{\sum_{v=1}^{M_i} \sum_{q=1}^{M_j} p_{iv} a_{jq} F_{d_{vq}} K_{S_{ij}}}{\sum_{x=1}^{N} \sum_{n=1}^{M_j} \sum_{m=1}^{M_x} p_{in} a_{xm} F_{d_{nm}} K_{S_{ix}}} P_i$$

where:

T_{ij} = **trips produce in zone I and attracted to zone j**
P_{iv} = **trips produced by atom v of zone I**
P_i = **total trips produce in zone I such that:**

$$P_i = \sum_{m=1}^{M_i} p_{im}$$

a= relative attraction factor atom q of zone j
A= relative attraction factor for zone j such that:

$$A_j = \sum_{m=1}^{M_j} a_{jm}$$

F= relative trip length factor for estimated separation between atom pair vq
K= bias factor for sector pair containing zones I and j
N= number of zones
My= number of atoms in zone y

In addition to the zonal trip productions and attractions produced in the trip generation process, the trip distribution model requires the zone-to-zone travel times for the estimated minimum time paths on the highway network with 24-hour speeds. The model also requires:

- **estimated zonal radii values**
- **a set of F-factors defining trip length frequency distributions by purpose**
- **any necessary bias factors (K-factors) by trip purpose**

Since the Atomistic Model uses a gravity model analogy that considers travel opportunities within a zone to be spatially distributed rather than concentrated at a single theoretical point (the zone centroid), the spatial dimension of zones is represented by 400 atoms with zonal productions and attractions uniformly distributed among all 400 atoms. The model requires that the distance from the center of a zone to the perimeter be defined in minutes – a zonal radii value. These radii values in conjunction with skimmed travel times determine the spatial distribution of atom pairs for all zonal pairs.

The initial set of F-values was derived from the 1985 model output. For the 1990 model, these values were normalized and constrained to be continually decreasing F-factors. The F-factors were further adjusted for the 1995 validation to increase the average trip lengths. The calibrated F-factors by purpose are shown in Table 4.7

K-factors historically, have been used to improve model performance in addressing two natural barriers within the Houston-Galveston TMA: the Houston Ship Channel and the separation between Galveston Island and the mainland. These physical barrier K-factors are included in the 1990 model for both work and non-work trip purposes.

Distinct socioeconomic and land-use characteristics that require introduction of K-factors are the underrepresentation of both HBW attractions to the Houston CBD and intra-county

HBW trips for the surrounding seven counties. In addition to the CBD, three other major activity centers (Greenway area, Galleria-Post Oak, and Texas Medical Center) also required K-factors. In the current 1990 model, the original 1985 model K-factors have been retained, except in Brazoria County. Additional K-factors refinements were subsequently made for Brazoria County, in conjunction with a county roadway planning effort.

Table 4.7
Calibrated F-Factors by Trip Purpose

Time	Friction Factors					
(minutes)	HBW	HBSCH	HBSHP	HBOTH	NHB	TRTX
1	401.9208	241.4285	279.3284	269.3586	270.0977	326.8355
2	283.1946	234.5422	269.2858	251.0646	235.6013	254.9863
3	185.1868	190.9848	198.4806	192.1733	178.6852	201.3123
4	128.9452	135.9528	138.6924	136.8544	130.0613	140.6904
5	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
6	80.9902	75.6770	75.0723	76.9799	79.4625	76.7709
7	67.8665	58.2830	57.3979	60.9947	64.4701	60.6697
8	59.2294	45.2798	44.3676	49.0029	52.6707	48.1512
9	51.7218	35.3829	34.1987	39.3906	42.9260	38.3266
10	45.6543	27.6394	26.2972	31.9932	34.9562	30.6354
11	41.1420	21.7660	20.6708	26.1398	28.8820	25.0124
12	36.3174	17.0710	16.3479	21.2708	24.0092	20.6922
13	33.0294	13.5022	12.9545	17.4303	20.2498	17.6426
14	29.8117	10.8658	10.2926	14.3845	17.1964	15.0333
15	27.6833	8.6577	8.0791	11.7966	14.7444	13.0229
16	25.4784	6.7241	6.3571	9.6633	12.4996	11.2102
17	23.4899	5.2012	5.0236	7.9883	10.6483	9.6209
18	21.6731	4.0641	4.0045	6.6362	9.1326	8.3507
19	19.7913	3.2226	3.2217	5.5512	7.8603	7.2669
20	18.4598	2.5840	2.6172	4.6775	6.8468	6.3876
21	16.9552	2.0800	2.1224	3.9503	5.9667	5.6174
22	15.7838	1.6707	1.7241	3.3724	5.2260	4.9488
23	14.5713	1.3508	1.4157	2.8837	4.6021	4.4153
24	13.6229	1.1019	1.1707	2.4675	4.1046	3.9993
25	12.7462	0.8939	0.9718	2.1308	3.6906	3.6331
26	11.7851	0.7307	0.8006	1.8581	3.3128	3.2766
27	11.1242	0.6000	0.6528	1.6258	2.9806	2.9555
28	10.2265	0.4856	0.5320	1.4096	2.6461	2.6460
29	9.3865	0.3880	0.4337	1.2224	2.3710	2.3812
30	8.7136	0.3133	0.3576	1.0558	2.1209	2.1444
31	8.0382	0.2537	0.2955	0.9104	1.8724	1.9104
32	7.5748	0.2022	0.2436	0.7841	1.6634	1.7040
33	7.0308	0.1655	0.2006	0.6798	1.4830	1.5236
34	6.6705	0.1380	0.1675	0.5954	1.3314	1.3815
35	6.3697	0.1147	0.1405	0.5217	1.2066	1.2635
36	6.0570	0.0947	0.1165	0.4512	1.0846	1.1532
37	5.7673	0.0772	0.0968	0.3973	0.9730	1.0462
38	5.3706	0.0647	0.0812	0.3498	0.8756	0.9511
39	4.9617	0.0544	0.0675	0.3050	0.7871	0.8696
40	4.5765	0.0448	0.0559	0.2626	0.7063	0.7992

Table 4.7
Calibrated F-Factors by Trip Purpose
(continued)

Time	Friction Factors					
(minutes)	HBW	HBSCH	HBSHP	HBOTH	NHB	TRTX
41	4.2406	0.0372	0.0452	0.2259	0.6342	0.7441
42	3.9700	0.0306	0.0376	0.1970	0.5777	0.6882
43	3.6984	0.0257	0.0322	0.1752	0.5247	0.6215
44	3.4842	0.0212	0.0281	0.1560	0.4751	0.5704
45	3.2513	0.0172	0.0249	0.1395	0.4328	0.5390
46	3.0117	0.0149	0.0208	0.1221	0.3992	0.5084
47	2.7963	0.0130	0.0177	0.1075	0.3680	0.4710
48	2.6210	0.0111	0.0157	0.0949	0.3344	0.4344
49	2.4583	0.0095	0.0132	0.0836	0.3010	0.3961
50	2.3050	0.0086	0.0118	0.0746	0.2726	0.3545
51	2.1425	0.0080	0.0104	0.0659	0.2456	0.3204
52	1.9929	0.0072	0.0089	0.0588	0.2210	0.3034
53	1.8263	0.0065	0.0078	0.0518	0.2001	0.2875
54	1.6769	0.0058	0.0072	0.0457	0.1803	0.2701
55	1.5604	0.0054	0.0066	0.0401	0.1651	0.2472
56	1.4499	0.0052	0.0061	0.0358	0.1499	0.2266
57	1.3148	0.0047	0.0055	0.0324	0.1368	0.2099
58	1.2830	0.0045	0.0049	0.0298	0.1249	0.1997
59	1.1918	0.0045	0.0043	0.0265	0.1135	0.1893
60	1.1605	0.0044	0.0041	0.0237	0.1029	0.1801
61	1.0648	0.0042	0.0040	0.0209	0.0930	0.1655
62	0.9887	0.0042	0.0039	0.0192	0.0854	0.1521
63	0.9403	0.0040	0.0038	0.0184	0.0775	0.1401
64	0.8651	0.0039	0.0038	0.0167	0.0710	0.1253
65	0.7946	0.0038	0.0037	0.0147	0.0661	0.1171
66	0.7391	0.0038	0.0037	0.0130	0.0607	0.1115
67	0.6872	0.0037	0.0037	0.0122	0.0548	0.1069
68	0.6499	0.0036	0.0036	0.0114	0.0506	0.0998
69	0.6196	0.0035	0.0035	0.0104	0.0463	0.0929
70	0.6016	0.0034	0.0034	0.0096	0.0413	0.0860
71	0.5735	0.0033	0.0033	0.0093	0.0391	0.0843
72	0.5289	0.0032	0.0032	0.0088	0.0369	0.0825
73	0.5218	0.0031	0.0031	0.0085	0.0343	0.0807
74	0.4888	0.0030	0.0030	0.0078	0.0315	0.0789
75	0.4645	0.0029	0.0029	0.0077	0.0303	0.0758
76	0.4318	0.0000	0.0000	0.0077	0.0297	0.0740
77	0.4132	0.0000	0.0000	0.0075	0.0291	0.0685
78	0.3933	0.0000	0.0000	0.0074	0.0285	0.0679
79	0.3566	0.0000	0.0000	0.0073	0.0280	0.0662
80	0.3217	0.0000	0.0000	0.0072	0.0275	0.0656

Table 4.7
Calibrated F-Factors by Trip Purpose
(continued)

Time (minutes)	Friction Factors					
	HBW	HBSCH	HBSHP	HBOTH	NHB	TRTX
81	0.3178	0.0000	0.0000	0.0000	0.0000	0.0000
82	0.3177	0.0000	0.0000	0.0000	0.0000	0.0000
83	0.3143	0.0000	0.0000	0.0000	0.0000	0.0000
84	0.3028	0.0000	0.0000	0.0000	0.0000	0.0000
85	0.3027	0.0000	0.0000	0.0000	0.0000	0.0000
86	0.3026	0.0000	0.0000	0.0000	0.0000	0.0000
87	0.3025	0.0000	0.0000	0.0000	0.0000	0.0000
88	0.3024	0.0000	0.0000	0.0000	0.0000	0.0000
89	0.3009	0.0000	0.0000	0.0000	0.0000	0.0000
90	0.2672	0.0000	0.0000	0.0000	0.0000	0.0000
91	0.2334	0.0000	0.0000	0.0000	0.0000	0.0000
92	0.1996	0.0000	0.0000	0.0000	0.0000	0.0000
93	0.1712	0.0000	0.0000	0.0000	0.0000	0.0000
94	0.1618	0.0000	0.0000	0.0000	0.0000	0.0000
95	0.1492	0.0000	0.0000	0.0000	0.0000	0.0000
96	0.1445	0.0000	0.0000	0.0000	0.0000	0.0000
97	0.1444	0.0000	0.0000	0.0000	0.0000	0.0000
98	0.1443	0.0000	0.0000	0.0000	0.0000	0.0000
99	0.1442	0.0000	0.0000	0.0000	0.0000	0.0000
100	0.1441	0.0000	0.0000	0.0000	0.0000	0.0000
101	0.1440	0.0000	0.0000	0.0000	0.0000	0.0000
102	0.1439	0.0000	0.0000	0.0000	0.0000	0.0000
103	0.1438	0.0000	0.0000	0.0000	0.0000	0.0000
104	0.1437	0.0000	0.0000	0.0000	0.0000	0.0000
105	0.1436	0.0000	0.0000	0.0000	0.0000	0.0000
106	0.1435	0.0000	0.0000	0.0000	0.0000	0.0000
107	0.1434	0.0000	0.0000	0.0000	0.0000	0.0000
108	0.1433	0.0000	0.0000	0.0000	0.0000	0.0000
109	0.1226	0.0000	0.0000	0.0000	0.0000	0.0000
110	0.0994	0.0000	0.0000	0.0000	0.0000	0.0000
111	0.0835	0.0000	0.0000	0.0000	0.0000	0.0000
112	0.0834	0.0000	0.0000	0.0000	0.0000	0.0000
113	0.0833	0.0000	0.0000	0.0000	0.0000	0.0000
114	0.0832	0.0000	0.0000	0.0000	0.0000	0.0000
115	0.0831	0.0000	0.0000	0.0000	0.0000	0.0000
116	0.0765	0.0000	0.0000	0.0000	0.0000	0.0000
117	0.0708	0.0000	0.0000	0.0000	0.0000	0.0000
118	0.0667	0.0000	0.0000	0.0000	0.0000	0.0000
119	0.0618	0.0000	0.0000	0.0000	0.0000	0.0000
120	0.0513	0.0000	0.0000	0.0000	0.0000	0.0000

Table 4.7

Calibrated F-Factors by Trip Purpose
(continued)

Time	Friction Factors					
(minutes)	HBW	HBSCH	HBSHP	HBOTH	NHB	TRTX
121	0.0409	0.0000	0.0000	0.0000	0.0000	0.0000
122	0.0372	0.0000	0.0000	0.0000	0.0000	0.0000
123	0.0345	0.0000	0.0000	0.0000	0.0000	0.0000
124	0.0297	0.0000	0.0000	0.0000	0.0000	0.0000
125	0.0285	0.0000	0.0000	0.0000	0.0000	0.0000
126	0.0275	0.0000	0.0000	0.0000	0.0000	0.0000
127	0.0274	0.0000	0.0000	0.0000	0.0000	0.0000
128	0.0273	0.0000	0.0000	0.0000	0.0000	0.0000
129	0.0272	0.0000	0.0000	0.0000	0.0000	0.0000
130	0.0271	0.0000	0.0000	0.0000	0.0000	0.0000
131	0.0270	0.0000	0.0000	0.0000	0.0000	0.0000
132	0.0269	0.0000	0.0000	0.0000	0.0000	0.0000
133	0.0268	0.0000	0.0000	0.0000	0.0000	0.0000
134	0.0267	0.0000	0.0000	0.0000	0.0000	0.0000
135	0.0266	0.0000	0.0000	0.0000	0.0000	0.0000
136	0.0265	0.0000	0.0000	0.0000	0.0000	0.0000
137	0.0264	0.0000	0.0000	0.0000	0.0000	0.0000
138	0.0178	0.0000	0.0000	0.0000	0.0000	0.0000
139	0.0177	0.0000	0.0000	0.0000	0.0000	0.0000
140	0.0176	0.0000	0.0000	0.0000	0.0000	0.0000
141	0.0175	0.0000	0.0000	0.0000	0.0000	0.0000
142	0.0174	0.0000	0.0000	0.0000	0.0000	0.0000
143	0.0173	0.0000	0.0000	0.0000	0.0000	0.0000
144	0.0172	0.0000	0.0000	0.0000	0.0000	0.0000
145	0.0171	0.0000	0.0000	0.0000	0.0000	0.0000
146	0.0170	0.0000	0.0000	0.0000	0.0000	0.0000
147	0.0063	0.0000	0.0000	0.0000	0.0000	0.0000
148	0.0062	0.0000	0.0000	0.0000	0.0000	0.0000
149	0.0061	0.0000	0.0000	0.0000	0.0000	0.0000
150	0.0060	0.0000	0.0000	0.0000	0.0000	0.0000
151	0.0059	0.0000	0.0000	0.0000	0.0000	0.0000
152	0.0058	0.0000	0.0000	0.0000	0.0000	0.0000
153	0.0057	0.0000	0.0000	0.0000	0.0000	0.0000
154	0.0056	0.0000	0.0000	0.0000	0.0000	0.0000
155	0.0055	0.0000	0.0000	0.0000	0.0000	0.0000
156	0.0054	0.0000	0.0000	0.0000	0.0000	0.0000
157	0.0053	0.0000	0.0000	0.0000	0.0000	0.0000
158	0.0052	0.0000	0.0000	0.0000	0.0000	0.0000
159	0.0051	0.0000	0.0000	0.0000	0.0000	0.0000
160	0.0050	0.0000	0.0000	0.0000	0.0000	0.0000
161	0.0049	0.0000	0.0000	0.0000	0.0000	0.0000

Table 4.8
Average Trip Length by Purpose

Purpose	1990 Average Trip Length	1995 Average Trip Length
Home-Based Work	20.879	22.072
Home-Based School	9.126	9.835
Home-Based Shopping	9.732	10.294
Home-Based Other	12.165	12.947
Non-Home-Based	12.740	13.273
Truck-Taxi	13.006	13.379
External-Local	40.964	41.773

Source: H-GAC Model Application Results

4.4 Mode Choice

Mode choice models are mathematical expressions used to estimate travel market modal shares given various competing modes' time and cost characteristics, and the urban residents' demographic and socioeconomic characteristics. Mode choice models predict travelers' decisions to choose a particular mode of travel and are designed to be an integral link in the travel demand chain, with *possible* direct feedback mechanisms to a number of related model components – auto ownership, trip generation and trip distribution.

4.4.1 Original Mode Choice Model

The original Houston mode choice model was a nested logit model that addressed eight separate modes:

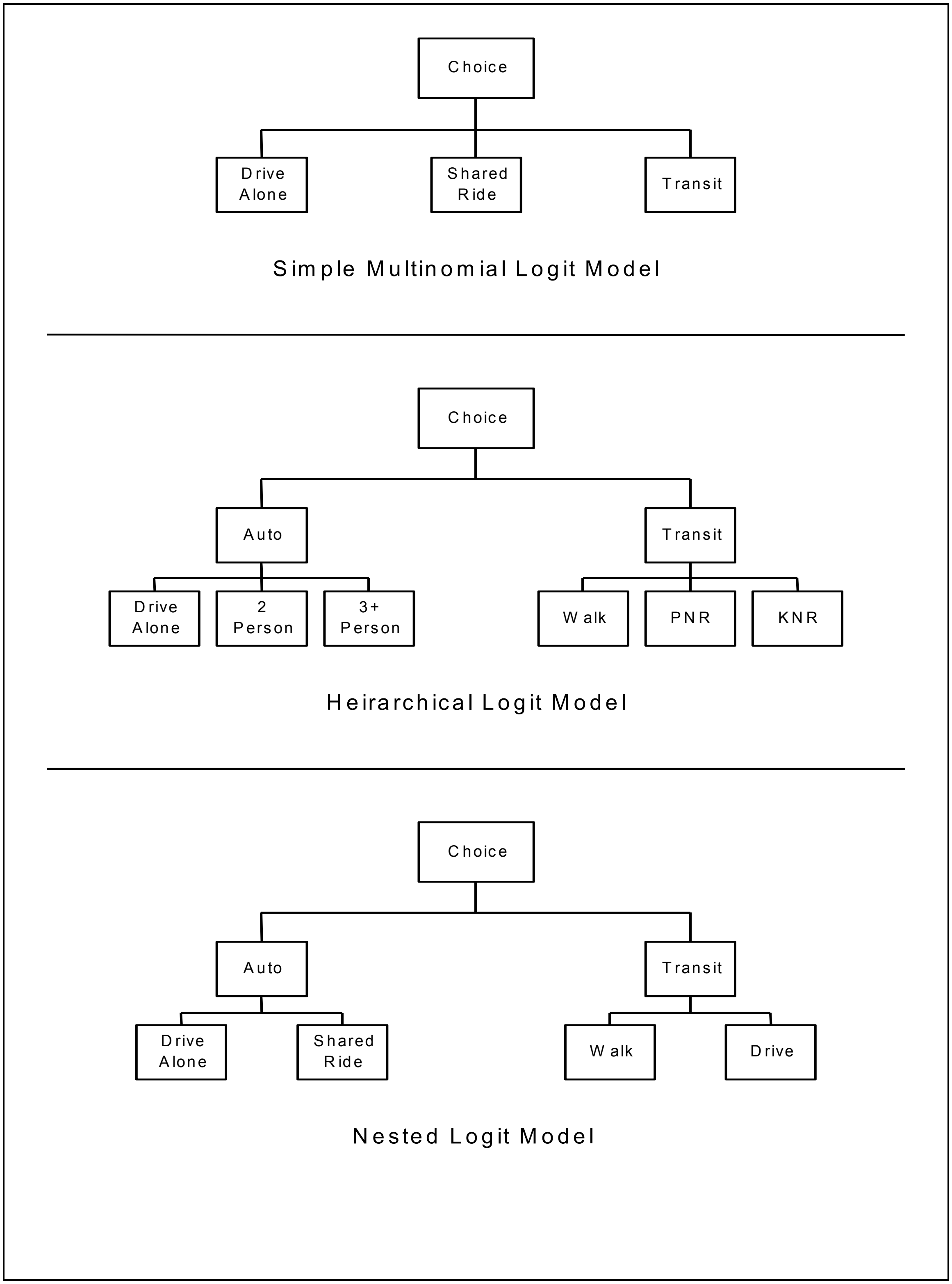
- Drive alone
- Two-person auto
- Three-person auto
- Four-plus-person auto
- Transit-walk access Local Bus
- Transit-walk access Commuter Bus
- Transit-drive access Park-and-Ride
- Transit-drive access Kiss-and-Ride

Mode usage is calculated for five income levels and three individual trip purposes (Home-Based Work, Home-Based Non-Work, and Non-Home Based). The model was originally estimated based on 1985 Home-Interview and On-Board Transit Rider Survey data and was calibrated through the mathematical adjustment of bias constants[1] to replicate locally observed travel values.

Figure 4-1

[1] Bias Constants are computed by mode, trip purpose, and income level.

The model was subsequently recalibrated/validated for the 1990 base year[2] based on



updated land-use and demographic data and an On-Board Transit Rider survey conducted in the same year. The model accurately responded to the input changes in land-use and demographic data inputs (1985 to 1990), and served to clarify the likely impact of forecasting errors in the 1985 input data.

4.4.2 Enhanced Nested Logit Mode Choice Model

As part of a Major Investment Study, enhancements were made to the mode choice model. The fundamental approach followed in specifying and implementing enhancements to the mode choice model can be summarized as follows:

- Utilize the existing nested logit mode choice as the starting point for the enhanced model specification
- Design and specify an expanded nested structure and select additional model coefficients which are reasonable and rational based upon experience in Houston and elsewhere

A graphical depiction of the enhanced nested logit model structure for each trip purpose is displayed in Figure 4-2. Lower-level nests are defined in the diagram for each of the primary modes – auto and public transit.

In the case of public transit, the second-level nest distinguishes between walk and drive access (as before), while the third level would now differentiates between local bus transit, express bus, commuter bus, and urban rail for walk access, and park-and-ride and kiss-and-ride for drive access. Sufficient aggregate ridership data was available on a regional basis to calibrate a set of model bias constants for each of these submodes (except urban rail, which currently does not exist in the region in any form). The existing set of variable coefficients will be used for each of the respective transit submodes. The existing model differentiates (using Boolean coefficients) between the Houston downtown and the three remaining major activity centers. In the enhanced version, each of three major activity centers was individually separated.

The highway mode is subdivided at the second level of the nest into shared ride and drive alone. Shared ride is further subdivided into two-person and three-person vehicles, and four-plus-person autos at the third level. This distinction is necessary, since many ramp locations and lane configurations within the region may explicitly distinguish between occupancy levels. The single additional variable added at this level of the nest was an HOV time savings variable (as compared to drive-alone travel time) that was preset at 70 percent of in-vehicle time. The inclusion of this variable is based directly on recommendations stemming from the Shirley Highway Corridor model estimation.[3] Each of the individual highway submodes – drive-alone, two-person auto, three-person auto, and four-plus-person auto – now include a special path choice nest that differentiates between a toll and non-toll path. Other than a set of modal bias constants, two additional variables are a coefficient on toll cost (stratified by income group) and a coefficient on travel time savings.

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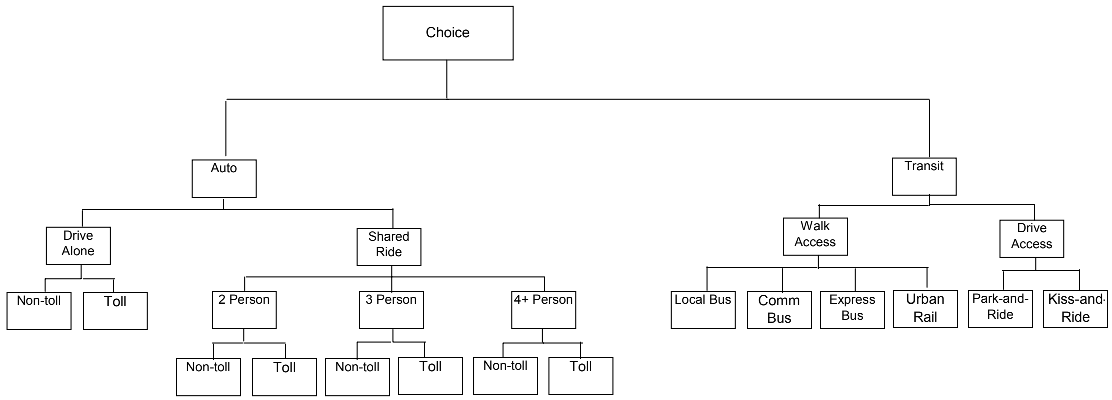
[2] "1990 Houston Long-Range Patronage Forecasting Model Validation, Draft Technical Memorandum: Model Validation Methodology and Results," prepared for the Metropolitan Transit Authority of Harris County, by KPMG Peat Marwick, June 21, 1995.
[3] "Review of the Shirley Highway Corridor Mode Choice Analysis," COMSIS Corporation, October, 1990.

Figure 4-2
H-GAC Regional Mode Choice Model - Nested Logit Model Structure



4.4.3 Modifications of Mode Choice Model For 1995 Validation

Following the validation of the enhanced mode choice model to the year 1990 and use of the model in several forecast applications, it was noted that on the conversion of the highway person trips by mode (drive alone, two-person and three-plus-person trips) to highway vehicle trips by mode and assignment of those trip tables, regional VMT was less than expected. An analysis of estimated vehicle occupancy by time separation revealed that the trip tables resulting from the mode choice model predicting continually increasing vehicle occupancies by separation. This result was counter to survey observed vehicle occupancy data for separations longer than 30 minutes. This finding led to the modification of Home-Base Non-Work and Non-Home-Based models in two ways.

First, the way in which auto operating costs were handled was modified. The models were modified to allow the user to specify whether auto-operating costs were shared among auto occupants or not. It was observed in survey data that most multiperson (two or more persons in vehicle) home-based non-work and non-home-based trips are made my persons from the same household. In that sense, auto operating costs are not really a shared-cost, since it might be in a shared ride work trip made by persons from two different households.

The second modification was to add an additional household size variable to the model. In this way, the model would be sensitive to the size of a household in determining the probability of a multi-occupant trip. In the case of a two-person household, the probability for a three-or-more-occupant home-based non-work or non-home-based trip is much lower than for a three-or-more person household given that many of these trips are made by members of the same household.

The complete set of coefficient values for the Home-Based Work nested logit model is shown in Table 4.9. The Home-Based Non-Work and Non-Home Based values are presented in Tables 4.10 and 4.11, respectively.

Table 4.9
Coefficient Values for Home-Based Work Mode Choice Model

Variable	Multinomial Value	Mode
In-vehicle time	-0.02200	All modes
1 Wait less than 4.5 minutes	-0.05680	Transit
1 Wait over 4.5 minutes	-0.02200	Transit
Walk	-0.05680	Transit
Transfer time	-0.05680	Transit
Number of transfers	-0.08800	Transit
Transit fare (all)	-0.00614	Transit
Drive to transit time	-0.05680	Transit
Parking cost (all)	-0.01540	Highway
Highway Operating Cost (all)	-0.00614	Highway
Tolls (income group)	-0.00819 -0.00717 -0.00614 -0.00512 -0.00410	Highway
HOV/Toll Time Savings	+0.01542	Highway
Residential Density Indicator	+0.13947	Transit (Walk)
Nesting Coefficients		
Between transit and access	0.75000	Transit
Between access and path	0.60000	Transit
Between single and drive group	0.75000	Highway
Between group and 2/4+	0.60000	Highway
Between 2/4+ and toll/free	0.45000	Highway
Between drive and toll/free	0.45000	Highway

Table 4.10
Coefficient Values for Home-Based Non-Work Mode Choice Model

Variable	Multinomial Value	Mode
In-vehicle time	-0.01727	All modes
1st Wait time	-0.03454	Transit
Walk	-0.02591	Transit
Transfer time	-0.04318	Transit
Transit fare (all)	-0.00592	Transit
Drive to transit time	-0.02591	Transit
Parking cost (all)	-0.01479	Highway
Highway Operating Cost (all)	-0.00592	Highway
Tolls (income group)	-0.01093 -0.00957 -0.00820 -0.00683 -0.00547	Highway
HOV/Toll Time savings	+0.01270	Highway
Household Size 2 Person 3 Person 4+ Person	 +0.07427 +0.44870 +0.75530	 Highway
Residential Density Indicator	+0.07767	Transit (Walk)
Nesting Coefficients		
Between transit and access	0.75000	Transit
Between access and path	0.60000	Transit
Between single and drive group	0.75000	Highway
Between group and 2/4+	0.60000	Highway
Between 2/4+ and toll/free	0.45000	Highway
Between drive and toll/free	0.45000	Highway

Table 4.11
Coefficient Values for Non-Home Based Mode Choice Model

Variable	Multinomial Value	Mode
In-vehicle time	-0.02370	All modes
1st Wait time	-0.04740	Transit
Walk	-0.03555	Transit
Transfer time	-0.03593	Transit
Transit fare (all)	-0.00562	Transit
Drive to transit time	-0.03555	Transit
Parking cost (all)	-0.01404	Highway
Highway Operating Cost (all)	-0.00562	Highway
Tolls (all)	-0.00562	Highway
HOV/Toll time savings	+0.01660	Highway
Nesting Coefficients		
Between transit and access	0.75000	Transit
Between access and path	0.60000	Transit
Between single and drive group	0.75000	Highway
Between group and 2/4+	0.60000	Highway
Between 2/4+ and toll/free	0.45000	Highway
Between drive and toll/free	0.45000	Highway

4.4.4 Calibration of Modal Bias Constants

Following specification of additional model variables and coefficient values, a key element in the overall mode choice model development process was to insure that the resulting models were able to accurately simulate travel behavior characteristics and patterns within the Houston region.

It is essential that the mode choice model set be able to estimate observed modal trips within a reasonable degree of accuracy. The models were applied at the aggregate (zone) level and the mode specific constants were adjusted to match observed control values[4]. Applying the models at the aggregate level utilizes the full set of network-based travel times and costs, zonal-level socioeconomic and other related data (i.e., parking costs) and the input trip distribution model person trip tables. In this manner, the models are applied as they would be in forecasting future year trips. Tables 4.12 - 4.14 summarize the final set of bias constant values for each trip purpose.

[4] The calibration target values by trip purpose were presented in Table 3.3.

Table 4.12
Modal Bias Constants - Home Based Work Mode Choice Model

	Income Level				
Constant	**1**	**2**	**3**	**4**	**5**
Drive Alone - Toll	4.002	3.277	2.512	2.203	1.705
2 Person - Toll	5.190	4.057	3.146	2.337	1.910
3 Person - Toll	5.664	4.723	4.116	4.053	3.829
4+ Person - Toll	6.353	5.454	4.925	4.776	4.466
3 Person Auto	-2.243	-2.329	-2.660	-2.758	-3.149
4+ Person Auto	-3.103	-3.347	-3.938	-4.193	-4.450
Shared Ride	-1.937	-2.072	-2.265	-2.466	-2.786
Auto	0.352	0.813	1.502	2.292	2.497
Local Bus	0.513	-0.228	-0.998	-2.362	-5.163
Commuter Bus	-2.687	-4.192	-2.809	-3.732	-3.175
Express Bus	-1.676	-2.362	-2.121	-2.543	-3.980
Park-and-Ride	-2.332	-1.404	-0.458	-0.103	-0.207
Drive Access	-2.334	-2.019	--1.258	-0.955	--1.099

Table 4.13
Modal Bias Constants - Home Based Non Work Mode Choice Model

	Income Level				
Constant	**1**	**2**	**3**	**4**	**5**
Drive Alone - Toll	2.466	3.223	3.717	4.234	5.257
2 Person - Toll	1.029	1.646	2.109	2.319	2.873
3 Person - Toll	1.873	2.619	3.008	3.440	4.221
4+ Person - Toll	2.179	2.972	3.452	3.908	4.700
3 Person Auto	-2.908	-2.989	-2.989	-3.073	-3.188
4+ Person Auto	-5.149	-5.120	-5.120	-5.177	-5.280
Shared Ride	-0.845	-0.914	-0.914	-0.953	-0.991
Auto	1.578	2.429	3.055	4.214	5.918
Commuter Bus	-2.341	-2.699	0.291	-2.141	2.355
Express Bus	-1.159	-1.175	-1.100	-1.632	0.102
Park-and-Ride	0.122	-0.383	1.647	0.692	1.566
Drive Access	-3.417	-4.089	-4.089	-3.165	-2.873

Table 4.14
Modal Bias Constants - Non Home Based Mode Choice Model

Constant	Value
Drive Alone – Toll	5.056
2 Person – Toll	1.761
3 Person – Toll	2.475
4+ Person – Toll	1.822
3 Person Auto	-1.246
4+ Person Auto	-1.519
Shared Ride	-1.649
Auto	2.477
Commuter Bus	-1.296
Express Bus	n/a
Park-and-Ride	1.807
Drive Access	-3.813

4.4.5 Toll Road Bias Constant Calibration, Target Values and Time Savings Threshold

Although tabulations from the 1994 Household Survey provided an initial estimate of the magnitude of toll road usage, subsequent analysis (comparing assigned volumes to observed toll road volumes) clearly demonstrated that the overall magnitude of toll road travel was significantly higher than these tabulations suggested, ranging from 60 percent to 100 percent higher. Given the small number of observations on which these values were derived, this was not an unexpected result. The relative distribution of these target values by purpose, auto submode and income group appeared to be reasonable. Home-based work trips comprise about 50 percent of all toll road trips, with the remaining 50 percent split quite evenly between home-based non-work and non-home based. However, the initial number of toll trips suggested by the 1994 Home-Interview Survey did not yield valid toll road volumes; the resulting assigned volumes were significantly lower than the observed volumes. Thus, it became necessary to implement a series of iterative revisions for the three conditions listed above until the assigned volumes adequately matched observed conditions.

In general, the Hardy toll road tends to serve longer-distance, work-related travel, while the Sam Houston toll road attracts somewhat shorter trips and a larger portion of non-work travel. The travel time savings threshold value serves to eliminate trip interchanges, in which the savings in time provided by the toll path does not exceed a certain minimum value – 2.5 (non-work) or 3 (work) minutes. The absolute value of this time savings parameter is to some extent a function of the accuracy of the network assignment generated travel times (and their relative differences) and the perception by the traveler of the value of this time savings – which could be more accurately described as a reliability factor.

Stratification of the toll cost coefficient values by income had a very positive impact on the ability of the model to match calibration target values and explicitly represent differences in the value of time for different segments of travelers.

The ultimate test, and corresponding motivation for adjusting each of the above parameters from originally proposed or computed levels, was the comparison between observed and assigned volumes on the toll road facilities. These comparisons are presented later in this chapter.

4.5 Commercial Vehicles

Typically, commercial vehicles are directly estimated as vehicle trips at the trip generation stage and included with automobile trips during trip assignment. Generally, truck trips tend to comprise between 5 percent and 15 percent of internal vehicle travel. A unique feature of the existing model is the inclusion of taxi trips along with commercial vehicle trips, thus the trip purpose is labeled truck and taxi. In the H-GAC region, taxi travel represents a very small fraction of the daily VMT and, hence, was combined with the truck trips for convenience. The truck-taxi trip generation models were implemented in for the 1985 models. New commercial vehicle models being developed using the 1995 travel surveys are not yet available for modeling applications.

4.5.1 Truck and Taxi Trip Generation

The existing trip generation model requires that an estimate of total truck trip productions for the entire region be entered as a single value in the trip generation model. Subsequently, zonal truck trip productions and attractions are estimated based on a zone's employment composition. Initially, zonal truck attractions are derived using the following equation:

Zonal Attractions = 0.25 (Zonal Retail Employment) + 0.22 (Zonal Office Employment) + 0.39 (Zonal Industrial Employment) + 0.22 (Other Zonal Employment) + 0.02 (Zonal Households)

Once zonal truck and taxi vehicle trip attractions have been estimated, productions are scaled and set equal to zonal attractions.

4.5.2 Distribution and Assignment

For distribution and assignment purposes the highway network is used as the truck network; highway travel times represent the purpose impedance. Auto travel times are used in distribution, however, a specific trip length frequency curve is determined and input to trip distribution.

4.6 External Travel

Typically, external travel is a small percentage of total regional travel; for Houston, 1990 total external trips amounted to 190,767 or 1.9 percent of total vehicle trips. External trips are categorized into two purposes: external local (external-internal travel) and external through (external-external travel). External trip productions are based on growth factored average daily traffic (ADT) volumes. To determine the number of external local and external through trips at each external station, historical growth trends and O&D data are used to apportion factored ADTs between the two external trip purposes. These volumes in turn govern development of the local and through trip matrices.

The trip distribution model employs the gravity model form in conjunction with a specified trip length frequency curve. Zonal NHB vehicle attractions are used as relative external local attractions to distribute external productions. External through trip matrices are derived by frataring historical through trip tables based on current estimated external volumes.

4.7 Trip Assignment

4.7.1 Highway Trip Assignment Methodology

Using the mode choice model, person trips classified by trip purpose are separated into automobile and transit trips and auto person trips are converted to vehicle trips based on vehicle occupancy factors. These vehicle trip tables are summed and converted to origin-destination format and assigned to the appropriate highway network (base year or forecast year). This is a 24-hour capacity restraint assignment performed at the detailed 2,666 TAZ level. Six iterations of the capacity restraint model precede computation of the final assignment results. The model adjusts link impedance between iterations, based on each link's assigned V/C ratio. The weighted average of the assigned volumes from the preceding iterations is used to calculate the V/C ratio. The impedance adjustment function used in this model is based on the FHWA impedance adjustment function. This function assumes impedance is based on a "zero-volume" link speed. However, since traditional coding of Texas highway networks used a 24-hour speed rather than a zero-volume speed, a modified version of the FHWA impedance adjustment function was developed, which is represented by the following formula:

$$I_{n+1} = \left(0.92 + 0.15\left({}^{v}\!/_{c}\right)^{4}\right) \times I_0$$

Where:

- I_0 = initial impedance using 24-hour input speed
- I_{n+1} = link impedance for iteration n + 1
- v = weighted average link volume from iterations 1 to n
- c = link capacity

The constraint is applied to limit the magnitude of the impedance adjustment, the maximum of which varies by iteration. After the initial assignment, the maximum impedance factor is two (essentially reducing the 24-hour speed by one-half) and is increased by one for each of the subsequent iterations. The final assignment results are computed following the six iterations, using a weighted average of the link volumes from those iterations. The iteration weights specified for the 1990 base year assignment are determined by an equilibrium capacity restraint process, where each trip is assigned the path with the shortest travel time until equilibrium is achieved.

4.7.2 Comparison to 1995 Counted Volumes

In the 1995 network, there are 20,603 highway links (one-way links), excluding centroid connectors. Of the 20,603, there are 18,535 with count-based volume estimates. To demonstrate the validity of the models, comparison of the assigned versus counted VMT is normally summarized to demonstrate the capabilities of the models in matching estimated 1995 base year conditions. As may be noted, nearly half of the freeway and tollway links have counted volume estimates. Over 90 percent of the arterial and collector links have counted volume estimates.

Table 4.15 summarizes the total assigned VMT on all 20,603 links by 5 roadway types. The assigned VMT on the 18,535 links with counted volumes are also summarized by roadway type. The assigned VMT as a percentage of the counted VMT was computed and summarized for each of the roadway types. As may be observed, the assigned VMT on freeways, principal arterials and minor arterials are within 3 percent of the counted VMT estimates. Tollways and collectors VMT are within approximately 9 percent of the counted VMT estimate.

Table 4.16 summarizes the total assigned VMT on all 20,603 links by 5 area types. The assigned VMT on the 18,535 links with counted volumes are also summarized by area type. The assigned VMT as a percentage of the counted VMT was computed and is summarized for each of the area types. While the CBD Assigned VMT is approximately 85 percent of counted VMT, this is not unusual for CBDs and is considered within acceptable limits. The assigned and counted VMT in the other area types compare very favorably.

Table 4.17 summarizes the total assigned VMT on all 20,603 links by the 8 counties in the region. The assigned VMT on the 18,535 links with counted volumes are also summarized by county. The assigned VMT as a percentage of the counted VMT was computed and is summarized for each of the counties. The assigned VMT in seven of the eight counties are within 10 percent of the counted VMT. Brazoria County's VMT is 86 percent of the counted which was considered acceptable.

Overall, the comparisons of the assigned and counted VMT were considered acceptable and reasonably demonstrate that the models reasonably replace the observed conditions for 1995.

Table 4.15
1995 VMT by Roadway Type

Roadway Type	Number of Links	Total Assigned VMT (all Links)	Number of Links with Counts	Assigned VMT on Links With Counts	Assigned VMT as Percent of Counted VMT
Freeway	1,542	44,887,556	714	21,948,520	102.2%
Tollway	152	2,161,848	82	1,214,459	109.2%
Prin. Arterial	4,202	16,812,426	3,709	15,061,744	97.7%
Other Arterial	9,669	25,148,964	9,163	24,003,826	102.6%
Collectors	5,038	6,967,832	4,867	6,614,278	91.5%
All Types	20,603	95,978,632	18,535	68,843,016	100.3%

Table 4.16
1995 VMT by Area Type

Area Type	Number of Links	Total Assigned VMT (all Links)	Number of Links With Counts	Assigned VMT on Links With Counts	Assigned VMT as Percent of Counted VMT
CBD	690	1,040,953	621	522,547	85.2%
Urban	3,603	17,452,560	3,089	9,848,581	106.2%
Urban Fringe	7,576	40,931,972	6,600	27,784,780	101.7%
Suburban	5,015	24,006,514	4,568	19,261,336	97.7%
Rural	3,719	12,546,944	3,657	11,425,600	97.6%
All Areas	20,603	95,978,632	18,535	68,843,016	100.3%

Table 4.17
1995 VMT by County

County	Number of Links	Total Assigned VMT (all Links)	Number of Links With Counts	Assigned VMT on Links With Counts	Assigned VMT as Percent of Counted VMT
Brazoria	1,792	3,897,874	1,790	3,621,052	86.2%
Chambers	308	1,979,986	308	1,597,395	103.5%
Fort Bend	1,337	4,943,114	1,287	4,551,563	94.5%
Galveston	1,549	4,016,705	1,527	3,915,186	91.5%
Harris	13,519	72,797,304	11,577	47,157,800	104.0%
Liberty	526	1,535,194	522	1,491,676	97.3%
Montgomery	1,198	5,864,526	1,156	5,680,502	95.0%
Waller	374	944,049	368	827,662	91.4%
All Counties	20,603	95,978,632	18,535	68,843,016	100.3%

5.0 HPMS VMT ADJUSTMENT

5.1 Introduction

The H-GAC Regional Travel Models have been validated to observed vehicle miles of travel (VMT) that are estimated based on 18,500 traffic counts. The estimates and forecasts of vehicle miles of travel produced by the model set are used directly in all transportation planning applications conducted by H-GAC and its transportation planning partners. For purposes of air quality conformity analysis of RTPs and TIPs and the development of State Implementation Plans, H-GAC, through consultation with the Texas Department of Transportation (TxDOT), Texas Commission on Environmental Quality (TCEQ), U.S. DOT and EPA has chosen to reconcile its Base Year (1995) model estimated regional VMT against regional 1995 VMT estimated by the U.S. DOT Highway Performance Monitoring System (HPMS). The factor needed to reconcile model estimated VMT to HPMS estimated VMT is used for all air quality conformity analysis and development of SIPs.

5.2 Comparison of Estimated VMT

In order to compare Base Year (1995) estimated regional VMT to HPMS estimated 1995 VMT, an estimate of total model estimated regional VMT is calculated. Model assigned regional network VMT is combined with assigned regional centroid connector VMT and an estimate of travel within each zone (intrazonal VMT). Because the reconciliation is made for estimated non-summer weekday VMT, both VMT estimates (model and HPMS) are made to represent nonsummer weekday VMT. The model VMT is produced in its original form as nonsummer weekday VMT, as shown. HPMS VMT represent average annual daily travel (AADT) and are adjusted to represent average nonsummer weekday travel, based on an adjusted factor developed using TxDOT permanent traffic recorder data.

Model estimated average non-summer weekday travel (ANSWT)
= (Model network VMT) + (Model Centroid Connector VMT) + (Model Intrazonal VMT)
= (96,346,168) + (9,792,064) + (691,294)
= 106,830,156

HPMS estimated average non-summer weekday travel (ANSWT)
= (HPMS AADT) * (AADT to Non-Summer Weekday Travel Adjustment Factor)
= (97,926,113) * (1.06125)
= 103,924,087

5.3 Calculation of HPMS Adjustment Factor

The factor used to reconcile model estimated regional VMT to HPMS estimated regional VMT is calculated by dividing the HPMS estimated average nonsummer weekday VMT by the Houston-Galveston regional travel model estimated average nonsummer weekday VMT as follows:

HPMS Adjustment Factor

= (HPMS estimated ANSWT) / (Model estimated ANSWT)
= (103,924,087) / (106,830,156)
= 0.9728

5.4 Application of HPMS Adjustment Factor

The HPMS adjustment factor is applied to the model estimated time-of-day VMT prior to the estimation of time-of-day speed. In this way, the time-of-day speeds used in the estimation of emissions are based upon HPMS adjusted VMT.