Appendix H: Demographics and Modeling Maps

- Demographics and Modeling Data and Maps
  This PowerPoint summarizes regional population and employment data and outputs of travel demand model, performs data analysis for 2020 and 2045 that include PM Peak period congestion levels for freeway/tollway only and regional roadway network, vehicle and transit commute travel time results by four activity centers, facility type, 30 Vs 45 minutes commute times, level of mobility by facility types, and delays.

  Published: N/A
  Status: Completed February 2023
  Staff Contact: Weijie Zhuo, Weijie.Zhuo@h-gac.com

- A Brief Overview of H-GAC's Regional Growth Forecast Methodology
  H-GAC's Regional Growth Forecast of population, employment, and land use data for the 8-county H-GAC Transportation Management Area is updated annually. The forecasting system produces outputs in 5-year increments from 2015 through 2050. The base year for the forecast is 2015. The model makes predictions about the location, type, and size of residential and non-residential development projects which would be needed to accommodate the expected growth in households and jobs.

  URL: https://www.h-gac.com/regional-growth-forecast
  Published: 2018
  Status: Completed November 2017
  Staff Contact: Pramod Sambidi, Pramod.Sambidi@h-gac.com

- H-GAC Travel Model 2016 Validation Report
  H-GAC has updated and validated the Track-1 trip-based regional travel demand model to the year 2016. The primary motivation for updating the model was to make use of a new source of observed travel data collected between 2007 and 2016. By updating the trip-based model, H-GAC will have increased travel demand analysis flexibility as well as the ability to compare results of the two models; not only for the base year that the models share, but also for any other applications of the models.

  URL: https://www.h-gac.com/getmedia/6c744eb1-17bf-4636-bcdf-edbe2fe83118/Appendix4.pdf
  Status: Completed March 2019
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A Brief Overview of H-GAC's Regional Growth Forecast Methodology

-Houston-Galveston Area Council
Email: forecast@h-gac.com
Data updated; November 8, 2017

Introduction

H-GAC releases an updated forecast each year. The forecasted items include population, employment, and land use. The forecasting system produces outputs in 5 year increments from 2015 through 2045. The base year for the forecast is 2015.

The forecast is produced in phases.

1. We forecast the total number of people and households in the region.
2. Based on the future labor force, we forecast the number of jobs.
3. The model makes predictions about the location, type, and size of residential and non-residential development projects which would be needed to accommodate the expected growth in households and jobs.
4. The expected growth in households and jobs is allocated to different areas in such a way that each household has a home (housing unit) and each job has a work site.

These phases correspond to different components of our forecasting system:

- Demographic Evolution Model
- Employment Model
- Real Estate Development Model
- Household Location Model
- Employment Location Model

There are several important features of our forecasting system: disaggregation, interrelation, and property of being data-driven. *Disaggregation* means that our models deal with individual elementary entities: people, households, jobs, land parcels, and buildings. All summary statistics, such as county population or total jobs in a census tract, are derived from data on the individual entities. For a future year, that data is not observed but rather created in a process known as "simulation". A simulation is a computational game-like technique which aims to imitate the dynamics of real life by setting up the "players" (entities or agents) and "rules" (propensities or parameters) and then letting the action unfold over time. In that respect, when we develop a forecast, we construct long lists of plausible future events for millions of entities.

Interrelation means that the different models are connected:

- Population determines the short-term supply of labor force;
- Change in the number of households determine the demand for housing;
- The development industry responds to demand for housing and non-residential buildings; and
- Employers' and households' location choices are limited to what is available at the moment.

Data-driven means that inside each model there are dozens of tables with data elements that control the "rules" which govern the simulation. In that respect, the forecast can be viewed as a particular "what if" scenario predicated upon thousands of very specific "assumptions." That makes it very easy to make updates when new information becomes available or when a correction is needed.

<u>Demographic Evolution Model</u>

Population change over a period of time in any area stems from either addition or removal of residents, as compared with the previous time period. The sources of addition are births to local residents and in-migration of people from other areas. The sources of removal are deaths of local residents and out-migration of local residents to other areas. Our model represents all four processes and estimates directly the number of births, deaths, in-migrants, and out-migrants in the area. Additionally, the model represents the household formation and dissolution processes.

The Demographic Evolution Model is a computer simulation which uses the probabilistic approach to imitate both the biologic events (dying, giving birth) and social events (marriage, divorce, migrating in or out of the area) for the synthesized individuals and households.

Population in the model is stratified into four race/ethnicity categories (non-Hispanic White, Hispanic White, Black, and Other), two sex categories (male, female) and 111 age categories (single year, from 0 through 110). The base-year data is constructed from the block-level 2010 Census data (SF1 tables). The base-year data consists of a list of individuals and a list of households. The two biological parameters, survival rates and birth (fertility) rates, are provided by demographers at the Texas State Data Center. We use these rates as event probabilities, that is the likelihood that a person will live another year, and the likelihood that a female will give birth in a given year. These rates change over time, reflecting the trends for longer life spans and decreasing fertility.

Migration probabilities or rates control the in-flow and out-flow of households. There are three separate migration rates dealing with different origins and destinations of the flows: domestic in-migration, domestic out-migration, and foreign in-migration. Some foreign out-migration does occur; however, we are not modeling it explicitly due to lack of data). We constructed the migration rates from the American Community Survey (ACS) Public Use Microdata Sample (PUMS) records. We used the same source to construct the two parameters that control the household dynamics--marriage and divorce rates--as well as a set of auxiliary probabilities, which are used to "match" brides and grooms.

The essence of the simulation technique is in comparing, for each individual, event probabilities with a randomly generated number. If certain conditions are met, the event (death, birth, migration) “occurs.” For example, assume that an individual’s survival rate is 0.95 (there is 5% probability that a person will not survive into the next year). A randomly drawn number is constrained to be between 1 and 0. The condition that can be established in this case is this:

- If a random number is smaller than 0.05, then the individual will not survive into the next year; or
- If that number is 0.05 or greater, then the individual will survive into the next year.

When this experiment is repeated many times, the observed frequency of the “death” event is very close to 5% (which is the event probability).

The Demographic Evolution Model creates a virtual accounting of all people and households in the region in the future years. In the current release specification, we use the outputs of the Demographic Evolution Model to create regional totals for population and households.

Employment Model

In the short run, the workforce (and jobs) is constrained by the resident population. Due to age, disability, family responsibilities or other factors, some people do not seek employment. The parameter that controls this attrition is the labor force participation rate (LFPR). Other people cannot find work and remain unemployed. The parameter that controls this imbalance is the average (overall) unemployment rate (UR). Therefore, in the short-term framework, employment can be estimated given the population and the rates (LFPR and UR). We use the ACS PUMS data to derive LFPR and UR specific for age and ethnicity cohorts. While LFPR is not expected to fluctuate over time, that is not true with respect to the UR, which reflects macroeconomic conditions.

These macroeconomic conditions are represented with an average (as opposed to cohort-specific) unemployment rate. For forecasting purposes, we assume that the future average unemployment rate will be 5.6% (a historical long-term regional average). Once the labor force (based on the resident population) is established by applying the LFPR to the population, the total employment can be calculated and distributed back to the cohorts using the UR. Total jobs in the region are then allocated to 20 two-digit NAICS sectors using the shares derived from the employment forecast produced by Woods & Poole economics Inc and The Texas Workforce Commission.

Further, the total jobs by sector are converted to "location-specific" jobs which include wage and salary jobs and some self-employment jobs. “Location-specific” refers to jobs being tied to individual buildings. In the base year (2015), firm-level jobs derived from Infogroup and other employment data sources are linked to specific locations (individual buildings) by matching company and parcel addresses.

Real Estate Development Model

The Real Estate Development Model generates predictions for specific projects on specific parcels, given the physical availability/suitability of land and economic feasibility.

First, we estimate annual demand for housing units and non-residential space based on the forecasted change in the number of households and jobs. With respect to demand for housing, we have to make an assumption about the future shares of the single-family and multi-family housing. In the current specification, we anticipate that the share of multi-family will increase in the future years. The following is the split between single-family and multi-family for the future residential development.

Y2015 to Y2030: 65% SF and 35% MF
Y2030 to Y2040: 60% SF and 40% MF
Y2040 to Y2050: 55% SF and 45% MF

These shares are based on the historical data for building permits issued in the region. Demand for non-residential space is determined by distributing the forecasted two-digit NAICS-sector jobs into different building types (office, retail, warehouse, etc.) and then applying building type-specific space consumption ratios (square feet per employee).

Second, we break the aggregate demand into different classes of projects (small single-family residential subdivision, medium-size apartment complex, large office building, etc.).

Third, we reduce the demand estimates to account for the supply coming from "known developments" (announced, planned, or under construction projects). We use various sources to compile information on such projects.

Fourth, once the quantity of different classes of projects is established, the model generates a large number of development "proposals." These proposals cover all possible combinations of projects that could be developed on the available parcels, irrespective of the economic feasibility. For each proposal, we calculate a total cost, which includes the cost of land and construction cost (per square foot cost multiplied by the square feet of the project), plus the cost of the existing buildings and demolition in the case of redevelopment.

Data related to parcels and buildings is derived primarily from the appraisal records. Our database includes over two million parcels. For each parcel, we know the land use type, value of land, and value and type of buildings. The construction costs are based on the recent industry survey and published data. In addition to local land use zoning regulations, the real estate model includes some development restrictions on a given parcel. It is similar to zoning; however, in this model it is defined based on theoretical and practical considerations of real estate development for specific areas. For example, parcels in the Houston downtown area are not allowed industrial and storage/warehouse projects; conversely, parcels in the Ship Channel area zone are restricted in its development only to industrial and storage/warehouse buildings. Model data excludes parcels that represent public transportation facilities, roads, water channels and canals, utilities, airports, storm water detention ponds, parks and open spaces, etc.; no development is assumed to occur on such lands. Development is also restricted on parcels with area more than 75% in the floodway. Parcels with certain land use types are excluded from redevelopment, they include Single-Family, Mobile Homes, Condominiums, Group Quarters, Government, Education, Hospital, Recreational, and Unknown parcels.

Fifth, we calculate the expected sale price of a project using the coefficients from a series of regression models. These models establish the relationships between the per square foot prices for different types of buildings and various intra-urban proximity and accessibility measures.

Six, the profitability (return on investment) for all the proposals is calculated (relating the expected sale price to the total costs). Finally, from a pool of most profitable, proposals are selected for "construction" until the demand is met.

We use additional procedure to analyze the distribution of retail and service jobs in primarily residential locations and locate retail and service buildings to ensure adequate levels of access to local retail and services in areas that experience growth in residential buildings. We use a similar procedure to place new schools and hospitals.

Future land use changes generated that way are called "model predictions." The other type of future land changes is called "known developments." Both types appear as layers in Regional Land Use Information System (RLUIS), our web mapping application.

<u>Household Location Model</u>

The household location model assigns households (demand) to housing units (supply). Housing units that are available for household assignment includes newly built housing units and vacant housing units resulting from relocation or death of a 1-person household. Conversely, households that need a housing unit include relocating households (households moving within the 8-county region), in-migrants (domestic and foreign in-migrants moving to the 8-county region) and households whose building was demolished because of redevelopment (in real estate development model). The in-migrating households are first assigned to each of the eight counties using the county-level domestic and foreign in-migration rates derived from ACS County to County Migration Flows and US Census Population Change Components data. In the next step, the count-level in-migrating households are assigned to individual housing unit within a given county using the grid-level (3 mile grid) location probabilities categorized by age-race-household size and income. Location probabilities are calculated based on the base-year household distribution. In case, if there are not enough housing units available to accommodate the new households then those households will be allocated to available housing units in other counties based on county-level vacancy rates and the grid-level location probabilities. Similar to the in-migrating households, relocating households and households whose building was demolished are first assigned to individual counties using the county to county relocation rates derived from the ACS. The households are then assigned to specific housing unit using the grid-level location probabilities specified above. So, at the end each household in the region is tied to a specific housing unit.

Employment Location Model

In the current specification, new jobs are assigned to available space inside buildings controlling for the type of building and applying building type-specific space consumption ratios. This ensures that, for example, retail jobs are assigned to retail buildings and there is enough space to accommodate these jobs. With respect to the locational aspect, the probabilistic assignment is designed to maintain the existing sectoral composition of jobs.

HOUSTON-GALVESTON AREA COUNCIL

REGIONAL TRAVEL MODELS

2016 Model Validation and Documentation Report

March 2019

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Executive Summary

H-GAC has updated and validated the Track-1 trip-based regional travel demand model to the year 2016. The primary motivation for updating the model was to make use of a new source of observed travel data collected between 2007 and 2016. This same set of travel data is being used by H-GAC in the development, calibration and validation of an activity-based model (ABM) for the region. By updating the trip-based model, H-GAC will have increased travel demand analysis flexibility as well as the ability to compare results of the two models; not only for the base year that the models share, but also for any other applications of the models.

The 2016 Track-1 model is structured exactly the same as the 2012 Track-1 model. The traffic count data for model validation is updated to year 2016 traffic counts collected by the Texas Department of Transportaiton. The 2016 Track-1 model used the same survey data as the 2012 Track-1 model.

Full documentation of the 2016 Track-1 model is presented starting in Chapter 1 of this document. This full documentation contains more details and presents model results.

Traffic Analysis Zones (TAZs)

The TAZ structure of the 2016 Track-1 travel models was slightly modified from the 2012 Track-1 model. A few TAZs in the year 2012 Track-1 model were split to finer TAZs to reflect developments and re-developments withiin some sub-regions. The total number of internal TAZs increased from 5,117 to 5,217, the external TAZs remained the same at 46, and the number of total TAZs increased from 5,159 to 5,263.

Demographics

The TAZ demographics of the Track-1 model were updated to represent the year 2016. Estimates of TAZ-level cross-tabulations of households by size, income and workers per household were developed using H-GAC's population synthesizer. The estimates were controlled to 2010 Census SF1 and 5-year (2011-2015) American Community Survey (ACS) household size, income and worker distributions. Employment estimates by employment type and TAZ for the year 2016 were developed from a variety of sources of business data as well as local appraisal district building data.

Area Type

TAZ area type was updated to reflect the 2016 demographic density based on the updated 2016 TAZ demographics.

Trip Generation

Trip Rates

The trip production rates of the previous Track-1 model have been replaced with trip rates derived from the 2007-2009 regional household survey. The production rates have been enhanced to include a third dimension, workers per household, in addition to household size and household income. In this way, trip demand is sensitive to differences in the number of workers in a household, be that with respect to the base year 2016 or in application of the models to forecasted number of workers per household. While the trip attraction rates are dimensioned as they were in the previous Track-1 model, updated rates were developed based on the 2010/2011 regional workplace survey.

Special Generators

Site trip control totals for Bush Intercontinental and Hobby airports were updated using data from the 2010/2011 regional special generator survey.

Non-resident trips

Estimates of trip ends for trips made by non-residents for the coastal portions of the region were updated based on year 2016 estimates of tract-level seasonal housing as well as hotel and seasonal housing vacancy rates.

Truck Trips

Truck trip demand for the 2016 Track-1 model was developed using H-GAC's Cube Cargo-based truck model. The procedures of this model segment truck demand into cargo truck and service truck demand and estimates of both internal and external truck movements in the H-GAC region. As opposed to estimating truck demand based on trip rates, H-GAC's truck model estimates demand for cargo-carrying trucks based on demand for and flow of commodities to, from and through the Houston region.

External travel

External travel demand, both local and through, was updated based on external volume and vehicle classification counts conducted by H-GAC in 2011. The new volume and classification counts were used to create external-local and through trip ends for auto travel and external-through trips for truck travel. External-local truck travel was estimated separately through the Cube Cargo-based truck demand modeling.

Trip Distribution

The source of Track-1 model off-peak highway travel time impedances used in the distribution of the non-work trip purposes was changed for the 2016 model update from average daily impedance to mid-day impedances. The mid-day impedances were based on assignment output volume-to-capacity ratios from a mid-day traffic assignment. Friction factors for all internal trip purposes other than truck trips were re-calibrated as part of the 2016 Track-1 model update so that model-estimated average trip lengths by trip purpose were consistent with 2007-2009 household survey observed average trip length.

Mode Choice

The regional mode choice model was re-calibrated with year 2016 observed modal target values developed from the 2007-2009 regional household survey and a 2016 transit on-board survey. As previously mentioned, the one change in model structure involved the movement of the toll demand estimation procedures from the mode choice model to the assignment model. For this reason the toll sub-nests of the mode choice model were not included in the re-calibration.

Time-of-Day Models

A fifth time-of-day period was added to the time-of-day modeling procedures of the 2016 Track-1 model to acknowledge peak spreading that has occurred in the region, particularly the spreading of the PM peak period. This fifth period, referred to as the 'evening' period is designed to capture the PM peak period spill-over congestion while maintaining the length of the original PM peak period. As a result of the creation of the evening period, the length of the overnight period was reduced

Using data from the 2007-2009 regional household travel survey, time-of-day factors for the five time-of-day periods were developed. As with the prior set of diurnal factors, the updated factors perform two functions. First, to factor the daily demand to the demand for the time period of interest, and second, impart the appropriate directionality of travel for the time period of interest.

Traffic Assignment

The Track-1 2016 model estimates toll demand via the traffic assignment component. This was accomplished through a generalized-cost (GC) assignment for each of the five time-of-day periods. Generalized-cost assignment allows for the use of the same assignment procedures for both the trip-based model and the H-GAC's in-development ABM. The GC assignment method made use of values-of-time that are segmented by trip purpose, income and mode. In this way, toll demand was affected not only by time-of-day, but also by the purpose of the trip and whether the trip is an SOV trip or an HOV trip. H-GAC's travel model divided a day into four time-of-day periods and ran traffic assignment for each time-of-day period. H-GAC used summed time-of-day assignments to represent daily traffic assignment demand.

Feedback

The feedback procedures used in the Track-1 model evaluates AM peak and Mid-day period assignments and impedance statistics for trip distribution. The 2016 Track-1 model update achieved the convergence criteria in three iterations.

Assignment Validation

The results of the time-of-day traffic assignments were summed to represent daily traffic volume on the modeling network. The resulting daily traffic volumes were then compared to the year 2016 daily traffic counts both on the basis of traffic volume and vehicle miles of travel (VMT). The comparison of assigned and counted volumes and VMT are presented in Chapter 4 of the validation document.

Summary

The 2016 Track-1 model set is structured virtually the same as the 2012 Track-1 model set, except for movement of toll demand estimation from the mode choice to the traffic assignment procedure. The trip generation, trip distribution, and mode choice components were updated and calibrated to match a new set of survey data and external count data while the modified traffic assignment procedures were validated against counted daily traffic.

1. 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 update, calibration and validation of the H-GAC trip-based travel model set – referred to as the “Track-1” model set to the Base Year 2016 by H-GAC. The “Track-1” model set that was last validated to the year 2012 has been updated with new survey data, year 2016 demographic data, updated highway and transit network and level-of-service data and validated against year 2016 traffic counts and year 2017 transit on-board survey.

1.1. Report Structure

Chapter 2 of the report discusses the development of TAZ, demographic and cost data for the Base Year 2016. Included in this section is also a discussion and depiction of the zone system used in the H-GAC modeling efforts. Chapter 3 outlines the development of both highway and transit networks. This is followed in Chapter 4 with a discussion of travel modeling components and the efforts in their update as part of the model validation.. The 2016 traffic assignment validation results are also presented 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.

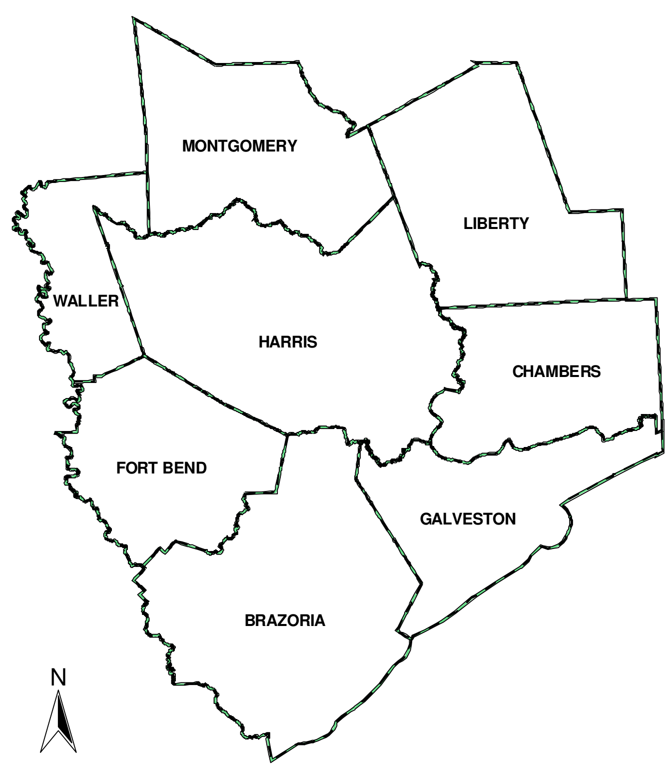
2. TAZs & Demographics

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. Demographic estimates and forecasts for the TMA are developed by H-GAC.

2.1. Zone System Definition

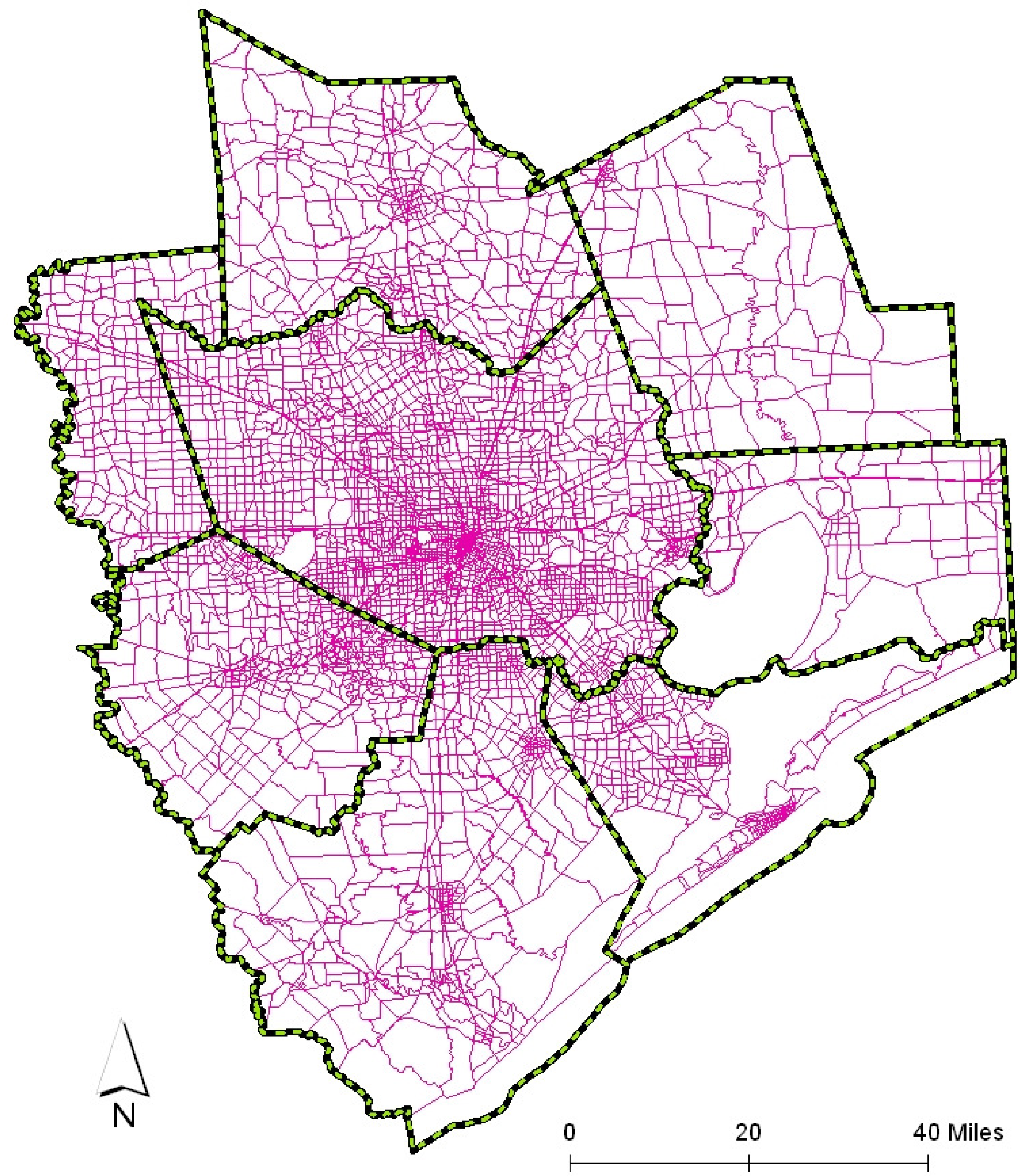
The level of detail of the Traffic Analysis Zone (TAZ) system of the Track-1 model was increased as part of the 2016 Track-1 model update. The 2016 Track-1 model makes use of 5,263 traffic analysis zones (TAZs) to represent the Houston-Galveston TMA. This includes 5,217 internal zones and 46 external stations. Figures 2-1 and 2-2 present the geographic extent of the TMA and the internal TAZ structure that is used in the 2016 Track-1 travel model. Table 2.1 presents a comparison of the previous TAZ and new TAZ structure of the Track-1 model set.

Figure 2-1 H-GAC Transportation Management Area (TMA)



Source: H-GAC

Figure 2-2 H-GAC TAZ Structure



Source: H-GAC

Table 2.1 TAZ By County

COUNTY	# of TAZs	
	2012 TRACK-1	2016 TRACK-1
Harris	2,868	2,941
Brazoria	522	552
Fort Bend	548	548
Waller	225	225
Montgomery	333	333
Liberty	126	126
Chambers	94	94
Galveston	397	398
External Stations	46	46
Region Total	5,159	5,263

2.2. Year 2016 Demographic Estimates

Demographic inputs to the 2016 Track-1 model update and validation were year 2016 household and employment by TAZ. Population and household inputs were developed using H-GAC's population synthesizer and, in the case of households, were controlled to 2010 Census data. Employment for the year 2016 was developed using business and employment data sets along with building data.

2.2.1 Households

H-GAC's population synthesizer uses detailed information on a small sample of the region's population and then uses iterative proportional fitting (IPF) and various simulation techniques to develop the detailed cross-tabulation of households and distributions by household size, household income and workers for each TAZ. Household data creation took place in two phases: the first phase involved creation of population and households by household size while the second phase involved development of household income and worker status of the population.

In phase I, the margins of multi-way (age, sex, age of householder) contingency tables were filled with the block-level 2010 SF1 U.S. Census data and then the cell values of these tables were developed using IPF to match the margins. After all the tables were filled in with the values, the distributions of households and persons was created from the summary tables. The resulting households and persons are called the base year 2015 population. Next, a simulation is ran produce year 2016 population and household by evolving base year 2015 popluation. The simulation simulates immigration, emigration, natural birth and death, and marriage which all impact population and household mix.

In phase II, American Community Survey (ACS) data was used to "impute" worker status for individuals and income for households. Household income was imputed by constructing household income frequency distribution table contingent on age and race of the householder. Next, each householder from the disaggregate data developed in phase I was matched with the income data by county, age, and race. Then, a simulation technique was used to assign a specific income level to each householder. Worker status was imputed using 2006-2010 ACS Public Use Survey Microdata (PUMS). Individuals from phase I were matched to individuals in PUMS on up to 8 dimensions simultaneously. This method “finds” individuals in PUMS that are similar to phase I individuals in personal and household characteristic and then develops a frequency distribution to impute worker status using the same simulation method used to assign a income.

For purposes of application in the 2016 Track-1 models, the households were assigned to one of five size groups (1- 5+ persons per household), one of three workers per household group (0-2+ workers per household group) and one of five household income groups. The five income groupings used in the 2016 Track-1 models are listed in Table 2.2

Table 2.2 Year 2016 Household Income Groupings

Income Group	Range (2016 $)
1	0 - 22,499
2	22,500 - 39,999
3	40,000 - 64,999
4	65,000 - 99,999
5	100,000+

Table 2.3 presents a summary of the year 2016 households summarized by each of the dimensions by which they are input into the travel model.

Table 2.3 2016 Households By Size, Income & Workers Per Household Dimensions

HOUSEHOLD SIZE	# HHs	HOUSEHOLD INCOME	# HHs	WORKERS PER HH	# HHs
1	618,802	$0 - $22,499	444,762	0	624,043
2	679,812	$22,500 - $39,999	411,576	1	1,046,573
3	403,199	$40,000 - $64,999	498,394	2+	728,279
4	327,132	$65,000 - $99,999	440,165		
5+	369,950	$100,000+	603,998		
Total	2,398,895	Total	2,398,895	Total	2,398,895

Table 2.4 summarizes households at the county-level for the years 2010 and 2016. Region wide households increased almost 17 percent, from 2.05 million in 2010 to nearly 2.39 million in 2016. Relative household growth by county ranged from a low of 11.77 percent in Harris County to a high of 38.0 percent in Fort Bend County. Table 2.5 summarizes the household population by county (which excludes group quarters such as prisons). The growth rate household population are generally below the growth rate in households, reflecting a trend of smaller household size of newer households.

Table 2.4 County Households for 2010 and 2016

County	Year 2010	Year 2016	Change	% Change
Brazoria	106,589	128,007	21,418	20.09%
Chambers	11,952	13,670	1,718	14.37%
Fort Bend	187,384	258,521	71,137	37.96%
Galveston	108,969	121,800	12,831	11.77%
Harris	1,435,144	1,619,701	184,557	12.86%
Liberty	25,073	29,734	4,661	18.59%
Montgomery	162,530	208,612	46,082	28.35%
Waller	14,040	18,850	4,810	34.26%
Region Total	2,051,692	2,398,895	347,203	16.92%

Source: H-GAC 2017

Table 2.5 County Household Population for 2010 and 2016

County	Year 2010	Year 2016	Change	% Change
Brazoria	302,607	351,550	48,943	16.17%
Chambers	34,867	38,144	3,277	9.40%
Fort Bend	579,439	735,971	156,532	27.01%
Galveston	287,012	330,321	43,309	15.09%
Harris	4,334,947	4,519,007	184,060	4.25%
Liberty	70,499	82,328	11,829	16.78%
Montgomery	452,522	546,225	93,703	20.71%
Waller	39,502	51,495	11,993	30.36%
Region Total	6,101,395	6,655,041	553,646	9.07%

Source: H-GAC 2017

2.2.2 Employment

TAZ employment for the year 2016 was developed from two primary datasets; the first comprised of buildings and the second comprised of businesses. The building data was obtained from county appraisal district data. The business data, which becomes the employment data, came from a variety of sources including the Texas Workforce Commission, InfoUSA, Texas Education Agency, Texas Department of State Health Services, the Houston Business Journal as well as various local government agencies. As the data is derived from multiple sources, it does include some self-employment and other unique employment types that are typically not included in common public employment data sources.

After data from the various data sources was standardized to company name and address, the businesses were geocoded to buildings from the county appraisal district data. Following geocoding, the employment was reviewed at the building level to identify issues with headquarters offices that result in overcrowding of the building. Building overcrowding is addressed through review of secondary data sources for location of branch office and/or adjustment of building employment to a typical value for the building type.

Following clean-up of the employment locations, the six-digit NAICS employment data was converted the employment categories used by the Track-1 travel demand model at the parcel level. The last step in the process was to summarize the parcel level employment to TAZ.

Table 2.6 presents a summary of the year 2016 employment by the employment categories used in the 2016 Track-1 model.

Table 2.6 Year 2016 County Employment by Employment Type

COUNTY	RETAIL	OFFICE	INDUSTRIAL	MEDICAL	EDUCATIONAL (K-12)	EDUCATIONAL (POST SECONDARY)	GOVERNMENT	TOTAL
Brazoria	46,552	28,416	16,837	9,766	9,153	506	6,242	11,7472
Chambers	5,064	2,243	7,215	595	1,001	0	1,311	17,430
Fort Bend	67,756	52,726	35,305	25,520	19,649	1,164	12,622	214,742
Galveston	61,191	26,593	2,720	13,488	10,387	6,047	9,692	130,118
Harris	651,128	915,191	401,521	278,222	128,410	57,188	78,138	2,509,798
Liberty	6,959	3,229	1,699	1,926	24,45	8	1,779	18,045
Montgomery	65,409	70,134	25,241	24,246	148,70	1,468	10,914	212,282
Waller	5,219	4,586	7,036	1,072	1,752	0	768	20,434
Region Total	90,9278	1,103,118	497,574	354,835	187,667	66,381	121,466	3,240,321

Updated 08/02/2019

A comparison of the year 2010 and year 2016 employment for the eight county region, as presented in Table 2.7, shows that employment increased comparably with household growth, 18.12% percent overall. Harris County gained over 272,829 jobs while Montgomery County employment grew more than 51% percent (72,398 jobs). In addition to the household, population and employment values themselves, the ratio of these variables to each other is frequently used to asses changes to a region's demographic characteristics over time.

Table 2.7 County Employment for Years 2010 and 2016

County	Year 2010	Year 2016	Change	% Change
Brazoria	84,422	117,472	33,050	39.15%
Chambers	12,403	17,430	5,027	40.53%
Fort Bend	148,418	214,742	66,324	44.69%
Galveston	95,512	130,118	34,606	36.23%
Harris	2,236,969	2,509,798	272,829	12.20%
Liberty	14,286	18,045	3,759	26.31%
Montgomery	139,884	212,282	72,398	51.76%
Waller	11,273	20,434	9,161	81.26%
Region Total	2,743,167	3,240,321	497,154	18.12%

Source: H-GAC

Table 2.8 presents comparisons among these demographic comparison metrics between the year 2010 and the year 2016.

Table 2.8 Comparative Statistics – County Level —Years 2010 and 2016

County	Year	Person/HH	Pop/Emp	Emp/HH
Brazoria	2010	2.84	3.58	0.72
	2016	2.75	2.99	0.92
Chambers	2010	2.92	2.81	1.04
	2016	2.79	2.19	1.28
Fort Bend	2010	3.09	3.90	0.79
	2016	2.85	3.43	0.83
Galveston	2010	2.63	3.00	0.88
	2016	2.71	2.54	1.07
Harris	2010	3.02	1.94	1.56
	2016	2.79	1.80	1.55
Liberty	2010	2.81	4.93	0.57
	2016	2.77	4.56	0.61
Montgomery	2010	2.78	3.23	0.86
	2016	2.62	2.57	1.02
Waller	2010	2.81	3.50	0.80
	2016	2.73	2.52	1.08
Region	2010	2.97	2.22	1.34
	2016	2.77	2.05	1.35

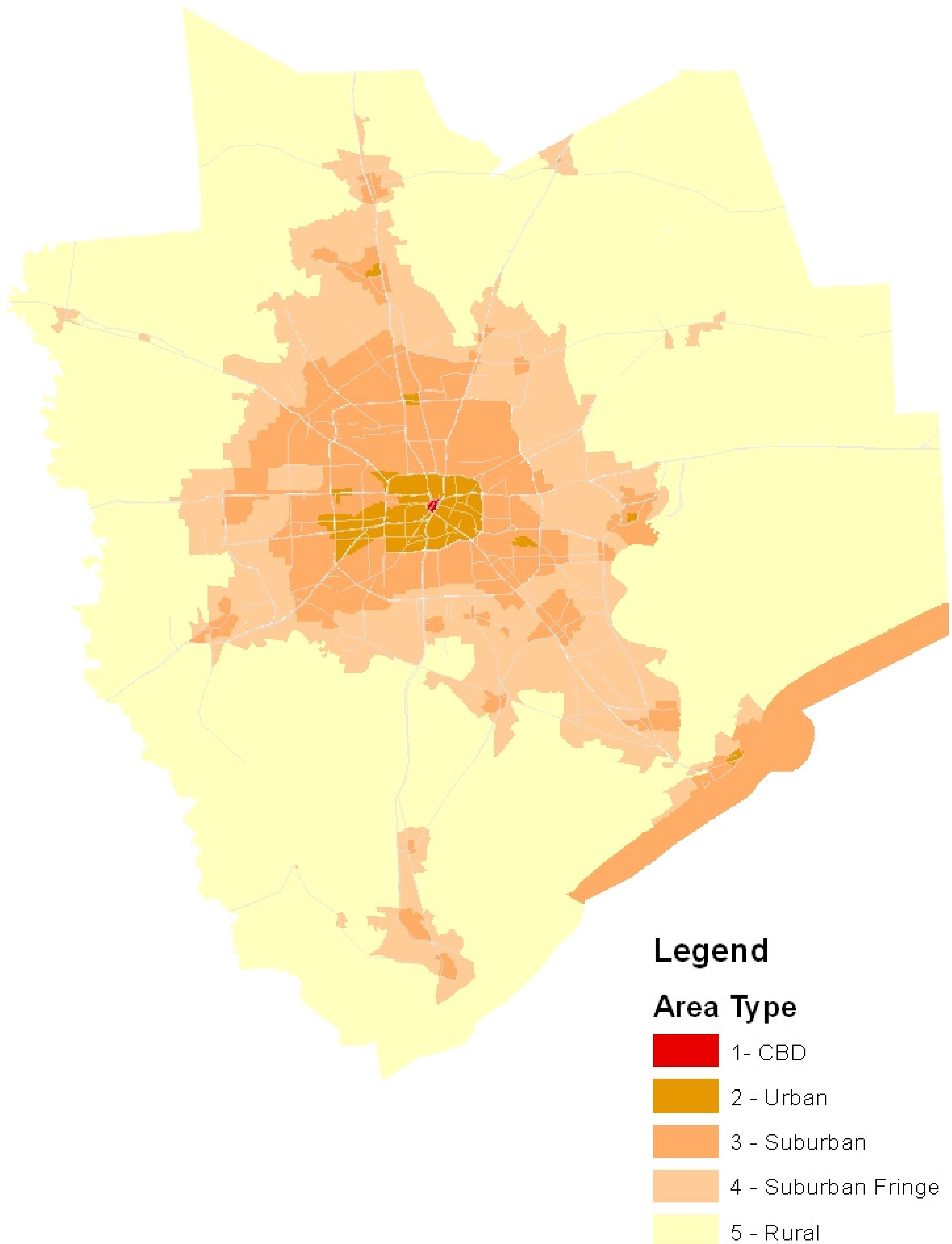
The regional employment to household ratios are almost identical between the two years, but the population-to-employment ratio and population-to-households ratio are lower in year 2016. The employment growth attracts more new households, particularly smaller households. Overall both employment and population grows rapidly in similar rate regionwide, but locally these two grow rates could be different.

2.3. Year 2016 Area Types

The TAZ area type was calculated based upon the population and the employment total of the subject TAZ and eight neighboring TAZs. In this way, the area type was not only a function of the TAZs individual demographic density but also reflects characteristics of the surrounding area. Year 2016 area types were calculated using the zonal population and employment estimates along with the regional population/employment ratio.

Following automated calculation of each TAZs area type, the resulting area types were reviewed and further smoothed, as needed. Figure 2-3 presents the final 2016 TAZ area types.

Figure 2-3 Year 2016 TAZ Area Types



3. Highway/Transit Networks & Related Data

3.1. Highway Network Characteristics

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

The 2016 base year highway network includes key operational features for approximately 12,700 center-line miles of roadways in the Houston-Galveston TMA, and consists of more than 24,000 roadway links (one-way for freeway and managed lanes, two-way for arterials and collectors, and excluding centroid connectors). Each link's physical and operating characteristics are described in a link data record. 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 daily and time-of-day weekday traffic count and direction (one-way/two-way) are also carried in the modeling network. Link data items such as facility type classification, daily speed and time-of-day capacity were from this operational-oriiented information. Highway link facility types include nearly 40 different classifications. These are listed in Table 3.1 along with the link type codes for transit and HOV access.

Table 3.1 Facility Type Classification Codes

Code	Description
0	Centroid Connector
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	Reversible HOV/transitways (barrier-separated)
21	HOV ramps – bus only
22	Transfers from park-and-ride (PNR) 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 (TC)
27	HOV-only slip ramps
28	Transfer from pseudo-PNR to transit stop
29	HOV terminal ramps
30	Light Rail
31	Commuter Rail
32	Transfers from rail station
40	High-Occupancy Toll (HOT) Lane
41	HOT ramp to PNR/TC
47	HOT slip ramp
49	HOT ramp
50	Freeway frontage road
51	Tollway frontage road
52	Freeway/tollway ramps to/from frontage roads
53	Freeway/tollway direct connector (DC) ramps
60	Diamond lane (non-barrier separated HOV lane)
80	Reversible HOT Lane (barrier-separated)
99	Walk to Transit Only Centroid Connector

3.1.1. Link Capacity

The 2016 Track-1 travel models make use of multi-hour time-of-day capacities in the traffic assignment component. The multi-hour capacities are based on hourly capacities which vary by facility type and area type.

The hourly capacities themselves represent level-of-service (LOS) “E” capacities and are based on Highway Capacity Manual (HCM) flow rates. The HCM flow rates were then adjusted, as appropriate for the capacity effects of turns, and in the case of non-freeways, intersection control. Additionally, as the capacities are expressed in terms of vehicles, there is an accounting for the effects of trucks on the flow rate as part of the capacity development. assumed typical to account LOS E.

The hourly capacity per lane was calculated as a function of the hourly saturation flow rate as follows:

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

Where: CS = saturation flow rate (2,300 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 × V in the peak 15 minutes);
U = lane utilization factor (assumed to be 1.0 for freeways);
P_t = percent of trucks;
E_t = truck equivalency factor; and
LTVP = left turn volume in the peak hour and peak direction.

The capacity of a freeway link is simply the hourly per lane capacity times the number of lanes coded on the link. For non-freeway facilities, the lane utilization factor varies based on the number of lanes. For this reason, the capacity of a non-freeway varies slightly among different lane configurations of a link. Freeway and non-freeway hourly capacities are presented in Appendix A.

The process for developing multi-hour capacities which correspond to the time-of-day assignment periods was simply a matter of multiplying the length of the time period by the hourly capacity. In other words, the capacity for the three hour AM peak period is the hourly capacity multiplied by three while the capactity for the four hour PM peak period is the hourly capacity times four. This method of multi-hour capacity development was used with the intended use of the assignment results in mind. As the assignment results, in particular, the resulting volume-to-capacity (V/C) ratios are used in development of inputs for mode choice and for emissions estimation, the (V/C) ratios should represent the average hourly V/C across the time period. For this to be case, the “C” portion of the V/C ratio should be the full capacity for the time period of interest.

3.1.2. Link Speed

Besides time-of-day capacity, each link was populated with a link speed that is used to develop travel time impedances used in the initial round of trip distribution and in the initial iteration of all traffic assignments. For non-centroid connector links, the initial link speed is simply the free-flow (zero-volume) speed, which varies by link type and area type, The initial link speeds for non-centroid links are presented in Appendix A.

Speeds on auto 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 the area type 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 (rural) zone sizes will increase accordingly. Thus, each of the five area types have a unique set of equations for determining centroid connector speeds. A representative table of centroid connector speeds for a distance of one mile would be as shown in Table 3.2. Appendix B presents additional detail on the process used to calculate centroid connector speed.

Table 3.2 Example Centroid Connector Speeds

Area Type	Distance (miles)	Speed (mph)
CBD	0.05	20.0
Urban	0.95	40.0
Suburban	1.20	40.0
Fringe Suburban	1.70	40.0
Rural	1.80	40.0

Source: H-GAC

3.1.3. Link Toll Costs

Toll costs were used in the assignment model as part of the generalized cost path building. The toll costs were placed on the links in the network that represent the locations where the tolls are actually collected. The costs represent the average cost paid among both toll tag and cash patrons. Table 3.3 lists the year 2016 toll costs.

Table 3.3 Year 2016 Toll Costs

Location	Toll Cost
Hardy - North Plaza	$1.35
Hardy - FM 1960 Ramp	$1.00
Hardy - Richey Ramp	$1.00
Hardy - Rankin Ramp	$0.75
Hardy - South Plaza	$1.33
Hardy - Bush IAH Ramp	$1.00
Hardy - Greens Road Ramp	$0.75
Hardy - Aldine Mail Ramp	$1.00
Hardy - Little York Ramp	$1.00
Hardy - Tidwell Ramp	$0.75
Sam Houston North Plaza	$1.33
Sam Houston North - SH 249 Ramp	$1.00
Sam Houston North - North Gessner Ramp	$1.00
Sam Houston North - Fallbrook Ramp	$1.00
Sam Houston Central - West Road Ramp	$0.75
Sam Houston Central Plaza	$1.33
Sam Houston Central - Clay Road Ramp	$1.00
Sam Houston Central - Hammerly Ramp	$0.75
Sam Houston Southwest Plaza	$1.33
Sam Houston Southwest - South Main (90-A)	$0.75
Sam Houston Southwest – Fort Bend Tollway	$0.75
Sam Houston Southwest - West Fuqua	$1.00
Sam Houston Southwest – Almeda	$1.00
Sam Houston South Plaza	$1.33

Sam Houston South – Deerwood	$1.00
Sam Houston South - Briar Forest	$1.00
Sam Houston South – Westheimer	$1.00
Sam Houston South – Bellaire	$0.75
Sam Houston South - Westpark Tollway	$0.50
Sam Houston Southeast Plaza	$1.33
Sam Houston Southeast - Cullen	$0.75
Sam Houston Southeast – Wayside	$1.00
Sam Houston Southeast – Telephone Rd	$1.00
Sam Houston Southeast – Monroe	$0.75
Sam Houston East Plaza	$1.33
Sam Houston East - Fairmont Parkway	$1.00
Sam Houston East - Spencer Highway	$1.00
Sam Houston East - Red Bluff	$0.75
Sam Houston Ship Channel Bridge	$1.58
Sam Houston Northeast – Tidwell	$0.50
Sam Houston Northeast – Garrett	$0.75
Sam Houston Northeast – Winfield	$0.75
Sam Houston Northeast Plaza	$1.33
Sam Houston Northeast – W. Lake Houston Pkwy	$0.75
Sam Houston Northeast – John Ralston	$0.50
Sam Houston Northeast – Wilson	$0.50
Fort Bend Toll Main Plaza	$0.85
Lake Olympia Pkway Ramp	$0.35
McHard Road FM 2234 Ramp	$0.65
Fort Bend Parkway FM 2234 Mainline	$0.40
Fort Bend Parkway Highway 90A Plaza	$1.50
Westpark Toll Peek Mainlane	$0.65
Westpark Toll Grand Mission Mainline	$0.65
Westpark Toll HW6 westbound Ramp	$0.50
Westpark Toll Wilcrest Mainline	$1.30
Westpark Toll Gessner Road Entrance/Exit	$0.35
Westpark Toll Fondren East Exit	$0.50
Westpark Toll Fondren East Entrance	$0.75
Westpark Toll Fondren East Mainline	$1.30
Westpark Toll Fondren West Mainline	$1.30
Westpark Toll Westpark Drive East Ramp	$0.35
Westpark Toll South Post Oak Exit	$0.35
Katy Managed Lanes Wirt Plaza	$0.36 – 1.20
Katy Managed Lanes Wilcrest Plaza	$0.36 – 1.20
Katy Managed Lanes Eldridge Plaza	$0.48 – 1.60
Tomball Tollway – Mainlane Plaza	$1.50

Tomball Tollway – Boudreaux Ramp	$1.20
Tomball Tollway – SH 249 Business Ramp	$0.90
SH 99 Segmetn D - Riverpark Plaza	$0.35
SH 99 Segment D - New Territory Plaza	$0.35
SH 99 Segment D - US 90A Plaza	$0.35
SH 99 Segment D - Harlem Plaza	$0.35
SH 99 Segment D – West Bellfort Plaza	$0.35
SH 99 Segment D – Bellaire Plaza	$0.35
SH 99 Segment D – Westpark Plaza	$0.35
SH 99 Segment D – Colonial Parkway Ramp	$0.46
SH 99 Segment E – FM 529 Mainline Plaze	$2.12
SH 99 Segment E – US 290 Mainline Plaza	$1.10
SH 99 Segment E – Franz Rd Ramp	$0.46
SH 99 Segment E – West Rd Ramp	$0.46
SH 99 Segment E – Louetta Ramp	$0.46
SH 99 Segment E – Bridgeland Creek Pkwy Ramp	$0.46
SH 99 Segment E – N. Bridgeland Pkwy Ramp	$0.46
SH 99 Segment E – Morton Rd Ramp	$0.58
SH 99 Segment E – Clay Rd Ramp	$0.82
SH 99 Segment E – FM 529 Ramp	$0.67
SH 99 Segment F1 – US 290 Mainline Plaza	$1.45
SH 99 Segment F1 – US 249 Mainline Plaza	$1.02
SH 99 Segment F1 – Cumberland Ridge Ramp	$0.46
SH 99 Segment F1 – Mueschke Rd Ramp	$0.46
SH 99 Segment F1 – Telge Rd Ramp	$0.47
SH 99 Segment F2 – FM 2920 Mainline Plaza	$1.29
SH 99 Segment F2 – I-45 Mainline Plaza	$1.18
SH 99 Segment F2 – FM 2920 Ramp	$0.46
SH 99 Segment F2 – Gosling Ramp	$0.46
SH 99 Segment F2 – I-45 Direct Connectors	$0.46
SH 99 Segment F2 – Gleannlock Forest Dr Ramp	$0.48
SH 99 Segment G – I-45 Mainline Plaza	$0.46
SH 99 Segment G – Hardy Toll Road Mainline Plaza	$0.70
SH 99 Segment G – I-69 Mainline Plaza	$1.86
SH 99 Segment G – FM 1314 Ramp	$1.07
SH 99 Segment G – Rayford Rd Ramp	$0.46
SH 99 Segment I2 – FM 565 Mainline Plaza	$1.36
SH 99 Segment G – FM 565 Ramp	$0.59
San Luis Pass-Vacek Toll Bridge	$2.00

3.2. 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 TAZ's 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.

3.2.1. 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. Many local bus routes and the light rail routes run more frequently during peak periods. Similarly, not all routes or subroutes operate during the course of the entire day. Express and Commuter bus routes, in particular, generally operate only during the morning and afternoon peak periods. In order to properly reflect these differences, separate peak and off-peak 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 tradeoff stems from the manner in which the path-building algorithm measures the frequency of service between boarding and alighting locations. The algorithm first determines the best paths between the orign and destination, and then recognizes that several lines of same transit modes as the best path coice 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 models where this recognition ignores some transit routes from irrelavent transit modes.

3.2.2. Transit Modes

Every transit route contains a number identifier for each transit modes. The following transit modes are used:

- 1: local bus
- 2: express bus
- 3: commuter bus
- 4: light rail
- 5: commuter rail

There was no existing commuter rail service in the region in for year 2016. The commuter rail mode is reserved for model forecasting and alternative analysis.

3.2.3. Transit Travel Times

Transit 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. Two basic types of TTFs are included in the model:

I. Simple assumed speed

II. Auto speed multiplied by an auto-to-transit time factor and added by a constant

Type I TTFs are coded with an assumed speed, which is constant across all links. Type 1 TTF are applied on HOV, HOT, access and egrees inside a park-and-ride, and walk links. The speed is 3 miles per hour (mph) for walking, 12 mph inside park-and-ride, 53 mph on HOV link. Type II TTFs apply a multiplicative factor and an additive factor to auto time to relate transit link travel time to the corresponding auto travel time. The general form of Type II TTFs is

$$S_{transit} = C + \alpha \times S_{auto}$$

where S_{auto} is the congested auto travel speed, C is the additive factor, and α is a multiplicative factor. The values of C and α varies by different transit modes and stop/non-stop portion of the routes.

Light rail and commuter rail do not apply the TTF as these modes operate in separate rights-of-way. Therefore, their speeds are minimally impacted by congestion.

The values of C and alpha are presented in Table 3.4.

Table 3.4 Transit Time Function Parameters

Transit Route Type	Additive Factor	Multiplicative Factor	
		Area Type 1	Area Types 2-5
Local Bus Stop	4	0.217	0.447
Local Bus Non-Stop	0	0.625	0.930
Express Bus Stop	4	0.230	0.480
Express Bus Non-Stop	0	0.625	0.930
Commuter Bus Stop	4	0.230	0.540
Commuter Bus Non-Stop	0	0.625	0.930

3.2.4. Waiting Times

Waiting times are the times between the passengers arriving at the transit stop and boarding to transit vehicles. Assuming every passengers arrive the transit stop totally random, their average waiting time should be one half of the bus headway. When the headway exceeds certain theresold, the waiting time should stop increasing and remains constant because passenger could avoid extremely long waiting time.

Passengers also perceive waiting time and in-vehicle time differently. They often perceive the same amount of time waiting longer than then in-vehicle time because they are less comfortable while waiting. Weather, safety, and anxiety waiting for a bus arrival factors which make waiting less comfortable than in a transit vehicle. As a result, passengers perceives waiting time longer than its actual value, The model should use the perceived waiting time in transit path building and in mode choice to represent that passengers are less comfortable to wait than to be inside a transit vehicle.

There are two kinds of waiting times: initial waiting time and transfer waiting time. Initial waiting time is the waiting time before any transfer – which is the waiting time for the first transit leg. Transfer waiting time is the waiting time between transferring from one transit route to another transit routes.

The model calculates the perceived waiting time as a function of headway. It assumes the actual waiting time is one half of the headway for headway less than two hours, and the actual waiting time remains constant afterwards. Then, the model will factor the actual waiting time with a weighing factor to get the perceived waiting time. The followings are the actual-to-preceived waiting time weight factors:

- First 4.5 minutes of HBW initial waiting times 1.00
- After 4.5 minutes of HBW initial waiting times 2.00
- HBW transfer waiting times 2.58
- HBNW and NHB initial waiting times 2.00
- HBNW and NHB transfer waiting times 2.00

After applying the weighing factors above, the perceived waiting time functions have these forms. The headways and perceive waiting time are as shown in Table 3.5.

Table 3.5 Turning Points of Various Waiting Time vs Headway Functions

Headway	0	1	9	120	180
HBW Initial Wait Time	0	1	9	64.5	64.5
HBW Transfer Wait Time	0	1.29	11.61	154.80	154.80
HBNW NHB Initial Wait Time	0	1	9	120	120
HBNW NHB Transfer Wait Time	0	1	9	120	120

3.2.5. Transit Path Building

Path building between each pair of zones relies upon 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 2016 validated model (all times are in minutes):

- Preceived Boarding Penality: 10.0 minutes
- Transfer Penality: 4 minutes
- Local Bus In-vehicle time weight factor(for premium modes pathing): 1.30
- Commuter Rail In-vehicle time weight factor(for peak premium modes pathing): 0.80
- Maximum transfer allowed: 2
- Maximum weight travel time: 300 minutes
- Waiting time weight factor: 1.0

- Auto access time weight factor: 1.0
- Peak walk time weight factor: 2.58
- Off-peak walk time weight factor: 2.0

4. Model Components

4.1. Introduction

The 2016 Track-1 models, with two exceptions, ars structured in the same way as the 2009 Track-1 model. The first exception deals with the estimation of toll demand. The modeling procedures have been modified such that toll demand is estimated in the traffic assignment stage rather than the mode choice stage. The second structural change has to do with commercial vehicle (i.e., truck) travel. Truck travel is estimated by a truck model that functions separately from the 2016 Track-1 model rather than through the trip generation model.

The 2016 Track-1 models represent an update of the trip generation, trip distribution and mode choice models with new travel survey data. During 2008 and 2009, TxDOT and H-GAC conducted a household travel survey for the 8-county Houston-Galveston Region. The survey obtained general household and person data as well as travel activity data from over 5,800 households and over 18,600 persons for a single travel day (24 hours). A workplace travel survey was also conducted by TxDOT and H-GAC in 2010 and 2011 and involved the collection of travel data from employees and non-employees at 500 workplaces in the H-GAC region. Travel data was collected from nearly 1,800 employees of and nearly 3,000 visitors to the surveyed worksites.

Although no external travel survey has been performed since the 1995 Houston external travel survey, external volume and classification counts were collected by H-GAC in 2011. These counts are the basis for estimating external station control totals and auto and truck splits at the external stations.

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, that is, the total number of trip ends (trip productions and trip attractions), for each of the 5,217 detailed traffic analysis zones.

Trip generation is performed for fourteen trip purposes:

- Home-based Work Income Group 1 person trips (HBW-INC1);
- Home-based Work Income Group 2 person trips (HBW-INC2);
- Home-based Work Income Group 3 person trips (HBW-INC3);
- Home-based Work Income Group 4 person trips (HBW-INC4);
- Home-based Work Income Group 5 person trips (HBW-INC5);
- Home-based Nonwork Retail person trips to Retail (HBNW-RET);
- Home-based Nonwork ED1 (K-12) School Bus person trips (HBNW-ED1-SB);
- Home-based Nonwork person trips to ED1 by other (HBNW-ED1);
- Home-based Nonwork person trips Airport (HBNW-AIR);
- Home-based Nonwork person trips to Other (HBNW-OTHER);
- Non-home-based person trips – Work-based (NHB-WB);
- Non-home-based person trips – Non-work-based (NHB-NW);

- Taxi vehicle trips (TAXI);
- External-local auto vehicle trips (EXTL-AUTO);
- External-through auto vehicle trips (EXTHR-AUTO);
- External-through truck vehicle trips (EXTHR-TRK)

The HBNW-ED1 trip purpose excludes the person trip by school bus but includes those that use normal transit. The HBNW-ED1-SB purpose was defined as a separate trip purpose as the mode choice model used in the model set assumes that the person trips by school bus have been removed from the data which is input to the mode choice model. As can be seen in the trip purpose definitions, the non-work person trip purposes are defined around the land use and the attraction end of the trip. Also, non-home-based trips have been separated into those that in which the production is the trip-makers place of employment (work-based) and those in which the production is not the trip makers place of employment (not work-based).

4.2.1. Trip Production

The H-GAC trip household production models use cross-classification trip production rates developed from the H-GAC 2008/09 Household Travel Survey data. These rates were developed for a three-way cross classification of households dimensioned by household size, number of workers, and by household income. In the model calibration process, some of the resulting rates were smoothed to removed sampling noise due to the small sample sizes being employed. The resulting production rates (i.e., the dependent variables) are the trips per household by purpose. Cross-classification models allows the nonlinearity of the model with respect to the independent variables.

The trip production model determines the relationship between trips generated per household, number of workers, and household income in combination with household size. Thus, trip production rates were stratified by household size, household income and number of workers. The updated trip production rates are presented in Tables 4.1-4.8. The household survey revealed thats less than 1 percent of classified non-workers made work trips and hence the production rates do include work trip rates for zero-worker households.

Table 4.1 Home-Based Work Person Trips

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.013	0.024	0.023	0.026	0.031
	1	0.765	0.899	1.078	1.241	1.259
	2+	N/A	1.579	1.858	2.230	2.425
2	0	0.013	0.024	0.023	0.026	0.031
	1	0.854	1.034	1.124	1.259	1.303
	2+	N/A	1.858	2.184	2.416	2.602
3	0	0.013	0.024	0.023	0.026	0.031
	1	0.944	1.124	1.214	1.303	1.349
	2+	N/A	2.137	2.416	2.602	2.788
4	0	0.013	0.024	0.023	0.026	0.031
	1	0.989	1.169	1.259	1.349	1.393
	2+	N/A	2.276	2.555	2.741	2.927
5	0	0.013	0.024	0.023	0.026	0.031
	1	1.034	1.214	1.303	1.393	1.438
	2+	N/A	2.323	2.648	2.788	3.020

Source: H-GAC

Table 4.2 Home-Based Non-Work to Education-1 (K-12th) Person Trip Rates

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.058	0.074	0.641	1.262	2.759
	1	0.146	0.245	0.817	2.424	3.958
	2+	0.000	0.145	0.424	1.078	3.419
2	0	0.067	0.169	0.779	1.290	3.695
	1	0.125	0.182	0.975	3.264	5.431
	2+	0.000	0.145	0.878	1.819	3.929
3	0	0.076	0.234	0.596	2.119	4.204
	1	0.106	0.169	1.068	3.824	5.983
	2+	0.000	0.145	1.070	2.379	4.279
4	0	0.087	0.356	0.550	3.132	4.989
	1	0.098	0.128	1.374	4.290	6.443
	2+	0.000	0.145	1.093	2.975	4.481
5	0	0.105	0.422	0.505	4.976	6.467
	1	0.091	0.102	1.653	4.477	6.259
	2	0.000	0.145	1.124	3.727	4.718

Source: H-GAC

Table 4.3 Home-Based Non-Work to Education-1 (K-12th) by School Bus Person Trip Rates

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.000	0.045	0.262	0.830	2.032
	1	0.000	0.010	0.311	1.176	1.516
	2+	0.000	0.011	0.057	0.098	0.138
2	0	0.000	0.016	0.209	0.622	1.551
	1	0.000	0.010	0.263	0.980	1.611
	2+	0.000	0.021	0.099	0.146	0.188
3	0	0.000	0.017	0.136	0.521	1.387
	1	0.000	0.010	0.204	0.852	1.706
	2+	0.000	0.032	0.142	0.195	0.239
4	0	0.000	0.003	0.104	0.570	1.260
	1	0.000	0.010	0.165	0.833	1.895
	2+	0.000	0.043	0.184	0.244	0.289
5	0	0.000	0.000	0.162	0.632	1.145
	1	0.000	0.010	0.126	0.833	2.085
	2+	0.000	0.054	0.227	0.293	0.339

Source: H-GAC

Table 4.4 Home-Based Non-Work to Retail Person Trip Rates

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.559	1.173	1.341	1.565	1.788
	1	0.652	1.411	1.628	1.955	2.172
	2+	0.000	1.143	1.416	1.611	1.742
2	0	1.005	1.732	1.900	2.124	2.347
	1	0.706	1.628	1.846	2.389	2.714
	2+	0.000	1.253	1.634	1.830	2.177
3	0	1.453	2.291	2.459	2.682	2.905
	1	0.760	1.792	2.008	2.714	3.149
	2+	0.000	1.416	1.851	2.048	2.505
4	0	1.900	2.738	2.905	3.129	3.465
	1	0.814	1.932	2.149	3.040	3.475
	2+	0.000	1.524	2.069	2.265	2.832
5	0	2.347	3.185	3.353	3.576	4.024
	1	0.869	2.172	2.389	3.258	3.692
	2+	0.000	1.634	2.287	2.483	3.158

Source: H-GAC

Table 4.5 Home-Based Non-Work to Airport Person Trip Rates

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.013	0.024	0.032	0.039	0.041
	1	0.010	0.021	0.027	0.039	0.047
	2+	0.000	0.007	0.018	0.039	0.047
2	0	0.011	0.019	0.027	0.046	0.055
	1	0.011	0.023	0.031	0.051	0.063
	2+	0.000	0.010	0.023	0.042	0.055
3	0	0.021	0.042	0.049	0.057	0.085
	1	0.012	0.025	0.036	0.062	0.079
	2+	0.000	0.015	0.028	0.046	0.061
4	0	0.024	0.049	0.057	0.067	0.103
	1	0.013	0.027	0.043	0.074	0.091
	2+	0.000	0.020	0.035	0.050	0.068
5	0	0.026	0.053	0.062	0.077	0.124
	1	0.015	0.032	0.049	0.084	0.101
	2+	0.000	0.024	0.040	0.055	0.076

Source: H-GAC

Table 4.6 Home-Based Non-Work Other Person Trip Rates

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.705	1.323	1.718	2.097	2.237
	1	0.539	1.144	1.467	2.116	2.562
	2+	0.000	0.376	0.962	2.125	2.560
2	0	0.882	1.839	2.191	2.568	3.591
	1	0.599	1.272	1.685	2.753	3.439
	2+	0.000	0.570	1.250	2.301	2.979
3	0	1.117	2.286	2.662	3.099	4.593
	1	0.658	1.373	1.964	3.391	4.316
	2+	0.000	0.789	1.504	2.478	3.340
4	0	1.293	2.653	3.077	3.631	5.594
	1	0.731	1.492	2.360	4.028	4.953
	2+	0.000	1.069	1.889	2.711	3.698
5	0	1.411	2.898	3.372	4.162	6.713
	1	0.814	1.713	2.639	4.546	5.471
	2+	0.000	1.300	2.178	3.005	4.118

Source: H-GAC

Table 4.7 Non-Home-Based Work-Based Person Trip Rates

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.008	0.015	0.014	0.016	0.019
	1	0.307	0.384	0.430	0.538	0.615
	2+	0.000	0.737	0.899	1.106	1.253
2	0	0.008	0.015	0.014	0.016	0.019
	1	0.460	0.538	0.583	0.691	0.769
	2+	0.000	1.031	1.179	1.326	1.548
3	0	0.008	0.015	0.014	0.016	0.019
	1	0.615	0.691	0.737	0.844	0.922
	2+	0.000	1.326	1.473	1.548	1.798
4	0	0.008	0.015	0.014	0.016	0.019
	1	0.769	0.844	0.892	0.998	1.075
	2+	0.000	1.592	1.769	1.842	2.064
5	0	0.008	0.015	0.014	0.016	0.019
	1	0.922	0.998	1.045	1.153	1.229
	2+	0.000	1.842	2.035	2.131	2.284

Source: H-GAC

Table 4.8 Non-Home Based Other Person Trip Rates

Income Group	Number of Workers	1 Person Household	2 Person Household	3 Person Household	4 Person Household	5+ Person Household
1	0	0.764	1.546	2.161	2.593	3.169
	1	1.400	1.604	1.719	1.863	2.578
	2+	0.000	1.368	1.569	1.821	2.055
2	0	1.152	1.873	2.593	3.096	3.600
	1	1.400	2.030	2.078	2.291	3.008
	2+	0.000	1.597	2.008	2.259	2.471
3	0	1.584	2.305	3.025	3.600	4.105
	1	1.400	2.334	2.507	2.793	3.538
	2+	0.000	1.901	2.286	2.550	2.777
4	0	2.088	2.737	3.456	4.032	4.608
	1	1.400	2.582	2.793	3.295	4.010
	2+	0.000	2.185	2.521	2.842	3.028
5	0	2.593	3.241	3.961	4.464	5.041
	1	1.400	2.700	3.079	3.624	4.440
	2+	0.000	2.434	2.711	2.987	3.333

Source: H-GAC

4.2.2. Trip Attractions

Trip attraction rates have been updated for the 2016 Track-1 model based on the 2010/2011 TxDOT and H-GAC workplace survey. The attractions rates are stratified by area type and employment category. The rates also include a stratification for households so as to allow for the estimation of trip attractions to households. Additionally, productions for non-home-based work-based trips are estimated based on area type and employment. Tables 4.9 through 4.21 present the 2016 Track-1 trip attraction rates. Attraction rates were not developed for the HBNW-AIR trip purpose as the attractions are estimated based on the 2010/2011 airport special generator survey.. Truck trip demand is estimated outside the Track-1 model set via H-GAC CUBE Cargo-based truck model and not part of the Track-1 trip generation process,

Table 4.9 HBW Person Trip Attraction Rates – Income Group 1

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	ED-1	ED-2A	ED-2B
1	0.0120	0.0710	0.0680	0.1140	0.0480	0.0750	0.1710	0.2890	0.1859
2	0.0090	0.1290	0.0700	0.2070	0.1010	0.1080	0.1530	0.0340	0.0219
3	0.0110	0.1330	0.1080	0.1610	0.0590	0.0780	0.1010	0.0820	0.0527
4	0.0070	0.1170	0.0560	0.0770	0.0160	0.0730	0.0950	0.0830	0.0534
5	0.0110	0.1460	0.0470	0.0510	0.0300	0.0500	0.0950	0.3350	0.2155

Table 4.10 HBW Person Trip Attraction Rates – Income Group 2

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	ED-1	ED-2A	ED-2B
1	0.0200	0.0970	0.0970	0.2080	0.3460	0.2300	0.0890	0.4010	0.2579
2	0.0270	0.1440	0.0920	0.4460	0.2100	0.2590	0.4010	0.1470	0.0945
3	0.0160	0.1570	0.2000	0.2760	0.1350	0.1170	0.1990	0.1770	0.1138
4	0.0070	0.1800	0.1010	0.1670	0.0790	0.0800	0.0960	0.1190	0.0765
5	0.0220	0.1450	0.1740	0.0870	0.0860	0.0730	0.0750	0.3280	0.2110

Table 4.11 HBW Person Trip Attraction Rates – Income Group 3

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	ED-1	ED-2A	ED-2B
1	0.1350	0.1540	0.2710	0.2330	0.5970	0.5090	0.3270	0.2103	0.8151
2	0.2190	0.2040	0.1640	0.2650	0.2320	0.2710	0.1860	0.1196	0.8121
3	0.2300	0.2860	0.2890	0.2420	0.1560	0.3480	0.3720	0.2393	0.8676
4	0.2700	0.2280	0.2960	0.2790	0.1710	0.2700	0.1320	0.0849	0.8676
5	0.2040	0.2350	0.1390	0.5380	0.1370	0.5790	0.3280	0.2110	1.0718

Table 4.12 HBW Person Trip Attraction Rates – Income Group 4

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	ED-1	ED-2A	ED-2B
1	0.2620	0.2820	0.3340	0.2410	0.4230	0.1800	0.3270	0.2103	0.8151
2	0.1190	0.2570	0.2060	0.3150	0.2490	0.1910	0.3030	0.1949	0.8121
3	0.1610	0.3080	0.1770	0.3050	0.1780	0.3390	0.2580	0.1659	0.8676
4	0.2930	0.3000	0.2960	0.2000	0.1780	0.4340	0.4330	0.2785	0.8676
5	0.3200	0.2720	0.3850	0.2450	0.1620	0.3890	0.3280	0.2110	1.0718

Table 4.13 HBW Person Trip Attraction Rates – Income Group 5

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	ED-1	ED-2A	ED-2B
1	0.2930	0.7400	0.3240	0.1900	0.1790	0.3640	0.3270	0.2103	0.8151
2	0.2040	0.4010	0.0720	0.1870	0.3180	0.4010	0.3470	0.2232	0.8121
3	0.1800	0.6020	0.0760	0.3380	0.2590	0.3380	0.1270	0.0817	0.8676
4	0.2990	0.4610	0.0570	0.4510	0.2050	0.3670	0.2490	0.1601	0.8676
5	0.2140	0.2740	0.0920	0.1750	0.3290	0.1760	0.3540	0.2277	1.0718

Table 4.14 Home Based Non-Work to Education-1 Person Trip Attraction Rates (Grade 12 and under)

Area Type	ED-1
1	7.529
2	3.903
3	7.735
4	7.978
5	5.989

Table 4.15 Home Based Non-Work to Education-1 on School Bus Person Trip Attraction Rates (Grade 12 and under)

Area Type	ED-1
1	32.701
2	46.391
3	26.264
4	41.872
5	23.400

Table 4.16 Home-Based Non-Work to Retail Person Trip Attraction Rates

Area Type	Retail
1	3.866
2	3.237
3	4.732
4	3.219
5	3.200

Table 4.17 Home Based Non-Work Other Person Trip Attraction Rates

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	Enroll A	Enroll B
1	0.4440	0.0000	1.4320	0.5060	2.5930	4.1080	0.5603	0.5557
2	0.4440	0.0000	1.7340	0.4770	1.0890	1.9290	0.5603	0.5557
3	0.4440	0.0000	1.2160	0.4420	1.0890	5.9660	0.5603	0.5557
4	0.4440	0.0000	1.8070	1.1910	3.7830	3.4580	0.5603	0.5557
5	0.4440	0.0000	1.8570	0.5960	6.3370	3.4980	0.5603	0.5557

Table 4.18 Non-Home-Based Work-Based Person Trip Attraction Rates

Area Type	Households	Retail	Office	Industrial	Govt	Medical	ED-1	ED-2A	ED-2B
1	0.0581	0.5570	0.6565	0.3618	0.2206	0.4249	0.2890	0.1951	0.1255
2	0.0923	0.3214	0.7951	0.4210	0.1740	0.2138	0.2236	0.1989	0.1279
3	0.0891	1.3949	0.4076	0.1810	0.1855	0.4961	0.2651	0.2349	0.1511
4	0.0886	0.3000	0.5441	0.3420	0.3939	0.3745	0.3857	0.2361	0.1519
5	0.0880	0.3979	0.3326	0.4274	0.2625	0.4010	0.4511	0.2585	0.1663

Table 4.19 Non-Home-Based Other Person Trip Attraction Rates

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	ED-1	ED-2A	ED-2B
1	0.2309	2.7190	0.1095	0.1212	0.5024	0.5111	0.7640	0.4029	0.2592
2	0.1967	1.6456	0.2009	0.1160	0.2930	0.2202	0.5664	0.3991	0.2567
3	0.1999	3.9691	0.2274	0.2220	0.2815	0.6259	0.7879	0.3631	0.2335
4	0.2004	0.9650	0.3319	0.4640	0.6841	0.4665	1.2003	0.3619	0.2327
5	0.2010	1.0701	0.4334	0.4456	0.4375	0.4490	1.2129	0.3395	0.2183

Table 4.20 Taxi Vehicle Trip Attraction Rates

Area Type	Households	Retail	Office	Industrial	Govt	Medical	ED-1	ED-2A	ED-2B
1	0.0063	0.0342	0.0063	0.0038	0.0342	0.0228	0.0228	0.0038	0.0024
2	0.0063	0.0342	0.0063	0.0038	0.0342	0.0228	0.0228	0.0038	0.0024
3	0.0063	0.0342	0.0063	0.0038	0.0342	0.0228	0.0228	0.0038	0.0024
4	0.0048	0.0257	0.0048	0.0029	0.0257	0.0171	0.0171	0.0029	0.0018
5	0.0032	0.0171	0.0032	0.0019	0.0171	0.0114	0.0114	0.0019	0.0012

Table 4.21 External-Local Auto Vehicle Trip Attraction Rates

Area Type	Households	Retail	Office	Industrial	Govt.	Medical	ED-1	ED-2A	ED-2B
1	0.0139	0.0948	0.0692	0.0324	0.0614	0.0707	0.1333	0.1180	0.0759
2	0.0154	0.0985	0.0731	0.0316	0.0621	0.0687	0.1266	0.1151	0.0740
3	0.0236	0.1909	0.0769	0.0236	0.0701	0.0723	0.1449	0.1342	0.0863
4	0.0239	0.2355	0.0786	0.0240	0.0784	0.0741	0.1507	0.1381	0.0888
5	0.0235	0.2090	0.0607	0.0199	0.0682	0.0616	0.1320	0.1227	0.0789

4.2.3. Special Generators

The 2016 Track-1 models treat the two commercial airports as special generators. The number of trip ends at the airports was estimated based on surveys done at the airports in 2010/11. This data collection involved intercept surveys of employees of and visitors to the airports at various activity locations (i.e., terminals, rental car sites, cargo sites). The trips captured through these surveys was expanded to a total person count that was derived from vehicle counts made at all vehicle entry/exit locations of the airports.

4.2.4 Non-resident travel

Due to the high concentration of hotels, motels, and seasonal housing on Galveston Island, the Bolivar Pennisula and the coastal portion of Brazoria County, generation of non-resident trips was also performed. An average Galveston Island hotel occupancy rate was applied against the number of hotel rooms on 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 was applied to estimated seasonal housing on Galveston Island, the Bolivar Pennisula and the coastal portion of Brazoria County to estimate occupied seasonal housing units. This estimate of seasonal housing units was then multiplied by a NHB trip rate yielded seasonal housing non-resident NHB trips. As part of the 2016 Track-1 model update, the estimate of seasonal housing units was updated using 2010

Census data and the estimate of hotel rooms updated using information from the Galveston Visitors Bureau.

4.2.4. Truck travel

Year 2016 truck travel was based on procedures developed by H-GAC using the Cube Cargo modeling software platform. Cube Cargo is a model of demand for the transport of goods and services. As with models used for individual travel, Cube Cargo contains the traditional steps of trip generation, trip distribution, and modal split. In models of individual travel, the results of the modal split will be in people or vehicles. In the freight modelling context used in Cube Cargo, the results of mode split is a matrix in tons. Additional modelling is required to determine how those tons are allocated to vehicles.

Whereas four-step travel demand models treat the generation and distribution of different trip types (e.g. Home-Based Work, Home-Based Other) separately, the Cube Cargo model similarly does so but in terms of commodities and by consumption and production. The model then distributes and matches up consumptions with productions and determines if the goods get there by truck or rail based on user supplied inputs.

In addition to the freight model component, Cube Cargo also produces estimates for other generators of regional truck traffic, in particularly light trucks, in terms of service vehicles – which are those that provide for deliveries, as well as other service, to household and employment centers. Therefore, the year 2016 truck demand was segmented by cargo and service trucks for both internal and external truck travel.

4.2.5. External Travel

External trip demand is separated into auto and truck demand and the total demand is controlled to match the counted station volumes at each external station.

External-local ruck demand comes from outside the four-step demand model process through H-GAC's Cube Cargo model, the external-local truck volume from these counts is set aside in lieu of the volumes from the Cargo model.

The counted auto volumes at each external station are separated into local and through auto volumes based on the local and through split from the most recent (1995) external travel survey. The local auto volumes are the basis for the external-local auto productions and each station. The through auto and truck volumes are used as inputs to a FRATAR process that grows the base 1995 external-through auto trip table to a 2016 external-through auto trip table.

4.2.6. Trip Generation Results

Table 4.22 summarizes the 2016 trip generation estimates by trip purpose.

Table 4.22 Regional Trip Estimates by Purpose

PURPOSE	2016 TRIPS		% OF TOTAL
HBW Income 1	195,549		
HBW Income 2	393,523		
HBW Income 3	646,824		
HBW Income 4	726,349		
HBW Income 5	1,120,524		
HBW Total		3,082,769	12.03%
HBNW-Educational 1 by School Bus	59,1921		
HBNW-Educational 1 by Other	3,440,872		
HBNW Retail	4,368,570		
HBNW-Airport	84,207		
HBNW-Other	4,644,905		
HBNW - Total		13,130,475	51.25%
NHB-Work-Based	2,103,515		
NHB-Other	5,833,026		
NHB Total		7,936,541	30.97%
NON-RESIDENT	297,720		1.16%
EXTERNAL AUTO	247,573		0.97%
TAXI	61,113		0.24%
CARGO TRUCK (including external)	116,687		
SERVICE TRUCK	7,49870		
Total Truck		866,557	3.38%
Regional Total		25,62,2748	100.00%

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 of potential zonal destinations. The trip distribution of all HBW trips uses composite travel time as the measure of zonal impedance, while all other trip purposes make use of the more typical highway travel time. The composite time used in the HBW distribution is a combination of the AM peak period traffic assignment results and peak transit travel time. The zonal impedance is iteratively updated over the course of multiple applications of the trip distribution, mode choice and traffic assignment portions of the model set.

4.3.1. Zonal Impedance

Two measures of zonal impendance are used in the 2016 Track-1 model trip distribution process. For all trip purposes other than home-based work (HBW), zonal impedance is based on mid-day period highway travel time. For the five HBW trip purposes, the measure of zonal separation or impedance is a combination of AM peak period highway travel time and peak period transit travel time. This combined or "composite" travel time provides sensitivity in zonal attractiveness to changes in both highway and transit levels-of-service. The formulation of the composite time varies by income group to acknowledge the variation in sensitivity to transit service changes among households.

$$Composite\ Time = \frac{1}{\frac{1}{HT}+\frac{X}{TT}}$$

Where: HT = highway travel time (minutes)
TT = transit travel time (minutes)
X = weighting factor for each income group

An example application of the composite time formulation with example travel times is presented in Table 4.23. The weighting factors used in the feedback procedure represent the regional mode shares for each of the 5 HBW trip purposes.

Table 4.23 Composite Time Impedeance Example

Income Group	Weighting Factor	Highway Time	Transit Time	Composite Time	Decrease from Highway Time
1	0.056	25	30	23.9	4.5%
2	0.051	25	30	24.0	4.1%
3	0.024	25	30	24.5	2.0%
4	0.023	25	30	24.5	1.9%
5	0.033	25	30	24.3	0.8%

Both the AM peak period and mid-day period highway travel times used in the development of zonal impedances are derived from H-GAC's post-assignment speed estimation model. The post-assignment speed model uses volume-to-capacity (V/C) ratios from AM peak period and mid-day period assignments to estimate link-level travel times.

As part of model feedback process, the AM peak period and mid-day period impedances are iteratively updated based on new traffic assignment travel times.

4.3.2. Trip Table Development

The Disaggregate Trip Distribution Model, or Atomistic Model, a gravity-analogy-based model, is used for trip distribution modeling in the Houston-Galveston region. This model is used to produce 13 trip tables for the HBW-INC1, HBW-INC2, HBW-INC3, HBW-INC4, HBW-INC5, HBNW-ED1, HBNW-ED1-SB, HBNW-RETAIL, HBNW-OTHER, HBNW-AIR, NHB-WB, NHB-

NW, Taxi, and External-local-Auto purposes. The distribution of HBNW-AIR is performed 'backwards' from the other purposes in that the trip ends at the airport are treated as productions and the trips ends at the home end are treated as attractions. Attractions for the external-local trip purposes as well as the origins and destinations for the external-through purposes are based upon patterns derived from 1995 H-GAC External survey and grown to match year 2016 traffic volumes at the external stations. The Atomistic model is a gravity-analogy trip distribution model which is enhanced in its treatment of intrazonal tirps. 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:

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

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 and the zonal impedances Track-1 trip distribution model also requires:

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

The 2016 Track-1 model update included calibration of new F-factors. Using F-factor calibration options of the ATOM software, F-factors were created using trip-length frequency distributions from the survey expanded trip tables using the same measure of impedance that is used in the distribution of trips. In other words, the AM peak period composite impedance-based trip length frequency of survey HBW trips and mid-day period highway impedance-based trip length frequency of survey trips for all other internal purposes were used in the development of 2016 Track-1 model F-factors. The F-factors were adjusted until the resulting trip length reasonably matched the survey observed trip length as shown in Table 4.24. The calibrated F-factors by purpose are presented in Appendix C.

Trip distribution bias 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 retained and updated in the 2016 Track-1 model set to improve trip flows, particularly on non-work flows.

Table 4.24 Survey Observed and Model Resulting Average Trip Length by Purpose

	2016 AVERAGE TRIP LENGTH (network minutes)	
PURPOSE	**SURVEY OBSERVED**	**MODELED**
HBW Income Group 1	19.0	18.4
HBW Income Group 2	20.8	19.9
HBW Income Group 3	20.8	19.8
HBW Income Group 4	22.4	21.2
HBW Income Group 5	22.9	21.9
HBNW-ED1	8.7	8.7
HBNW-Retail	11.0	10.9
HBNW-Airport	35.4	34.1
HBNW-Other	13.0	12.4
NHB Work-Based	12.9	11.9
NHB-Other	10.8	10.3
Taxi	12.9	12.2
External-Local Auto	40.4	37.1

Source: H-GAC Model Application Results

Bias factors were also updated for the 2016 Track-1 model in part based on ACS flow data. The combined HBW modeled trip table was compared to the ACS data at a district level. Revisions of HBW bias factors were made to encourage more intra-county HBW travel and to enhance work flows to various regional employment centers.

The 2016 Track-1 model also used bias-factors in the distribution of HBNW-ED1 trips to discourage trips from crossing the approximate public school district boundaries. Slight modifications of HBNW-Retail and HBNW-Other and NHB-Other bias factors were made to encourage travel among suburban communities in Fort Bend and Brazoria counties to activities just across the Harris County boundary.

4.4. Mode Choice

4.4.1. Auto Operating Costs

Auto operating cost is an input to the mode choice model and is used by the model in establishing the costs for the auto-related choice paths available in the roadway network. 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 upon 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.

4.4.2. Transit Fares

Year 2016 transit fares were used as transit fare inputs to 2016 model validation. Table 4.25 presents the year 2016 transit fares.

Table 4.25 Year 2016 Transit Fares

Local Bus	1.11
Light Rail	1.11
Express Bus	1.11
Commuter Bus	
0-10 miles	1.78
11-15 miles	2.89
16-20 miles	3.34
>20 miles	4.01

Source: Houston Metro

4.4.3. Parking Costs

Table 4.26 summarizes the estimated parking costs used at the four major activity centers, including the Houston CBD, Greenway Plaza, Texas Medical Center, and Uptown/Galleria. This variable is defined as an estimate of the actual (or average) out-of-pocket cost paid on a daily basis per vehicle.

Table 4.26 Parking Costs for Activity Centers

Activity Center	Range of Costs	Average Cost
Houston CBD	$0.29-$6.73	$2.21
Greenway Plaza	$0.03-$1.30	$0.64
Texas Medical Center	$0.47$2.42	$1.65
Uptown/Galleria	$0.07-$0.17	$0.10
UTMB Galveston	$1.10	$1.10

Source: Houston METRO

4.4.4. Model Choice Model

The Houston mode choice model is a nested logit model that addressed four separate auto and five different transit modes segmented among three different mode of access:

- Drive alone
- Two person
- Three person
- Four-plus person
- Transit-walk access Local Bus
- Transit-walk access Commuter Bus
- Transit-walk access Express Bus
- Transit-walk access Light Rail
- Transit-walk access Commuter Rail
- Transit-park-and-ride access Local Bus
- Transit-park-and-ride access Commuter Bus
- Transit-park-and-ride access Express Bus
- Transit-park-and-ride access Light Rail
- Transit-park-and-ride access Commuter Rail
- Transit-kiss-and-ride access Local Bus
- Transit-kiss-and-ride access Commuter Bus
- Transit-kiss-and-ride access Express Bus
- Transit-kiss-and-ride access Light Rail
- Transit-kiss-and-ride access Commuter Rail

The model was originally estimated based upon 1995 Home-Interview and On-Board Transit Rider Survey data and was re-calibrated locally observed travel values devired from the 2008/9 household suvery and 2017 transit origin-destination survey. Table 4.27 presents the target and model shares by mode.

Table 4.27 Year 2016 Mode Choice Modal Targets and Modeled Shares

Mode	Target Percentage	Modeled Percentage
HBW		
Drive Alone Auto	85.27%	85.53%
2 Person Auto	8.42%	8.09%
3+ Person Auto	2.18%	2.05%
Transit Walk Access	2.11%	2.39%
Transit Park-and-ride Access	1.61%	1.73%
Transit Kiss-and-ride Access	0.38%	0.21%
HBNW		
Drive Alone Auto	54.97%	54.77%
2 Person Auto	28.13%	28.09%
3+ Person Auto	16.43%	16.62%
Transit Walk Access	0.38%	0.44%
Transit Park-and-ride Access	0.05%	0.04%
Transit Kiss-and-ride Access	0.04%	0.04%
NHB		
Drive Alone Auto	58.25%	58.14%
2 Person Auto	26.43%	26.41%
3+ Person Auto	14.99%	15.11%
Transit Walk Access	0.24%	0.25%
Transit Park-and-ride Access	0.06%	0.06%
Transit Kiss-and-ride Access	0.03%	0.03%

A graphical depiction of the nested logit model structure for each trip purpose is displayed in Figure 4-1. The complete set of coefficient values for the Home-Based Work nested logit model is shown in Table 4.28. The Home-Based Non-Work and Non-Home Based values are presented in Tables 4.29 and 4.30, respectively.

Figure 4-1 H-GAC Regional Mode Choice Model – Nested Logit Model Structure

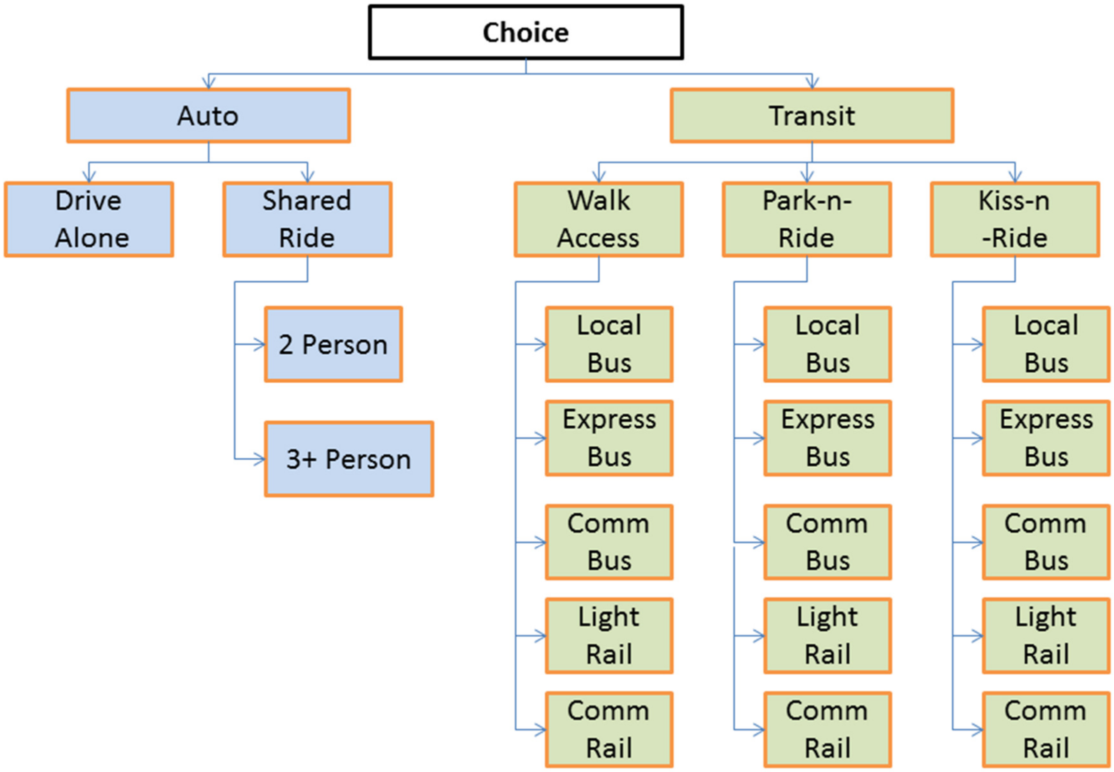


Table 4.28 Coefficient Values for Home-Based Work Mode Choice Model

Variable	Multinomial Value	Mode
In-vehicle time	-0.022026	All modes
1 Wait less than 4.5 minutes	-0.022026	Transit
1 Wait over 4.5 minutes	-0.022026	Transit
Walk	-0.056796	Transit
Transfer time	-0.022026	Transit
Number of transfers	-0.088120	Transit
Transit fare (all)	-0.006144	Transit
Drive to transit time	-0.033045	Transit
Parking cost (all)	-0.015364	Highway
Auto Operating Cost (all)	-0.006145	Highway & Transit (Drive)
HOV/Toll Time Savings	+0.01542	Highway
Residential Density Indicator	+0.13947	Transit (Walk)
CBD	-0.44240	Transit
Texas Medical Center	+1.27232	Transit
Uptown	-0.62705	Transit
Greenway	-0.59310	Transit
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 2/3+	0.60000	Highway

Table 4.29 Coefficient Values for Home-Based Non-Work Mode Choice Model

Variable	Multinomial Value	Mode
In-vehicle time	-0.01727	All modes
1st Wait time	-0.01727	Transit
Walk	-0.03454	Transit
Transfer time	-0.01727	Transit
Transit fare (all)	-0.00592	Transit
Parking cost (all)	-0.01479	Highway
Auto Operating Cost (all)	-0.00592	Highway & Transit (Drive)
HOV/Toll Time savings	+0.01270	Highway
Household Siz 2 Person 3 Person	 +0.07427 +0.44870	Highway
Residential Density Indicator	+0.07767	Transit (Walk)
CBD	-3.1971	Transit
Texas Medical Center	-0.3714	Transit
Uptown	-1.5919	Transit
Greenway	-2.6730	Transit
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 2/3+	0.60000	Highway

Table 4.30 Coefficient Values for Non-Home Based Mode Choice Model

Variable	Multinomial Value	Mode
In-vehicle time	-0.02370	All modes
1st Wait time	-0.02370	Transit
Walk	-0.04740	Transit
Transfer time	-0.02370	Transit
Transit fare (all)	-0.00562	Transit
Parking cost (all)	-0.01404	Highway
Auto Operating Cost (all)	-0.00562	Highway & Transit (Drive)
HOV/Toll time savings	+0.01660	Highway
CBD	-2.29877	Transit
Texas Medical Center	-0.03953	Transit
Uptown	-0.52611	Transit
Greenway	-0.56524	Transit
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 2/3+	0.60000	Highway

4.4.5. Calibration of Modal Bias Constants

A key element in the overall mode choice model development process is to insure that the resulting models are 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. Applying the models at the aggregate level utilizes the full set of network based travel times and costs, zonal level socio-economic 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 4.31 - 4.33 summarize the final set of bias constant values for each trip purpose.

Table 4.31 Mode Bias Constants – Home Based Work Mode Choice Model

Constant	Income Level				
	1	2	3	4	5
Drive Alone	0	0	0	0	0
2 Person	-1.89132	-1.96642	-2.16756	-2.48749	-2.68329
3+ Person	-2.76117	-2.89996	-3.0756	-3.48378	-3.78049
Walk to Local Bus	-1.01501	-0.48474	-1.30204	-3.14622	-6.59803
Walk to Express Bus	0.366829	0.273947	-0.7715	-2.33897	-3.12977
Walk to Commuter Bus	-1.48557	-1.03662	-2.1527	-3.7757	-7.28177
Walk to Light Rail	0.726531	1.846138	1.489438	-1.23029	-2.45531
Walk to Commuter Rail	-0.726531	1.846138	1.489438	-1.23029	-2.45531
PNR to Local Bus	-3.82575	-3.4036	-3.56679	-4.56405	-6.18984
PNR to Express Bus	-1.50781	-2.28376	-2.53382	-3.15845	-4.11039
PNR to Commuter Bus	-2.50498	-1.90818	-1.16038	-1.28328	-1.25411
PNR to Light Rail	-0.54329	-0.37801	0.325563	-0.34632	-0.72723
PNR to Commuter Rail	-0.54329	-3.7801	0.325563	-0.34632	-0.72723
KNR to Local Bus	-3.15966	-2.65625	-3.45813	-4.52262	-6.21323
KNR to Express Bus	-2.87772	-2.48415	-3.78735	-4.49273	-5.50057
KNR to Commuter Bus	-3.01302	-2.77199	-2.69286	-3.15941	-3.53282
KNR to Light Rail	-1.14132	-1.33299	-1.17354	-2.04465	-2.59656
KNR to Commuter Rail	-1.14132	-1.33299	-1.17354	-2.04465	-2.59656
Walk to Premium Transit	-0.01007	0.15746	-0.57345	-2.23815	-4.95006

Table 4.32 Mode Bias Constants – Home Based Non-Work Mode Choice Model

Constant	Income Level				
	1	2	3	4	5
Drive Alone	0	0	0	0	0
2 Person	-0.39753	-0.49344	-0.50838	-0.55865	-0.6061
3+ Person	-1.59726	-1.74863	-1.79133	-1.88661	-1.97844
Walk to Local Bus	-2.13935	-1.86189	-2.37739	-3.68905	-6.10221
Walk to Express Bus	0.974222	0.614064	0.165461	-0.66364	-3.27668
Walk to Commuter Bus	0.932278	0.657009	-0.56298	-1.24555	-0.96044
Walk to Light Rail	-0.94648	-0.98227	-2.31307	-3.35917	-5.92053
Walk to Commuter Rail	-0.94648	-0.98227	-2.31307	-3.35917	-5.92053
PNR to Local Bus	-5.90289	-5.9542	-6.38576	-7.19069	-8.22399
PNR to Express Bus	-693.744	-666.148	-633.616	-582.024	-562.028
PNR to Commuter Bus	-2.7403	-2.71685	-2.79933	-3.06465	-3.21696
PNR to Light Rail	-2.77065	-2.73813	-2.694661	-3.26538	-3.60371
PNR to Commuter Rail	-2.77065	-2.73813	-2.694661	-3.26538	-3.06371
KNR to Local Bus	-4.27047	-4.47943	-5.09581	-6.07881	-7.78648
KNR to Express Bus	-3.00406	-4.02952	-3.81938	-5.6491	-563.172
KNR to Commuter Bus	-3.18578	-3.42514	-3.57862	-5.02998	-3.74083
KNR to Light Rail	-2.88672	-2.82792	-3.38556	-4.12959	-4.68071
KNR to Commuter Rail	-2.88672	-2.82792	-3.38556	-4.12959.	-4.68071
Walk to Premium Transit	-1.23281	-1.20423	-2.03406	-3.33192	-5.904

Table 4.33 Mode Bias Constants – Non-Home Based Mode Choice Model

Constant	Value
Drive Alone	0
2 Person	0.42269
3+ Person	0.66616
Walk to Local Bus	-3.21831
Walk to Express Bus	-1.3864
Walk to Commuter Bus	-0.75125
Walk to Light Rail	-0.98556
Walk to Commuter Rail	-0.98556
PNR to Local Bus	-8.57898
PNR to Express Bus	-21.7333
PNR to Commuter Bus	-4.41897
PNR to Light Rail	-4.76787
PNR to Commuter Rail	-4.76787
KNR to Local Bus	-6.5983
KNR to Express Bus	-4.69551
KNR to Commuter Bus	-4.59863
KNR to Light Rail	-4.59863
Walk to Premium Transit	-2.32128

The product of the mode choice models of the 2016 Track-1 model are daily auto vehicle and transit trips segmented by trip purpose, mode and income. The auto trip tables are portrayed in Table 4.34.

Table 4.34 Mode Choice Auto Trip Tables

PURPOSE	MODE	INCOME GROUP				
		1	2	3	4	5
HBW	Drive-Alone	✓	✓	✓	✓	✓
	2-person	✓	✓	✓	✓	✓
	3+-person	✓	✓	✓	✓	✓
HBNW	Drive-Alone	✓	✓	✓	✓	✓
	2-person	✓	✓	✓	✓	✓
	3+-person	✓	✓	✓	✓	✓
NHB	Drive-Alone	✓	✓	✓	✓	✓
	2-person	✓	✓	✓	✓	✓
	3+-person	✓	✓	✓	✓	✓

4.5. Time-of-Day Models

Following mode choice modeling, the 2016 Track-1 models converted the daily post-mode choice trip tables, the external auto trip tables and the truck tables from the Cargo model to time-of-day trip tables. The process for developing the time-of-day trip tables is the same as in the 2009 Track-1 models; the use of diurnal trip table factors. The diurnal trip table factors converted the daily auto vehicle trip tables from mode choice to time-of-day trip tables and impart of the appropriate directionality to the time-of-day demand. The diurnal trip tables factors that converted the post-mode choice vehicle trips by trip purpose were updated with data from the 2008/09 household survey. The diurnal trip table factors used to factor the daily truck trip tables from Cargo were developed from TxDOT time-of-day vehicle classification counts while the diurnal trip table factors used to convert the daily external auto trips to time-of-day trip tables were created using the H-GAC 2011 external traffic counts.

Using the diurnal trip table factors, the daily demand was factored to represent demand for the following five time periods:

- AM peak period (3 hours)
- Mid-day period (6 hours)
- PM peak period (4 hours)
- Overnight period (11 hours)

During the iterative feedback applications of the 2016 Track-1 models, only AM peak period and mid-day period trip table factoring were performed. These two time periods were the basis for the iterative cycle of trip-distribution, mode choice, traffic assignment and convergence assessment. Upon achievement of convergence, the time-of-day trip tables were developed for the other three times-of-day.

4.6. Trip Assignment

4.6.1. Traffic Trip Assignment Methodology

The AM peak and mid-day period auto trip tables from mode choice were prepared for assignment to the AM peak period and mid-day period highway networks, respectively as part of the iterative application of the assignment model during congestion feedback. Following achievement of convergence , the PM peak, evening and overnight period trip tables were assigned to the corresponding time-of-day network.

The 2016 Track-1 model uses a multimodal multiclass generalized cost (G/C) assignment methodology to facilitate development of toll demand. As mentioned in section 3.1.3 of this report, toll costs are coded onto the links which contain the toll plazas/booths. The toll costs were converted to time using a values-of-time. The values of time vary by trip purpose, mode, and income group. To accommodate a 3-tiered value-of-time scheme (low, medium and high income) among certain trip purpose/mode combinations, the 5 income group segmentation present in the models through mode-choice is collapsed to three groups for all trip purpose/mode combinations except for work-related drive alone demand. A single value-of-time is used for external auto demand while the truck demand was maintained in the cargo and service truck categories with their own values-of-time. Table 4.35 presents the values of time used in the G/C assignment.

Table 4.35 Assignment Values-of-Time

PURPOSE	INCOME	MODE	VOT ($/hr.)
Work Related	1	Drive Alone	$9.60
Work Related	2	Drive Alone	$15.04
Work Related	3	Drive Alone	$20.48
Work Related	4	Drive Alone	$27.52
Work Related	5	Drive Alone	$37.12
Non-Work	Low (1-2)	Drive Alone	$7.03
Non-Work	Medium(3)	Drive Alone	$13.44
Non-Work	High (4-5)	Drive Alone	$23.65
Work Related	Low (1-2)	2 Person	$21.56
Work Related	Medium(3)	2 Person	$35.84
Work Related	High (4-5)	2 Person	$56.56
Non-Work	Low (1-2)	2 Person	$12.30
Non-Work	Medium(3)	2 Person	$23.52
Non-Work	High (4-5)	2 Person	$41.39
Work Related	Low (1-2)	3+ Person	$30.80
Work Related	Medium(3)	3+ Person	$51.20
Work Related	High (4-5)	3+ Person	$80.80
Non-Work	Low (1-2)	3+ Person	$17.57
Non-Work	Medium(3)	3+ Person	$33.60
Non-Work	High (4-5)	3+ Person	$59.12
Service Vehicle	n/a	n/a	$40.00
Cargo Truck	n/a	n/a	$64.00
Other (External, Taxi)	n/a	n/a	$18.94

In addition to the aggregation of five income groups to three among worked-related shared ride and all non-work-related demand, NHB-WB demand was combined with HBW demand by mode and by income group. The traffic assignment, therefore, involved the simultaneous assignment of 23 different classes of demand as listed below.

- Classes 1-5: Work-related drive-alone income groups 1-5;
- Classes 6-8: Non-work drive alone income groups low (1-2), medium (3), high (4-5);
- Classes 9-11: Work-related shared ride 2 person income groups low (1-2), medium (3), high (4-5);
- Classes 12-14: Non-work SR shared ride 2 person income groups low (1-2), medium (3), high (4-5);
- Classes 15-17: Work related shared ride 3+ person income groups low (1-2), medium (3), high (4-5);
- Classes 18-20: Non-work shared ride 3+ person income groups low (1-2), medium (3), high (4-5);
- Class 21: Service truck;
- Class 22: Cargo truck;

- Class 23: External.

The generalized cost function used in the time-of-day traffic assignment was as follows:

$$G_{n+1} = T_{n+1} + F_l/VOT_{p,o}$$

Where G_{n+1} = generalized time cost for iteratin n+1
T_{n+1}= link travel time for iteration n + 1
F_l = link toll cost
$VOT_{p.o}$= value of time for each trip purpose (work-related, non-work related) and occupancy and income group

Link travel time is based on the BRP volume-delay function (VDF) which was represented by

$$T_{n+1} = \left(1 + \alpha\left(\frac{v}{c}\right)^{\beta}\right) \times T_0$$

Where: T_0 = free-flow link travel time
T_{n+1}= link travel time for iteration n + 1
v = user equilibrium link volume from iterations 1 to n
c = link capacity
α, β= coefficients

The 2016 Track-1 model assignment validation included adjustment of the VDF parameters to improve performance of the assignment model. The 2016 Track-1 assignment model uses two sets of VDF parameters, as shown in Table 4.36, to reflect the response to congestion in the assignment.

Table 4.36 Assignment VDF Parameters

Facility Type	α	β
Freeway/Tollways/Managed Lanes	0.3	5.5
Other	0.4	5.5

The 2016 Track-1 assignment used the bi-conjugate Frank Wolfe (BCFW) user equilibrium algorithm due to its faster computation time and ability to achieve tighter convergence. The algorithm is coded into a CUBE traffic assignment script which also makes use of five convergence criteria plus a sixth criteria involving a count on the number of iterations. The assignment ends either when all five criteria are satisfied or when the maximum number of iterations is reached. Table 4.37 lists the six assignment criteria and stopping criteria associated with each.

Table 4.37 Assignment Stopping Criteria

CRITERIA	STOPPING VALUE
Gap	0.0001
Relative Gap	0.0001
Average Absolute Difference (AAD)	0.01
Relative Average Absolute Difference (RAAD)	0.0001
RMSE	0.1
Iterations	40

4.7. Post-Assignment Speed Estimation

Time-of-day highway speeds are developed from a post-assignment operational speed model that contains procedures adapted from the *Highway Capacity Manual* (HCM) methodology. The procedures used in this model employ different methodologies to estimate freeway and non-freeway link speeds are estimated. Freeway speed is estimated as 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 (based on link distances), 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.

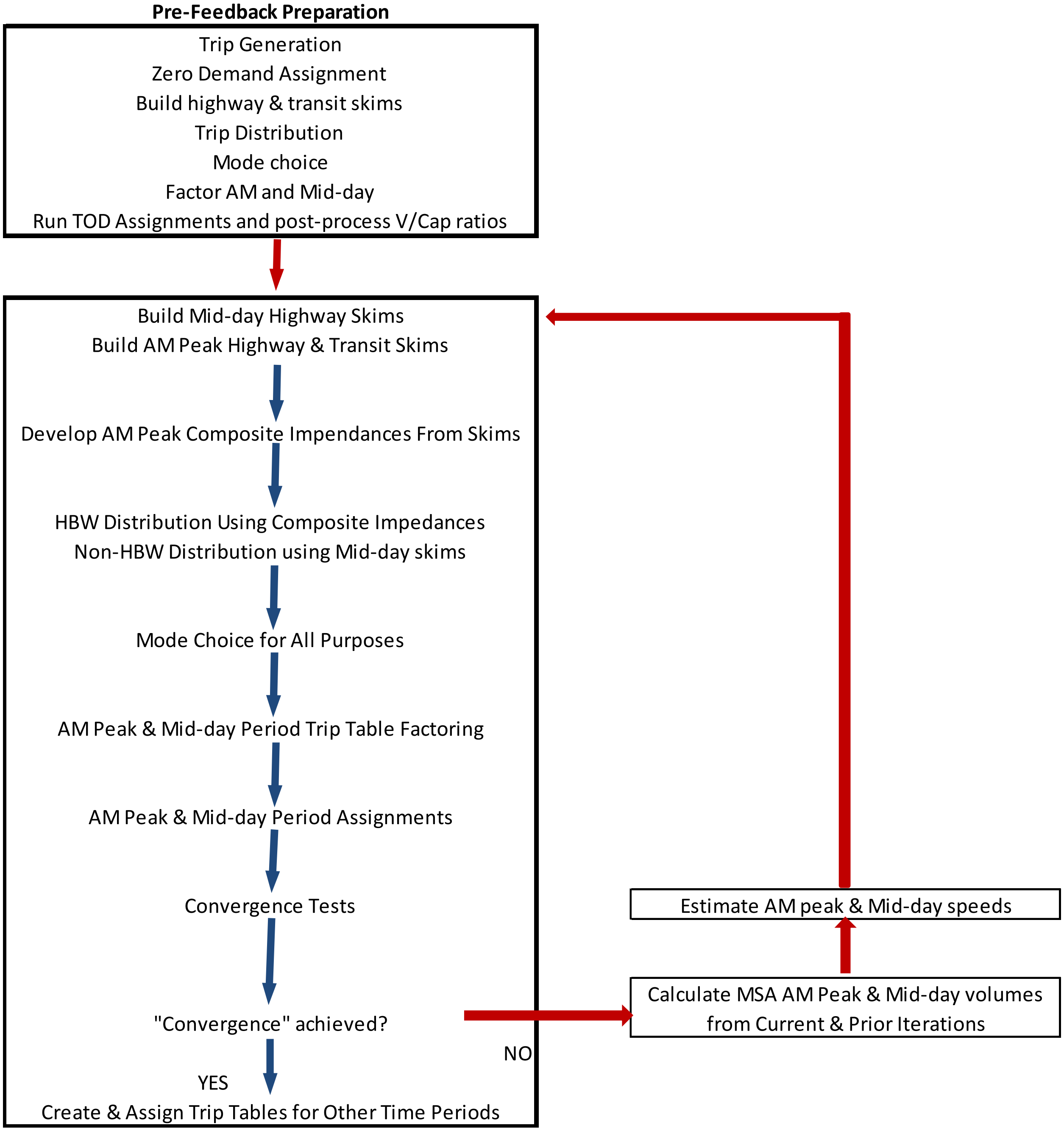
The V/C ratios that served as input to the speed model are output from the time-of-day assignment. Since capacities used during the equilibrium assignment represent LOS E, the resulting link's V/C ratio were applied to the speed model to develop a time-of-day speed. In other words, the traffic assignment results are post-processed to compute a estimated congested speed for the time period of the assignment based on the assigned V/C ratio.

4.8. Iterative Congestion Feedback

As previously mentioned, the 2016 Track-1 models used two measures of zonal impedance in the distribution of trip ends. These impedance measures were iteratively updated following traffic assignment and fed-back to the trip distribution models for repititave applications of the trip distribution-mode choice and traffic assignment steps.

For HBW trips, a composite measure of AM peak period congestion was fed-back. The composite measure is developed by combining highway travel times based upon post-processed speeds from an AM peak period traffic assignment and transit travel time based on peak transit service levels. The technique used to feedback congested travel times to the non-work trip distribution process used post-procesed speeds from a mid-day period traffic assignment Figure 4-2 presents a diagram of the model application process with inclusion of the feedback component.

Figure 4-2 Feedback Process



Both the HBW and non-work feedback used the Method of Successive Average (MSA) technique to calculate values of the traffic volumes to be used to calculate the travel times to be fed-back to trip distribution. In the case of HBW feedback, MSA-based AM peak period link volumes were calculated and input to the post-assignment speed estimation model to estimate AM peak period times for the composite time feedback. For non-work trip purpose feedback, MSA mid-day period assignment link volumes were calculated and input to the post-assignment speed estimation model to estimate mid-day period travel times.

4.8.1. Measurement of Convergence

The 2016 Track-1 model iterative feedback process relied on several forms of measurement of equilibrium or stability and more than one procedure for quantifying change between iterations. These measures dealt with changes among iterations of the model set at the link, trip table and travel time matrix levels.

The trip table-based measures of stability were based on the HBW drive alone and the combined HBNW post-mode choice modal trip tables.

Zonal impedance matrices were also part of the convergence process. As two different measures of zonal impedance were used in feedback to trip distribution, the convergence process measures stability of two different zonal impedances. As the HBW trip purpose was segmented by income to facilitate the use of composite impedance, one of five possible measures of AM peak composite impedance were used for convergence measurement. The other impedance-based convergence measure was the mid-day zonal impedance.

The statistical measures of stability among these two matrix based measures used in the 2016 Track-1 models were root mean square change (RMSC) and a statistic named total misplaced flow (TMF). TMF measures the sum of the absolute values of cell differences divided by the sum of all cell values.

The 2016 Track-1 models also included two measures of link-level stability for convergence evaluation. The link-level measures of stability were the percent of links for which the change in link assigned mid-day period volume between iterations is greater than five percent and the GEH statistic. The GEH statistic is a formulation used to compare two sets of traffic volumes, but is not a pure statistical test. The formulation of the statistic is:

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}}$$

Where M is current iteration volume
and C is the previous iteration volume

A second link-based volume change measure was the percent of links for which the change in link assigned mid-day period volume between iterations is greater than five percent.

In order for convergence or “stability” to be achieved both criteria from among each criteria group (link change, trip table change, skim table change) must be met. In addition to the convergence measures, the feedback process stopping criteria also included a count on the number of iterations. This criteria is included as a practical need to keep model run times from becoming a hindrance to efficient use of the models. The maximum number of iterations was been set to 6 iterations. Convergence is declared if the statistics of any three of the measures (i.e., change in link volumes, % TMF of trip tables or % RMSC of skims) achieve the target value.

0
For the 2016 Track-1 model validation, the link change criteria were consistently satisfied before other criteria, usually after three iterations of feedback. Table 4.39 presents the convergence measurement criteria, the statistic values that represent convergence and convergence statistic values achieved in the 2016 Track-1 model validation. The 2016 Track-1 model achieved these convergence results after three iterations.

Table 4.38 Convergence Measure and Associated "Convergence" Values

Measure	Value of Convergence	Model Results
% Links Over 5% Change in AM Peak volume	5.0%	1.4%
%Links Over 5% GEH – AM Peak volume	3.0%	0.4%
% Links Over 5% Change in mid-day volume	5.0%	2.7%
% Links Over 5% GEH – mid-day volume	3.0%	0.2%
% TMF – HBW Drive-Alone Trip Table	2.0%	4.2%
% TMF – HBNW Drive-Alone Trip Table	1.0%	0.0%
%RMSC – HBW Income Group 1 Composite Skim	0.10%	0.15%
% RMSC mid-day 3+ Person Pay Skim	0.10%	0.00%

4.9. Assignment Validation

Following the establishment of stability or convergence using the iterative feedback procedures among the AM peak period and mid-day period assignments, traffic assignments were performed for the three other time periods. The link volume results of assignments for the 5 times periods were then combined for comparison to the daily traffic counts.

Table 4.39 summarizes the assigned and counted travel both on the basis of volume by aggregated road type. These results reflect links with counts only. The detailed road types used in designation of links for purposes of link capacity have been collapsed to five categories of road type.

Table 4.41 summarizes the assigned and counted travel volumes by area type.

Table 4.42 summarizes the counted and assigned volumes among the eight counties that make up the H-GAC modeling region.

Table 4.39 Year 2016 VMT by Roadway Type

Roadway Type	Number of Links With Counts	Counted Volume on Links With Counts	Assigned Volume on Links With Counts	Assigned Volume as Percent of Counted Volume
Freeway	317	36,827,061	37,250,320	101.15%
Toll Roads	75	3,834,733	4,213,698	109.88%
Prin. Arterial	903	20,351,865	20,608,666	101.26%
Other Arterial	3,433	54,004,513	53,931,101	99.86%
Collectors	2,000	10,251,033	9,606,760	93.72%
Region	6,728	125,269,205	125,610,546	100.27%

Table 4.40 Year 2016 VMT by Area Type

Area Type	Number of Links With Counts	Counted Volume on Links With Counts	Assigned Volume on Links With Counts	Assigned Volume as Percent of Counted Volume
CBD	60	916,282	925,787	101.04%
Urban	1,134	27,605,094	29,494,903	106.85%
Suburban	2,884	66,638,889	67,216,302	100.87%
Fringe Suburban	1,451	22,560,199	20,569,878	91.18%
Rural	1,199	7,548,741	7,403,677	98.08%
Region	6,728	125,269,205	125,610,546	100.27%

Table 4.41 Year 2016 VMT by County

County	Total Number of Counts	Counted Volume on Links With Counts	Assigned Volume on Links With Counts	Assigned Volume as Percent of Counted Volume
Brazoria	554	5,032,419	4,197,957	83.42%
Chambers	125	1,077,134	1,066,086	98.97%
Fort Bend	630	9,828,979	9,917,278	100.90%
Galveston	354	4,336,637	3,925,111	90.51%
Harris	4,146	94,853,630	96,458,260	101.69%
Liberty	192	1,097,755	1,241,927	110.67%
Montgomery	547	8,026,6324	7,824,741	97.48%
Waller	180	8,026,632	7,824,741	97.48%
Region	6,728	125,269,205	125,610,546	100.27%

5. HPMS VMT ADJUSTMENT

5.1. INTRODUCTION

The 2016 Track-1 model validation necessitated re-calculation of the factor by which travel model VMT is made to be consistent with VMT estimated by the FHWA Highway Performance Monitoring System (HPMS). The H-GAC Track-1 Regional Travel Models have been validated to observed vehicle miles of travel (VMT) that are estimated based on roughly 14,000 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 Implementations 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 (2016) model estimated regional VMT against regional 2016 VMT estimated by 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 2016 estimated regional VMT to HPMS estimated 2016 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 non-summer weekday VMT. The model VMT is produced in its original form as non-summer weekday VMT, as shown. HPMS VMT represent average annual daily travel (AADT) and is adjusted to represent average non-summer weekday travel, based on an adjusted factor developed using TxDOT permanent traffic recorder data.

2016 HPMS VMT

County	HPMS VMT
Brazoria	8,129,044
Chambers	2,926,505
Fort Bend	11,893,199
Galveston	6,877,234
Harris	104,891,842
Liberty	2,244,970
Montgomery	13,713,224
Waller	2,183,184
Total Non-Toll VMT	**152,859,202**
Brazoria	322
Chambers	26,665
Fort Bend	788,944
Galveston	2,924
Harris	11,042,153
Montgomery	288,880
TotalToll VMT	**12,149,888**
Total 2016 Regional HPMS VMT	**165,009,090**

HPMS estimated average non-summer weekday travel (ANSWT)
= (HPMS AADT) * (AADT to Non-Summer Weekday Travel Adjustment Factor[A])
= (165,009,090) * (1.06178)
= 175,203,352

A – Provided by Dennid Perkinson, TTI, August 2017

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 non-summer weekday VMT as follows:

HPMS Adjustment Factor

= (HPMS estimated ANSWT) / (Model estimated ANSWT)
= (175,203,352) / (186,710,076)
= 0.93837

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.

APPENDIX A
NON-CENTROID SPEEDS & HOURLY CAPACITIES

Table A.1 Hourly Capacity and Initial Speed for Assignment

Area Type	Facility Type	Lanes	Speed	Hourly Capacity
1	1	2	50	4222
1	1	3	50	6333
1	1	4	50	8444
1	1	5	50	10556
1	1	6	50	12667
1	1	7	50	14778
1	1	8	50	16889
2	1	2	51	4444
2	1	3	51	6667
2	1	4	51	8889
2	1	5	51	11111
2	1	6	51	13333
2	1	7	51	15556
2	1	8	51	17778
3	1	2	57	4444
3	1	3	57	6667
3	1	4	57	8889
3	1	5	57	11111
3	1	6	57	13333
3	1	7	57	15556
3	1	8	57	17778
4	1	2	59	4385
4	1	3	59	6578
4	1	4	59	8770
4	1	5	59	10963
4	1	6	59	13155
5	1	2	62	4299
5	1	3	62	6449
5	1	4	62	8598
5	1	5	62	10748
1	2	2	52	5022
1	2	3	52	7133
1	2	4	52	9244
1	2	5	52	11356
1	2	6	52	13467
1	2	7	52	15578
1	2	8	52	17689
2	2	2	52	5244

2	2	3	52	7467
2	2	4	52	9689
2	2	5	52	11911
2	2	6	52	14133
2	2	7	52	16356
2	2	8	52	18578
3	2	2	55	5244
3	2	3	55	7467
3	2	4	55	9689
3	2	5	55	11911
3	2	6	55	14133
3	2	7	55	16356
3	2	8	55	18578
4	2	2	59	5099
4	2	3	59	7249
4	2	4	59	9398
4	2	5	59	11548
5	2	2	64	5099
5	2	3	64	7249
5	2	4	64	9398
5	2	5	64	11548
1	3	2	51	4000
1	3	3	51	6000
1	3	4	51	8000
1	3	5	51	10000
1	3	6	51	12000
1	3	7	51	14000
1	3	8	51	16000
2	3	2	52	4444
2	3	3	52	6667
2	3	4	52	8889
2	3	5	52	11111
2	3	6	52	13333
2	3	7	52	15556
2	3	8	52	17778
3	3	2	62	4444
3	3	3	62	6667
3	3	4	62	8889
3	3	5	62	11111
3	3	6	62	13333
3	3	7	62	15556

3	3	8	62	17778
4	3	2	62	4385
4	3	3	62	6578
4	3	4	62	8770
4	3	5	62	10963
5	3	2	64	4299
5	3	3	64	6449
5	3	4	64	8598
5	3	5	64	10748
1	4	2	52	4800
1	4	3	52	6800
1	4	4	52	8800
1	4	5	52	10800
1	4	6	52	12800
1	4	7	52	14800
1	4	8	52	16800
2	4	2	52	5244
2	4	3	52	7467
2	4	4	52	9689
2	4	5	52	11911
2	4	6	52	14133
2	4	7	52	16356
2	4	8	52	18578
3	4	2	55	5244
3	4	3	55	7467
3	4	4	55	9689
3	4	5	55	11911
3	4	6	55	14133
3	4	7	55	16356
3	4	8	55	18578
4	4	2	59	5185
4	4	3	59	7378
4	4	4	59	9570
4	4	5	59	11763
5	4	2	64	5099
5	4	3	64	7249
5	4	4	64	9398
5	4	5	64	11548
1	5	2	57	4325
1	5	3	57	6487
1	5	4	57	8649

1	5	5	57	10811
1	5	6	57	12974
1	5	7	57	15136
1	5	8	57	17298
2	5	2	58	4552
2	5	3	58	6828
2	5	4	58	9104
2	5	5	58	11381
2	5	6	58	13657
2	5	7	58	15933
2	5	8	58	18209
3	5	2	60	4547
3	5	3	60	6821
3	5	4	60	9095
3	5	5	60	11369
3	5	6	60	13642
3	5	7	60	15916
3	5	8	60	18190
4	5	2	67	4544
4	5	3	67	6816
4	5	4	67	9089
4	5	5	67	11361
5	5	2	71	4538
5	5	3	71	6807
5	5	4	71	9076
5	5	5	71	11345
1	6	2	60	5050
1	6	3	60	7212
1	6	4	60	9374
1	6	5	60	11536
1	6	6	60	13699
1	6	7	60	15861
1	6	8	60	18023
2	6	2	60	5402
2	6	3	60	7678
2	6	4	60	9954
2	6	5	60	12231
2	6	6	60	14507
2	6	7	60	16783
2	6	8	60	19059
3	6	2	63	5347

3	6	3	63	7621
3	6	4	63	9895
3	6	5	63	12169
3	6	6	63	14442
3	6	7	63	16716
3	6	8	63	18990
4	6	2	66	5294
4	6	3	66	7566
4	6	4	66	9839
4	6	5	66	12111
5	6	2	71	5088
5	6	3	71	7357
5	6	4	71	9626
5	6	5	71	11895
1	7	2	57	4325
1	7	3	57	6487
1	7	4	57	8649
1	7	5	57	10811
1	7	6	57	12974
1	7	7	57	15136
1	7	8	57	17298
2	7	2	57	4552
2	7	3	57	6828
2	7	4	57	9104
2	7	5	57	11381
2	7	6	57	13657
2	7	7	57	15933
2	7	8	57	18209
3	7	2	63	4547
3	7	3	63	6821
3	7	4	63	9095
3	7	5	63	11369
3	7	6	63	13642
3	7	7	63	15916
3	7	8	63	18190
4	7	2	65	4544
4	7	3	65	6816
4	7	4	65	9089
4	7	5	65	11361
5	7	2	71	4538
5	7	3	71	6807

5	7	4	71	9076
5	7	5	71	11345
1	8	2	60	5050
1	8	3	60	7212
1	8	4	60	9374
1	8	5	60	11536
1	8	6	60	13699
1	8	7	60	15861
1	8	8	60	18023
2	8	2	60	5402
2	8	3	60	7678
2	8	4	60	9954
2	8	5	60	12231
2	8	6	60	14507
2	8	7	60	16783
2	8	8	60	19059
3	8	2	63	5347
3	8	3	63	7621
3	8	4	63	9895
3	8	5	63	12169
3	8	6	63	14442
3	8	7	63	16716
3	8	8	63	18990
4	8	2	66	5294
4	8	3	66	7566
4	8	4	66	9839
4	8	5	66	12111
5	8	2	71	5088
5	8	3	71	7357
5	8	4	71	9626
5	8	5	71	11895
1	9	1	38	1082
1	9	2	38	2106
1	9	3	38	3074
1	9	4	38	4098
2	9	1	40	1160
2	9	2	40	2258
2	9	3	40	3295
2	9	4	40	4395
3	9	1	43	1148
3	9	2	43	2235

3	9	3	43	3262
3	9	4	43	4349
4	9	1	50	1136
4	9	2	50	2212
4	9	3	50	3228
4	9	4	50	4304
5	9	1	62	1110
5	9	2	62	2163
5	9	3	62	3156
5	9	4	62	4209
1	10	1	22	892
1	10	2	22	1738
1	10	3	22	2536
1	10	4	22	3380
1	10	5	22	4226
2	10	1	35	883
2	10	2	35	1719
2	10	3	35	2509
2	10	4	35	3346
2	10	5	35	4182
3	10	1	40	873
3	10	2	40	1701
3	10	3	40	2483
3	10	4	40	3311
3	10	5	40	4139
4	10	1	46	864
4	10	2	46	1684
4	10	3	46	2456
4	10	4	46	3276
4	10	5	46	4095
5	10	1	60	814
5	10	2	60	1585
5	10	3	60	2313
5	10	4	60	3084
5	10	5	60	3855
1	11	1	22	783
1	11	2	22	1505
1	11	3	22	2174
1	11	4	22	2865
2	11	1	35	815
2	11	2	35	1566

2	11	3	35	2262
2	11	4	35	2982
3	11	1	40	807
3	11	2	40	1551
3	11	3	40	2242
3	11	4	40	2955
4	11	1	46	800
4	11	2	46	1537
4	11	3	46	2221
4	11	4	46	2925
5	11	1	60	752
5	11	2	60	1447
5	11	3	60	2091
5	11	4	60	2758
1	12	1	22	803
1	12	2	22	1563
1	12	3	22	2282
1	12	4	22	3043
2	12	1	35	857
2	12	2	35	1668
2	12	3	35	2434
2	12	4	35	3246
3	12	1	39	848
3	12	2	39	1650
3	12	3	39	2409
3	12	4	39	3212
4	12	1	43	839
4	12	2	43	1633
4	12	3	43	2384
4	12	4	43	3177
5	12	1	55	789
5	12	2	55	1538
5	12	3	55	2244
5	12	4	55	2991
1	13	1	22	744
1	13	2	22	1430
1	13	3	22	2064
1	13	4	22	2722
2	13	1	34	799
2	13	2	34	1536
2	13	3	34	2219

2	13	4	34	2925
3	13	1	38	791
3	13	2	38	1523
3	13	3	38	2199
3	13	4	38	2896
4	13	1	42	784
4	13	2	42	1507
4	13	3	42	2178
4	13	4	42	2870
5	13	1	54	762
5	13	2	54	1465
5	13	3	54	2117
5	13	4	54	2790
1	19	1	22	992
1	19	2	22	1975
1	19	3	22	2947
1	19	4	22	3908
1	19	5	22	4861
2	19	1	35	992
2	19	2	35	1975
2	19	3	35	2947
2	19	4	35	3908
2	19	5	35	4861
3	19	1	40	992
3	19	2	40	1975
3	19	3	40	2947
3	19	4	40	3908
3	19	5	40	4861
4	19	1	46	992
4	19	2	46	1975
4	19	3	46	2947
4	19	4	46	3908
4	19	5	46	4861
5	19	1	60	954
5	19	2	60	1899
5	19	3	60	2834
5	19	4	60	3759
5	19	5	60	4684
1	14	1	18	818
1	14	2	24	1635
1	14	3	24	2396

1	14	4	24	3118
1	14	5	24	3897
1	14	6	24	4676
1	14	7	24	5455
1	14	8	24	6235
2	14	1	36	826
2	14	2	37	1652
2	14	3	37	2420
2	14	4	37	3149
2	14	5	37	3936
2	14	6	37	4723
2	14	7	37	5510
2	14	8	37	6298
3	14	2	42	1637
3	14	3	42	2397
3	14	4	42	3120
3	14	5	42	3899
3	14	6	42	4679
3	14	7	42	5460
3	14	8	42	6239
4	14	2	48	1621
4	14	3	48	2374
4	14	4	48	3090
4	14	5	48	3863
4	14	6	48	4635
4	14	7	48	5408
4	14	8	48	6180
5	14	2	62	1524
5	14	3	62	2232
5	14	4	62	2905
5	14	5	62	3630
5	14	6	62	4356
5	14	7	62	5083
5	14	8	62	5809
1	15	1	24	818
1	15	2	24	1635
1	15	3	24	2396
1	15	4	24	3118
1	15	5	24	3897
1	15	6	24	4676
1	15	7	24	5455

1	15	8	24	6235
2	15	1	37	826
2	15	2	37	1652
2	15	3	37	2420
2	15	4	37	3149
2	15	5	37	3936
2	15	6	37	4723
2	15	7	37	5510
2	15	8	37	6298
3	15	1	42	818
3	15	2	42	1637
3	15	3	42	2397
3	15	4	42	3120
3	15	5	42	3899
3	15	6	42	4679
3	15	7	42	5460
3	15	8	42	6239
4	15	1	48	811
4	15	2	48	1621
4	15	3	48	2374
4	15	4	48	3090
4	15	5	48	3863
4	15	6	48	4635
4	15	7	48	5408
4	15	8	48	6180
5	15	1	62	762
5	15	2	62	1524
5	15	3	62	2232
5	15	4	62	2905
5	15	5	62	3630
5	15	6	62	4356
5	15	7	62	5083
5	15	8	62	5809
1	16	1	21	744
1	16	2	21	1430
1	16	3	21	2064
1	16	4	21	2722
1	16	5	21	3167
2	16	1	34	776
2	16	2	34	1492
2	16	3	34	2154

2	16	4	34	2839
3	16	1	38	768
3	16	2	38	1479
3	16	3	38	2134
3	16	4	38	2812
4	16	1	41	761
4	16	2	41	1463
4	16	3	41	2115
4	16	4	41	2786
5	16	1	53	740
5	16	2	53	1422
5	16	3	53	2055
5	16	4	53	2708
1	17	1	20	563
1	17	2	20	1046
1	17	3	20	1551
1	17	4	20	2181
2	17	1	30	590
2	17	2	30	1097
2	17	3	30	1612
2	17	4	30	2268
3	17	1	36	589
3	17	2	36	1094
3	17	3	36	1612
3	17	4	36	2268
4	17	1	40	589
4	17	2	40	1094
4	17	3	40	1612
4	17	4	40	2268
5	17	1	49	553
5	17	2	49	1030
5	17	3	49	1515
5	17	4	49	2124
1	18	1	16	350
2	18	1	16	350
3	18	1	16	350
4	18	1	16	350
5	18	1	16	350
1	20	1	58	1500
1	20	2	58	3000
1	20	3	58	4500

1	20	4	58	6000
2	20	1	58	1500
2	20	2	58	3000
2	20	3	58	4500
2	20	4	58	6000
3	20	1	61	1500
3	20	2	61	3000
3	20	3	61	4500
3	20	4	61	6000
4	20	1	64	1500
4	20	2	64	3000
4	20	3	64	4500
4	20	4	64	6000
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5	20	2	70	3000
5	20	3	70	4500
5	20	4	70	6000
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1	21	2	13	3000
2	21	1	13	1500
2	21	2	13	3000
3	21	1	13	1500
3	21	2	13	3000
4	21	1	13	1500
4	21	2	13	3000
5	21	1	13	1500
5	21	2	13	3000
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1	26	2	13	3000
2	26	1	13	1500
2	26	2	13	3000
3	26	1	13	1500
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4	26	2	13	3000
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1	27	1	58	1500
1	27	2	58	3000
1	27	3	58	4500
1	27	4	58	6000

2	27	1	58	1500
2	27	2	58	3000
2	27	3	58	4500
2	27	4	58	6000
3	27	1	61	1500
3	27	2	61	3000
3	27	3	61	4500
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4	27	3	64	4500
4	27	4	64	6000
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5	27	2	70	3000
5	27	3	70	4500
5	27	4	70	6000
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4	29	1	58	1500
4	29	2	58	3000
5	29	1	58	1500
5	29	2	58	3000
1	30	1	18	0
1	30	1	18	0
1	30	2	18	0
1	30	3	18	0
1	30	4	18	0
2	30	1	33	0
2	30	1	33	0
2	30	2	33	0
2	30	3	33	0
2	30	4	33	0
3	30	1	33	0
3	30	1	33	0
3	30	2	33	0
3	30	3	33	0
3	30	4	33	0

4	30	1	33	0
4	30	1	33	0
4	30	2	33	0
4	30	3	33	0
4	30	4	33	0
5	30	1	33	0
5	30	1	33	0
5	30	2	33	0
5	30	3	33	0
5	30	4	33	0
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1	31	1	18	0
1	31	2	18	0
1	31	3	18	0
1	31	4	18	0
2	31	1	33	0
2	31	1	33	0
2	31	2	33	0
2	31	3	33	0
2	31	4	33	0
3	31	1	33	0
3	31	1	33	0
3	31	2	33	0
3	31	3	33	0
3	31	4	33	0
4	31	1	33	0
4	31	1	33	0
4	31	2	33	0
4	31	3	33	0
4	31	4	33	0
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5	31	2	33	0
5	31	3	33	0
5	31	4	33	0
1	40	1	58	1500
1	40	2	58	3000
1	40	3	58	4500
1	40	4	58	6000
2	40	1	58	1500
2	40	2	58	3000

2	40	3	58	4500
2	40	4	58	6000
3	40	1	61	1500
3	40	2	61	3000
3	40	3	61	4500
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4	40	1	64	1500
4	40	2	64	3000
4	40	3	64	4500
4	40	4	64	6000
5	40	1	70	1500
5	40	2	70	3000
5	40	3	70	4500
5	40	4	70	6000
1	41	1	13	1500
1	41	2	13	3000
2	41	1	13	1500
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3	41	2	13	3000
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4	41	2	13	3000
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5	41	2	13	3000
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1	47	2	58	3000
1	47	3	58	4500
1	47	4	58	6000
2	47	1	58	1500
2	47	2	58	3000
2	47	3	58	4500
2	47	4	58	6000
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3	47	2	61	3000
3	47	3	61	4500
3	47	4	61	6000
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4	47	2	64	3000
4	47	3	64	4500
4	47	4	64	6000
5	47	1	70	1500

5	47	2	70	3000
5	47	3	70	4500
5	47	4	70	6000
1	49	1	33	1500
1	49	2	33	3000
2	49	1	33	1500
2	49	2	33	3000
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3	49	2	58	3000
4	49	1	58	1500
4	49	2	58	3000
5	49	1	58	1500
5	49	2	58	3000
1	50	1	25	787
1	50	2	25	1527
1	50	3	25	2088
1	50	4	25	2694
2	50	1	37	827
2	50	2	37	1606
2	50	3	37	2196
2	50	4	37	2834
3	50	1	42	819
3	50	2	42	1590
3	50	3	42	2173
3	50	4	42	2804
4	50	1	46	810
4	50	2	46	1573
4	50	3	46	2150
4	50	4	46	2774
5	50	1	52	768
5	50	2	52	1491
5	50	3	52	2035
5	50	4	52	2623
1	51	1	22	751
1	51	2	22	1458
1	51	3	22	2021
1	51	4	22	2605
2	51	1	38	790
2	51	2	38	1533
2	51	3	38	2125
2	51	4	38	2740

3	51	1	43	782
3	51	2	43	1518
3	51	3	43	2103
3	51	4	43	2711
4	51	1	48	773
4	51	2	48	1502
4	51	3	48	2081
4	51	4	48	2682
5	51	1	55	732
5	51	2	55	1422
5	51	3	55	1967
5	51	4	55	2533
1	52	1	22	1372
2	52	1	35	1444
3	52	1	39	1444
4	52	1	43	1425
5	52	1	55	1397
1	52	2	22	2744
2	52	2	35	2889
3	52	2	39	2889
4	52	2	43	2850
5	52	2	55	2794
1	52	3	22	2196
2	52	3	35	4332
3	52	3	39	4332
4	52	3	43	4275
5	52	3	55	4191
1	53	1	49	1372
1	53	2	49	2744
1	53	3	49	4117
1	53	4	49	5489
1	53	5	49	6861
1	53	6	49	8233
2	53	1	49	1444
2	53	2	49	2889
2	53	3	49	4333
2	53	4	49	5778
2	53	5	49	7222
2	53	6	49	8667
3	53	1	54	1444
3	53	2	54	2889

3	53	3	54	4333
3	53	4	54	5778
3	53	5	54	7222
3	53	6	54	8667
4	53	1	54	1425
4	53	2	54	2850
4	53	3	54	4276
4	53	4	54	5701
5	53	1	54	1397
5	53	2	54	2794
5	53	3	54	4192
5	53	4	54	5589
1	60	1	58	1500
1	60	2	58	3000
1	60	3	58	4500
1	60	4	58	6000
2	60	1	58	1500
2	60	2	58	3000
2	60	3	58	4500
2	60	4	58	6000
3	60	1	61	1500
3	60	2	61	3000
3	60	3	61	4500
3	60	4	61	6000
4	60	1	64	1500
4	60	2	64	3000
4	60	3	64	4500
4	60	4	64	6000
5	60	1	70	1500
5	60	2	70	3000
5	60	3	70	4500
5	60	4	70	6000
1	80	1	58	1500
1	80	2	58	3000
1	80	3	58	4500
1	80	4	58	6000
2	80	1	58	1500
2	80	2	58	3000
2	80	3	58	4500
2	80	4	58	6000
3	80	1	61	1500

3	80	2	61	3000
3	80	3	61	4500
3	80	4	61	6000
4	80	1	64	1500
4	80	2	64	3000
4	80	3	64	4500
4	80	4	64	6000
5	80	1	70	1500
5	80	2	70	3000
5	80	3	70	4500
5	80	4	70	6000
1	90	1	20	1025
1	90	2	20	1998
1	90	3	20	2918
1	90	4	20	3891
1	90	5	20	4864
1	90	6	20	5837
2	90	1	34	1014
2	90	2	34	1978
2	90	3	34	2889
2	90	4	34	3851
2	90	5	34	4814
2	90	6	34	5777
3	90	1	39	1004
3	90	2	39	1957
3	90	3	39	2859
3	90	4	39	3811
3	90	5	39	4764
3	90	6	39	5716
4	90	1	43	976
4	90	2	43	1902
4	90	3	43	2777
4	90	4	43	3703
4	90	5	43	4629
4	90	6	43	5555
5	90	1	59	919
5	90	2	59	1790
5	90	3	59	2615
5	90	4	59	3486
5	90	5	59	4358
5	90	6	59	5229

1	91	1	28	1082
1	91	2	28	2106
1	91	3	28	3074
1	91	4	28	4098
2	91	1	36	1204
2	91	2	36	2345
2	91	3	36	3422
2	91	4	36	4563
2	91	5	36	5704
2	91	6	36	6845
3	91	1	42	1192
3	91	2	42	2321
3	91	3	42	3387
3	91	4	42	4517
3	91	5	42	5646
3	91	6	42	6775
4	91	1	46	1136
4	91	2	46	2212
4	91	3	46	3228
4	91	4	46	4304
4	91	5	46	5380
4	91	6	46	6456
5	91	1	60	1053
5	91	2	60	2050
5	91	3	60	2992
5	91	4	60	3991
5	91	5	60	4988
5	91	6	60	5986

APPENDIX B
CENTROID CONNECTOR SPEEDS

Centroid connectors of less than one-tenth mile within the Houston CBD are assigned a speed of eleven 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

APPENDIX C
CALIBRATED F-FACTORS

Table C.1 Calibrated F-Factors by Trip Purpose

Time (minutes)	Friction Factors						
	HBW INC Grp 1	HBW INC Grp 2	HBW INC Grp 3	HBW INC Grp 4	HBW INC Grp 5	TAXI	EXTL-AUTO
1	514.107239	300.104889	370.151245	445.572296	354.442932	335.937012	16.33280
2	306.287262	220.568985	230.202805	279.981201	235.521912	243.877350	14.71530
3	192.856873	168.121124	178.120636	186.197495	181.918854	169.704163	13.82830
4	132.788635	119.599823	124.445091	129.675140	123.478600	125.163979	13.05260
5	100.000000	100.000000	100.000000	100.000000	100.000000	100.000000	12.03020
6	85.250519	85.024261	84.867577	85.070686	82.215347	79.335503	10.84530
7	73.432091	71.904449	70.043053	74.684296	66.251434	61.867062	9.62330
8	63.034725	57.979973	59.008663	64.571846	55.958069	49.127468	8.65170
9	50.688385	46.232933	47.679382	53.734589	47.390850	38.809814	7.91070
10	41.818012	37.325356	39.187550	44.142754	41.289719	30.511103	7.31400
11	34.579052	30.280441	32.454174	36.437248	35.765347	23.572901	6.63570
12	28.125746	24.890846	26.761078	29.676039	30.844599	17.726925	5.95670
13	22.309353	20.662556	22.514578	24.332315	25.320972	14.164465	5.28220
14	18.741444	17.436695	19.138865	19.856064	20.785559	11.044847	4.69610
15	15.742883	14.627840	16.478493	16.409157	17.060665	9.157674	4.18060
16	13.337146	12.679819	14.308930	13.920365	14.282129	7.697894	3.73510
17	11.417889	11.102739	12.631548	11.880345	12.236019	6.505482	3.34040
18	9.896170	9.858839	11.243273	10.391848	10.553404	5.297529	2.93180
19	8.695370	8.933642	9.924524	9.251200	9.285540	4.611560	2.52100
20	7.707771	8.087455	8.584678	8.288593	8.241692	3.875304	2.23900
21	6.910826	7.445615	7.621731	7.461421	7.049815	3.181346	2.01170
22	6.210604	6.813641	6.669475	6.761466	5.926759	2.621890	1.79820
23	5.578340	6.236336	5.940836	6.077179	5.283240	2.295249	1.59040
24	5.030081	5.729202	5.144917	5.333150	4.777235	2.064678	1.41040
25	4.550843	5.299999	4.696433	4.739078	4.303539	1.775562	1.25300
26	4.122393	4.924005	4.210023	4.347028	3.941275	1.517538	1.12110
27	3.673809	4.548100	3.718811	4.096188	3.601173	1.360569	1.01850
28	3.280088	4.017910	3.430504	3.843037	3.263806	1.275105	0.91520
29	2.965077	3.427183	3.168849	3.621238	2.977132	1.202850	0.80760
30	2.737074	2.917074	2.940913	3.442834	2.772180	1.134224	0.67610
31	2.374777	2.535982	2.758981	3.326613	2.621294	1.076132	0.57000
32	2.104620	2.075618	2.597114	3.215557	2.535018	0.900691	0.50210
33	1.871217	1.773680	2.443243	2.981835	2.308511	0.858513	0.43850
34	1.661875	1.501635	2.161720	2.744602	2.189333	0.773856	0.38750
35	1.523584	1.240555	1.902530	2.425207	2.107499	0.716734	0.33440
36	1.433987	1.131306	1.730449	2.175953	2.043917	0.673185	0.30830
37	1.432254	1.064047	1.634262	1.940141	1.942222	0.560633	0.28490
38	1.346913	1.000774	1.534402	1.726105	1.875986	0.488166	0.25680
39	1.250709	0.944681	1.443648	1.670909	1.828144	0.447025	0.21830
40	1.144014	0.897411	1.362966	1.630437	1.791421	0.412889	0.18940

Table C.1 Calibrated F-Factors by Trip Purpose (continued)

Time	Friction Factors						
(minutes)	HBW INC Grp 1	HBW INC Grp 2	HBW INC Grp 3	HBW INC Grp 4	HBW INC Grp 5	TAXI	EXTL-AUTO
41	1.009359	0.854373	1.289547	1.601708	1.741886	0.385419	0.16580
42	0.953916	0.809050	1.213041	1.561663	1.415470	0.359289	0.15040
43	0.905690	0.768594	0.980946	1.522620	1.329169	0.288531	0.14140
44	0.798066	0.724771	0.872826	1.486092	1.189637	0.263904	0.12920
45	0.720136	0.681058	0.797183	1.265634	1.082717	0.254704	0.11890
46	0.676882	0.637553	0.780443	1.115882	1.006629	0.234200	0.10940
47	0.514829	0.594048	0.770526	0.994327	0.937923	0.213723	0.10080
48	0.460933	0.571862	0.769774	0.943200	0.893920	0.191680	0.09300
49	0.380198	0.547939	0.767185	0.888849	0.850969	0.169627	0.08580
50	0.321426	0.540665	0.692994	0.834918	0.782941	0.141504	0.07920
51	0.285251	0.532084	0.683392	0.814026	0.708793	0.138940	0.07320
52	0.278729	0.525161	0.540082	0.716934	0.629355	0.138302	0.06770
53	0.272515	0.518663	0.441415	0.658773	0.528361	0.136477	0.06260
54	0.266456	0.512019	0.399568	0.598442	0.516506	0.135928	0.05800
55	0.260746	0.505700	0.326771	0.590607	0.491063	0.134579	0.05370
56	0.254595	0.499797	0.319799	0.582753	0.481897	0.133230	0.04980
57	0.248279	0.494975	0.313433	0.575445	0.472540	0.120691	0.04620
58	0.241454	0.491634	0.307329	0.570304	0.467085	0.116486	0.04290
59	0.234766	0.486781	0.301287	0.566958	0.466160	0.115224	0.03990
60	0.228200	0.480834	0.294793	0.543545	0.363812	0.112928	0.03710
61	0.221500	0.474020	0.288237	0.452061	0.315838	0.109584	0.03450
62	0.213715	0.467741	0.244776	0.451797	0.230848	0.104169	0.03220
63	0.204980	0.443370	0.234998	0.450265	0.217721	0.098754	0.03000
64	0.196967	0.418999	0.225158	0.450042	0.205906	0.097245	0.02800
65	0.188686	0.378215	0.215373	0.449922	0.193437	0.095352	0.02610
66	0.179810	0.341759	0.204876	0.449576	0.178997	0.093458	0.02440
67	0.164546	0.266854	0.194199	0.440665	0.166012	0.083998	0.02280
68	0.149345	0.259291	0.182199	0.431754	0.152935	0.083236	0.02130
69	0.131828	0.255573	0.170416	0.422842	0.143575	0.076333	0.01990
70	0.112361	0.250448	0.130595	0.413931	0.142832	0.064940	0.01870
71	0.103523	0.242327	0.123188	0.405020	0.142554	0.029580	0.01750
72	0.072152	0.232775	0.114376	0.327330	0.140945	0.029513	0.01640
73	0.063770	0.223990	0.104982	0.273396	0.139510	0.029159	0.01540
74	0.057381	0.213801	0.095235	0.215953	0.137187	0.028780	0.01450
75	0.055973	0.197449	0.084655	0.142745	0.136155	0.028406	0.01360
76	0.053336	0.153959	0.084012	0.121606	0.135328	0.028037	0.01280
77	0.050451	0.130575	0.083369	0.111245	0.133311	0.027672	0.01210
78	0.047418	0.106075	0.082726	0.102786	0.131379	0.027312	0.01140
79	0.044836	0.079878	0.082083	0.099247	0.130961	0.026957	0.01070
80	0.042734	0.065996	0.081440	0.097028	0.129717	0.026607	0.01010

Table C.1 Calibrated F-Factors by Trip Purpose (continued)

Time (minutes)	Friction Factors HBW INC Grp 1	HBW INC Grp 2	HBW INC Grp 3	HBW INC Grp 4	HBW INC Grp 5	TAXI	EXTL-AUTO
81	0.039950	0.051239	0.080797	0.096396	0.129646	0.026261	0.00950
82	0.036336	0.031808	0.080154	0.096304	0.128984	0.025920	0.00900
83	0.032725	0.030864	0.079511	0.095915	0.128947	0.025583	0.00850
84	0.029122	0.029808	0.078867	0.095242	0.127771	0.025250	0.00810
85	0.025361	0.028419	0.078224	0.093883	0.127015	0.024922	0.00760
86	0.021395	0.027528	0.077581	0.092519	0.126035	0.024598	0.00720
87	0.016944	0.026707	0.076938	0.092296	0.125178	0.024278	0.00690
88	0.011852	0.025627	0.076295	0.092241	0.124613	0.023962	0.00650
89	0.008382	0.024784	0.075652	0.090472	0.121681	0.023651	0.00620
90	0.007963	0.023420	0.075009	0.088387	0.117512	0.023343	0.00590
91	0.007565	0.021091	0.074366	0.086703	0.107409	0.023040	0.00560
92	0.007187	0.018577	0.073853	0.085569	0.096188	0.022740	0.00530
93	0.006827	0.015512	0.073723	0.083480	0.095625	0.022445	0.00500
94	0.006486	0.008330	0.072418	0.081950	0.080740	0.022153	0.00480
95	0.006162	0.006537	0.070829	0.081915	0.079778	0.021865	0.00460
96	0.005853	0.006406	0.069211	0.079388	0.072269	0.021581	0.00440
97	0.005561	0.006278	0.067071	0.078797	0.064702	0.021300	0.00420
98	0.005283	0.006153	0.063795	0.076428	0.061322	0.021023	0.00400
99	0.005019	0.006030	0.060034	0.076189	0.057097	0.020750	0.00380
100	0.004768	0.005909	0.055191	0.074449	0.050493	0.020480	0.00360
101	0.004529	0.005791	0.048275	0.074211	0.045599	0.020214	0.00350
102	0.004303	0.005675	0.039788	0.072436	0.041272	0.019951	0.00330
103	0.004088	0.005561	0.030213	0.071609	0.040102	0.019692	0.00320
104	0.003883	0.005450	0.029609	0.070178	0.036769	0.019436	0.00310
105	0.003689	0.005341	0.029017	0.058303	0.032761	0.019183	0.00300
106	0.003505	0.005234	0.028436	0.046393	0.029683	0.018934	0.00280
107	0.003329	0.005130	0.027868	0.033282	0.029043	0.018688	0.00270
108	0.003163	0.005027	0.027310	0.031951	0.027300	0.018445	0.00260
109	0.003005	0.004927	0.026764	0.030673	0.025082	0.018205	0.00250
110	0.002855	0.004828	0.026229	0.029446	0.023122	0.017968	0.00240
111	0.002712	0.004731	0.025704	0.028268	0.021578	0.017735	0.00000
112	0.002576	0.004637	0.025190	0.027137	0.020076	0.017504	0.00000
113	0.002447	0.004544	0.024686	0.026052	0.018905	0.017277	0.00000
114	0.002325	0.004453	0.024192	0.025010	0.017970	0.017052	0.00000
115	0.002209	0.004364	0.023709	0.024009	0.017083	0.016830	0.00000
116	0.002098	0.004277	0.023234	0.023049	0.016205	0.016612	0.00000
117	0.001993	0.004191	0.022770	0.022127	0.015850	0.016396	0.00000
118	0.001894	0.004108	0.022314	0.021242	0.015191	0.016182	0.00000
119	0.001799	0.004025	0.021868	0.020392	0.013745	0.015972	0.00000
120	0.001709	0.003945	0.021431	0.019577	0.012244	0.015764	0.00000

Table C.2 Calibrated F-Factors by Trip Purpose

Time minutes	Friction Factors					
	HBNW-ED1	HBNW-RETAIL	HBNW-AIRPORT	HBNW-OTHER	NHB Work-Based	NHB Non-Work-Based
1	469.462097	396.883728	0.000000	562.017700	295.210236	305.624634
2	284.392944	200.778961	87.515884	327.053864	235.982910	232.162979
3	186.969406	185.017670	103.387547	207.740067	170.963821	166.626587
4	141.633224	136.119507	102.196688	140.172684	126.372231	123.413063
5	100.000000	100.000000	100.000000	100.000000	100.000000	100.000000
6	74.345695	73.804611	88.092404	75.500290	78.796677	78.235847
7	49.453655	53.676311	81.895695	52.411060	61.455517	60.639755
8	34.069950	38.567181	78.057737	38.918488	48.374268	45.217926
9	22.887098	26.446436	75.192912	27.968241	36.962982	32.551388
10	16.119810	19.446812	73.025317	19.616817	28.202356	24.729874
11	12.914672	15.262584	71.269617	13.958101	21.517532	19.186024
12	10.163768	10.890317	69.917426	10.188935	16.026688	15.107874
13	7.792601	7.390912	68.493847	7.541087	12.758224	11.135723
14	5.925422	5.031461	67.174473	5.545444	10.002880	8.095463
15	4.382248	3.416955	66.249489	4.263978	8.353618	6.192147
16	3.154277	2.473196	65.632922	3.228028	7.090659	5.197272
17	2.314983	1.990000	65.325164	2.505966	6.045355	4.049120
18	1.877343	1.515802	65.335653	1.980964	4.898099	3.306489
19	1.314032	1.172324	65.585737	1.530704	4.205086	2.891359
20	0.860087	0.917079	65.857665	1.215182	3.518345	2.377297
21	0.719853	0.715117	66.429795	1.001605	2.881752	1.838656
22	0.636810	0.566310	67.447927	0.758198	2.401801	1.446853
23	0.475754	0.463087	68.593522	0.618016	2.130441	1.336613
24	0.354828	0.388661	69.729481	0.498777	1.923023	1.237351
25	0.231882	0.287959	70.882529	0.410709	1.652934	1.146532
26	0.185050	0.205142	72.056681	0.324624	1.407567	1.060319
27	0.163165	0.157218	73.152061	0.278007	1.267157	0.908416
28	0.154592	0.135830	74.148709	0.216406	1.202523	0.719788
29	0.146019	0.131128	75.061140	0.168049	1.144792	0.628381
30	0.128617	0.100279	76.062055	0.145819	1.085992	0.582664
31	0.112184	0.068983	77.275217	0.119156	1.032379	0.511801
32	0.098840	0.063520	78.537695	0.088503	0.869380	0.457231
33	0.078870	0.058057	79.812493	0.083254	0.830966	0.433340
34	0.071565	0.051517	81.044389	0.078805	0.754030	0.403769
35	0.064291	0.045518	82.249681	0.074515	0.701297	0.360886
36	0.057597	0.040215	83.358646	0.071137	0.659169	0.293869
37	0.051203	0.035466	84.315136	0.067711	0.548771	0.249212
38	0.045013	0.031214	84.945473	0.064605	0.478638	0.223458
39	0.040481	0.027294	85.441680	0.061608	0.440870	0.209961
40	0.032745	0.023740	84.196208	0.054238	0.409445	0.196660

Table C.2 Calibrated F-Factors by Trip Purpose (continued)

Time (minutes)	Friction Factors					
	HBNW-ED1	HBNW-RETAIL	HBNW-AIRPORT	HBNW-OTHER	NHB Work-Based	NHB Non-Work-Based
41	0.026699	0.020577	81.440391	0.052546	0.384827	0.183662
42	0.022560	0.017677	79.273216	0.051322	0.358941	0.171516
43	0.018570	0.014993	77.964578	0.049855	0.285219	0.159610
44	0.018393	0.012500	76.373724	0.048576	0.260282	0.146833
45	0.018255	0.010220	74.499669	0.047435	0.251296	0.112581
46	0.017111	0.008178	72.337117	0.046205	0.231626	0.110600
47	0.016007	0.007044	69.851811	0.040923	0.210955	0.107791
48	0.014976	0.006404	67.012252	0.035825	0.189136	0.101245
49	0.013934	0.005850	63.689478	0.034041	0.166742	0.094451
50	0.012890	0.005361	59.922367	0.024071	0.138171	0.087270
51	0.011879	0.004901	56.010088	0.023426	0.136365	0.079968
52	0.010914	0.004471	52.061729	0.017362	0.135906	0.072718
53	0.009952	0.004057	48.126050	0.014841	0.135446	0.065358
54	0.008955	0.003666	44.186568	0.014601	0.135245	0.057846
55	0.007932	0.003315	40.304343	0.014242	0.127482	0.043458
56	0.006489	0.002995	36.527204	0.013998	0.122282	0.041702
57	0.005016	0.002701	32.943757	0.013754	0.117081	0.039768
58	0.003025	0.002411	29.464133	0.012872	0.112812	0.037630
59	0.001168	0.002119	26.157653	0.011870	0.107677	0.035331
60	0.001021	0.001839	23.170085	0.010862	0.107582	0.033024
61	0.000957	0.001581	20.494271	0.009963	0.105592	0.030522
62	0.000872	0.001519	18.024145	0.009043	0.093009	0.027813
63	0.000790	0.001321	15.735575	0.008061	0.092397	0.025181
64	0.000726	0.001202	13.628221	0.006996	0.090187	0.022389
65	0.000641	0.001085	11.730859	0.006943	0.089765	0.019433
66	0.000629	0.000976	10.074825	0.006932	0.085669	0.016517
67	0.000620	0.000873	8.610077	0.006837	0.076712	0.013447
68	0.000612	0.000778	7.325028	0.006814	0.076303	0.009746
69	0.000606	0.000682	6.174787	0.006792	0.066875	0.009683
70	0.000603	0.000589	5.208608	0.006769	0.057446	0.009148
71	0.000596	0.000565	4.357188	0.006582	0.026013	0.008792
72	0.000581	0.000542	3.629540	0.006550	0.026011	0.008386
73	0.000563	0.000520	3.009840	0.006493	0.025800	0.007930
74	0.000554	0.000504	2.461677	0.006476	0.025599	0.007432
75	0.000547	0.000488	1.993125	0.006409	0.025546	0.006876
76	0.000537	0.000474	1.592617	0.006389	0.025211	0.006332
77	0.000534	0.000462	1.257219	0.006258	0.025137	0.005760
78	0.000523	0.000450	1.003585	0.006133	0.025003	0.005180
79	0.000513	0.000440	0.975874	0.006010	0.024994	0.004596
80	0.000502	0.000438	0.948928	0.005890	0.024958	0.003980

Table C.2 Calibrated F-Factors by Trip Purpose (continued)

Time (minutes)	Friction Factors					
	HBNW-ED1	HBNW-RETAIL	HBNW-AIRPORT	HBNW-OTHER	NHB Work-Based	NHB Non-Work-Based
81	0.000494	0.000424	0.922727	0.005772	0.024907	0.003325
82	0.000483	0.000409	0.897249	0.005657	0.024453	0.003259
83	0.000474	0.000391	0.872474	0.005544	0.024420	0.003193
84	0.000464	0.000372	0.863749	0.005433	0.024407	0.003129
85	0.000456	0.000353	0.855112	0.005324	0.024405	0.003067
86	0.000445	0.000335	0.846561	0.005218	0.024336	0.003006
87	0.000436	0.000314	0.838095	0.005113	0.024303	0.002945
88	0.000428	0.000288	0.829714	0.005011	0.024281	0.002887
89	0.000421	0.000262	0.821417	0.004911	0.024179	0.002829
90	0.000410	0.000230	0.813203	0.004813	0.024152	0.002772
91	0.0000	0.000190	0.805071	0.004716	0.023790	0.002717
92	0.0000	0.000188	0.797020	0.004622	0.023433	0.002662
93	0.0000	0.000186	0.789050	0.004530	0.023081	0.002609
94	0.0000	0.000184	0.781159	0.004439	0.022735	0.002557
95	0.0000	0.000183	0.773348	0.004350	0.022394	0.002506
96	0.0000	0.000181	0.765614	0.004263	0.022058	0.002456
97	0.0000	0.000179	0.757958	0.004178	0.021727	0.002407
98	0.0000	0.000177	0.750379	0.004094	0.021401	0.002358
99	0.0000	0.000175	0.742875	0.004012	0.021080	0.002311
100	0.0000	0.000174	0.735446	0.003932	0.020764	0.002265
101	0.0000	0.000172	0.728092	0.003854	0.020453	0.002220
102	0.0000	0.000170	0.720811	0.003776	0.020146	0.002175
103	0.0000	0.000168	0.713603	0.003701	0.019844	0.002132
104	0.0000	0.000167	0.706467	0.003627	0.019546	0.002089
105	0.0000	0.000165	0.699402	0.003554	0.019253	0.002047
106	0.0000	0.000163	0.692408	0.003483	0.018964	0.002007
107	0.0000	0.000162	0.685484	0.003414	0.018680	0.001966
108	0.0000	0.000160	0.678629	0.003345	0.018399	0.001927
109	0.0000	0.000159	0.671843	0.003278	0.018123	0.001889
110	0.0000	0.000157	0.665124	0.003213	0.017852	0.001851
111	0.0000	0.000155	0.658473	0.003149	0.017584	0.001814
112	0.0000	0.000154	0.651888	0.003086	0.017320	0.001777
113	0.0000	0.000152	0.645369	0.003024	0.017060	0.001742
114	0.0000	0.000151	0.638916	0.002963	0.016804	0.001707
115	0.0000	0.000149	0.632527	0.002904	0.016552	0.001673
116	0.0000	0.000148	0.626201	0.002846	0.016304	0.001639
117	0.0000	0.000146	0.619939	0.002789	0.016059	0.001607
118	0.0000	0.000145	0.613740	0.002733	0.015819	0.001575
119	0.0000	0.000143	0.607603	0.002679	0.015581	0.001543
120	0.0000	0.000142	0.601527	0.002625	0.015348	0.001512

APPENDIX D
Sector Systems

The travel demand model makes use of a nested system of analysis zones which at its most detailed level is the 5,263 traffic analysis zones. It is composed of 5,217 internal zones and 46 external stations.

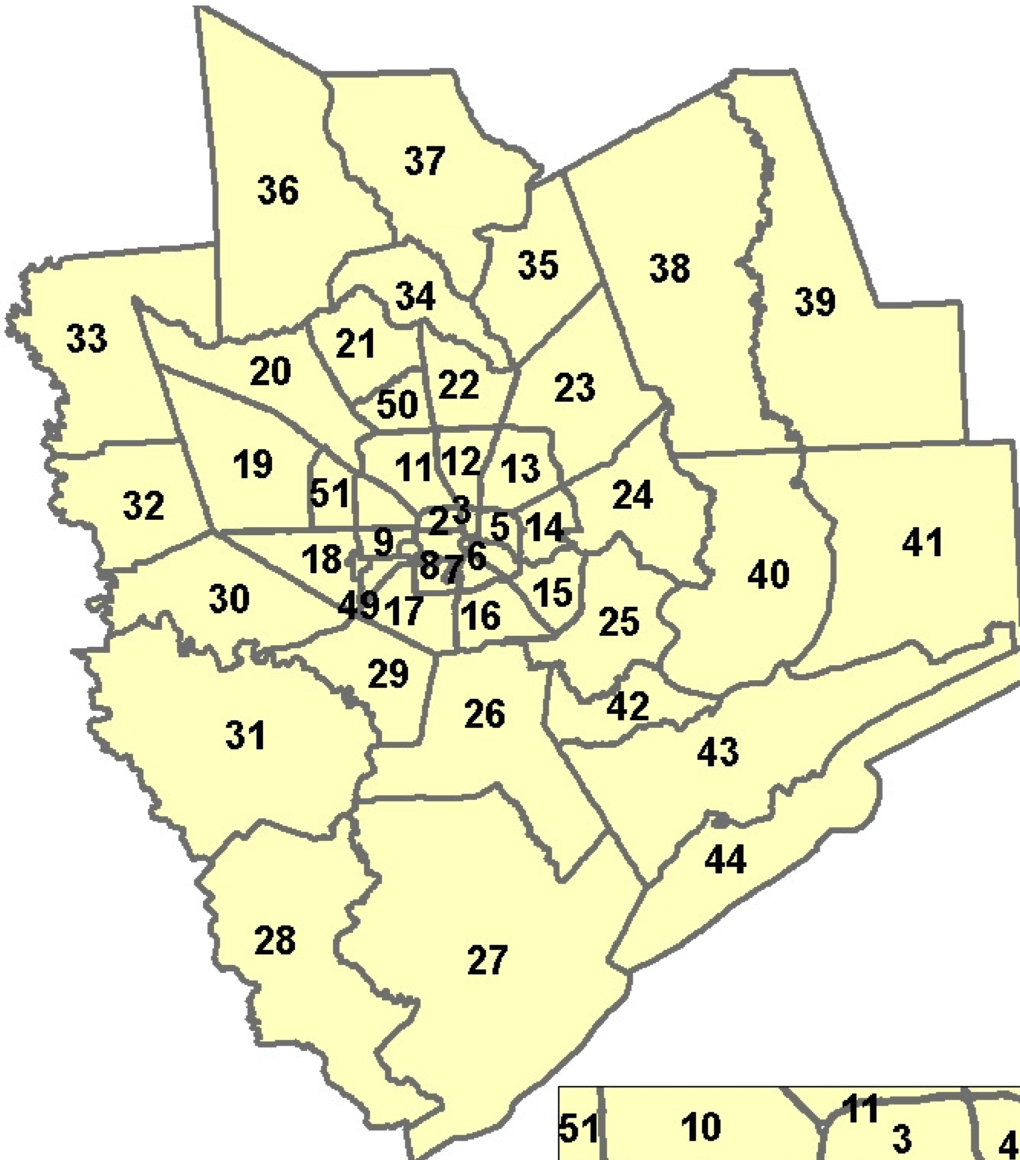
The next level of the nested zone structure is the sector system. A sector is a group of neighboring TAZs aggregated together as a single analysis unit. There are three different sector systems for general trip purpose, home-based work trip purpose, and the home-based school trip purpose. The sector structure serves two main purposes for travel demand process. Primarly, the sector structure provides a means to summarize various travel model results. It also facilitiaties the application of any bais factors which might prove necessary in the application of the trip distribution model.

The number of sectors in the general sector structure increases from 47 sectors in previous version to 51 sectors in this version of travel demand model. The previous 47 sectors were created for year 1985 validation. Even though the previously 47 sector structure served well, as the 8-county region growing rapidly, there is a need to modify the sector strcture to reflect the demographic shift and new infrastructure. The new 51 sectors are derived from the old 47 sectors. Some of the sector boundaries are re-aligned to major factilities built after 1985, particulary along Sam Houston Tollway. Four of the 47 sectors are spilt because the four sectors have substantially large amout of population and employment, bringing the total number of sectors to 51. Figure D.1 shows the new 51 sector system.

A special sector structure was created for HBW person trip table because of its distinct nature. HBW trips are significantly longer than the HBNW and NHB trips, and they have a higher percentage of transit usage. The HBW sector strcture provides greater detail with the 8-county region than the general 51 sector strcture with the addition of seven seven sectors. The additional HBW sectors are developed to separate pockets of major regional employment centers from adjacent residential or mixed-use areas within the same general sector. Figure D.2 shows the 58 HBW sector system.

The third sector structure represents the existing school districts. A high intra-sector bias factor is added to the trip distribution model to encourage HB-ED1 trips travel within the same school district of their home. Without the high intra-sector bias factor, the trip disbution model would assign too many cross-school district HB-ED1 trips. Figure D-3 shows the school district boundary.

Figure D-1 General Purpose Sectors



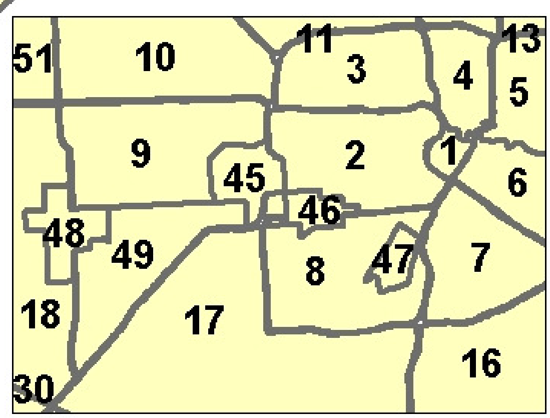


Figure D-2 Journey to Work (HBW) Purpose Sectors

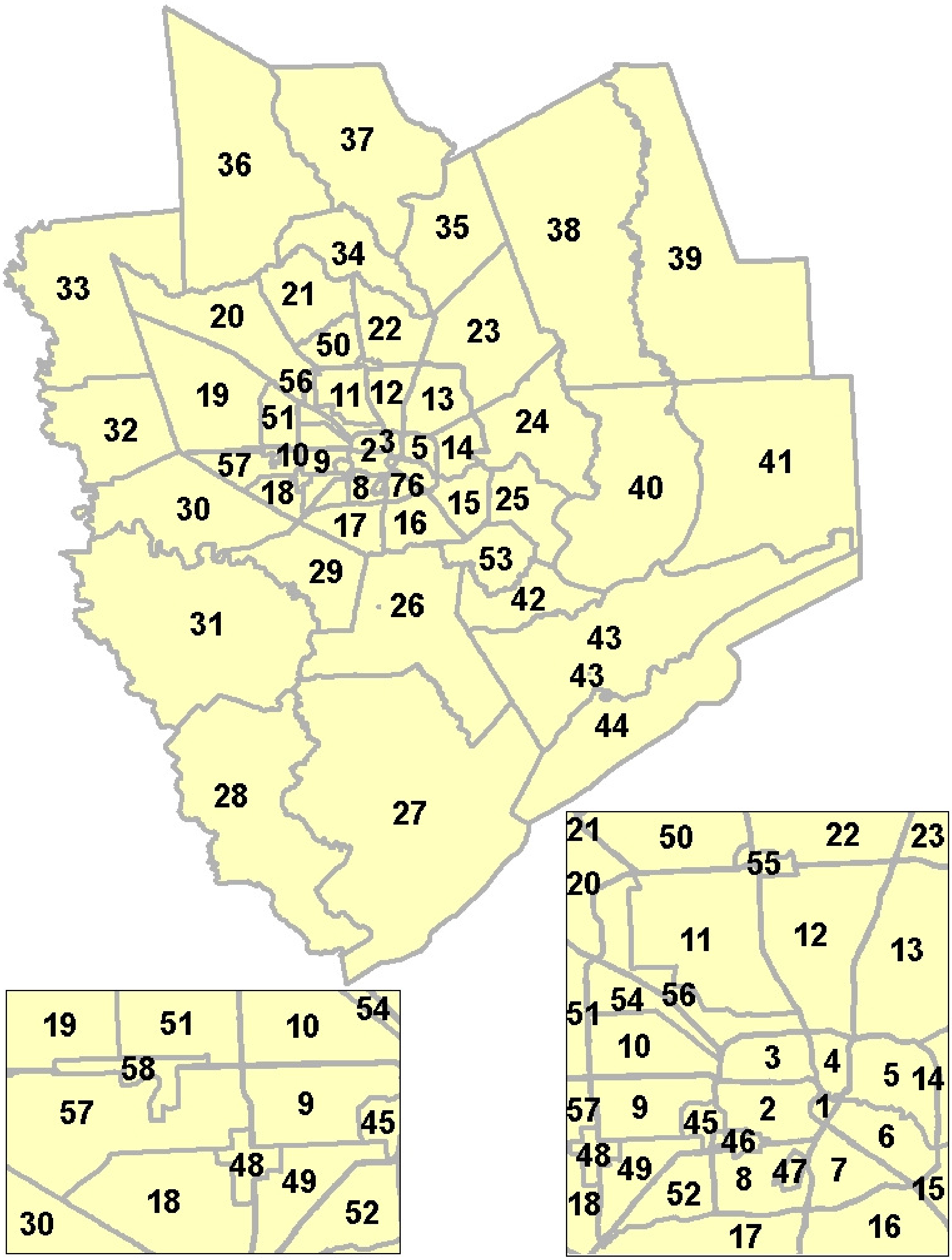
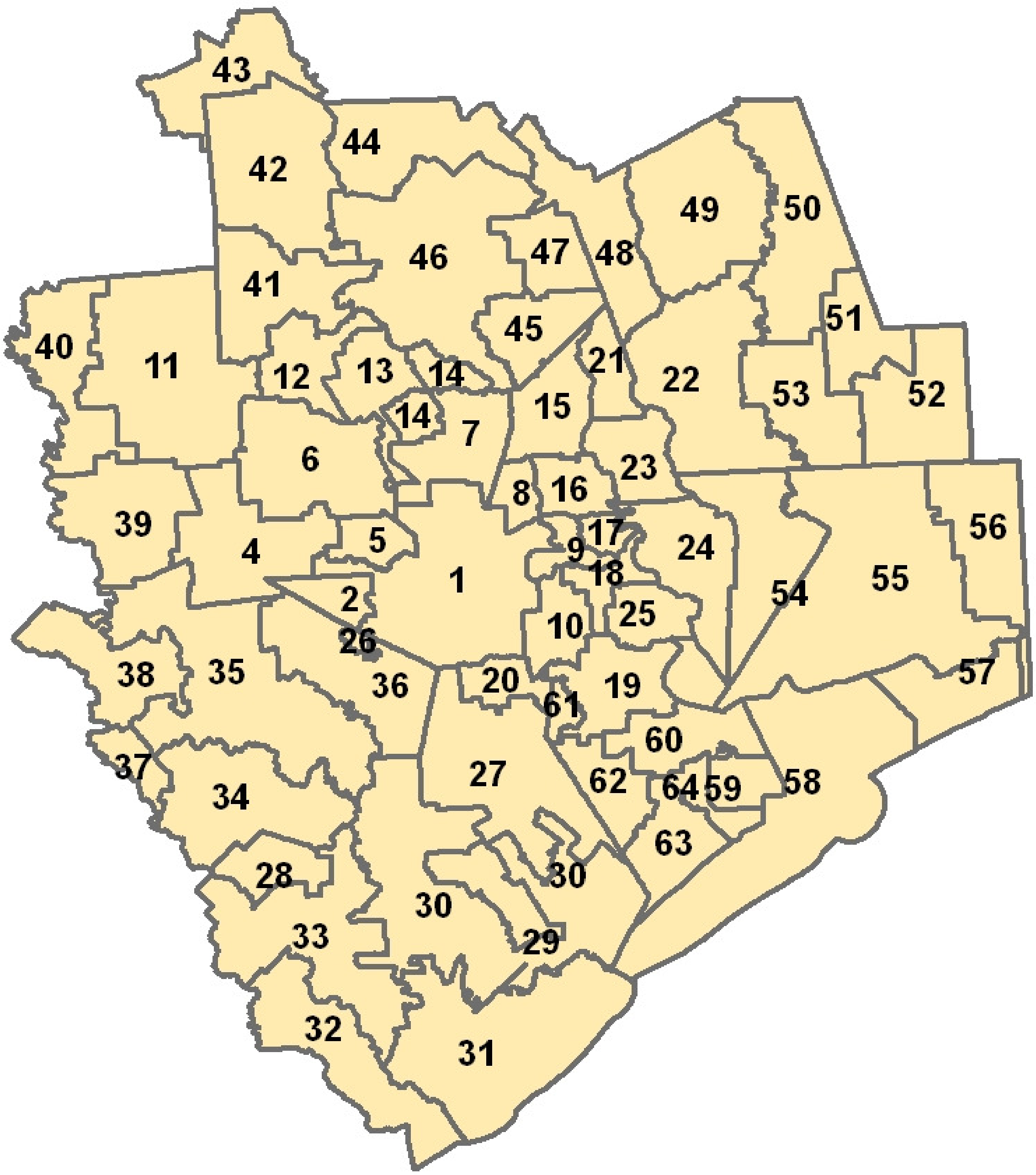


Figure D-3 School Districts Inside 8-County Region



Source: H-GAC

Table D.0.1 List of School Districts Inside 8-County Region

ID	Name
1	Houston Independent School District
2	Alief Independent School District
3	(Not used)
4	Katy Independent School District
5	Spring Branch Independent School District
6	Cypress-Fairbanks Independent School District
7	Aldine Independent School District
8	North Forest Independent School District
9	Galena Park Independent School District
10	Pasadena Independent School District
11	Waller Independent School District
12	Tomball Independent School District
13	Klein Independent School District
14	Spring Independent School District
15	Humble Independent School District
16	Sheldon Independent School District
17	Channelview Independent School District
18	Deer Park Independent School District
19	Clear Creek Independent School District
20	Pearland Independent School District
21	Huffman Independent School District
22	Dayton Independent School District
23	Crosby Independent School District
24	Goose Creek Consolidated Independent School District
25	La Porte Independent School District
26	Stafford Municipal School District
27	Alvin Independent School District
28	Damon Independent School District
29	Danbury Independent School District
30	Angleton Independent School District
31	Brazosport Independent School District
32	Sweeny Independent School District
33	Columbia-Brazoria Independent School District
34	Needville Independent School District
35	Lamar Consolidated Independent School District
36	Fort Bend Independent School District
37	Kendleton Independent School District
38	Brazos Independent School District
39	Royal Independent School District

40	Hempstead Independent School District
41	Magnolia Independent School District
42	Montgomery Independent School District
43	Richards Independent School District
44	Willis Independent School District
45	New Caney Independent School District
46	Conroe Independent School District
47	Splendora Independent School District
48	Cleveland Independent School District
49	Tarkington Independent School District
50	Hardin Independent School District
51	Hull-Daisetta Independent School District
52	Devers Independent School District
53	Liberty Independent School District
54	Barbers Hill Independent School District
55	Anahuac Independent School District
56	East Chambers Independent School District
57	High Island Independent School District
58	Galveston Independent School District
59	Texas City Independent School District
60	Dickinson Independent School District
61	Friendswood Independent School District
62	Santa Fe Independent School District
63	Hitchcock Independent School District
64	La Marque Independent School District

Source: H-GAC

RTP Demographics and Modeling Data and Maps (2020 & 2045)

Houston-Galveston Area Council

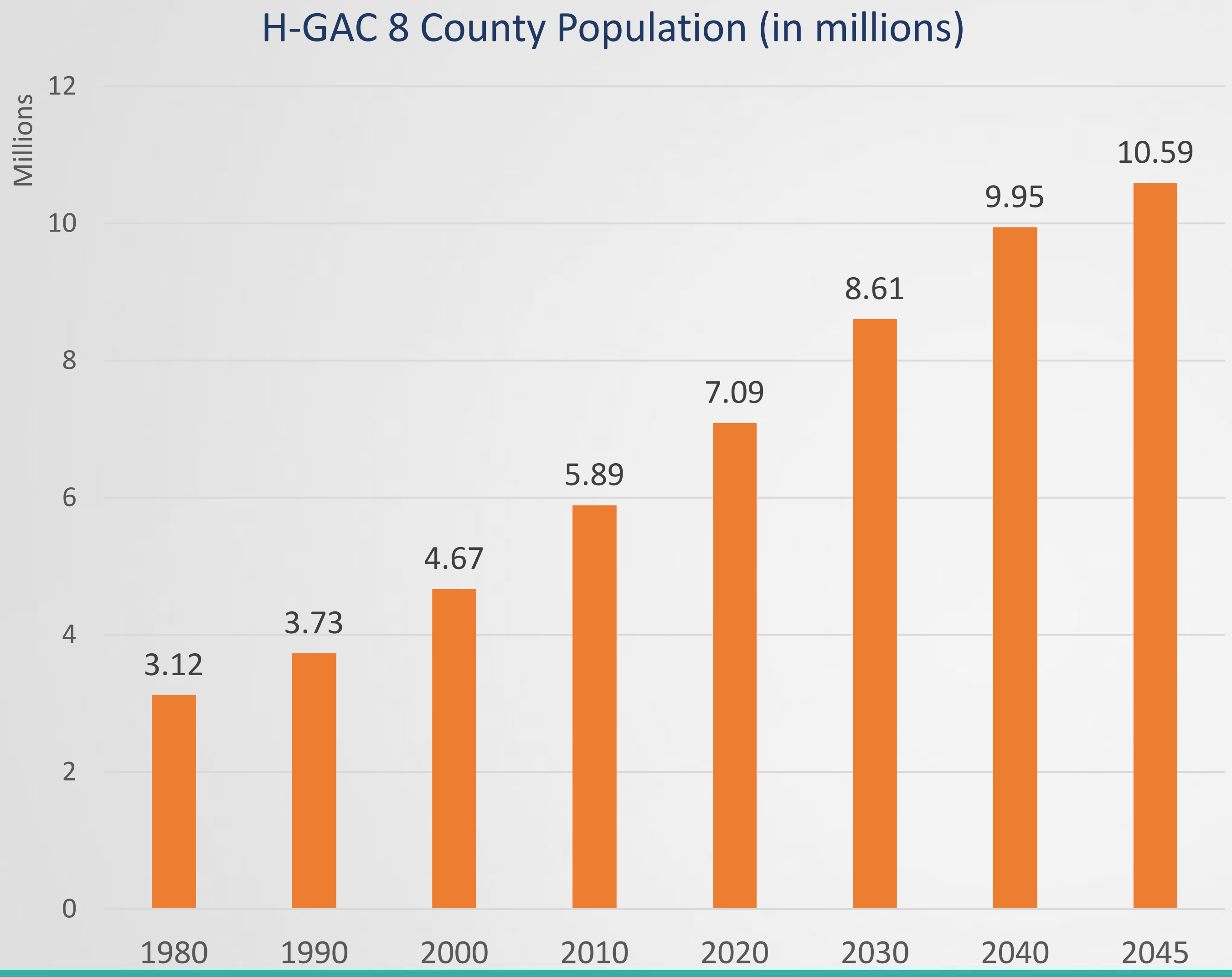
Regional Collaboration • Transportation Planning • Multimodal Mobility

RTP Demographics and Modeling Data and Maps

Included in this appendix:

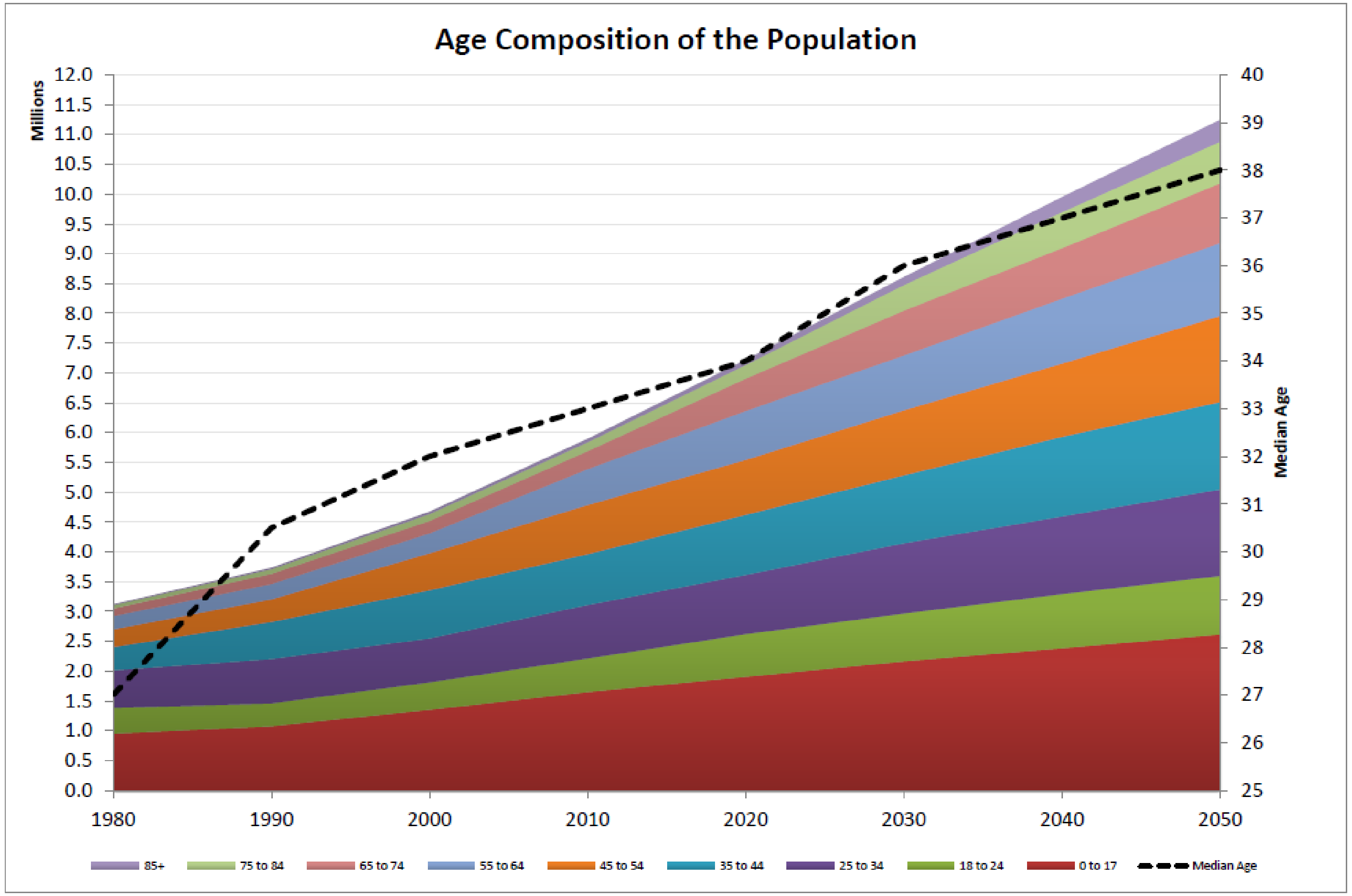
- Demographics Growth Forecast Charts and Maps
- Vehicle miles traveled(VMT), Vehicle hours traveled(VHT) and Delay Table
- PM Peak Period Congestion Maps
- Vehicle Travel Time Contour Maps
- Transit Travel Time Contour Maps

Historic Population and Projections



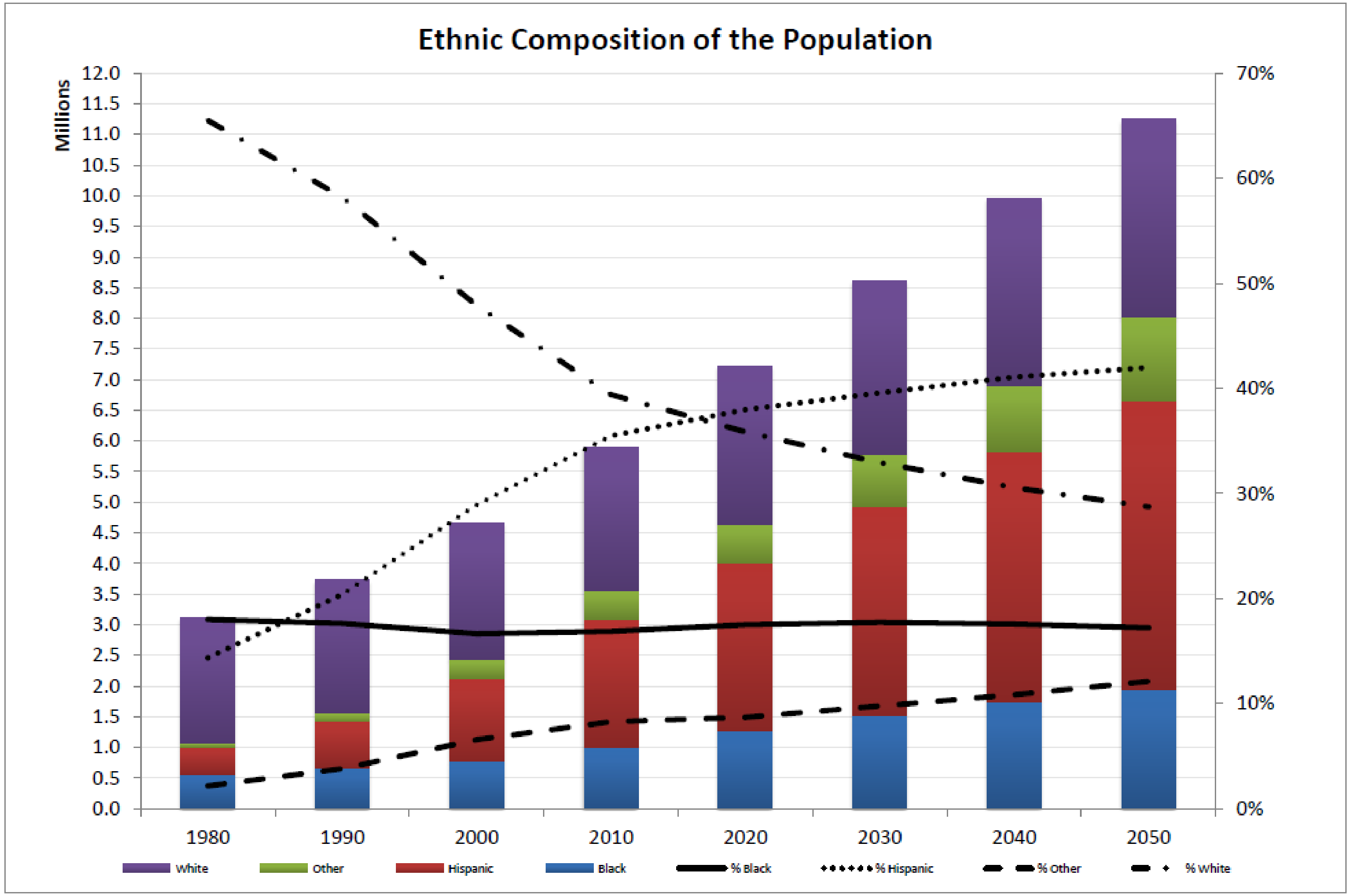
The H-GAC 8 County region added 1.2 million people each of the last two decades (2010 to 2020). The model predicts that the region will add 3.5 million people in the next 25 years.

Age Composition of the Population



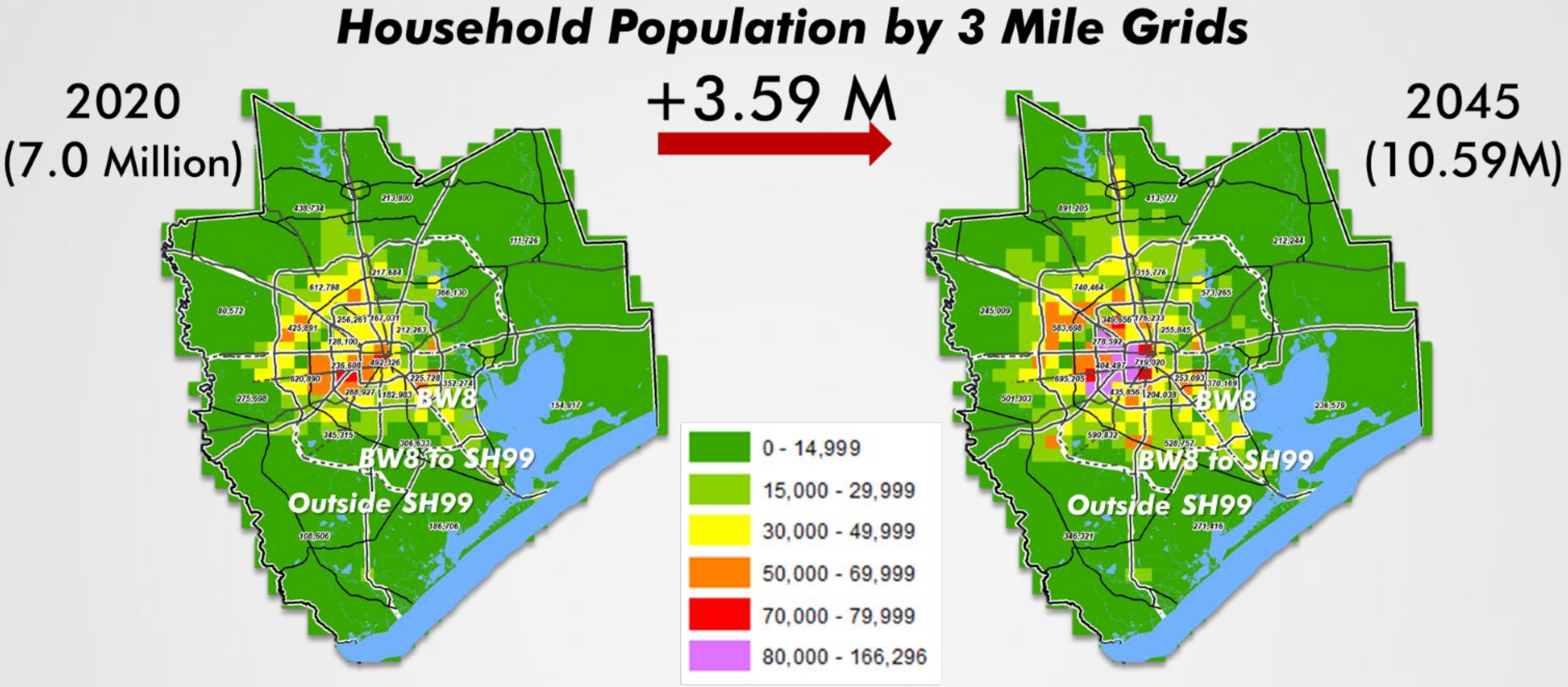
Short of a radical increase in the fertility rates, the share of the older cohorts in the population will increase gradually, driving the median age of the population from 33 in 2010 to close to 38 by 2050. The share of people 65 years and older will more than double, increasing from 9% in 2010 to close to 18% by 2050.

Ethnic Composition of the Population



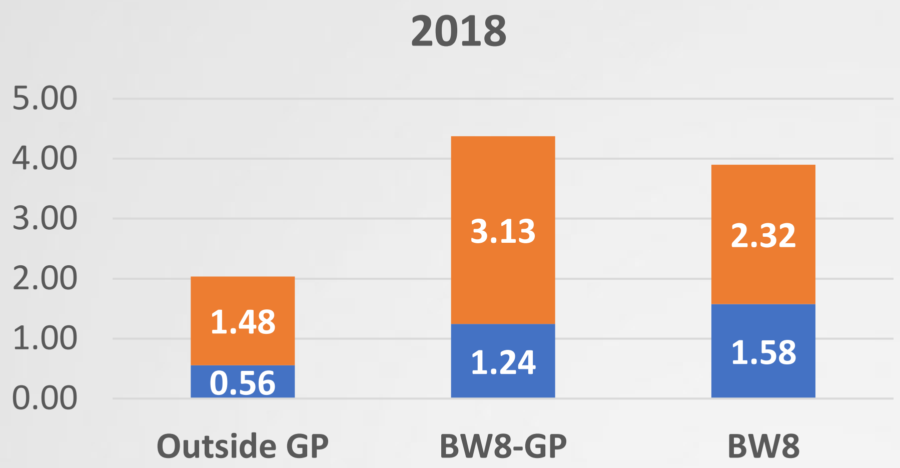
Our forecasting model also deals with ethnicity. While all groups will gain population in absolute terms, the relative shares will continue to change, most notably for the Hispanic and White populations. By the middle of the current decade, the share of Hispanic population is expected to equal (37%) that of the White population. By 2050, the share of the Hispanic population is expected to be over 40%. Ethnicity in our model is "inherited" by the child from the mother, which neglects the ethnicity of the other parent. As more and more children are being born from parents with different ethnicities, the meaning and usefulness of the current ethnic categories is likely to change.

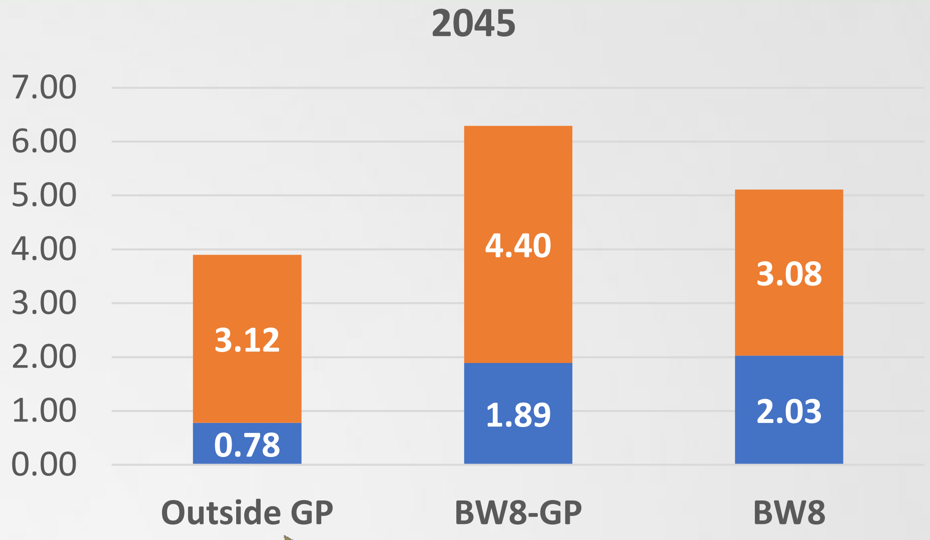
Regional Household Population

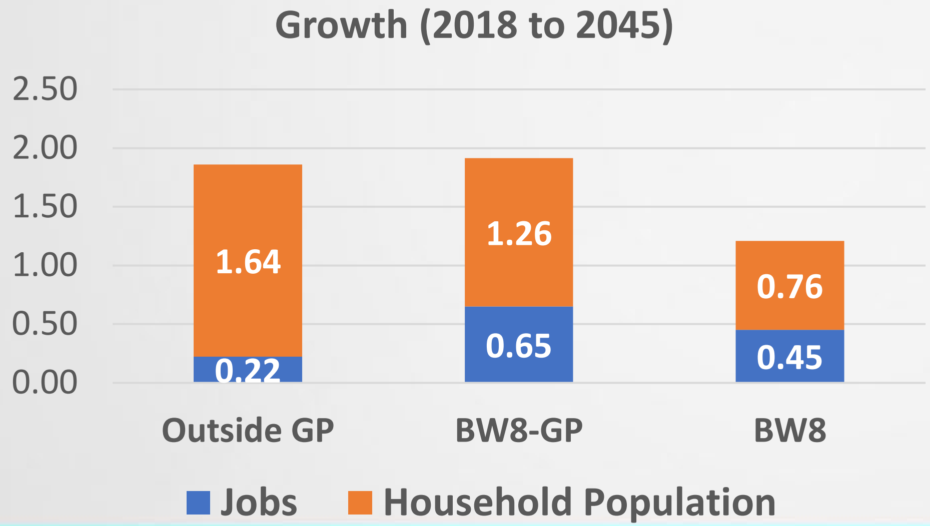


The Houston-Galveston area consistently ranks as one of the fastest growing metropolitan regions in the nation; fueled by a positive net migration and a relatively high rate of natural increase. The region's population grew about 2% annually from about 4.7 million residents in 2000 to over 7 million residents in 2020 – a 50% increase in 20 years. Since 1980, the region has grown on average by an additional one million residents per decade. The strong population growth trend is expected to slow slightly over the next 25 years to an annual growth rate of 1.7% with an estimated 10.6 million residents living in the region by the year 2045.

Household Population and Jobs (in millions) 2018-2045







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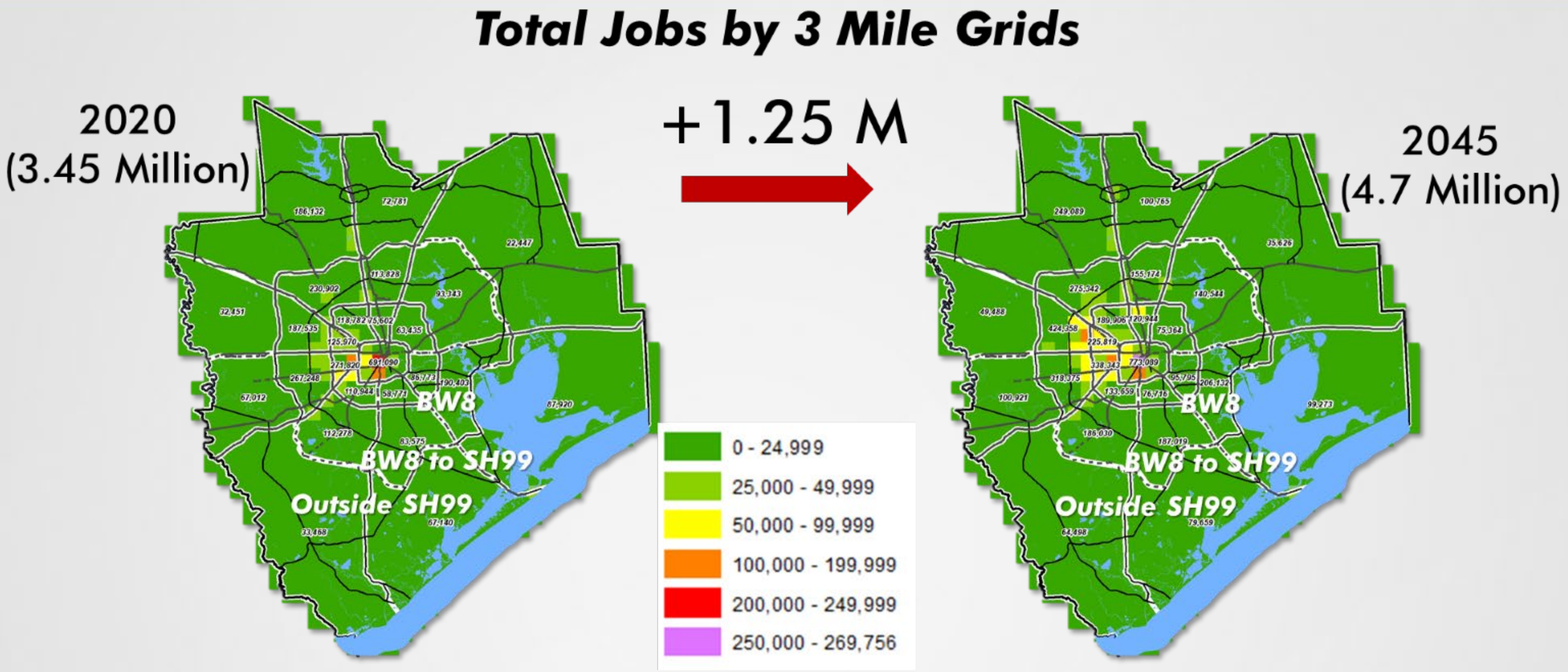
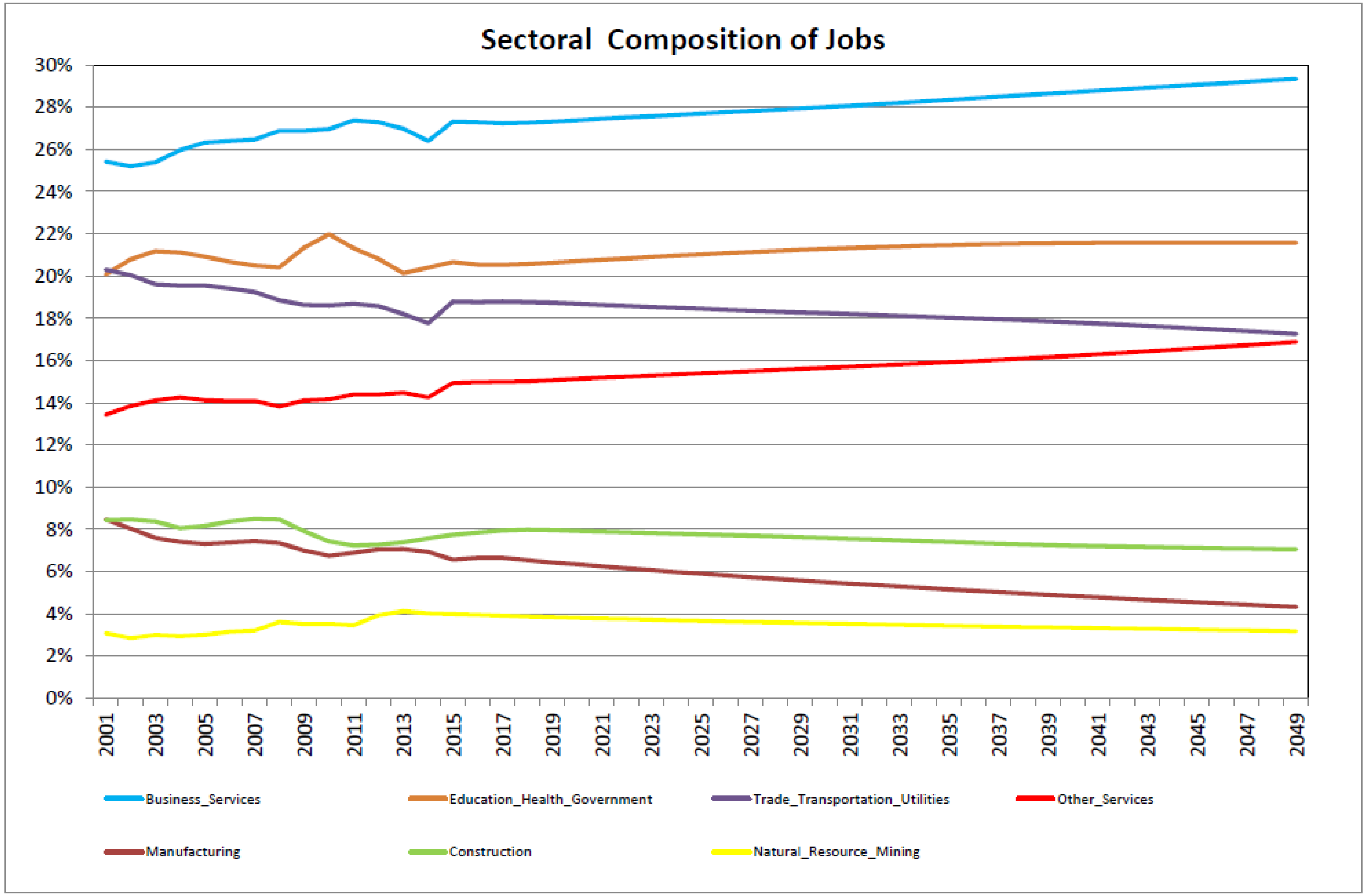
Regional Employment



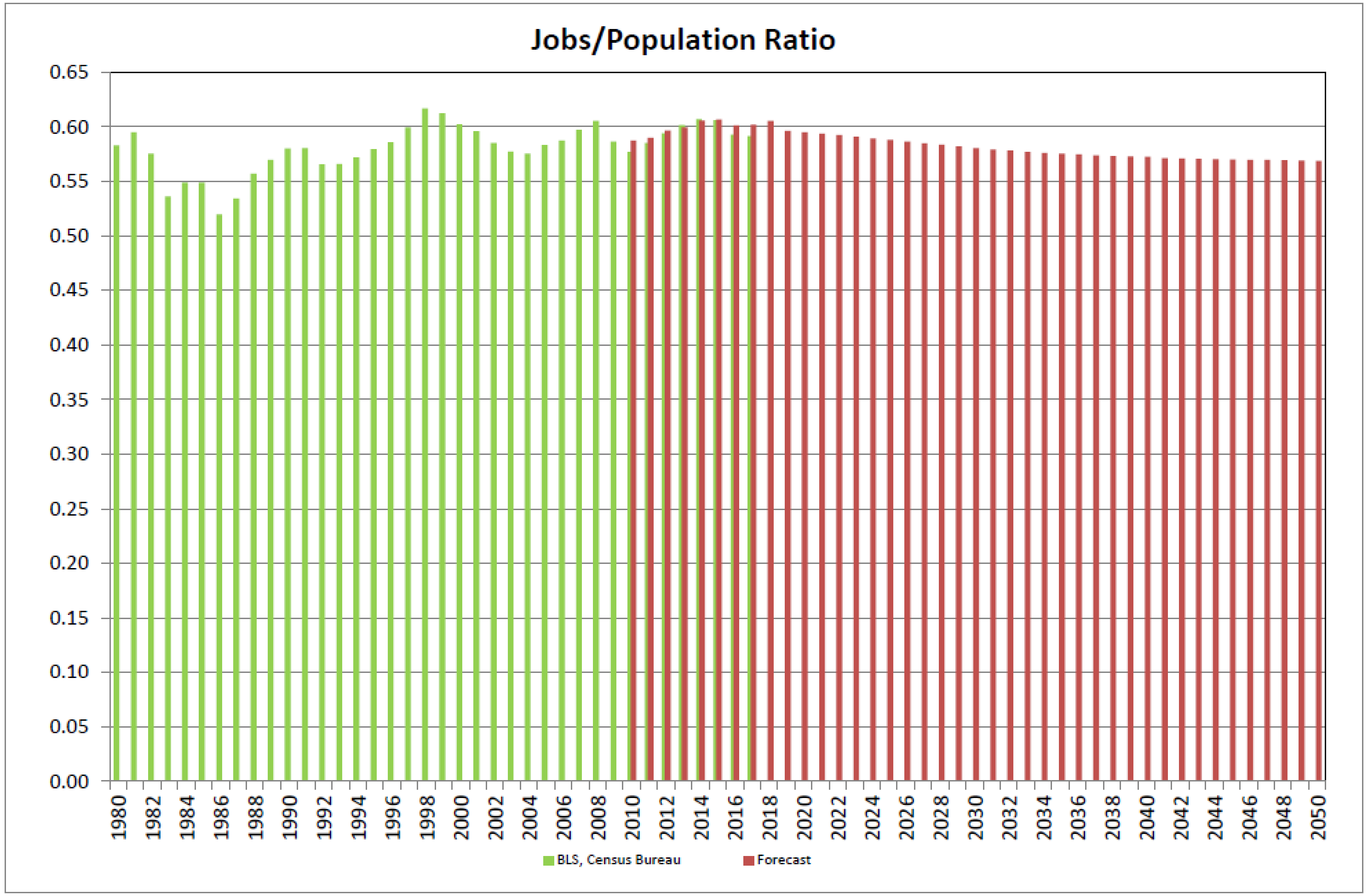
The Houston-Galveston region is one of the largest employment hubs in the nation. From 2000 to 2020, jobs in the region increased about 2% annually from about 2.3 million to over 3.4 million jobs. Over the next 25 years, employment is projected to slow to an annual increase of about 1.2%, adding about 4.7 million jobs by 2045.

Sectoral Composition of Jobs



Only minor shifts are expected in the sectoral composition of employment: by 2050, the share of manufacturing will drop by over 2 percentage points.

Jobs/Population Ratio



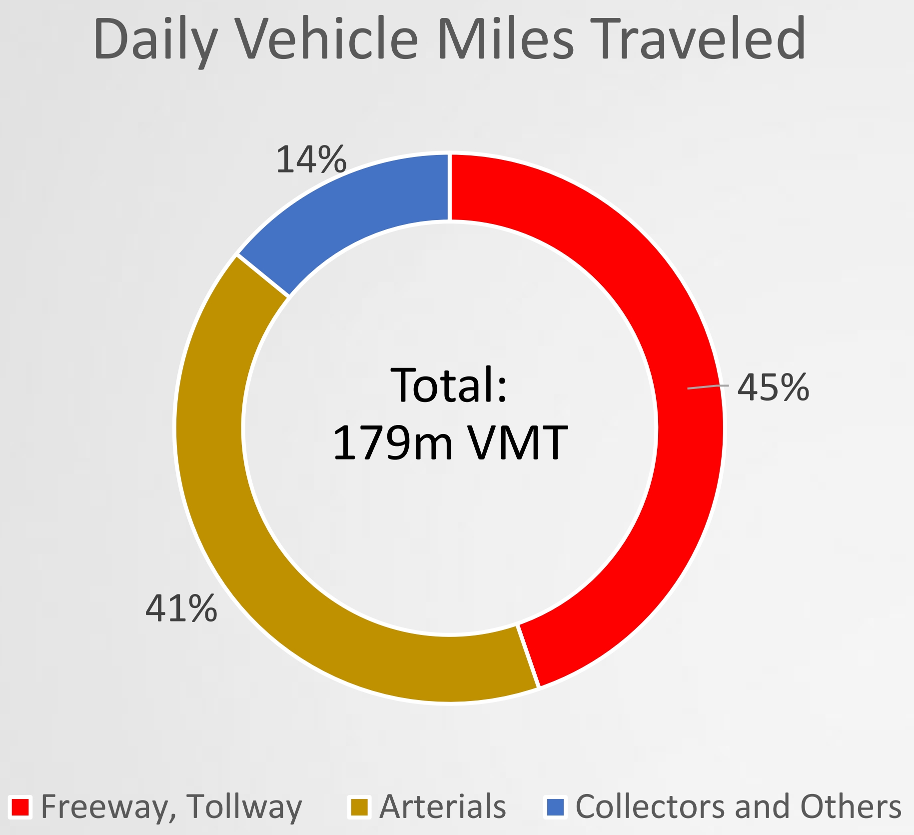
Jobs to population ratio responds to the changes in the employment as well as to the changes in the demographic composition of the population. While the job market is expected to remain strong in the future, the aging of the population will drive the ratio down. Nevertheless, over the next 35 years the ratio will remain well within the sustainable range.

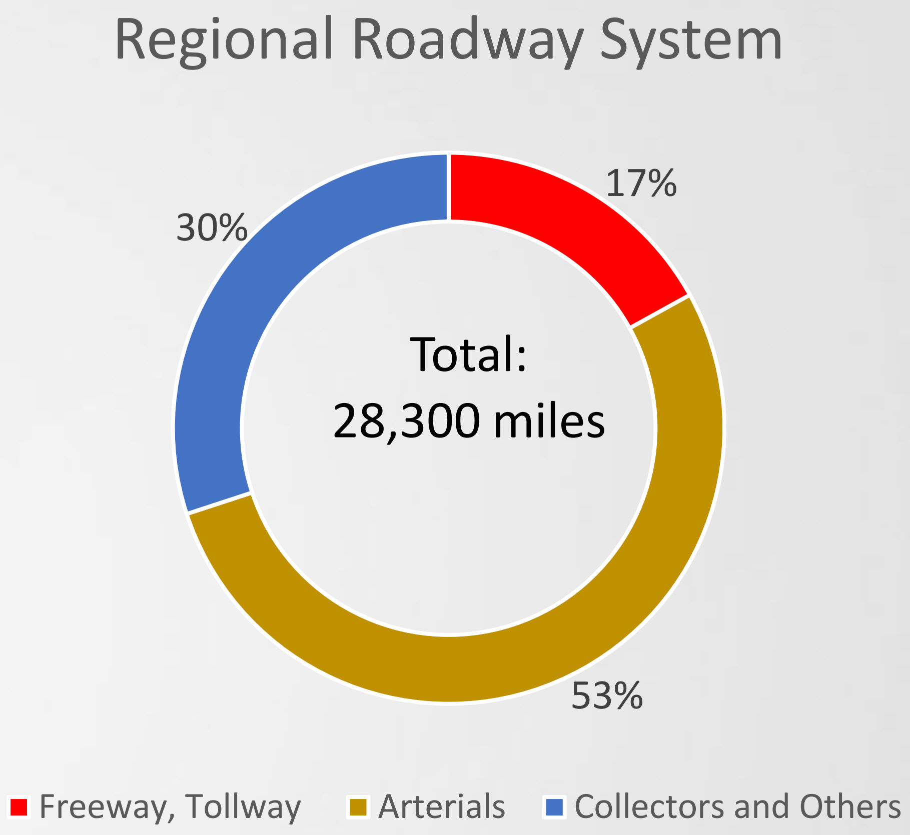
Travel Demand Modeling Key Performance Measures
(VMT, VHT & Delay)

Time of Day	VMT		VHT		Delay (Vehicle-Hours)	
	2020	2045	2020	2045	2020	2045
AM3hr	33,035,200	49,585,800	866,800	1,386,900	129,700	309,000
PM4hr	55,831,500	86,031,700	1,565,100	2,615,300	296,000	726,000
24hr	179,241,400	272,271,400	4,670,200	7,421,700	N/A	N/A

This table shows comparison of regional total vehicle miles traveled(VMT), vehicle hours traveled (VHT) and delay (in vehicle hours) for 2020 Base and 2045 horizon years, by daily, AM and PM peak periods. AM3hr peak refers to 6 AM to 9 AM and PM4hr peak refers to 3 PM to 7 PM. Delay is the difference of vehicle travel time while driving at peak-hour speed (congestion) and free-flow speed. It is only for peak periods, not for daily.

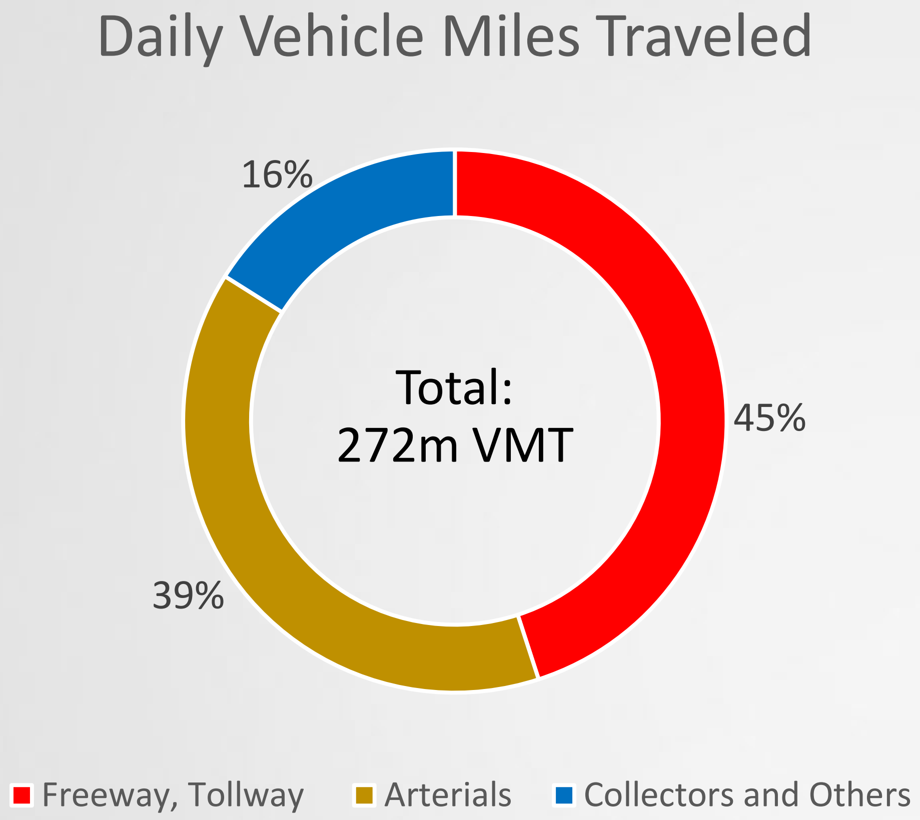
2020 Base Year Daily VMT, Lane Miles by Facility Type

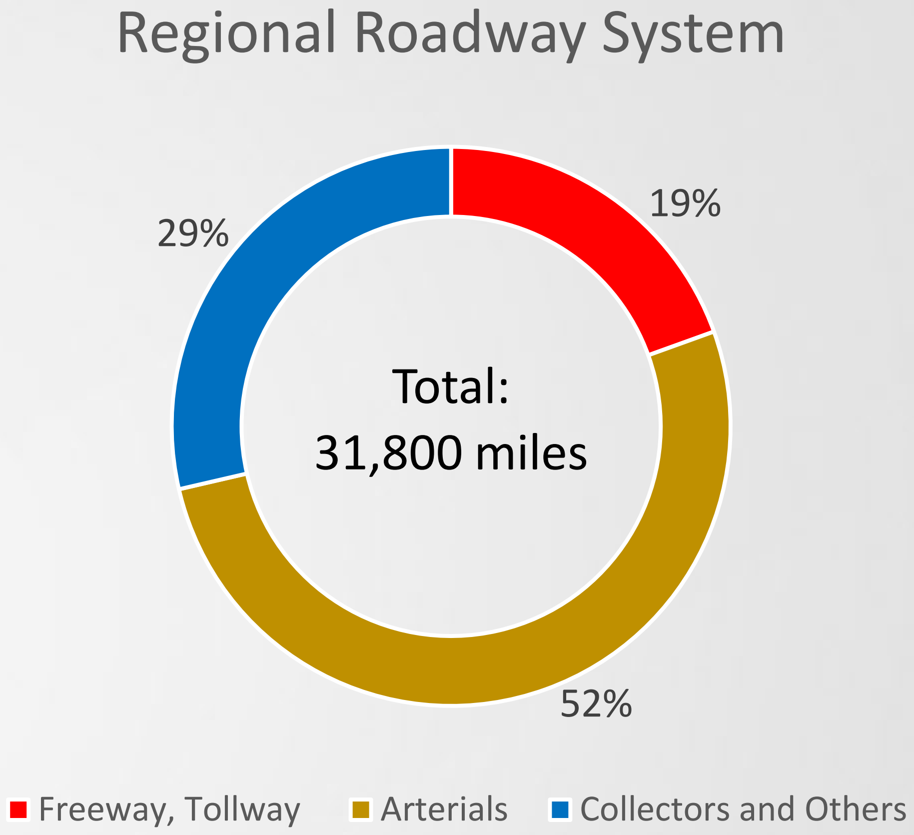




This shows the 24-hr percent share of the vehicle miles traveled by facility types and total lane miles of the H-GAC eight-counties regional highway network for the base year 2020.

2045 Daily VMT, Lane Miles by Facility Type





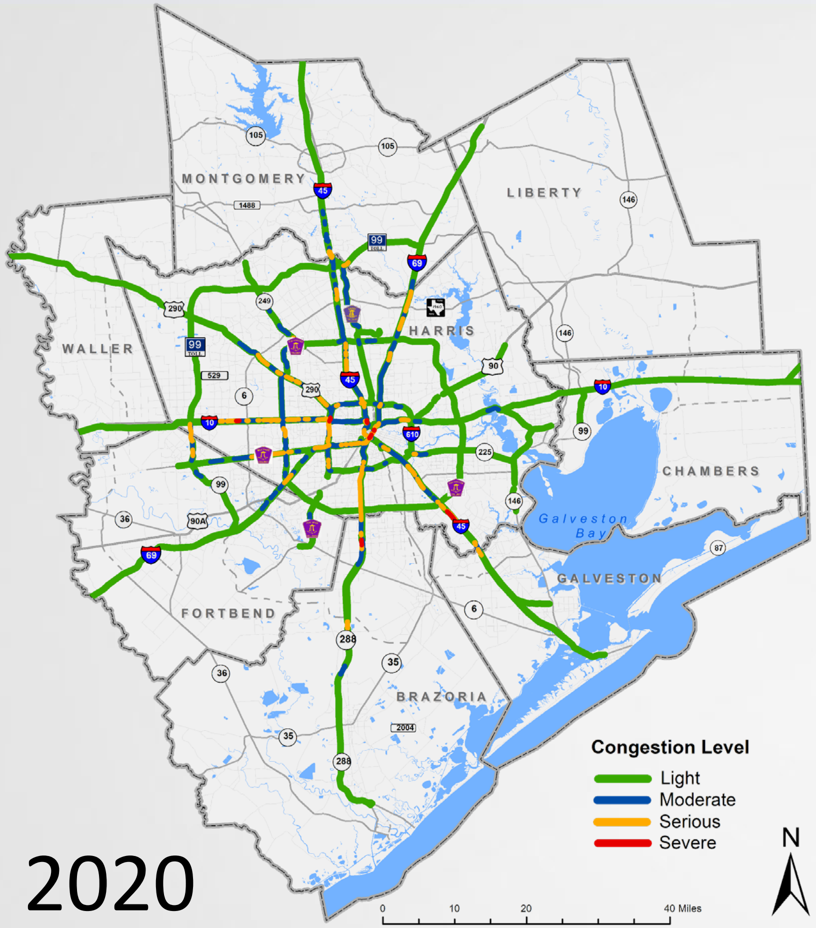
This shows the 24-hr percent share of the vehicle miles traveled by facility types and total lane miles of the H-GAC eight-counties regional highway network for horizon year 2045.

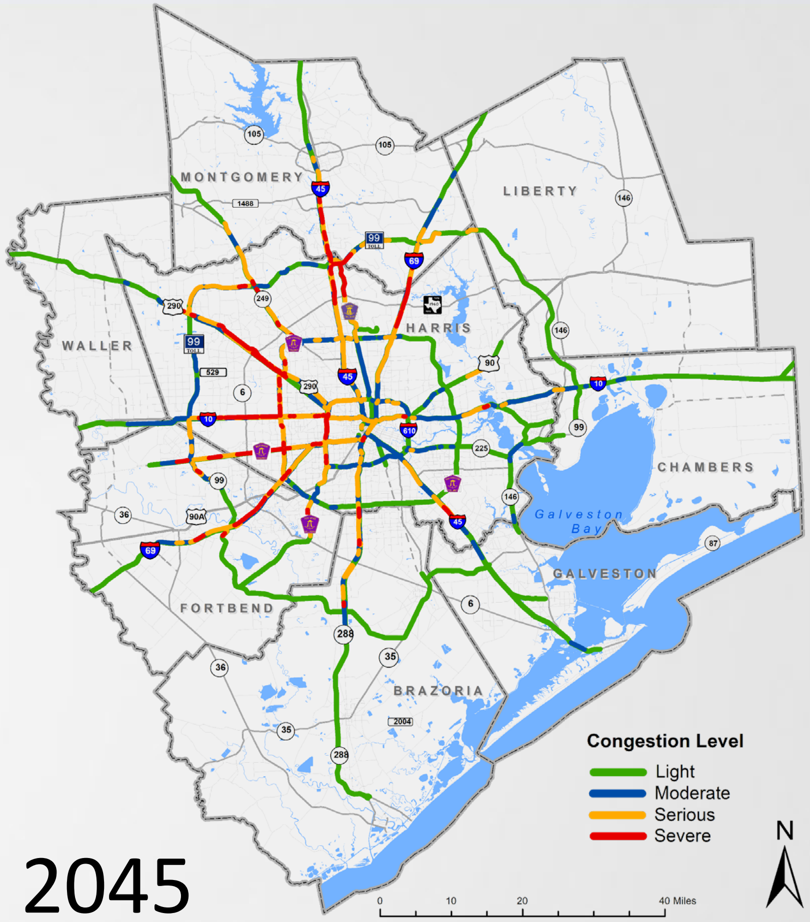
2020 & 2045 VMT, VHT, Delay Per V/C Category, PM 4hr

Facility	Level of Mobility	v/c Range	VMT		VHT		Delay (Vehicle-Hours)	
			2020	2045	2020	2045	2020	2045
Freeway, and tollway	Light	v/c ≤ 0.85	17,045,100	18,329,000	307,000	327,200	34,800	39,000
	Moderate	0.85 < v/c ≤ 1.00	4,726,900	7,595,000	111,700	173,700	32,900	49,600
	Serious	1.00 < v/c ≤ 1.25	2,306,300	8,751,800	61,100	232,000	22,900	88,600
	Severe	v/c > 1.25	132,500	3,513,800	4,000	110,400	1,800	54,000
Arterials	Light	v/c ≤ 0.85	18,507,700	18,048,200	605,200	579,000	79,300	79,900
	Moderate	0.85 < v/c ≤ 1.00	2,845,800	6,133,200	119,800	250,800	38,200	77,900
	Serious	1.00 < v/c ≤ 1.25	1,813,900	6,222,700	87,100	283,600	35,900	113,100
	Severe	v/c > 1.25	361,400	3,575,600	21,700	201,800	11,400	107,700
Collectors and Others	Light	v/c ≤ 0.85	6,621,800	8,070,300	192,400	229,100	21,600	26,600
	Moderate	0.85 < v/c ≤ 1.00	788,300	1,812,300	28,100	60,500	7,700	15,400
	Serious	1.00 < v/c ≤ 1.25	549,900	2,078,600	21,200	76,100	7,200	26,600
	Severe	v/c > 1.25	131,800	1,901,100	5,700	91,000	2,400	48,600

This table shows level of mobility for base year 2020 and horizon year 2045 by volume/capacity ratio categories for 4-Hr PM peak period. According to this table, because the VMTs for 2020 and 2045 are ≤ v/c ratio 0.85, the level of mobility is classified "light" for freeway and tollways.

Congestion Maps - 2020 & 2045 Freeway and Tollway 4-Hr PM Peak Period





PM Peak period traffic volumes are used to develop these congestion maps for years 2020 and 2045 because the PM Peak traffic volumes represents better traffic spread of other tree times of days (AM, MD-Day & OV-Night).

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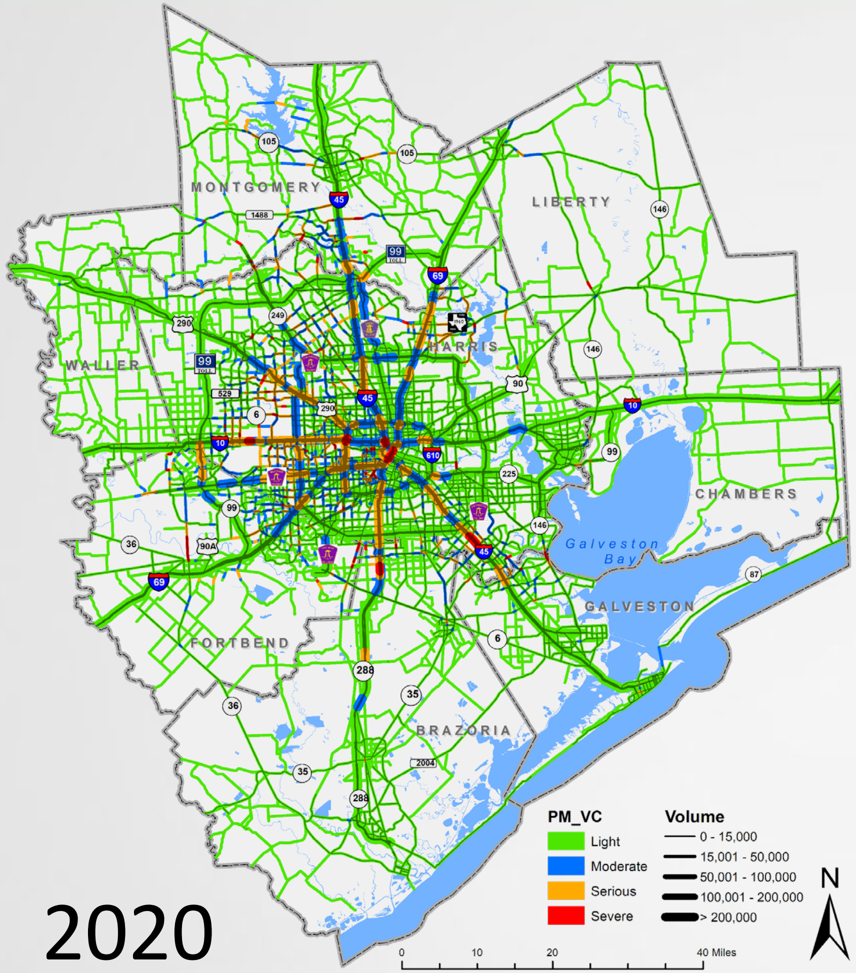
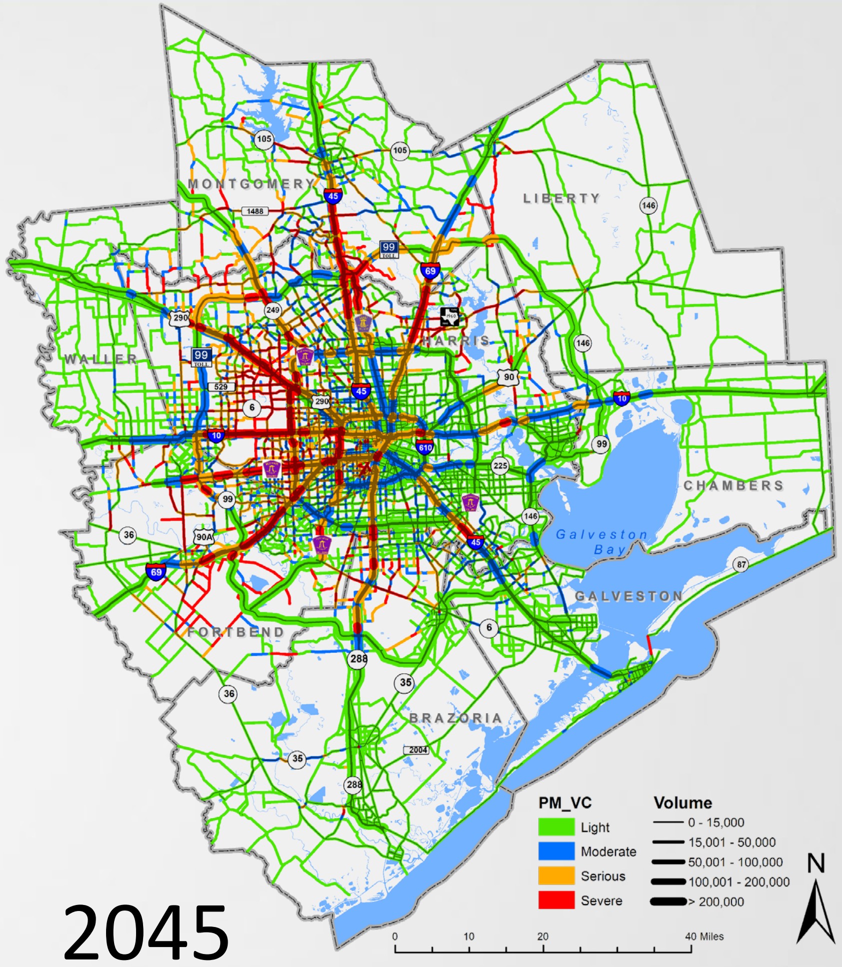
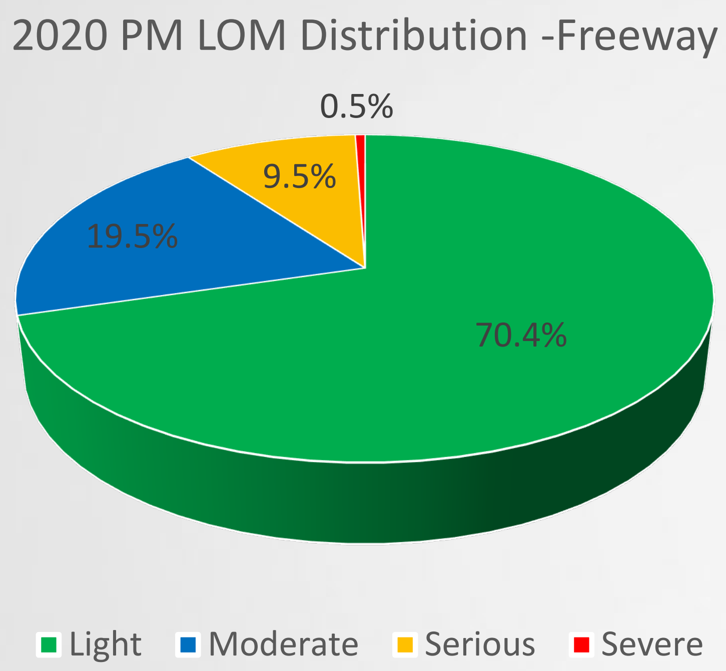
Congestion Maps - 2020 & 2045 4-Hr PM Peak Period for All Roadways

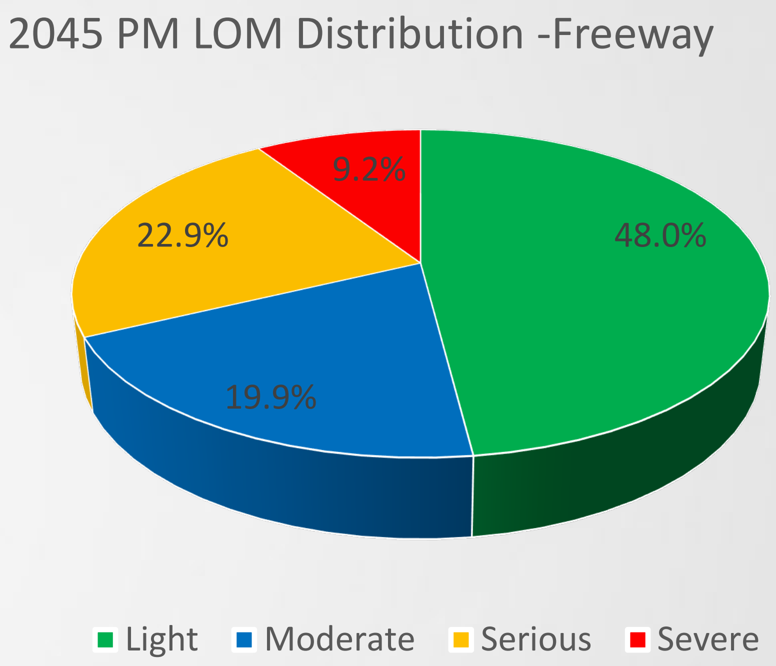




2020 & 2045 PM Peak period congestion maps for all facility types in the H-GAC Region.

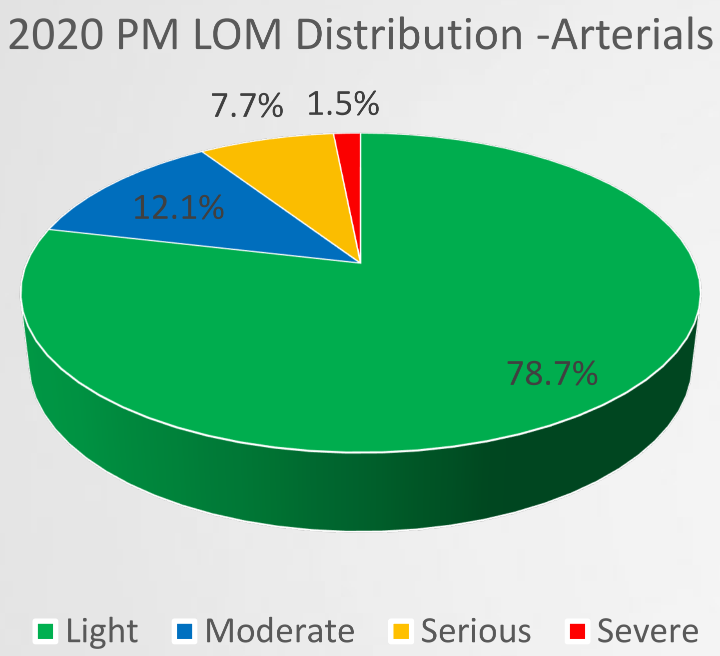
2020 & 2045 % PM Peak VMT by Level of Mobility for Freeway/Tollway/HOV

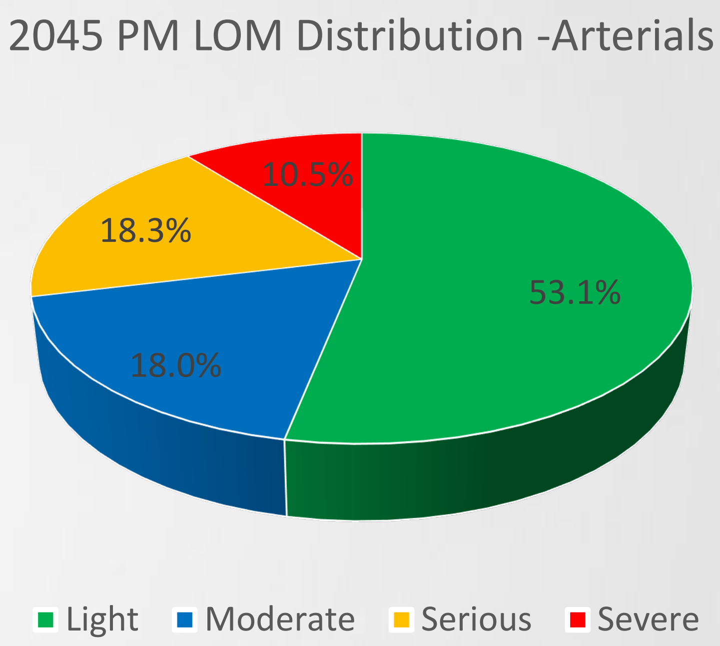




Each of these pie charts represents level of mobility for 2020 & 2045. On the 2020 pie chart, 0.5% of VMT is classified as “Severe”, 9.5% is classified as “Serious,” while on the 2045 pie chart, 9.2% of VMT is classified as “Severe”, 22.9% is classified as “Serious” for Freeway/Tollway/HOV in the model.

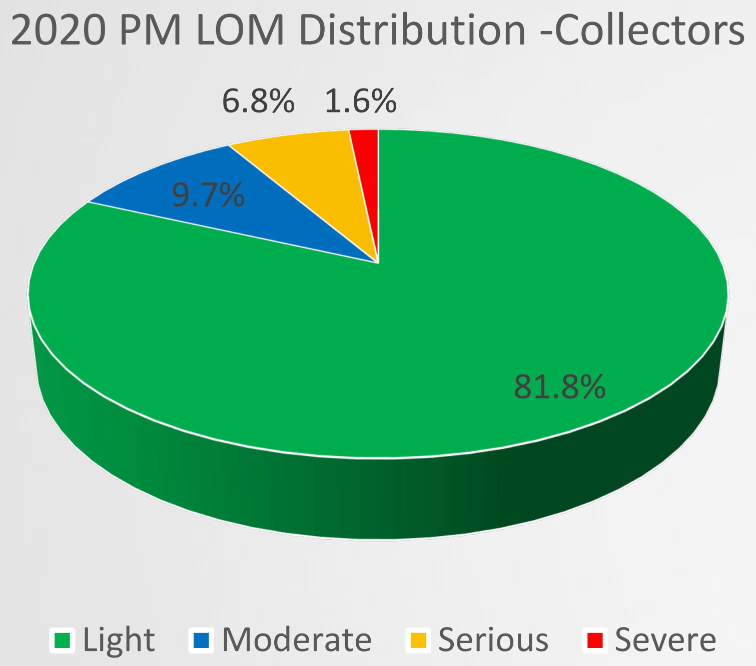
2020 & 2045 % PM Peak VMT by Level of Mobility for Arterials

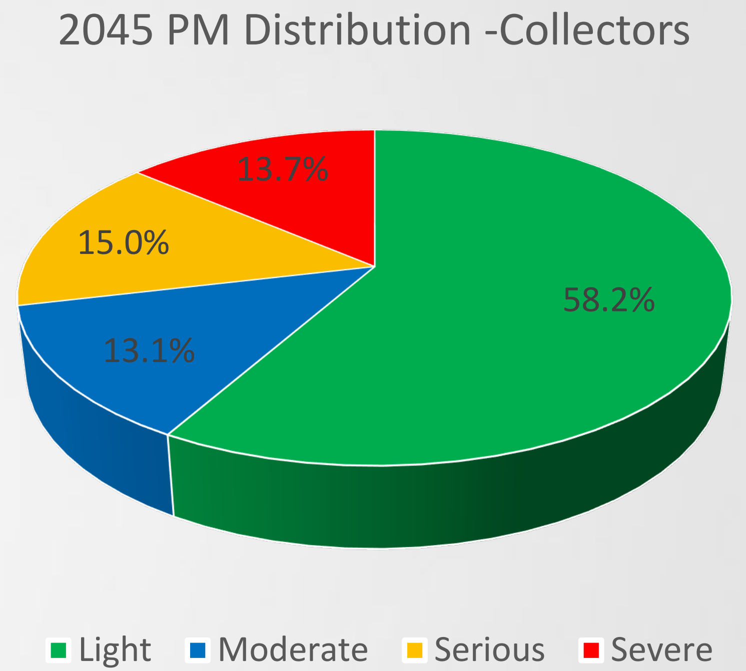




Each of these pie charts represents level of mobility for arterials in the model. On the 2020 pie chart, 1.5% of VMT is classified as "Severe", 7.7% is classified as "Serious," while on the 2045 pie chart, 10.5% of VMT is classified as "Severe", 18.3% is classified as "Serious".

2020 & 2045 % PM Peak VMT by Level of Mobility for Collectors





Each of these pie charts represents level of mobility for all collectors' facilities in the model. On the 2020 pie chart, 1.6% of VMT is classified as “Severe”, 6.8% is classified as “Serious,” while on the 2045 pie chart, 13.7% of VMT is classified as “Severe”, 15% is classified as “Serious.

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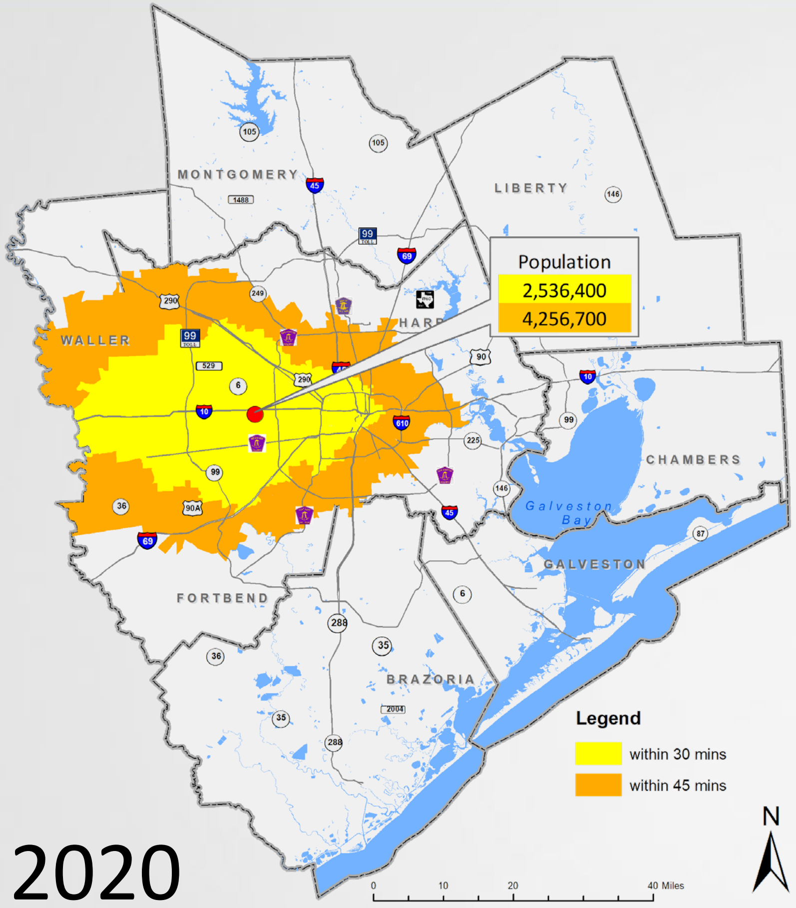
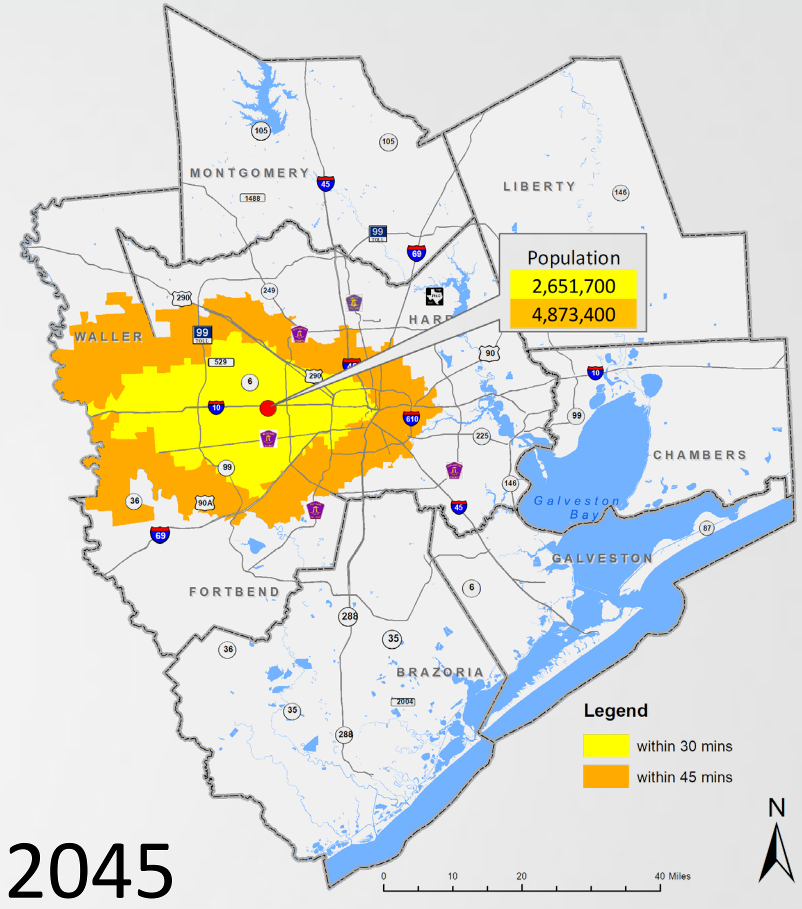
2020 & 2045 Outbound PM Peak Period Vehicle Commute Time from Four Major Activity Centers

- The next set of nine maps represent 4hr PM Peak Outbound vehicle travel times (30 & 45 minutes) maps and a transit PM Peak travel time map (45 minutes) with population of each shaded areas:
- (1) Energy Corridor
- (2) Hobby Airport
- (3) Sharpstown
- (4) Galveston

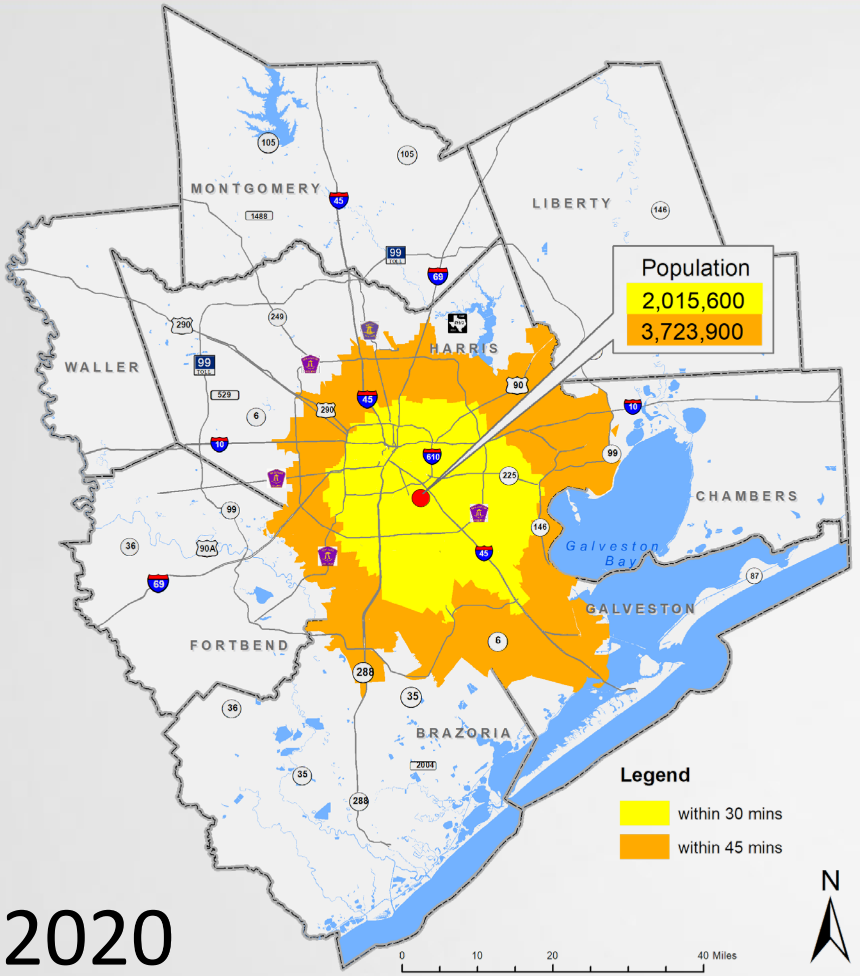
2020 & 2045 PM Peak Vehicle Travel Time
30 - Vs 45 - Minutes Comparison - Outbound Energy Corridor

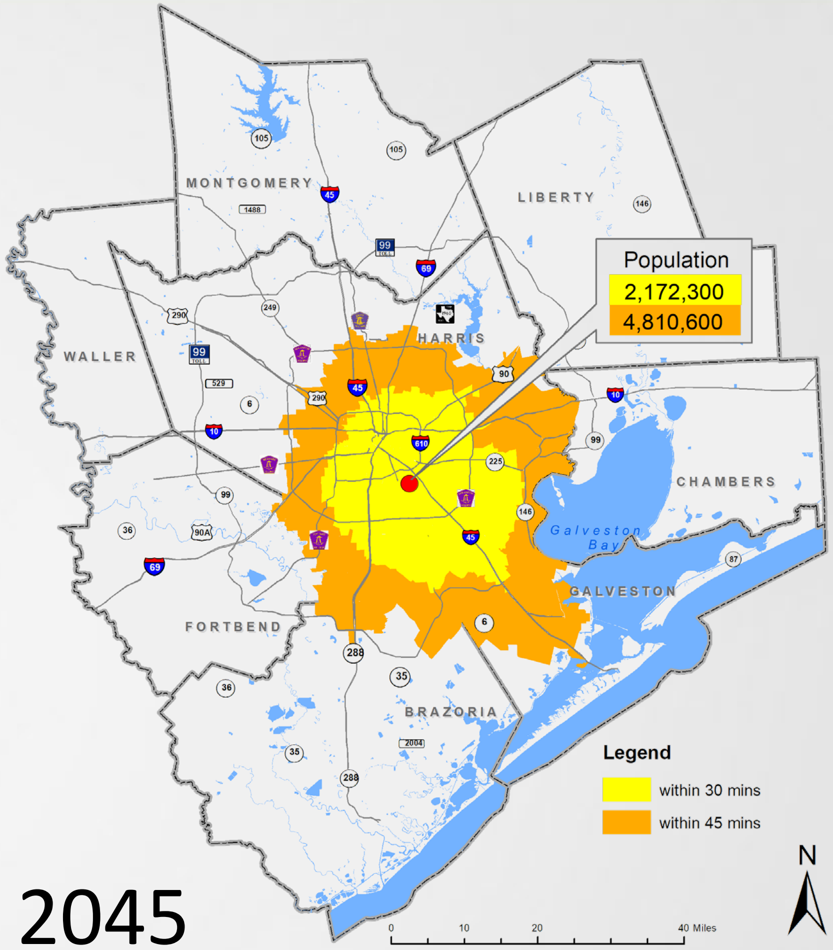




The shaded areas, in 2020 and 2045 are within 30- & 45-minutes PM peak time period travel time respectively, outbound the Energy corridor. The populations covered by these areas are as shown on the map, respectively.

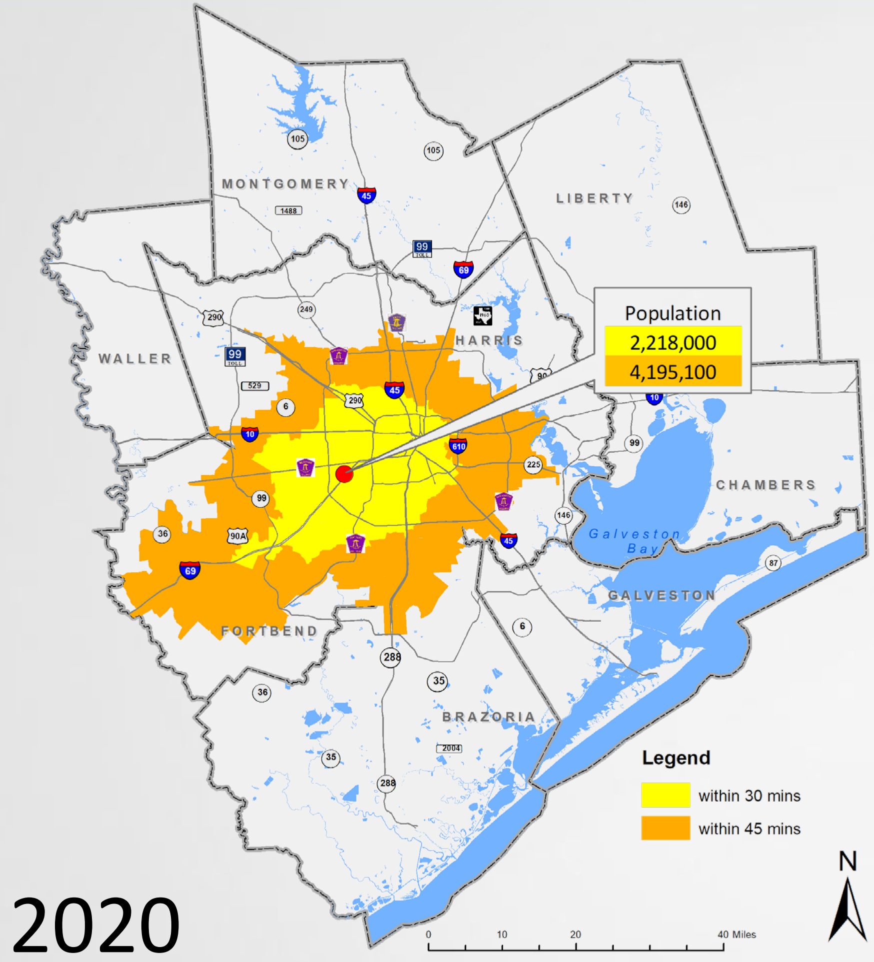
2020 & 2045 Vehicle Travel Time
30 - Vs 45 - Minutes Comparison - Outbound William Hobby Airport

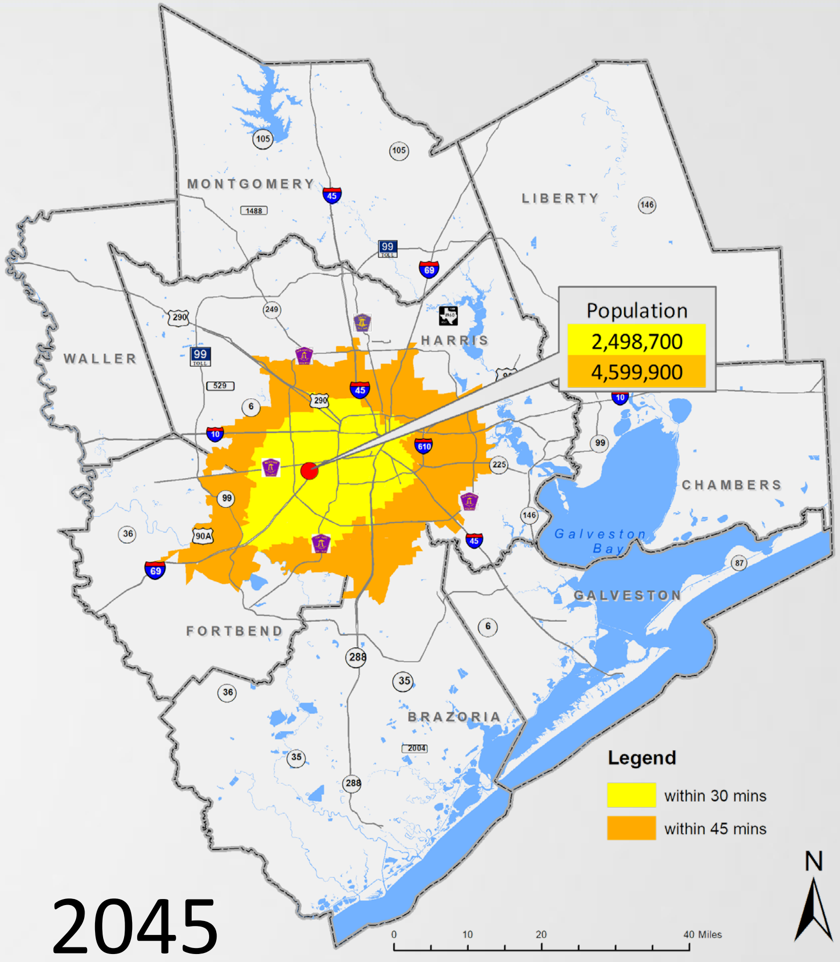




These maps represent same scenario as in the previous maps. This is for William P. Hobby Airport shown in “red dot”.

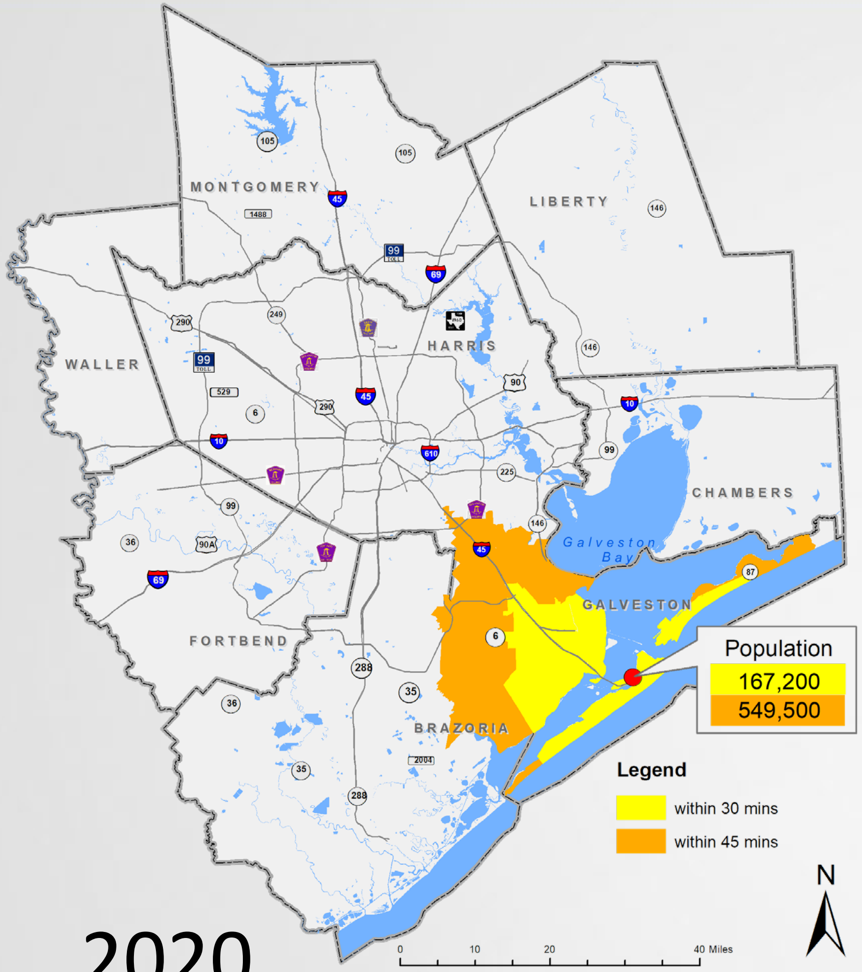
2020 & 2045 Vehicle Travel Time
30 - Vs 45 - Minutes Comparisons - Outbound Sharpstown



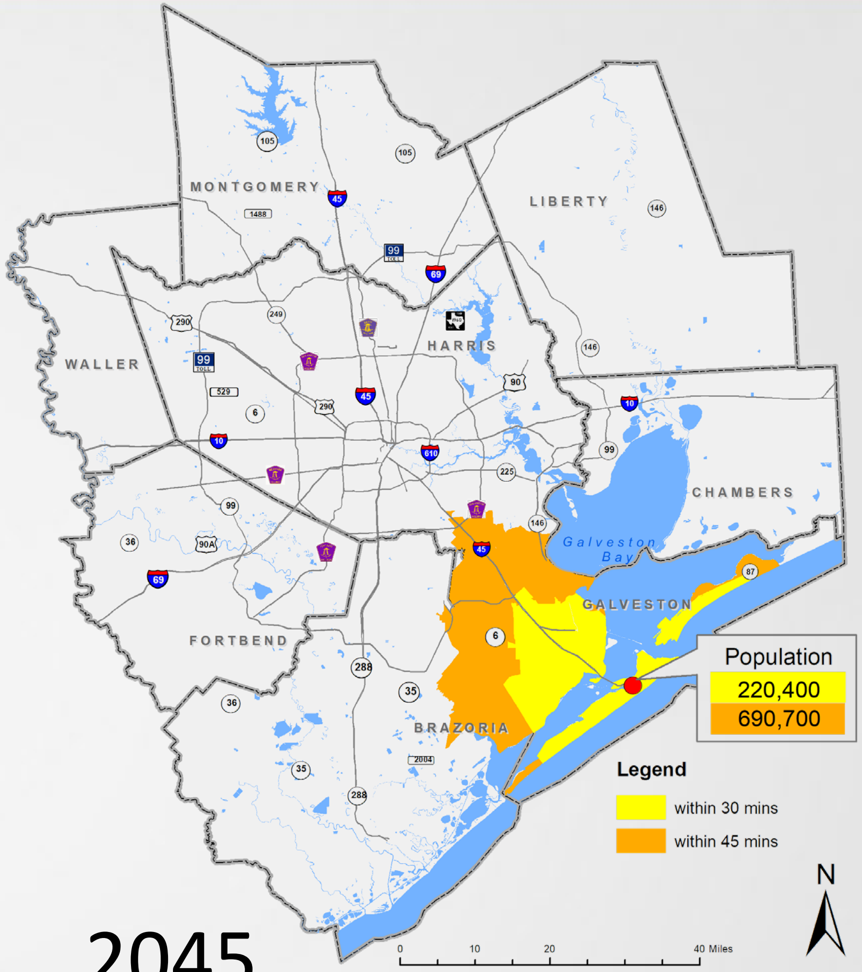


These maps represent same scenario as in the previous maps. This is for Sharpstown shown in "red dot".

2020 & 2045 Vehicle Travel Time
30 - Vs 45 - Minutes Comparisons - Outbound Galveston



2020

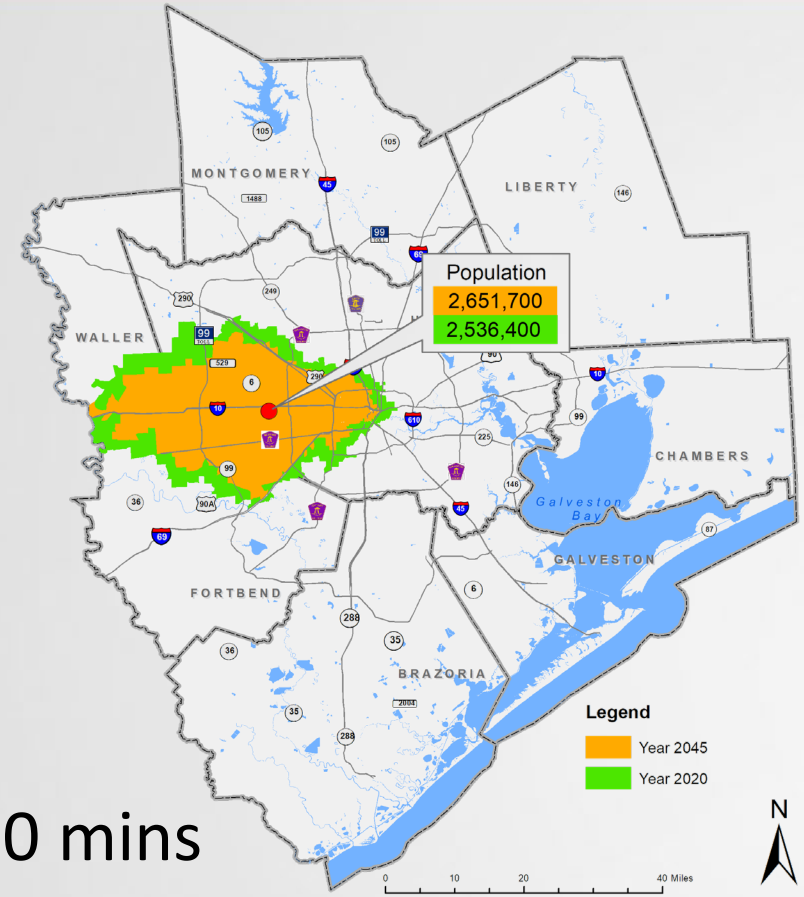


2045

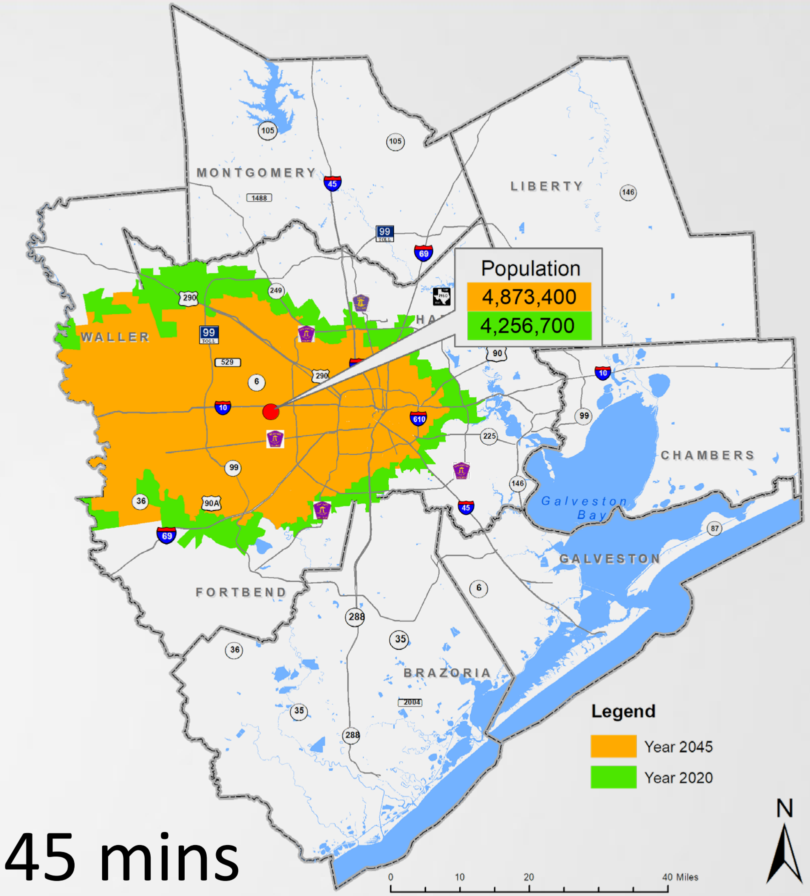
These maps represent same scenario as in the previous maps. This is for Galveston shown in “red dot”.

2020 & 2045 PM Peak Vehicle Travel Time

30 Vs 30 – Minutes & 45 Vs 45 - Minutes Comparisons, Outbound Energy Corridor



30 mins

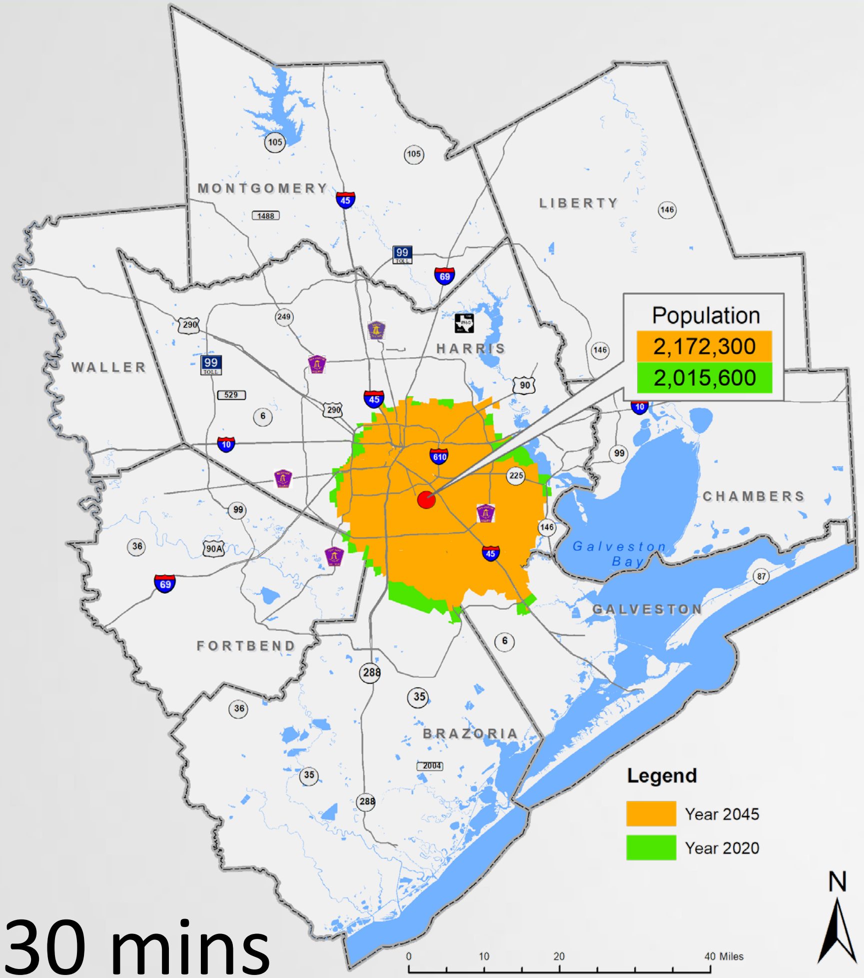


45 mins

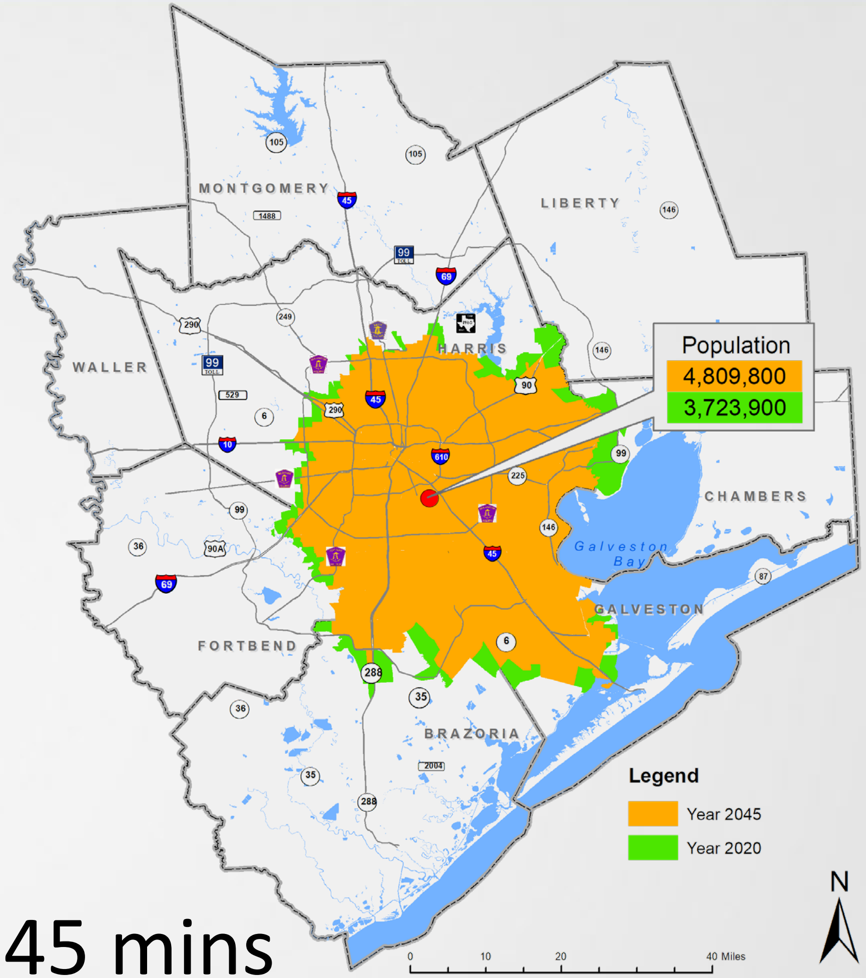
The difference between these next set of four activity centers maps and the previous maps is that the 30 - minutes PM Peak period travel time (shaded areas) for 2045 & 2020 are overlayed on top of each other, same for the 45 – minutes. The populations covered by these areas area are as shown on the map for each scenario year.

2020 & 2045 PM Peak Vehicle Travel Time

30 Vs 30 – Minutes & 45 Vs 45 - Minutes Comparisons, Hobby Airport



30 mins

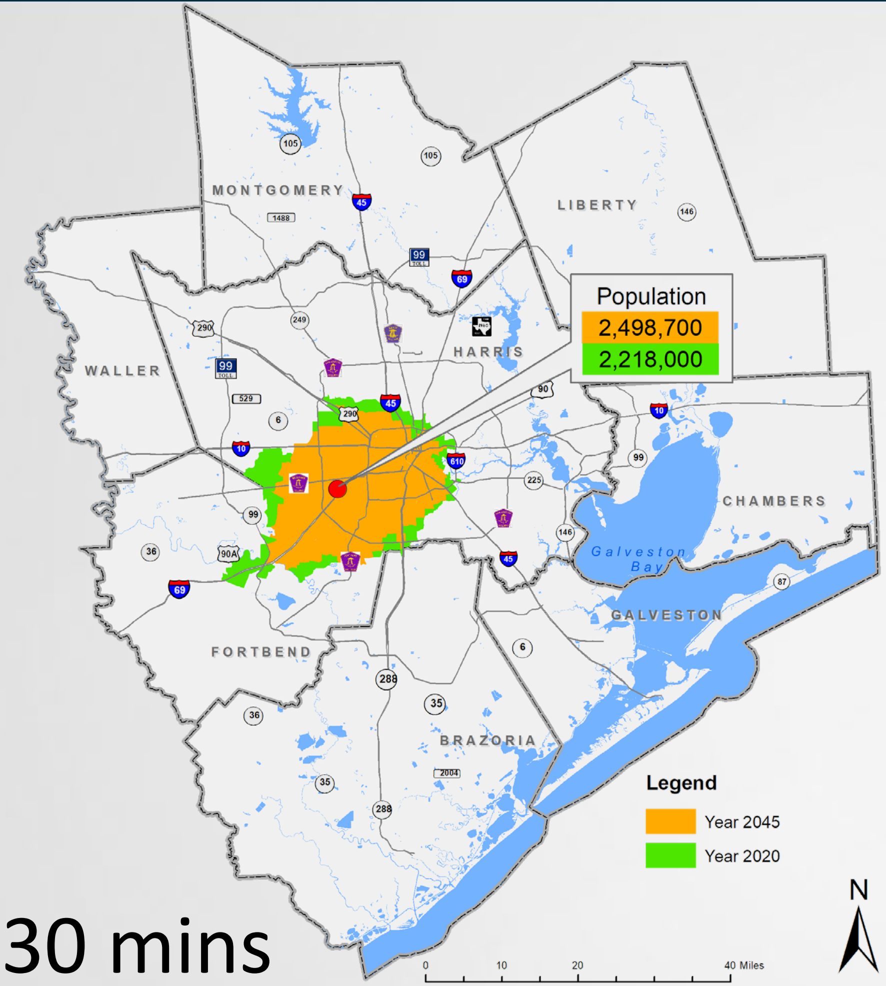


45 mins

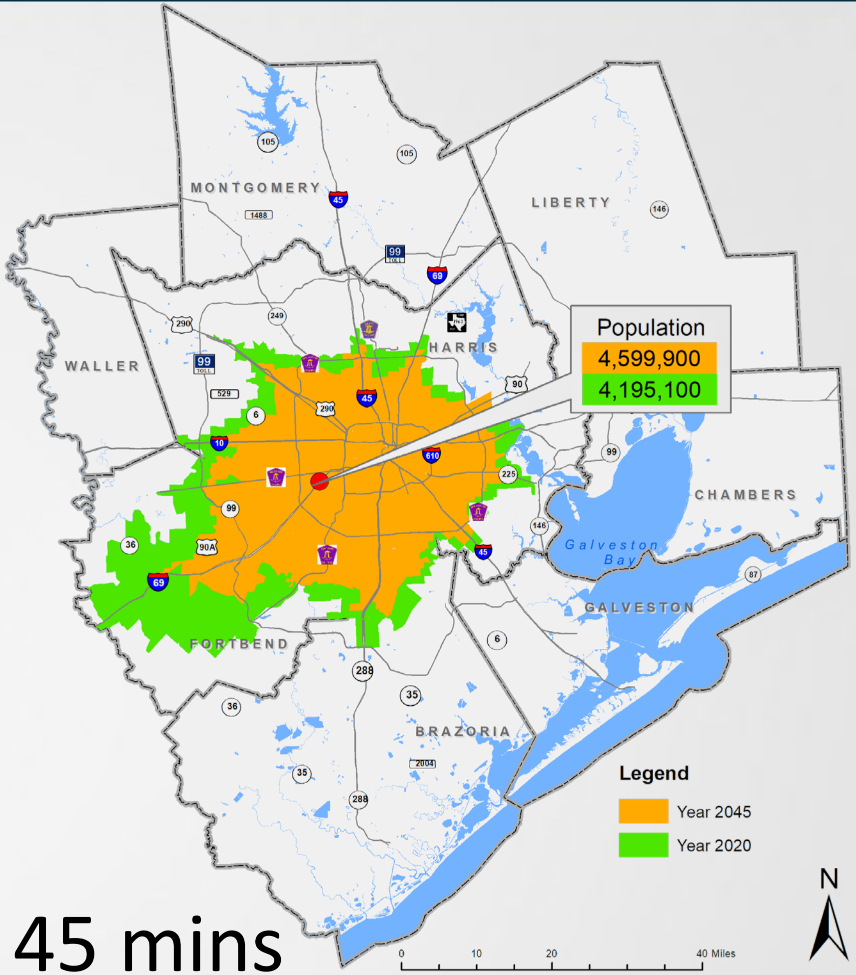
These scenarios represent same in the outbound direction of William P. Hobby Airport indicated with a “red dot”.

2020 & 2045 PM Peak Vehicle Travel Time

30 Vs 30 – Minutes & 45 Vs 45 - Minutes Comparisons, Sharpstown



30 mins

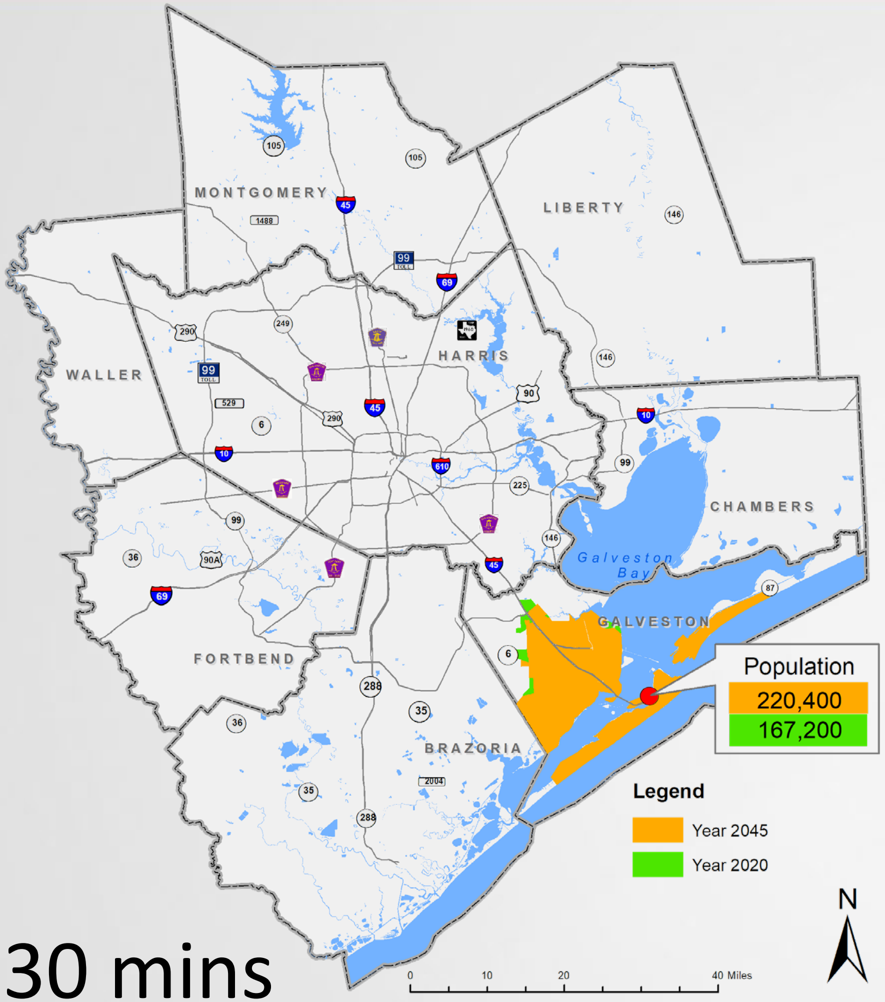


45 mins

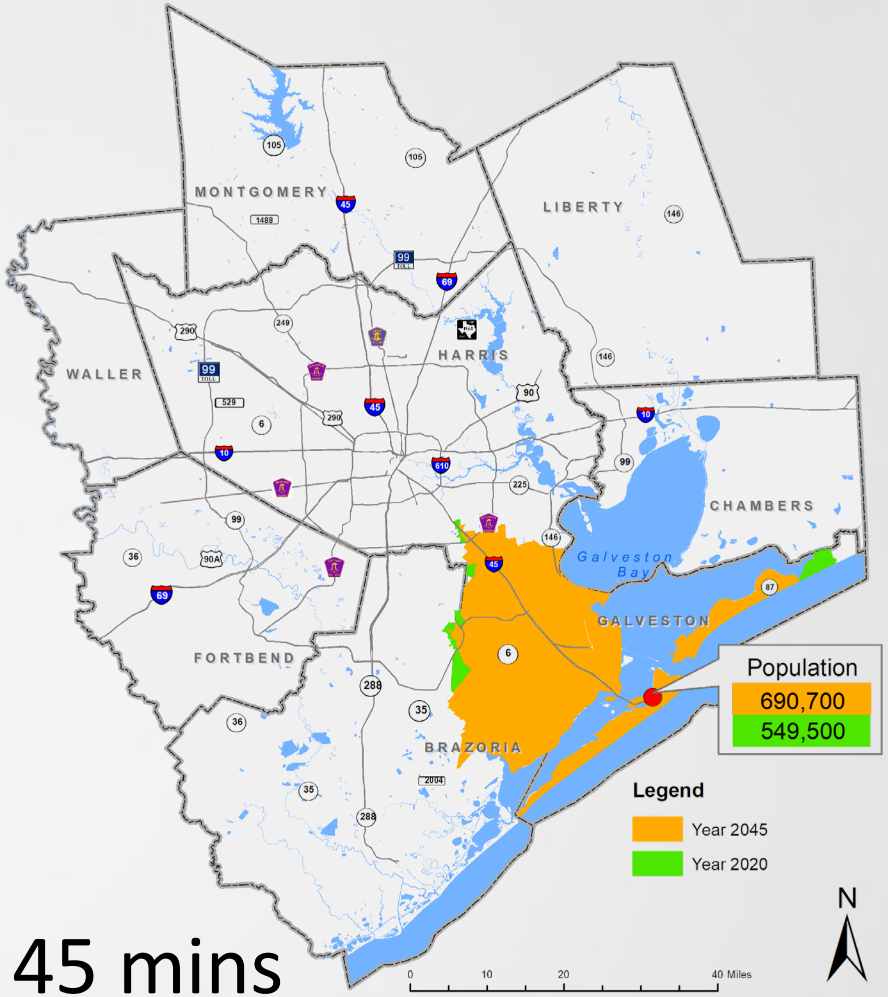
The Sharpstown activity center (red dot) scenarios are shown in the above maps.

2020 & 2045 PM Peak Vehicle Travel Time

30 Vs 30 – Minutes & 45 Vs 45 - Minutes Comparisons, Galveston



30 mins

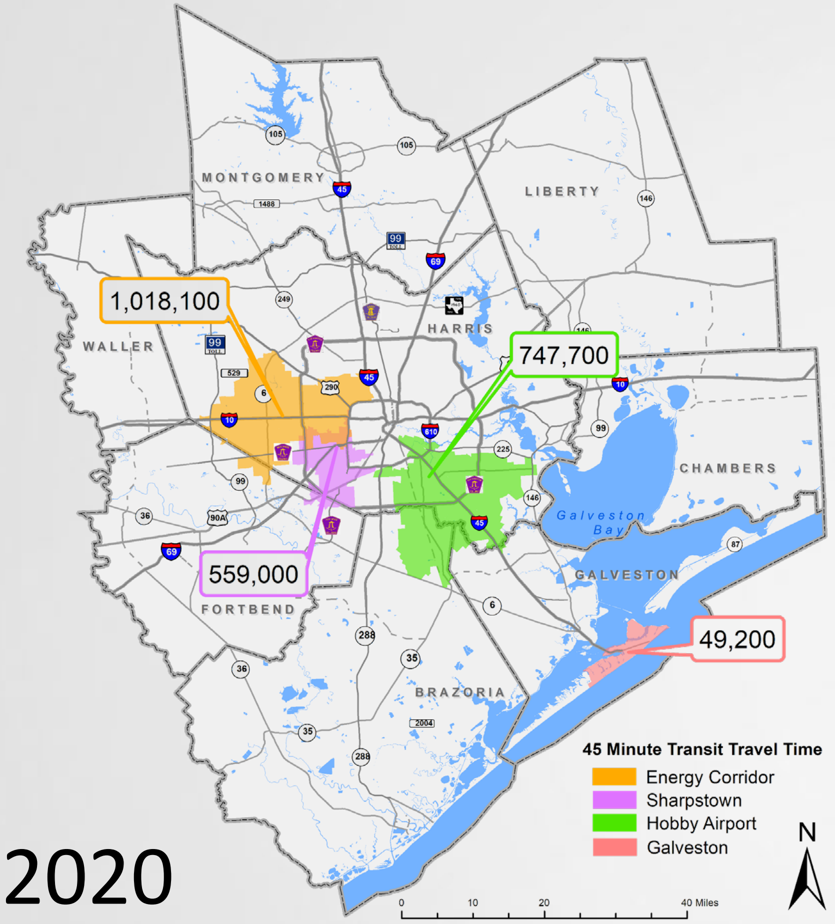


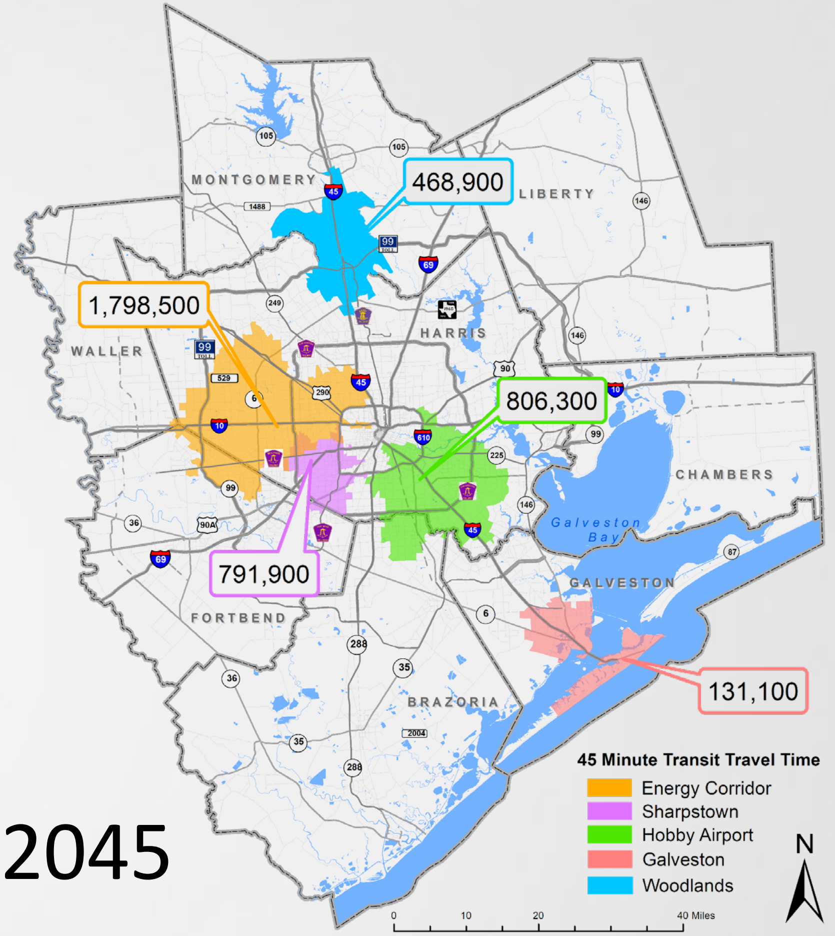
45 mins

The above maps represent the Galveston scenarios.

2020 & 2045 45-mins PM Peak Transit Travel Time

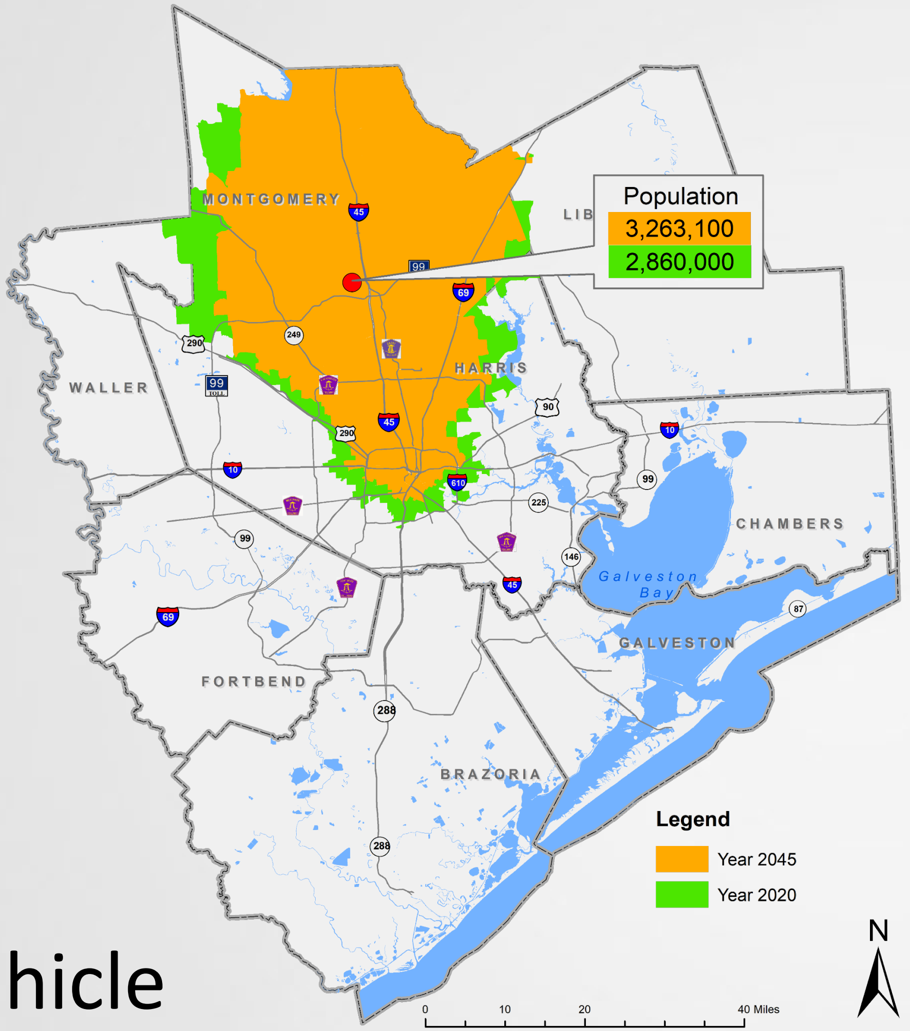
Outbound from Activity Centers



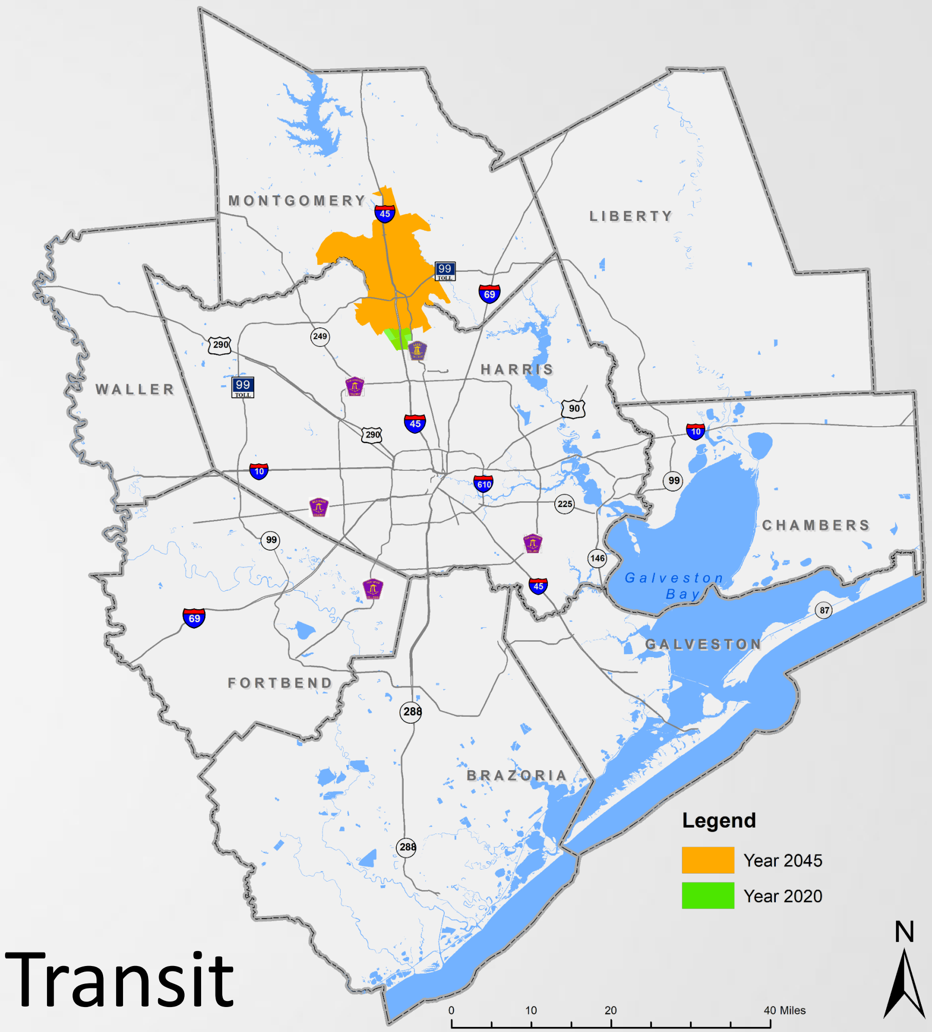


These maps show the populations for 45-minutes PM Peak period transit commute time outbound each of the major activity centers for base year 2020 and horizon year 2045.

2020 & 2045 PM Peak Vehicle and Transit Travel Time
45 – Minutes Comparison, Woodlands



Vehicle



Transit

Houston-Galveston Area Council