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Integrating High Speed Rail Systems into Urban Environments: A Comprehensive Evaluation

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Integrating High Speed Rail Systems into Urban Environments: A Comprehensive Evaluation

by

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Thesis

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Abstract

Integrating High Speed Rail Systems into Urban Environments: A Comprehensive Evaluation

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The University of Texas at Austin, 2016

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Construction of a high speed rail system comes with an exhaustive list of challenges. Integrating the system into an existing urban environment is a particularly difficult proposition, given the dense developments and infrastructure systems already in place. Locating a station within a city is a delicate balance between a multitude of factors that include cost, station accessibility, required infrastructure and intermodal connectivity. Acquiring the rail alignment requires even more diplomacy. This thesis explores existing urban integration of current high speed rail systems and stations, evaluating prevalent high speed systems around the world to gauge best practices. Several European countries are notable for their direct connections into city center stations and urban transportation systems, providing passengers with quick, direct access to their final destinations. China and Taiwan have adopted a different approach with many cities, locating stations at the urban fringe and providing a base for transit-oriented development. After a review of existing systems around the world and high speed rail proposals in the United States and specifically, Texas, case studies are performed on the cities of Dallas and Houston. Using

current and prior proposals by the Texas TGV and Texas Central Railroad, potential station sites in the two Texas cities will be analyzed for their potential for development and connectivity to transit and roadway systems. The selection of an optimal station location will be aided using criteria from the Federal Railroad Administration and from interviews with planning professionals familiar with both metropolitan areas. In Dallas, the South Side site immediately south of the existing Union Station is recommended for future development while in Houston, a station connecting into the Northwest Transit Center is preferred.

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List of Abbreviations

ADA	Americans with Disabilities Act
API	Application Program Interface
ARRA	American Recovery and Reinvestment Act
AVE	Alta Velocidad Española
BART	Bay Area Rapid Transit
CaHSRA	California High Speed Rail Authority
CAMPO	Capital Area Metropolitan Planning Organization
CBD	Central Business District
DAL	Dallas Love Field Airport
DART	Dallas Area Rapid Transit
DB	Deutsche-Bahn
DFW	Dallas-Fort Worth International Airport
EIS	Environmental Impact Statement
FEMA	Federal Emergency Management Agency
FRA	Federal Railroad Administration
H-GAC	Houston-Galveston Area Council
HOU	Houston Hobby Airport
HSR	High Speed Rail
IAH	George Bush Intercontinental Airport
ICE	Intercity-Express
JR	Japan Railways
KTX	Korea Train eXpress
MSA	Metropolitan Statistical Area

NCTCOG	North Central Texas Council of Governments
ODOT	Oklahoma Department of Transportation
ROW	Right-of-Way
RTP	Regional Transportation Plan
TGV	Train à Grande Vitesse
THSRA	Texas High Speed Rail Authority
THSRTC	Texas High Speed Rail and Transportation Corporation
TNC	Transportation Network Companies
TOD	Transit-Oriented Development
TOPRS	Texas-Oklahoma Passenger Rail Study
TRE	Trinity Railway Express
TSA	Transportation Security Administration
TTA	Texas Turnpike Authority
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
UIC	International Union of Railways
UP	Union Pacific

Chapter 1: Introduction

As high speed rail (HSR) systems have continued to gain popularity over the past few decades, countries across the world have labored to implement their own systems. The integration of an HSR system into an existing urban environment comes with an exhaustive list of challenges. The station must be designed to allow maximum throughput and passenger volume and must be located to facilitate connections into an urban area's existing transportation systems and central business district (CBD). The speed of the train is limited to increase safety and the right-of-way (ROW) is often shared with conventional passenger rail or freight services. In the meantime, both passenger and systems costs must be minimized and public disruption through construction and operation must be severely limited.

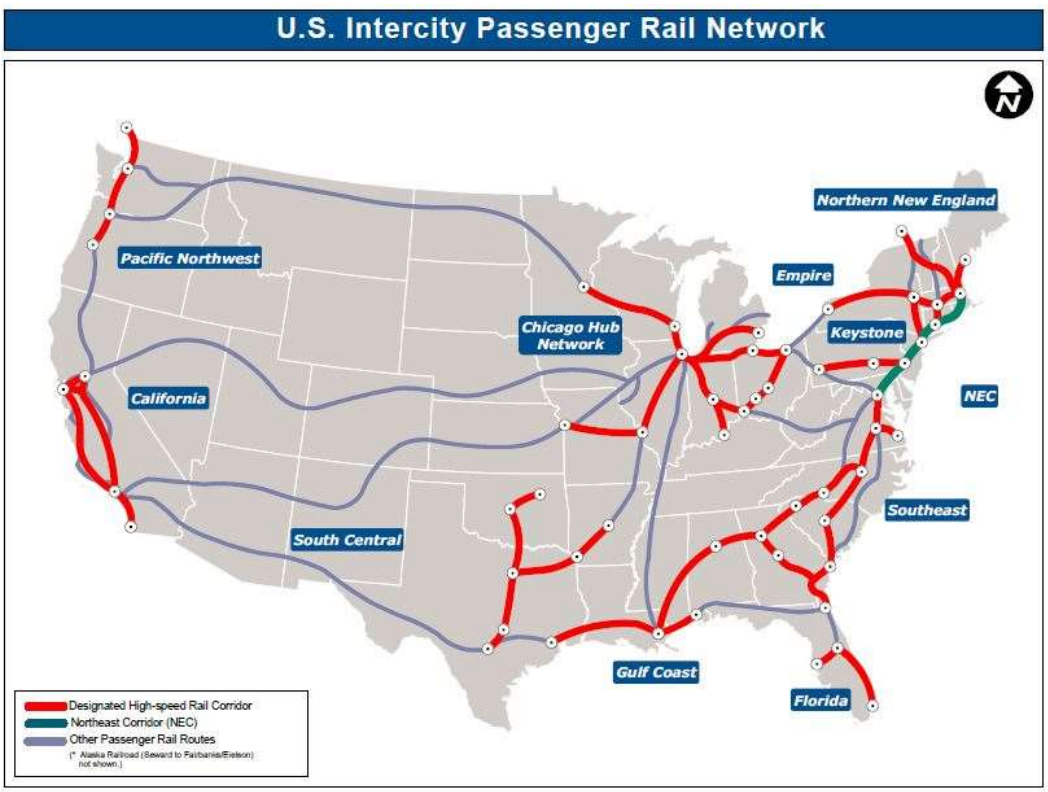
Despite all these challenges, high speed rail remains a quick, convenient and affordable transportation method. In 2009, the Federal Railroad Administration (FRA) designated ten new HSR corridors across the country, shown in Figure 1, maintaining the United States' commitment to the development of a high speed rail network across the country. The FRA has put forth four definitions associated with HSR and Intercity Passenger Rail (Federal Railroad Administration, 2009):

1. HSR – Express – frequent service between destinations 200-600 miles apart with top speeds of at least 150 mph on grade-separated, dedicated ROW;
2. HSR – Regional – frequent service between destinations 100 to 500 miles apart with top speeds of 110 to 150 mph on grade-separated, dedicated and shared ROW;
3. Emerging HSR – rail corridors with service between destinations 100 to 500 miles apart with top speeds of 90 to 110 mph and potential for future Regional or Express HSR development;

4. Conventional Rail – traditional rail services between destinations more than 100 miles apart with top speeds of 79 to 90 mph on generally shared track.

Within the state of Texas, HSR planning has a long history. Though various prior HSR proposals in the state have ultimately failed to materialize, current efforts are focused on the planning of the FRA-designated South Central corridor from San Antonio through Dallas and Fort Worth to Oklahoma and the Texas Central Railroad from Dallas to Houston.

Figure 1: FRA-designated HSR corridors



Source: (Federal Railroad Administration, 2009).

This thesis will explore the challenges of integrating a new HSR line into an urban environment with a major focus on station orientation, design and location. Chapter 2 presents the results of a literature review on current HSR systems, stations and urban integration. Several HSR systems around the world are analyzed to determine if there are preferred methods of design. There is an emphasis on HSR systems in China, France, Germany, Japan, South Korea, Spain and Taiwan as these systems all have a significant length of dedicated HSR lines, as opposed to upgraded or shorter lines. An overview of the current HSR system and initiatives in the United States is given in Chapter 3 and a history of HSR in Texas is presented in Chapter 4. US systems are reviewed to gain an understanding of best practices and current guidelines for urban integration.

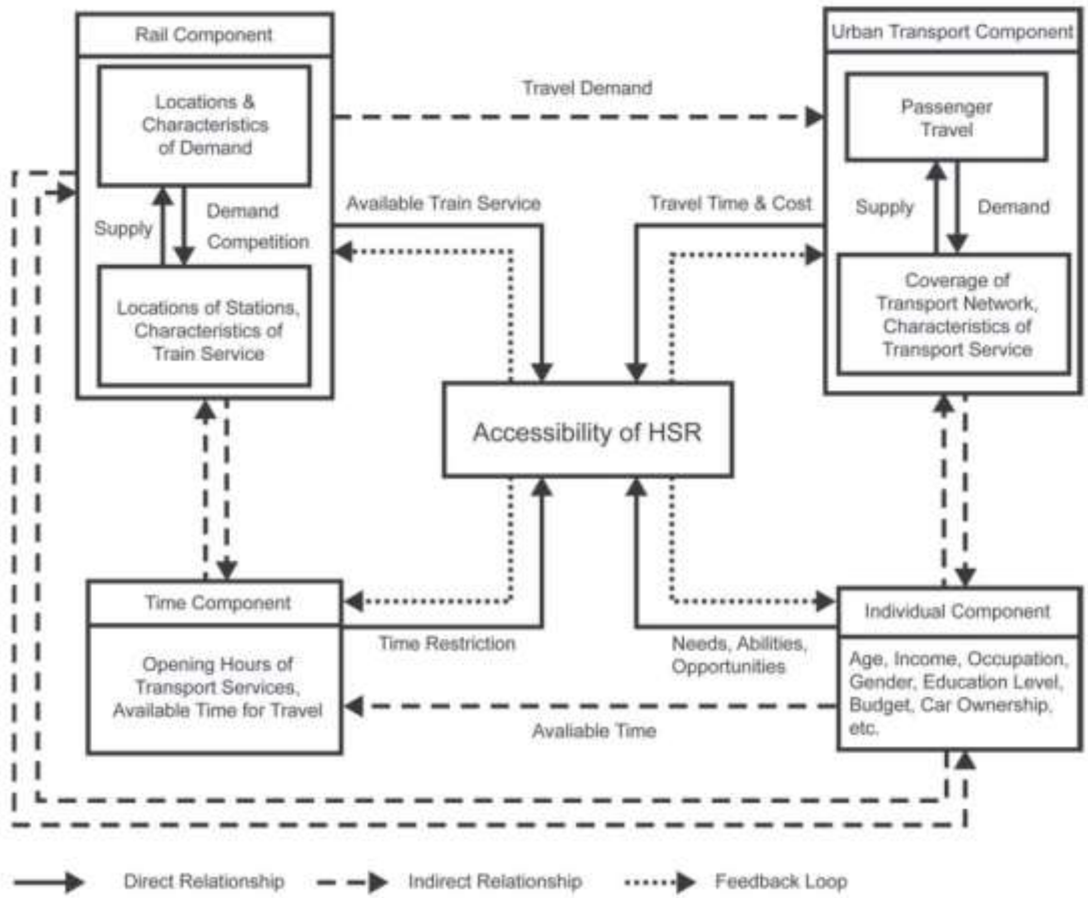
The knowledge gained from these reviews and from conversations with transportation and planning professionals will be applied to case studies in the Texas cities of Dallas and Houston in Chapters 5. Since both cities are currently served by Amtrak, enlargement of the existing Amtrak station will form one alternative in each case study. Stations currently proposed by the Texas-Oklahoma Rail Study, the Texas Central Railway, or stations previously proposed by Texas HSR studies will also be considered.

The overarching goal of this thesis will be to develop a framework or set of guidelines for integrating a new HSR system into a populated urban environment and then apply those recommendations to two major cities in the state of Texas. Chapter 6 will summarize the recommendations and comment on the applicability of these design standards to magnetic levitation (Maglev) trains.

Chapter 2: Existing System Evaluation

There is a significant list of challenges confronting the construction and operation of a new HSR line and with these challenges comes a trade-off between access and cost. Furthermore, each country is faced with a unique task prior to planning and implementing an HSR system within or across its borders. This chapter explores the current challenges faced by HSR planners in urban areas and presents international examples of HSR projects that have successfully integrated their systems into existing cities. Throughout the review, the important themes of accessibility and feasibility will be highlighted. Accessibility refers to the ability of travelers to gain access to the system, emphasized by Figure 2 (Wang, Xu, & He, 2013). The top two boxes, Rail Component and Urban Transport Component, are retained as variable components as it is assumed that the Individual Component has been justified prior to constructing the system and that the Time Component will be optimized following construction. Feasibility refers to the ability to construct an HSR system and provide access to a large population of potential travelers.

Figure 2: HSR Accessibility Components



Source: (Wang, Xu, & He, 2013).

TRACK

The location of HSR tracks within an urban environment is a cost-prohibitive challenge faced by engineers and planners. Often, the required infrastructure already exists in the form of passenger or freight rail lines and conventional regional or inter-city passenger rail stations. The incorporation of HSR trains onto this existing infrastructure is not so straightforward however. Rail lines must be upgraded or constructed in order to allow HSR to access the city. European Council Directive 96/48 details that HSR lines shall be composed of one of the following:

1. Specifically built High Speed lines equipped for speeds generally equal to or greater than 250 km/h (155 mph),

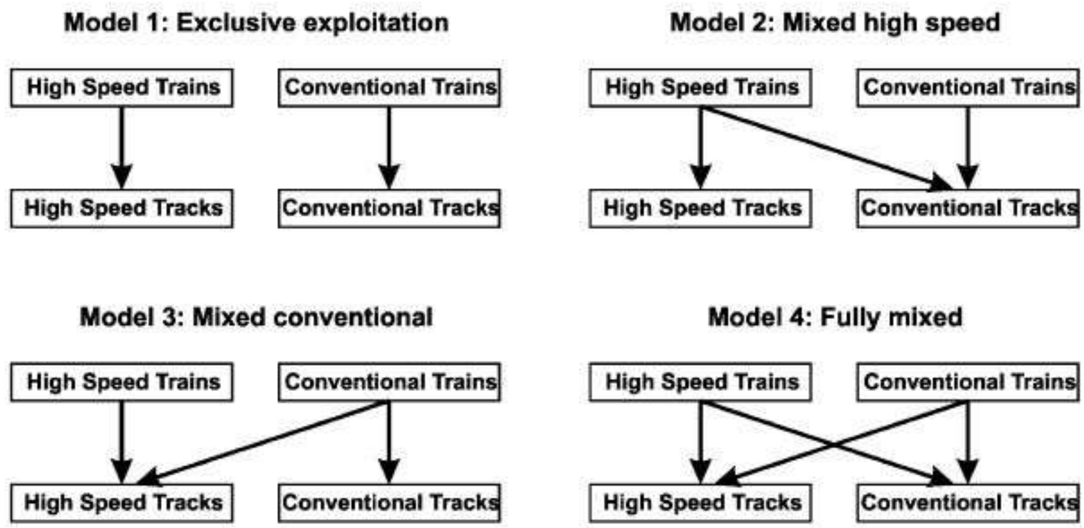
2. Specially upgraded High Speed lines equipped for speeds of the order of 200 km/h (124 mph),

3. Specially upgraded High Speed lines which have special features as a result of topographical, relief or town-planning constraints, on which the speed must be adapted to each case. (UIC, 2016)

Though the first case, specifically constructed lines, would generally be preferred for operational purposes, it is anticipated that upgraded lines are a much more feasible and cheaper alternative within an urban environment.

Figure 3 presents four models detailing the relationships between HSR and conventional rail systems (Campos & de Rus, 2009). Model 1 represents exclusive infrastructure for both systems, with each having separate tracks and most likely separate rail stations. For each of the three remaining models, there exists some shared infrastructure between the systems. The incorporation of a mixed model, though more cost-effective, comes with a number of operational challenges involved with multiple-speed and multiple-operator trains on the same stretch of line (Campos & de Rus, 2009).

Figure 3: Relationships between HSR and Conventional Rail Systems.



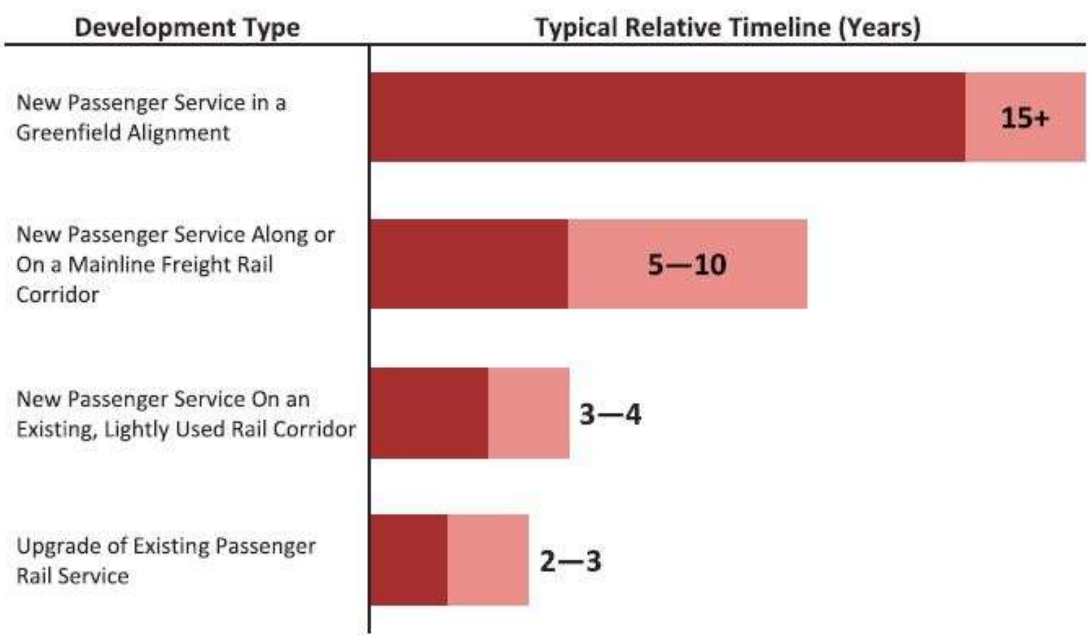
Source: (Campos & de Rus, 2009).

As with a conventional rail system, the negative external effects of an HSR system include pollution, noise and accidents. Due to the higher speed of an HSR system, it is anticipated that noise pollution will be especially heightened. The existence of viaducts, tunnels and at-grade crossings increase safety risks. To lessen the impact of noise and increase safety, the speed of an HSR train within an urban area is often restricted far below its designed operating speed (Campos & de Rus, 2009).

The HSR system is most frequently designed to complement an existing conventional rail service (i.e. incorporate one of the mixed models in Figure 3), evolving from the existing network and replacing routes or upgrading ROW in small chunks (Levinson, 2012). This process is especially true within urban areas, where new HSR lines are forced to utilize old lines on the approaches to central stations (Hall, 2009). Loukaitou-Sideris (2013) conducted a series of interviews aimed at determining the potential integration of an HSR system into California cities. Most of the interviewees indicated that constructing tunnels or using shared tracks were preferred techniques. Nevertheless, neither comes without a challenge as tunnels are very costly (compared to surface tracks) and shared tracks could lead to operational inefficiencies.

The cost and time of construction is dependent on the type of system development required. Figure 4 displays the typical relative timeline for construction of an intercity rail service (Morgan, et al., 2016). Upgrading existing rail lines into a new passenger rail service could take as little as 2 to 4 years (depending on length of the segment), whereas a new line construction could take 15 years or more. This initial investment for both system cost and development time is no doubt a detriment to the development of a new intercity rail system. The long term nature of construction in a greenfield alignment, more than 15 years, is enough to span multiple political generations and to potentially increase the difficulty of gaining support for the system.

Figure 4: Typical Relative Timelines for Intercity Passenger Rail Construction



Source: (Morgan, et al., 2016).

New greenfield track alignment is preferred for passenger service since train speeds, train frequency and engineering design can be optimized. However, this orientation, especially in urban areas, is not necessarily feasible. ROW acquisition through property seizures can be a lengthy, costly process, reflected in the extended timeline of construction in Figure 4. A shared track operation or new dedicated track on existing rail alignments are more feasible alternatives. These alternatives do not come without their own set of challenges. Extensive cooperation and enthusiasm for completing the project is required from all involved parties for both types of development. Additionally, a number of engineering and safety constraints, including track curvature, grade crossings and signaling, add complexity to a shared track operation. For a dedicated track on an existing alignment, costs are higher since a new line is required and freight companies may be reluctant to allow operations in their corridors. The added congestion represents a potential detriment to their further growth and may require relocation of the main freight line within the corridor. Again, track curvature and grade crossings become significant hazards in this type of development (Morgan, et al., 2016). It should be noted that shared track operations between HSR and freight rail services are not anticipated nor practical due to the requirements of track design for each service. It is anticipated that these shared operations will involve ROW rather than existing lines.

Grade crossings signify a significant barrier to HSR passenger train speed, especially within urban areas. Above 125 miles per hour (mph), the Federal Railroad Administration prohibits grade crossings. Below or equal to 125 mph, grade crossings are permitted with added barriers (Morgan, et al., 2016). This speed requirement represents a challenge to HSR planning and implementation. Speed must be restricted wherever these grade crossings exist, or a bridge or tunnel must be built to reroute the train over or under the road in question, adding significant cost to the project.

The challenges in providing a corridor for an HSR system within an urban area are not trivial. Often designed with the purpose of traversing large swaths of countryside in a short amount of time, these systems face numerous roadblocks when entering urban areas and delivering their customers to their final destinations at HSR stations. Delivering the customer closer to the central business district of the city results in higher costs, longer construction time and limited options in determining the route of an HSR system.

STATIONS

Inherently related to the location of the HSR tracks is the location of the HSR station. The location of a station is an important transportation policy issue (Martínez, Moyano, Coronado, & Garmendia, 2016) and relates to the accessibility of an HSR system (Figure 2). Loukaitou-Sideris and Peters note that HSR has a distinct advantage over air travel because it offers a direct connection into the center of cities. However, this connection is dependent on proper station location close to central business districts and integration with existing transit systems. Stations also provide an opportunity for transit-oriented development (TOD) and urban planning if built from scratch or in depressed regions (Garmendia, Ribalaygua, & Ureña, High speed rail: implication for cities, 2012).

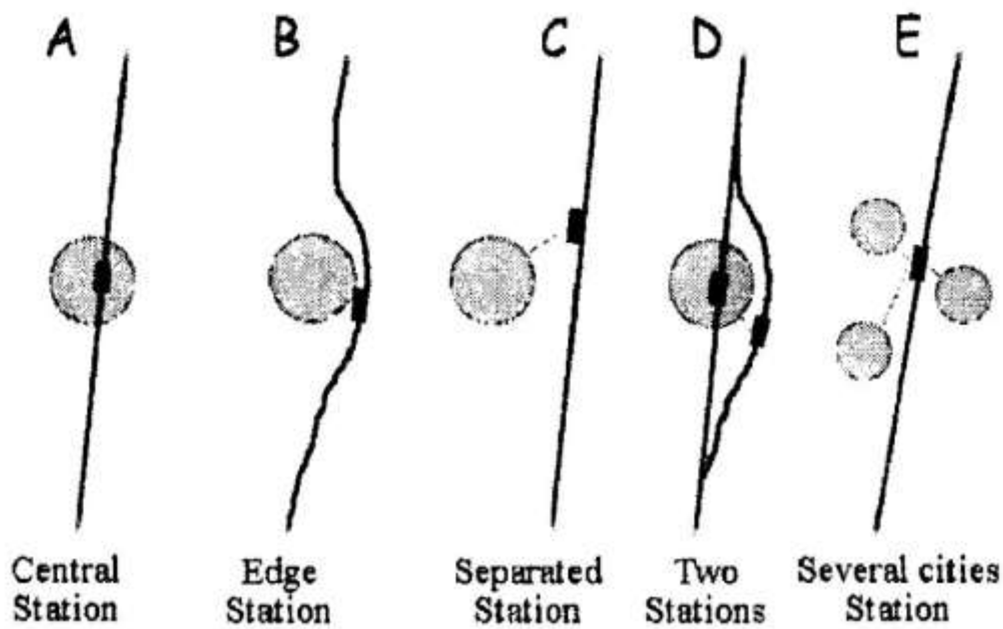
Several scholars have listed types of stations based on their locations relative to the center of a city. Hanna & Kaufmann (2014) provide the following three types to consider when developing an HSR station:

1. Urban-centered (<5 km from center) – most successful station since it provides quick access to central business district and retail centers. However, this station is not very feasible unless there is an existing centrally located rail station.

2. Urban-edged (5-15 km from center) – lacks quick access to center. This station is most commonly built since most cities do not have ability to provide urban-centered station.
3. Urban-fringed (>15 km from center) – very low accessibility. This station is mostly built in small to medium cities or for future city planning.

Menéndez et al. (2002) provides a visual framework for station locations, replicated in Figure 5. Although the article discusses the location of stations in reference to small cities in France and Germany, important parallels can be drawn between the station types proposed by Hanna & Kaufmann (2014). Typologies A, B and C in Figure 5 represent the urban-centered, urban-edged and urban-fringed stations, respectively. Typology D represents a special case with two stations serving one city whereas Typology E represents one station serving two or more cities and acting as a regional station.

Figure 5: HSR Station Typologies



Source: (Menéndez, et al., 2002).

The location of stations presents a trade-off between many variables including public transportation access, business and retail access, land cost and development opportunities. The central stations are most often preexisting and have been upgraded from their original design in order to serve increasing passenger traffic and new rail lines (Menéndez, et al., 2002). Central stations benefit from greater integration into existing transportation networks and closer location to retail and business centers (Facchinetti-Mannone, 2009). Additionally, these European central railway stations have served as a central location where goods and people converge (Tiry, 1999). Peripheral stations will often require purchasing land and building the required infrastructure, but provide opportunities for further growth and development in the immediate area. Central stations may have the required land and infrastructure already in place, but if starting from scratch, these costs are likely much greater than the costs of a peripheral station. The centralized location is not as necessary in the United States, where passengers are more likely to reach the station by private automobiles than by public transportation (Lovett, Munden, Saat, & Barkan, 2013).

It is important to note, however, that the track orientation in Figure 5, Typology A is very deceptive when relating to older, larger European cities. The figure suggests that tracks proceed straight through the city. In older stations that have been upgraded to serve HSR, such as London St. Pancras or Paris Gare du Nord, the station remains as an end design, where trains are forced to back out of the station to continue on their journey. Though not common in the United States, the Federal Railroad Administration (2005) specifically prohibits end stations (and therefore, reversible track) when designing station sites for corridor applications. Through stations are more operationally efficient, since trains are not forced to reverse direction nor circumnavigate the city once outside of the station. The trains pass through the city in addition to passing through the station. However, the type of station requires tracks proceeding through the city, which is neither desired nor feasible in older European city centers. End stations are more amenable to passengers, frequently allowing closer access to a central business district while not requiring passengers to traverse tunnels or overpasses inside the station to reach platforms (Walker, 2009).

Similarly related to the type and location of the station within a city is the location of the city within the HSR network (Martínez, Moyano, Coronado, & Garmendia, 2016). Levinson (2012) discusses that many HSR networks have a hub-and-spoke architecture, where a large, centrally located city such as the capital serves as the main hub and there are various HSR lines branching out from this city towards the rest of the region or country. France is a typical example of the hub-and-spoke network, with Paris as the hub. According to this architecture, it would be expected that all cities on the spokes of the network would have a through station design, exemplifying one of the five station typologies in Figure 5. The hub of the network, the major city, could be of either station design since trains normally would not pass through the city, but would terminate at a city station. Further reinforcing this hub-and-spoke architecture is the previous development of separate termini for rail lines entering the city from different regions of the country, most notably seen in London, Paris, Berlin, Madrid and Barcelona (Hall, 2009).

Since HSR stations are becoming attractive locations for economic activities and potential centers for urban growth, urban planning and development has become an increasingly important consideration when determining the location of the HSR station (Garmendia, Romero, Ureña, Coronado, & Vickerman, 2012). Although central urban stations are desired for the closest connections into a city, edge stations are becoming attractive alternatives. These peripheral stations have more regional implications, allowing access from a potentially wider geographical area while encouraging local growth

(Martínez, Moyano, Coronado, & Garmendia, 2016). The construction of an HSR station on the urban periphery or in a city that previously did not have an HSR system provides an opportunity for the transformation and reshaping of the local or regional area (Loukaitou-Sideris, 2013). The potential benefits cannot be ignored.

De Jong (2007) conducted a study of eight HSR stations in Northwest Europe, a mix of central and peripheral locations, determining the ten most important factors for attractiveness for offices and retail at HSR stations (Figure 6). Regional economy and location image appear very high on both lists, while traditional operational factors for HSR stations, including accessibility by public transit, densities, car accessibility and parking are not considered as important. It should be noted that this study does not consider passengers using the HSR station to access the city.

Figure 6: Factors of Attractiveness for HSR Stations

10 most important factors that constitute the attractiveness of HST locations for Offices.

1. Regional Economy
2. Location Image
3-4. Regional Rail Accessibility
3-4. Good Car Accessibility & Parking Places
5-6. Urban Embeddedness
5-6. Mixed Use
7-10. Public Support
7-10. Good National Accessibility
7-10. International Accessibility
7-10. Clustering

10 most important factors that constitute the attractiveness of HST locations for Retail.

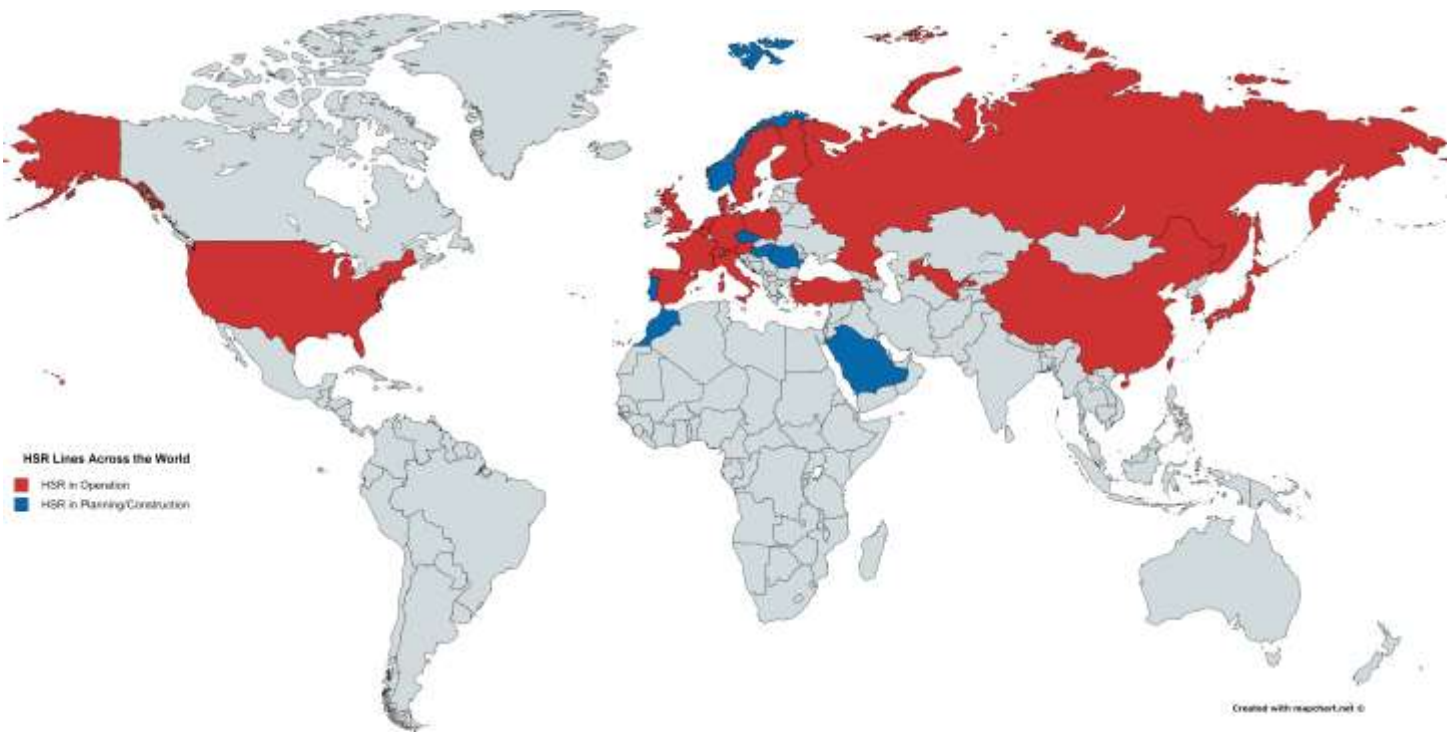
1. Passenger Flows
2. Regional Economy
3-5. Location Image
3-5. Accessibility by Public Transport
3-5. Quality of the Public Space
6-8. Other Stores
6-8. Densities
6-8. Car Accessibility & Parking Possibilities
9-10. Local Employees & Residents
9-10. Mixed use

Source: (De Jong, 2007).

INTERNATIONAL SYSTEMS

There are currently almost 30,000 kilometers (18,641 miles) of high speed rail lines in operation around the world, carrying 1.6 billion passengers per year (UIC, 2016). The amount of HSR systems around the world is dramatically increasing, now operating in over 20 countries. HSR is under development or in construction in a number of additional countries across three continents, as shown in Figure 7. In this thesis, several international HSR systems were studied to determine their methods for integrating an HSR system into their cities. The systems studied include China, France, Germany, Japan, South Korea, Spain and Taiwan. These systems were selected due to their large extent of dedicated HSR lines (versus upgraded lines) and due to the availability of applicable literature.

Figure 7: HSR Lines Across the World



Source: (Map Chart, 2016).

China

The Chinese HSR system is responsible for 60%, or 19,000 kilometers (11,806 miles), of the total HSR lines around the world, carrying 50%, or 800 million, of the total HSR passengers (The Economic Times, 2016). With further expansion planned, the Chinese system represents an optimal model of implementation of a large-scale HSR network in a short time period. The system has been constructed on infrastructure segregated from conventional rail tracks and stations. The quick expansion has not come without drawbacks or oversights, however, as the Chinese have elected to skip the problem of integrating HSR stations into urban environments by designing a vast majority of the stations on the urban periphery (Yin, Bertolini, & Duan, 2015). Of the 93 stations connected by the Gaosu (G-series) or Chengji (C-series) trains in China, 15 are upgraded existing stations, while 78 are newly built (Diao, Zhu, & Zhu, 2016).

The reasons for these urban periphery locations are not entirely clear. These locations have very poor, if any, connection to urban city centers and transportation systems. Scholars have pointed to a variety of reasons for these peripheral locations. The new stations are often planned in accordance with future land planning forecasts, in anticipation that these peripheral locations will no longer be so distant in the years to come (Garmendia, Ribalaygua, & Ureña, 2012). This criterion is difficult to judge at this moment since the forecast year of 2020 has not yet been reached.

Yin, Bertolini & Duan (2015) identify four factors that may explain the choice of peripheral station locations:

1. City governments want to develop new city centers located around the new HSR station and want to make a profit selling the land surrounding the new stations;

2. City governments do not want to construct a new HSR station or upgrade an existing HSR station due to the high costs of building a station in an urban environment;
3. Traditional railway stations located in urban areas maintain the image of a poor, depressed environment;
4. Urban environments increase technical, engineering and design challenges of constructing a new HSR system.

These factors identify an interesting angle on integrating HSR into an urban environment, suggesting that many Chinese cities prefer new, peripheral stations that can be more adequately planned, even for future population growth and city expansion, with lower costs, engineering difficulty and construction time. Additionally, building these new stations does not constrain the alignment of HSR lines nor does it hinder the operation of existing rail services during construction, as would exist during a station upgrade (Diao, Zhu, & Zhu, 2016). City governments may also find it difficult to seize the land required for urban track and stations (Wang, Xu, & He, 2013).

Wang, Xu & He (2013) add that the Chinese HSR system is incompatible with the conventional system in operation techniques, including signaling. Although the infrastructure upgrades required to make both systems compatible would be minimal compared to the overall cost of the new HSR system, it appears that in most cases, the Chinese have elected to build new infrastructure rather than upgrade the existing. There is an added benefit of separated infrastructure, requiring minimal, if any, cooperation or coordination between conventional and HSR operators.

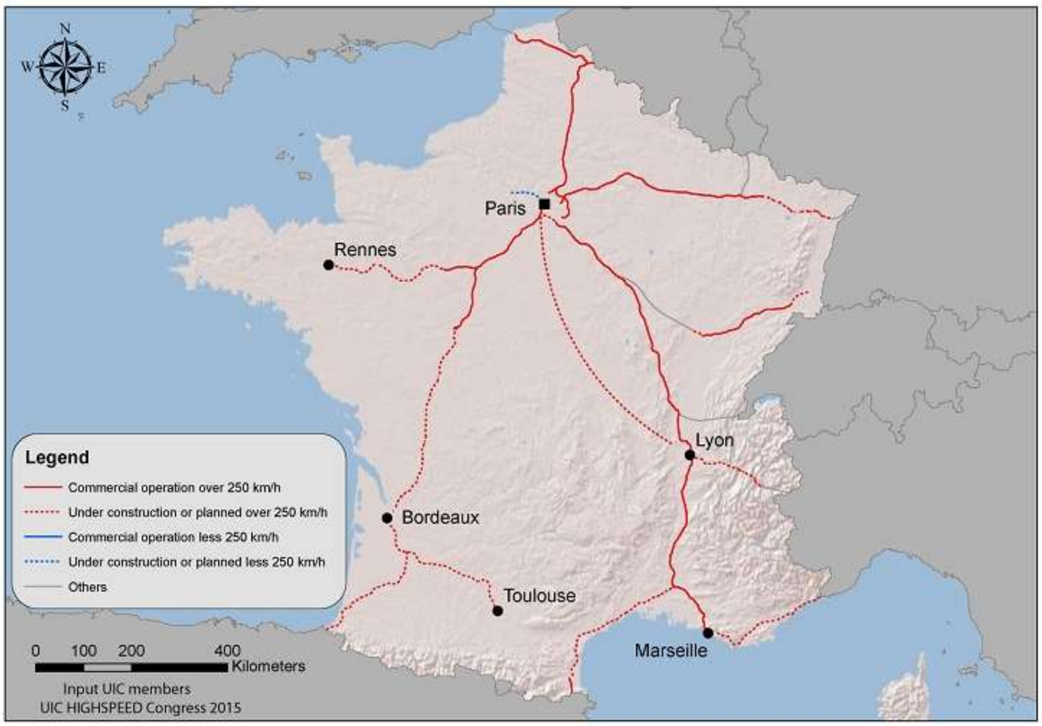
The textbook planning and low costs of these new, peripheral stations does come with one significant drawback: inconvenience to travelers (Diao, Zhu, & Zhu, 2016). Since HSR looks to compete with air travel on a regional or national level, the access time to stations (as with airports) is a very important consideration to potential travelers. A peripheral station fails to provide quick access to the travel. In the case of many Chinese cities with peripheral stations, public transportation access does not exist and highways needed to be built to connect these stations to the city (Yin, Bertolini, & Duan, 2015). The distance from the city centers to HSR stations can be as large 24 km (in Suzhou), averaging 11.23 km in the newly built peripheral stations on the G-series or C-series trains (Diao, Zhu, & Zhu, 2016). Passenger access time for these stations is significant, representing an unwanted leg on a long distance HSR journey. In Shanghai, access time has increased from 20 minutes to 50 minutes once the new peripheral HSR station was constructed (Yin, Bertolini, & Duan, 2015).

Passenger consideration does not appear to have been a very important thought in Chinese HSR station design. The size of many stations hinders passenger movement. For example, the Shanghai Hongqiao transport hub, designed to connect HSR, Maglev HSR, express buses and other transportation options with Shanghai International Airport, requires passengers to travel 700 meters to the airport, a substantial walking distance. Additionally, Nanjing South station requires an eight-minute transfer between the metro station and the HSR waiting hall despite the station being considered one of the best practices among new stations (Yin, Bertolini, & Duan, 2015).

France

The French Train à Grande Vitesse (TGV) system was the first HSR line established in Europe in 1981. The French TGV has a distinct hub-and-spoke architecture, with the capital Paris serving as the hub, as seen in Figure 8. Levinson (2012) proposes that this hub-and-spoke architecture achieves economies of density in track and line usage and enables frequent services from the hub to multiple destinations. The hubs of the system are reinforced as central urban population centers due to the increased accessibility benefits of the HSR system. In the case of France, Paris is a logical choice for a hub. Not only serving as a population and tourist center and the country capital, Paris is relatively centrally located and serves as a terminus for many conventional rail services.

Figure 8: French TGV Network Map

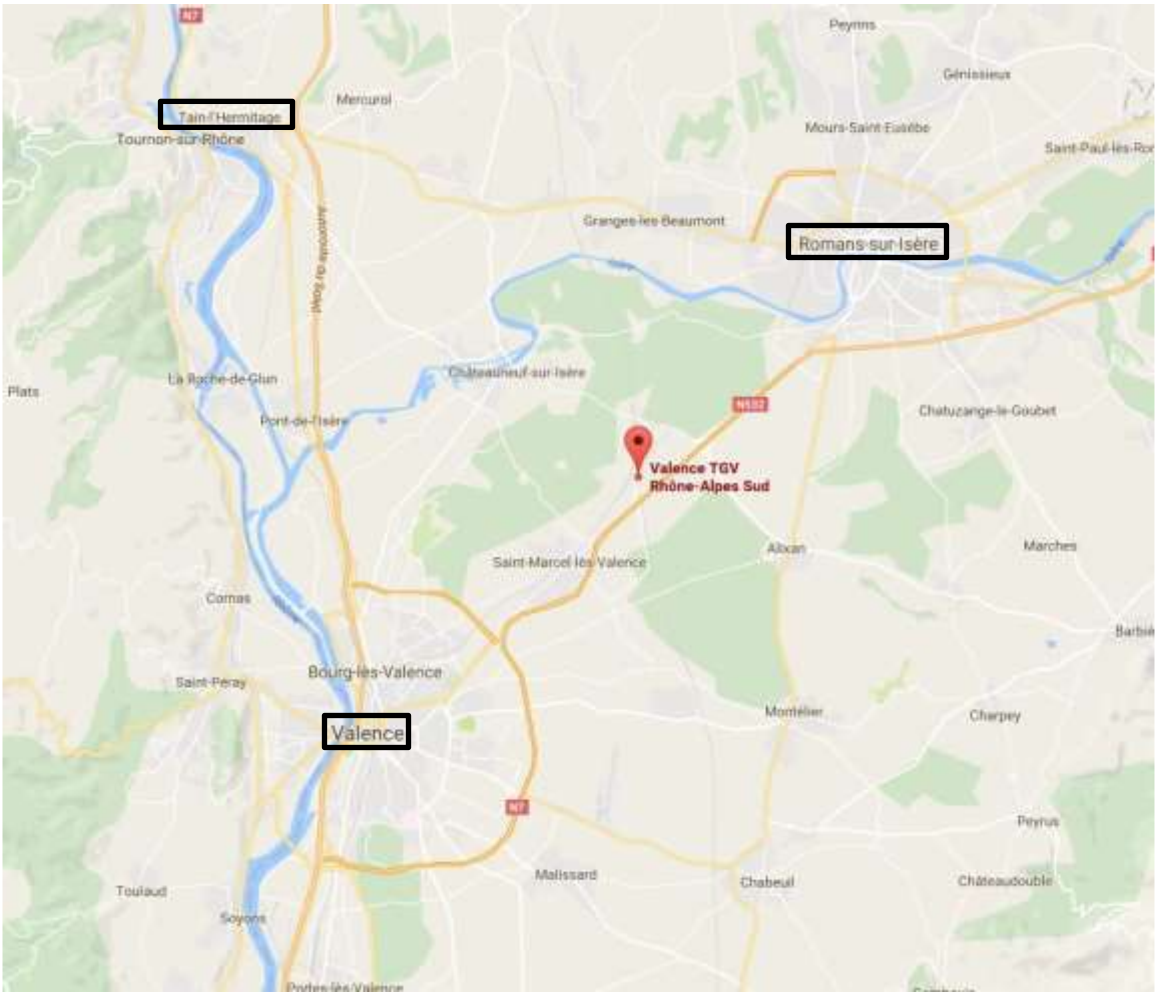


Source: (UIC, 2016).

Paris has several main train stations, each serving a different region of the country (Voyages-SNCF, n.d.). The hub-and-spoke network architecture encourages end stations at the hub and through stations along the spokes (until spoke terminus). The French TGV system operates on both high speed and conventional tracks, identified as Model 2 by Campos & de Rus (2009) in Figure 3. The TGV often runs onto existing conventional tracks for a few kilometers in urban areas into existing termini, supporting the use of the existing stations and reinforcing these central stations as attractive places for commercial investment (Hall, 2009).

The spokes of the TGV system include relatively few and distant stations (Ureña, Menerault, & Garmendia, 2009). These stations, as with the Chinese system, are often designed where it is most convenient for the overall system, rather than for passengers traveling to a specific city. France has several notable examples of stations designed to accommodate several small- to medium-sized cities within a region rather than one specific city. The Haute-Picardie TGV station, north of Paris, lies halfway between St. Quentin and Amiens, a significant 25 km from each city (Hall, 2009). The Valence TGV station, depicted in Figure 9, is located 10 km from Valence and significantly outside the urban boundaries, serving the three cities of Valence, Romans and Tain l'Hermitage (Maillard, 2001). Passengers are required to transfer to conventional regional services to reach these cities (Facchinetti-Mannone, 2009).

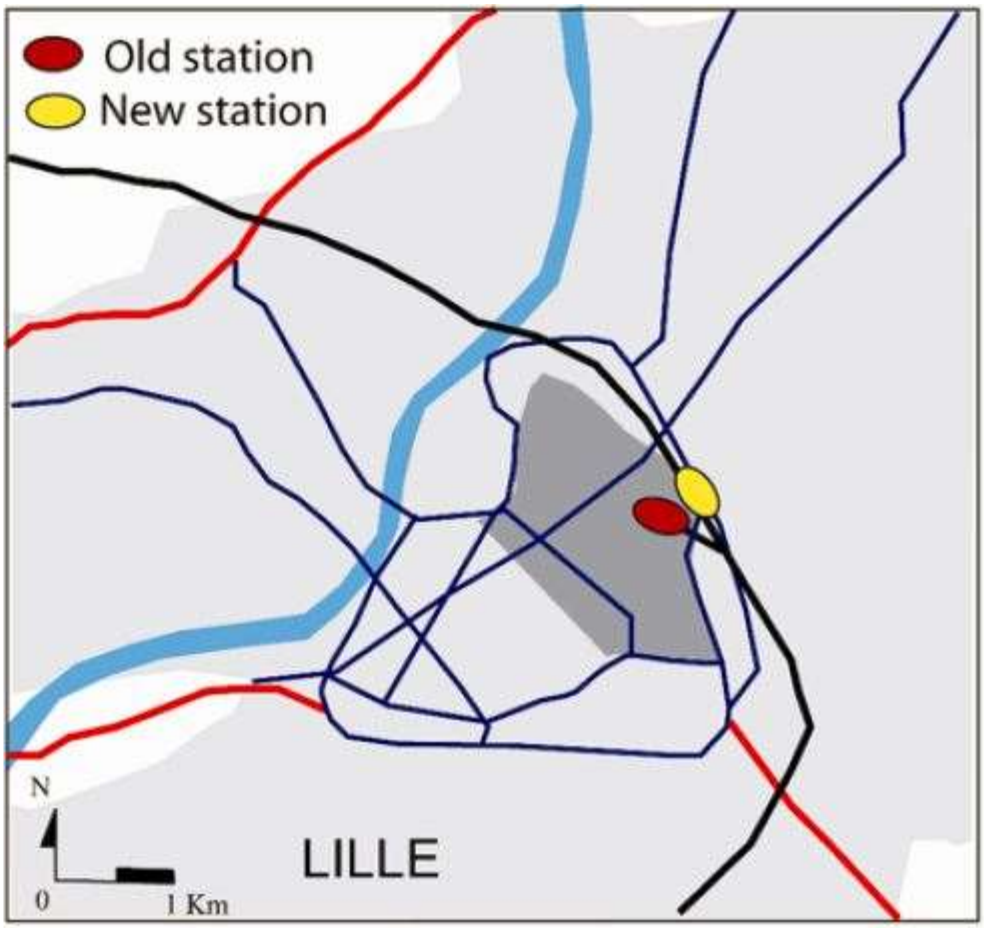
Figure 9: Valence TGV Station



Source: (Google, 2016).

Paris and Lille have both developed new stations, allowing TGV services to pass through the cities rather than having trains back out of end stations or requiring passengers to transfer between city stations. In Paris, these stations were developed at Charles de Gaulle airport and at Disneyland Paris. However, the usage of these stations is still very limited (Hall, 2009). In Lille, a new station was constructed adjacent to the original end station, shown in Figure 10 (Ureña, Menerault, & Garmendia, 2009). Lille was transformed from a spoke terminus into a through city, allowing high speed connections to north points and London.

Figure 10: Lille Station Locations



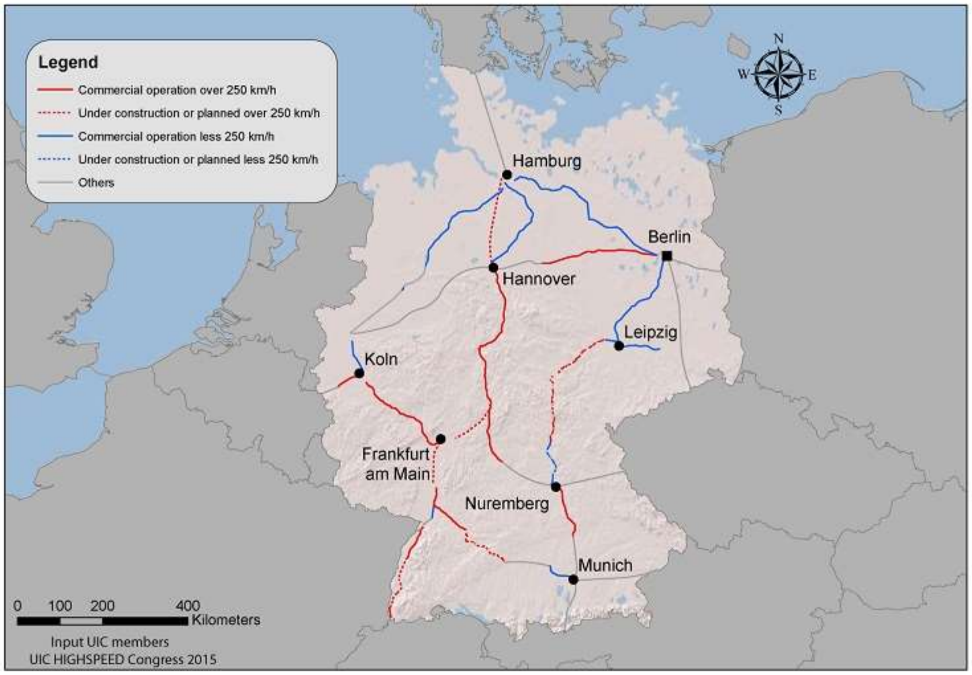
Source: (Ureña, Menerault, & Garmendia, 2009).

Similar to the Chinese system, the French TGV system has prioritized traversing rural areas at high speeds, leaving the first mile and last mile of travel to the passenger by constructing stations outside city limits or significantly slowing the speed of their trains by operating on existing conventional rail tracks inside urban areas. These practices limit the costs and detrimental impacts of constructing an HSR line in an urban area, again at the price of passenger inconvenience. Interestingly, the French have also added acoustic fencing around tracks passing near towns or villages, due to the large amount of noise complaints (Hall, 2009).

Germany

The Germany Intercity-Express (ICE) HSR system began service in 1991 and is markedly different than the previous examples of HSR systems in China and France. The German ICE network (Figure 11) was designed to utilize existing tracks, corridors and stations, by upgrading tracks and stations or building new dedicated high speed lines as necessary (Loukaitou-Sideris & Peters). The variety of infrastructure can be seen in Figure 10, with dedicated high speed lines represented in solid red and upgraded lines in solid blue. It can also be seen that the German HSR system does not exhibit the hub-and-spoke architecture of the French TGV system. The lack of system architecture is most likely due to the country's strong federalism, decentralization and late formation into a united nation after the fall of the Berlin Wall (Levinson, 2012).

Figure 11: Germany ICE Network Map



Source: (UIC, 2016).

The upgrading of existing lines and the integration between conventional and high speed services limits the speed of high speed trains on many corridors. In contrast to prioritizing speed, the Germany system instead promotes modal connectivity at the station level. Deutsche-Bahn (DB), the national German railway company, has elected to re-purpose and re-construct several existing rail stations, including Berlin South Cross, Kassel Wilhelmshohe and most notably, Berlin Hauptbahnhof (Loukaitou-Sideris & Peters). The modal connectivity at these inner-city rail stations extends beyond rail services, as many cities have located their main bus stations nearby, promoting integrated timetables and mode transfers. German rail stations also provide business and retail stores, often open 7 days per week, that serve the local community and travelers passing through the station (Menéndez, et al., 2002). Interestingly, DB also cooperates with Lufthansa, the German national airline (Loukaitou-Sideris & Peters). The integration between the German ICE and other transportation modes is second to none, even extending to air travel, a mode normally competing with HSR operations at short- to medium-distances of travel. The ICE HSR lines serve as a feeder for air travel at Frankfurt airport (Albalate, Bel, & Fageda, 2015).

Discussions for the transformation of the Berlin Hauptbahnhof into the magnificent glass structure seen in Figure 12 began as early as 1992, immediately following German reunification. Peters (2010) suggests that the large-scale transformation of this station and the related infrastructure investments and expansions would not have been possible without the context of reunification. Nevertheless, the construction of the new station, completed in 2006, required significant rail improvements, including a new north-south tunnel through the Tiergarten immediately south of the station and the rebuilding of the east-west Stadtbahn viaduct (Railway Gazette, 1997). The station is remarkable in the fact that it allows trains to pass through without changing direction of travel and includes multiple levels for the various directions of travel, with north-south trains on the lower levels and the east-west trains on the upper levels above street level.

The new station has not come without its fair share of criticism, however. From the very beginning, the location of the station was questioned. The existing site was isolated, providing few amenities in the immediate area, and it suffered from poor connectivity to the existing subway, tram and S-Bahn lines. Although improvements have been forthcoming and interconnectivity has improved (seen by the bus in Figure 12), the development money required for further improvements, such as connecting into north-south S-Bahn lines, is now tethered to this station for years to come, when it could have been better utilized elsewhere (Peters, 2010).

Figure 12: Berlin Hauptbahnhof (Central Train Station)

Additionally, the Hauptbahnhof, though centrally located, has actually proved detrimental to passengers, increasing access time for nearly 65% of Berliners, while cutting off the Zoo Station from HSR transport. Within the station, retail stores and restaurants dominate the central, non-train levels. Passenger flows have not been optimized for connections (there is no direct connection between train levels), as instead they have been routed past the various outlets on the different floors in the hopes they will stop and shop (Peters, 2010).

The German ICE system provides an optimal model for integration between HSR and various other transportation modes. Though speeds are often restricted far below top speeds in other HSR systems across the world, the time difference is easily overcome by connection into central areas of cities rather than the outskirts. DB has also attempted to make these central stations attractive places to travel and shop; but, not all of their transit-oriented development initiatives have been successful, as seen by the mixed reviews of the newly-built Berlin Hauptbahnhof.

Japan

The Japanese Shinkansen was the first HSR service, first operating in 1964, nearly two decades before HSR was established in Europe (Garmendia, Ribalaygua, & Ureña, High speed rail: implication for cities, 2012). Japan's HSR infrastructure was constructed separately to the existing conventional rail lines (Campos & de Rus, 2009). The conventional rail network operates on narrow gauge (1067 mm) tracks and it was decided that the HSR network would be built completely separated from the conventional network on full-scale, standard gauge tracks (Takatsu, 2007). The Japan Shinkansen network (Figure 12) resembles a hub-and-spoke pattern, with Tokyo at the center and lines emanating northeast, northwest and due west from the city (Levinson, 2012).

A large majority of the Shinkansen lines were constructed to tie into existing railway stations. Many Japanese cities had developed around the railway stations, since these provided the main means of transportation and therefore, these stations were readily accessible from various areas of each city (Okada, 1994). Similar to German rail stations, Shinkansen stations are often redeveloped to include a variety of retail and business uses. Okada (1994) notes that of the 18 stations on the Tohoku Shinkansen line between Tokyo and Aomori, seven have large-scale department stores and business uses, including three stations that have hotels with conference room access.

Figure 13: Japan Shinkansen Network Map

Source: (UIC, 2016).

Beyond the development of existing stations, the Japanese Shinkansen is also a leader in urban safety and environmental standards. The Tokaido Shinkansen line between Tokyo and Osaka (the first constructed) was designed to eliminate all at-grade railroad crossings (Takatsu, 2007). Additionally, due to the high speed of the system and the steel-wheel on steel-rail technology, noise and vibration became an unpleasant side-effect to residents living near the rail lines. As early as December 1972, the Japanese Environmental Agency (now the Ministry of the Environment) issued recommendations to reduce noise levels (Takatsu, 2007). Strict noise and vibration regulations have been established for the operation of the Shinkansen system.

Despite constructing a totally separated infrastructure system for the Shinkansen HSR system, the Japanese have managed to tie these new lines into renovated existing stations, providing passengers access to dense city centers and new retail and business uses and accommodations at some stations. Safety and environmental considerations have been paramount in the design and operation of the system.

South Korea

The Korea Train eXpress (KTX) began service on April 1, 2004, becoming the third country in Asia to add HSR service after Japan and China. The system extends between Seoul to the north, Gwangju to the southwest and Busan to the southeast, as seen in Figure 14. Development and operations of the system has been plagued by delays, cost overruns and low ridership. The network was notably developed in segments, with a dedicated HSR line constructed between Seoul and Daegu (line to Busan) for the grand opening in 2004. Remaining segments of the system utilized newly electrified conventional lines until construction could be completed on the rest of the required segments (Rutzen & Walton, 2011). Though the system has taken years to materialize, the practice of utilizing existing conventional lines for higher speed rail to complement newly built sections of HSR corridors can provide a model for other nations seeking to implement HSR over an extended period of time or with a limited budget.

Figure 14: South Korea KTX Network Map

Source: (UIC, 2016).

Since the KTX lines closely follow or parallel conventional rail lines, the system has utilized many of the existing stations, instead electing to renovate and expand these facilities to include a variety of retail and commercial uses. The new station buildings include innovative architectural designs and multiple stories above and below ground (Chun-Hwan, 2005). Two new stations were built for the initial KTX opening in 2004 (Suh, Yang, Lee, Ahn, & Kim, 2005).

The KTX network is also noteworthy because it was constructed largely without major disruptions or suspensions of conventional rail services. The electrification of the conventional rail lines and the upgrading of existing stations was done mostly at night, limiting the interruptions to rail services. Upon completion and implementation of the system, conventional services were not reduced but instead optimized to feed into KTX services (Suh, Yang, Lee, Ahn, & Kim, 2005). Maintaining existing levels of services is remarkable given that KTX and conventional rail lines shared a new electrified rail line, resulting in difficulties of managing the increased number of trains, along with the different speeds of services.

Spain

The Spanish Alta Velocidad Española (AVE) HSR service began in 1992, shortly after its European counterparts (Loukaitou-Sideris & Peters). As seen in Figure 15, the system exhibits a notable hub-and-spoke architecture, with the capital Madrid at the geographical center (Levinson, 2012). The AVE system has adopted a mixed conventional model (#3 in Figure 3), where some conventional trains operate on specifically constructed high speed tracks (Campos & de Rus, 2009). The Spanish HSR system was constructed on a different gauge than the conventional rail system. However, there is still compatibility between systems as a number of gauge change stations have been implemented across the network, allowing trains to change gauge without having to stop. This practice provides the flexibility of allowing trains to travel on either gauge of track and allows the AVE trains to travel at higher average speeds than the German ICE, which also shares tracks with its conventional rail system. However, a limited number of gauge change locations has proved detrimental to the system's operation.

Figure 15: Location of Spanish HSR Stations Relative to City Centers

Source: (Bellet, 2016).

Madrid is connected with several other urban centers across the country via the AVE system, including Barcelona, Valencia, Alacant, Malaga, Sevilla and Valladolid. The AVE is connected into these major urban centers with central stations. Figure 15 provides a map of the Spanish HSR system, with an indication of whether each station is located centrally, on the urban fringe or on the periphery (Bellet, 2016). Similarly to the French system, many intermediate stops have stations located on the urban fringe or on the periphery. Bellet (2016) notes that these stations were constructed as a result of pressure from local officials wanting access to the HSR system. These stations, many of which were constructed in the past ten years, may be located adjacent to one or more smaller municipalities, serving a large geographical area and eliminating the so-called tunnel effect. The tunnel effect refers to the spectacle where a HSR system will provide significant benefits to areas where it stops, but may have no impact or may even prove detrimental to areas along the route that the train does not serve due to its poor accessibility to the system. A conventional rail system or highways can provide access to these intermediate locations, limiting the negative impacts (Martínez, Moyano, Coronado, & Garmendia, 2016).

The centrally located Spanish HSR stations serve a variety of personal and social uses to the neighboring community with the inclusion of restaurants, retail stores, hotels and even museums. Loukaitou-Sideris & Peters note that these central stations are very well connected to public transit and provide access to various areas of the city and important destinations. These stations, therefore, do not require a significant amount of parking that would be required at a less adequately accessible station.

Taiwan

Taiwan implemented its HSR system relatively recently, first operating in 2007. As seen in Japan and Spain, Taiwan's HSR chose a different (standard) gauge than its conventional rail system. The track geometry of its existing tracks also proved to be incompatible, as the HSR system required a much larger curve radius than the conventional system could provide. As such, upgrading the existing lines or using the same ROW, the methods originally proposed by the Taiwanese government, were not possible (Cheng, 2010).

Figure 16: Taiwan HSR Stations Access Times

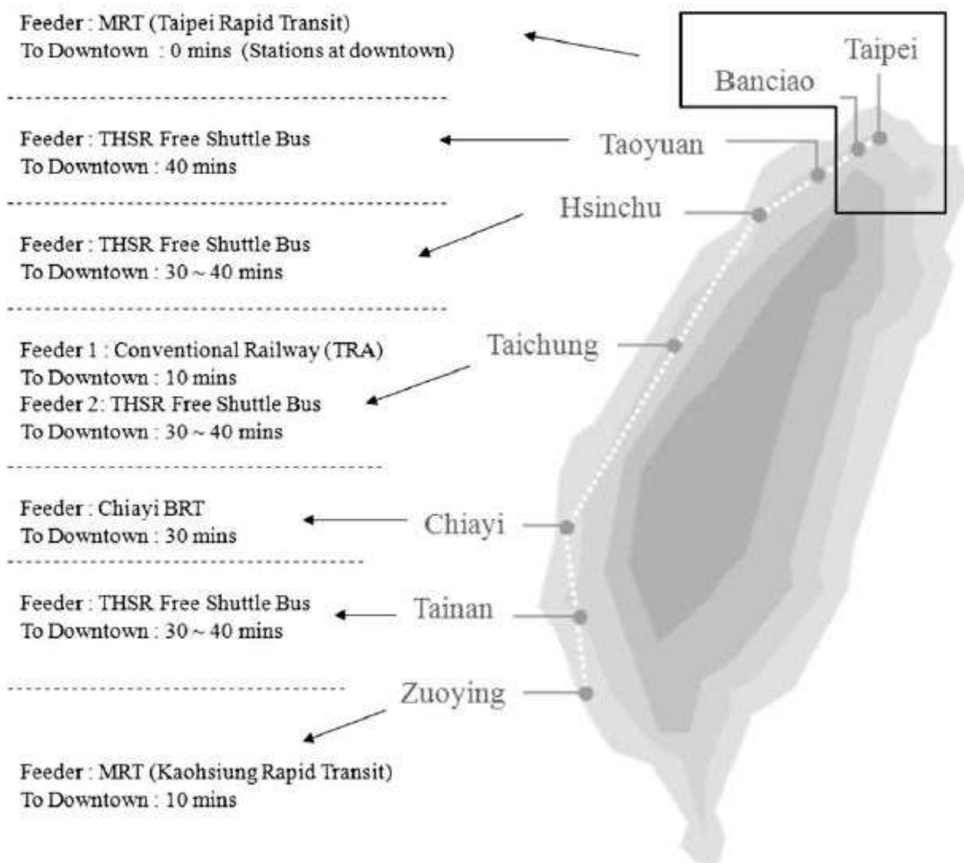


Fig. 6. Access time estimation to HSR stations.

Source: (Cheng, 2010).

The Taiwan HSR system is characterized by the location of a significant number of its stations on the outskirts or periphery of cities and by the poor accessibility from those peripheral stations to city centers. Figure 16 displays the access times and public transportation connections for each station on the Taiwan HSR system. In fact, only Taipei, Banciao, Taichung and Zuoying have stations at or near city centers. These stations are also the only stations with access to conventional rail or metro rapid transportation modes. The remaining cities rely on bus rapid transit or shuttle bus service for connection into downtowns, a journey taking at least thirty minutes. The decision to locate many stations outside city centers was made in the hopes of increasing property values while attracting development and new residents (Cheng, 2010).

There appears to be little to no connectivity between conventional and HSR services in Taiwan. Timetables are not optimized to transfer between systems and despite using some of the same stations in major cities, Cheng (2010) notes that the systems are competing against each other. The long access times between many HSR stations and city centers are disadvantageous to the HSR system since it is competing against both the conventional rail system and air travel.

Chapter 3: High Speed Rail Status in the United States

Though many HSR projects have been discussed or proposed in the last 50 years in the United States, few have generated any real traction. As such, there are few existing HSR corridors in the United States (Table 1). Segments of the Amtrak Northeast Corridor have been cleared for travel as high as 150 mph between Boston and New York City. However, the 2009 average speed of the 229-mile-long segment was only 68 mph, reflecting the difficulties in obtaining top speeds over long distances for trains on the congested Northeast Corridor. Four other corridors have been approved for travel at top speeds of 90 to 110 mph, with additional corridors planned in Florida and California.

Table 1: High Speed Rail Corridors in the United States

Corridor	Length (Miles)	Motive Power	Current Top Speed (mph)	Current Average Speed (mph)
Los Angeles – San Diego, CA	130	Diesel-electric	90	55
Chicago, IL – Detroit/Pontiac, MI	304	Diesel-electric	95	53
New York City – Albany/Schenectady, NY	158	Diesel-electric	110	56
Philadelphia – Harrisburg, PA	104	Electric	110	66
Northeast Corridor (NEC)	454	Electric		
Boston, MA – New York City, NY, segment	229		150	68
New York City, NY – Washington, DC, segment	225		135	82

Source: (Peterman, Frittelli, & Mallett, 2009).

The United States officially pursued the prospects of HSR as early as 1965, when Congress passed an HSR bill that contributed to the creation of the Metroliner between Washington, D.C. and New York City on the Northeast Corridor. The Metroliner was later acquired by Amtrak. Congressional spending for infrastructure improvements on the corridor continued into the 1990s with the purchase of Amtrak's Acela trains. Congress also funded research into HSR and Maglev technologies and trains. Without adjusting for inflation, it was estimated by the FRA that $4.17 billion was spent to fund HSR projects, improvements and research between 1990 and 2007 (Peterman, Frittelli, & Mallett, 2009).

More recently, in February 2009, Congress passed the American Recovery and Reinvestment Act (ARRA), appropriating $8 billion for intercity passenger rail projects, including high speed rail projects (Peterman, Frittelli, & Mallett, 2009). In response to the passing of ARRA, the FRA designated ten high-speed rail corridors (Figure 1) in addition to the Northeast Corridor for future development. While initial planning and preparation have progressed on several of these designated corridors, many others have fallen flat, due to lack of funding and political quarrels. The governors of Florida, Ohio and Wisconsin have rejected federal funding for high speed rail projects in recent years (Jaffe, 2013). The most notable success of recent publicly-funded HSR initiatives is that of the California High-Speed Rail Authority (CaHSRA). In 2008, California approved Proposition 1A, which authorized issuance of $9.95 billion in bonds for funding an HSR system and improving existing rail lines (Peterman, Frittelli, & Mallett, 2009). Combined with a $3.3 billion federal grant from the ARRA, the California HSR system had the initial funding to get off the ground, finally beginning construction in 2015 on a corridor from San Francisco to Anaheim. Further extensions of the corridor are planned to Sacramento and San Diego (California High-Speed Rail Authority, 2016).

Private (or semi-private) HSR initiatives have also surfaced in recent years, with generally greater success. Following the cancellation of the Florida HSR program, Brightline, an express train service introduced by All Aboard Florida, began planning and construction on a higher-speed corridor (up to 125 mph) from Miami to West Palm Beach with a later extension north to Orlando. Construction is already underway, with service expected to begin in Summer 2017 (Brightline, 2016a). In Texas, the Texas Central

Railway, having partnered with JR Central, has proposed an alignment between Dallas and Houston bringing bullet train technology to the Lone Star State (Mekelburg, 2016). Further west, the XpressWest HSR line seeks to connect Las Vegas, Nevada with Victorville, California, with further expansion to Los Angeles and Burbank, California and connection into the California HSR system (XpressWest, 2016).

With regards to specific station location and design, the FRA has published a Guidance Manual for Railroad Corridor Transportation Plans with recommendations and requirements for station accessibility. The following guidelines for station location are listed in the manual (Federal Railroad Administration, 2005):

1. Each city should have a station located in or near the central business district. This is a mandatory requirement for larger Metropolitan Statistical Areas (MSAs) with a population of 150,000 or greater.
2. One or more suburban stations need to be provided in larger metropolitan areas with easy access to the local primary road system.
3. Every effort should be made to have each corridor station serve as a regional intermodal passenger terminal for all forms of regional and local transportation systems.

Furthermore, the FRA recommends the following design guidelines for corridor rail stations:

1. Each station track configuration should provide for the through movement of trains along the corridor without having to reverse the train's direction at any time.
2. Where interlockings are located at both ends of the station, the distance between the opposing home signals must be great enough to hold the longest anticipated passenger train.

3. Where the normal movement of a corridor train requires a diverging movement through a turnout or crossover to access a platform, the turnout size should be as large as feasible given other local design parameters. Turnouts or crossovers should not be placed adjacent to a platform.
4. The length of a corridor platform should be as long as the longest anticipated passenger train.
5. The platform height should be equal to the car floor height in order to minimize station dwell time and comply with the Americans with Disabilities Act (ADA).

The FRA has also provided planning principals for stations in a separate guidance manual for station area planning. The following primary objectives are recommended for intercity and high speed passenger rail station planning (Federal Railroad Administration, 2011):

1. Optimize the station location.
2. Maximize station connections with other transportation modes.
3. Shape it [the station] through urban design.
4. Focus infill development around the station.

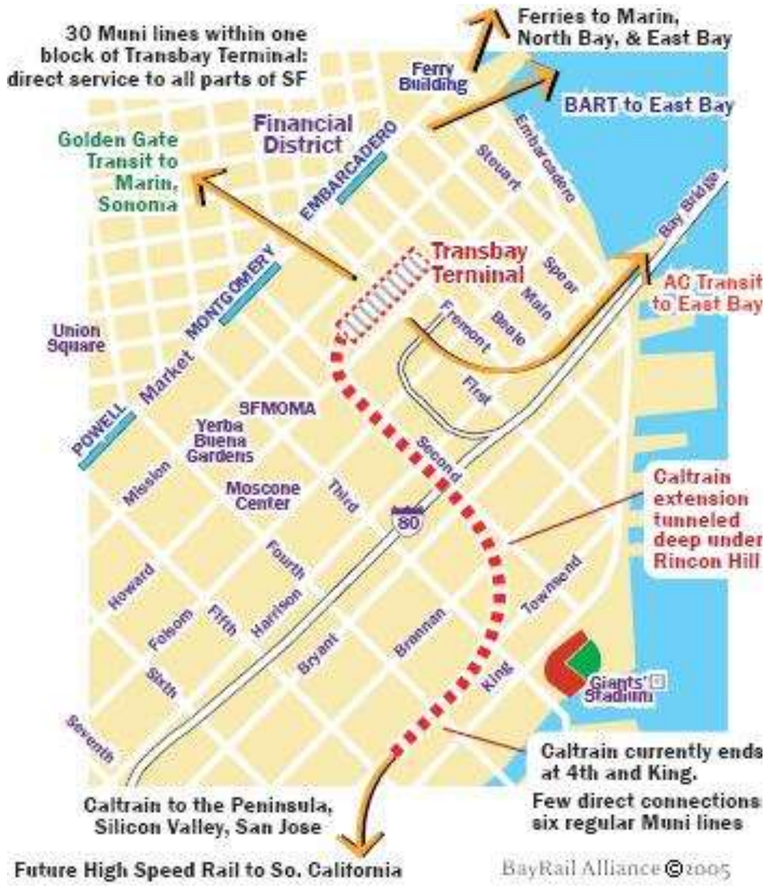
These guidelines will be used to evaluate potential station locations and designs in Dallas and Houston in Chapter 5 of this thesis.

Both California's HSR system and Florida's Brightline have required the construction of new stations along each corridor. In California, the HSR system will connect into the existing Union Station in Los Angeles. This station is an existing rail hub, serving several Amtrak routes and many of Los Angeles County Metropolitan Transportation Authority's Metro Rail (rail rapid transit), Metro Busway (bus rapid transit), Metrolink (commuter rail) and bus system routes. The HSR track alignment on the approach to Union Station is still under discussion. Initial plans for new tunnels or utilizing existing tracks on the approach have been rejected, while a new proposal for HSR tracks flowing through the station has come forward (City News Service, 2016). On the other end of the proposed HSR system, service will connect into the Transbay Transit Center currently under construction in downtown San Francisco. The transit center is slated to replace the Transbay Terminal as San Francisco's transit hub, linking transportation systems including Alameda-Contra Costa (AC) Transit, Bay Area Rapid Transit (BART), Caltrain, Golden Gate Transit, Greyhound, San Francisco Municipal Railway (Muni), San Mateo County Transit (SamTrans), Western Contra Costa Transit (WestCAT) Lynx, Amtrak, paratransit and the future California HSR system (Transbay Transit Center, 2016). The construction of the new transit center includes a 1.3-mile downtown rail extension for use by Caltrain and the California HSR system. This rail extension (Figure 17) will allow direct rail connections into downtown San Francisco.

Outside of the major metropolitan centers of Los Angeles and San Francisco, the CaHSRA has recommended a TOD approach, defining the following TOD characteristics (California High-Speed Rail Authority, 2011):

1. Development density that is greater than the community average;
2. A mix of uses;
3. Compact, high quality pedestrian-oriented environment;
4. An active defined center;
5. Limited, managed parking;
6. Public leadership.

Figure 17: San Francisco Downtown Rail Extension



Source: (BayRail Alliance, 2016)

Loukaitou-Sideris (2013) finds that these general guidelines cannot necessarily be strictly applied to all stations along the proposed corridor, as each city must have a unique design and approach tailored for its community. She also notes that the traditional TOD guidelines should be applied to larger urban cores such as Los Angeles and San Francisco. However, new guidelines and goals should be developed for intermediate communities.

In contrast to the use of existing stations in major hubs along California's HSR corridor, Florida's Brightline has elected to construct new stations along its route. The Brightline stations under construction in Miami, West Palm Beach and Fort Lauderdale (all Phase One) are notable for their downtown locations, modern designs and wealth of new commercial and retail development. Though each station provides adequate public transportation connections, the stations do not provide access to Amtrak services and have been designed separately (Brightline, 2016b). Trains will enter MiamiCentral Station on elevated platforms (Figure 18). The Brightline will use an existing Florida East Coast Railway corridor for a majority of its route, from Miami to Cocoa. Phase Two of the program includes the construction of a new corridor along State Road 528 between Cocoa and Orlando. The Orlando Brightline Station will be located in the currently under construction Orlando International Airport's South Intermodal Center (All Aboard Florida, 2016a).

Figure 18: Brightline's MiamiCentral Station Rendering

Source: (All Aboard Florida, 2016b).

Chapter 4: High Speed Rail in Texas

The state of Texas has a particularly eventful history with regards to proposed HSR corridors. With many major cities situated around the Texas Triangle at favorable distances, the state seems optimally suited for HSR development. Cooper (2008) theorizes that HSR in Texas dates back to the 1930s when Rock Island Rockets ran between Houston and Dallas. More modern efforts date back to the 1980s with the creation of the Texas High Speed Rail Authority (THSRA) (Roco & Olson, 2004). Since the cancellation of the Texas TGV HSR franchise, numerous other corridors have been proposed, including three current efforts to link Dallas with Houston, Dallas with Fort Worth and San Antonio with Oklahoma City. Nevertheless, the spirit of HSR continues to live on within the state as Texans eagerly await their first successful HSR venture.

MOTIVATION

Five major cities in Texas, Houston, San Antonio, Dallas, Austin and Fort Worth, represent five of the top sixteen cities by population (in that order) in the United States (United States Census Bureau, 2016). The distance between cities, extracted from the shortest path road distance on Google Maps, are given in Table 2 below (Google, 2016).

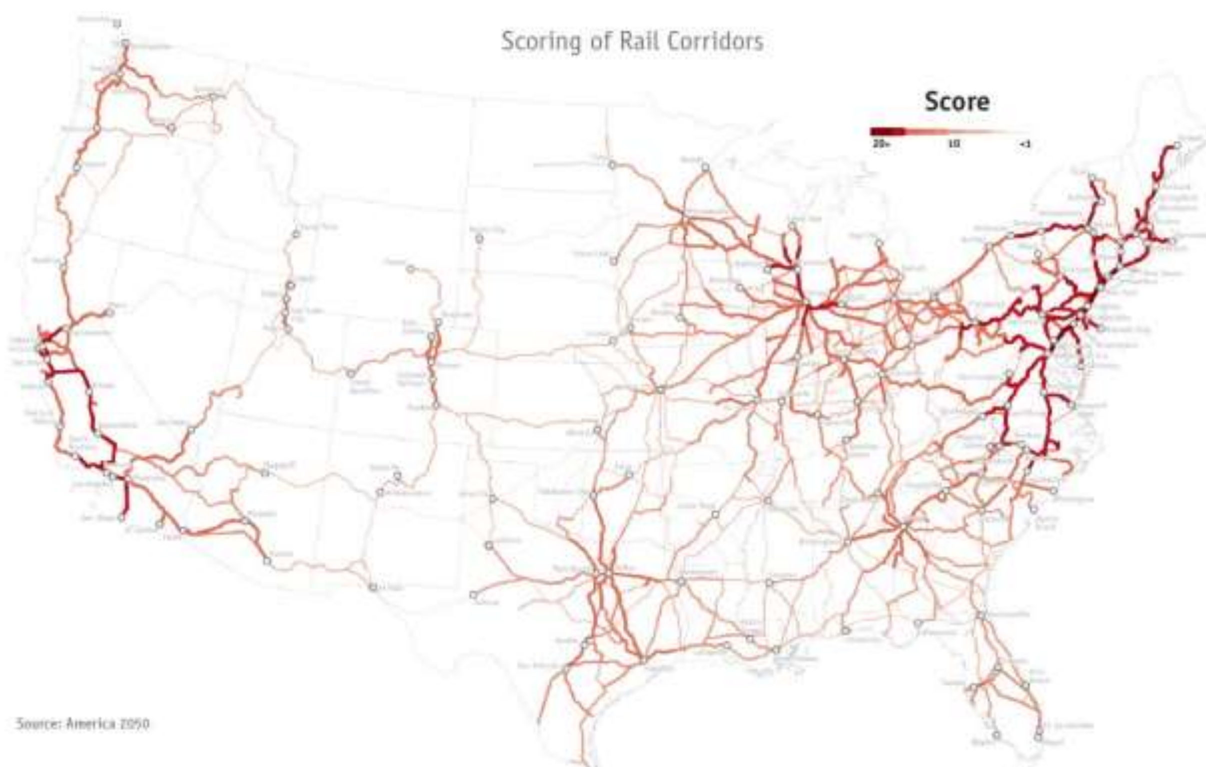
Table 2: Shortest Path Mileage and Driving Travel Time between Texas Triangle Cities

Route	Shortest Path Mileage	Driving Time (h:mm) (without traffic)
Dallas to Houston	239	3:22
Fort Worth to Houston	262	3:43
Houston to San Antonio	197	2:45
San Antonio to Austin	80	1:14
Austin to Fort Worth	189	2:43
Austin to Dallas	195	2:46

Source: (Google, 2016).

With the exception of San Antonio to Austin, all of these routes fall within the preferred HSR intercity corridor distance of 100 to 600 miles (Federal Railroad Administration, 2009). Additionally, with large spaces of open land between the major metropolitan centers, the acquisition of land and construction of an HSR system may be easier than in more densely population regions of the country. However, despite the seemingly strong case for an HSR system across the Texas Triangle, the aforementioned Texas corridors ranked below many potential corridors in the Northeast, Chicago Region, California and even the Pacific-Northwest in a study by America 2050 (2011). Figure 19 is a map showing the rankings of potential HSR corridors across the United States, determined using the criteria in Figure 20.

Figure 19: Scoring of Potential United States HSR Corridors



Source: (America 2050, 2011).

Figure 20: America 2050 HSR Corridor Scoring Criteria

Primary Factors: Weighted 3X	
Regional Population (25 Mile)	(RP)
Employment CBD (2 Mile)	(ECBD)
Secondary Factors: Weighted 2X	
Transit Connectivity Employment	(TCE)
Transit Connectivity Population	(TCP)
City Population (10 Mile)	(CP)
City Employment (10 Mile)	(CE)
Regional Population Growth Factor	(RPGF)
Regional Air Market	(RAM)
Tertiary Factors: Weighted 1X	
Commuter Rail Connectivity Population	(CRP)
Corridor Traffic Congestion	(CTC)
Share of Financial Workers	(SF)
Share of Workers in Tourism Industry	(ST)

Source: (America 2050, 2011).

The America 2050 report notes that decentralization of the cities within the Texas Triangle is particularly detrimental to any potential HSR system. Thus, despite many cities having large regional populations – Houston and Dallas rank 5th and 7th in the country, respectively – these same cities suffer from lower rankings for CBD employment (13th and 12th) and especially poor transit and commuter rail connectivity. The report notes that just over 1 percent of the population of Houston lived within 0.5 to 1 mile of public transit (called the transit accessibility zone) in 2009, while just 5 percent of total jobs were situated within this same radius. Additionally, Houston has no commuter rail connectivity. Dallas fared slightly better, with 11 percent of the population and 26 percent of jobs within the transit accessibility zone (America 2050, 2011). These transit figures provided by the report do not specify which transit systems are considered when calculating population and employment transit accessibility. These figures only consider light rail lines in both Dallas and Houston, perhaps unfairly omitting bus transit. A separate analysis reports that 81.3 percent of the population and 86.5 percent of jobs in Houston are located within half a mile of transit. In Dallas, these figures are 92.1 and 94 percent, respectively (Center for Neighborhood Technology, 2016).

The major Texas Triangle cities have very aggressive projected population and employment growth rates by 2040, supporting the potential for HSR. Additionally, the regional air markets in Texas are very large, with nearly 1.25 million passengers traveling by air between Dallas and Houston in 2009. Also in 2009, 4.4 million passengers began their journeys in Dallas airports with a destination in Texas or the Gulf Coast Megaregion. In Houston, those passengers number 3.5 million (America 2050, 2011). An analysis of updated statistics shows that 1.38 million passengers traveled from Dallas to Houston airports in 2015, with 1.37 million traveling in the opposite direction (Bureau of Transportation Statistics, 2016). There are certainly enough passenger journeys between Texas Triangle cities to warrant the introduction of an HSR system to potentially draw those passengers away from road and air travel. Nevertheless, these existing transportation methods may actually spurn the development of HSR, as has been the case with several previous proposals in Texas.

The Texas A&M Transportation Institute (TTI) performed a study analyzing 18 potential intercity passenger transit corridors in Texas. From these corridors, they concluded that the Texas Department of Transportation (TxDOT) should prioritize linking the Dallas-Fort Worth region with San Antonio and Houston by an improved rail system. However, the report also expressed uncertainty regarding the alignment of the rail system, theorizing that Houston should be linked to the DFW-San Antonio corridor to increase ridership (Morgan, et al., 2009).

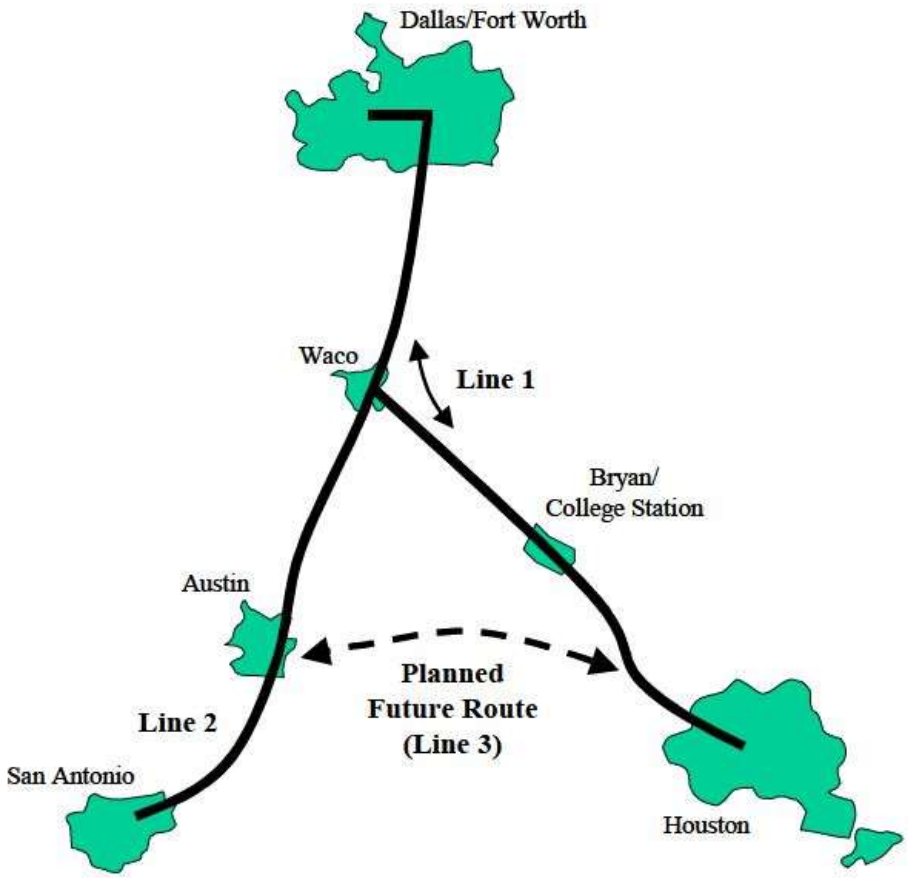
PREVIOUS PROPOSALS

The first HSR franchise in the state of Texas had its origins in a report to the Texas Legislature in 1985 (later updated in 1987) highlighting the rail technology of the Germany ICE system. Though no formal action was recommended or implemented by the Legislature, the Texas Turnpike Authority (TTA) picked up the idea. Soon after, House Bill 1678 was passed by the 70th Legislature, supporting an HSR feasibility study. A study team led by Lichliter/Jameson & Associates, including Morrison Knudsen Engineers, Wilbur Smith Associates, Underwood Neuhaus & Co., Andrews & Kurth and M. Ray Perriman, was selected to prepare the study (Roco & Olson, 2004).

The HSR feasibility study recommended proceeding with the design of an HSR system across Texas. The Texas Legislature passed Senate Bill 1190, also known as the Texas High Speed Rail Act, at the 71^{st} Legislature, creating the Texas High Speed Rail Authority (THSRA). The objectives of the THSRA were to review HSR franchise applications, with the intent to grant a franchise for the financing, construction, operation and maintenance of an HSR system. Importantly, the act did not allow use of public funds on the project. Two consortia submitted complete applications to the THSRA, Texas FasTrac, which incorporated German ICE technology, originally presented to the Texas Legislature, and Texas High Speed Rail Corporation (later changed to Texas TGV), which incorporated French technology as the name suggests (Roco & Olson, 2004).

Texas FasTrac proposed two HSR lines (Figure 21), one connecting Dallas-Fort Worth to Houston via Waco and Bryan-College Station and the other connecting Dallas-Fort Worth to San Antonio via Waco and San Antonio. A future expansion line was planned between Houston and Austin (Roco & Olson, 2004). As will be seen with the following proposals, HSR alignments are focused on the Texas Triangle, with the line between Dallas and Houston serving as the main line, often constructed first (Carroll & Walton, 2011).

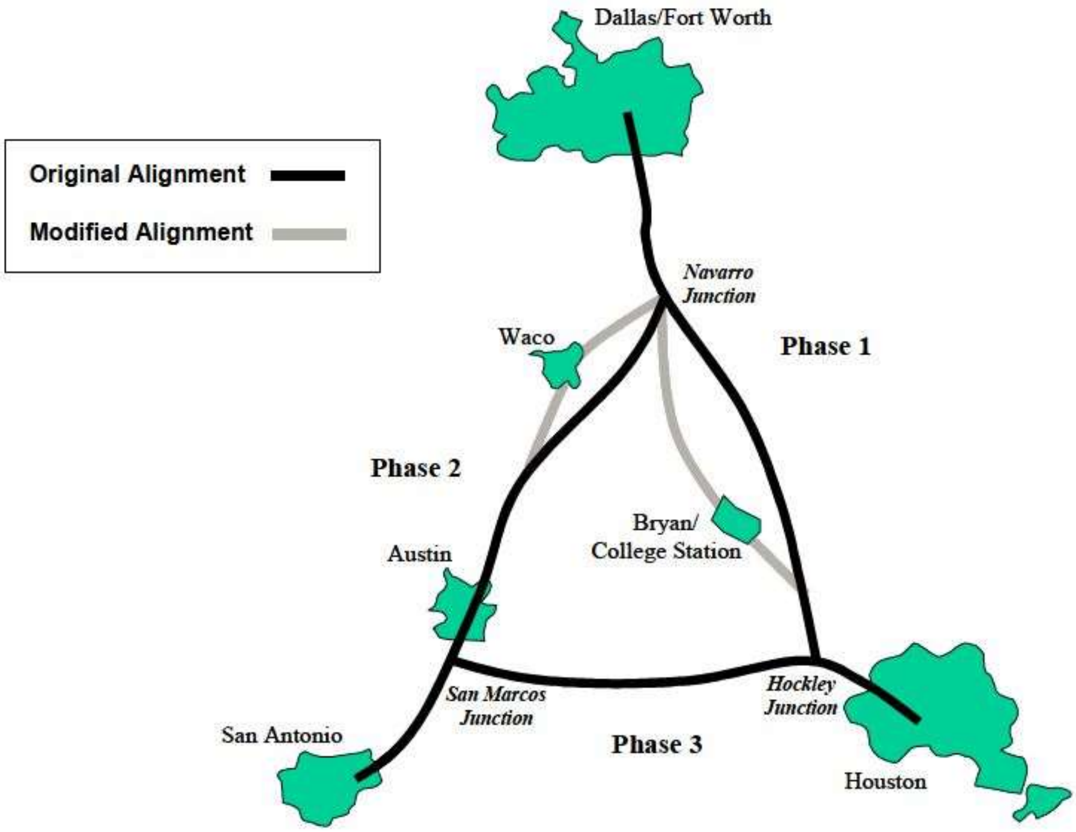
Figure 21: Texas FasTrac Proposed Alignment



Source: (Roco & Olson, 2004).

The Texas TGV application proposed a similar alignment and phasing plan (Figure 22), but omitting intermediate stations in Waco and Bryan-College Station. Phase 1 of the proposal included a HSR line from DFW Airport to Houston. The alignment was later modified to include stations in Waco and Bryan-College Station (Roco & Olson, 2004).

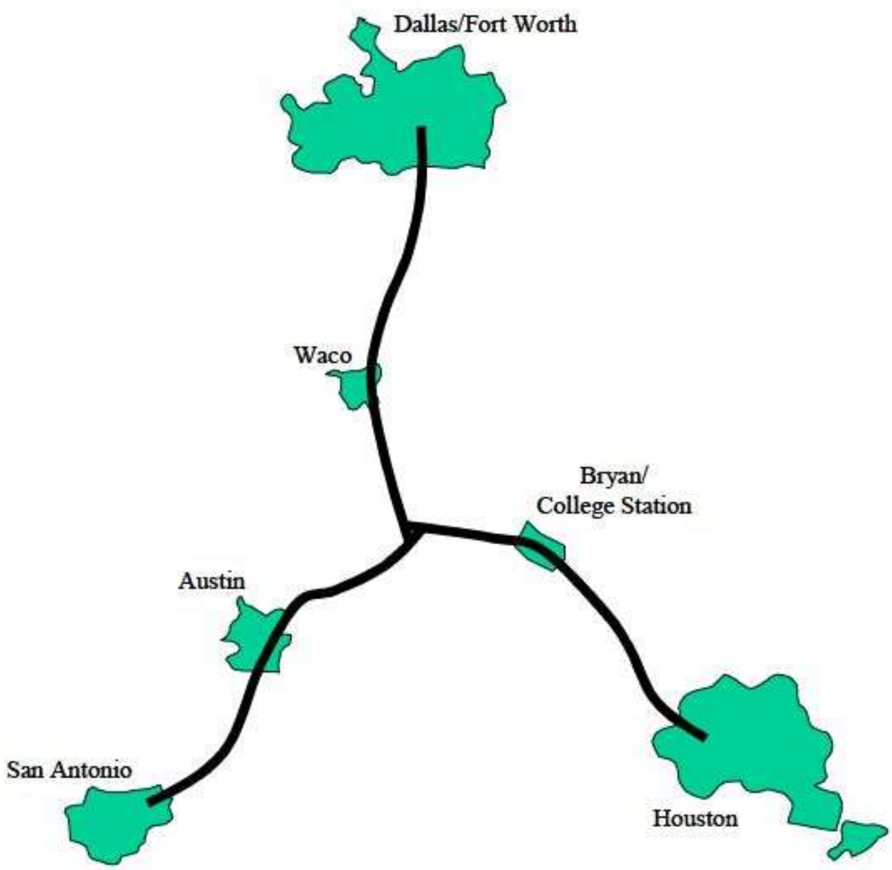
Figure 22: Texas TGV Proposed Alignment



Source: (Roco & Olson, 2004).

The awarding of the franchise to the Texas TGV consortium would become a contested decision. TTI reviewed the ridership estimates from both proposals, concluding that the FasTrac projections were optimistic, but reasonable, while the Texas TGV projections were overly optimistic and unreasonable. Roco and Olson (2004) cannot conclude why the franchise was awarded and note that the entire process was overly biased as the TGV consortium was formed primarily from members of the original TTA consulting team. In a possible effort to merge the route maps proposed by both consortia, a new “Corporation Preferred Alignment” was proposed (Figure 23) (Roco & Olson, 2004).

Figure 23: Texas TGV Corporation Preferred Alignment



Source: (Roco & Olson, 2004).

Three years later in August 1994, the franchise agreement with the Texas TGV consortium was ended and the THSRA was abolished the following spring, ending the first serious effort at bringing HSR to the state of Texas. The project may have been doomed from the start, suffering from the overly optimistic ridership (and revenue) projections. Funding was and always will be a major hurdle for any HSR system in the United States and the lack of public funding for Texas TGV and a potential lack of commitment from the consortium members prevented the system from getting off the ground. A final recommendation from the THSRA chairman advised that the entire project should be reevaluated, including the proposed alignment, should HSR be brought to Texas in the future (Roco & Olson, 2004).

In 2002, Governor Rick Perry announced a proposal for a 4,000-mile network of multi-use corridors throughout the state known as the Trans-Texas Corridor. Routes would generally parallel existing interstate highways. The corridors, depicted in Figure 24, could be as wide as 1,200 feet, allotting 6 roadway lanes for passenger car travel, 4 lanes for truck travel, 6 railroad tracks for HSR, high speed freight, commuter rail and conventional freight transport and up to 200 feet for utility lines and pipelines (Palacios, 2005). The inclusion of HSR in the proposal marked the first serious effort at creating a HSR system outside the Texas Triangle.

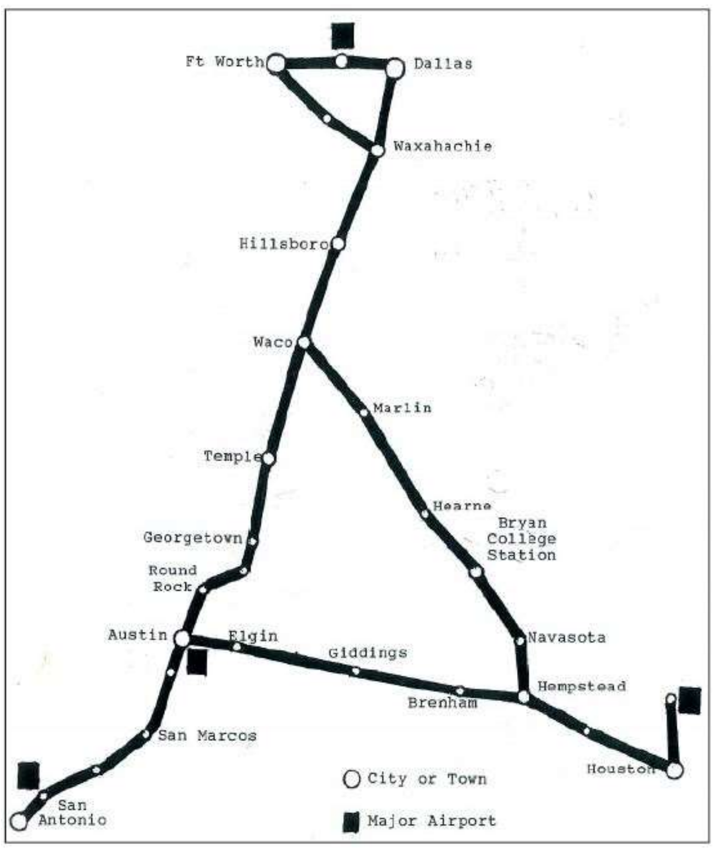
Figure 24: Trans-Texas Corridor Conceptual Rendering

Source: (Palacios, 2005).

As could be expected, the project was not well received by the public due to its enormous cost – estimated at $145.2 to $183.5 billion – and the large amount of land required to build the corridors. The proposal was finally phased out in 2009 as TxDOT elected to pursue separate ROWs for the proposed uses for the Trans-Texas Corridor (The Texas Tribune, 2016).

Three other alignments have been proposed in the Texas Triangle in recent years, all incorporating more stops than the original FasTrac and TGV proposals. The Triangle Railroad Holding Company proposed the alignment in Figure 25. The alignment allows connections to all four major airports in the Texas Triangle and includes a spur line from Waco to Hempstead so that passengers may reach Houston from Dallas (Carroll & Walton, 2011).

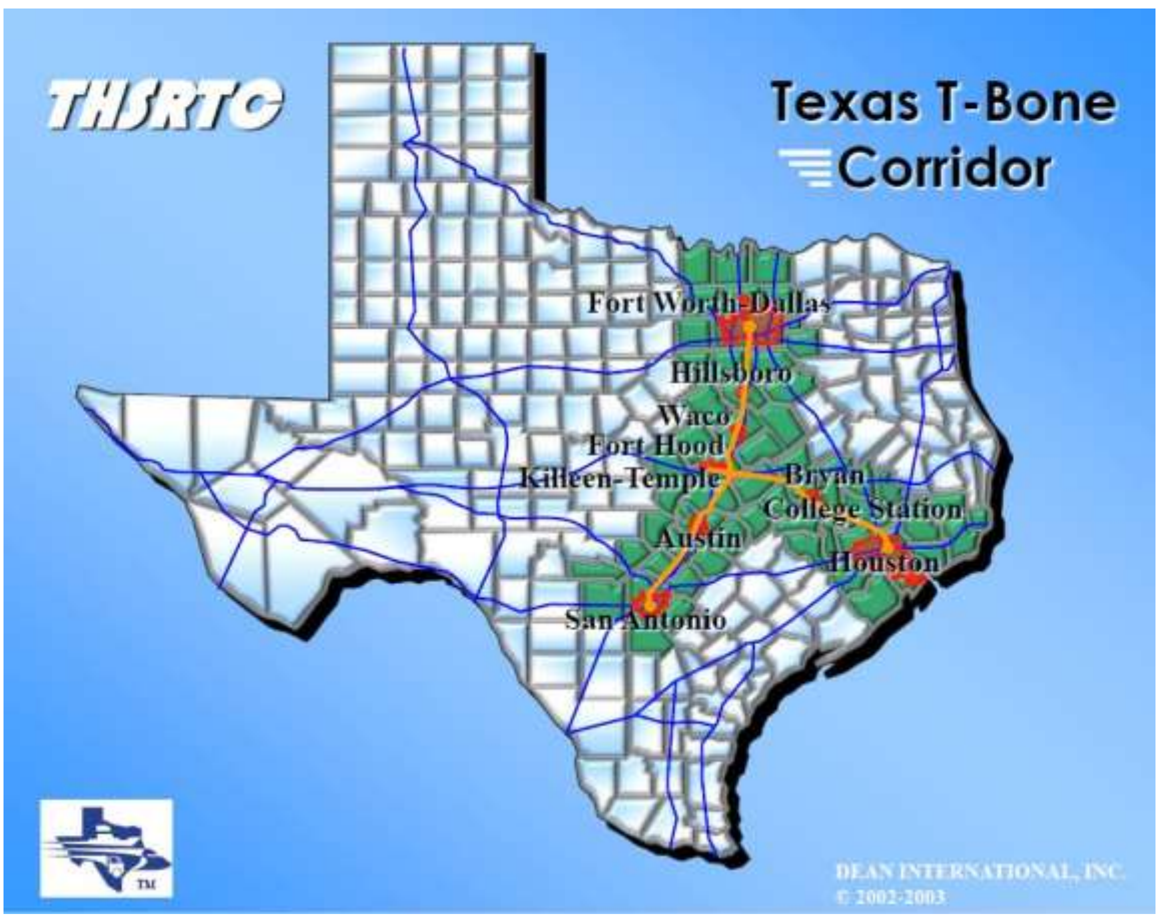
Figure 25: Texas Triangle Holding Company Proposed Alignment.



Source: (Carroll & Walton, 2011)

In an effort to limit the mileage of a proposed HSR system while ensuring a large majority of Texans had access to the system, the Texas High Speed Rail and Transportation Corporation (THSRTC) proposed the Texas T-Bone Corridor (Figure 26). The proposal called for two lines, one running from DFW Airport to San Antonio with intermediate stops at Hillsboro, Waco, Killeen-Temple and Austin. A second line ran from Killeen-Temple to IAH Airport with an intermediate stop at College Station-Bryan. This proposal also allowed for future connections into the South Central and Gulf Coast FRA-designated HSR corridors (THSRTC, 2003).

Figure 26: THSRTC Proposed T-Bone Alignment

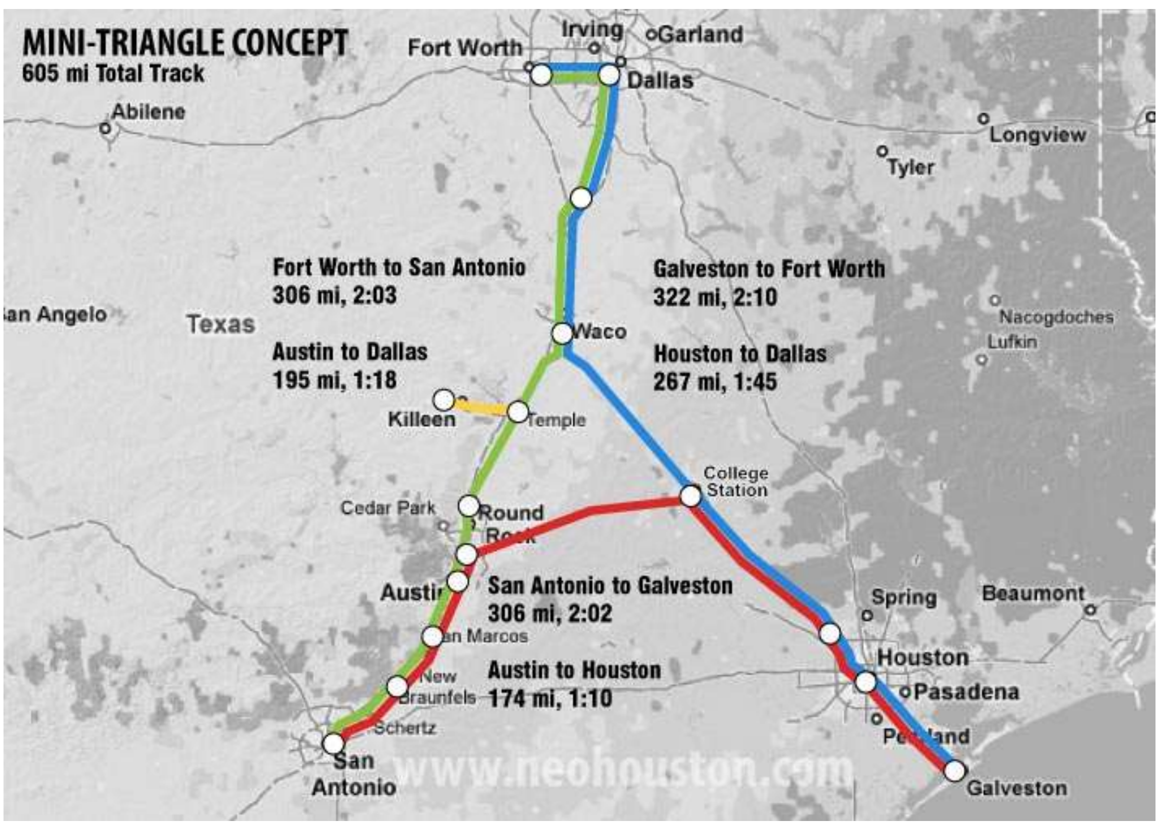


Source: (THSRTC, 2003).

The THSRTC proposal is notable because it does not provide a one-seat ride from Dallas to Houston, as passengers will be required to change trains at Killeen-Temple unless trains are specifically routed onto the Houston spur. Stations are not provided in downtown areas of Dallas, Fort Worth, or Houston, but instead are planned at DFW and IAH airports (Carroll & Walton, 2011).

Burleson (2009) proposed an alignment combining certain aspects of the Texas Triangle Holding Company and the THSRTC alignments. The alignment (Figure 27) specifies three separate lines, connecting the major cities in the triangle with more intermediate stations than any previous proposal (Burleson, 2009).

Figure 27: Burleson Mini-Triangle Proposed Alignment



Source: (Burleson, 2009)

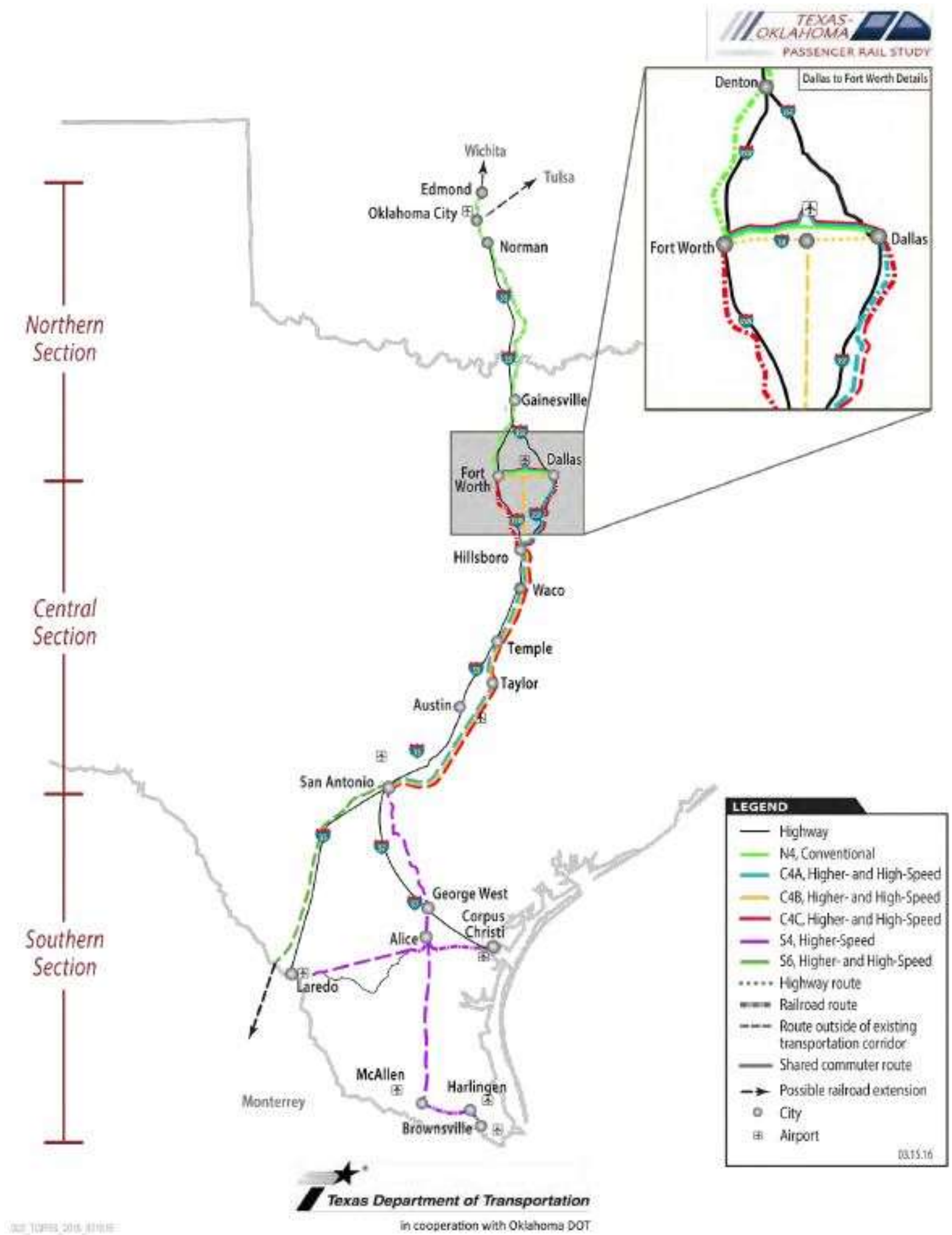
Notably, the alignment provides for downtown stations in both Dallas and Houston and is the only proposed alignment to run to Galveston.

CURRENT PROPOSALS

There are currently three efforts under consideration for bringing HSR to the Lone Star State. The most notable route is under public consideration by TxDOT, the Oklahoma Department of Transportation (ODOT) and the FRA. Running approximately 850 miles from Oklahoma City to South Texas via Dallas, Fort Worth and San Antonio, the Texas-Oklahoma Passenger Rail Program is evaluating several potential corridors and speeds for the proposed line (Figure 28). The Draft Environmental Impact Statement (EIS), published in July 2016, recommends high speed (up to 220 to 250 mph) and higher speed (up to 110 to 125 mph) alignments on the Central and Southern Sections of the route for further study (TxDOT, 2016b). All alignments recommended for further study utilize Dallas Union Station (TxDOT, 2014).

Another Texas HSR project currently under environmental review is the Dallas-Fort Worth Core Express Service. TxDOT, in coordination with the FRA and private stakeholders, is evaluating a potential HSR corridor linking potential future HSR corridors in Dallas and Fort Worth including the aforementioned Texas-Oklahoma Passenger Rail Program. Two routes are currently under consideration, the Trinity Rail Express (TRE) Communter Rail corridor and the I-30 corridor (Figure 29). The scoping report for the project notes that specific station locations have not yet been determined (Parsons Brinckerhoff, Inc., 2015).

Figure 28: Texas-Oklahoma Passenger Rail Program Proposed Alignment



Source: (TxDOT, 2016b).

Figure 29: Dallas-Fort Worth Core Express Proposed Alignment

Source: (Parsons Brinckerhoff, Inc., 2015).

The third effort currently under way and perhaps the most pertinent to the case studies presented in this thesis is the Texas Central High Speed Railroad, a private company proposing a HSR system between Dallas and Houston. Several station locations have been discussed and evaluated in both cities and the company anticipates adding an additional station in the Brazos Valley (Texas Central Partners, LLC, 2016). The system will use the N700-I Bullet Train technology currently used by JR Central Railway on the Tokaido Shinkansen in Japan. The FRA is preparing an EIS for the project. An analysis of corridor and alignment alternatives, along with a last mile analysis, have already been published and will be evaluated during the Dallas and Houston case studies in the following chapter (Texas Central High-Speed Railway, LLC, 2016).

CHALLENGES

HSR systems proposed within Texas often look to the state's large air market to draw travelers onto their system. However, this approach has drawn criticism from airlines previously, hampering efforts for development. Southwest Airlines was formerly a noted opponent of proposed HSR in Texas. Cooper (2009) notes that the status of Southwest Airlines in the 1970s prevented further development of a short-distance rail passenger market. He also notes that only the creation of the National Railroad Passenger Corporation (Amtrak) saved the rail passenger market across the country. More specifically, Southwest conducted a lobbying campaign against the Texas TGV franchise in the early 1990s. The airline believed that the proposed HSR system sought to draw passengers away from its strong short-haul air market in Texas (Batheja, 2014). Southwest Airlines even filed a lawsuit in Travis County District Court, and later appealed to the Texas Third District Court of Appeals, protesting the constitutionality of the Texas High Speed Rail Act and the authority of the THSRA (Justia, 1993).

However, the view of airlines towards proposed HSR systems in the United States appears to have changed in recent years. Representatives from American Airlines and Continental Airlines joined the THSRTC board during their proposal in the mid-2000s. Though the airlines did not publicly lend their support to the plan, the THSRTC proposed T-Bone corridor included major termini at DFW and IAH airports, suggesting that airlines would benefit from increased passenger flows. Additionally, rising costs for short-haul flights popular within the state may have shifted airlines' stance toward HSR (McGraw, 2008). Batheja (2014) quotes Robert Mann, an aviation consultant, as saying that Southwest has now diversified their business to the point where a new Texas HSR system would not be as damaging. Southwest now does not oppose the development of a HSR system within the state.

Another transportation system that may adversely impact any proposed HSR line is the freight rail system. Carroll and Walton (2011) note that there are shortages of existing ROW in metropolitan areas in Texas, meaning that new proposed passenger systems are forced to share (or attempt to share) ROW with freight railroads currently operating in those areas. As seen with the Lone Star Rail Project in Central Texas and an alignment of the DFW Core Express, Union Pacific has not allowed these potential passenger lines to share its ROW. Union Pacific and BNSF have proposed certain guidelines for any potential ROW sharing with passenger rail operations (Carroll & Walton, 2011):

1. Safety should not be compromised;
2. Capacity must be provided for current and future operations;
3. Compensation must be made to the railroads for any additional costs imposed by expanded passenger rail service, such as new infrastructure, increased maintenance costs and any other related operational costs;
4. Liability should be capped.

Additionally, Union Pacific stipulated that should its ROW be shared with passenger rail, the passenger service would be required to purchase additional ROW and construct the lines so that there was at least fifty feet of separation. The freight railroads were also concerned about grade crossings for HSR operations (Carroll & Walton, 2011). Since these freight systems contain many at-grade crossings, especially in metropolitan areas, significant infrastructure improvements would be needed for any at-grade crossings proposed for systems operating above 125 mph. The FRA prohibits at-grade crossings above this speed.

Chapter 5: Case Studies

The evaluation of existing HSR systems across the world and an analysis of FRA guidelines for station development shows that there is a large disparity in potential and successful integration of an HSR system in an existing urban environment. Countries such as Germany and Japan have prioritized intermodal connectivity and prime locations for new HSR stations, while China and Taiwan have elected to pursue greenfield alignments, locating stations at the fringes of urban areas. France and Spain have a mix of station designs, connecting into existing stations in major metropolitan areas but electing to construct a regional or suburban station in smaller cities throughout the route. Spain is also notable in that it has built its HSR system on a separate gauge than its conventional services. This gauge difference limits potential connectivity between the HSR and conventional train alignments.

The FRA has provided a mix of station recommendations for intercity passenger rail service that allow for interpretation. While only suggesting that the station design should be optimized, the FRA also mandates that connections with other transportation modes should be maximized and that the station should be shaped through urban design and development. Additionally, a larger metropolitan area should be provided with a suburban station that allows for access to the local road network. With regards to specific station design, the FRA dictates that the station should allow for through movement of trains.

Another major consideration in urban areas is safety as grade crossings can be extremely dangerous for passenger vehicles due to the high speed of trains. The FRA prohibits grade crossings for train speeds above 125 mph. Though this speed restriction still allows for very high speeds, HSR systems may be highly impacted in urban areas (especially in Texas) through the sharing and use of freight rail lines.

CORRIDOR SELECTION

For this case study, the cities of Dallas and Houston were chosen for further analysis. These two large metropolitan cities anchor two sides of the Texas Triangle and the HSR corridor between the two cities has been included in every major HSR system proposal for the state of Texas (including the current Texas Central Railroad proposal). Amtrak does not currently provide direct intercity rail service between these two cities, as passengers are forced to change at San Antonio. The large air market between the two cities, estimated at 1.37 million passengers traveling each way, also warrants further analysis of a potential HSR system.

The Texas Central Railroad currently proposes that services will run between the cities at 30 minute intervals during peak times and 60 minutes at other times, with 6 hours reserved for maintenance and inspection of the system per day. This suggests that approximately 21 services will run between the two cities per day. Furthermore, Texas Central suggests that the journey will take 90 minutes and that the price will be competitive with air services (Texas Central, 2016). An analysis of airline services between these two cities indicates that there is certainly a market for a new HSR system to compete with existing air services. FlightAware (2016) indicates that Southwest operates 21 daily flights, on average, between Dallas Love Field (DAL) and Houston Hobby (HOU) airports, with a similar number operating in the reverse direction. An evaluation of airlines websites indicates that, as of early September 2016, Southwest operates 20 daily flights between DAL and HOU, with American and United (or their regional partners) operating 15 and 9 flights, respectively, between Dallas and Houston airports.

The HSR service, a 90-minute journey, will compete directly with the air services, operating with an approximate one-hour gate to gate time. The difference in time between the two services is negligible considering the extra time required to proceed through Transportation Security Administration (TSA) security checkpoints at air terminals. Furthermore, the difference in price and frequency of services will also be negligible, meaning that the competition between air and HSR services between the two cities may simply rely on easier access to the population and employment centers of each city.

Four potential station locations have been chosen in Dallas for study and six locations in Houston. The stations, along with their corresponding alignments, have been put forward by various HSR proposals over the years, most notably the Texas TGV and the Texas Central Railroad. Through site visits of these potential locations, conversations with planning professionals, and an analysis of passenger, road and transit connectivity and the costs and impacts of each location, a station and alignment will be recommended for each city. Access to airports in each city will also be studied for their access to population and employment.

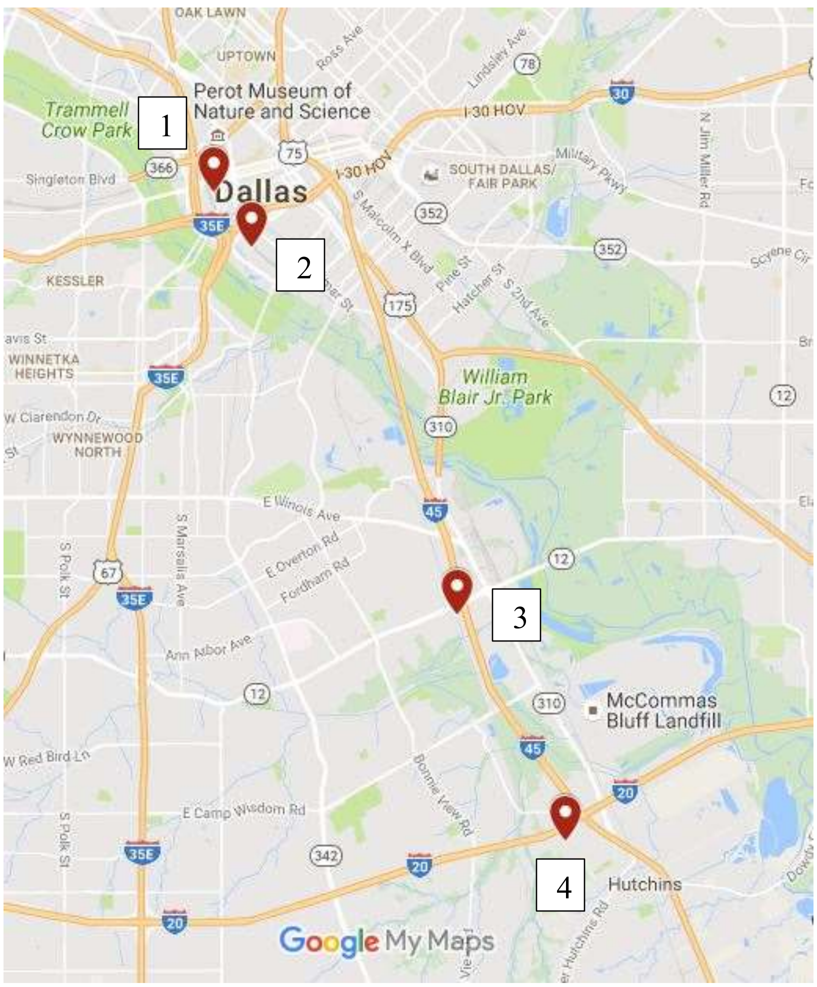
DALLAS

Four potential HSR station locations were evaluated in the city of Dallas. The potential station sites, illustrated in Figure 30, are the following (listed in order of distance from downtown Dallas):

1. Union Station – existing station with Amtrak, Trinity Railway Express and Dallas Area Rapid Transit (DART) rail services. Located in downtown Dallas immediately east of I-35E. Bound by Reunion Boulevard East to the south, South Houston Street to the east, Reunion Boulevard West to the north and railroad tracks to the west.

2. South Side – located southeast of Union Station across I-30. Bound approximately by S. Riverfront Boulevard to the south, North Corinth Street Road to the west, South Austin Street to the north and Cadiz Street to the west.
3. I-45/Loop 12 – located approximately 0.5 miles south of Loop 12 on the west side of I-45.
4. I-45/I-20 – located between the existing Wilmer Hutchins High School and Whites Branch Creek on the south side of Langdon Road.

Figure 30: Proposed Dallas HSR Station Sites

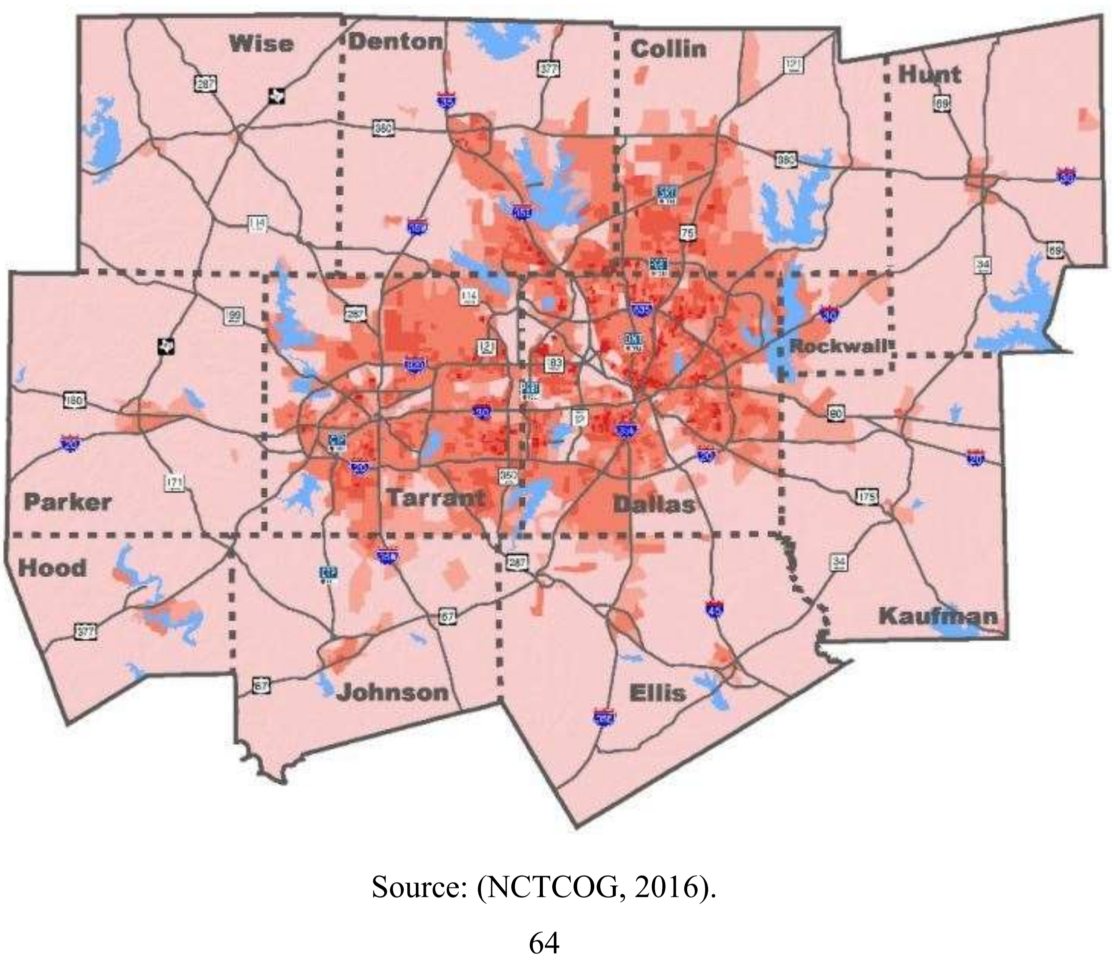


Source: (Google, 2016).

In addition to these four sites, an additional location originally proposed by the Texas TGV project proposal was initially considered. This site, located immediately north of Union Station and Spur 366, is now home to the Victory Park development.

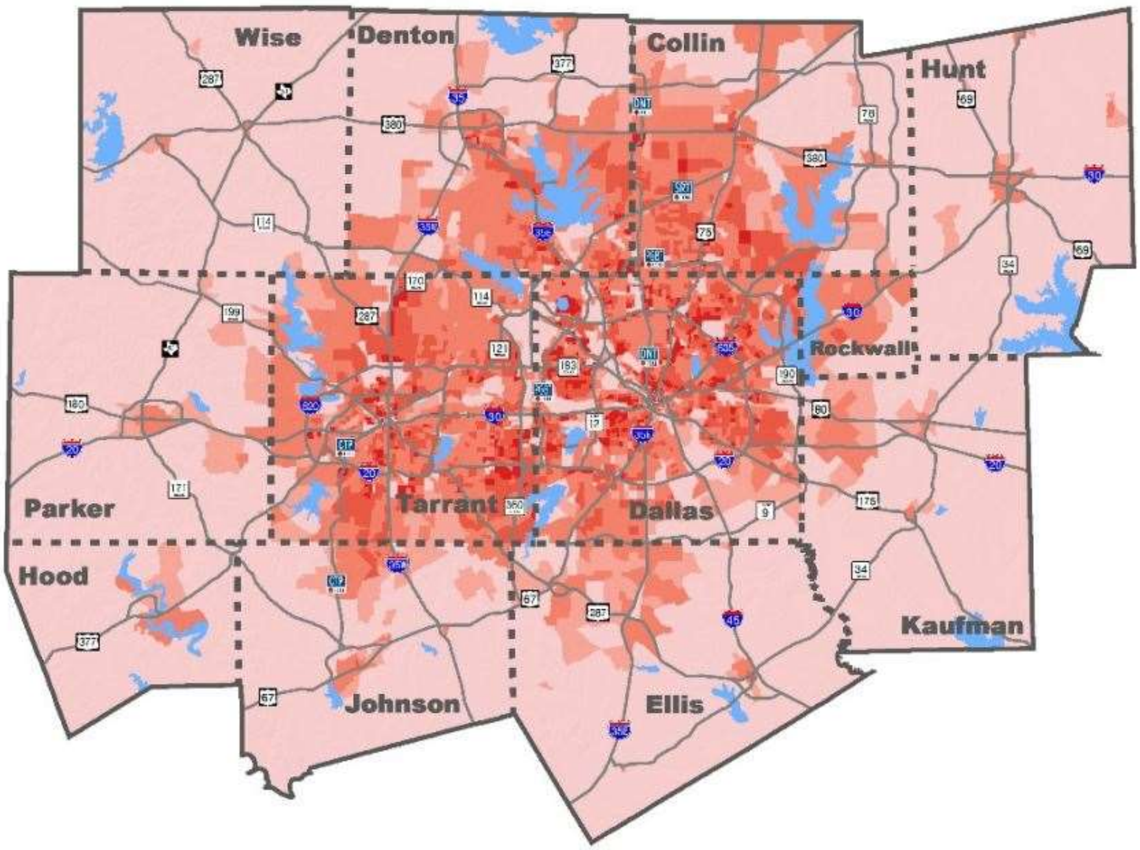
Population and employment forecasts published by the North Central Texas Council of Governments (NCTCOG) for 2017 and 2040 will be used to determine if station locations have adequate accessibility to larger population and employment centers. The population forecasts (Figures 31 and 32) show that current population centers exist in several neighborhoods surrounding downtown. The deepest color of red represents traffic survey zones with population densities of 10,001 or more per mile.

Figure 31: NCTCOG 2017 Population Forecast



Source: (NCTCOG, 2016).

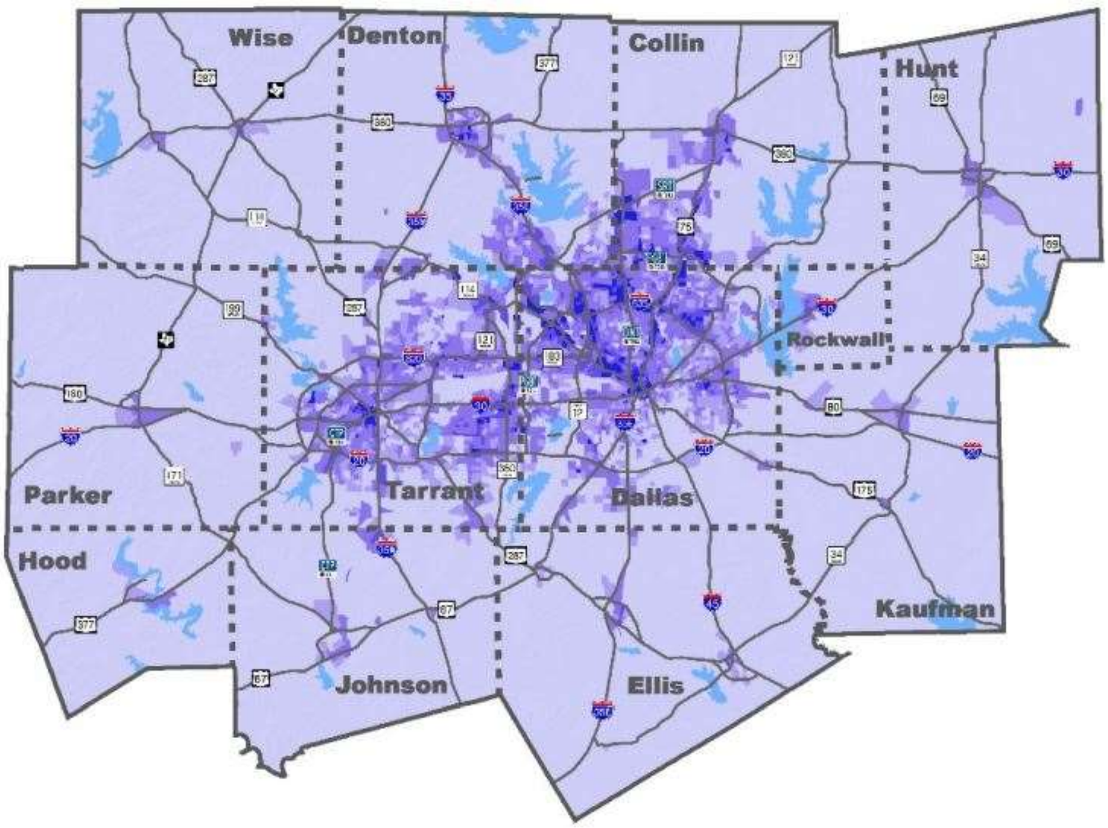
Figure 32: NCTCOG 2040 Population Forecast



Source: (NCTCOG, 2016).

Perhaps a more important indicator for potential high speed rail use is employment. The NCTCOG employment forecasts show a large portion of current employment (Figure 33) focused around I-35E northwest of downtown Dallas. In the employment forecast for 2040 (Figure 34), employment clusters appear to form around major highways north and west of downtown Dallas. The deepest color of blue represents traffic survey zones with employment densities of 10,001 or more per mile.

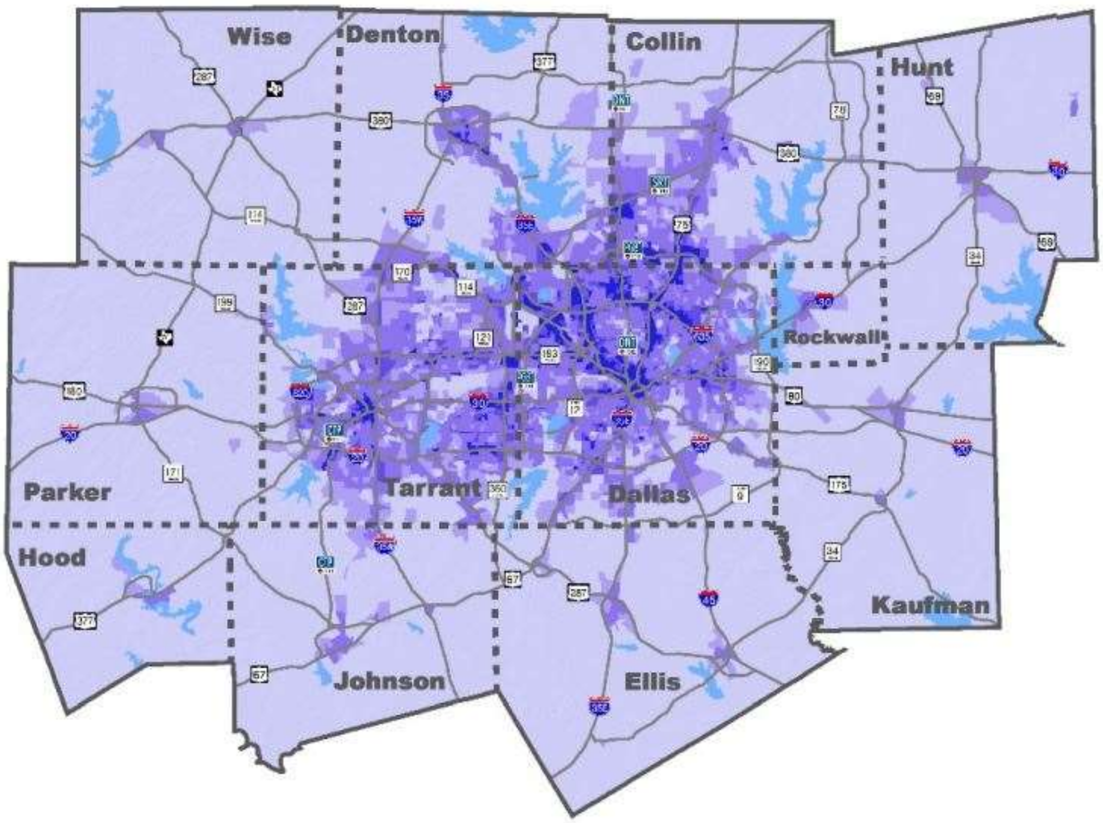
Figure 33: NCTCOG 2017 Employment Forecast



Source: (NCTCOG, 2016).

A cursory glance at these forecast maps in comparison to the proposed station locations indicates that any proposed system must have optimal connections to the DART and the highway network around Dallas to ensure that a large majority of potential travelers can access the HSR system relatively easily. The major sprawl of Dallas is a detriment to the implementation of a HSR system serving its city, as indicated by the America 2050 report. Optimal transit and road connectivity can aid in overcoming this shortcoming.

Figure 34: NCTCOG 2040 Employment Forecast



Source: (NCTCOG, 2016).

Dallas is currently served by two major airports, Dallas-Fort Worth International Airport (DFW), a hub for American Airlines, and Dallas Love Field (DAL), a hub for Southwest airlines. Both include ground transportation connections to the DART Green and Orange lines. DFW has its own DART station, with trains departing approximately every 20 minutes during weekdays according to current DART schedules. The journey time to West End Station in downtown Dallas is approximately 49 minutes. West End Station also serves the Blue and Red DART lines. From Love Field, trains are much more frequent (nearly every 10 minutes on weekdays) as the station is also served by trains originating in Carrollton. The journey takes only 11 minutes to West End Station (DART, 2016a). The Love Field DART station is located slightly southeast of the airport, requiring travelers to take the Love Link 524 connecting shuttle service. A one-way journey on the Love Link is approximately 8 minutes, with shuttles departing as much as every 15 minutes at peak periods (DART, 2016b). DFW is also served by the Trinity Railway Express. Shuttles from DFW to Centerpoint Station in Fort Worth depart every 15 minutes for a 15-minute journey (DART, 2016c). The TRE journey to Dallas Union Station takes approximately 30 minutes, with trains departing every 30 minutes during peak periods. Train service is much less frequent (as much as 90 minute headways) during off-peak times and on Saturdays. There is no TRE service on Sundays (TRE, 2016).

Using a JavaScript application program interface (API) developed by Route360, 30-minute travel time bands were calculated for driving travel times from DFW, Dallas Love Field, and all station sites considered in this thesis. These interactive maps will provide visual representation of automobile access to and from the locations of interest. These maps do not take congestion into account, meaning that the 30-minute accessibility may be significantly limited within peak periods. Each color in the map represents five-minutes of further driving time. Additionally, 30-minute transit travel time bands will be produced using the Mapnificent website. This website produces interactive maps for locations within the cities of Dallas and Houston (DFW airport not included). Again, these maps will show the potential accessibility to the station sites proposed in this thesis. These maps have been provided in full-page format in Appendix A.

DFW provides reasonable driving access to both downtown Dallas and downtown Fort Worth, with areas in between and north of both cities, including Arlington, also served. Love Field provides much better driving access to Dallas, with all communities within the I-635/I-20 beltway lying within the 30-minute driving travel time band. The cities of Mesquite, Richardson, Plano, Garland, Frisco and Arlington also lie on the fringes of the

30-minute accessibility band. Unfortunately, Mapnificent does not account for the Love Link 524 in its system, but the 30-minute transit accessibility from the Love Field DART station allows reasonable access to a large portion of Dallas and northwest areas of the city. A 15-minute delay from the airport terminal to the locations predicted in Appendix A.2 can be anticipated since the Love Link 524 has approximately 15-minute headways (assumed 7.5-minute average wait time) and the journey takes approximately 8 minutes.

Union Station

Dallas's Union Station has been put forward as a potential station location by nearly every major proposal, including the Texas TGV, Texas Central Railroad and the Texas-Oklahoma Passenger Rail Study. The station site, currently located in the southwestern area of downtown Dallas, provides quick access to most areas downtown and provides direct connections to Amtrak, the Trinity Railway Express, the Blue and Red DART rail lines and the Dart D-Link 722 bus, with only a short walk to the Dallas Streetcar serving the Bishop Arts District. Additionally, the station is currently a planned terminus on the DFW Core Express and a planned stop on the Texas-Oklahoma Passenger Rail Program. A 30-minute drive from this location allows travelers to access the entire city of Dallas, as well as neighboring communities, reaching as far as the eastern edge of downtown Fort Worth, Frisco or Waxahachie. It should be noted, however, that these travel times do not account for congestion. The station will allow for through movement of trains and currently has the available capacity to handle a new system. The size of the station may be an issue for the new HSR trains, though, as the existing platforms at Union Station may not be able to accommodate the longer trains by the Texas Central Railway (Feldt, 2016).

Parking at Union Station and the surrounding areas is very limited. The station does have one circulation loop around the main station building that may be used for passenger pick-up and drop-off. However, it is anticipated that this loop will become extremely congested upon the arrival of an HSR service from Houston. Additionally, areas may be reserved for taxi stands, limiting vehicular access even further. The recent surge in use of Transportation Network Companies (TNC) suggest that suitable areas for passenger pick-up and drop-off will be required for this type of transportation terminus (Rutter, 2016). Due to the poor circulation and lack of suitable areas for pick-ups in the vicinity of Union Station (neither South Houston Street nor Reunion Boulevard next to the station allow for safe pick-ups), this station site lacks the vehicular access required for a new HSR station.

Since the existing station is located in the downtown area and hemmed in by the Reunion Tower and nearby developments to the west, by Reunion Boulevard to both the north and south and by South Houston Street to the east, there are scare opportunities for development (including TOD) in the immediate vicinity around the station. Any development would likely need to be located significantly off-site.

Due to its central location, there are significant alignment and construction costs and issues associated with this location. The Texas-Oklahoma Passenger Rail Study (TOPRS) Draft EIS (2016) currently recommends entering the Dallas area via the existing TRE tracks (or a parallel alignment). South of Union Station, the TOPRS recommends utilizing the DART and BNSF alignments all the way to Waxahachie. The Texas Central Railroad recommends an alignment utilizing DART and BNSF ROWs on the immediate exit from downtown Dallas before crossing the Trinity River. Following the crossing of the river, the system will utilize a Union Pacific (UP) alignment until nearly reaching I-20. Though the Texas Central Railroad intends to use or share several ROWs on its entry into Dallas, Kevin Feldt from the NCTCOG cautions that due to the limited platform size at Union Station, the system will need to be elevated and require longer platforms, ensuring that the sharing of ROW would be of available land rather than actual tracks. Both Allan

Rutter from TTI and Ashby Johnson from CAMPO (formerly of Houston-Galveston Area Council) noted that HSR access to downtown Dallas was much easier than access to Houston due to the availability of DART ROW. Elevation may also be necessary along a portion of the alignment as there are several existing grade crossings along the alignment north of I-20. These elevated alignments will increase safety with the operation of two separate systems on the same ROW, but the elevated sections will need to be constructed so that further development of the freight lines are not hindered (Feldt, 2016).

The significant extended length of alignment into the city center itself will no doubt result in more expensive construction costs and longer construction times, even for shared alignment. The Texas Central Railroad estimated that the Union Station alternative with extended alignment will take 3.5 years to construction, with a 13% increase in cost of the project over an alignment terminating south of I-20. The alignment proposed by Texas Central also included several other major constraints. The alignment will require 4 major structures over I-20, Loop 12, I-30 and the Trinity River. Several curves on the approach to the station will limit train speeds, but these curves are not expected to severely impact train operations as they are located so close to the terminus that the train will not be operating at full speed. There is a potential environmental impact due to the presence of wetlands around the Trinity River and woodlands along the proposed development. Additionally, a stretch of the proposed alignment between Loop 12 and East Overton Road is highly residential. The UP ROW in this area appears to be rather narrow, meaning that any proposed HSR alignment through this section will have to be elevated and/or displace current residents. An approach from the northwest, as recommended by the TOPRS, may also require elevation, speed restrictions and careful coordination with existing services. The proposal recommends the use of the TRE alignment. A grade crossing and single tracking once the alignment reaches the Medical/Market Center DART stop in North Dallas will be problematic, with the ROW limited in size by development on both sides.

Summary of Key Points:

- Downtown Dallas accessible directly from station site;
- Transit access and connections with existing public transportation services in downtown Dallas;
- Central location allows driving access to many areas of the city, but could be hindered by congestion;
- Poor circulation around station may delay passenger pick-up and drop-off;
- Limited size of existing station may require elevation of new HSR system;
- Extended alignment has increased cost and longer construction time, along with several engineering, environmental and social constraints and may need to be elevated;
- New development around station may be limited.

South Side

Just southeast of the existing Union Station and across I-30 is a second potential HSR station location in Dallas, adequately named the South Side. Due to its proximity to Union Station, this location shares many of the same accessibility benefits and implementation difficulties. Driving access to many areas of Dallas is nearly equivalent to Union Station. However, this station location does not provide direct connections to the DART rail system or the TRE. Bus access is currently also very limited with only local DART routes 155 and 161 in the immediate vicinity of the station. The limited transit access is reflected in the 30-minute transit access map presented in Appendix A, with much less of the Dallas area illuminated. Should this station be constructed, a direct connection into the existing DART rail station at the Convention Center or preferably, Union Station, should be constructed. Direct walking access to the Convention Center is approximately 0.25 to 0.5 mile depending on the station location in this area. Any walk above 0.25 mile may be seen as inconvenient to passengers, suggesting that an alternative system of passenger transfer to the Convention Center or Union Station (approximately 1 mile from South Side site) should be developed.

There is currently no existing station infrastructure at this site. A station development would need to be optimized for vehicular circulation on the ground and would provide ample opportunities for retail, commercial and/or residential development nearby. This site would eliminate the need for a major elevated structure over I-30 when considering the alignment approach from the south, but would still require three major structures (including one environmentally-sensitive structure over the Trinity River) and may require displacement of residents between Loop 12 and East Overton Road. Construction of the station would need to take into consideration the flood hazard areas of the nearby Trinity River, as the potential station may require building in the vicinity of these areas (FEMA, 2016).

There may be significant difficulties in connecting this station site to destinations north and west of the city of Dallas. In order to connect to the proposed TOPRS alignment, an elevated structure over I-30 would be required, along with elevated tracks in the vicinity of Union Station. If elevated tracks must be built over Union Station, an HSR station at that site should definitely be preferred due to its ground transportation connections and existing infrastructure.

If only the southern approach (entry from Houston) is considered, this station site will most likely have much smaller construction costs and a shorter timeline due to its greenfield nature. However, when considering both northern and southern approaches, the added costs of building a new station along with the poor transit accessibility make the benefits of this location questionable.

Summary of Key Points:

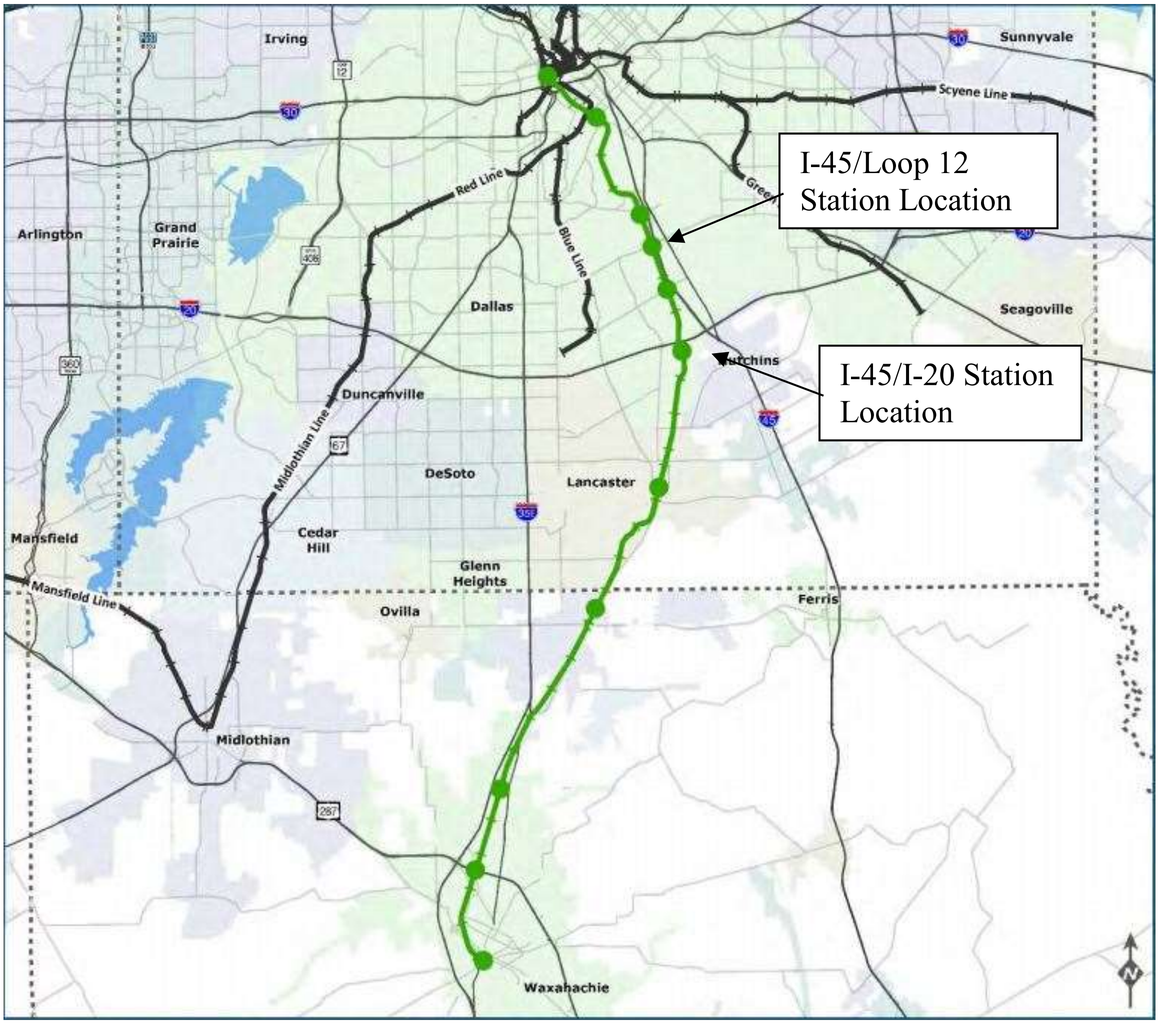
- Most of Downtown Dallas accessible quickly from site, including the nearby Dallas Convention Center;
- Driving access is very similar to Union Station, providing opportunities for travel to many areas of the city;
- Public transportation access is not optimal due to existing distances to current rail stations;
- Alignment has similar engineering, environmental, and social constraints as Union Station site and could prove awkward for through access to northern alignments;
- Site allows optimal design of station, circulation and nearby developments.

I-45/Loop 12

A third potential station site in Dallas, proposed by the Texas Central Railroad, is located southwest of the intersection of I-45 and Loop 12 in South Dallas. The location avoids many of the constraints associated with building or sharing an alignment into downtown Dallas. Only one major structure is required over I-20 and the alignment avoids the environmental constraints near the Trinity River as well as preventing the potential relocation of residents north of Loop 12. Additionally, only a minor section of the alignment, between I-20 and Loop 12, will be shared with UP near the Dallas metropolitan area. The location is not completely free of environmental concerns, however, as it is located just north of several small bodies of water, including Fivemile Creek. There is a significant flood hazard zone associated with this area, even stretching towards the proposed station site, which may impact the exact location and elevation of the structure and tracks (FEMA, 2016). This potential station site is completely undeveloped at the current time, providing an opportunity for optimal station design and TOD.

Though this location will benefit from decreased construction cost (only 6% cost increase versus alignment terminating south of I-20) and shorter construction time (2.6 years compared to 3.5 years for downtown Dallas alignment), the location does not provide good accessibility to the Dallas metropolitan area. Driving access to destinations north and west of the city is very limited and there is no reasonable transit access into downtown Dallas. Should an HSR terminus be built at this location, a rapid transit connection into the downtown areas of the city should be built to more adequately connect travelers to their final destinations. The NCTCOG Mobility 2040 currently calls for the planning and construction of the Waxahachie Line, seen in Figure 35, a regional rail connection from downtown Dallas to the city of Waxahachie. The current alignment proposed a station in the vicinity of this potential HSR station near the intersection of Loop 12 and I-45. However, perhaps due to its $1.488 billion price tag, the project has remained at the conceptual phase for many years and the current goal is implementation between 2028 and 2037, well after the proposed start of service for the new Texas Central Railroad. If the Waxahachie Line does tie into this potential HSR station, the schedule of the regional rail line must be coordinated to service HSR passengers immediately upon arrival. Nonetheless, even should the current timelines for implementation hold, the Waxahachie Line will not be fully operational for up to 16 years following construction of the HSR system. This proposed regional rail line also does not provide a one seat ride to major employment centers north and west of downtown Dallas as travelers will be forced to change in downtown Dallas.

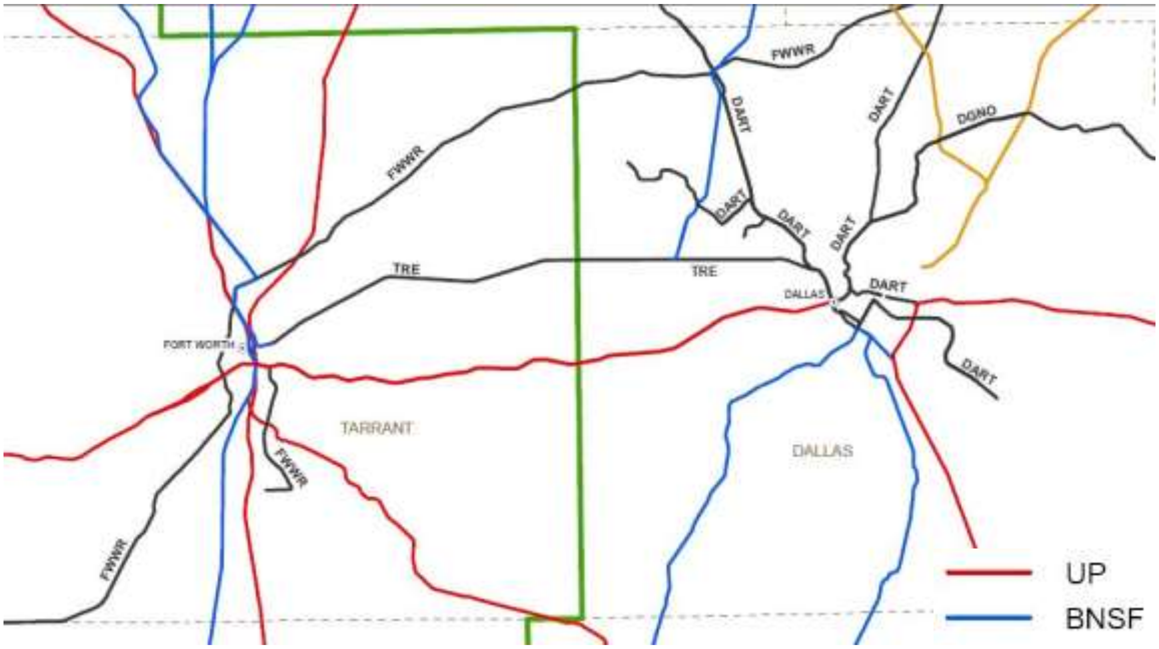
Figure 35: Proposed Waxahachie Line Alignment



Source: (NCTCOG, 2016).

This potential station site presents significant obstacles for through train flow and connections into Fort Worth and points north of Dallas. The location site favors a dead-end station, since a through station would require a major structure over Loop 12 and displacement of residents on the other side of Loop 12. An alignment to points north and west would also be problematic, most likely circumventing Dallas or the entire Metroplex. Most existing railroad lines in the Metroplex (Figure 36) travel through the center of Dallas, meaning circumventing the entire area would require a new alignment.

Figure 36: Existing Railroad Lines in Dallas-Fort Worth Metroplex



Source: (TxDOT, 2013).

Summary of Key Points

- Site provides easy access to Loop 12 and I-45, but long driving time to points north and west of downtown Dallas;
- Transit access to downtown is not reasonable; planned Waxahachie Line regional rail service may provide service well into the future, after construction of HSR system;
- Greenfield site allows optimal design of station, circulation and nearby developments;
- Site has less engineering, environmental or social constraints than both downtown alternatives;
- Proposed location presents difficulties for future expansion of HSR alignment to points north and west.

I-45/I-20

The fourth potential station site in Dallas is located just inside the southern boundaries of the city near the intersection of I-45 and I-20. The site is located on Langdon Road between Wilmer Hutchins High School and Whites Branch Creek. Like the Loop 12 site location, this site allows for optimal design of an HSR station to suit the needs of travelers. Vehicle circulation can be optimized and there is plenty of available land for transit oriented development in the near vicinity. The site provides very easy access to both I-45 and I-20 and avoids major structures that would be required for a downtown alignment, as well as any potential displacement of residents north of Loop 12. Acquiring alignment for this site would be much easier than any of the other three potential Dallas sites. As proposed by the Texas Central Railroad, the rail alignment on the southern approach to the station would be at grade and on a utility corridor, meaning that no ROW sharing with freight railroads would be required.

Located approximately 4 miles southeast of the potential Loop 12 station, this site provides even more limited driving access to the Dallas metropolitan area. Transit access, barring the potential future Waxahachie Line regional rail connection, is non-existent. Though a seemingly optimal location for engineering and construction a new HSR station, travelers will be thoroughly inconvenienced by the rural location. The system may fail to attract many passengers, especially considering the close location of Dallas Love Field airport in relation to downtown Dallas and employment locations northwest of the city.

The potential site suggests the consideration of the dead-end station, especially given the location of I-45 immediately to the north. The addition of any future alignment to points north and west would require trains reversing in the station and then circumventing the city of Dallas or the entire Metroplex, greatly inconveniencing travelers due to added travel times and reduced speeds for many curves.

Summary of Key Points:

- Site provides easy access to I-45 and I-20, but longer driving time to points north and west of downtown Dallas than Loop 12 station;
- Transit access to downtown is not reasonable; planned Waxahachie Line regional rail service may provide service well into the future, after construction of HSR system;
- Greenfield site allows optimal design of station, circulation and nearby developments;
- Site has least engineering, environmental or social constraints of all alternatives;
- Proposed location presents difficulties for future expansion of HSR alignment to points north and west.

Selection of Preferred Site

The existing public transportation system in the city of Dallas and the requirement of connecting into large population and employment centers north and west of downtown are two main reasons for direct connection of an HSR system into downtown Dallas. The two potential station locations located south of the city along I-45 are just not feasible options, despite how quickly, easily and cheaply they are able to construct, compared against the two downtown locations.

Both downtown locations will most likely require elevated alignments. Tunneling into the city of Dallas would be much too expensive, especially given the availability of shared alignments and land along a majority of the route. Additionally, a tunnel into downtown would most likely require digging under or near the Trinity River, greatly increasing the cost and complexity of the project and increasing the future risk of flooding the tunnel. Union Station provides many direct public transportation connections in the area, but lacks proper driving access and circulation, along with potential for future development around the station. The South Side site is located slightly away from direct public transportation connections, but provides the opportunity for optimal station development, including driving access, parking and circulation, along with the possibility for transit oriented development of adjoining land.

The South Side site is recommended for the construction of the HSR station for the city of Dallas. This site provides the necessary access to the citizens and employees within and near the city and also allows for future expansion of the HSR line to points north and west, assuming construction of a station that allows through movement of trains. A second station site is not recommended, as future expansion to Fort Worth via the DFW Core Express is planned and since any additional station would severely limit speeds and operating efficiency of the HSR system.

HOUSTON

Six potential HSR station locations were evaluated in the city of Houston. The potential station sites, illustrated in Figure 37, are the following (listed in order of distance from downtown Houston):

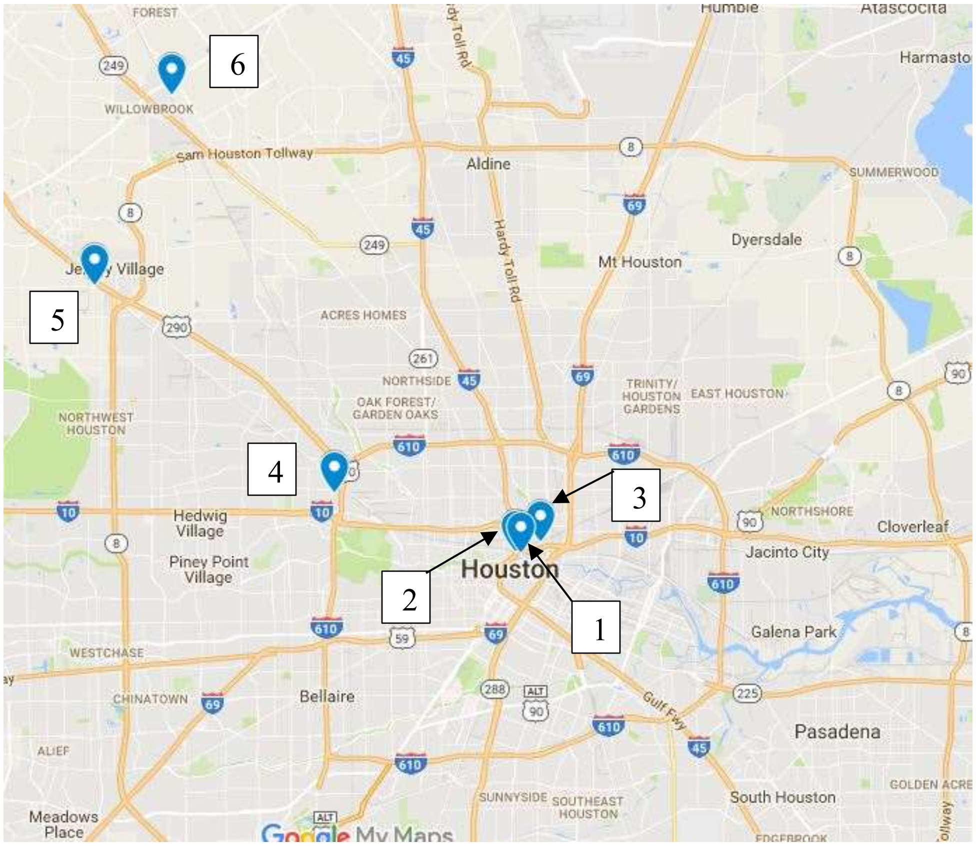
1. Post Office Building – located at northeast corner of Franklin Street and Bagby Street intersection in downtown Houston.
2. Amtrak Station – located immediately west of Post Office Building site across I-45. Located at northeast corner of Washington Ave. and Elder St. intersection.
3. Hardy Yards – located immediately north of downtown across I-10. Bound approximately by North Main Street to the west, Burnett Street to the north, and Elysian Street to the east.

4. Northwest Transit Center – located immediate west of I-610. Bound approximately by I-10 and the existing Northwest Transit Center to the south, Post Oak Road to the west and Hempstead Road to the north.
5. US 290/Beltway 8 – located outside Loop 8. Bound approximately by US 290 to the north and east, Spencer Road to the south and Charles Road to the west.
6. Willowbrook Mall – located immediately northeast of the existing mall structure, along the Willowbrook Drive loop.

In addition to these six locations under consideration, three sites proposed by the Texas Central Railroad or the Texas TGV project proposals were initially considered, but then removed due to fundamental obstacles that would prevent development. These locations are the following:

1. Former Union Station Site – located at northeast corner of intersection of Texas Avenue and Crawford Street in downtown Houston. The site is the current location of Minute Maid Park, the home field of the Houston Astros professional baseball team.
2. Memorial/Studemont (Parkways) Site – located along Studemont Street between Memorial Drive and Washington Avenue in the Montrose neighborhood of Houston, west of downtown. Since originally proposed as a potential location by the Texas TGV project, the site has undergone significant development.
3. TC Jester Station – located outside the I-610 loop in the Oak Forest neighborhood of Houston. Bound approximately by West 34th Street to the south, Ella Boulevard to the east, Judiway Street to the north and East TC Jester Boulevard to the west. While proposed as a potential site by the Texas Central Railroad, the site is the current site of Waltrip High School, which is currently undergoing a $30 million expansion project (Houston ISD, 2016).

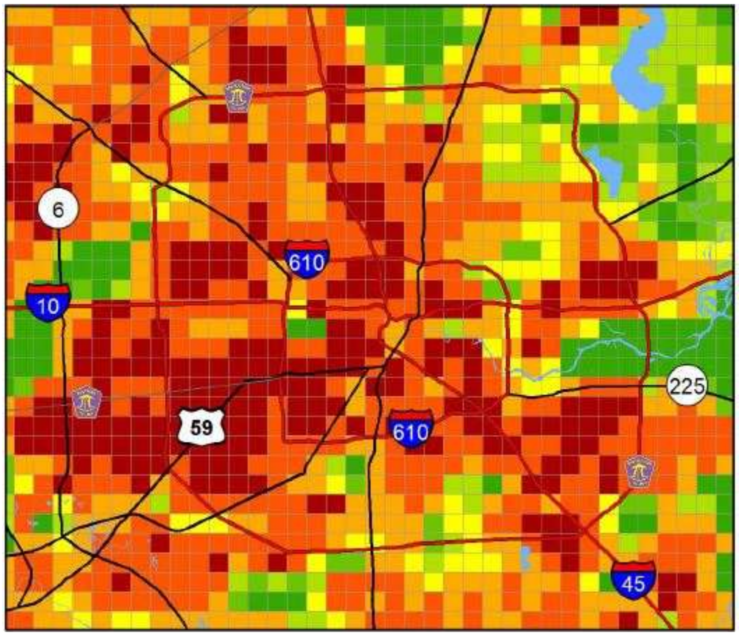
Figure 37: Proposed Houston HSR Station Sites



Source: (Google, 2016).

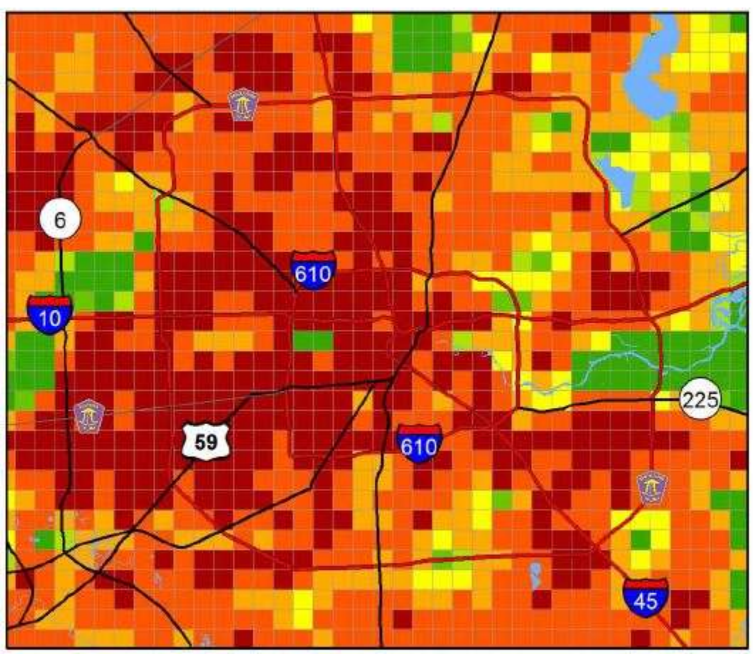
Population and employment estimates and forecasts published by the Houston-Galveston Area Council (H-GAC) for 2010 and 2040 will be used to determine if station locations have adequate accessibility to larger population and employment centers. The population estimate and forecast (Figures 38 and 39, respectively; legend in Figure 40) show that current population centers are scattered throughout the city within the Sam Houston Tollroad (Beltway 8). Most notable is the cluster in southwest Houston around I-69/SH-59. By 2040, the population density in west Houston is expected to continue to grow. The darkest color in these images, red, represents population densities of over 5,000 per square mile.

Figure 38: H-GAC 2010 Population Estimate



Source: (H-GAC, 2016a).

Figure 39: H-GAC 2040 Population Forecast



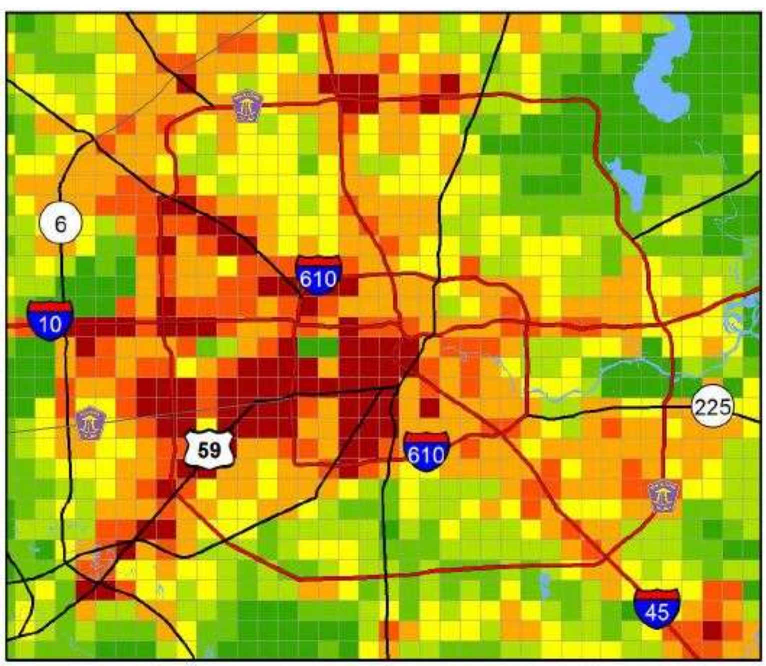
Source: (H-GAC, 2016a).

Figure 40: H-GAC Population and Employment Forecasts Legend

Source: (H-GAC, 2016a).

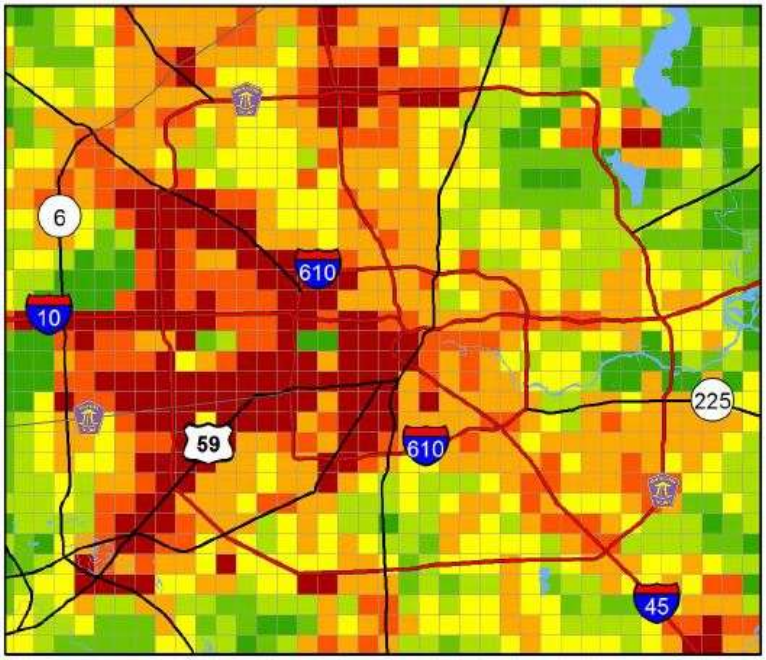
The employment estimate and forecast (Figures 41 and 42, respectively) indicate that current employment centers in downtown and the Galleria areas of Houston are expected to continue to grow by 2040. Additional employment clusters are predicted along SH-290 in northwest Houston and I-10 in west Houston. As with the population density maps, the red color indicates an employment density of over 5,000 per square mile.

Figure 41: H-GAC 2010 Employment Estimate



Source: (H-GAC, 2016a).

Figure 42: H-GAC 2040 Employment Forecast



Source: (H-GAC, 2016a).

Houston is currently served by two major airports, George Bush Intercontinental Airport (IAH), a hub for United Airlines, and William P. Hobby Airport (HOU), a hub for Southwest Airlines. Both airports are located relatively far from downtown Houston, with HOU located outside the inner I-610 beltway and IAH located outside Beltway 8. Driving access to population centers in western areas of Houston is very limited (as seen in the maps in Appendix B), opening the possibility for a HSR system to better serve the residents of the city. Public transportation access from these airports is particularly poor. One Houston Metro bus line (102 for IAH, 40 for HOU) connects each airport to downtown. Official Houston Metro bus schedules show these routes taking 68 and 53 minutes for their journeys from IAH and HOU, respectively, to downtown Houston (Houston Metro, 2016). However, both airport websites note that these journeys can take much longer, up to 1.5

hours from IAH and up to 1 hour from HOU. Traveling by public transportation to population or employment centers in west Houston is even more difficult.

Two additional major concerns in Houston involve flooding and the soil properties within the area. Houston is prone to flooding and any alignment or structures that are depressed or underground are at risk of major flooding. The soil in the city contains a large concentration of clay, meaning that underground structures may be much more expensive than comparable systems. These concerns suggest an at-grade alignment or elevated structure within the urban area is recommended (Johnson, 2016).

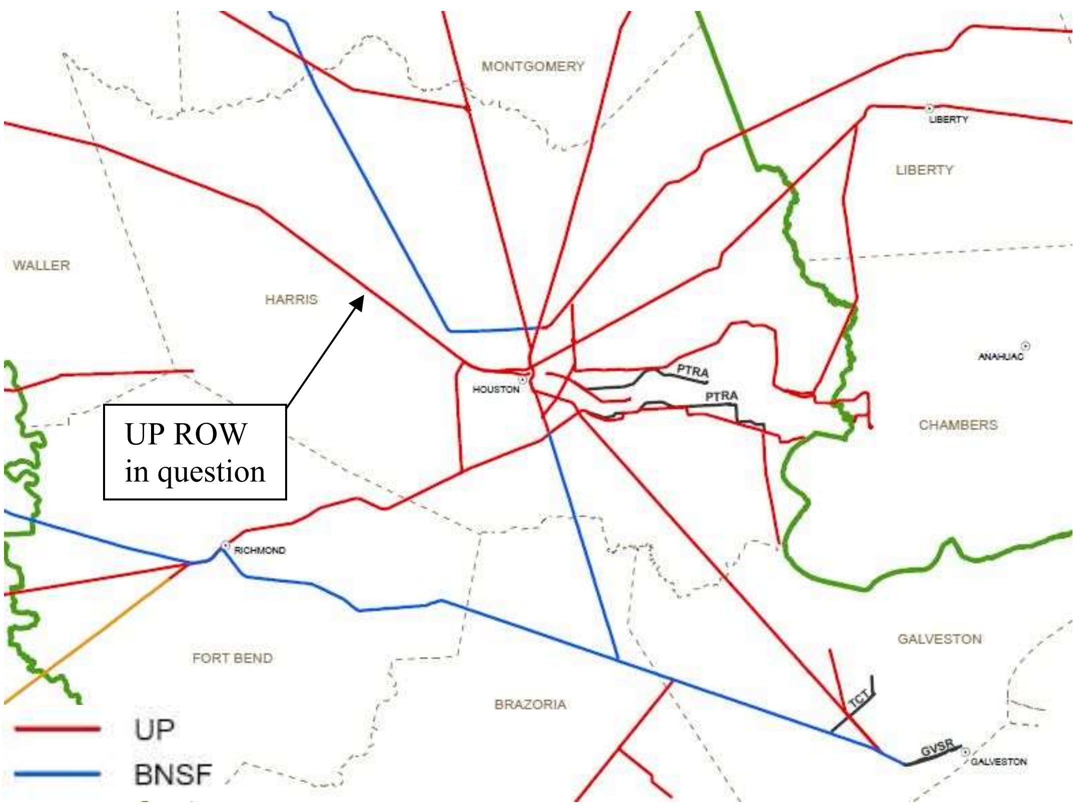
Post Office Building

Located just inside downtown Houston along Franklin Street, the Post Office Building is a former rail station. Existing UP tracks lie north of the current building and this alignment carries Amtrak services from San Antonio to New Orleans. This potential station site would provide reasonable driving access to many areas of the city due to its proximity to I-45 and I-10. The station is located in close proximity to the Houston Metro Red Line light rail and travelers would be able to access a large portion of the central areas of Houston relatively quickly. Transit access to the Galleria and Energy Corridor employment centers would not be as convenient.

The existing site contains a large amount of parking and driveways for use in US Postal Service operations. Though these existing facilities would not provide anywhere near the amount of parking required for the new HSR station site, drop-off/pick-up areas could be created and vehicular circulation be optimized. Potential development around the site (including parking) would be limited since it is located in the relatively dense downtown area.

The Texas Central Railroad presents two alternatives alignments for accessing downtown Houston (Arup Texas Inc., 2015). One utilizes a large stretch of BNSF ROW and the other a large stretch of UP ROW. Both alignments can be seen in Figure 43 below. The BNSF ROW is depicted in blue and the UP ROW is immediately counterclockwise from the BNSF ROW, located just above the Harris County label. Both alignments have significant obstacles to access downtown Houston. As previously discussed, tunneling into the city would add significant costs to the project, and the tunnels would always be at risk for flooding. These two potential alignments contain a number of grade crossings and are single tracked in many stretches. The UP ROW is a main line to the port of Houston, meaning that sharing the alignment would not be probable (Johnson, 2016).

Figure 43: Existing Railroad Lines in the City of Houston



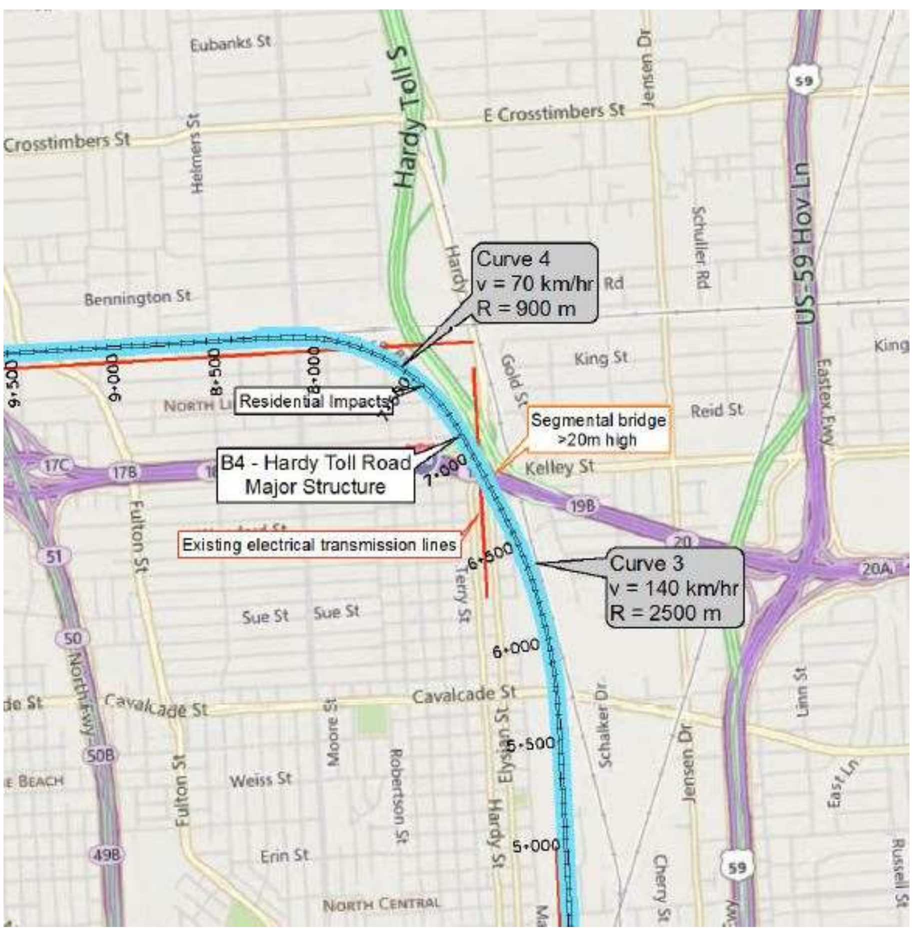
Source: (TxDOT, 2013).

Due to all of these complications, any alignment accessing downtown Houston would need to be elevated for a significant stretch. The track elevation would need to begin pretty far out from the central areas of Houston, as far as the Grand Parkway, State Highway 99. An elevated alignment would also run into many issues. As opposed to Dallas, where the proposed southern alignment accesses the city through low population density areas, the proposed northern alignment in Houston travels through high population density regions, meaning that the potential for displacements and inconveniences to current residents is very high. Both of the ROWs in question are relatively narrow through these residential areas, adding to the complexity of building an elevated alignment. Ashby Johnson noted that residents were opposed to elevated sections of I-10 in this area and would not be supportive of elevated rail lines in closer proximity to their homes.

In addition to the elevated nature of these potential alignments, there are additional engineering obstacles, notably the large number of superstructures, defined as extraordinary large or complex structures, required. Both alignments would need approximately six superstructures, each adding major costs and construction time. The BNSF ROW alignment requires six superstructures according to the Texas Central Railroad Last Mile Analysis Report: one each over SH 249/Beltway 8, Sam Houston Tollway/Beltway 8, I-45, I-610, the Buffalo Bayou and I-10. The UP ROW alignment (called the Utility Corridor by Texas Central) would also most likely require six superstructures: one each over Highway 6, SH 99 (The Grand Parkway), Beltway 8, I-10, I-610 and I-45. The last superstructure over I-45 is not included in the Texas Central Report as it does not consider accessing the Post Office Site from the UP ROW alignment, only the adjacent Amtrak Station.

The BNSF ROW alignment is particularly problematic. First, a curve near the intersection of US 290 and I-610 will limit speeds of the train to 45 mph. This speed restriction will affect train operations within the city of Houston as the train will be required to decelerate earlier than normal and delay full acceleration out of the city until passing through this area. A second major issue with this alignment is the superstructure over I-610 near the Hardy Toll Road. The curve, depicted in Figure 44, not only severely restricts the speed of the train due to a ninety degree turn, but traverses over I-610, parts of the Hardy Toll Road, existing electrical lines and very dense residential areas. Especially due to the potential impacts to residents, this curve is particularly problematic for the BNSF ROW alignment.

Figure 44: Hardy Toll Road Superstructure



Source: (Arup Texas Inc., 2015).

Summary of Key Points:

- Downtown Houston accessible directly from station site;
- Transit access and connections with existing public transportation services in downtown Houston;
- Central location allows driving access to many areas of the city, but could be hindered by congestion;
- Circulation around station could be optimized for passenger pick-up and drop-off;
- Extended alignment has increased cost and longer construction time, along with several engineering, environmental and social constraints and will need to be elevated;
- The elevation of the alignment will cause numerous obstacles to constructing the system;
- New development around station may be limited.

Amtrak Station

Located just west of I-45 and across the highway from the Post Office Building is the existing Houston Amtrak Station. The station is relatively small, serving as a stop on the Amtrak route from San Antonio to New Orleans. The site shares many of the same accessibility benefits as the nearby Post Office Building, but is located slightly further away from the existing light rail Red Line. Due to its location, new development around the station will be limited. Parking is also very limited and vehicular circulation around the area is extremely poor. Should this station be converted into an HSR station, parking and vehicular movement in the vicinity of the station would need to be redeveloped.

The preferred alignment for this location would be along the UP ROW as the BNSF ROW would be too difficult and would require an additional superstructure over I-45 (bringing the total to 7). The alignment is exactly the same as described for the Post Office Building, except a superstructure over I-45 into downtown Houston is no longer required. The station will most likely require trains to reverse in order to continue to future destinations. These train movements are not inconvenient for destinations to the west, such as San Antonio, but will be very inconvenient for destinations to the east, requiring either a continuation of the alignment through downtown Houston or an additional alignment circumventing the city of Houston to the north.

Summary of Key Points:

- Downtown Houston accessible directly from station site;
- Transit access and connections with existing public transportation services in downtown Houston;
- Central location allows driving access to many areas of the city, but could be hindered by congestion;
- Poor circulation around station may delay passenger pick-up and drop-off;
- Extended alignment has increased cost and longer construction time, along with several engineering, environmental and social constraints and will need to be elevated;
- The elevation of the alignment will cause numerous obstacles to constructing the system;
- New development around station may be limited.

Hardy Yards

Location just north of downtown Houston is a former rail yard known as Hardy Yards. The site was vacant for many years, but now is the site of a planned mixed-use development (Design Workshop, 2016). This impending development means that the window for developing and constructing an HSR station at this site is rapidly closing. The site itself provides many of the similar accessibility benefits as the other two station sites previously discussed near downtown Houston. Driving access is similar, with nearby connections to I-10, I-45 and I-69. The Burnett Transit Center (4 bus lines) and Red Line station are located towards the western portion of the site, providing more direct connections to public transit systems than either of the other downtown locations. These connections, however, do not allow a one-seat ride to western areas of the city. Development in the areas around the station could be optimized or coordinated with the potential mixed-use development.

The approach for this location would utilize the problematic BNSF ROW corridor. Though only four superstructures would be required, the superstructure near the Hardy Toll Road (Figure 44) would still be utilized. The site would need a dead-end station, and trains would need to reverse back out to the north in order to proceed to future destinations. Speed restrictions from the curve near US 290 and I-610 would affect train operations through delayed acceleration and early deceleration into the city.

Summary of Key Points:

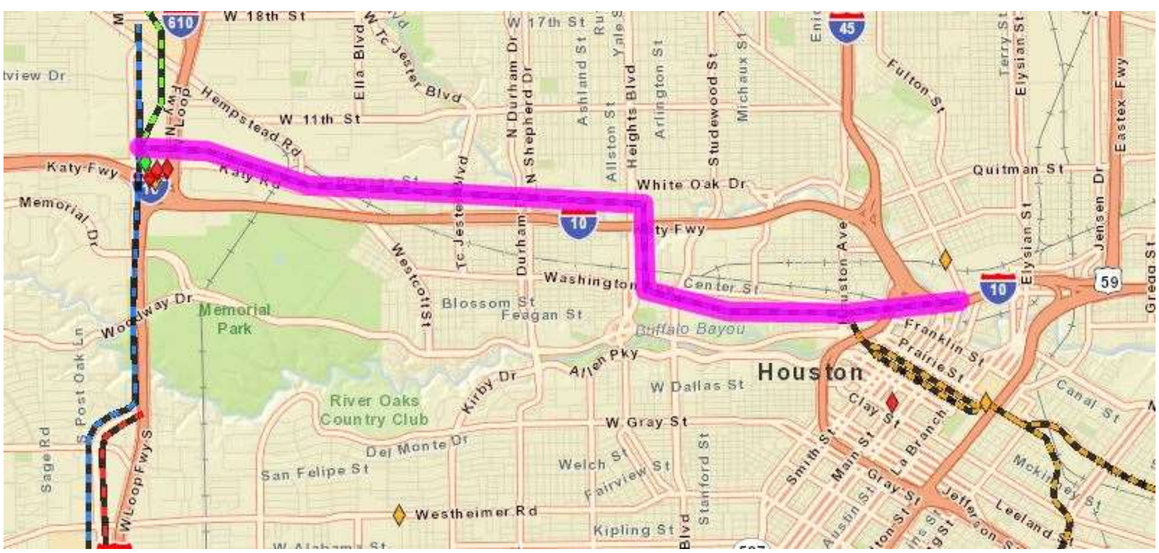
- Downtown Houston accessible directly from station site;
- Transit access and connections with existing public transportation services in downtown Houston;
- Central location allows driving access to many areas of the city, but could be hindered by congestion;
- Circulation around station could be optimized for passenger pick-up and drop-off;
- Extended alignment has increased cost and longer construction time (though less than Post Office Building and Amtrak Station options), along with several engineering, environmental and social constraints and will need to be elevated;

- The elevation of the alignment will cause numerous obstacles to constructing the system;
- The potential for development of the area as a HSR station is rapidly closing.

Northwest Transit Center

Located northwest of the intersection between I-10 and I-610 is the Northwest Transit Center. This location currently serves 16 bus routes, providing access to downtown, the Galleria, Energy Corridor and many other points towards the western areas of the city. With direct access to I-10 and I-610, this site allows relatively quick access to many of the more populated areas in north and west Houston. Though only included in the long range forecast (2030-2040) of the H-GAC Regional Transportation Plan (RTP), the Inner Katy Corridor Rapid Transit system will provide direct access between the Northwest Transit Center and the University of Houston-Downtown Metrorail Station. The system (Figure 45) has a $420 million price tag (H-GAC, 2016b).

Figure 45: Proposed Inner Katy Corridor Rapid Transit System



Source: (H-GAC, 2016b).

Ashby Johnson notes that the current transit access to this site will need to be improved should an HSR station be located there. He suggests that timetables will have to be integrated and that an additional system of transport, such as a streetcar, be constructed to connect to downtown.

Rail access to this site will be via either the UP or BNSF ROW alignments, with three major structures required on both alignments according to the Texas Central Railroad Last Mile Analysis Report. Though these alignments still pass near a large number of residential areas, it avoids many of the narrow sections of the alignments inside the I-610 Beltway. A large majority of the properties adjacent to the UP ROW alignment are industrial, including the properties that may be displaced to create the HSR station. Assuming that these properties can be displaced for the construction of the new HSR station, the design of the station could be optimized for vehicular circulation, parking and nearby developments. The BNSF ROW alignment passes near a large number of residential areas between Beltway 8 and I-610, so a large number of residents may be affected by the proposed construction. Unless another superstructure is constructed over I-10, the station will need to be a dead-end terminus station, requiring trains to reverse back out on the same alignment in order to proceed to any other destinations. These train movements are not as inconvenient for travel to San Antonio, but are very inconvenient for travel to eastern destinations. The trains would most likely have to circumvent the city of Houston, adding considerable distance, construction cost and time to the project.

Summary of Key Points:

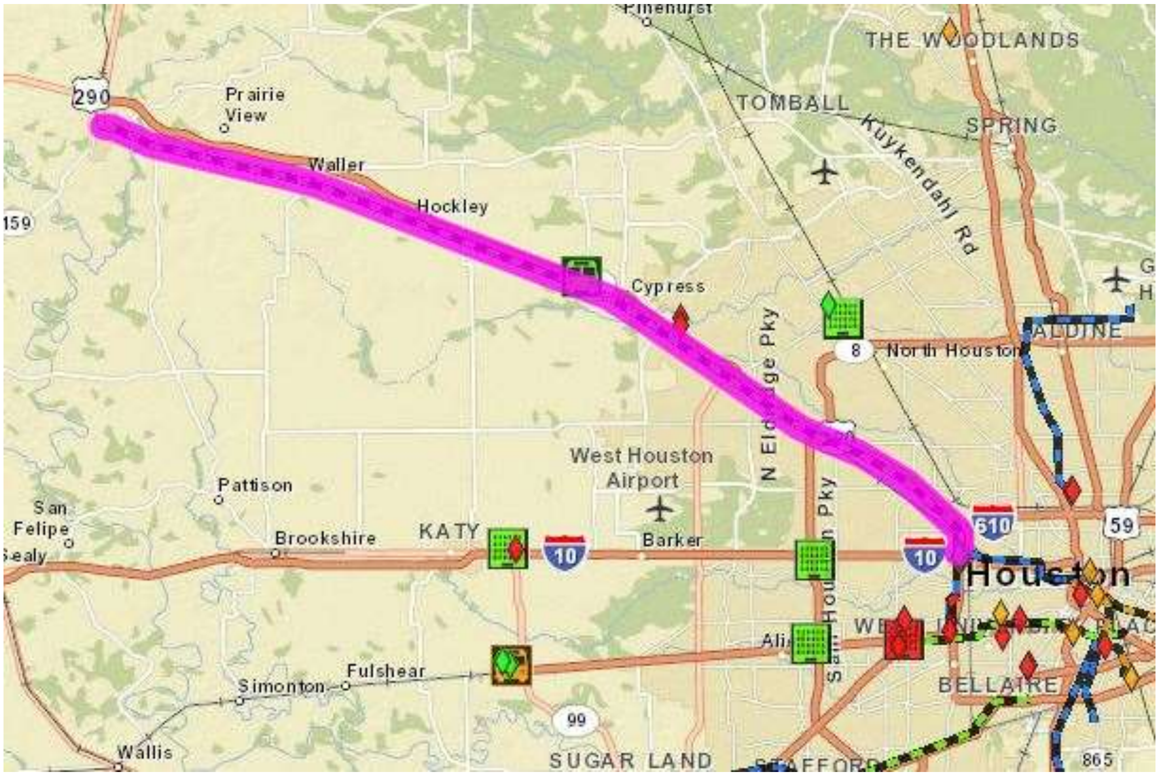
- Site provides easy access to I-610 and I-10, and quicker access to the Galleria and Energy Corridor but longer driving time to points south and east of downtown Houston;

- Existing transit access to many areas of the city through the Northwest Transit Center; planned rapid transit service to downtown may provide quicker service well into the future, after construction of HSR system;
- Site allows optimal design of station, circulation and nearby developments;
- Site has less engineering, environmental or social constraints than all downtown alternatives;
- Proposed location presents difficulties for future expansion of HSR alignment to points east; allows relatively easy expansion to the west.

US 290/Beltway 8

Further northwest along the proposed UP ROW alignment is a potential station location along US 290 near the intersection with Beltway 8. This site provides quick access to US 290 and Beltway 8, but adds significant driving time to downtown Houston and the Galleria. Transit access at the existing site is non-existent, meaning passengers must rely on automobile transport (through personal cars, TNCs or taxi services) once at the site. Transit access may improve with the future construction of the Hempstead Corridor Commuter Rail. This project (Figure 46) is listed in the short range forecast (2020-2029) of the H-GAC RTP with a price tag of just over $1 billion. Current plans do not account for a station at the proposed HSR station location, but it is anticipated that a station would be added to connect the systems if the HSR station was located along this corridor (Klotz Associates, 2012). The construction of this system is not planned until after the Texas Central Railroad begins operations, so travelers will be left without proper public transportation access at the beginning of service.

Figure 46: Proposed Hempstead Corridor Commuter Rail System



Source: (H-GAC, 2016b).

The alignment would only require two superstructures, one over Highway 6 and one over SH 99 (The Grand Parkway). This alignment also avoids a significant amount of residential areas situated between Beltway 8 and I-610. This alignment would cost much less than any of the downtown alignments or the Northwest Transit Center location. However, the Texas Central Railroad still estimates a construction time of nearly 5 years, in line with all of the other alternatives. Since there are no major curves in the approach to the station, train operations (including acceleration and deceleration) could be maximized.

Summary of Key Points:

- Site provides easy access to US 290 and Beltway 8, but long driving time to downtown and points south and east of downtown Houston;

- Transit access is not reasonable; planned Hempstead Corridor Commuter Rail service may provide service well into the future, after construction of HSR system;
- Site allows optimal design of station, circulation and nearby developments;
- Site has less engineering, environmental or social constraints than all previous alternatives;
- Proposed location presents difficulties for future expansion of HSR alignment to points east; allows relatively easy expansion to the west.

Willowbrook Mall

The Willowbrook Mall, located just outside the Beltway 8 along SH 249, is the final alternative for the location of an HSR station within the city of Houston. This alternative is located along the BNSF ROW alignment and avoids a large portion of residential areas between Beltway 8 and I-610, along with all superstructures. This alignment still passes through many residential areas between The Grand Parkway and Beltway 8. It is single-tracked with a relatively narrow alignment, suggesting that an elevated alignment might be necessary. This elevated track might cause disruption to or displacements of existing residents. Unless major structures are constructed over SH 249 and Beltway 8, the station would most likely be a dead-end station. Train connections to other nearby cities would not be as difficult as locations closer to downtown Houston. The train would not be required to reverse for a significant distance since the station is so far outside more urban potential station locations. There are large existing parking areas and retail developments at the Willowbrook Mall and surrounding areas, so extensive parking facilities or future TOD near the station might not be required.

The proposed site provides relatively easy driving access to SH 249 and Beltway 8, though driving times are considerably increased to downtown Houston and points east and south of downtown. Transit access at the location is relatively limited, with only a handful of bus routes in the area. The H-GAC RTP includes the construction of the Willowbrook Transit Center in the short term forecast (2020-2029), but does not suggest any rail connections into downtown Houston will be built in the near future.

Summary of Key Points:

- Site provides easy access to SH 249 and Beltway 8, but long driving time to downtown and points south and east of downtown Houston;
- Transit access is not reasonable; planned Willowbrook Mall Transit Center may provide service well by completion of HSR system;
- Site allows optimal design of station, circulation and nearby developments;
- Site has less engineering, environmental or social constraints than all previous alternatives;
- Proposed location allows for relatively easy HSR expansion.

Selection of Preferred Site

As opposed to Dallas, where the existing public transportation system and population and employment centers dictated an HSR station in downtown, Houston has more freedom in selecting a location for its HSR station. With most of the more population dense neighborhoods located in areas north and west of the city and the employment centers in downtown, the Galleria and Energy Corridor, a station must be located so that it provides relatively easy access to many of these areas. The Northwest Transit Center is the most feasible option for the HSR station in the city of Houston.

The downtown locations have the most direct connections into the existing public transportation system, including the Metrorail. However, the cost of connecting the HSR system into downtown is much too large given the lack of accessibility benefits. The

Northwest Transit Center currently services 16 bus routes, with a rapid transit service planned for a more direct connection into downtown. This location will also serve as the southern terminus for the Hempstead Commuter Rail line once constructed. Existing transit connections are not ideal, and timetables will have to be coordinated to HSR system arrivals. Additionally, a more direct connection into downtown, such as a streetcar or bus rapid transit system, would need to be implemented prior to the start of operations of the HSR system. Due to the prohibitive cost and marginal benefits of connecting into downtown Houston, two stations are not recommended.

All potential locations will most likely require elevated alignments. Tunneling into the city of Houston would be much too expensive and dangerous given the type of soil and potential for flooding. The Northwest Transit Center utilizes a UP ROW closer to the city. There are few curves associated with this alignment and the potential impacts to residents are relatively limited compared with more central locations. There would be significantly fewer major structures required for connections into the Northwest Transit Center, limiting the cost of the project.

Chapter 6: Conclusions

HSR systems have been implemented across the world, with many more in the planning or construction phases. Countries have introduced varied methods for integrating these systems into urban areas, with varying degrees of success. France and Spain have developed a hub-and-spoke architecture for their HSR system, with central capitals, Paris and Madrid, serviced with existing downtown stations that provide quick access to regional rail and rapid transit systems. Regional destinations are also serviced by these HSR systems, but often with fringe or rural stations that do not hinder the speed of the system. Germany has instead prioritized connecting travelers directly into CBDs, sacrificing system speed for accessibility. China has instituted a completely different model, situating HSR stations on the outskirts of cities in hopes of creating new development. The system greatly inconveniences travelers, but alleviates many of the engineering concerns for urban alignments and comes with a much shorter construction time. This is no doubt one of the many reasons why the Chinese system has been able to incorporate so many new miles of HSR track in such a short period of time.

In the United States, HSR development has been relatively limited to the Acela in the Northeast Corridor. However, despite direct connections into city centers, this system has been hindered by many speed restrictions due to shared alignments. New HSR services are past due for implementation. Within Texas, HSR has a long history, but no plans have come to fruition. The Texas TGV theorized direct connections into Dallas and Houston, with another line connecting San Antonio to Dallas-Fort Worth. This system called for downtown stations in both Dallas and Houston. Other proposed alignments have been put forward since the failed Texas TGV venture. Some have again prioritized direct connections into downtown while others have only provided connections into DFW and IAH airports, both a significant distance from downtown.

The Texas Central Railroad is the most recent proposal for connecting the Texas cities of Dallas and Houston. This thesis provided an independent analysis of many of their proposed station locations in the two cities. Despite recommendations from the FRA and a host of other parties, determining the location for an HSR station in an existing urban environment must be taken on a case-by-case basis. Each city possesses its own characteristics that must be taken into account. Accessibility for travelers is a major consideration for HSR system development as travelers provide the key to a system's successful operation or survival. It appears that with an increase in accessibility also comes an increase in construction cost. A trade-off must be made between these two and many other considerations.

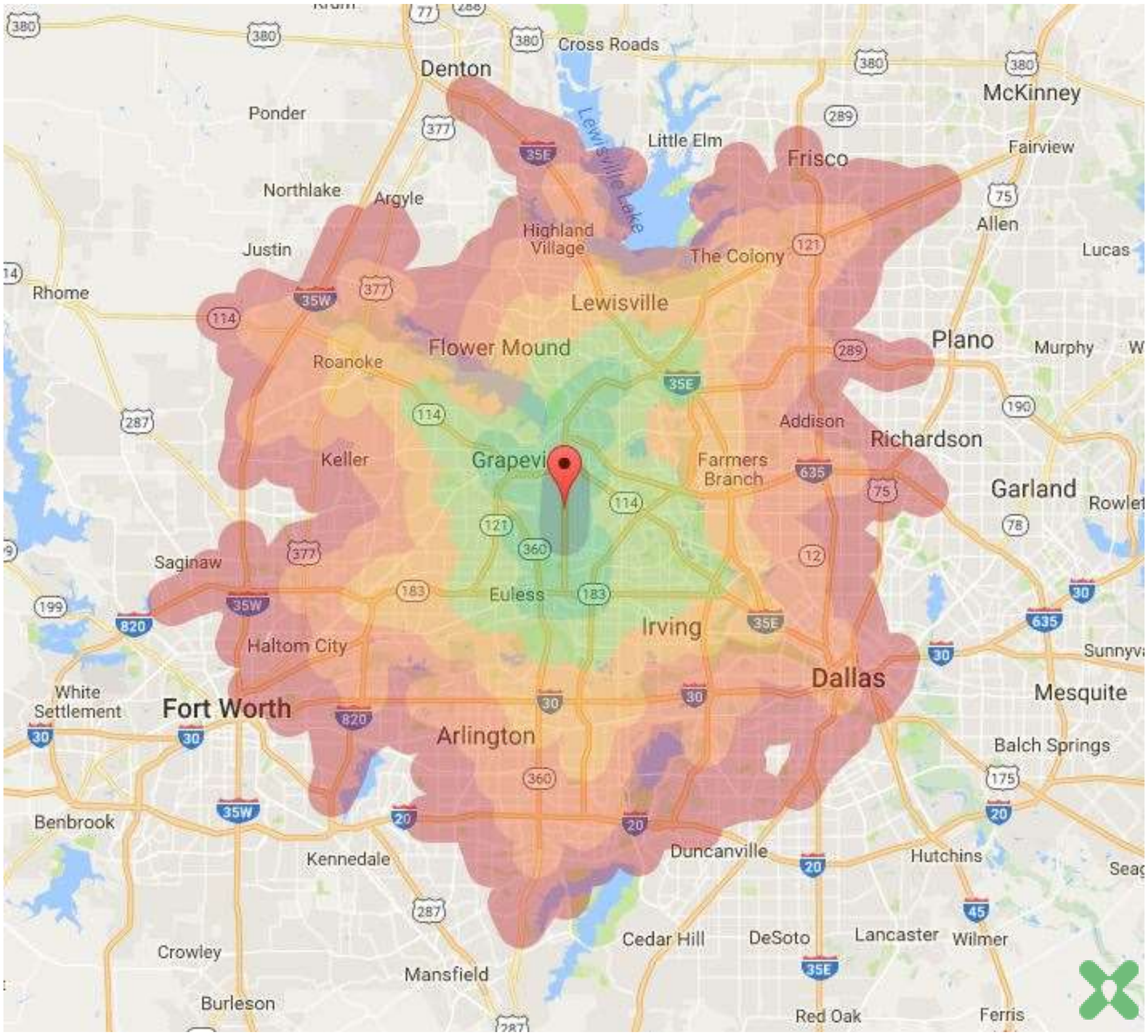
Within Dallas and Houston, the South Side site and the Northwest Transit Center, respectively, provide the best opportunities for a connecting HSR line between these cities. It is important that the stations be designed with the needs of travelers in mind and the needs of the future network. Station design should allow for more parking, more development, easier vehicular circulation and easier movement of trains. Due to the large urban sprawl in Dallas and especially Houston, there is some flexibility for planning the station location. In fact, locating a station in downtown Houston would be detrimental to system ridership, as this location would represent an inconvenience to large population and employment centers in western areas of Houston.

The introduction of Maglev trains into future HSR consideration presents its own set of considerations. These trains will require their own dedicated ROW and the significant noise impacts will require innovative resolutions in or strict avoidance of dense areas. In many densely populated cities in the northeastern United States and in Europe, the availability of more ROW is limited, even non-existent. The future growth of these systems will hinge on connecting with a passenger base that anticipates accessibility. Integrating new HSR or Maglev services into urban environments will require unique solutions for every situation. HSR is a transportation connection of the future, but without determining where and how to build a system, it will never get off the ground.

Appendix A – Dallas Maps

A.1 – Dallas-Fort Worth (DFW) Airport

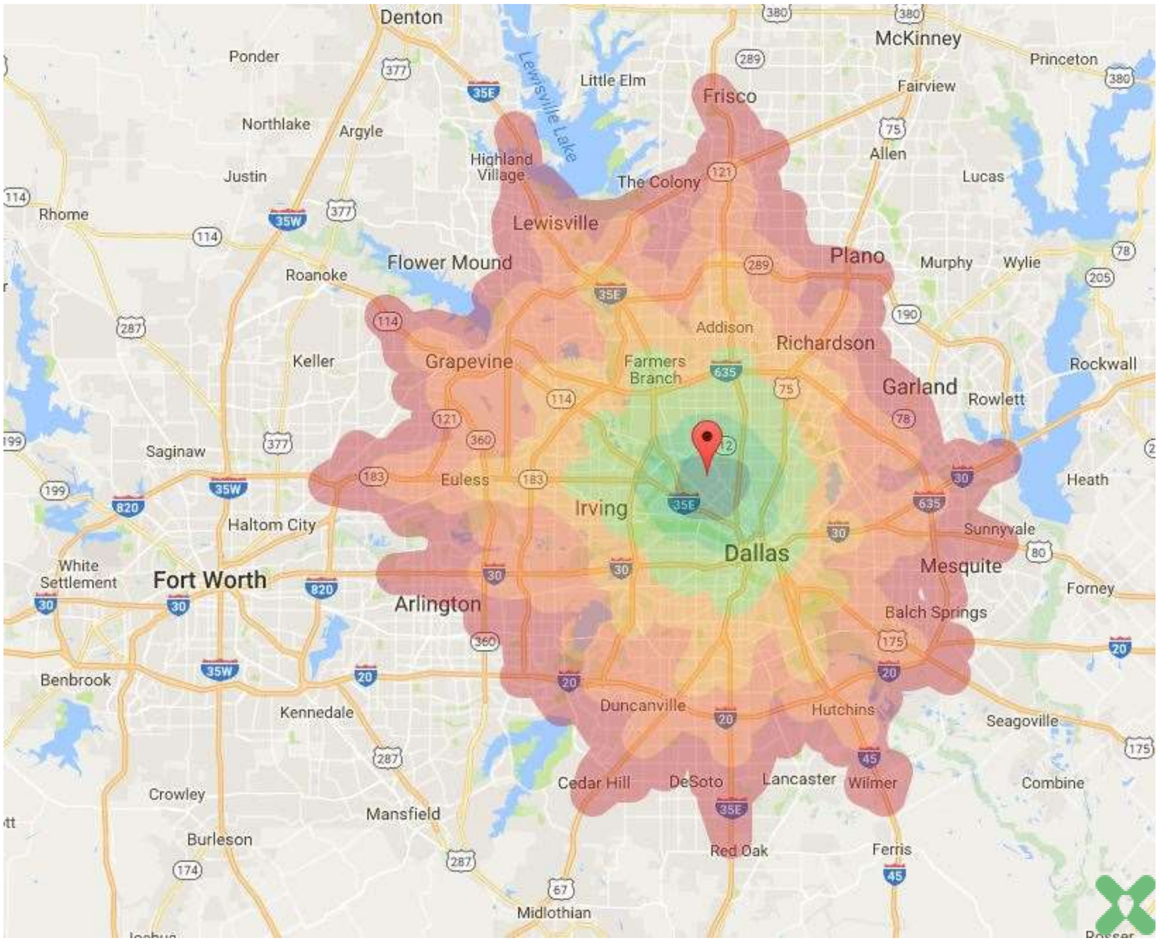
30-Minute Driving Time from Dallas-Fort Worth Airport



Source: (Route360, 2016).

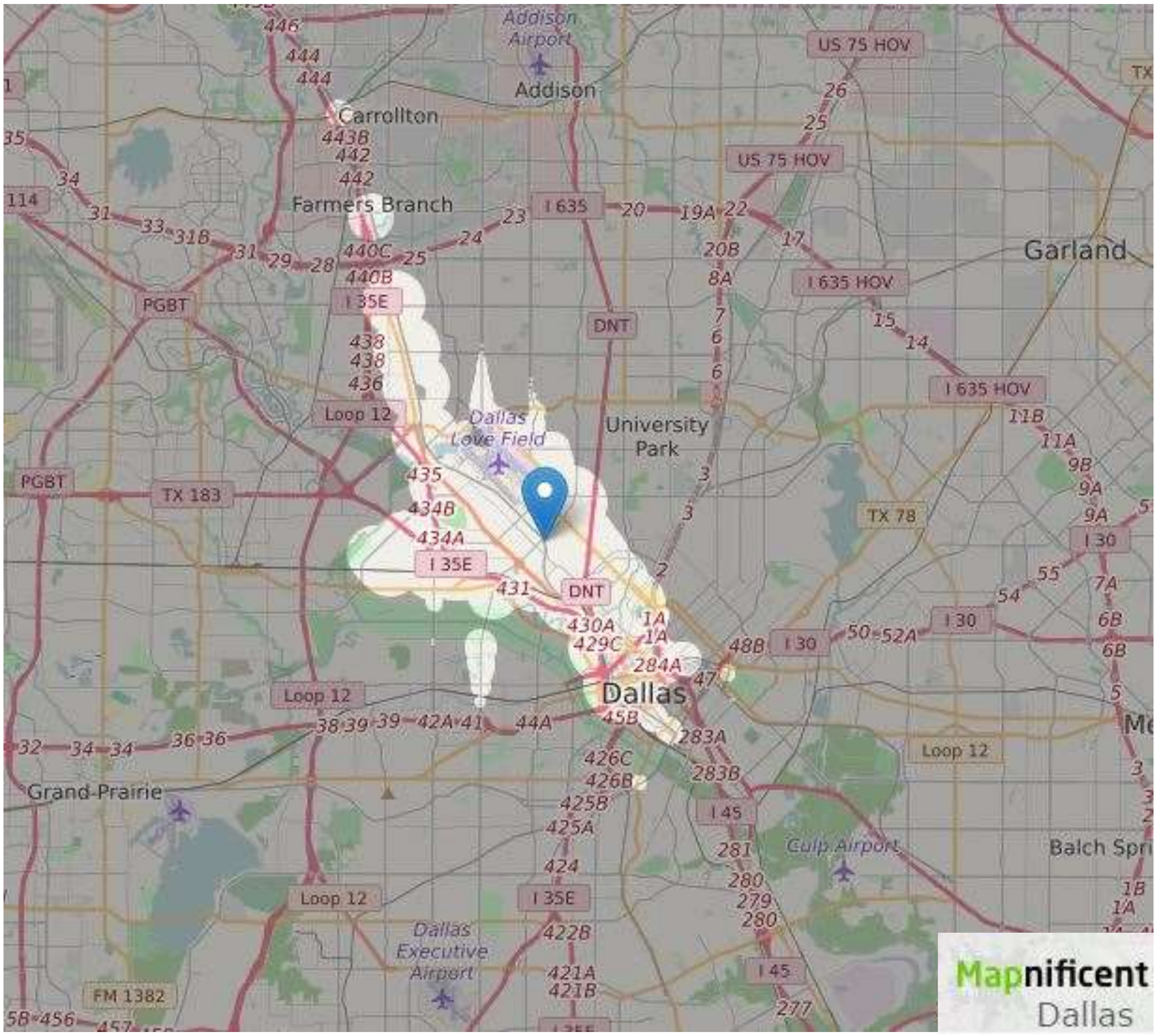
A.2 – DALLAS LOVE FIELD (DAL) AIRPORT

30-Minute Driving Time from Dallas Love Field Airport



Source: (Route360, 2016).

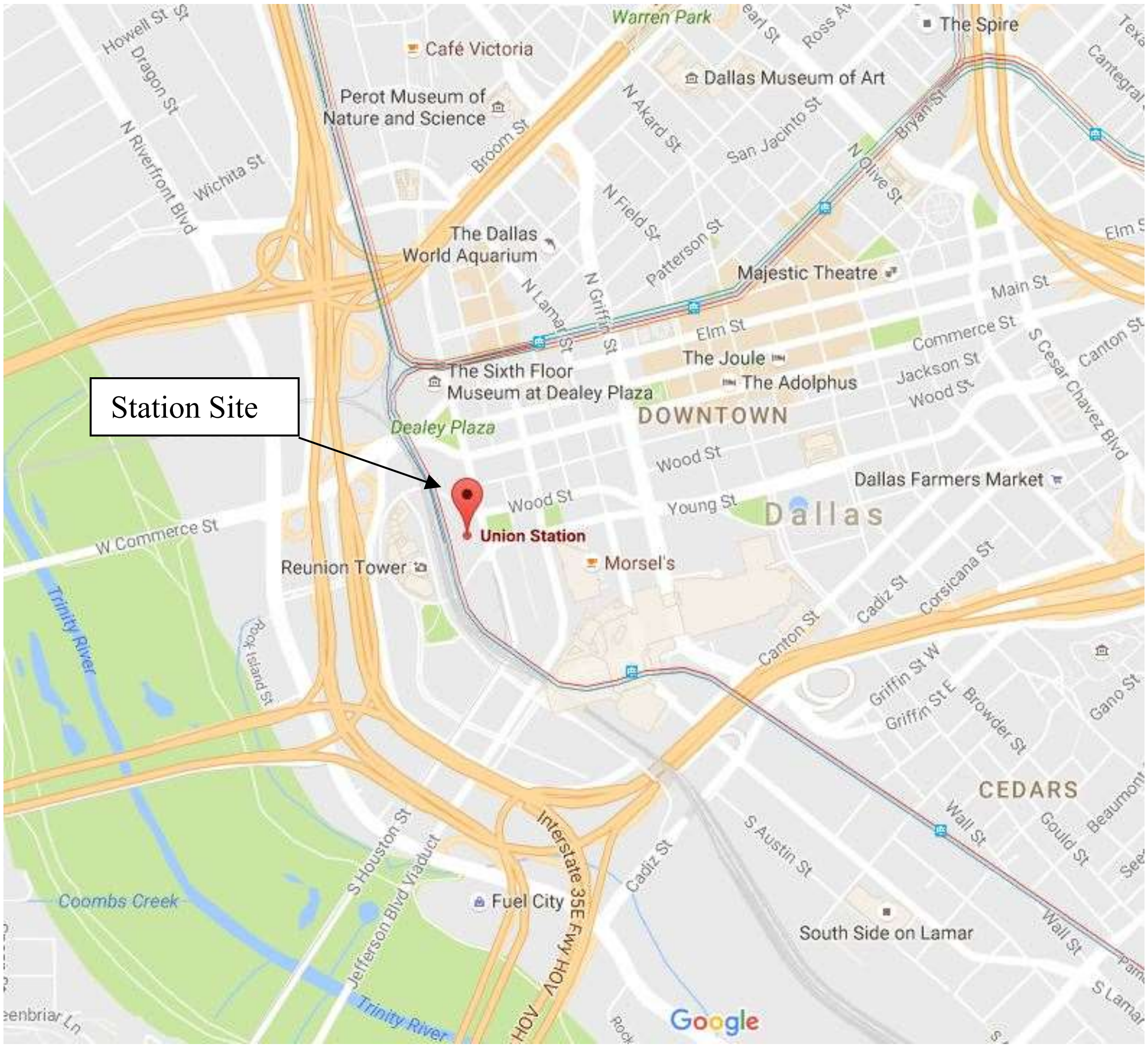
30-Minute Transit Time from Dallas Love Field Airport



Source: (Mapnificent Dallas, 2016).

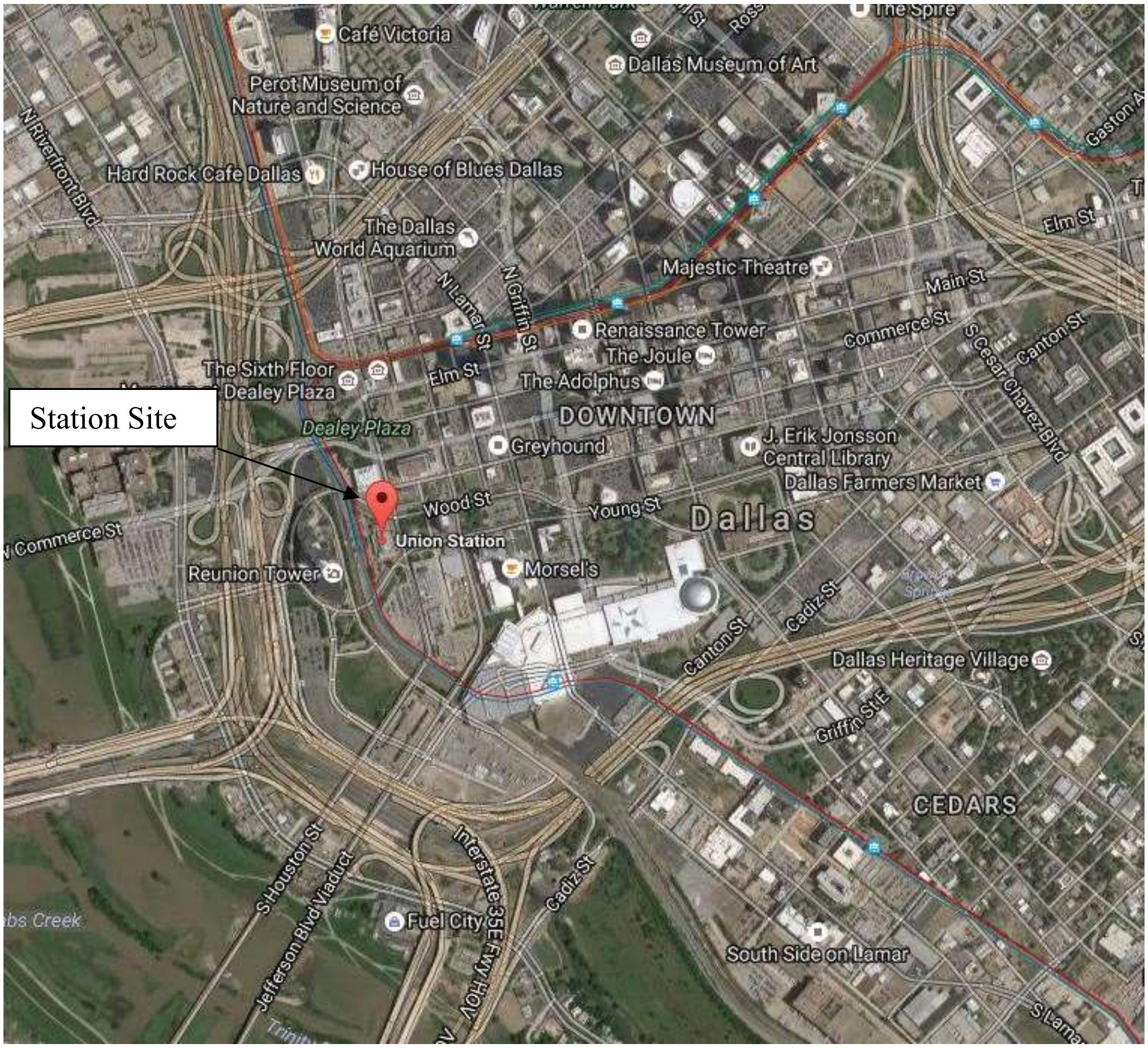
A.3 – DALLAS UNION STATION

Dallas Union Station Location



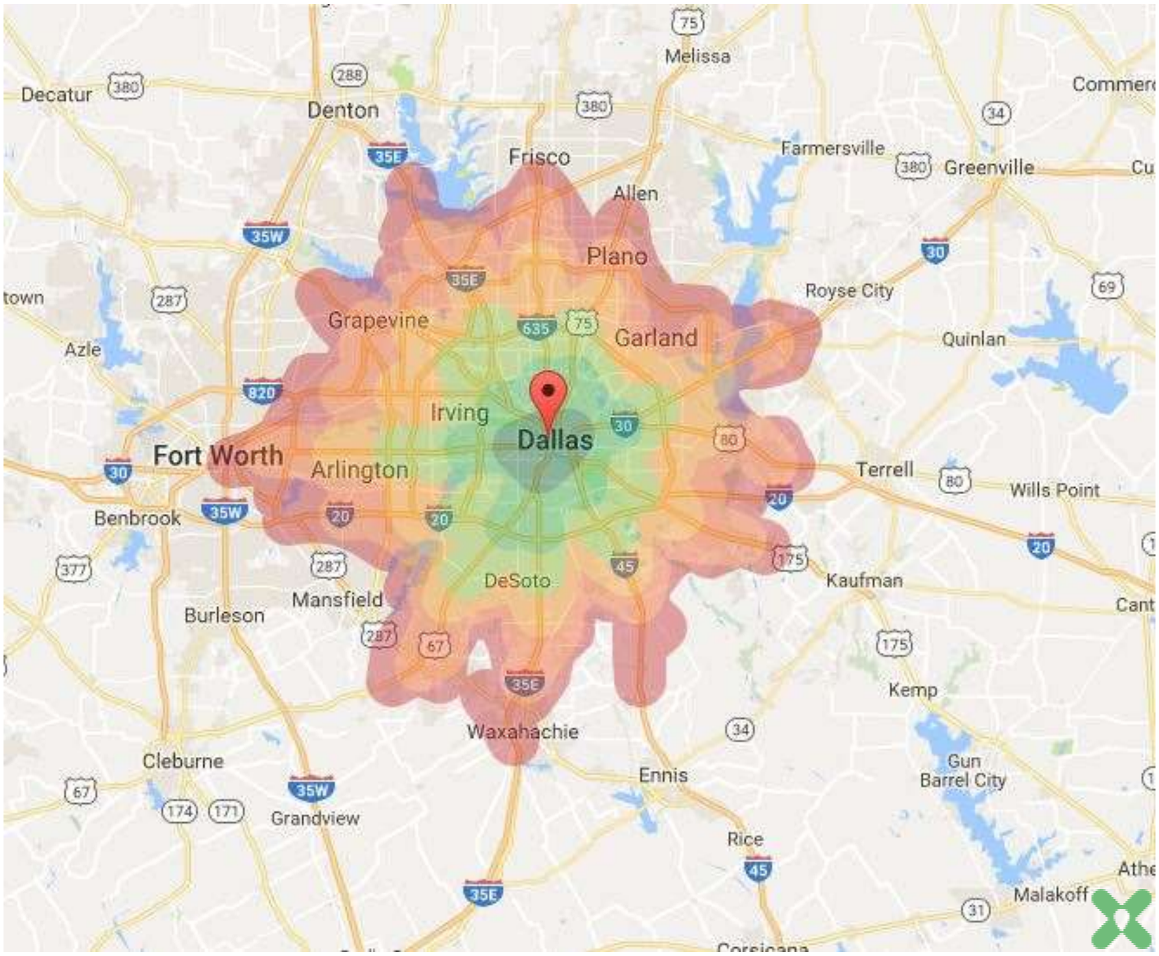
Source: (Google, 2016).

Dallas Union Station Satellite Image



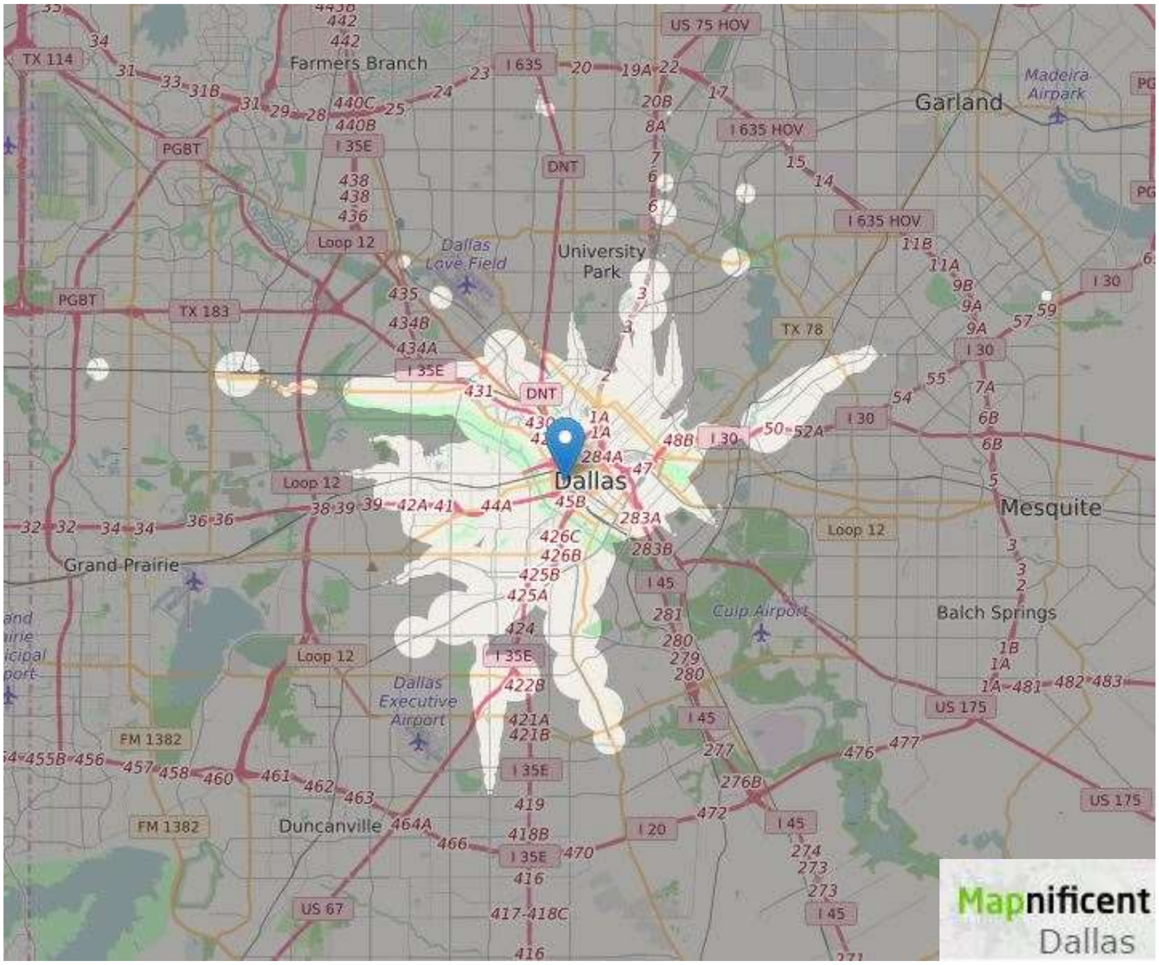
Source: (Google, 2016).

30-Minute Driving Time from Dallas Union Station



Source: (Route360, 2016).

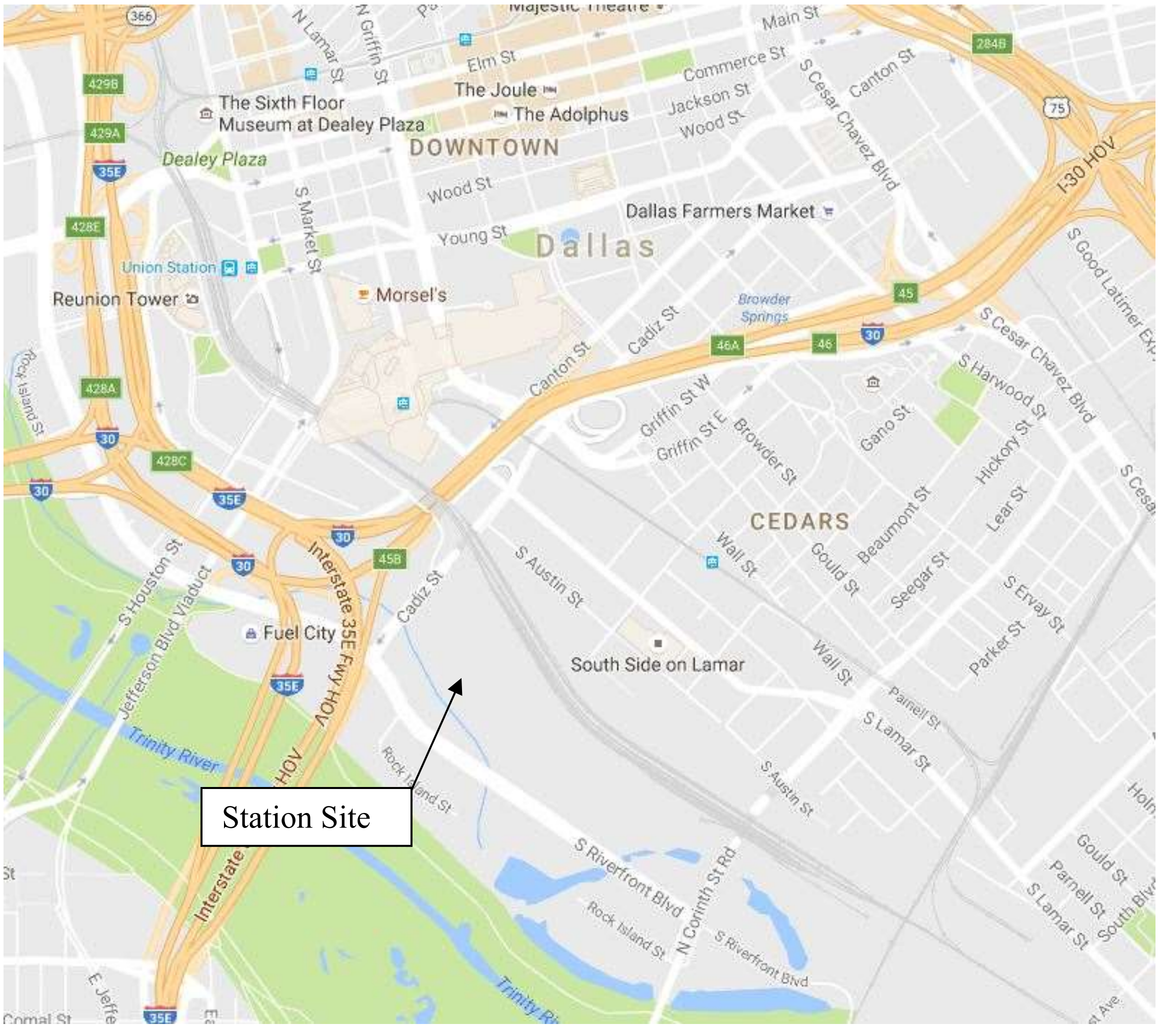
30-Minute Transit Time from Dallas Union Station



Source: (Mapnificent Dallas, 2016).

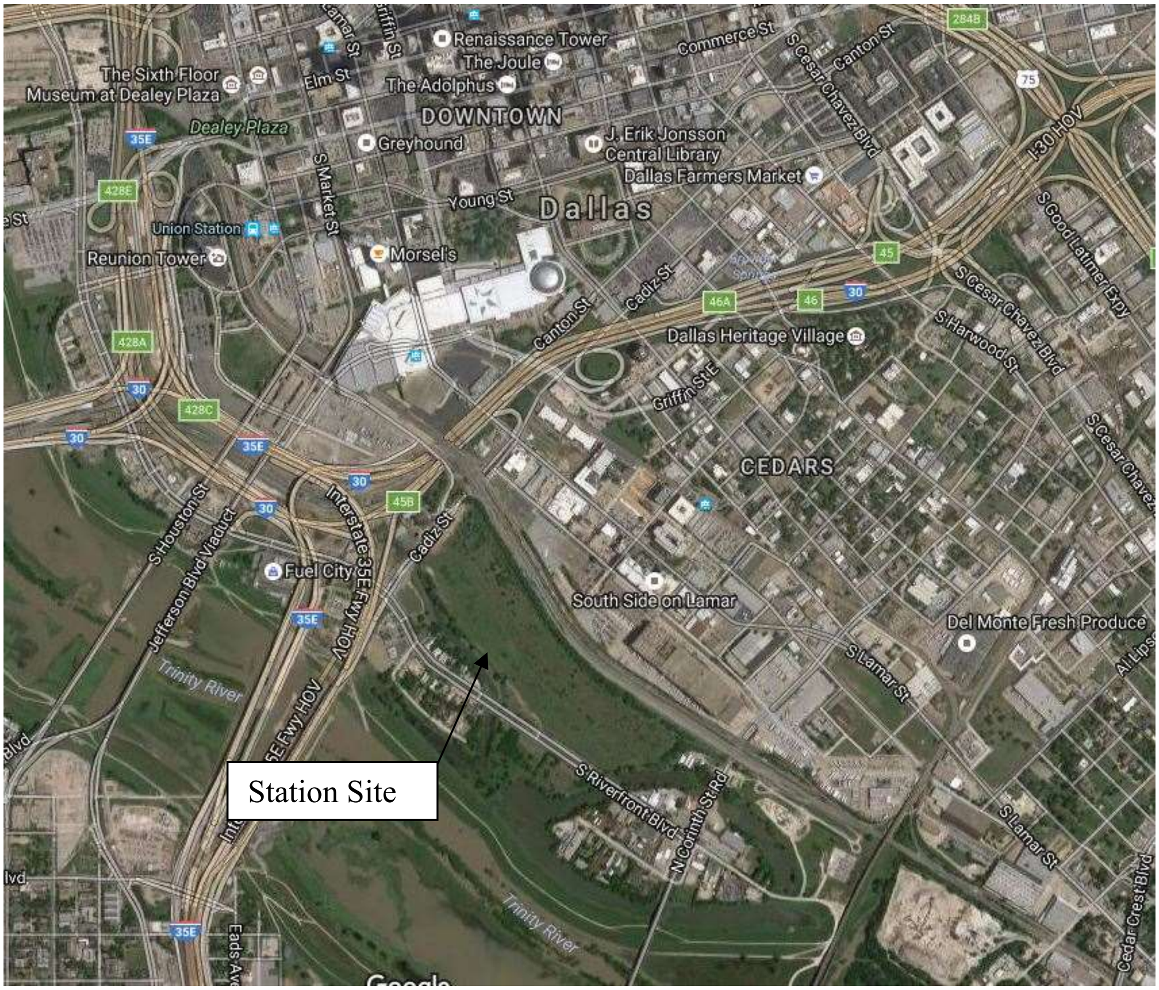
A.4 – Dallas South Side Station Location

Dallas South Side Station Location



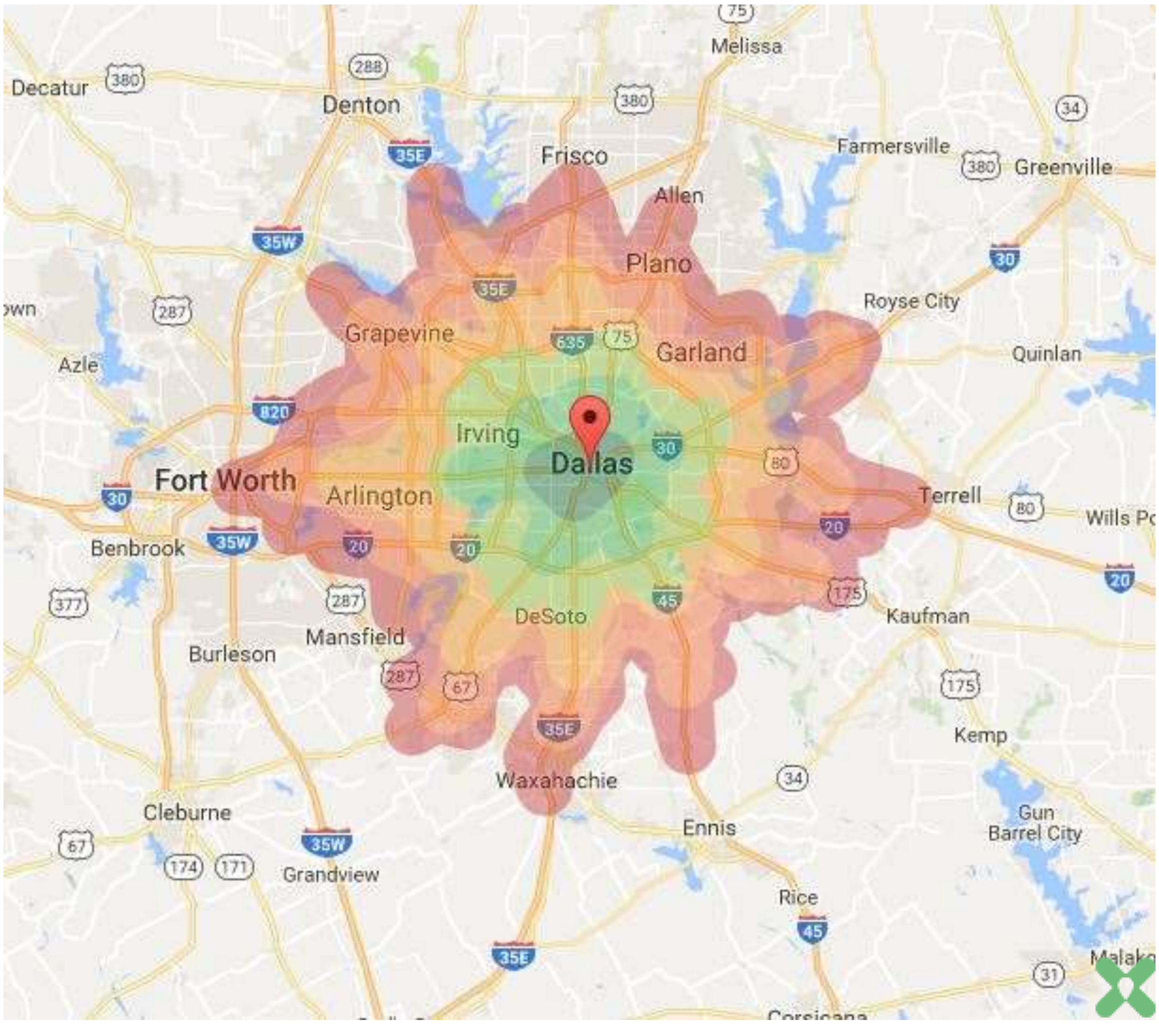
Source: (Google, 2016).

Dallas South Side Station Location Satellite Image



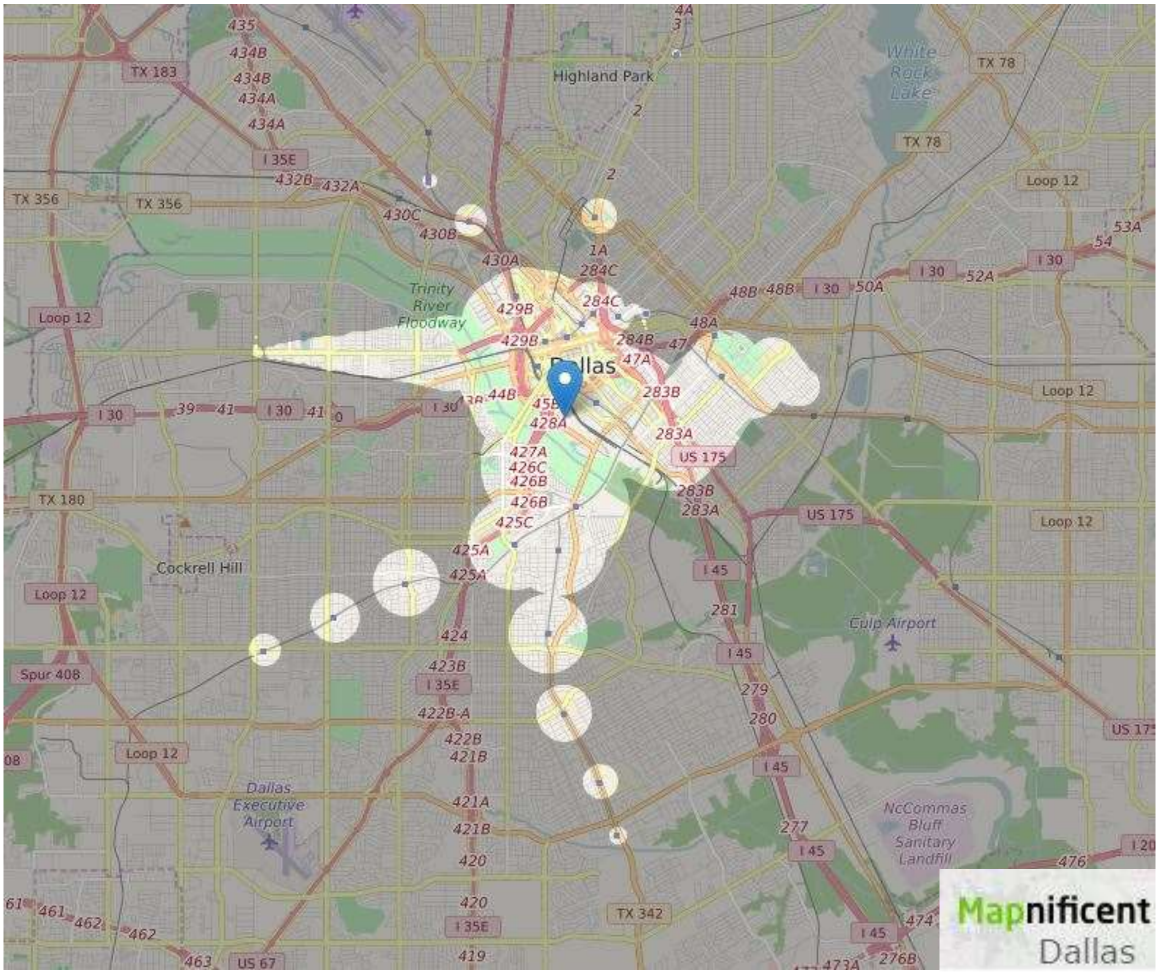
Source: (Google, 2016).

30-Minute Driving Time from Dallas South Side Station Location



Source: (Route360, 2016).

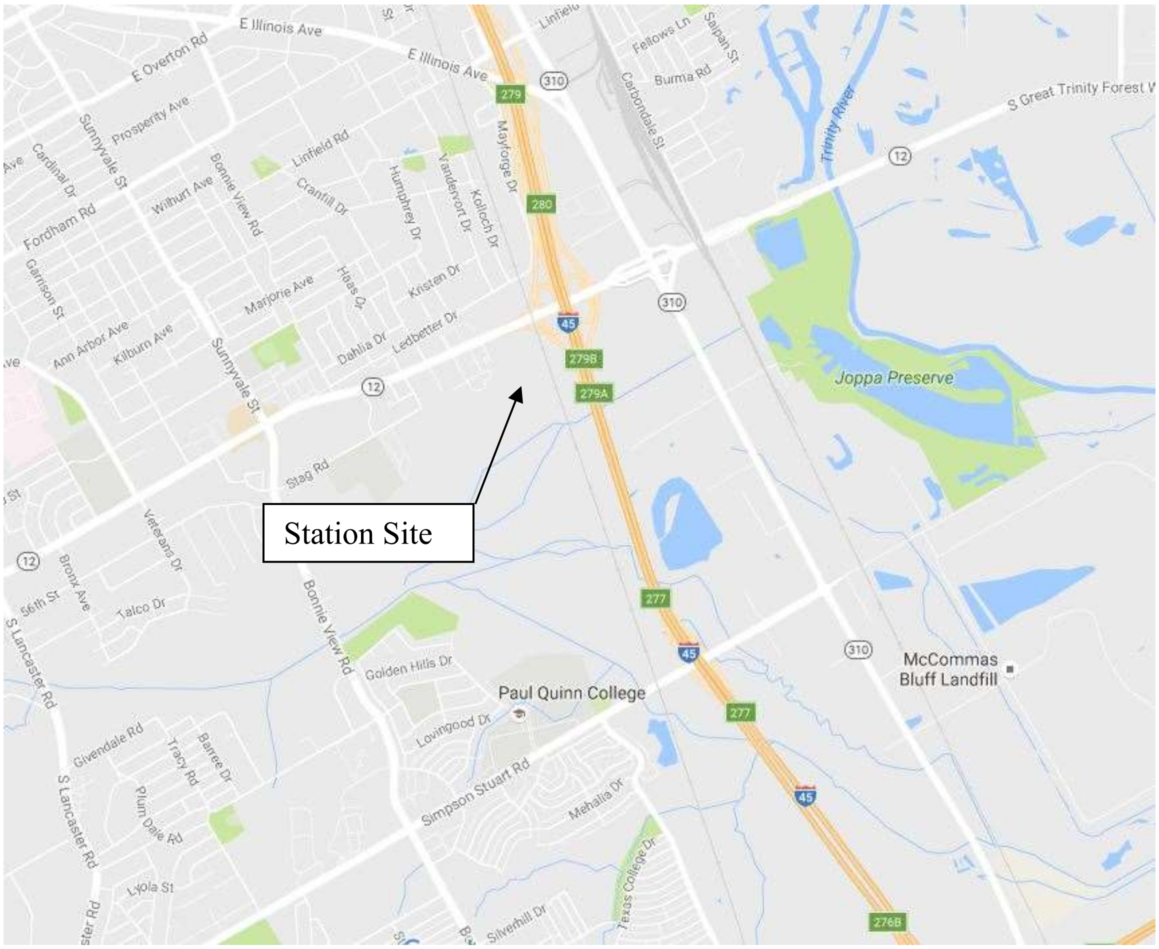
30-Minute Transit Time from Dallas South Side Station Location



Source: (Mapnificent Dallas, 2016).

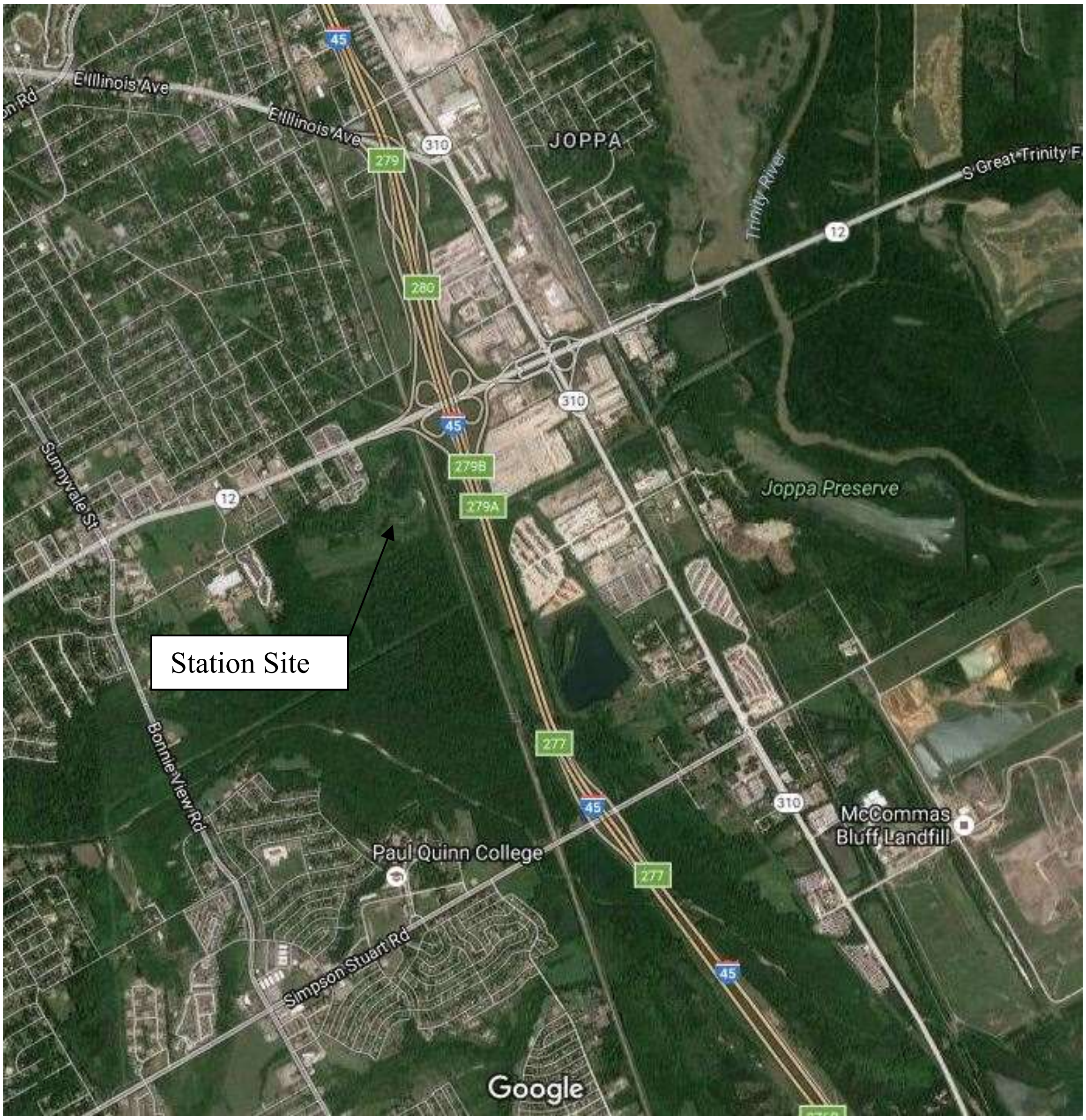
A.5 – DALLAS I-45/LOOP 12 STATION LOCATION

Dallas I-45/Loop 12 Station Location



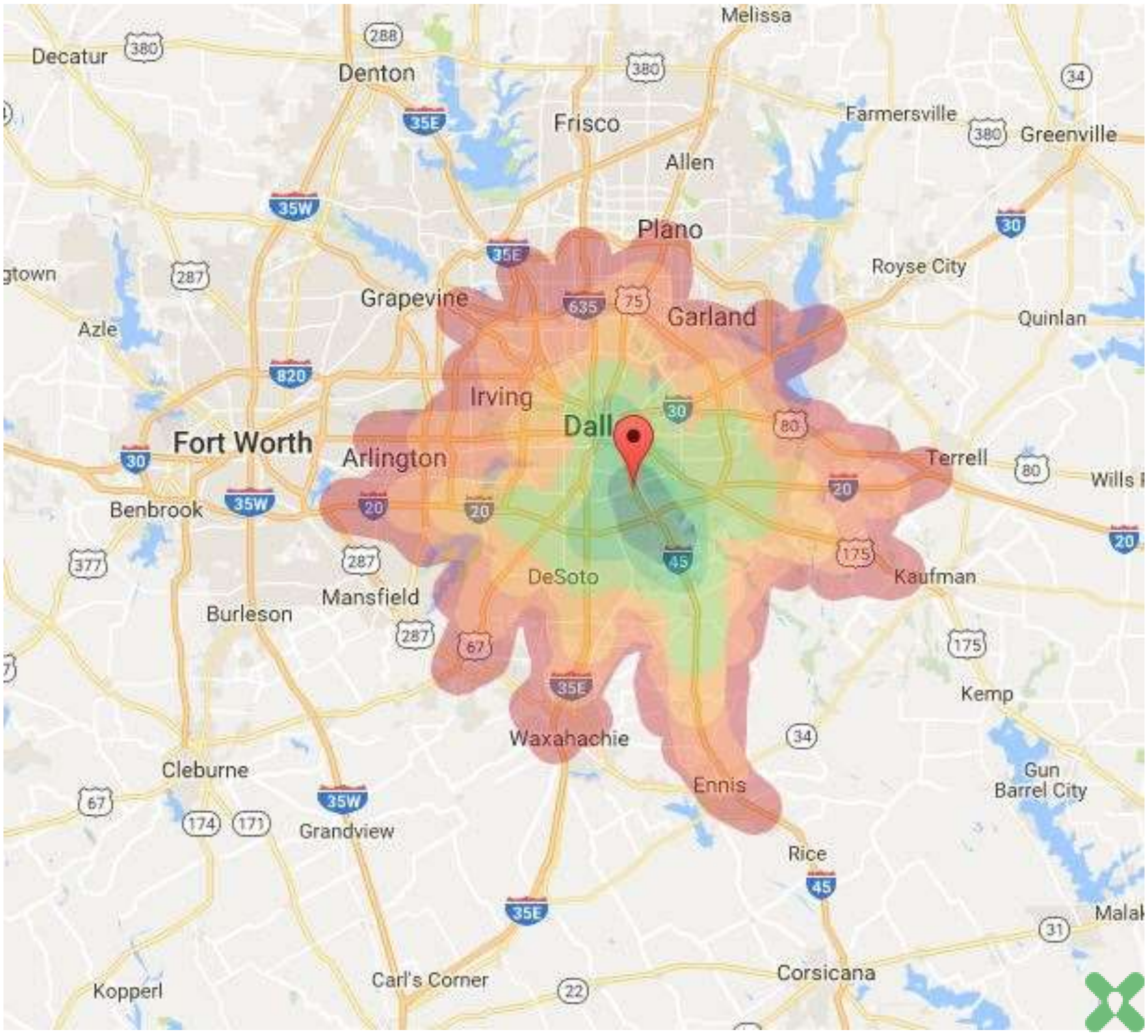
Source: (Google, 2016).

Dallas I-45/Loop 12 Station Location Satellite Image



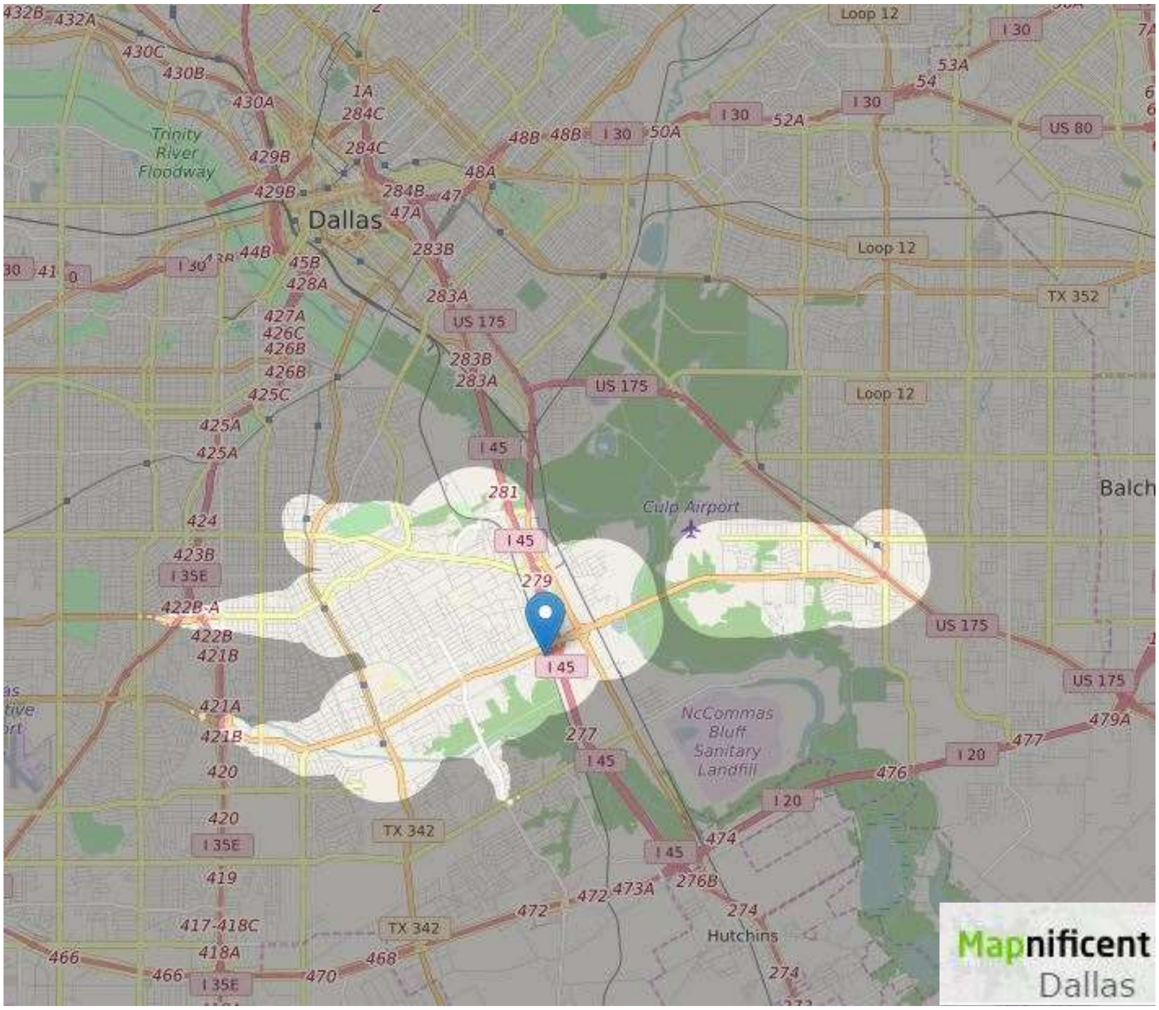
Source: (Google, 2016).

30-Minute Driving Time from Dallas I-45/Loop 12 Station Location



Source: (Route360, 2016).

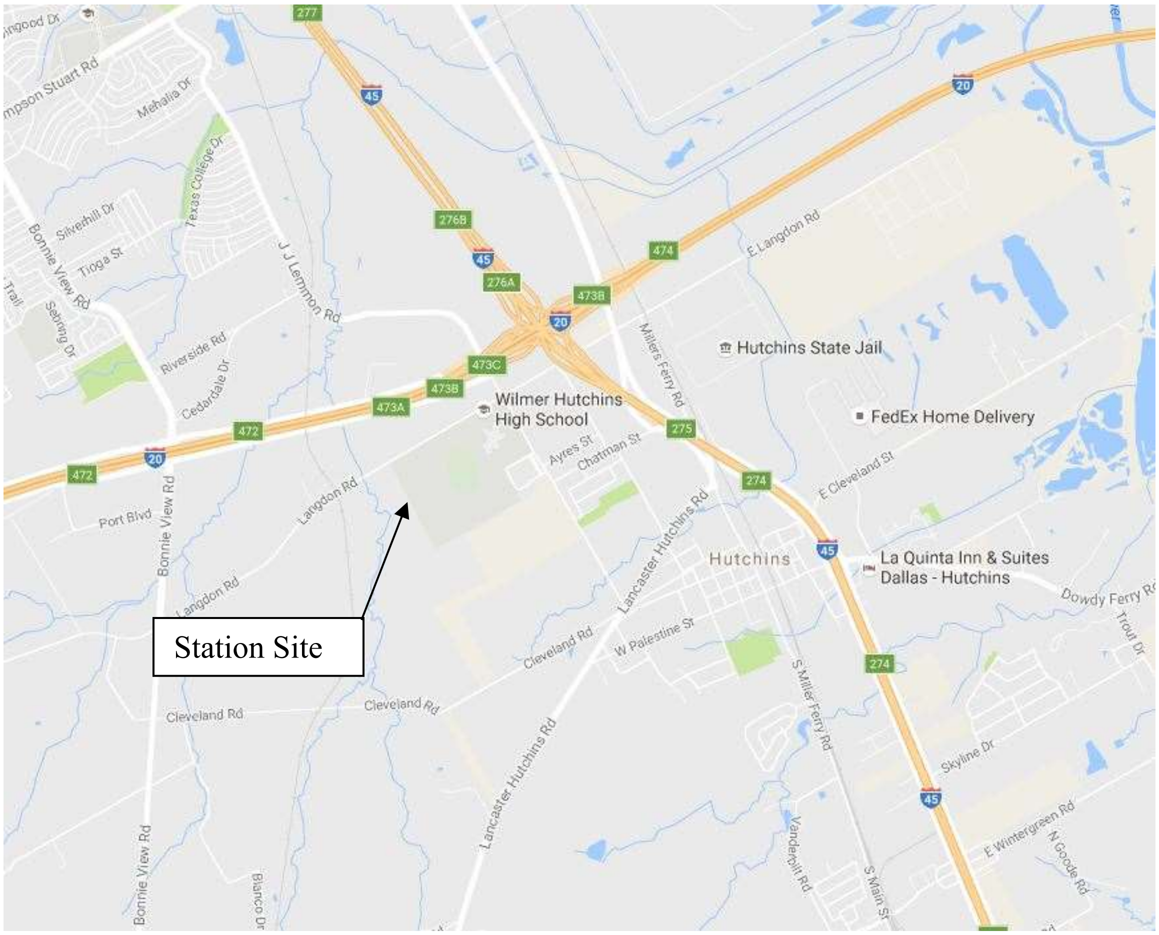
30-Minute Transit Time from Dallas I-45/Loop 12 Station Location



Source: (Mapnificent Dallas, 2016).

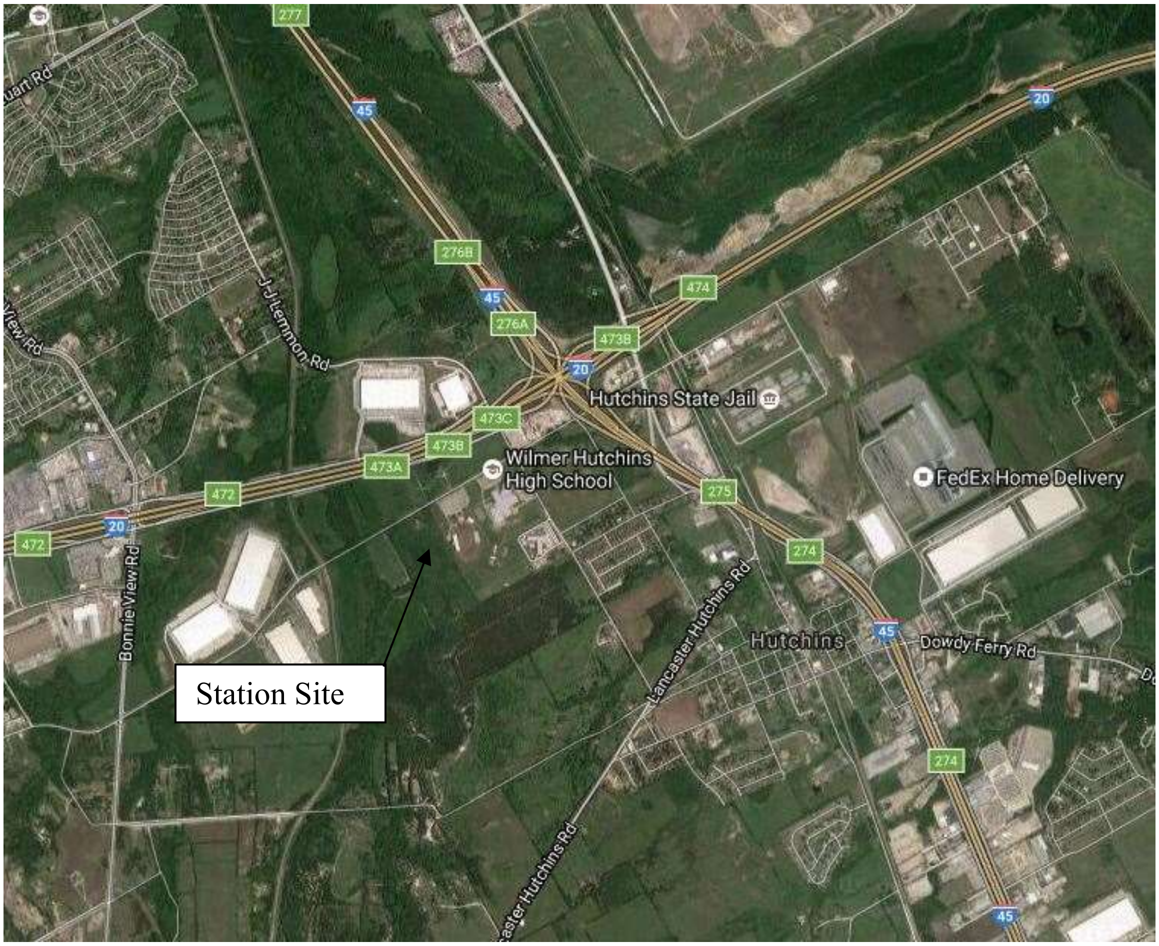
A.6 – DALLAS I-45/I-20 STATION LOCATION

Dallas I-45/I-20 Station Location



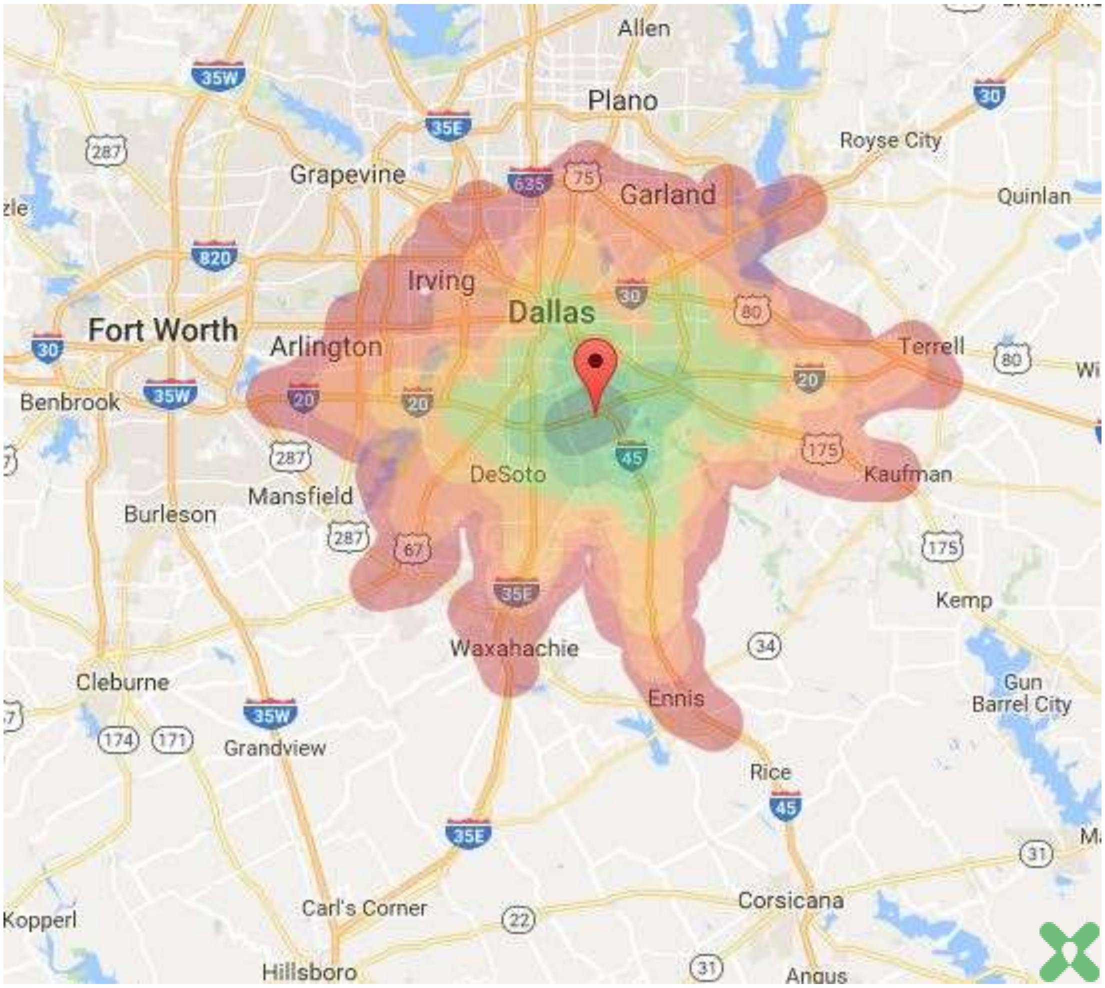
Source: (Google, 2016).

Dallas I-45/I-20 Station Location Satellite Image



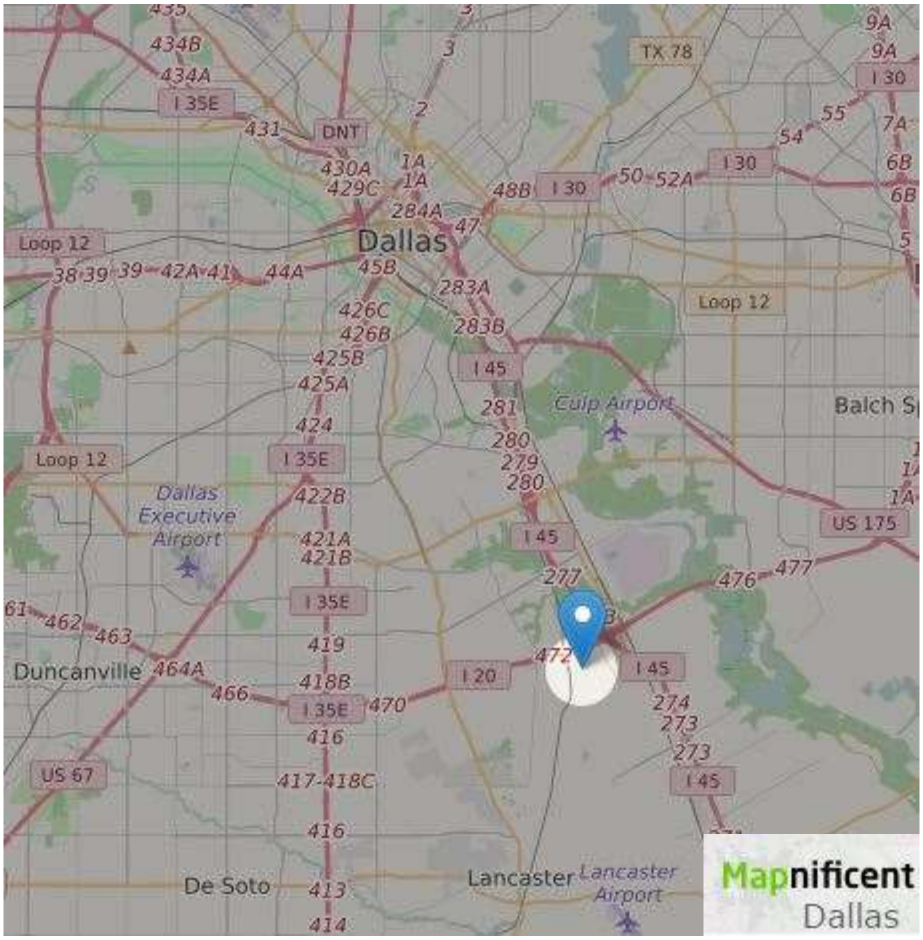
Source: (Google, 2016).

30-Minute Driving Time from Dallas I-45/I-20 Station Location



Source: (Route360, 2016).

30-Minute Transit Time from Dallas I-45/I-20 Station Location

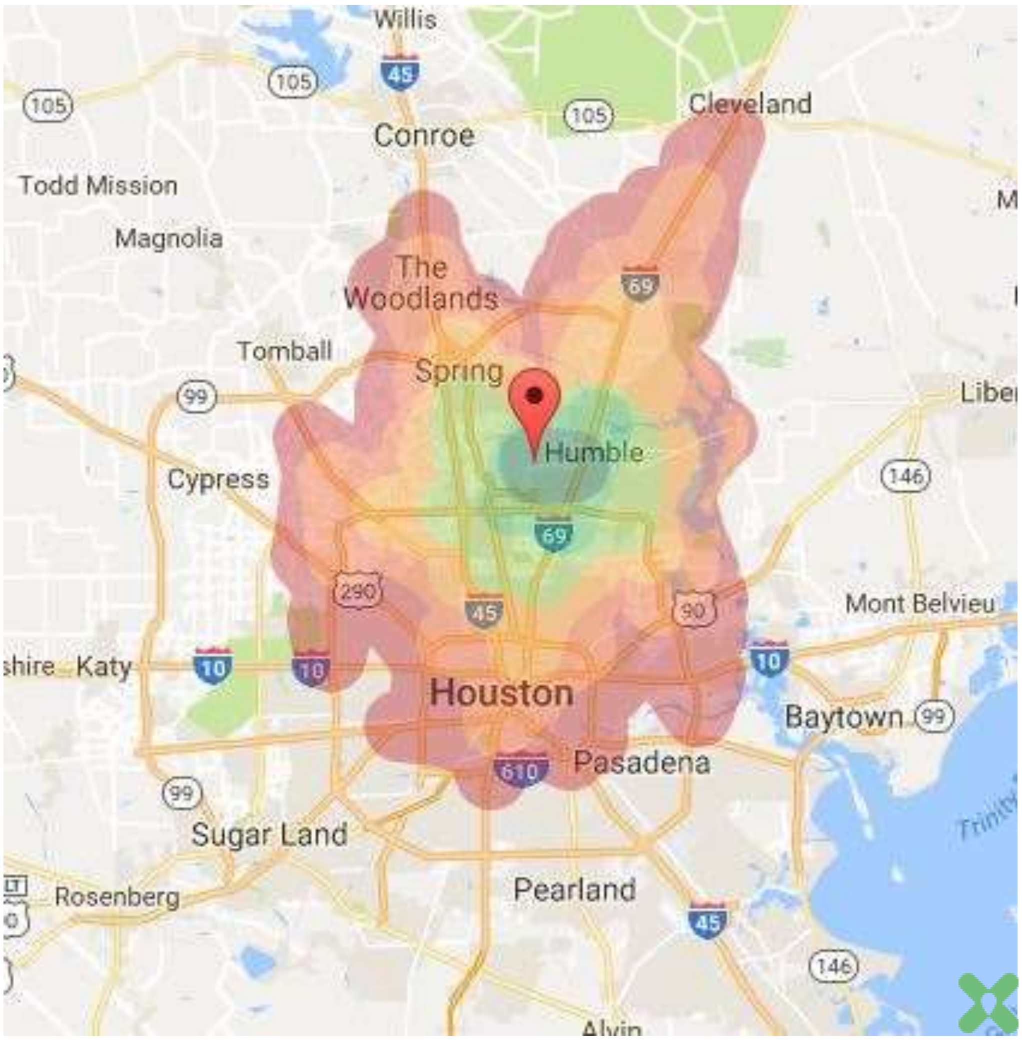


Source: (Mapnificent Dallas, 2016).

Appendix B – Houston Maps

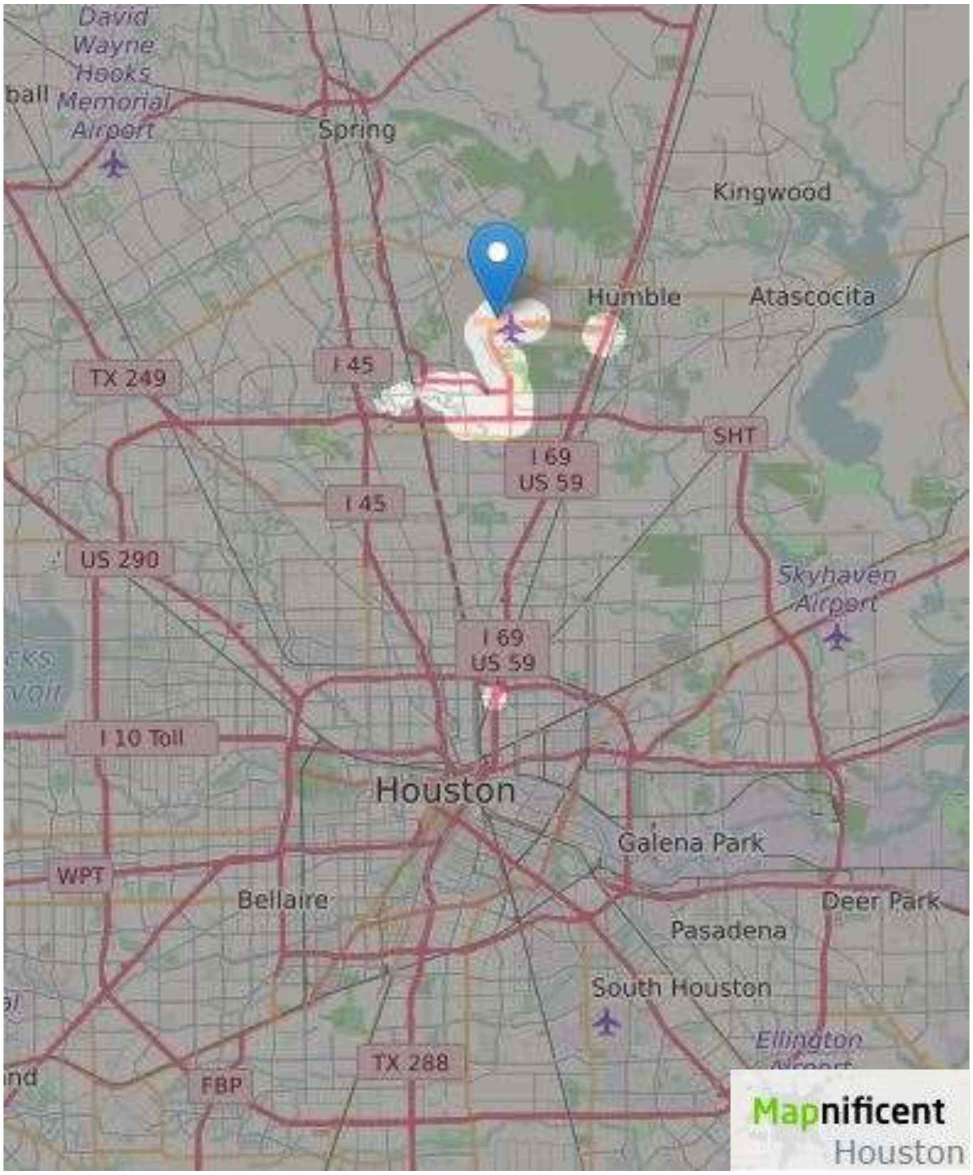
B.1 – George Bush Intercontinental (IAH) Airport Maps

30-Minute Driving Time from George Bush Intercontinental Airport



Source: (Route360, 2016).

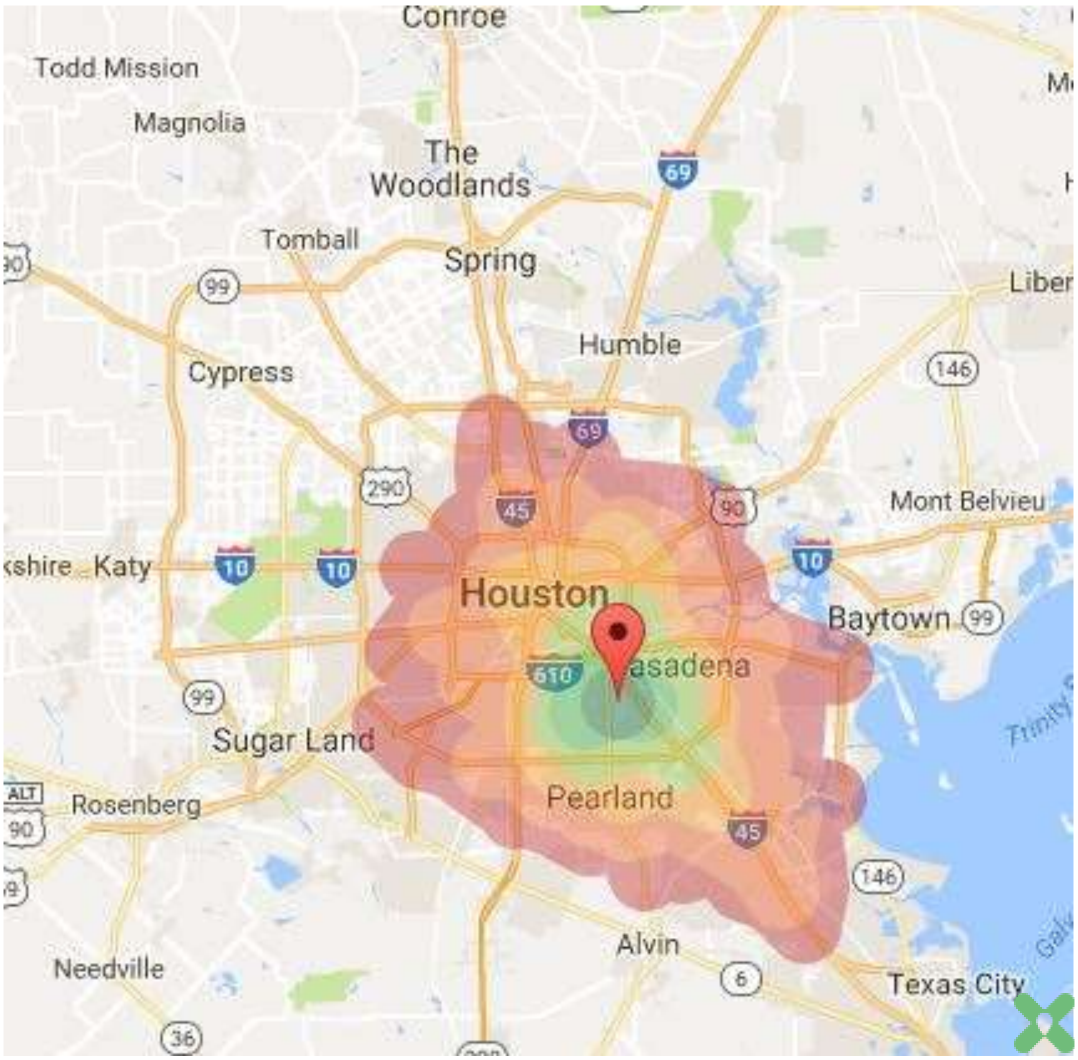
30-Minute Transit Time from George Bush Intercontinental Airport



Source: (Mapnificent Houston, 2016).

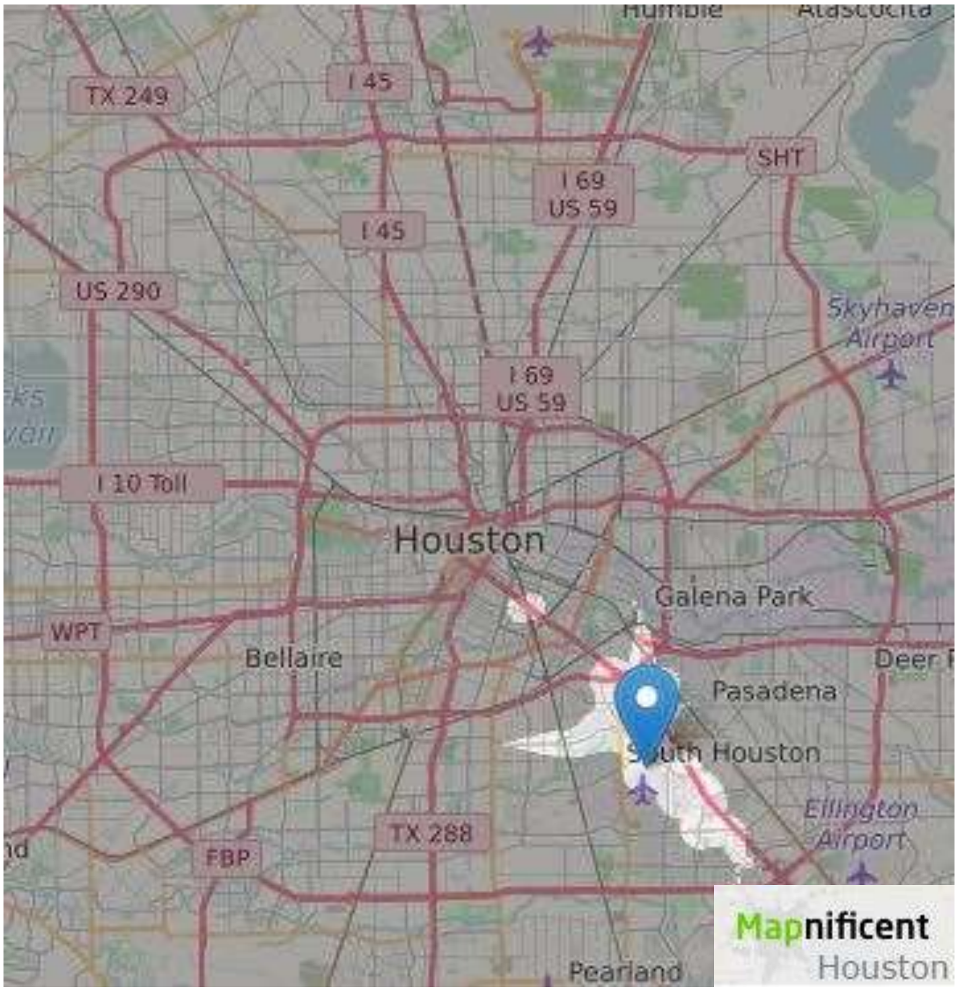
B.2 – Houston Hobby (HOU) Airport Maps

30-Minute Driving Time from Houston Hobby Airport



Source: (Route360, 2016).

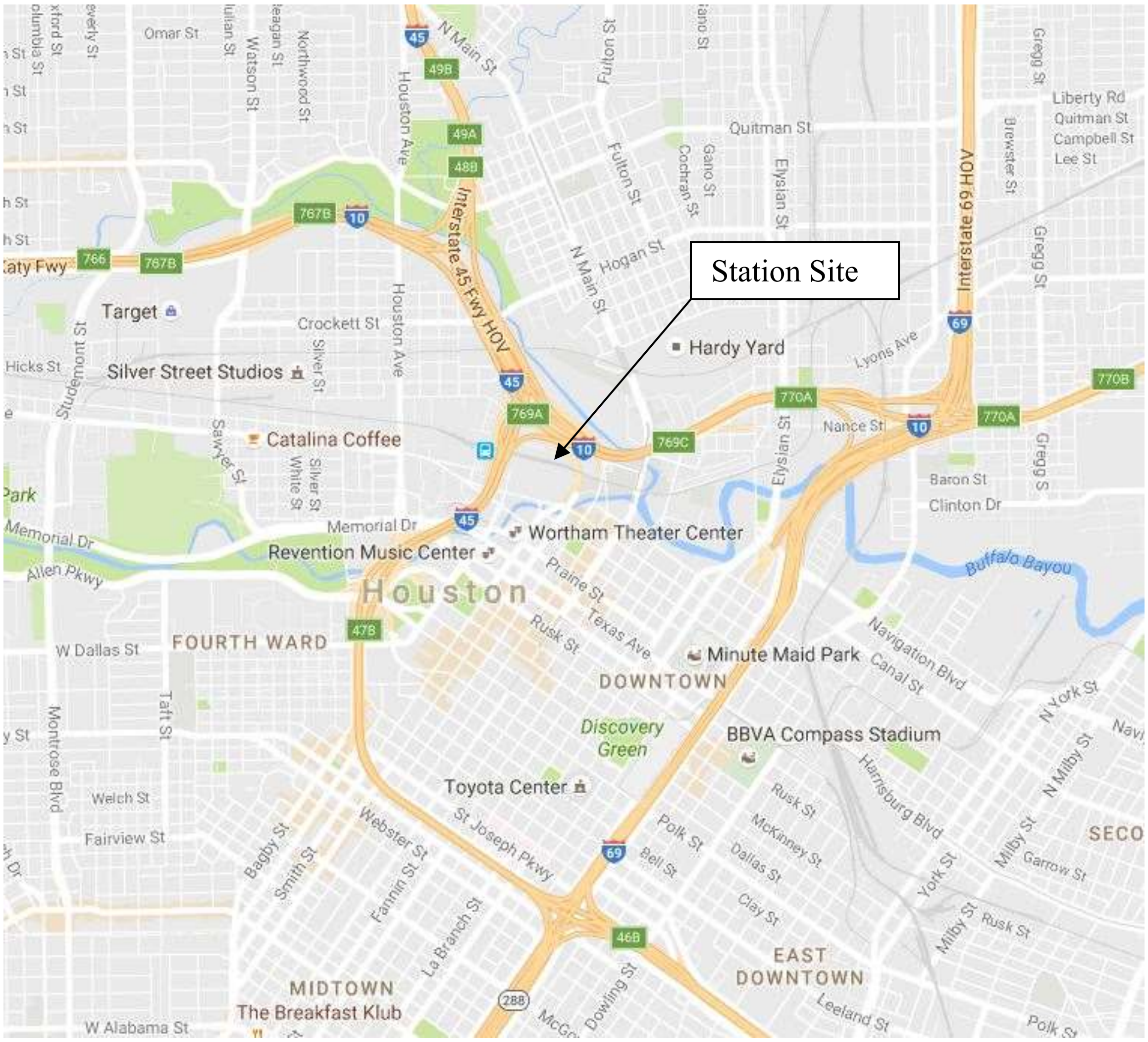
30-Minute Transit Time from Houston Hobby Airport



Source: (Mapnificent Houston, 2016).

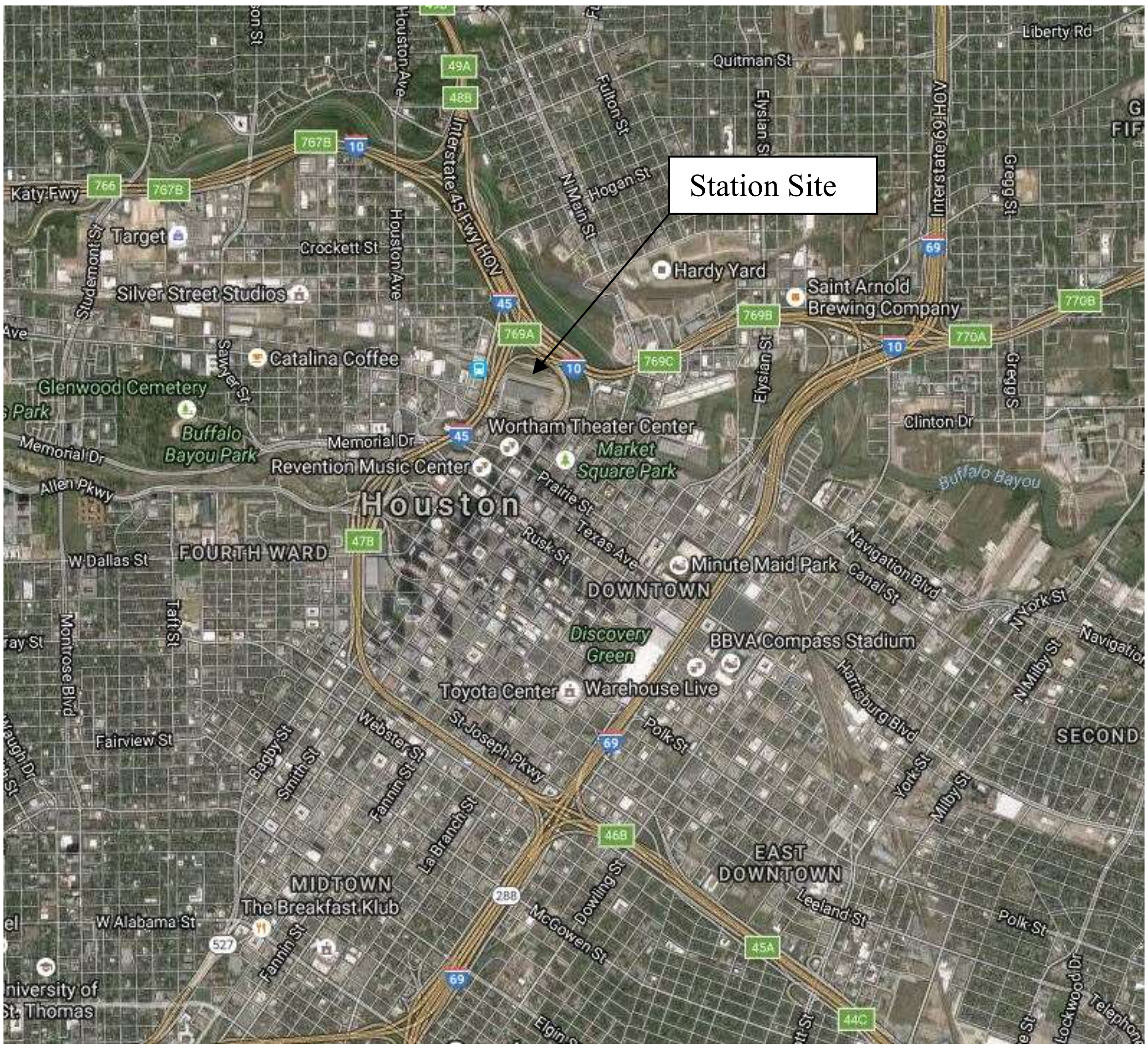
B.3 – Houston Post Office Building Station Location

Houston Post Office Building Station Location



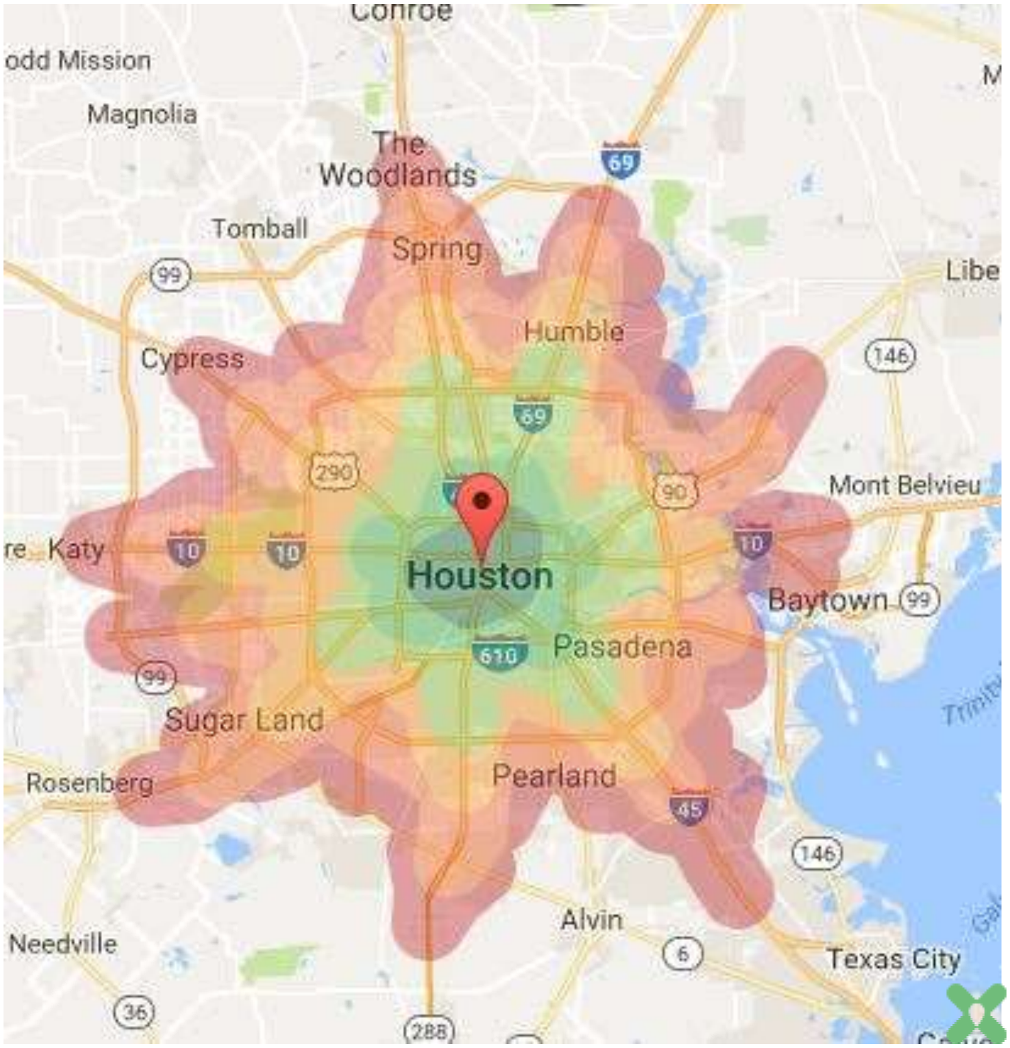
Source: (Google, 2016).

Houston Post Office Building Station Location Satellite Image



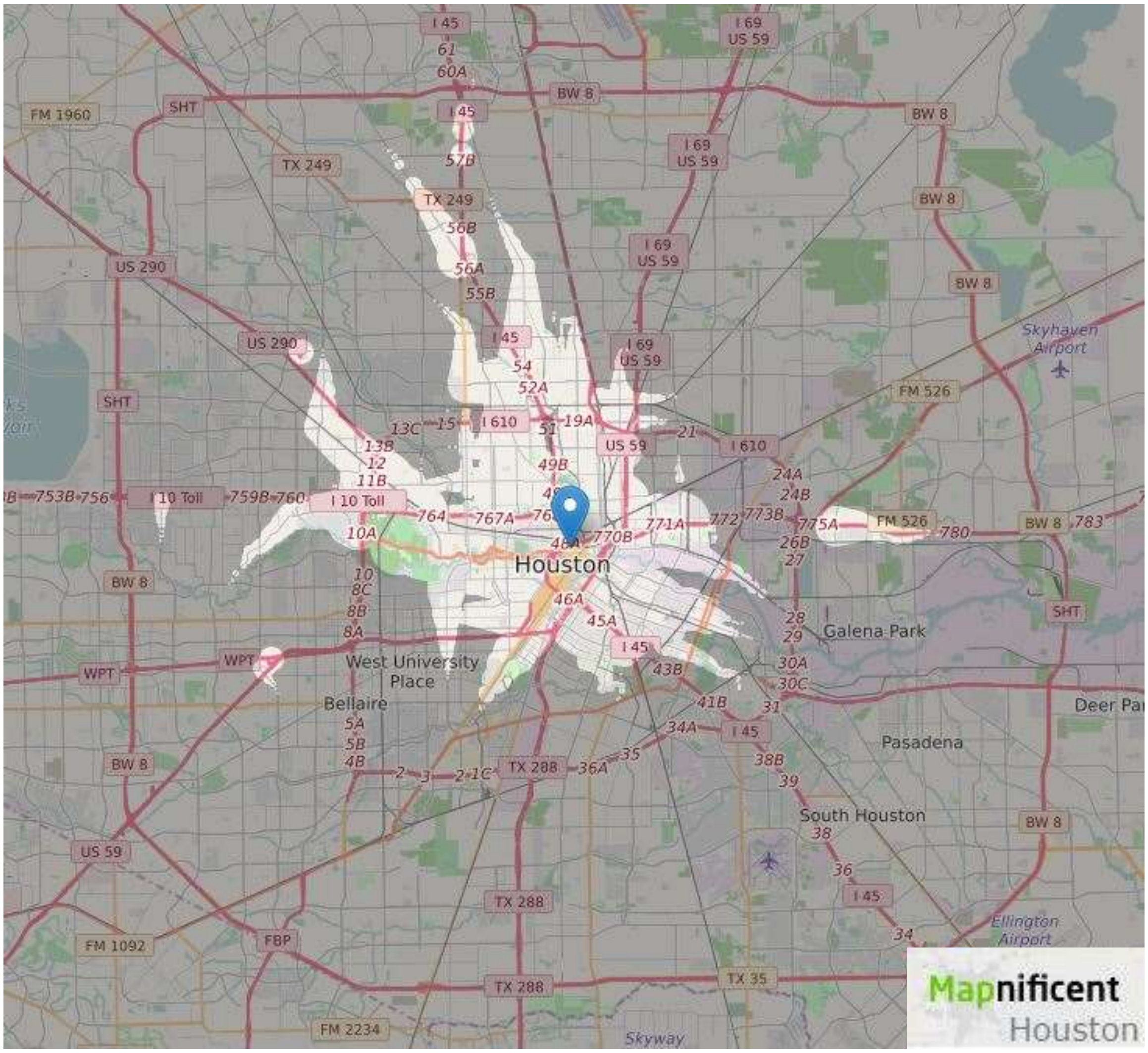
Source: (Google, 2016).

30-Minute Driving Time from Houston Post Office Building Station Location



Source: (Route360, 2016).

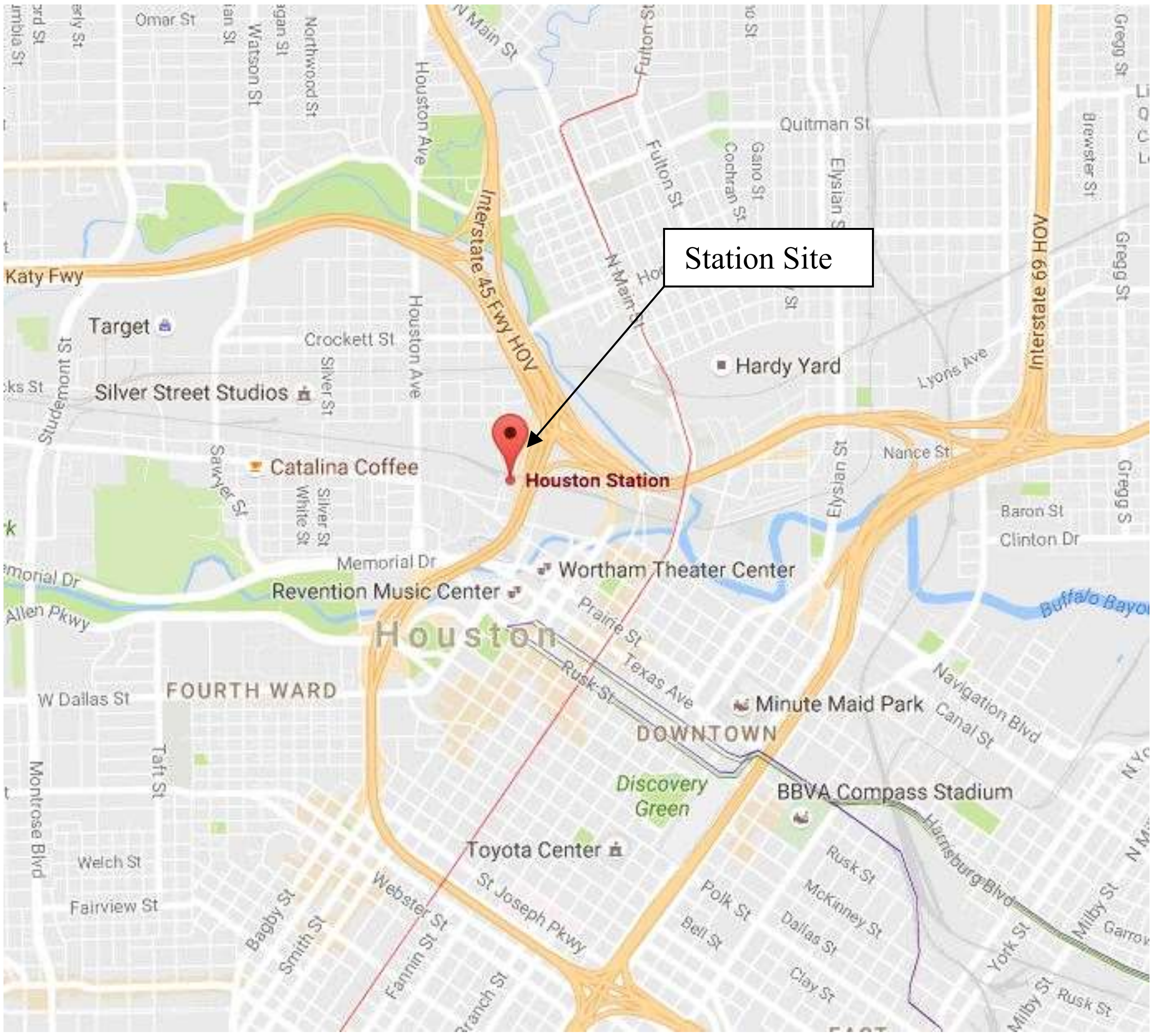
30-Minute Transit Time from Houston Post Office Building Station Location



Source: (Mapnificent Houston, 2016).

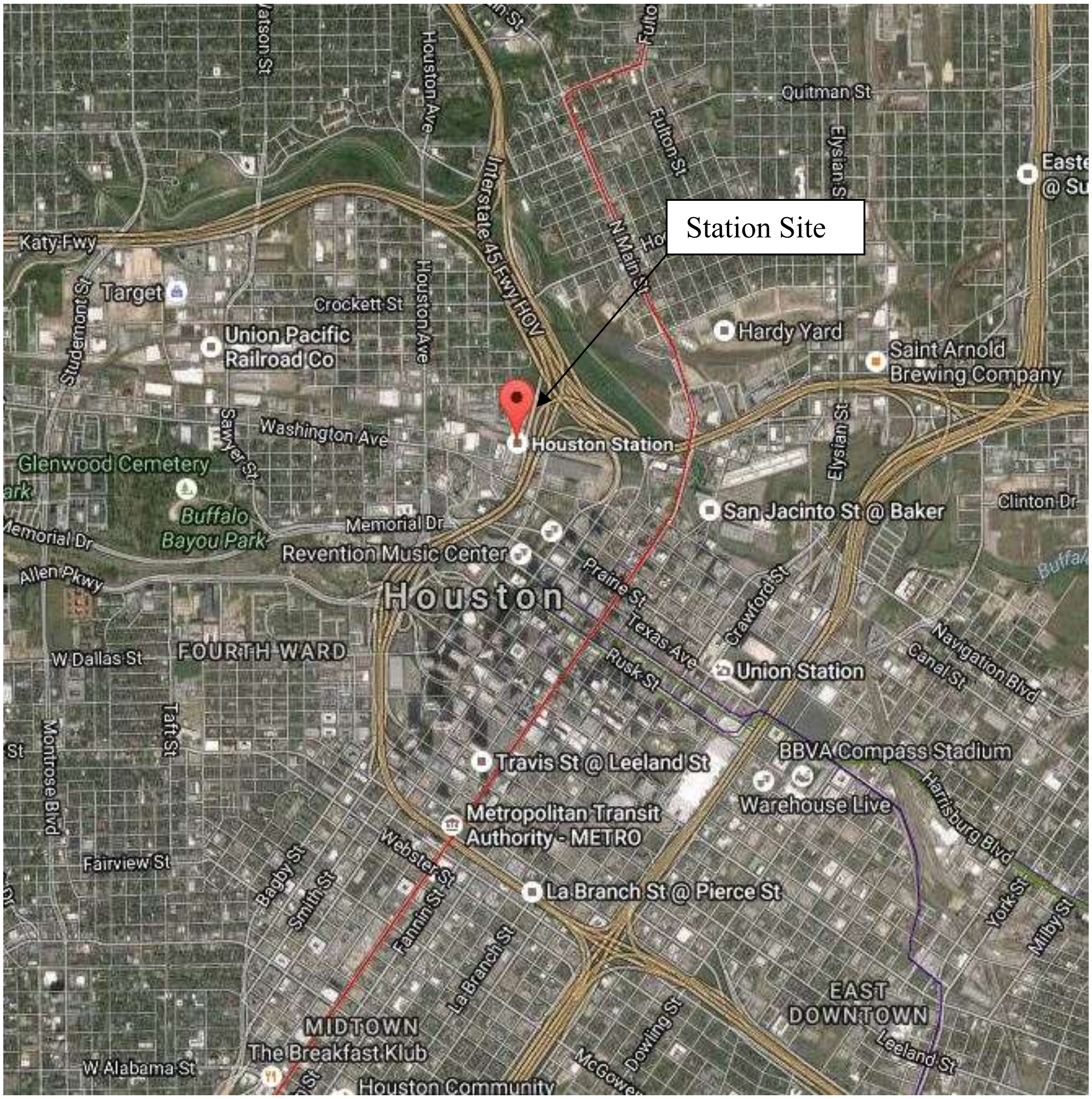
B.4 – HOUSTON AMTRAK STATION

Houston Amtrak Station Location



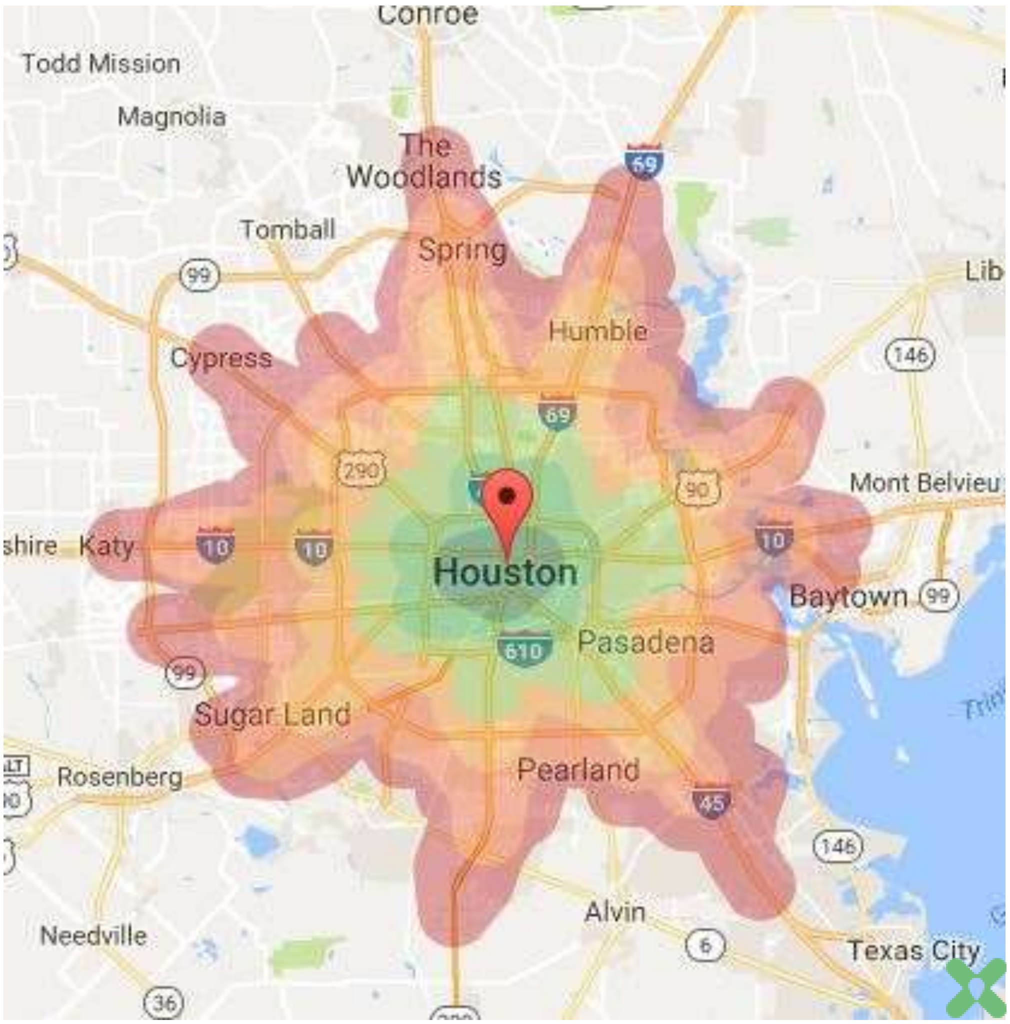
Source: (Google, 2016).

Houston Amtrak Station Satellite Image



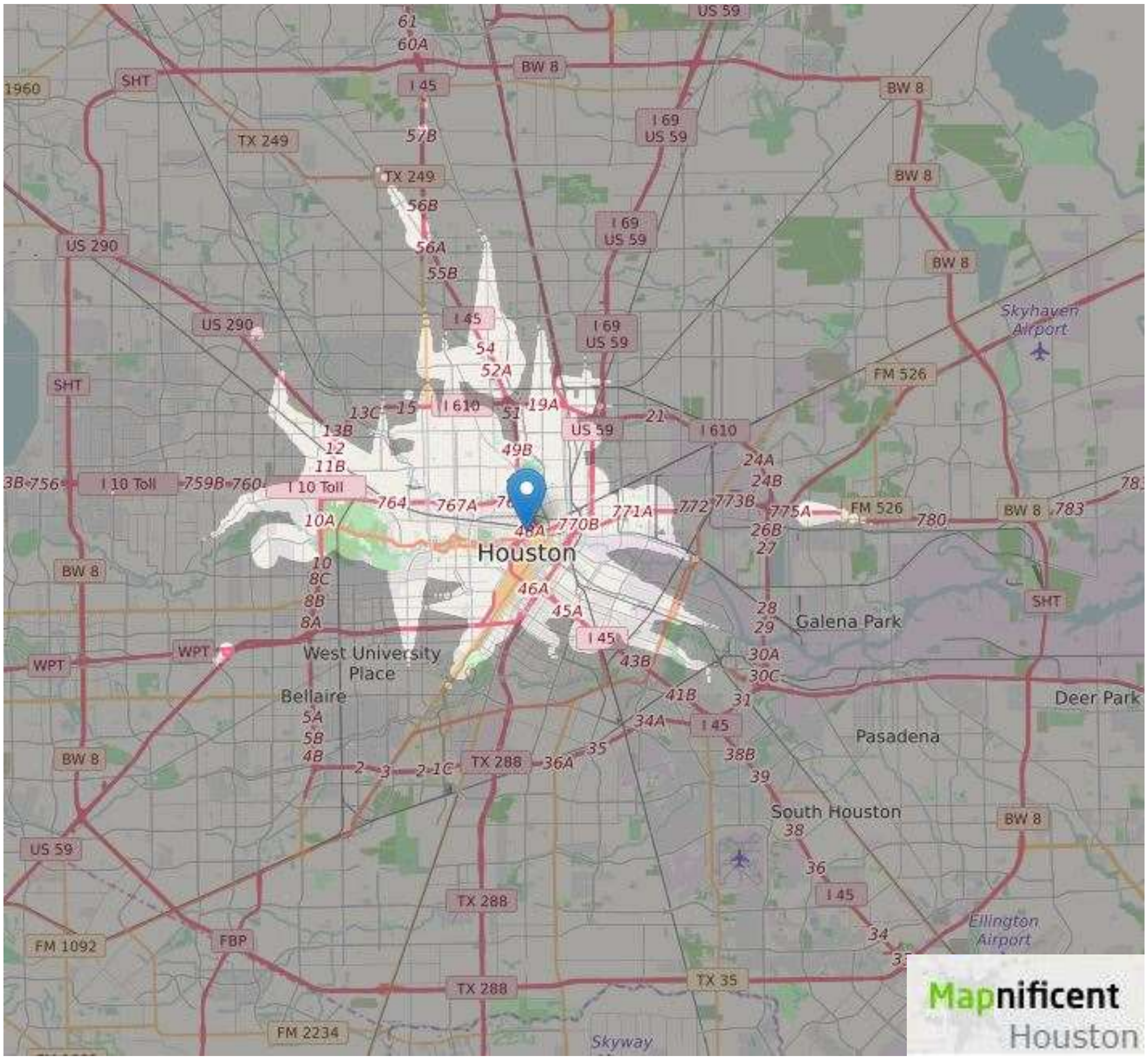
Source: (Google, 2016).

30-Minute Driving Time from Houston Amtrak Station



Source: (Route360, 2016).

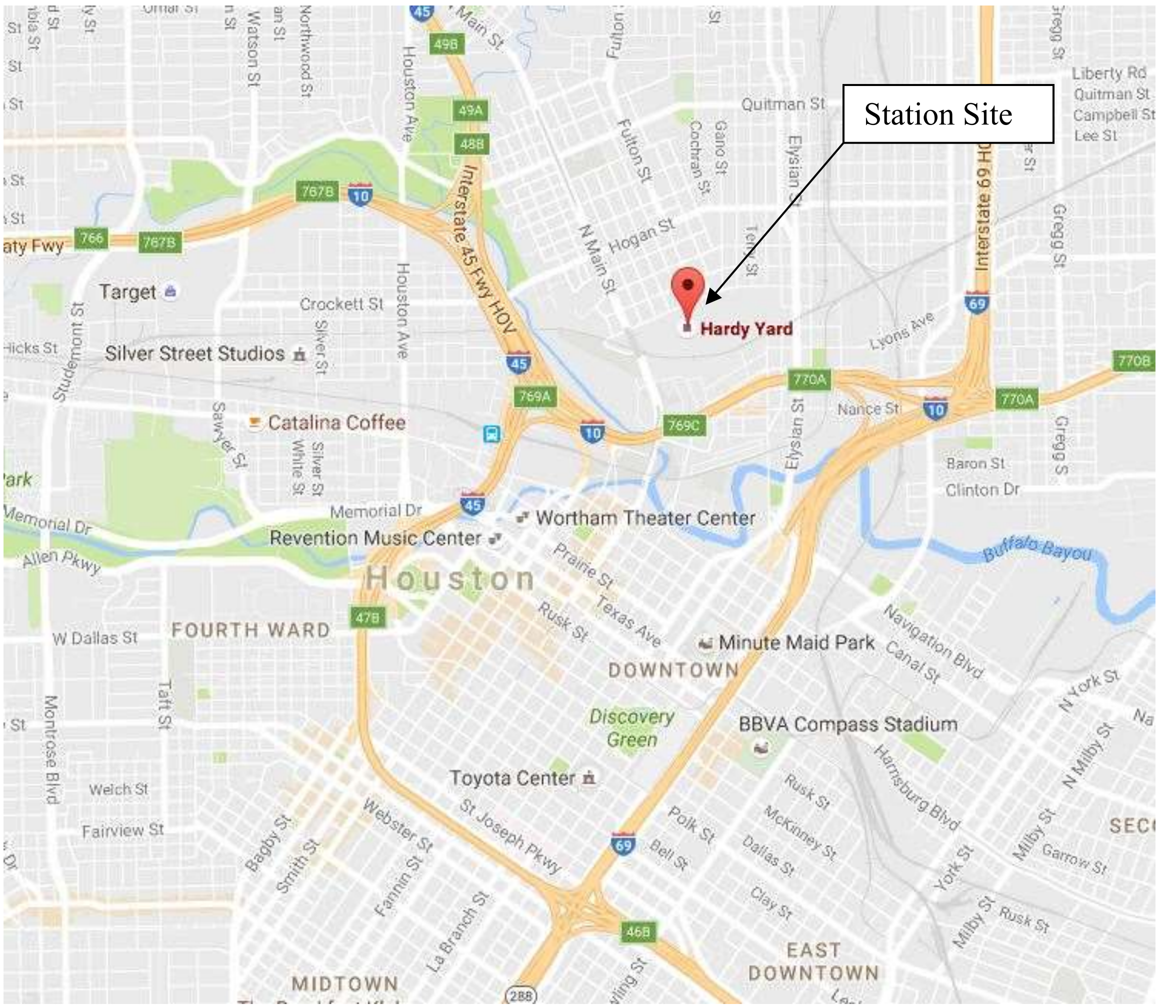
30-Minute Transit Time from Houston Amtrak Station



Source: (Mapnificent Houston, 2016).

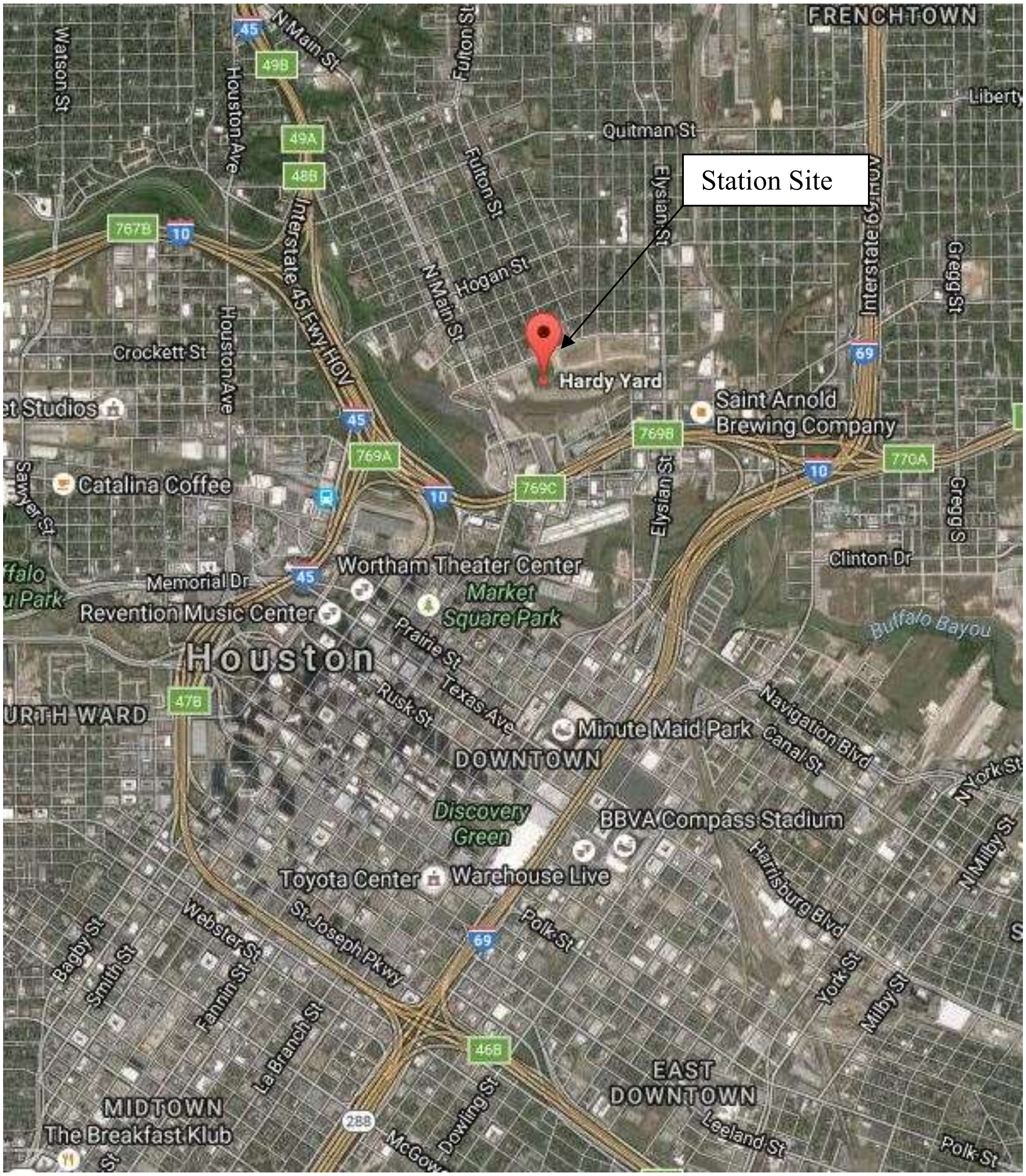
B.5 – HOUSTON HARDY YARDS STATION LOCATION

Houston Hardy Yards Station Location



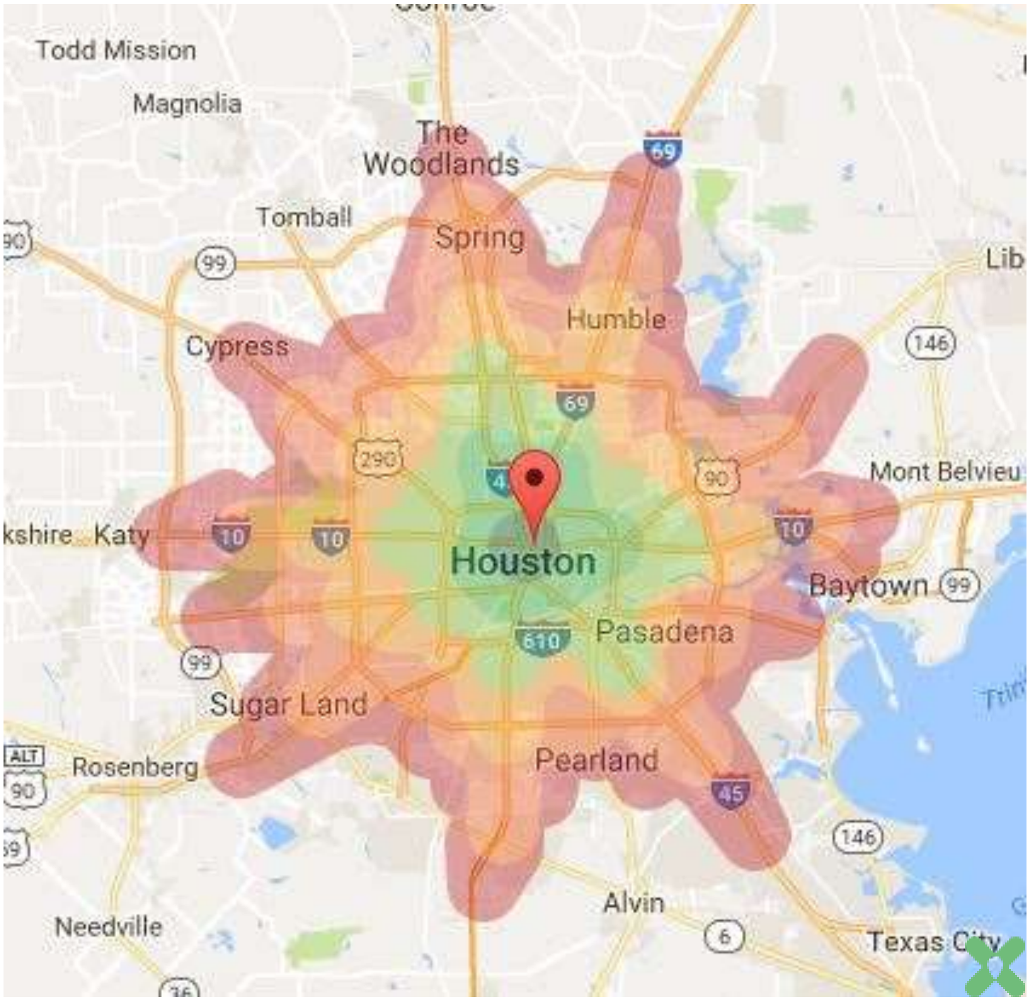
Source: (Google, 2016).

Houston Hardy Yards Station Location Satellite Image



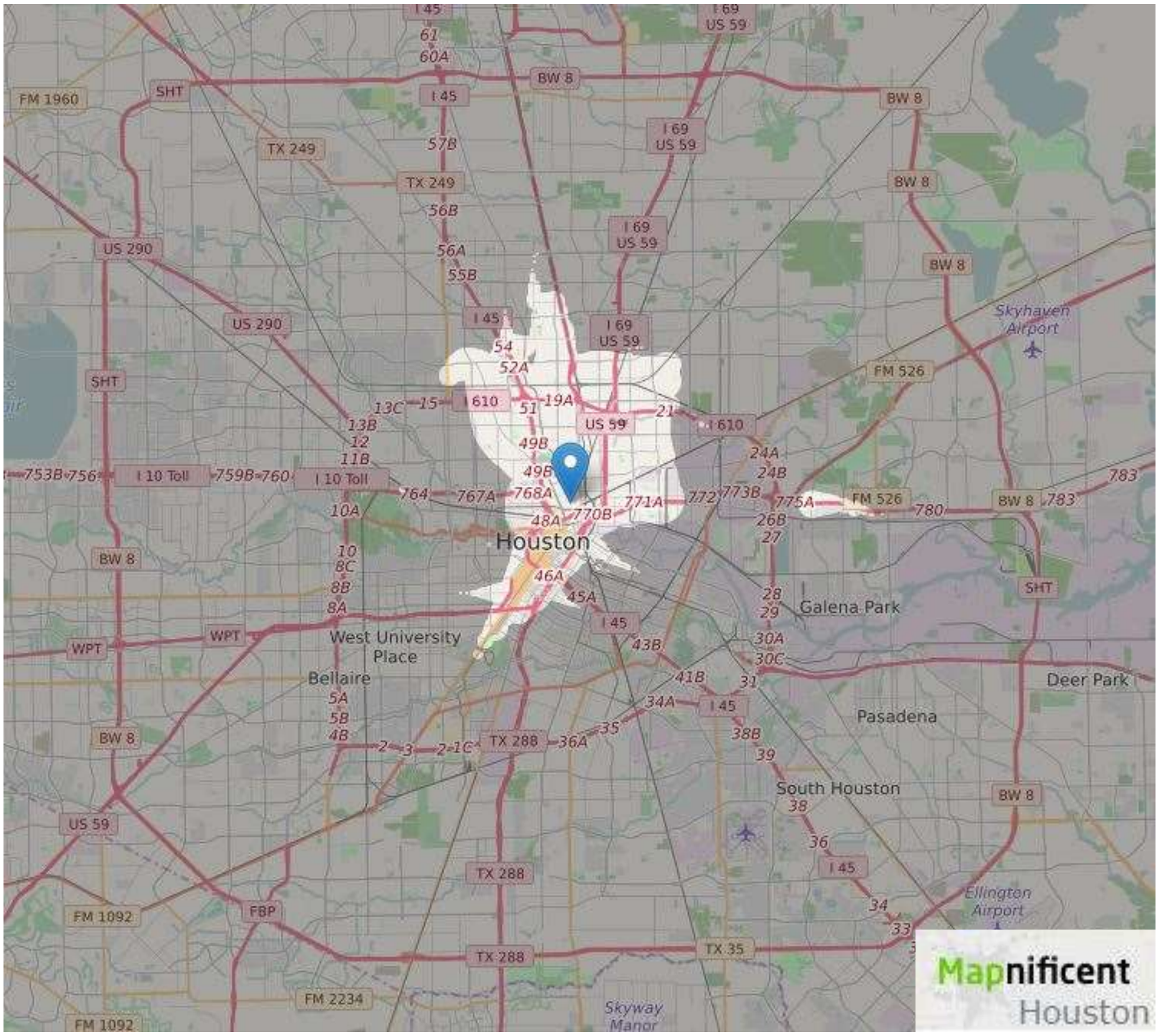
Source: (Google, 2016).

30-Minute Driving Time from Houston Hardy Yards Station Location



Source: (Route360, 2016).

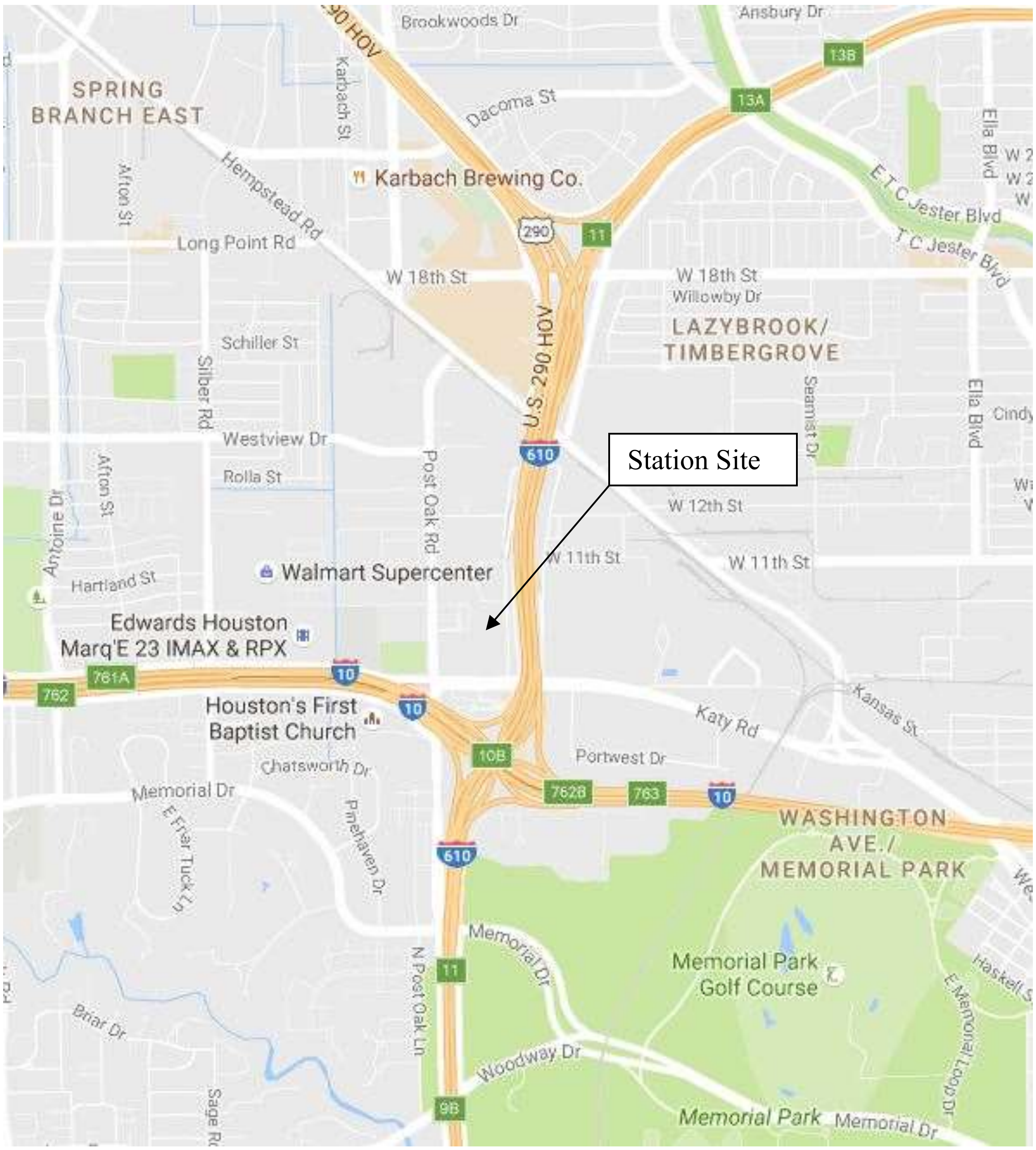
30-Minute Transit Time from Houston Hardy Yards Station Location



Source: (Mapnificent Houston, 2016).

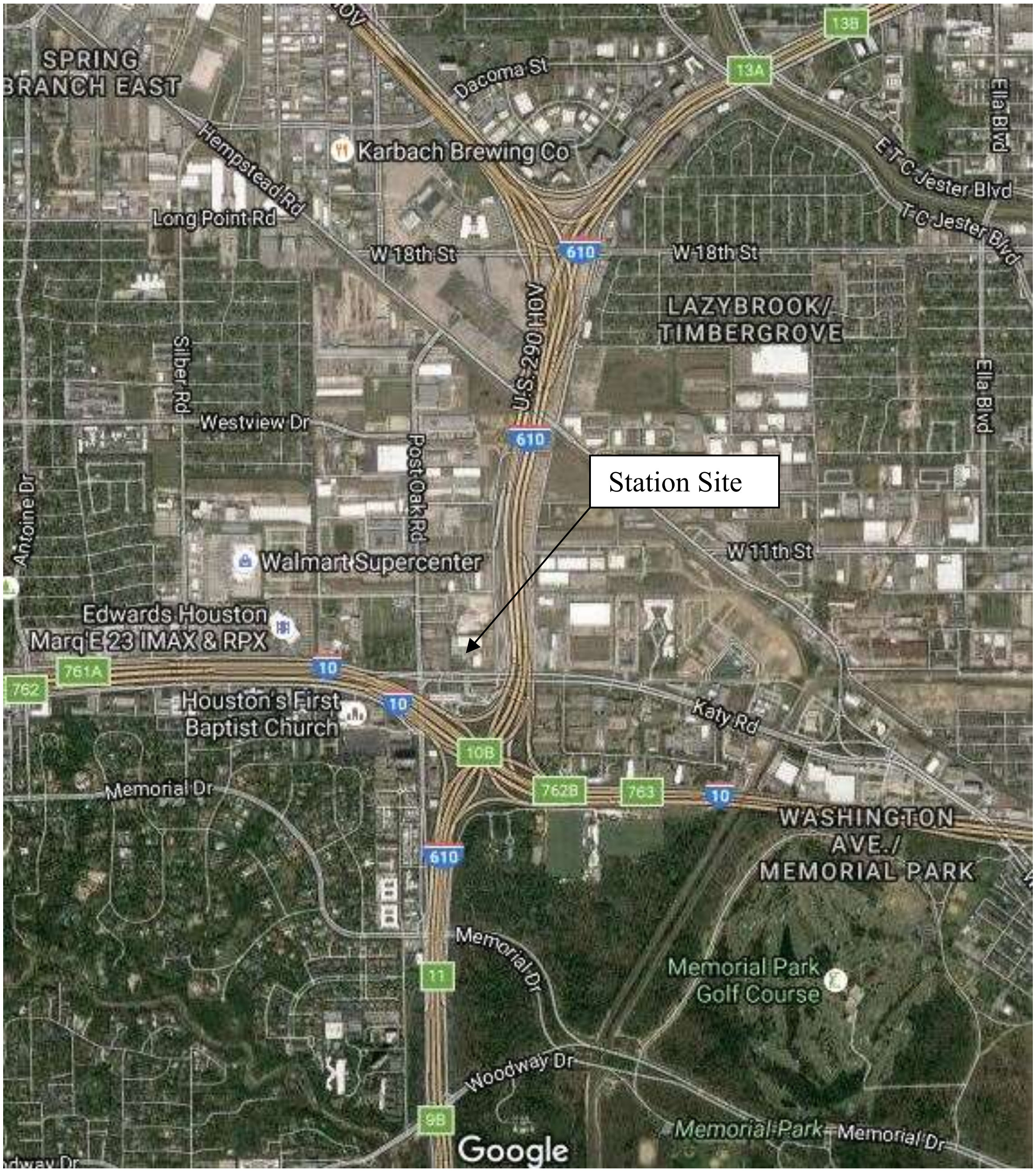
B.6 – HOUSTON NORTHWEST TRANSIT CENTER STATION LOCATION

Houston Northwest Transit Center Station Location



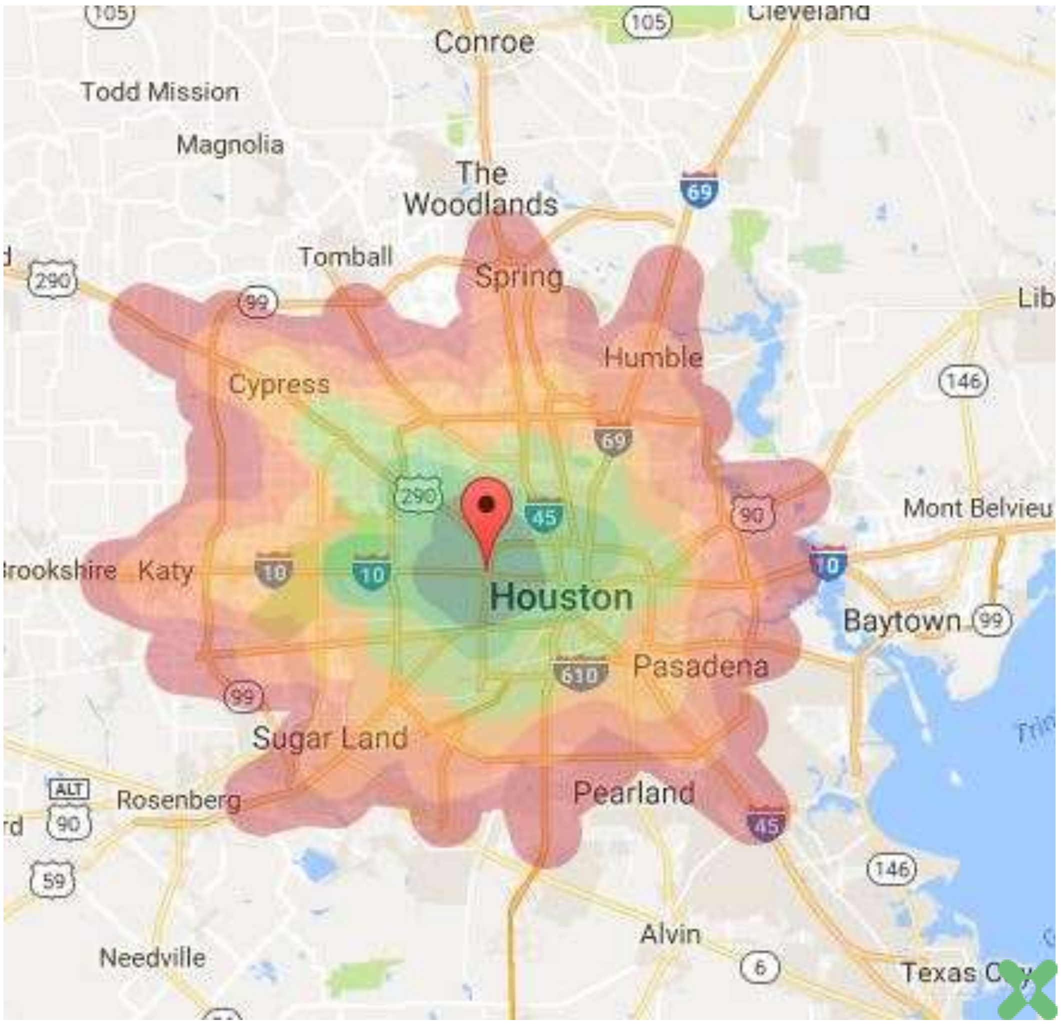
Source: (Google, 2016).

Houston Northwest Transit Center Station Location Satellite Image



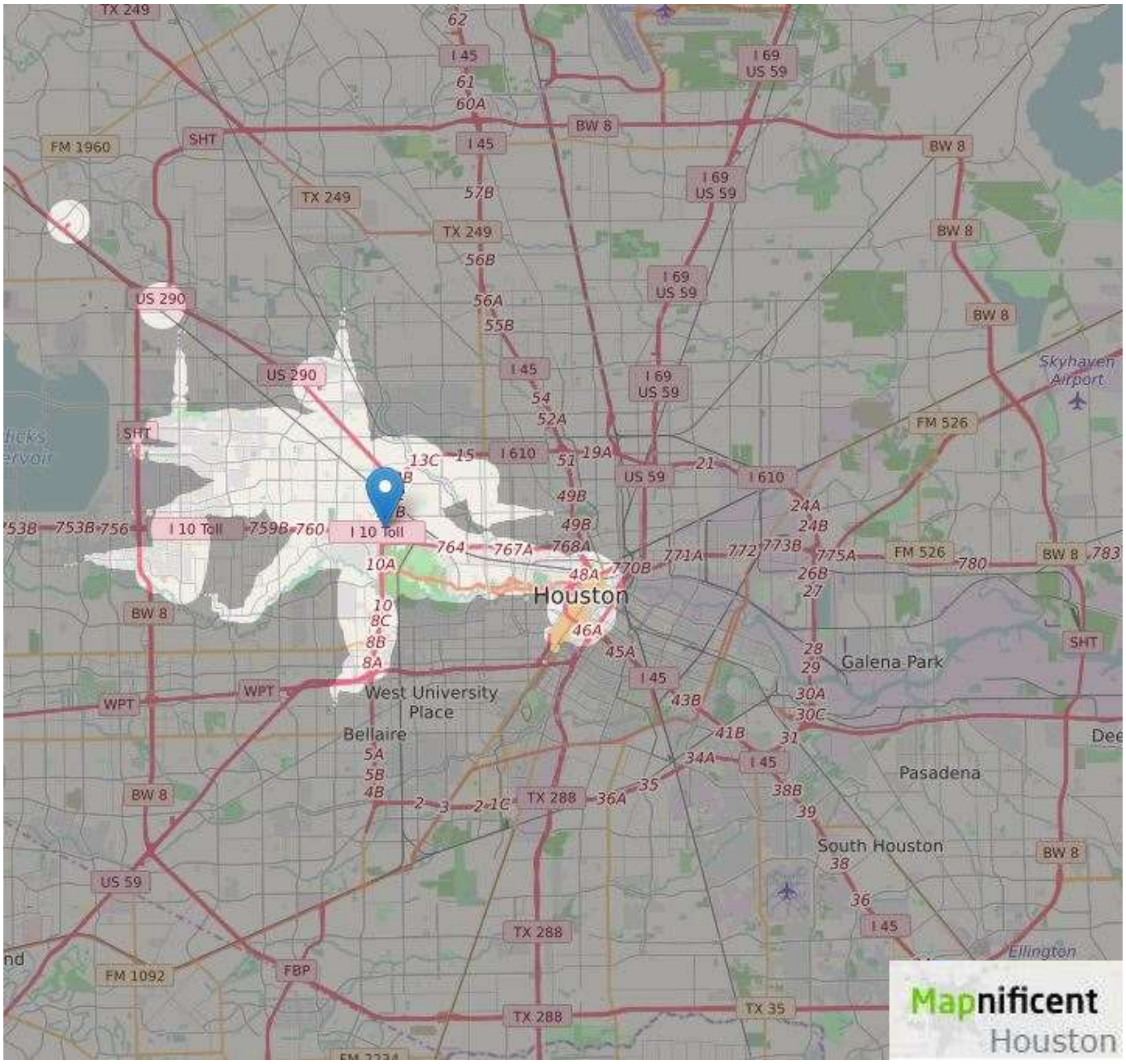
Source: (Google, 2016).

30-Minute Driving Time from Houston Northwest Transit Center Station Location



Source: (Route360, 2016).

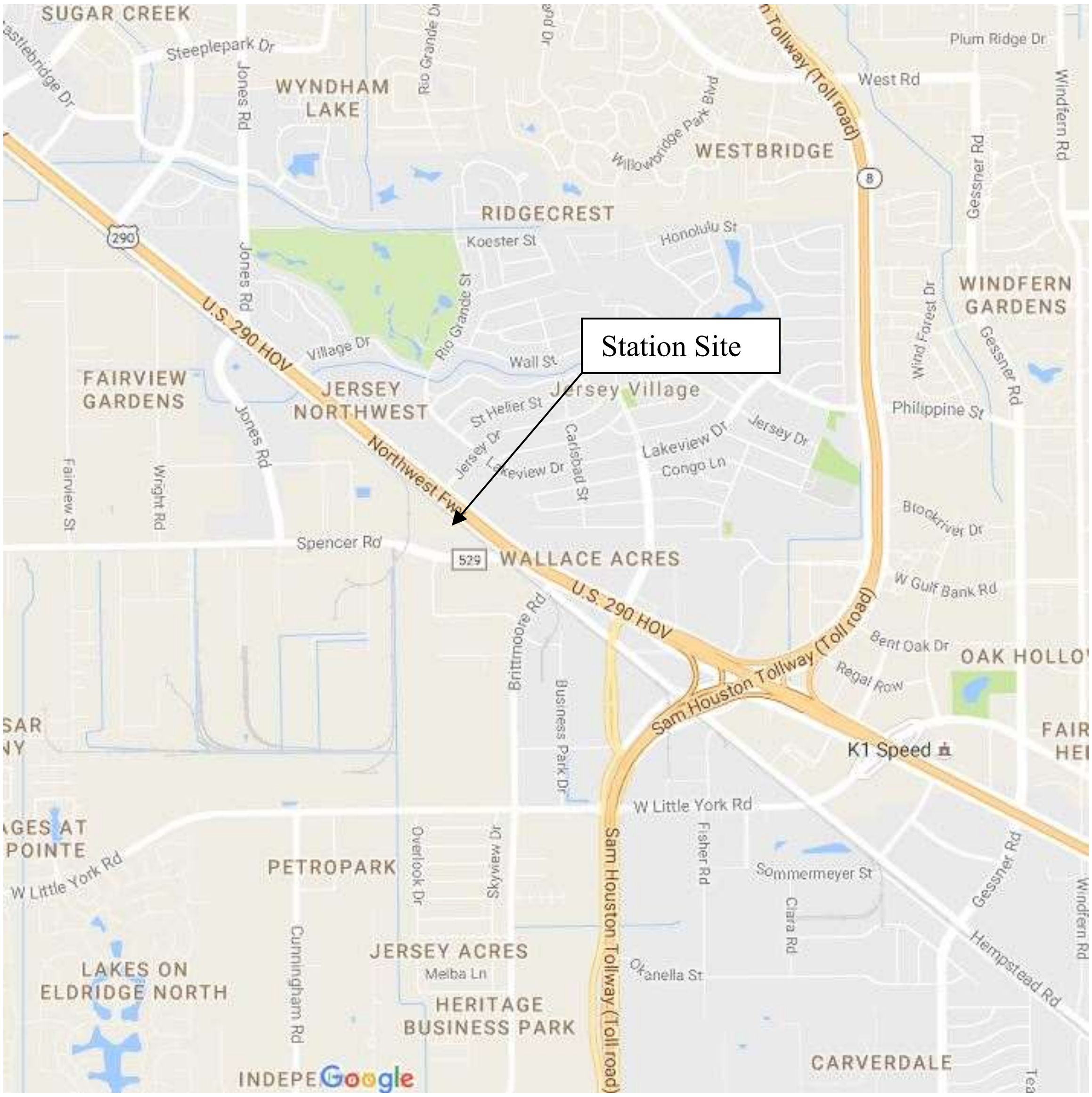
30-Minute Transit Time from Houston Northwest Transit Center Station Location



Source: (Mapnificent Houston, 2016).

B.7 – HOUSTON US 290/BELTWAY 8 STATION LOCATION

Houston US 290/Beltway 8 Station Location

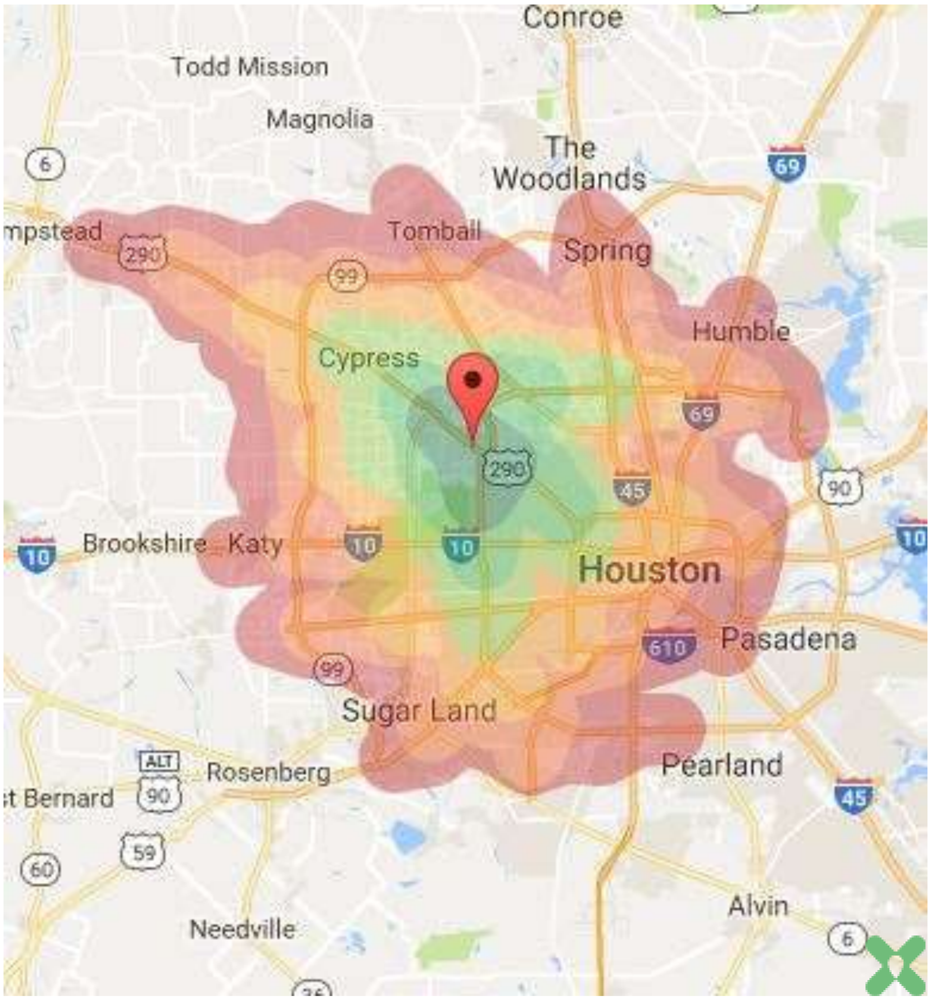


Source: (Google, 2016).

Houston US 290/Beltway 8 Station Location Satellite Image

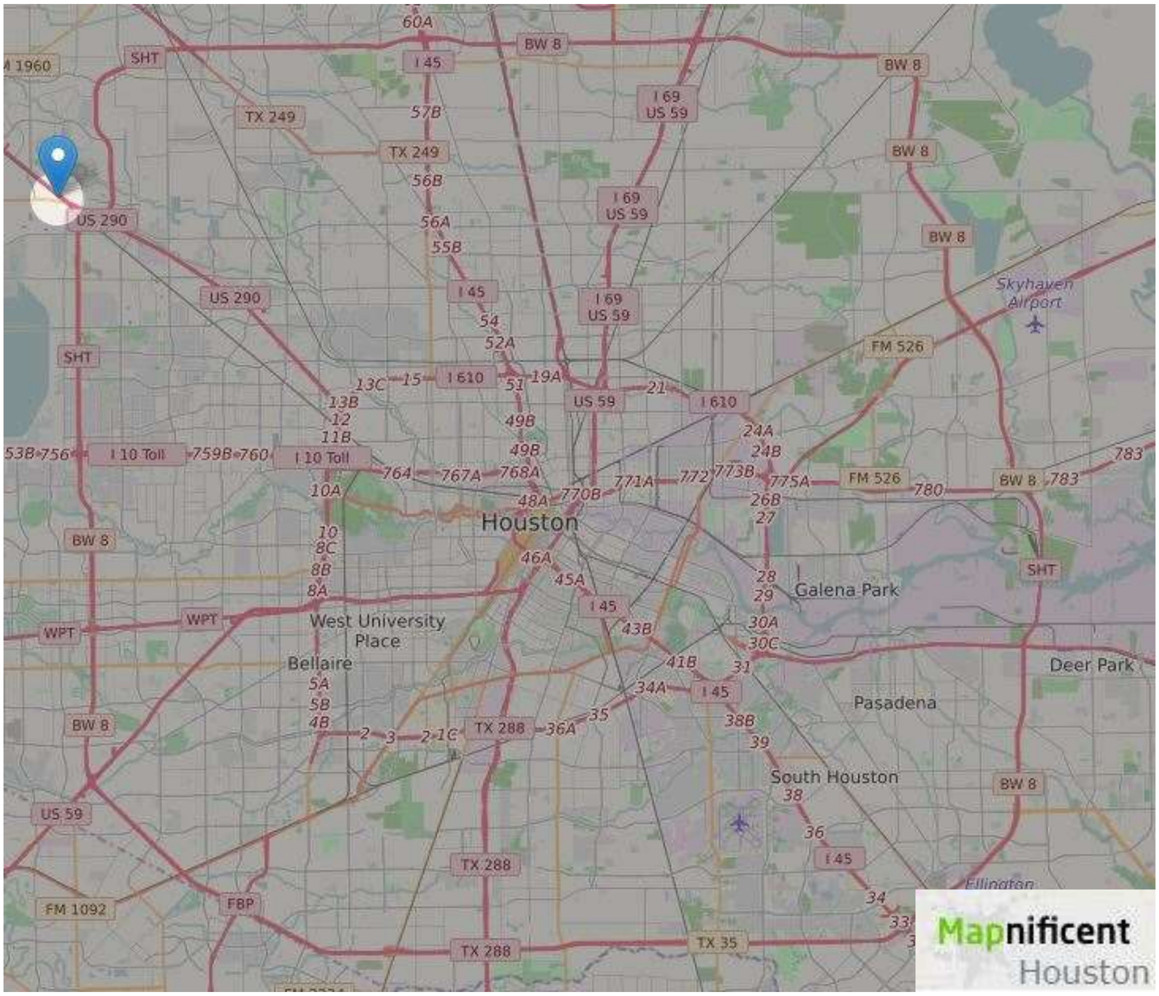
Source: (Google, 2016).

30-Minute Driving Time from Houston US 290/Beltway 8 Station Location



Source: (Route360, 2016).

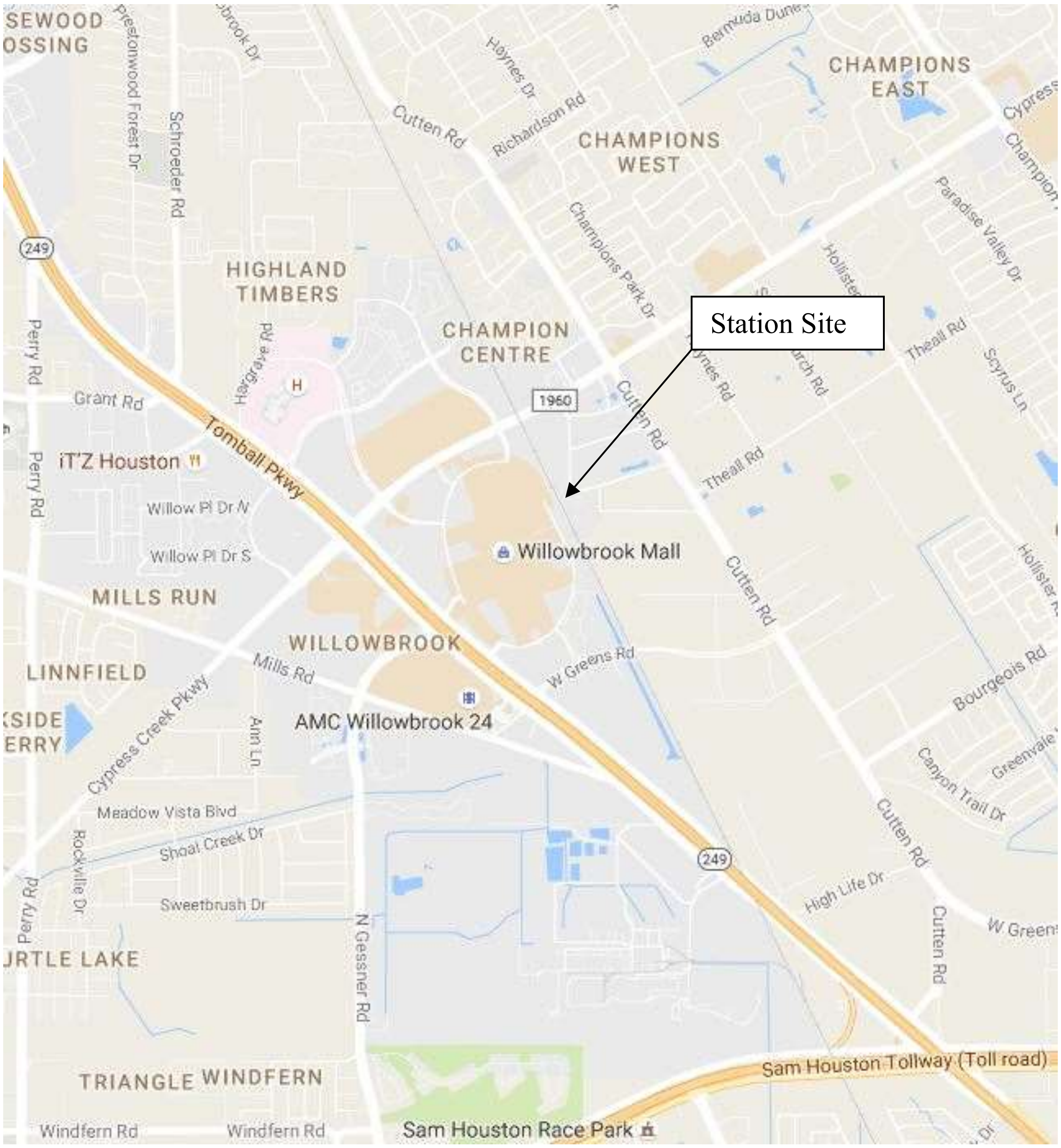
30-Minute Transit Time from Houston US-290/Beltway 8 Station Location



Source: (Mapnificent Houston, 2016).

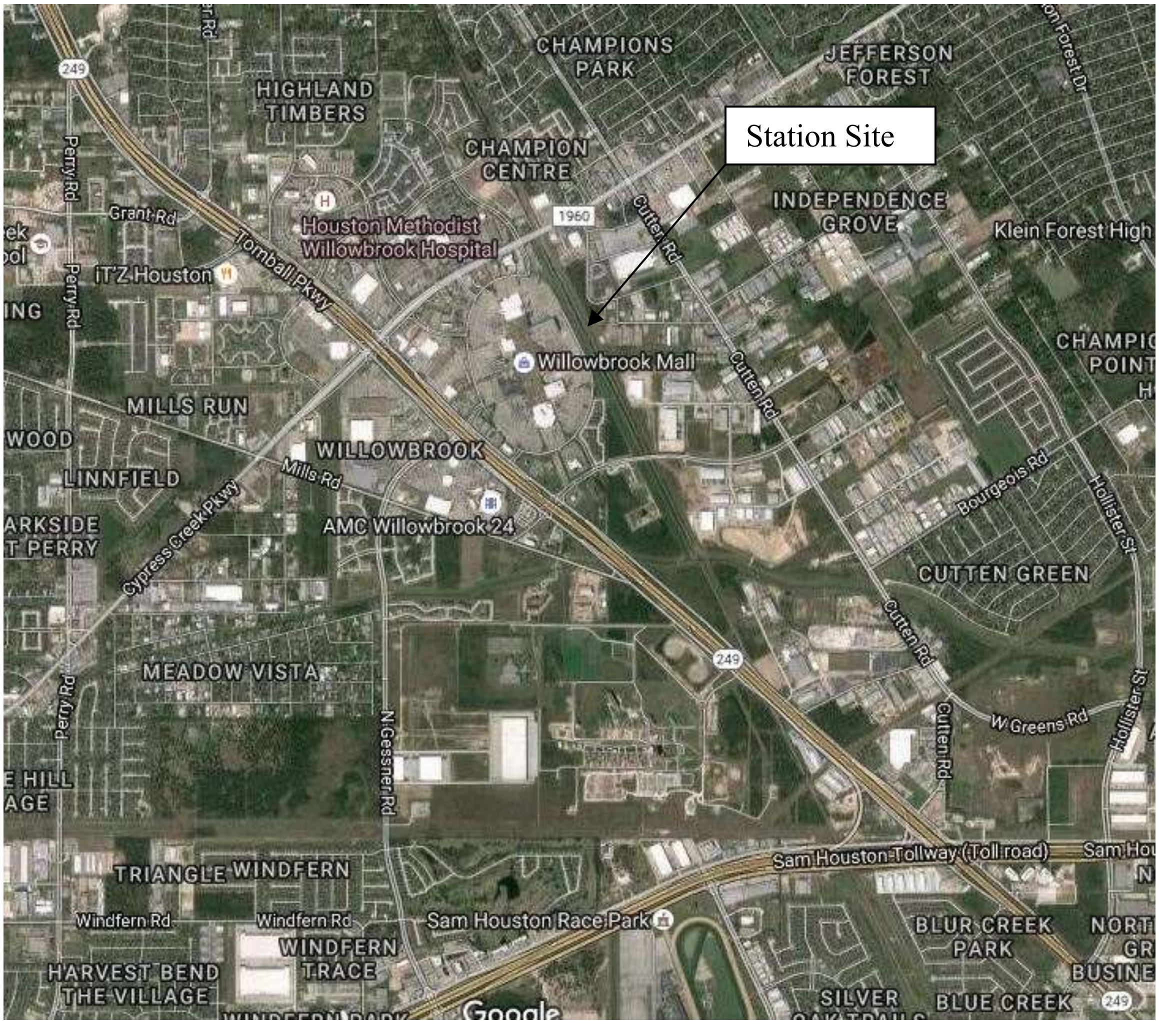
B.8 – HOUSTON WILLOWBROOK MALL STATION LOCATION

Houston Willowbrook Mall Station Location



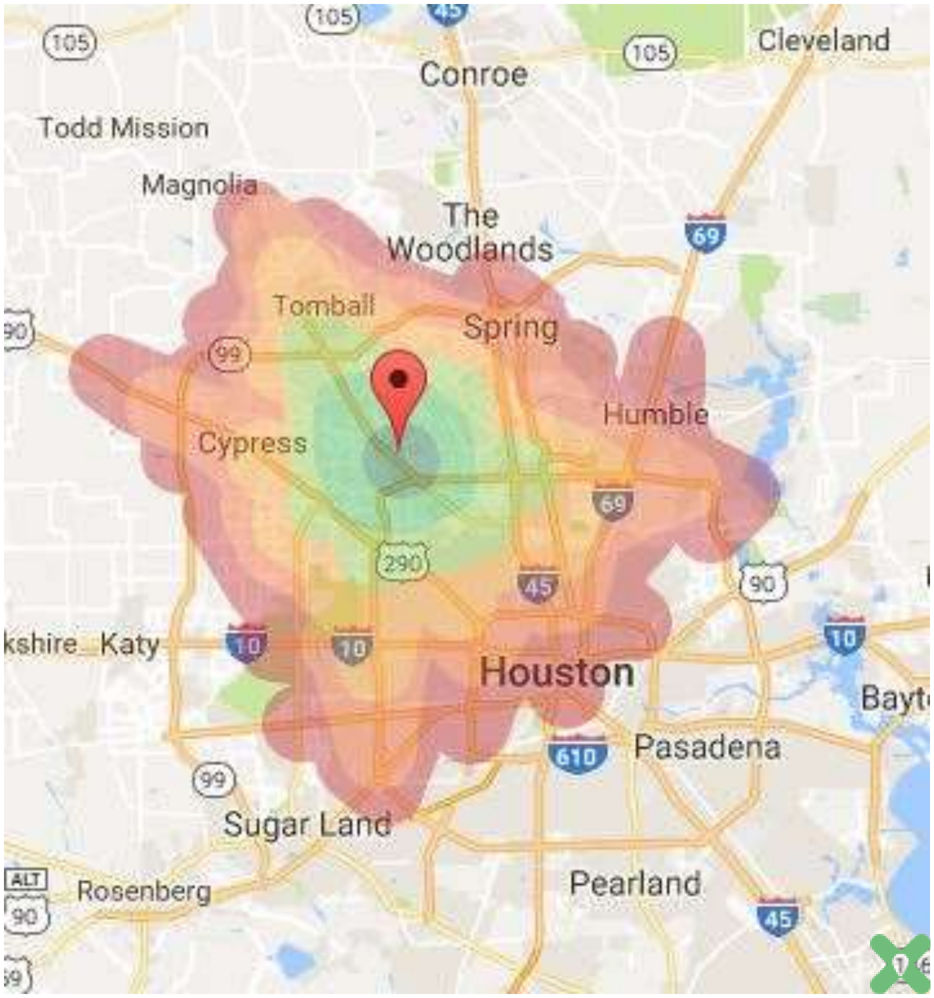
Source: (Google, 2016).

Houston Willowbrook Mall Station Location Satellite Image



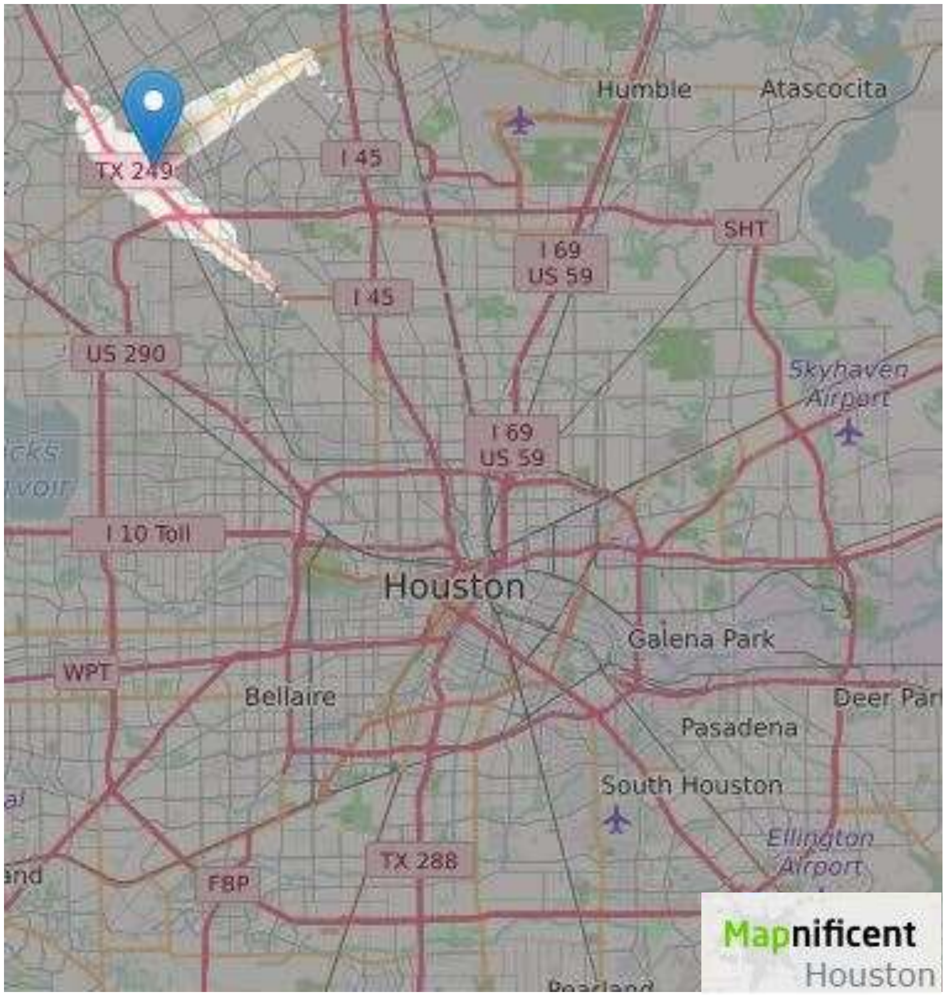
Source: (Google, 2016).

30-Minute Driving Time from Houston Willowbrook Mall Station Location



Source: (Route360, 2016).

30-Minute Transit Time from Houston Willowbrook Mall Station Location



Source: (Mapnificent Houston, 2016).

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