Dallas to Houston High-Speed Rail
Final Environmental Impact Statement

Appendix J:
Miscellaneous Memoranda

Federal Railroad
Administration

AECOM

TECHNICAL MEMORANDUM

RIDERSHIP DEMAND FORECASTING METHODOLOGY ASSESSMENT

To: Kevin Wright, FRA

From: Laura McWethy, AECOM

Date: November 7, 2019

RE: **Dallas to Houston HSR–Ridership Demand Forecasting Methodology Assessment**

This technical memorandum provides review of ridership demand forecasting methodology presented by Texas Central Railroad for use in forecasting ridership for the Texas Central High Speed Train (TCHST) and summarizes information presented in the TCHST Ridership Forecast Report dated March 25, 2019. This updated report follows a similar methodology to the previous Ridership Report dated June 19, 2018, but includes several refinements and contains the results of an updated travel survey effort. This memo focuses only on the methodology presented in the March 25th, 2019 report, which builds on, but differs in some ways from the June 19th, 2018 report, which AECOM had previously reviewed. In support of the Environmental Impact Statement, AECOM was requested to independently review and assess the suitability of the methodology on behalf the Federal Railroad Administration. This review does not constitute a validation of the model results but simply an assessment of the methodology.

Based on AECOM's review of the forecast documentation and discussion with Texas Central Railroad and L.E.K., who developed the methodology, the methodology used to forecast ridership is acceptable and consistent with the state of the practice for intercity rail forecasting. All components of the methodology were well-structured and at or above industry standards. Table 1 identifies specific elements of each component of the methodology and their suitability to intercity rail forecasting.

Table 1. Model Component Assessment

Model Component	Assessment	Fatal Flaws
Model Structure	Acceptable	None
Geographic Coverage	Acceptable	None
Survey	Acceptable	None
Total Travel Demand	Acceptable	None
Mode Choice	Acceptable	None

Source: AECOM

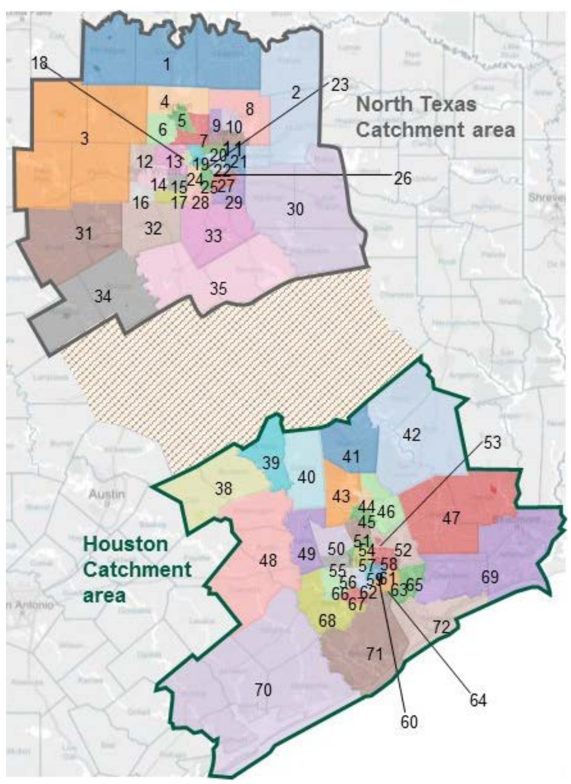
1. Model Structure

The model is similar to many intercity forecasting models in that it has two primary components: first is forecasting total travel demand at the zonal level, and then splitting the demand using a mode choice model. Within that structure, t/here are subcomponents that address issues such as demographic growth and stimulated demand, which ensures that there is clarity on where travel growth is occurring and how much growth can be attributed to demographics, the economy, and the provision of rail service. Overall the model structure is analytically rigorous and incorporates all the appropriate aspects of rail forecasting. Further description of the individual components of the methodology and model structure is described in detail below.

2. Geographic Coverage

The model covers the Dallas-Fort Worth-Arlington MSA, the Houston MSA, as well as the area joining the two, and surrounding counties that are within approximately a two-hour drive of one of the TCHST stations, for a total of 66 counties spanning the corridor (known as the TCHST Catchment Area). The TCHST Catchment Area contains 72 zones, which can each contain multiple counties at the edges of the study area, down to much smaller than county size in the urban areas and around the three station locations, and the zone structure can be seen in Figure 1. The rail stations are each associated with a catchment area (Houston, Brazos Valley, and North Texas). This geographic coverage and zone sizing is typical of many intercity travel demand models.

Figure 1. Zone System



The model allows for two types of travel markets, inter-regional trips greater than 180 miles (with the majority of trips being approximately 240 miles) between the North Texas and Houston catchment areas shown in Figure 1 (including between Brazos Valley and North Texas), as well as trips of approximately 100 miles between the Brazos Valley and Houston catchment areas. This excludes the zones in the center of the TCHST Catchment Area, as these zones are both too far from the rail stations and too close to the destination to reasonably expect travel by rail. These two markets are considered separately in the model, with the inter-regional market being the principal market addressed by the model, with greater time savings, while the Houston-Brazos Valley market has a higher number of student travelers and less significant time savings.

3. Survey

The basis for the model used for the 2019 forecast overall methodology was a set of two stated preference (SP) experiments, called the Modal Choice Survey (MCS) and Customer Offering Survey (COS), conducted in 2018. As part of the overall ridership modeling effort, L.E.K. has undertaken four data collection efforts, which are detailed in Table 2.

Table 2. L.E.K. Research Program

Item	Description	Date	Notes
Focus Groups	Four 8-Person Focus Groups	2016	Used to inform survey development, not directly applied to modeling methodology
Modal Choice Survey	Survey focused on current travel behaviors, and modal choice stated preference exercises	2016/ 2018	2016 survey responses were only used for the Bravos Valley-Houston market, 2018 responses were used for all other model estimation
Customer Offering Survey	Survey focused on customer offering stated preference exercises	2018	Used in model estimation

Source: TCHST Ridership Report

The MCS was identical to the 2016 survey which was the basis for the previous iteration of the model described in the TCHST Ridership Report dated June 19th, 2018, and included stated preference experiments regarding journey time and cost for four modes (road, air, bus, or TCHST). The COS focused only on TCHST, and asked respondents to choose between variations on attributes specific to the mode. There were a total of 2,224 respondents who participated in the MCS, and of these, 2,018 indicated a willingness to take TCHST in at least some circumstances, which qualified them to take the COS. Of those who qualified, 879 respondents completed the COS.

Prior to the 2016 survey, L.E.K. undertook four focus groups of eight people each, which informed the designs of both the 2016 and 2018 MCS. Participants were required to have traveled between Houston and North Texas at least once in the last 12 months, be over the age of 18, and have lived in the US for more than ten years (or five years for respondents under 30 years of age), as well as the selection ensure a representative mix of demographics. These focus groups discussed current travel behavior, including advantages and disadvantages, before discussion perceptions of high speed rail.

The 2018 surveys were conducted online between April 13 and June 13, 2018, with participants recruited by panel providers Research Now and SSI (now merged into Dynata) with the requirements that they be Catchment residents, at least 18 years of age, and that they disclosed their employment status and household income. This led to 14,460 respondents taking the MCS, but of these 12,236 respondents were screened out as they did not qualify for the survey. 95% of these were removed due to either not being residents of the catchment, or not having traveled between North Texas and Houston at least once in the last 12 months. The 2016 survey included a sample of non-travelers, although they did not take part in the stated preference experiments. The remainder of the respondents removed from the 2018 survey was due to either not meeting the resident or age requirements, or were excluded by the survey providers due to evidence of speeding through or not paying attention to the survey. All qualifying respondents were otherwise captured and considered in the study. As the COS respondents are a sub-set of the MCS respondents, all 879 respondents met the screening and cleaning criteria. Collectively, this report will refer to the 2018 MCS and COS as the 2018 L.E.K. Travel Survey.

The MCS included eight topics, shown in

- Introduction, which screened out respondents who did not qualify, as well as ensured a representative mix of respondents,
- Current travel behavior, asked about current trip attributes such as purpose, group size, mode, length of journey, access and egress, as well as mode-specific questions,
- Reasons for not traveling, which was only asked to 2016 respondents, as all 2018 respondents were required to have traveled at least once in the Catchment area,
- Decision making criteria, asked respondents to rate by importance the factors in deciding how to travel, as well as which mode they prefer and why,
- Advantages and disadvantages of types of travel, which was only asked to 2016 respondents, asking them to rate each mode against a variety of attributes,
- Perceptions of high speed rail, which defined the HSR offering (including a video showing the TCHST experience) and asking respondents to give their reactions,
- Modal choice stated preference exercise, which presented trade-off questions to the respondents about four different modes with varying attributes, and asks them which they would chose,
- Demographics/attitudinal questions.

The COS included three topics:

- Introduction and recap of HSR project, which was a reminder about the TCHST service and a recap of the respondent's reference trip discussed in the MCS,
- Customer Offering stated preference exercise, which presented trade-off questions to the respondents about various attributes of the TCHST product offering,
- Ideal HSR product offering and attributes, identified preferences and importance of different attributes of the HSR offering and the TCHST customer experience.

The overall sample size of the MCS is in the +/- 3% range with 99% confidence, while the overall sample size of the COS is +/-5% with 99% confidence. When the survey is broken down into smaller segments for analysis, all segments are +/-7% with 95% confidence or better. These statistical significance ranges are appropriate for the modeling methodology. The survey weighting was done based on age and household income, with three groups for each.

The stated preference exercises for both the MCS and COS were carefully designed and tested, both in the first phase through the focus groups and for the 2018 surveys. In particular, the major change from the 2016 survey was to split the stated preference exercises into two separate surveys, to limit respondent fatigue, with no more than ten attributes tested. As no single respondent can answer the entire number of choice sets required to estimate a model, the survey used a Choice-Based Conjoint (CBC) exercise, which split the universe of choice sets into 96 blocks, with each block containing 12 choice sets for each respondent. This allows the overall dataset to cover all options of choice sets while limiting respondent fatigue.

For the MCS, the following attributes were tested:

- Mode (car, bus, plane, and HSR)
- Price (car, plane, and HSR)
- Travel time (car, bus, plane, and HSR)
- Frequency of departure (HSR)
- Ride comfort (HSR)
- Ticket flexibility (HSR)

The MCS stated preference section was arranged so the respondents first selected their origin and destination zones from a map (or a corresponding list), and were then shown descriptions of "fixed attributes" for the four modes which stayed the same regardless of the particular journey, including:

- Timing (earliest and latest arrival)
- Reliability
- Allotted luggage
- Cell service and Wi-fi
- Security clearance time
- Transportation options at terminal

The respondents were then shown a series of 12 exercises, each with five choices (car, bus, plane, and two TCHST options). Information given for each choice included door-to-door travel time, one-way cost, departure frequency, ride comfort, and ticket flexibility. Travel time and cost were shown for all five choices, while changes in frequency, comfort, and ticket flexibility only applied to TCHST. The values shown to each respondent were varied by exercise, and values were set to discrete levels based on realistic ranges of values relating to that mode. For example, travel times were varied from -15 minutes to + 30 minutes for HSR, -15 minutes to +60 minutes for car, 0 minutes to + 60 minutes for bus, and -15 minutes to + 60 minutes for plane.

Respondents were classified as business or personal travelers, and in the 2016 survey, Brazos Valley to Houston travelers (BV-H) were also split out. The BV-H results from 2016 were used to calculate the modal shares for the updated model, as it had a comparatively small impact on market share.

For the COS, the following attributes were tested:

- Ticket flexibility
- Seating configuration
- Seat pitch
- Food and beverage on-board

- Passenger security and dwell
- Extra cost compared to basic ticket

COS respondents were first shown a summary of their most recent journey from the MCS, including their starting and ending zones and trip purpose. Respondents were then shown a description of the "Basic" Bullet Train ticket option (including a photo of seating comfort), which did not include any of the add-on features and services to be tested.

Respondents were then shown a series of 12 exercises, with three choices (the "Basic" Bullet Train ticket, plus two enhanced ticket options, which included at least one ticket attribute being superior, but with an associated cost). The choice blocks were set up with a Choice-Based Conjoint (CBC) exercise similarly to the MCS, with the attributes similarly being varied across discrete levels.

In order to ensure that the sample was representative of the population, individual responses were weighted based on age and household income, as these attributes were the most significant predictors of respondent attitudes for which there is external data on the catchment population. The weights were applied to nine segments, formed by three age groups (18-34, 35-64, 65+) and three household income groups (<$35K, $35-$100K, $100K+). Weights ranged from 0.44 for those aged 65+ with > $100k in household income to 4.2 for those aged 65+ with less than $35K in income.

The survey processing sought to remove or adjust for known types of biases including overstatement bias and uncertainty bias, as well as outlier data points. To mitigate the stated preference bias that can arise from respondents over-stating their willingness to take a new mode, L.E.K. used a downweighting method, which is a standard method of accounting for a new mode in transportation modeling. This method asks a follow-up question to the SP exercises to see on a five-point scale how confident the respondent is that their answers would reflect their behavior once the train is in operation. Based on their response, a weighting factor is applied to the SP exercises (i.e. lower confidence gets a smaller weight). Similarly, the responses were analyzed to remove outliers. The first reason to remove responses were those who indicated unrealistically low price-sensitivity in either SP survey, which was most common in the COS exercises, where some respondents appeared to have made their choices without adequate consideration of the fare attribute. This was dealt with by setting a threshold on the willingness to pay for a single attribute of $1,000 for business travelers and $750 for personal travelers, which excluded 40 total respondents (5.5% of the sample). The second reason for excluding responses from the final dataset was an overly high utility of the product attributes over the modal attributes, i.e. seat pitch is more important than travel time, which is not a reasonable assumption. Respondents were excluded whose total importance for the product attributes is 75% or more of the important of their preferred mode, which excluded an additional 20 respondents. After removing these outliers, the final dataset included 1,415 respondents who had only completed the MCS, and 749 respondents who had completed both the MCS and the COS.

Once the data was collected and processed, it was used to estimate the components of the travel demand model, as described in the sections below.

4. Total Travel Demand Model

The market growth component is based on demographic factors, including population and Gross Regional Product (GRP). GRP and population growth were applied at the county level, reflecting local variations in the forecast. Zones which are within counties have the county-level growth factors directly applied, while zones which are aggregations of counties have a weighted average growth applied from the counties of which they are made up. Verification and validity of the assumptions for the stimulated demand was not conducted by AECOM; however, the modeling methodology used appropriate resources overall in developing the total travel demand.

4.1. Structure

The total travel demand component of the model first estimates the base travel market based on existing data sources and then looks at both market growth and stimulated demand to forecast what the overall travel market for future years and alternative scenarios will be prior to splitting into the various modes, which is a standard method of determining demand at the intercity level. The base origin-destination trip table uses multiple sources and verification methods, which provides a robust picture of the existing travel market.

4.2. Current Travel Market Data Sources and Assumptions

The current travel market was built up from existing data sources to estimate the auto, air, and bus markets, for addressable journeys which included single leg, single person trips in both directions between North Texas and Houston, including all stages such as access and egress. The following data sources comprise the inputs for estimating the current travel market, which is an intermediate output of the model.

Auto trips were estimated using traffic counts from TxDOT and Bluetooth data, using a five step methodology. The five steps were:

- Determine total volume of trips on I-45
- Remove commercial vehicles
- Remove intermediate and out-of-catchment traffic
- Add I-35 traffic
- Estimate the number of travelers per vehicle

The data sources used for the five steps include:

- TxDOT traffic counts, Fairfield, Freestone County counter on I-45: used to calculate the upper bound of non-commercial vehicle trips between North Texas and Houston on I-45.
- AirSage cell phone tracking data, sample from 2015, including approximately 17 million devices: used to identify journey flows by origin and destination, and to identify the proportion of vehicle trips on I-45 that are traveling between North Texas and Houston.
- Inrix connected vehicle tracking data, used for triangulation of the AirSage data and identifying the proportion of vehicle trips on I-45 that are traveling between North Texas and Houston.
- TTI Bluetooth vehicle tracking data, from 2013: Used to estimate the proportion of travel on I-35 relative to I-45.
- NHTS and L.E.K. Survey: Used to calculate average auto occupancy to convert vehicle trips to person trips.
- Moody's Analytics demographic data: Used to grow the base trip table from 2016 numbers based on the data, to 2017 which is the base year for modeling. Variables used to grow the data include population (assumed an elasticity of 1) and GRP per capita (assumed an elasticity of 0.5).

- U.S. Energy Information Administration (EIA) Average fuel cost increases from 2016 to 2017: used short run fuel price elasticities to adjust base trip table from 2016 to 2017.

Air trips included direct flights between Dallas Fort Worth (DFW) or Dallas Love Field (DAL) and Houston George Bush Intercontinental Airport (IAH) or William P. Hobby Airport, Houston (HOU). The 2017 air trip table was built up using the USDOT T-100 database to determine the number of 2017 point-to-point flights between North Texas and Houston, excluding connecting flights.

The bus travel market was estimated using information from existing bus operators (Vonlane, Megabus, Greyhound, and Tornado). The bus market was built up using the daily frequency of each operator, multiplied by an assumed load factor.

In order to disaggregate the various markets by mode, L.E.K. applied the origin-destination distributions found in the AirSage cell phone data, while preserving the total amount of trips by mode. This was done in a similar manner to the auto travel market estimation, but ensuring that commercial travel is removed at the zone level, to preserve journey patterns at the zone level.

4.3. Travel Market Growth Data Sources and Assumptions

The travel market growth for future years of analysis (which combines with the current travel market to make up the final output of the model) is done using standard modeling practice of growing the base travel market according to changes in demographic conditions. This is done by applying elasticities to population, GRP / capital, and fuel cost (the model inputs), to capture the impacts of population changes, income and economic activity, and the cost of driving on people's propensity to travel. The elasticities for GRP per capita and fuel cost used were published by the University of California[1], based on long term regression models on transport data across the US. The elasticity for population was assumed based on expecting the new population to have the same propensity to travel as existing residents of the same demographics. These elasticities are 1.0 for population, 0.5 for GRP per capita (based on road travel, as the majority of current trips are auto), and -0.135 for fuel cost.

The population and GRP forecasts were obtained at the county level from Moody's Analytics, which were split to smaller zones based on the distribution of the variables in 2016 Census data, which is a standard method of dealing with disaggregating forecast data. This granularity is necessary for ensuring the travel market growth is at the same level of detail as the rail forecast.

Demographic growth rates from the Moody's Analytics data in the catchment area are shown in Table 3 below, comparing the total US, the state of Texas, and the catchment area. In all cases, the catchment area and Texas have higher growth rates than the US, but this is supported by historical data. The table also shows the fuel cost changes, calculated from EIA data.

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[1] Induced demand and rebound effects in road transport; Hymel et al; University of California, Joint Transport Research Centre of the International Transport Forum and the OECD (2010)

Table 3. Demographic Growth and Fuel Cost Changes

	Population		GRP		Fuel Cost		
CAGR%	1970-2017	2017-2050	1970-2017	2017-2050	2017-2026	2026-2050	2017-2050
US	1.0%	0.5%	2.8%	2.0%			
Texas	2.0%	1.3%	3.8%	2.9%			
Catchment	2.2%	1.5%	3.8%	3.0%	0.0%	-0.6%	-0.4%

Source: TCHST Ridership Report

Combining these three factors, the travel market is estimated to grow by 2.5% annually until 2026, and by 2.2% annually from 2026 to 2050. The majority of this growth is due to population growth.

In addition to growing the base travel market, the demographics of the catchment area are estimated to shift to being older and wealthier, based on splitting the forecast data based on the 2018 L.E.K. Travel Survey and analysis. As age and wealth are two factors that indicate a higher propensity to business travel as opposed to personal travel, based on the Travel Survey, the split of the total travel market that is anticipated to be business travel grows from 23% in 2017 to 26% in 2050.

Related to the total market size, there are four sources of ridership for TCHST:

- Capture from other modes – included in expected market growth w/o TCHST
- Stimulated demand
- Increased market growth from TCHST
- Additional demand from commercial actions

Stimulated demand is a commonly observed factor when new modes of travel are introduced, as introducing a new mode improves both the experience on that mode, as well as improving travel using existing modes, such as through reducing congestion. Based on the L.E.K. Travel Surveys (combined for 2016 and 2018), 84% of respondents were residents in the Catchment area, but did not currently take trips between North Texas and Houston, of which 83% said they would take at least one journey in the next year. The remaining 16% of survey respondents had taken at least one trip between North Texas and Houston, and of these 54% said they would take at least one additional trip. L.E.K also conducted a literature review of HSR systems across the world, focusing on systems that:

- Systems that exceed 150 mph
- Opened in 1990 or later
- Routes of 125 miles or greater
- Point-to-point studies to limit network effects
- Similar context to TCHST

This led to a list of 5 comparable systems in Europe and Japan, with a range of stimulated ridership from 11 to 26 percent, at an average of 18%. After examining and adjusting for factors including network effects, pricing, commercial actions, tourism, and upgrades to an existing line versus an entirely new mode, and ridership due to GRP per capita, the assumed stimulated ridership for TCHST is 12.5%. This number was compared with the change in travel utility before and after TCHST, which was 18.4%, which assumes a one-to-one relationship between ridership and utility. By taking a more conservative approach of assuming the 12.5% stimulation (on top of the base HSR ridership), anything further could represent additional upside for TCHST. While the 12.5% stimulation is reasonable in context of the international benchmarking, significant projections of stimulated demand represent an element of risk and uncertainty in the forecast.

Increased market growth from TCHST is due to premium modes experiencing a higher elasticity with regard to GRP per capita, and therefore premium modes would experience a greater share than cheaper, slower options. L.E.K. examined elasticities of premium modes for air from IATA and non-US long distance rail from the "Passenger Demand Forecasting Handbook" based on the GB rail market. These elasticities range from US domestic short haul air (1.8), non-US developed economy short haul air (1.5), non-US long distance rail (1.2), and US car (0.5). As short haul air has declined in the corridor over the past 15 years, TCR assumed a more conservative elasticity of 1.2, such as found for non-US long distance rail for TCHST to GDP per capita. This translates TCHST to grow at 3.2% annually, as opposed to 2.4% for the car and air markets. While air is a premium mode and has experienced higher elasticities as shown by the IATA, because of the decline in the air market in the corridor itself, TCR has chosen to keep the elasticity for air lower, along with a standard auto elasticity. This equates to the total market growing at 2.6% following the introduction of TCHST, as opposed to 2.2% without TCHST.

In addition to the stimulated growth, the Ridership Report assumed an additional growth in the rail market of 0.4% annually, due to commercial initiatives between 2030 and 2040. These initiatives include marketing, referral and loyalty program initiatives, and are based on benchmarking to other private railways and the 2018 L.E.K. Travel Survey.

The process for creating future year forecasts of TCHST ridership is first to grow the total market for each year, and then apply modal share based on that year's relative journey characteristics for each mode (e.g., journey cost, end-to-end journey time etc.) to obtain TCHST capture from currently existing modes. This ensures that the ridership forecast comes directly from the modal relationships as opposed to assumed growth rates and other factors separate from the mode offerings themselves. The method for determining capture is described in Section 5 of this document. Additional ridership due to stimulation and increased market growth for premium modes is added to capture according to the methods described above. For the initial 3 introduction and adoption years, modeled ridership for those years is discounted according to the profile (i.e., 50% in 2026, 75% in 2027, 90% in 2028).

4.4. Trip Rates

The base travel market for North Texas to Houston in the catchment area for 2017 is estimated to be 16.0 million trips (15.0 million auto, 0.9 million air, and 0.1 million bus). With 16.9 million residents in the area, of which 2.7 million are estimated to be travelers according to the travel survey data, this yields trip rates of 0.95 trips/resident and 6 trips/resident traveler. The average number of business trips per year per resident traveler is 1.4, while the average number of personal trips is 4.6 per year.

5. Mode Choice Model

The modal predispositions (comparable to alternative-specific constants) show reasonable patterns prior to HSR introduction, with auto being the most favorable, all things held constant, followed by air and bus. The pattern was the same for both business and personal travelers, with much closer predispositions for business travelers (i.e. auto is much less dominant than in the personal market). After the introduction of HSR, auto remains the most favorable, with HSR coming in second for both personal and business travelers. The modal disposition has the highest level of importance out of the product features in choosing a travel mode, with travel time and cost coming second. The HSR product attributes (pitch length, seat option, ticket flexibility, food, station experience, and frequency of schedule) all came lower on the importance level scale, with seat attributes slightly more important for business travelers. Most of the product attributes are equally rated lowly by personal travelers, with food being the one attribute that has a slightly higher importance.

The methodology documentation provided overall statistical fit measures indicating it is a reasonable fit to the data, and likely is producing reasonable estimates of mode choice. The nesting structure is also reasonable, and it was confirmed that adequate testing of alternative structures was done to ensure the appropriate fit. Calibrating the model was done by running a no build scenario and creating calibration factors, as is standard practice. The data was weighted to account for socioeconomic biases by accounting for age and income, which were found to be the two characteristics strongest in influencing choice. Overall, the mode choice model was well-designed and incorporated all the aspects of a good methodology.

5.1. Structure and Model Estimation

The mode choice component is the second step of the modeling methodology, and uses a Nested Logit Model (NL) for forecasting future modal shares, which is standard practice for mode choice models. The utilities used in the NL model are built up using a three stage process, first by calculating utilities for each of the MCS and COS responses separately using a hierarchical Bayes (HB) method. Next utilities from the two surveys are combined using bridging, via the two attributes the surveys have in common, and finally the modal choices for each zone OD pair are calculated using a market simulator. This methodology (particularly the HB method) is not a standard practice for intercity ridership forecasting in the US, but is theoretically sound and, while not widely applied, does have advantages in producing individual-level preferences, which is particularly useful for examining market segments.

The mode choice model is a NL model, containing three nest levels, as shown in Figure 1. The logsum parameters for the first stage of the nest is 0.31 and 0.35 for the second stage of the nest, indicating a good fit for the nesting structure. Nesting structures are typically based on service offerings (auto versus shared ride, differing levels of service for rail), as opposed to focused on fare type, as chosen here. The nesting structure is constrained by the need to bridge the surveys using the ticket flexibility attribute, and the journey cost. These attributes are used to calibrate the responses between the two surveys (MCS and COS) to establish a consistent set of attribute and level utilities.

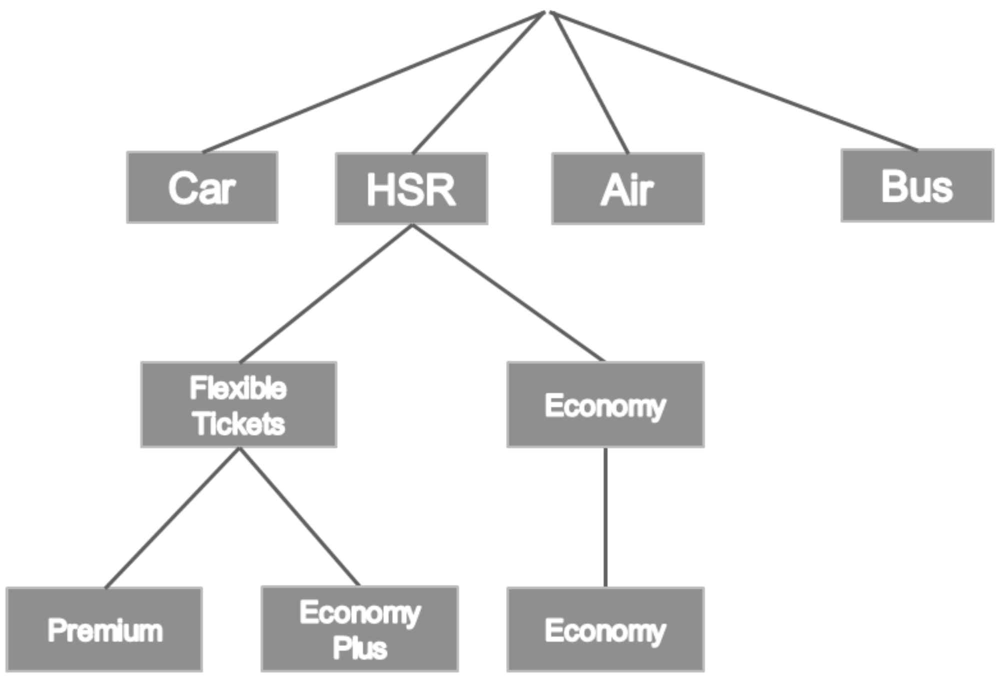

Figure 2. Mode Choice Nest Structure

Two standard statistical tests for the HB method are percent certainty, which measures how much better the solution is compared to random chance (ranging from zero for random chance to one for a perfect fit to the data), and root likelihood, which similarly measures the likelihood of seeing the calculated results compared to seeing it by chance (ranging from 1/number of available choices, 0.2 in this case, for a random outcome, to 1 for a perfect model). Tables 4 and 5 show the results for each of the markets (personal, business, and the short trips for Bravos Valley – Houston) in the two SP datasets. Both datasets have results that are in line with the expected accuracy.

Table 4. Modal Choice Survey (MCS)

	Sample Size	Percent Certainty	Root Likelihood
Personal	1,601	0.76	0.68
Business	623	0.65	0.57
BV-H (from 2016 MCS)	115	0.85	0.78

Source: TCHST Ridership Report

Table 5. Customer Offering Survey (COS)

	Sample Size	Percent Certainty	Root Likelihood
Personal	558	0.74	0.75
Business	225	0.61	0.65

Source: TCHST Ridership Report

Particularly since the mode choice model was developed using only stated preference data, as opposed to a combination of revealed preference and stated preference data, which allows the model to be tied back to actual behavior, it is important to verify the model coefficients and elasticities with respect to key variables (such as time, cost, and frequency) fall into acceptable ranges relative to modeling guidance and comparable intercity models. Because of the HB format, which estimates the model for each individual respondent, L.E.K. feels that it is not possible to create a value of time (VOT) that would be considered directly comparable to published figures. Because of this, they verified the validity of the model parameters by checking the internal consistency of the utilities, conducting a high-level assessment of VOT, and corroborating the aggregate results against external benchmarks.

The internal consistency of the utilities was ensured by checking that there were no outlier utilities for one attribute that were disproportionality higher than those of other attributes, and any respondents which fell into this category were excluded from the data set. Of the 2,224 Respondents, 60 Respondents were removed from the sample due to their responses to the COS. The remaining 2,164 remaining Respondents were used to calculate modal shares.

L.E.K. did conduct a high-level value of time assessment against external benchmarks to ensure the model coefficients were within a reasonable range. The modal share observed in the market today between the Central Business Districts of Dallas and Houston (90% road and 10% air) is consistent with travelers in the Catchment having a value of time the same as that recommended by the USDOT guidelines (70% of earnings for personal travel and 100% of earnings for business travel). Given the average household income for travelers in the Catchment, this is equivalent to $22.90/hour for personal travel and $37.79/hour for business travel, which fall into the acceptable ranges of VOT. These results are also consistent with the ridership forecast prior to stimulation and without considering the ramp-up period.

The final consideration that L.E.K. made in evaluating the suitability of the model coefficients was to corroborate the findings of the model using international benchmarks. As the modal shares are comparable to Acela Express, and lower than international examples which have other factors increasing their mode shares, this is another verification that the model is operating within expected parameters.

5.2. Data Sources, Model Inputs, and Assumptions

The validity of modeling methodology depends significantly on the quality of data that is used to both create the model and used as inputs into the forecast. Because of this, developing the service characteristics used for each mode requires care in each step of the modeling process, from survey development, to model estimation, and finally in model application. Verification of model inputs was not conducted by AECOM; however, the modeling methodology used appropriate resources overall in developing the modal characteristics for all modes.

The data sources and assumptions for the mode choice model travel time inputs include the following:

- Auto total travel time – consists of the following components:
    - Intra-city driving/freeway driving – calculated using peak travel times (7AM-10AM and 4PM-7PM) between zone centroids using TomTom drive time data. The average time between Dallas and Houston is 243/258 minutes (depending on direction of travel).
    - Rest stops – calculated from the L.E.K. Travel Survey data as being on average 26 minutes
- Air total travel time – consists of the following components:

  - Intra-city driving (access/egress) – calculated using peak travel times (7AM-10AM and 4PM-7PM) between zone centroids and airports using TomTom drive time data. All travelers are assumed to take auto, based on 93% of L.E.K. Travel Survey air travel respondents taking some form of auto (parked, dropped off, or taxi/ride share) to/from airports. This is a standard assumption.
  - Terminal access/egress (walking/waiting) – calculated as the average of L.E.K. Travel Survey air travel respondents, which is 35-57 minutes (depending on station airport pair and parking assumptions, with 45% of travelers assumed to park and therefore have additional time) for both before and after flights.
  - Processing – calculated as the average of L.E.K. Travel Survey air travel respondents, verified by the experience of L.E.K.'s US aviation team of time spent at each stage of processing (check-in/bag drop, security, dwell time, and boarding), which is 69 minutes
  - Flight – calculated using USDOT's Bureau of Transportation Statistics, including average scheduled travel time between airports plus average arrival delay. For the most common airport pair of DAL-HOU, this equals 64 minutes of average scheduled travel time plus 8 minutes of delay. The other airport pairs (DFW-IAH and DFW-HOU), these values range from 67-72 minutes for scheduled travel time and 6-15 minutes of delay.
- TCHST total travel time – consists of the following components:
  - Intra-city driving (access/egress) – calculated using peak travel times (7AM-10AM and 4PM-7PM) between zone centroids and stations using TomTom drive time data. This was assumed to be similar to the airport trips, in that all TCHST travelers would access the station via auto.
  - Station access/egress – As the stations are designed to be simple and quick to navigate, assumptions are lower for TCHST station access/egress compared to air. L.E.K. assumed it to be 17 to 25 minutes (45% of travelers were assumed to park at the station, and were given the higher time estimate, with the remainder given the lower time estimate).
  - Processing – As the stations are designed to be simple and quick to navigate, assumptions are lower for TCHST processing time compared to air. Security is assumed to take 5 minutes, dwell time of 5-10 minutes, and boarding time of 5 minutes, for a total assumed processing time of 20 minutes.
  - Train – Based an operating speed of 186 mph from 2026 to 2031 (direct trains between Dallas and Houston will take 83 minutes), and an operating speed of 205 mph after 2031 (direct trains between Dallas and Houston will take 77 minutes). These are higher relative speeds to other HSR services worldwide, but with only three stops, the train will not be subject to slowing down and speeding up as frequently as other services with more stops.

The average OD total travel times by mode are 272 minutes for auto, 267-291 minutes for air, and 177 – 203 minutes for TCHST. This varies based on the location of the origin and destination zones, with certain areas favoring auto or air over TCHST.

For future year analysis, auto congestion was calculated by continuing the congestion growth trends found in the NCTCOG Mobility 2040 and 2045 reports for North Texas and H-GAC 2040 RTP for Houston. This leads to an increase in travel time of 6 to 18 minutes in the Houston area, and 1 to 5 minutes in the North Texas area.

The data sources and assumptions for the mode choice model travel cost inputs include the following:

- Auto total travel cost – consists of the following components:
  - Gasoline price and fuel efficiency – Based on oil price trends taken from the US Energy Information Administration (EIA), fuel efficiencies based on Corporate Average Fuel Economy (CAFE) Industry standards, which is calculated as 11 cents per mile. Fuel prices are assumed to rise in the future, but be off-set by increased fuel efficiency, so therefore remains constant.
  - Additional operating costs (depreciation of vehicle, maintenance, insurance, road tolls, parking, vehicle taxes and registration, financing charges) – calculated as the difference between the perceived cost per mile from the L.E.K. Travel Survey and the fuel costs. The perceived cost from the survey was 15 cents per miles, which is comparable to AAA operating costs of 17 cents per mile. The incremental amount assigned to operating costs for model use is 4 cents per mile.
- Air total travel cost – consists of the following components:
  - Access/egress cost – calculated as the auto total cost for the access/egress distance of the trip.
  - Base airfare – calculated as the average fare paid from air travelers in the L.E.K. Travel Survey, which was $180. This was verified by comparing to the average one-way fare of $184 between Dallas/Fort Worth and Houston in Q2 of 2017, based on USDOT BTS data.
  - Changes in jet fuel cost – Calculated by estimating the relationship between jet fuel and air fares, based on USDOT and EIA data, assuming the average load factor will remain constant. This leads to a growth in air fares of approximately 0.5% per year.
- TCHST total travel cost – consists of the following components:
  - Access/egress cost – calculated as the auto total cost for the access/egress distance of the trip.
  - Base rail fare – SP fares tested ranged from $30 to $300, with the average fare for Dallas-Houston being $130 to $180. These fares were assumed by L.E.K.

5.3. Calibration and Sensitivity Testing

The model was calibrated to match existing mode shares. Prior to calibrating, the model was overestimating the total air market, at approximately 7 percent of the total market, as opposed to the actual air market which was approximately 6 percent. To adjust for this, L.E.K. used the pivot point method, which down-weighted HSR capture from air by 0.81, with HSR capture from auto up-weighted by 1.01.

L.E.K. conducted sensitivity testing and produced an addendum to the report dated June 20, 2019. The sensitivity tests were developed by creating a list of individual input assumptions and potential changes to these (both upside and downside) and grouping them into scenarios for testing, with 243 overall scenarios tested. The inputs, groupings, and the range of values tested are as follows:

- Macroeconomic drivers
  - Population growth (+0.1% and -0.2%)
  - GRP (+/- 0.5%)
  - Fuel price ($52/barrel and $229/barrel) and efficiency (marginally higher and marginally lower)
- Stimulated demand (7% and 16%)
- Modal Competition
  - Airline response (initial fare reduction of 20% with 10% after, removing short-term price reduction and introducing a partnership between TCHST and airlines)
  - Auto congestion (no congestion around TCHST stations)

    - AV impact (40% of car fleet by 2050, 50% of car fleet by 2050)
- Ramp-up period (100% by year 3, 100% by year 6)
- Commercial actions (ROI of 4.2, ROI of 1.4)

Table 6 presents the results of the sensitivity tests relative to the cumulative forecast ridership (2026-2050) of 227 million riders. They are arranged in terms of how likely the scenarios are (unlikely downside and upside scenarios have wider variations on the input values, with the mix of downside and upside is a set of scenarios closest to the base case). The sensitivity scenarios had an overall range of +/-18% from the base ridership case.

Table 6. Sensitivity Testing Results

	Unlikely Downside	Realistic Downside	Mix of Downside and Upside	Realistic Upside	Unlikely Upside
Ridership Forecast	185-200m	200-218m	218-236m	236-255m	255-270m
Percent Change from Base	-18% to -12%	-12% to -4%	-4% to 4%	4% to 12%	12% to 18%

Source: TCHST Ridership Report Addendum – Scenarios and Sensitivities

5.4. TCHST Service Level Characteristics

The TCHST forecasts are produced for three years, including 2026, 2029, and 2050. Table 7 provides key service level characteristics by year associated with the published forecasts. More information on the frequencies can be found in the Section 5.4 discussion on capacity constraints.

Table 7. TCHST Service Level Characteristics by Forecast Year

	2026	2029	2050
Forecast Description	Opening Year	Post Ramp-Up	Horizon Year
Stations Served	Dallas and Houston (all trains), Brazos Valley (50% of trains)		
Dallas-Houston Travel Time (speed increase in 2031)	83 minutes (direct) 88 minutes (w/ stop)	83 minutes (direct) 88 minutes (w/ stop)	77 minutes (direct) 83 minutes (w/ stop)
HSR Operating Duration	5:30 AM to 11:30 PM		
Hourly Frequencies	2 Peak 2 Off-Peak	2 Peak 2 Off-Peak	4 Peak 4 Off-Peak
Peak Periods	7:00 AM to 10:00 AM and 4:00 PM to 7:00 PM		
Seating Capacity	376 seats/train (approximately 30 premium class or 53 economy class per car, 8 cars per train)		

Source: TCHST Ridership Report

5.5. Model Output Metrics

Important model output metrics include trip rates, mode shares for the base year and the future alternatives, as well as the average annual load factor for the future case, which highlights any capacity constraint issues.

The base travel market for 2017 is highly auto-dominated, as seen in Table 8. This same mode share would be seen in the No Build case for any of the forecast years (2026, 2029, or 2050), with the number of trips growing based on the total demand model.

Table 8. 2017 Travel Market and Mode Share – North Texas to Houston Market

	Trips	Mode Share
Auto	15,000,000	94.0%
Air	900,000	5.6%
Bus	67,000	0.4%

Source: TCHST Ridership Report

Table 9 shows the mode shares forecast for the 2029 forecast in the North Texas to Houston market. Auto is still the dominant market for both business and personal travel, but TCHST is expected to pull a significant share away. There is still a small air market for business travelers, but almost all personal travelers are expected to shift from air to TCHST. The shifts to rail occur in logical geographic locations, close to the rail stations, in the urban areas.

Table 9. 2029 Forecast Mode Share – North Texas to Houston Market

	Business	Personal	Total
TCHST	39%	25%	29%
Auto	56%	73%	69%
Air	5%	1%	2%
Bus	0%	0%	0%

Source: TCHST Ridership Report

Table 10 splits the 2029 and 2050 forecast TCHST ridership into its respective sources, with the majority of trips coming from auto in both forecast years, but the rail market growth with GDP becoming a much more important source of ridership in the 2050 forecast, which contains a higher level of risk as a ridership forecast source compared to the ridership captured from current modes.

Table 10. Forecast TCHST Ridership By Source

	2029 Forecast		2050 Forecast	
	Trips (millions)	Percentage	Trips (millions)	Percentage
Auto	0.2	73%	7.6	57%
Air	0.7	14%	2.0	15%
Stimulated	0.9	11%	1.1	8%
Rail Market Growth with GDP	4.8	3%	2.7	20%
Total*	6.5	100%	13.6	100%

**Total may not match due to calculation rounding*

Source: TCHST Ridership Report

The TCHST share in the Houston-Brazos Valley market is much smaller, as it only has a small time advantage over auto for the majority of journeys, with only a 2% share of the addressable market.

Table 11 shows the trip rates in the interregional market (North Texas and Houston or Brazos Valley) for the forecasts, with increased number of total trips due to the stimulated demand once TCHST is introduced.

Table 11. Forecast Trips (in millions) and Trip Rates (trips/capita) by Mode

	2026	2029	2050
Auto Trips	16.7	15.7	25.9
Air Trips	0.8	0.4	0.2
HSR Trips	2.8	6.5	13.6
Total Trips	20.3	22.6	39.8
Catchment Population	18.8	19.7	26.3
Trips/capita - underlying growth	1.07	1.10	1.37
Trips/capita – stimulated growth	0.01	0.05	0.15
Total Trips/capita	1.08	1.15	1.52

Source: TCHST Ridership Report

The ridership report contained a benchmarking analysis, comparing survey results that L.E.K had commissioned to routes within Japan and Europe (with an average of 400 respondents), as well as Amtrak Acela Express (1000 respondents). The TCHST forecast mode share for 2029 was under all of the international routes, with approximately the same mode share as the combined HSR, conventional rail, and bus for the Northeast Corridor. This was assumed to be reasonable, as it reflects that TCHST's product is designed to address a wide range of customer types and journey purposes and does not have significant competition from other rail or bus. The benchmarking analysis also compared the rail-air modal share for the routes, given the time savings offered, and found it to be consistent with the international HSR routes. Similarly, the modal share against auto was compared to time savings across the routes, and the TCHST forecast auto capture is lower than the international HSR routes, as expected given the auto dominance in the market. For the Northeast Corridor, the rail mode share versus auto is slightly higher than that seen in the Northeast Corridor, despite much better time savings, due to the auto dominance in the Texas market, which is stronger than that of the NEC.

L.E.K. considered capacity constraints versus the demand forecasts and produced an addendum to the report dated June 20, 2019. First, L.E.K. estimating peaking behavior for the following:

- Within a day – using air travelers from the survey responses, determined a peak from 8-9 AM of 266% of the average and a peak from 5-6 PM of 175% of the average.
- Within a week – using intercity auto traffic counts, determined a peak of 126% of the average on Fridays.
- Within a year – using auto traffic counts and USDOT air travel data, determined a peak of 116% of the average in November and 111% of the average in July.

Pulling together the three peak figures, the total maximum hourly ridership in a year is set at 3.09 times the average ridership.

Next, L.E.K. prepared a revenue-optimized forecast, which allowed for the pricing to fluctuate given yield management, with increased pricing options for high demand and discounting to increase ridership on off-peak services based on the price elasticities determined through the stated preference survey. This led to a constrained forecast service pattern as found in Table 12.

Table 12. Forecast Service Pattern

Year	Peak Trains/Hour	Off-Peak Trains/Hour
2026	2	2
2033	3	2
2038	3	3
2046	4	3
2050	4	4

Source: TCHST Ridership Report

The final constrained forecast considering revenue management yielded a decrease of five percent from the opening year of 2026 to the horizon year of 2050, going from 240 million riders in the unconstrained forecast to 227 million riders in the constrained forecast. This percentage decrease is well within the range of realistic down-side shown in the sensitivity testing, which was up to a 12 percent decrease. Table 13 shows the unconstrained and unconstrained forecasts for 2029 (post ramp-up) and 2050 (horizon year) for both the Dallas-Houston and Brazos Valley-Houston markets. The average load factor over the time period for the constrained forecast is approximately 70 percent, with fluctuations according to increases in service pattern, but never exceeding 80 percent.

Table 13. Constrained versus Unconstrained Ridership Forecast

Year	Unconstrained Forecast (millions)	Constrained Forecast (millions)	Percent Change
2029	6.8	6.4	-5.9%
2050	13.9	13.3	-4.3%

Source: TCHST Ridership Report

AECOM also looked at the average annual load factors for the published unconstrained forecast for the years 2029 and 2050, assuming weekend and holiday service remains at the reported levels of 2 trains hourly for 2029 and 4 trains hourly for 2050. This yields average load factors of 0.77 and 0.79 respectively, which fall into reasonable ranges. Between the average load factors and the ability of TCR to apply yield management strategies with a minimal decrease in ridership, the capacity analysis indicates the model is forecasting a reasonable range of ridership given the available capacity.

6. Summary

As stated above, the methodology used to forecast ridership is acceptable and consistent with the state of the practice for intercity rail forecasting. All components of the methodology were well-structured and at or above industry standards.