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There is renewed interest in developing high-speed intercity passenger rail (HSIPR) in the United States, revitalizing a transport mode that has long since lost most intercity travelers to competing modes of transportation such as automobile and airplane. For the construction of an HSIPR network to be successful, it is important to understand the locational benefits and disparities associated with this proposed network. This dissertation examines the potential impact of HSIPR in the United States using accessibility and equity measures at both the national and local scales with three broad goals: (1) project the impact of HSIPR in the United States using location-based accessibility measures at a national scale, (2) evaluate the locational effect of both the current railway upgrade plans and the full HSIPR plan along the southeast corridor of the United States, and (3) assess the spatial patterns of multimodal accessibility at the census-tract level via different intercity travel modes, using a social-equity perspective in the case of seven metropolitan statistical areas along the Southeast HSR corridor of North Carolina. Unlike most past research, accessibility to HSIPR is measured using a multimodal transportation network in ArcGIS through a combination of road, railway, and air travel, considering access/egress time to/from train stations or airports as well as waiting and transfer times. Overall, the findings of this dissertation suggest that HSIPR will significantly lead to nationwide and local accessibility gains, and it will contribute to lessening the spatial disparity of accessibility with intercity travel both from the perspectives of personal travel and economic development. While the highest travel-time

accessibility gains will go to the central and eastern United States, the largest economic-potential accessibility gain is expected in the cities along the northeast rail corridor. The faster HSIPR service will compete with air mode by 34.3% more than current, specifically in the areas that are reachable within five hours by train. At the regional scale, there will be overall accessibility gains in the Southeast corridor from the upgraded speed of HSIPR, with more benefits concentrated in cities where the trains will stop, such as Raleigh, Greensboro, Charlotte in North Carolina and Greenville, South Carolina. However, a tract-level accessibility analysis reveals that the accessibility gains will be concentrated only in specific parts of a city, with the highest concentration found near rail station areas of Raleigh and Durham, North Carolina, Greenville, South Carolina, and Richmond, Virginia. It is expected that cities along the Southeast corridor will experience improved spatial equity, but the accessibility gap between cities with and cities off the HSIPR system remains. This suggests that upgrading regional intrastate transportation will be necessary to more equally distribute the accessibility benefits from HSR cities to non-HSR cities. Most census tracts in the Southeast will gain spatial equity, but less-accessible areas will receive greater benefits. While both the high- and low-income groups show better accessibility equity from all modes of transportation after completion of HSIPR in the Southeast region, the middle-income group will have less-accessibility equity. This may be a result of the scattered residential locations of the middle-income group compared to the centrally located populations of the high and low-income groups.

KEYWORDS: Accessibility, transportation equity, High-speed rail, Multi-modal accessibility, United States, Southeast high-speed rail, GIS and Network Analysis

HIGH-SPEED RAIL IN THE UNITED STATES: ACCESSIBILITY POTENTIAL AND SPATIAL EQUITY

by

Hyojin Kim

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Approved by

Selima Sultana
Committee Chair

DEDICATION

I dedicate this dissertation to my beloved family—

my wife HYOJIN KWON,

my daughter OLIVIA KIM, my son AIDEN KIM,

my mother, Wol-Suk Oh and my late father Bok-Gi Kim,

my parents-in-law, Seonyeop Kim and Suo Kwon, and my brother-in-law Kibong Kwon.

Without the presence, support, and love, I would not be able to achieve my goal.

APPROVAL PAGE

This dissertation, written by Hyojin Kim, has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Chair Selima Sultana

Committee Members Corey Johnson

Paul A. Knapp

Joe Weber

Date of Acceptance by Committee

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CHAPTER I

INTRODUCTION

1.1. Research Background and Significance

This dissertation investigates the potential impacts of High-Speed Rail (HSR) in the United States, proposed as a High-Speed Intercity Passenger Rail (HSIPR) system, at multiple spatial scales from the perspectives of accessibility and equity gains. The introduction of high-speed rail (HSR) systems has been discussed in the United States since the official government plan in 2009, with the goals of reducing inter-city travel time (Petterman et al., 2009). Though air and automobile are the principal modes of transportation in the U.S., the introduction of an HSIPR has potential to change the competition among modes of preferred transportation and the spatial accessibility of cities. Most rail stations in the U.S. are in city centers, providing the option of convenient travel between cities by avoiding additional travel to the airport, check-in, layovers and other delays. In addition, cities in low-access areas under the hub-and-spoke air transport network can benefit from the development of an HSIPR system. Successful construction of an HSIPR network requires careful examination of the locational benefits and disparities associated with this proposed network. The results of this study can identify the areas where improvement of the HSIPR infrastructure would be most efficient and would close the spatial accessibility/equity gap (Gutiérrez, 2001; Monzón et al., 2013).

The HSR system is a mass transportation mode that emerged during the past half-century (Kim, 2016). With train operating speeds ranging between 257-354 kmh, HSR reorganizes the spatial interaction and degrees of accessibility between cities (Garmendia et al., 2012; Levinson, 2012). Accessibility, commonly defined as the number of potential opportunities for interaction between places (Hansen, 1959), focuses on the importance of reaching desired destinations within a certain distance and travel time. Considering operational costs and a large number of passengers required to sustain its service, HSR systems must first be constructed in the most economically efficient corridors. Hence, HSR routes have been designed to connect large cities. HSR has been implemented in cities throughout the world, providing various benefits such as travel-time reduction, sustainability, safety, and improved accessibility for cities with HSR service. Countries adapted to HSR systems have experienced changes in the spatial structure of urban systems due to HSR's impact on interaction flows (Sasaki, 1997; Perl and Goets, 2014). In comparison to cities outside of the HSR network, small- and middle-sized cities along HSR corridors between major cities gain a locational advantage (Ureña et al., 2009; Vickerman, 2014), which contributes to the attractiveness of a city for economic activities and regional development (Vickerman et al., 1995; Martin et al., 2004; Givoni, 2006).

The improved accessibility and network efficiency from HSR have been widely documented as a major justification for further investment (Martin, 1997). Most studies soley considered the rail network when these performances were evaluated (Kotavaara et al., 2011), yet HSR competes with other transportation modes including roads and airlines (Campos and de Rus, 2009; Adler et al., 2010; Behrens and Pels, 2012; Cao et al., 2014). For example, HSR service can supplement intercity air travel under the hub-and-spoke system by enabling direct travel between non-hub cities. Therefore, the evaluation processes of the locational benefits of HSR needs to be conducted with consideration to competitiveness and supplementation with other types of transportation. Hence, the results of most studies today are limited in showing the increased accessibility of HSR systems. While the benefits of the HSR system are unevenly distributed across the country (Monzón et al., 2013), future HSR extensions may also play a role in relieving unequal accessibility distribution as well as in increasing the efficiency of the network (Bruinsma and Rietveld, 1993). The evaluation of spatial equity impacts of transportation networks, especially based on HSR, remains limited (Monzón et al., 2013). Since providing equality of transportation services is increasingly gaining popularity in transport policy, it is essential to integrate this concept into HSR-network design so that an acceptable level of equal access can be guaranteed while ensuring maximum network efficiency and economic benefits (Bröcker et al., 2010; Monzón et al., 2013).

Transportation equity is closely related to spatial inequality in terms of disparity of accessibility and service. As travel behavior has become important for geographers in implementations of urban dynamic structure and land use, it has affected urban policy and planning. By focusing on the evaluation of locations, geographers have tried to evaluate the different conditions of residence: quality of neighbors, amenities, safety, and transportation (Guilino, 1998; Levinson, 1998; Taylor and Ong, 1995). With the rapid urbanization and sprawl, travel between job and residence has become an important field of transportation equity (Cevero, 1989, Kwan, 1999; Delmelle and Casas, 2012; Karner and Niemeier, 2013). Further, accessibility has been used to examine the unequal levels of public transportation services for traveling between residential locations and employment opportunities for individuals without automobiles (Delmelle and Casas, 2012).

1.2. Purpose of the Dissertation

There is a paucity of a detailed investigation of the geographical impact of HSIPR specific to individual cities, but research has been conducted on the perspective of cost-benefits (e.g., Levinson, 2010; Parsons Brinckerhoff, 2011) and forecasting ridership (e.g., Peters et al., 2014). In effort to address this lack of understanding about HSIPR, this dissertation has three broad objectives to:

1. evaluate the impact of HSIPR in the U.S. using location-based accessibility measures with a multi-modal transportation network to consider modal competition.
2. assess the locational effect of both the current railway upgrade plans and the full HSIPR plan along the Southeast Corridor of the U.S. with a multiscale unit of analysis.
3. investigate the transportation equity measures and evaluate transport-related benefits by different modes of transportation and different income status.

1.3. Organization of the Dissertation

This dissertation is divided into five chapters. Chapter I provides an overview of the problem statement and discusses previous research. Chapter II presents the literature review including the historical development of the high-speed rail and research background. Chapter III evaluates the impact of HSIPR for cities within the coterminous U.S. using location-based accessibility measures with a multi-modal transportation network to consider modal competition. Chapter IV evaluates the locational effect of both the current railway upgrade plans and the full High-Speed Intercity Passenger Rail plan along the Southeast Corridor of the U.S. with a multiscale unit of analysis. Chapter V investigates the transportation equity measures and evaluate transport-related benefits by different modes of transportation and different income status. Chapter VI draws the overall conclusions for the dissertation.

CHAPTER II

LITERATURE REVIEW

2.1. Historical Development of High-Speed Rail

In 1964 Japan began operating Shinkansen, the world's first HSR running between Tokyo and Osaka. Since then HSR has been a leader in the revival of competitiveness in rail transportation (Givoni, 2006; Campos and de Rus, 2009). HSR's growth can be attributed to advancements in technology for high speed trains, the fluctuation of oil price, and an increase in attention to sustainable development due to global climate issues. Due to the benefits of HSR for intercity travel, HSR has been introduced in many European and Asian countries (Vickermann, 1997; Givoni, 2006) such as France, Germany, Italy, and the UK (Table 2.1). A concensus formed for the need of developing the Trans-European Network with high-speed rail by the European Community (Givoni, 2006; Vickerman, 1997). The HSR network aimed to increase the capacity and speed of the existing trunk network, and support the improvement of accessibility in more remote regions.

Figure 2.1 High-Speed Rail Network in Europe (source: UIC, 2019)

The strategy of international dimension of HSR influences the HSR network of Europe has been extended rapidly with the interest and intent of in connecting their rail networks with higher speed for the purpose of integration between countries (Vickerman, 1997). This service is possible because most of the HSR network in Europe is compatible with conventional railways, allowing high-speed trains to cross borders through the existing conventional railways. In 2019, the cross-border HSR service connected France, Belgium, Netherland, Luxembourg, Germany, UK, Italy, Switzerland, Austria, Hungary, Sweden, and Denmark. That year the European HSR network in operation reached 9,176 km, with 1,697 km under construction, and 2,787 km planned

(Table 2.1). As seen in Figure 2.1, the European HSR network will be extended beyond Western Europe to Northern and Eastern Europe and North Africa.

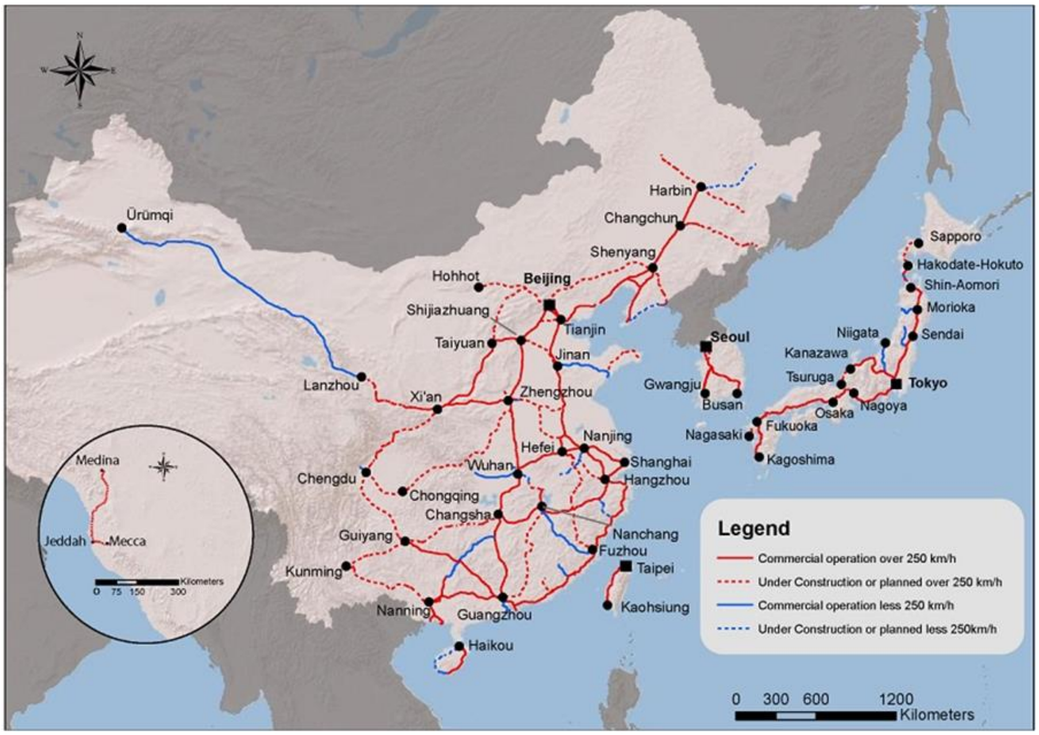


Figure 2.2 High-Speed Rail Network in Asia (source: UIC, 2019)

In addition to the early development of HSR in Japan and Europe, the HSR network has been extending in East Asia (Figure 2.2). South Korea started to operate an HSR connecting Seoul and Busan in 2004, and Taiwan opened their first HSR connecting Taipei and Kaohsiung in 2007. Like other early routes (i.e. Tokyo-Osaka, Paris-Lyon), South Korea and Taiwan also constructed their first HSR route along the existing main trunk route. China has rapidly developed a dense HSR network since the first HSR operation between Beijing to Tianjin in 2008, despite the large territory of the country. The Chinese government has focused on increasing the competitiveness of large cities by increasing HSR's intercity travel time saving (Cao et al., 2013; Shaw et al., 2014; Wu et al., 2014). The Chinese HSR network in operation reaches 31,403 km and will be extended to 39,578 km by the planned network as of early 2019 (Table 2.1). In 2018, Saudi Aribia began operation of the first HSR in the Middle East, connecting Medina and Mecca.

Table 2.1 High-Speed Rail in the World as of 2019 (source: UIC)

Region	Service area	Service open (year)	Max operating speed (kph)	Compatible with conventional railways	Distance in kilometers				
					In operation	Under construction	Planned	Long-term plan	Total
Asia	Japan	1964	320	No	3,041	402	194	-	3,637
Europe	France	1981	320	Yes	2,814	-	-	1,725	4539
Europe	Italy	1988	300	Yes	896	53	-	152	1,101
Europe	Germany	1988	320	Yes	1,571	147	81	210	2,009
Europe	Austria	1991	320	Yes	263	281	71	-	615
Europe	Spain	1992	310	Yes	2,852	904	1,061	-	4,817
Europe	Belgium	1997	300	Yes	209	-	-	-	209
Europe	Switzerland	2000	250	Yes	144	15	-	-	159
North America	USA	2000	240	Yes	735	192	1,710	449	3,086
Europe	United Kingdom	2003	300	Yes	113	230	320	-	663
Europe	South Korea	2004	305	Yes	887	-	49	-	936
Asia	Taiwan	2007	300	No	354	-	-	-	354
Europe	China	2008	350	Yes	31,043	7,207	1,071	257	39,578
Asia	Turkey	2009	250	Yes	594	1,153	2,230	2,859	6,836
Europe	Netherlands	2009	300	Yes	90	-	-	-	90
Europe	Poland	2014	200	Yes	224	-	484	598	1,306
Africa	Morocco	2018	320	Yes	200	-	139	975	1,314
Asia	Saudi Arabia	2018	300	Yes	453	-	-	-	453
Europe	Denmark	-	250	Yes	-	56	-	-	56
Europe	Sweden	-	250	Yes	-	11	-	739	750

2.2. Accessibility and Equity Concept in Transportation

2.2.1 Accessibility

The term accessibility is generally defined as the potential opportunity for spatial interaction among spatially separated human activities promoted by transportation. In other words, accessibility refers to the ability of people to overcome distance or other constraints to reach destinations that are desirable (Hansen, 1959; Bruinsma and Rietveld, 1998). The concept and measurement of accessibility is an important implication for urban transportation researchers and planners because it evaluates the impact of transportation systems on travel and land use patterns. Accessibility, therefore, has been used in various fields such as location choice, travel demand forecasting, and land use (Handy and Niemeier, 1997).

The concept of accessibility pursues practical applications in policy-making processes, while the measurement of accessibility is more central to transportation research (Páez et al., 2012). There are two components that influence accessibility measurement: ease of access and attractiveness of location (Páez et al., 2012). Geurs and van Wee (2004) identify four types of accessibility measures: infrastructure-based measures, location-based measures, person-based measures, and utility-based measures.

Infrastructure-based measures evaluate accessibility by the service level of infrastructure, such as the length of a transportation network or its level of congestion (Geurs and van Wee, 2004). Location-based accessibility measures include cumulative opportunities and gravity-based accessibility by using the distance decay function.

Cumulative opportunities calculate the number of opportunities within either a given distance or travel time (Handy and Niemeier, 1997; Geurs and van Wee, 2004). Gravity-based accessibility, or potential accessibility, measures the adjacency of opportunities (van Wee et al., 2001; Geurs and van Wee, 2004). The closer the opportunity, the higher the potential accessibility. Person-based measures analyze individual activities within a given time. Utility-based accessibility measures, based on microeconomic theory, analyze the probability of choice of one discrete activity in spatially distributed activities (López et al., 2012). The measure is based on random utility theory using log-sum, and later supplemented by the doubly constrained entropy model. Though utility-based accessibility is difficult to interpret, it is relevant to transport projects from social and economic perspectives as it provides a better explanation of relative accessibility benefits despite low absolute improvement (Geurs and van Wee, 2004; Páez et al., 2012).

From the perspective of regional development, one of the most important economic effects is the improvement of locational position, which is generally related to location-based accessibility measures (Givoni, 2006; Martin, 1997; Gutierez et al., 2001; Monzón et al., 2013). Accessibility can be interpreted as the potential of a location determined by travel cost, as well as the attractiveness of a location based on spatial distribution of travel behaviors (Handy and Niemeier, 1997; Páez et al., 2012). This concept of accessibility has been used for evaluating the impact of transportation infrastructure (Vickerman, 1997), location of facilities for welfare (Páez et al. 2012), and commuting convenience (Foth et al., 2013; Gregg, 2013). Improving accessibility is a common goal in almost all transportation plans (Handy and Niemeier, 1997), thus the expansion of the transport network is justified. Also, accessibility affects the determination of economic activities (Willingers and van Wee, 2011).

2.2.2 Equity

The concept of equity in transportation studies is rather ambiguous, which poses challenges in measuring transportation benefits. Historically, in the U.S., the importance of the freedom and equality of riders is most noticeable in the Civil Rights Movement of the 1960s, in which bus seating was segregated (Garrett and Taylor, 1999; Sanchez et al, 2003; Welch and Mishra, 2013). Also, when the Interstate Highway was constructed, the decision to construct routes through minority residences was significant from the perspective of transportation equity, and equity became an important consideration in the transportation policy (Bullard, 2003). Meanwhile, geographers focused on problems of social structure. In addition, geographical differences related to problems of inequality and injustice raised the need for reducing these disparities (Hay, 1995). Later, equity research expanded its theoretical boundary to cover the underlying process of social phenomena. Hay (1995) introduced the concept of equity in aspects of expectations, planning and policy, and spatial inequality to justify broadening equity. In the spatial context, equity is a framework to evaluate the distribution of opportunities for economic activity, such as travel behavior, which became important for geographers due to the implementations of urban dynamic structure and land use.

Transportation equity is deeply related to spatial inequality in terms of disparity of accessibility and service. As travel behavior has become important for geographers in implementations of urban dynamic structure and land use, it has affected urban policy and planning. By focusing on the evaluation of locations, geographers have tried to evaluate the different conditions of residence: quality of neighbors, amenities, safety, and transportation (Guilino, 1998; Levinson, 1998; Taylor and Ong, 1995). With rapid urbanization and sprawl, travel between jobs and residences has become an important field of transportation equity (Cevero, 1989, Kwan, 1999; Delmelle and Casas, 2012; Karner and Niemeier, 2013). In addition, accessibility has been used to examine the unequal levels of public transportation services for traveling between residential locations and employment opportunities for the auto-less (Delmelle and Casas, 2012).

In general, the term "equity" refers to the fairness and justice with which impacts (benefits and costs) are appropriately distributed by transportation projects. Historically, transport funding has been allocated so that the wealthier areas of a country or region get more transport benefits because of demand, and the peripheral regions receive inadequate transport services, which ultimately leads to a widening gap between regions due to transportation services. Transport equity analysis, especially as it is strongly related with accessibility in terms of discrete mobility and accessibility of low-income people interpreted as social exclusion, can be difficult because there are several types of equity, numerous impacts to consider, various ways to categorize people for analysis, and many ways of measuring impacts (Karner and Niemeier, 2013; Welch and Mishra, 2013; Litman, 2014). But the concept of equity has been insufficiently defined. Meanwhile, accessibility has been used to examine social exclusion with GIS software in the spatial context (Prestion and Raje, 2007; Foth et al., 2013). It is useful to compare different time periods, which shows the relative disadvantages of improvement of transportation services (e.g. Vickerman, 1997; Gutiérrez, 2001; Cao et al., 2013; Monzón et al., 2013).

Considering complexity, one approach found to be useful in measuring transportation equity as a target is to treat it as either horizontaly or verticaly (Litman, 2014). Horizontal equity refers to providing an even service to all target groups or locations. This approach focuses on the equal distribution of benefits from public services to all areas. However, it has been criticized for ignoring the geographical discordance of socioeconomic conditions. Thus, research focusing on evaluating public transportation service from the perspective of equity is closer to vertical equity, which treats relative service quality that benefits transportation-disadvantaged people (Foth et al., 2013). Vertical equity is also treated by researchers as social equity, which focuses on the fair distribution of resources between different income groups by different areas (Delbosc and Currie, 2011).

2.3. Evaluation of Accessibility and Equity from HSR

2.3.1 Evaluation of Locational Benefits from HSR

As an HSR project is conducted on a national scale and closely related with land use and travel activities, location-based measures have been used in many research studies on HSR. Location-based measures describe spatially distributed activities on a macro scale (Geurs and van Wee, 2004; Cao et al., 2013), and three indicators have been mainly used: weighted average travel time (location indicator), economic potential, and daily accessibility (contour measure) (Gutiérrez, 2001; Martin and Reggiani, 2007).

Some research studies have used change of travel time as an accessibility indicator. Martínez Sanchez-Mateos and Givoni (2009) assess “winner” and “loser” cities based on the travel time change after the introduction of HSR in the U.K. According to the concept of accessibility defined in the previous section, listing reductions of travel times between specific city pairs can hardly be assessed as an indicator reflecting the impact of HSR on a location.

Benefits provided by a new transportation system represent improved accessibility, including the chances of activities in different locations (Geurs and van Wee, 2004). The improved efficiency of the HSR network has been evaluated widely from the perspective of the positive changes in accessibility because this is a major justification for investment in HSR network construction (Martin, 1997). Thus, accessibility supports planners to make a decision and design the network of HSR projects based on regional development (Gutiérrez, 2001; Brocker et al., 2010; Monzón et al., 2013).

Much research on the evaluation of benefits from the new HSR corridor has been conducted in Europe because of the expectation of cohesion among European countries due to the extension of the HSR network by connecting tracks, including across borders (e.g., Gutiérrez et al., 1996; Vickerman, 1997; Vickerman et al. 1999, Gutiérrez, 2001; López et al., 2008; Monzón et al., 2013). This context for cohesion among European countries due to HSR induced research predicting the impact of the future HSR network in Europe. Vickerman (1997) assessed the implications of trans-European networks for regional economic development and cohesion of European countries by measuring changes of two selected accessibility measures: economic potential and daily accessibility. They showed that the new HSR network was expected to increase the disparity of accessibility between European core cities and peripheral regions, and also noticed the relative impacts of changes in accessibility based on their existing value of accessibility. Gutiérrez (2001) measured changes of accessibility after the new Madrid-Barcelona-French border HSR line in Europe using economic potential, weighted averaged travel time, and daily accessibility indicators. The results predicted a significant spread of benefits from accessibility beyond the planned HSR corridor.

China has developed the world's longest HSR network since the first HSR service began in 2008,. Accessibility research in China has been conducted to find and present the changes in accessibility values on a national scale, whereas European studies were more concerned with the cohesion effect and disparity of accessibility, which implies the approach of HSR to the area of a large country like the United States. Cao et al. (2013) evaluated relatively high accessibility improvement in the central east region compared with other transportation systems using potential accessibility, weighted average travel time, and daily indicators by comparing the HSR network and air transportation in China. They found that the eastern central cities show higher attractiveness or less total travel time for the current HSR network than for air travel because of locational advantage. Shaw et al. (2014) conducted an accessibility analysis of four construction stages of the Chinese HSR, focusing on the improved travel time (based on the time table), fare, and travel distance. The result showed the effect of travel time saving along the HSR routes.

The result of accessibility depends on different indicators, which may be confusing to the planners handling transportation policies. Therefore, some researchers have tried to develop a model to integrate various accessibility indicators. Martin et al. (2004) suggested a model referred to as DEA, which integrates the accessibility indicators used by Guiterrez (2001) and explains the appropriateness of those approaches to the planners. Later, Martin and Reggiani (2007) extended the previous DEA model by using PCA analysis to develop a single method for applying HSR investments to the HSR scenarios of 1996, 2005, and 2015 along the corridors between European cities. This approach can provide a simple result of accessibility measurement. However, each accessibility indicator has different criteria reflecting different spatial and non-spatial conditions of access by travel. Thus, simply synthesizing the results of indicators leaves questions regarding the possibilities of finding individually meaningful results.

2.3.2 Spatial Equity from HSR

Research focusing on assessment of the regional benefits of the newly operated or planned HSR network has been extended to the spatially uneven benefits of HSR and used equity to define the problem. But the evaluation of the spatial equity impacts of HSR is rather limited (Monzón et al., 2013). The reason is that the concept of equity in transportation studies is rather ambiguous, posing challenges in how to measure it in terms of transportation benefits. HSR research dealing with equity issues should be more appropriate for horizontal or spatial equity because the objects are cities, which focus on the distribution of accessibility by different regions from the transportation network (van Wee and Geurs, 2011).

In the planning process of a new transportation infrastructure like an HSR system, planners need to consider the two objectives of impacts of the HSR project: efficiency and equity, which sometimes conflict (Monzón et al., 2013). Considering construction costs, there is no choice but to construct the HSR project in the most economically efficient corridor first. Cities not served by HSR may suffer from relative disadvantages because of the relative loss of travel time to other cities (Vickerman, 1997; Ureña, et al., 2009, Monzón et al., 2013). Although cities without HSR may receive some advantage indirectly from the network effect of being connected with HSR, these benefits are usually limited (Garmendia et al., 2012). Thus, isolation from the initial HSR network has the possibility to intensify spatial disparities of interaction among cities.

The competitiveness of a city is affected by accessibility and whether or not the city is connected to a faster transportation network (Garmendia et al., 2012). Improved accessibility due to an extended HSR network has showed positive benefits for many large cities, which is a positive result from the economic perspective, and many previous research studies on HSR have concentrated on these kinds of results. Pursuing network efficiency, however, can be conversely interpreted as creating disadvantaged areas that are far from the HSR network. Some research has paid attention to the impact of HSR on the intermediate cities and peripheral cities of HSR corridors. Ureña et al. (2009) concentrated on intermediate cities such as Cordoba and Zaragoza along the HSR corridor in Spain. These cities naturally received HSR stations due to their locations between metropolitan cities. The result showed that HSR had a significant influence on the interconnection network among cities. In contrast, cities not linked to the HSR network suffered less development due to their weaker attractiveness (Garmendia et al., 2012). The problem of relative disadvantage from HSR has been found in some efficiency research showing discriminations or inequalities in accessibility values among cities (Gutiérrez et al., 1996; Martin, 1997; Vickerman, 1997; Gutiérrez, 2001; Martin et al., 2004; Ureña et al., 2009; Monzón et al., 2013).

The recent research on the perspective of equity from HSR therefore examines whether HSR fosters disparity of accessibility or a tendency of polarization in a country resulting from uneven improvement of transportation services (e.g., Gutiérrez, 2001; Martin et al., 2004; Monzón et al., 2013). Gutiérrez (2001) raised the issue of increasing inequality among cities in Europe from the development of the Madrid-Barcelona-French corridor, which he interpreted as a logical result of the different conditions of HSR connections. Since accessibility has usually been measured by different indicators that have different interpretations in accessibility gains (some of these will be discussed in the methodology section), Martin et al. (2004) tried to measure overall accessibility inequalities among the cities and regions in Spain from the Madrid-Barcelona-French border corridor line. The results of their inequality measures showed that the construction of the Madrid-Barcelona-French border HSR line will increase regional accessibility disparity. Monzón et al. (2013) specifically dealt with inequality as an important issue resulting from the HSR in Spain, focusing on the polarization caused by uneven growth of cities due to HSR. Using coefficient of variance and normalized values of the improvement of accessibility of each city, their study showed more equitable accessibility values for the Spanish cities after the HSR extensions in Spain, but this did not alter the existing differences and the dominant positions of certain cities. Shaw et al. (2014) pointed out the disparity of accessibility related with travel cost. The high travel fare of the HSR along the Beijing-Tianjin-Hebei high-accessibility route affects the reduced travel distance despite the improved mobility due to the HSR.

2.4. Conceptual and Methodological Framework of this Dissertation

2.4.1 Accessibility Measure

Location-based indicators will be used for the dissertation. First, weighted averaged travel time (WATT), a location indicator, is selected to emphasize the relationship between regions, which is significant for showing the benefits of the travel reduction due to HSR (Gutiérrez, 2001; Martin et al., 2004; López et al., 2008; Cao et al., 2013; Jiao et al., 2014). WATT calculates travel time between each city to all other destinations considering the mass of destinations. The mass of the destination is used as a weight in order to value the importance of the minimal travel time routes (Gutiérrez, 2001; Cao et al., 2013). The mathematical expression is as follows:

$$T_{\mathrm{i}} = \frac{\sum_{\mathrm{j}} M_{\mathrm{j}} \cdot t_{\mathrm{j}}}{\sum_{\mathrm{j}} M_{\mathrm{j}}}, \tag{1}$$

where T_{i} is the accessibility of location i, t_{j} is the travel time to destination j, and M_{j} is the mass of j. Generally, the minimal travel time is used for t_{j}, and the population size or gross domestic product is used for M_{j}. This indicator focuses on the shortest travel time rather than the shortest distance. The data of population or gross domestic product give value to the importance of the travel time route. The result of this indicator is simple; for example, the reduced value of T_{i} after the operation of the new HSR means a travel time saving of location *i*.

Another accessibility indicator selected in this study is potential accessibility, which focuses on the nearness of opportunity of economic activities in a location (Hansen, 1959; Gutiérrez, 2001; Martin et al., 2004; López et al., 2008; Cao et al., 2013; Monzón et al., 2013). It is a gravity-based measure determined by the volume of the mass of destinations divided by the travel time between them. The expression is as follows:

$$P_{\mathrm{i}} = \sum_{\mathrm{j}} \frac{D_{\mathrm{j}}}{t_{\mathrm{ij}}{}^{\alpha}}, \qquad (2)$$

where P_{i} is the potential accessibility of location i, t_{ij} is the travel time between locations i and j, D_{j} is the mass of destination j, and α is a distance friction parameter. In this study, the value used for α is 1. The use of a higher value of α has the problem of excessive reflection of adjacent destinations, so we use 1 as a parameter because it has been used by other researchers dealing with similar measures on a national scale (Gutiérrez, 2001; Cao et al., 2013). The result is interpreted as the chances of economic potential of each city caused by the new HSR extensions. Higher value indicates higher potential. The problem of self-potential or internal accessibility was pointed out from some research (Bruinsma and Rietveld, 1998; Gutiérrez et al., 2011).

A contour measure called daily accessibility indicates the amount of population or economic activities within the possible range of travel by fixed constraint for travel (Gutiérrez, 2001; López, 2004; Cao et al., 2013). The constraint can be travel time or distance, and a time limit of 3 or 4 was used in the previous HSR research (Gutiérrez, 2001; Cao et al., 2013). This is a simple and useful way to analyze the impact area of HSR in real life.

2.4.2 Equity

Vertical equity issues are increasingly important considerations in evaluating equity issues for any transportation project. For example, the impacts of HSR service are not only associated with spatial access (horizontal issues), they are also associated with vertical equity issues, such as the barriers of ticket prices or different HSR demands based on different kind of jobs. While we agree that ignoring vertical equity tends to underestimate spatial equity, considering vertical equity is beyond the limit of this dissertation work. In order to consider vertical issues in the evaluation of social equity, the social needs of various groups, tickets prices, and frequency of services should be considered to calculate travel time, and that information is non-existent at this stage of HSIPR planning in the U.S.

Nonetheless, focusing only on horizontal equity issues such as spatial equity does not undermine the contributions of this dissertation for various reasons. First, vertical equity issues are more important in areas that already have high-quality transportation or in micro-level analysis (van Wee and Geurs, 2011). In this case, HSIPR is only at an initial stage of thinking and aims to secure efficient intercity travel capacity compared to other modes of transportation (Givoni, 2006). In addition, the target of receiving benefits from HSR focuses on cities or regions rather than on individual passengers. HSR research dealing with equity issues should be more appropriate for horizontal or spatial equity because the objects are cities, which focus on the uneven distribution of network accessibility across different regions (van Wee and Geurs, 2011). Therefore, this research focuses on horizontal equity, targeting cities and metropolitan areas, and aims to present the predictable disparity of benefits from HSR in the U.S.

As a criterion for measuring the disparity in benefits from the improved accessibility among cities by the improved transportation infrastructure such as HSR and highway, the coefficients of variation (CV) index was used (Li and Shum, 2001; Martin et al., 2004; López et al., 2008; Monzón et al., 2013). This index, used in descriptive statistics, evaluates the degrees of balanced accessibility distribution. It can easily help to understand the trend of disparity in accessibility at each stage of the HSR network by comparing the calculated values of CV. CV is expressed as follows:

$$\mathrm{CV} = \frac{\sigma^P}{\frac{\sum A_\mathrm{i} \cdot P_\mathrm{i}}{\sum P_\mathrm{i}}} \tag{3}$$

where CV is the coefficient of variation for the whole area, σ^P is the standard deviation of accessibility values A_i, and P_i is population as weight. A decreased value of CV in this study means an increase in equality of accessibility values. The value reflects the global trend of calculated values of accessibility, so it has a possibility of not reflecting the locally existing situation of accessibility deviation, although the CV value is decreased (Monzón et al., 2013). To supplement the deficiency, we present maps of normalized change of accessibility between the stages of HSR extension to find relatively less improved accessibility along the HSR extension.

Lorenz curves represent the cumulative distribution function of wealth across the population, which is adopted to evaluate the degree of transportation service to various distributions of population. This measure can be used for assessment of equitable supply of HSR services. It can be applied to the relation between a certain attribute and population, which can be interpreted as the equitable or inequitable distribution of the attributes. The measurement of inequity is the Gini index, which is generally used in the calculation of distribution of wealth. Delbosc and Currie (2011) used Lorenz curves and the Gini index to examine the distribution of public transportation services in Melbourne. The result presented that 70% of the population in the city shared only 19% of public transit services.

2.4.3 Measures for Relationship between HSR and other Transit Modes

Kotavaara et al. (2011) integrated the railway and road network in Finland to identify the relationship between accessibility and population change. This research found that improvement of both the road and rail networks promoted a population increase. This approach has advantages for automatically searching the fastest routes between cities and evaluating the relationship between HSR and others by investigating the selection of routes. To increase the reality, the rail network may be connected at the major planned HSR stations with including transfer time.

Another approach can be compared to the results for accessibility of each transportation mode. Cao et al. (2013) used a formulation for indicating relative difference, defined as:

$$RelDiff_{T_i} = ({T_i}^{other\ mode} - {T_i}^{HSR})/max({T_i}^{other\ mode}, {T_i}^{HSR}) \qquad (4)$$

where ${T_i}^{other\ mode}$ indicates the calculated accessibility value of location I by selecting another mode of transportation. ${T_i}^{HSR}$ indicates the value of accessibility in location I of HSR. The range of $RelDiff_{T_i}$ is between -1 and 1. A positive value means the HSR system takes priority over the compared transportation mode.

CHAPTER III

THE POTENTIAL IMPACT OF HIGH-SPEED RAIL ON THE UNITED STATES: CHANGES IN ACCESSIBILITY AND SPATIAL EQUITY[1]

3.1. Introduction

There is increasing interest in developing a high-speed rail (HSR) system in the United States, where railroads have long since lost in the competition for intercity travelers. With an increase in speed to 250–350 kph, or twice that of current trains, high-speed systems offer improved accessibility and network efficiencies (Martin, 1997; Kotavaara et al., 2011; Monzón et al., 2013; Cao et al., 2013; Kim and Sultana, 2015; Wang et al., 2016; Wang and Duan, 2018). In 2009, the Federal Railroad Administration (FRA) announced the High-Speed Rail Strategic Plan (Lane, 2012), and $10.6 billion was allocated by the American Recovery and Reinvestment Act of 2009 for upgrading current railways to speeds of 145–266 kph in 33 states and the District of Columbia (Peterman et al., 2009; FRA, 2016). These speeds are much lower than high-speed trains in other countries, but this upgraded railway network plan, referred as to High-Speed Intercity Passenger Rail (HSIPR), will provide improved travel speed, safety, travel experience, and passenger capacity.

[1] Kim, Hyojin, Sultana, Selima, and Weber, Joe. 2019. This manuscript is submitted to *Journal of Transport Geography*.

It is expected that the planned upgraded speed of this system will result in significant change to intercity travel patterns. Like similar systems in Europe and Asia, it is expected to reduce highway congestion while allowing for increased travel frequency for Americans. This in turn can ultimately foster economic activities and better social inclusion across cities (Banister and Berechman, 2001; Garmendia et al., 2012). The degree of benefits stemming from the HSIPR infrastructure derives from locational advantage, which can be measured by accessibility. Past studies of the effects of high-speed trains have focused on improved cost-benefits (Levinson, 2010) and forecasting ridership for planned HSIPR infrastructures (Peters et al., 2014). There has not been detailed investigation of the geographical impact of HSIPR specific to individual cities within the U.S.

The impacts of HSR in various countries have been well studied using various accessibility and network analyses (e.g., Vickerman, 1997; Cao et al, 2013; Monzón et al., 2013; Kim and Sultana, 2015; Jiao et al., 2017). Studies have only taken into consideration the rail network (Kotavaara et al., 2011), yet HSR competes with other transportation modes such as highways and airlines (Campos and de Rus, 2009; Adler et al., 2010; Behrens and Pels, 2012; Cao et al., 2013). For example, fast trains can supplement airline travel under the hub-and-spoke system by enabling direct travel between non-hub cities. The evaluation of the locational benefits of HSR needs to include other types of transportation (Park, 2006; Adler, et al., 2010; Albalate et al., 2015). This study evaluates the impact of HSIPR in the U.S. using location-based accessibility measures with a multi-modal transportation network to consider modal competition.

3.2. Background

3.2.1 The Concept of Accessibility

For this study, accessibility refers to the potential for opportunities of spatial interaction that are supported by transportation (Hansen, 1959), which has been broadly used in assessing and estimating the impact of new transportation infrastructure in transportation planning research. The concept and measurement of accessibility is important for transportation researchers and planners because it evaluates the impact of transportation systems on travel and land-use patterns. Accessibility has been used in various fields, such as location choice, travel demand forecasting, and land use (Handy & Niemeier, 1997). By increasing accessibility, new transportation projects have the chance to attract greater interactions and related economic growth (Sun & Mansury, 2016).

The concept of accessibility pursues practical applications in policy-making processes, while the measurement of accessibility is more central to transportation research (Páez et al., 2012). There are two components that influence accessibility measurement: ease of access and attractiveness of location (Páez et al., 2012). The first refers to the ability to move through space, which varies by mode of transportation, travel budget, and other factors, while the second identifies the number and significance of destinations that can be reached.

Geurs and van Wee (2004) identified four types of accessibility measures: infrastructure-based, location-based, person-based, and utility-based measures. Infrastructure-based measures evaluate accessibility by the service level of infrastructure, such as the length of a transportation network or its level of congestion (Geurs & van

Wee, 2004). Location-based accessibility measures include cumulative opportunities and gravity-based accessibility, the latter using a distance decay function. Cumulative opportunities calculate the number of opportunities within a given distance or travel time (Geurs & van Wee, 2004; Handy & Niemeier, 1997) while gravity-based accessibility, or potential accessibility, measures the adjacency of opportunities (Geurs & van Wee, 2004; van Wee et al., 2001). The closer the opportunity, the higher the potential accessibility. Person-based measures analyze the mobility of individuals within a given time budget. Utility-based accessibility measures, which are based on microeconomic theory, analyze the probability of a choice of one discrete activity in spatially distributed activities (López et al., 2012). The measure is based on random utility theory using log sums and is supplemented by the doubly constrained entropy model. Though the utility-based accessibility measure is difficult to interpret, it is relevant to social and economic perspectives on transportation projects, as it provides a better explanation of relative accessibility benefits despite low absolute improvement (Geurs & van Wee, 2004; Páez et al., 2012).

From the perspective of regional development, one of the most important economic effects of accessibility is the improvement of locational position, which is generally related to location-based accessibility measures (Givoni, 2006; Gutierez et al., 2001; Martin, 1997; Monzón et al., 2013). Accessibility can be interpreted as the potential of a location determined by travel cost, as well as the attractiveness of a location based on spatial distribution of travel behaviors (Handy & Niemeier, 1997; Páez et al., 2012). This concept of accessibility has been used for evaluating the impact of transportation infrastructure (Vickerman, 1997), location of facilities for welfare (Páez et al. 2012), and commuting convenience (Foth et al., 2013; Gregg, 2013). Improving accessibility is a common goal in almost all transportation plans (Handy & Niemeier, 1997); thus, the expansion of the transport network is justified. Also, accessibility affects the configuration of economic activities such as the location of firms and households (Willingers & van Wee, 2011).

3.2.2 Accessibility and Spatial Equity

In recent HSR studies the focus has been on uneven regional development between those cities on the rail networks and others. HSR contributes to the overall efficiency of travel at the national level, yet gaps in absolute and relative accessibility of cities are widened. Vickerman (1997) investigated the implications of a trans-European HSR network from the perspective of regional cohesion and economic potential, comparing the current and planned scenario. The study predicted the concentration of increased accessibility in large cities on the European network. Gutiérrez (2001) found accessibility disparities in Spain. Conversely, Monzón et al. (2013) focused on spatial-equity analysis in recent and future Spanish HSR developments finding that high-speed extension in Spain contributed to rising global equity in accessibility. Similarly, Kim and Sultana (2015) found that the degree disparity of benefits of HSR in South Korea is expected to reduce after the completion of expansion plans.

The disparity issue among cities on high-speed lines has drawn attention to size of city (Vickerman, 1997; Ureña et al., 2009; Kim and Sultana, 2015; Vickerman, 2015). Sufficient demand for ridership demand for HSR exists in large cities, but lack of ridership can be problematic for smaller cities with HSR service (Vickerman 1997; 2015). The later scenario maybe results from the construction costs or corridor planning that often dictates a less central location for stations for intermediate cities (Kim et al., 2018)

3.2.3 Multi-Modal Travel Time in Accessibility

Some accessibility studies have focused on each stage of a journey when calculating travel times (Lei and Church, 2010; Salonen and Toivonen, 2013; Benenson et al., 2017; Chen et al., 2017). This door-to-door approach is helpful when calculating more accurate travel time, including extra travel time for public transportation and waiting time for buses/trains/airplanes. For example, Salonen and Toivonen (2013) conducted a door-to-door accessibility analysis by different modes of transport in Helsinki by calculating multi-modal travel times. Zhao et al. (2015) developed a travel-time accessibility measure based on multi-modal travel time by incorporating waiting time for public transportation; their research shows multi-modal travel time analysis is essential for improving public transportation systems. Chen et al. (2017) also calculated travel-time accessibility based on the multi-modal network in Nanjing and found that the mass-transit system plays a significant role in improving urban mobility. Tasic et al. (2017) evaluated the quality of transportation services by measuring multimodal accessibility in the case Chicago. Calculating multimodal accessibility using public transit, bicycle, and walking, they evaluated the performance of each transportation mode by normalizing multimodal accessibility values finding that the city center has the least equity in accessibility because of the lack of multimodal integration.

A few high-speed rail studies have measured accessibility based on a door-to-door travel time approach (e.g., Kim and Sultana, 2015; Wang et al., 2016; Wang and Duan, 2018). Kim and Sultana (2015) evaluated locational benefits of the Korean HSR according to different time scenarios, which considered the total travel time as the sum of car driving time to/from a station, waiting time for the train, and travel time between stations by train. Wang and Duan (2018) measured location-based accessibility values by adding intra-city travel times to inter-city travel time in their HSR network model of Yangtze River Delta in China.

3.3. Case Study: The High-Speed Rail Plan in the United States

Since the first operation by the Japanese Shinkansen in 1964, high-speed trains have led to a resurgence in rail competitiveness (Givoni, 2006; Campos and de Rus, 2009). HSR's growth can be attributed to advancements in technology for high-speed trains, fluctuations in oil prices, and an increase in attention to sustainable transport due to global climate issues. Due to the benefits of HSR for intercity travel, high-speed trains have been introduced in many European and East Asian countries (Murayama, 1994; Vickermann, 1997; Givoni, 2006; UIC, 2018). The European network reached 7349 km in length as of 2018 and will extend to 21093 km by 2025. China has also rapidly developed a dense high-speed rail network, despite the large territory of the country, reaching 11131 km in 2018. This is expected to ultimately reach 22480 km with the completion of the planned network (UIC, 2019).

HSR network developments in Europe and China have implications for the rail in the United States. The successful operation of high-speed trains and their continual extensions show significant advantages for enhancing accessibility within regions, despite the existing airline and highway network. In comparison to other countries, rail transportation in the United States is much less developed. Acela Express is the only high-speed service in the United States, though the maximum speed remains at 240 kph, which is closer to the semi-HSR standards in other countries. Except for this Northeast corridor, passenger services lag the expansion of interstate highways and aviation networks (Peterman et al., 2009). Additionally, road congestion continues to worsen while over-crowded airports encounter increases in delays (Peters et al., 2014).

In 2009, President Obama declared the development of the high-speed rail network in the United States as a priority (Lane, 2012). Following this, the Federal Railroad Administration (FRA) announced the High-Speed Rail Strategic Plan in 2009, funded by the American Recovery and Reinvestment Act of 2009 (Prum and Cats, 2012). The plan, also called the High-Speed Intercity Passenger Rail plan (HSIPR), focuses on the creation of fast connections between cities through high-speed trains. An amount of $10.1 billion was allocated to upgrade and improve current railways in 33 states and the District of Columbia.

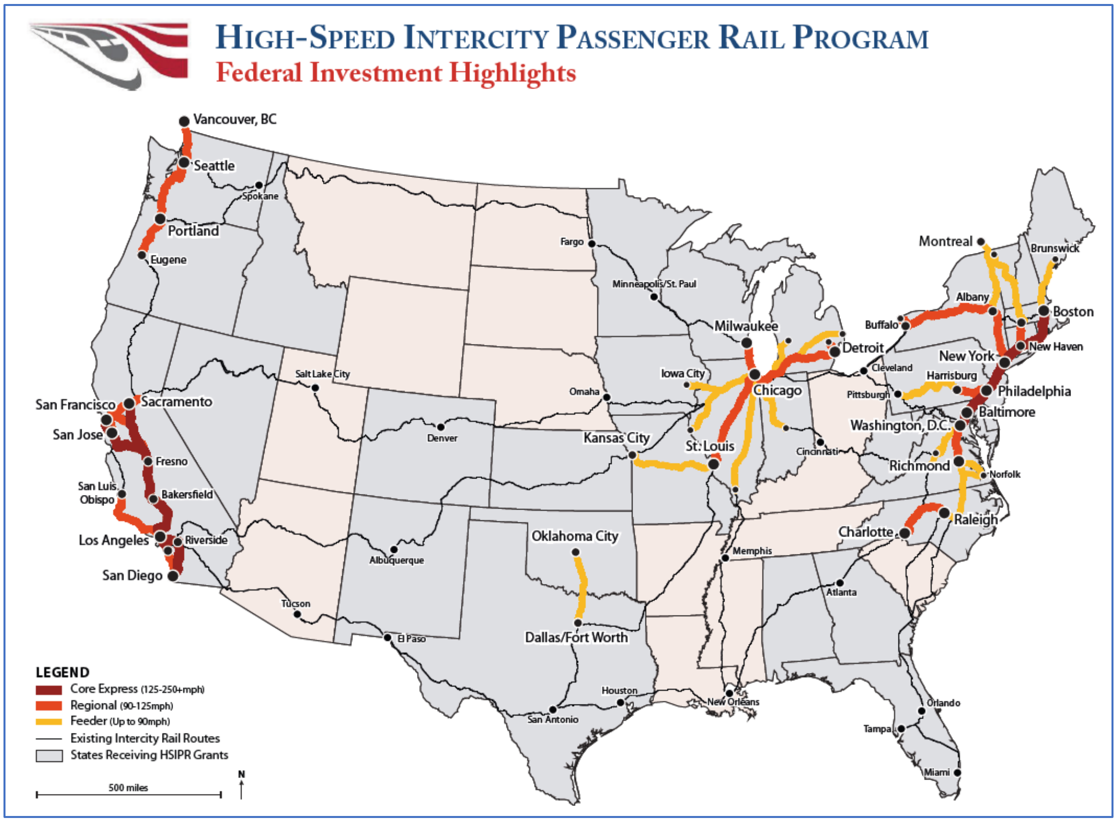


Figure 3.1 High-Speed Intercity Passenger Rail Program (source: FRA)

This HSR project focuses on upgrades to conventional railway (Figure 3.1). There are three strategies included in the proposed HSIPR, according to the population density of a service area: core express, regional service, and emerging services. The FRA applies the “hub” concept to central cities in their plans for the HSIPR network. The Core Express corridor (dark red line on Figure 3.1), supported by the fastest speeds of 200-400 kph, is planned to connect between the dense areas referred to as ‘cores’ or ‘hubs.’ The Regional corridor, with speeds of 145-200 kph (orange line on Figure 3.1), covers travel between a dense city and smaller cities, and would be an improvement to current rail speeds. The Emerging corridors reach speeds up to 145 kph, supporting connections to the Core Express and Regional corridors (yellow line on Figure 3.1).

In the Northeast corridor, New York City is connected to Albany, Rochester, Montreal, and New Haven. In the California corridor, Los Angeles serves as a hub. In Texas, Dallas is the center of connection for Houston, Austin, Oklahoma City, and Memphis. The hub with the largest railway network connection in HSIPR is Chicago, which includes multiple cities on several regional rail lines. Another notable section of the HSIPR is the Southeast region, where Atlanta and Raleigh would serve as regional hubs in the proposed system. Although investment is currently focused on the corridor between Washington, D.C., and Atlanta via Charlotte, this corridor has two important merits. First, it will connect with the Northeast corridor in Washington, D.C., which means the extension of the Northeast corridor to major cities of North Carolina such as Charlotte, Raleigh, and Greensboro. Second, this corridor promotes the interaction of cities around the trunk corridor between Charlotte and Raleigh via Greensboro.

The progress of the HSR project in the United States, however, faces several obstacles. First, despite the economic benefits associated with high-speed trains, the most fundamental issue is the cost of construction, which is estimated at approximately $50-82 million per mile (O'Toole, 2008; Peterman et al., 2009; Button, 2012). For that reason, Florida, Ohio, and Wisconsin rejected it out of concern for budget deficits, though California proceeded with an ambitious construction program. Also, the actual operation of high-speed trains is somewhat distant. Train speed in most corridors remains 145-175 kph, which is far slower than that of high-speed trains in other countries (Johnson, 2012).

The increased speed is still greater than the speed of highway traffic, making rail attractive in many corridors with heavy road and air traffic. Therefore, the HSIPR plan needs to address the doubts surrounding the effectiveness of these trains for intercity travel.

Meanwhile, an additional effort has been progressing in Texas to connect Houston to Dallas (Texas Central, 2018). This line has accepted private investors to help fund it while California HSR has depended on public money. Private funding could be an alternative when a rail project faces financial challenges from public investment.

3.4. Data and Methodology

3.4.1 Data

We conducted an accessibility analysis of 377 metropolitan statistical areas (MSAs) in the 48 contiguous states to investigate the expected locational effects due to improvements in the rail system if the plan is adopted. Population data for 2015 from the U.S. Census Bureau is used for the size of each MSA. Current and future HSR scenarios are based on the plan of Federal Railway Authority and state transportation authorities of Georgia, North Carolina, South Carolina, and Virginia (FRA, 2017).

We developed a multi-modal transportation network (Figure 3.3) combining with road, rail, and air networks for calculating more realistic intercity travel time. A road network containing major streets and highways are obtained from the Census Bureau Tiger files and modified by the authors. This street network is used for calculating intra-city travel times to airports and train stations from various locations. The existing passenger railway network is used for calculating the current intercity travel time by train. The future HSIPR network is used to calculate future intercity travel times. The air network is based on 2015 flight data from the Federal Aviation Administration (FAA).

3.4.2 Methodology

We used two location-based accessibility measures to evaluate the impact of high-speed services in the U.S. Also, we investigated accessibility changes within different distances to evaluate if there are distance ranges in which HSR is superior to other modes of transportation. Figure 3.2 illustrates the methodological framework of the accessibility analysis.

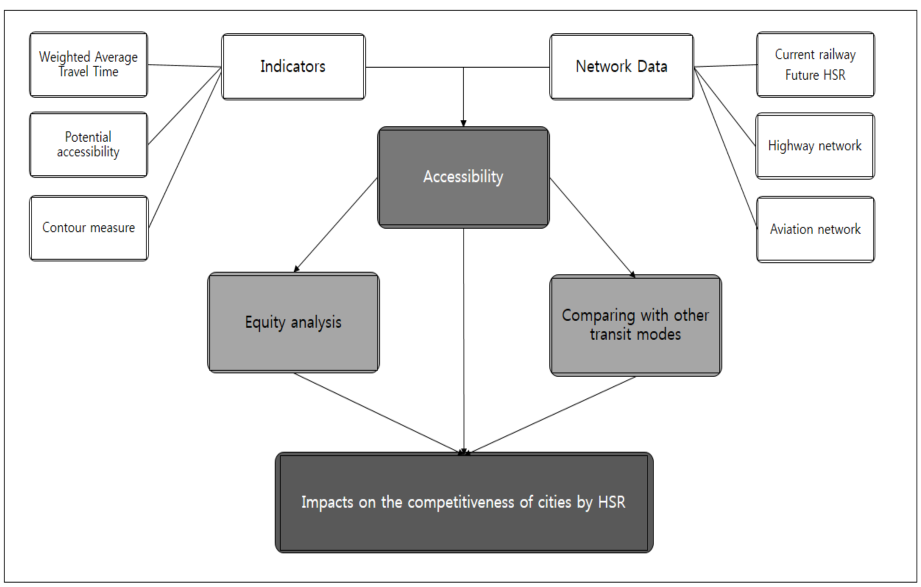


Figure 3.2 Methodological Framework

The weighted average travel time (WATT), called the location indicator, emphasizes the relationship between regions and is useful for analyzing HSR impacts (López et al., 2008; Gutiérrez, 2001; Chang et al., 2008). WATT calculates travel times between each city to all other destinations and considers the mass (populations) of destinations. The mathematical expression is as follows:

$$T_i = \frac{\sum_j M_j \cdot t_j}{\sum_j M_j} \tag{1}$$

where T_i is the accessibility of location i, t_j is the travel time to destination j, M_j is the mass of j.

Another widely used indicator is potential accessibility (PA), which focuses on the opportunity of economic activities in a city influenced by a rail network (Hansen, 1959; Gutiérrez, 2001; Martin et al., 2004; López et al., 2008; Cao et al., 2013). It is a gravity-based measure determined by the volume of the mass of destinations divided by the travel time between them. The potential accessibility indicates the attractiveness of each city by the number of activities and the ease of travel from a location to another location (Gutiérrez el al., 2001; López et al., 2008; Cao et al., 2013; Monzón et al., 2013). The expression is as follows:

$$P_i = \sum_j \frac{D_j}{{t_{ij}}^{\alpha}} \tag{2}$$

where P_i is the potential accessibility of location i, t_{ij} is travel time between location i and j, D_j is the mass of destination j, in our case, it is the total population of the city, and α is a distance friction parameter.

3.4.3 Study Design

We used the Network Analyst extension within ArcGIS for the network modeling and for calculating a travel time matrix. In the multi-modal network, road and railway services are connected at the railway station, which is expected to be a rail station based on the current plan and its city size. Road and air networks are connected at airports (Figure 3.3). After the physical integration of all modes of transportation, transfer time is allocated.

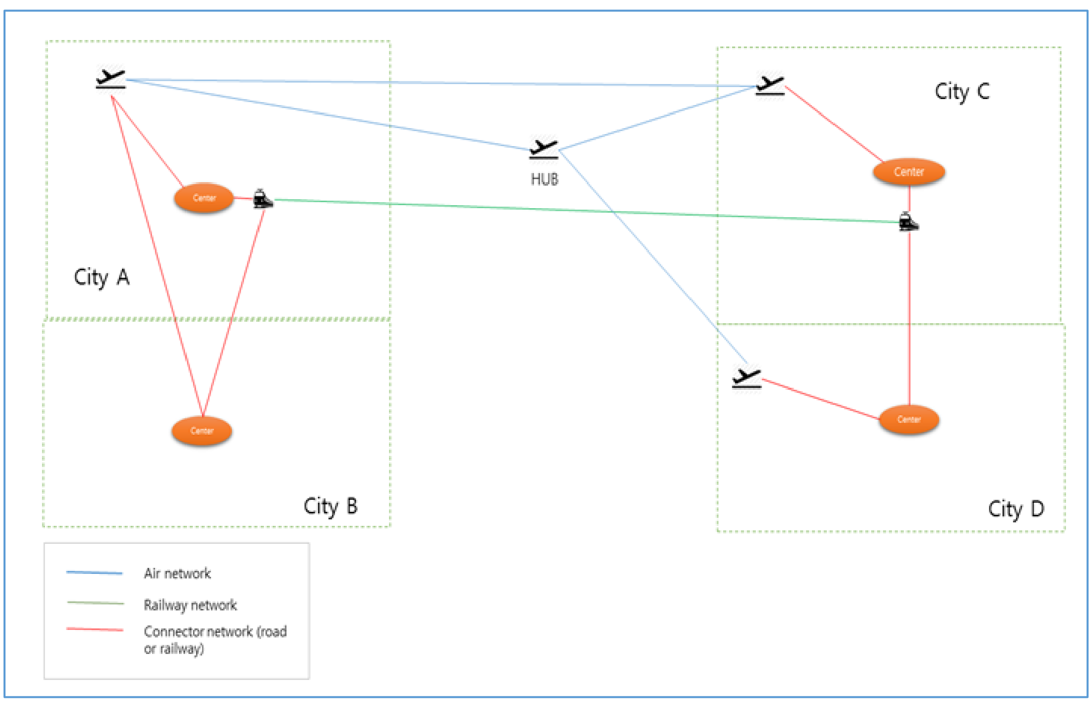


Figure 3.3 The Concept of Multi-Modal Network Model

We considered time spent in the airport two different ways. First, access and egress time are added to total travel times based on airport size. Also, layover time includes check-in, security check-up, waiting, and boarding times. The FAA and TSA provide real-time processing times of security checks (https://www.tsa.gov/mobile), but the information is limited to select airports and varies by terminals within the same airport. For that reason, required check-in times suggested by carriers and the average processing time was used for allocating the expected time for each airport. Total time at the airport was found as follows:

$$T_i = C_i + S_i + W_i \tag{3}$$

where Ti is total time in the airport i and C_i is check-in time. S_i is security check time and W_i is waiting time for flight boarding. Time spent in the airport is categorized by different sizes of airports based on passenger traffic and requirement for bagging cutoff time by multiple airlines such as Delta, American Airlines, and United Airlines (Table 3.1).

Table 3.1 Time Expenditure in the Airport

Groups	Airport Size	Allocated time in the airport (min.)	
		Before boarding	After landing
Group A	Large	116	35
Group B	Middle	85	30
Group C	Small	53	25

Based on the developed transportation network, an accessibility analysis is conducted for the three scenarios of the railway network in the United States:

P1: current railway network

P2: HSIPR (upgrading conventional railways and the new HSR in California)

P3: HSR (proposed full speed HSR projects)

Also, two types of multi-modal network are used for the accessibility analysis. Firstly, the combination of railway and road networks is used for ground transportation. The combination of air, railway, and road networks is used for the total intercity travel network. Travel time for both networks is calculated from to central point to the central point of each MSA. Thus, all destinations are also the center of each MSA where economic activities are concentrated.

3.5. Results

Accessibility of 377 MSAs was calculated for the different HSR scenarios using the WATT and PA accessibility measures. Specifically, the WATT focuses on travel-time reductions in MSAs while the PA values show the increase of the competitiveness of MSAs related to accessibility improvement. As both accessibility measurements are based on the combined road and railway network (ground) as well as the combined road, railway, and air network (ground and air), the results effectively show the expected benefits of HSR scenarios.

3.5.1 Spatial Patterns of Accessibility

Table 3.2 shows the result of WATT and PA accessibility. The resultsshow decreasing WATT and increasing PA values for each HSR scenario, which indicates increased accessibility. The mean WATT value decreased from 1259 to 1148 (an 8.8% reduction) in the case of the ground network after the current improvement of the railway system in the P2. Also, the mean WATT value is expected to decrease again to 1066 after the full HSR plan in P3, an overall reduction of 193 minutes (or 15.3%) from P1 to P3. The mean PA values show an overall increase of 33.1% after P3.

Table 3.2 Accessibility Changes by HSR Phases

Stage	WATT			PA		
	Mean	SD	CV	Mean	SD	CV
P1	1259	295	0.234	177177.9	48895.6	0.276
P2	1148	267	0.233	194343.8	56271.0	0.290
P3	1066	258	0.242	209846.3	65102.1	0.310

Figure 3.4 shows the spatial distribution of WATT and PA for MSAs in the U.S. according to the current and the future HSR plans. The MSAs with the lowest WATT values are mainly located in the eastern United States, including parts of the Midwest, Mid-Atlantic, and Southeast regions. The increased accessibility is also found in the increased proportion of MSAs below 18 hours of WATT, which is expected to increase from 38.7% to 64.9% between P1 and P2. This shows the current railway upgrade projects (P2) significantly increase accessibility despite only limited speed increases.

Specifically, MSAs in the Midwest corridors such as Chicago, Kansas City, and St. Louis will receive decreased WATT scores, lower than 15 hours. The decreased WATT under HSR scenarios P2 and P3 will spread to more MSAs to the Northeast as well as the Southeast. To be specific, the number of MSAs of WATT under 15 hours will increase from 10 to 116 between P2 and P3. Also, the increase of accessibility by the full HSR in P3 will be concentrated along the high-speed corridors, especially in the Southeast corridor via Charlotte and Raleigh. MSAs in the West, such as Los-Angeles, Phoenix, and San Francisco also show an increase of accessibility despite their locational disadvantage on the periphery of the transportation network.

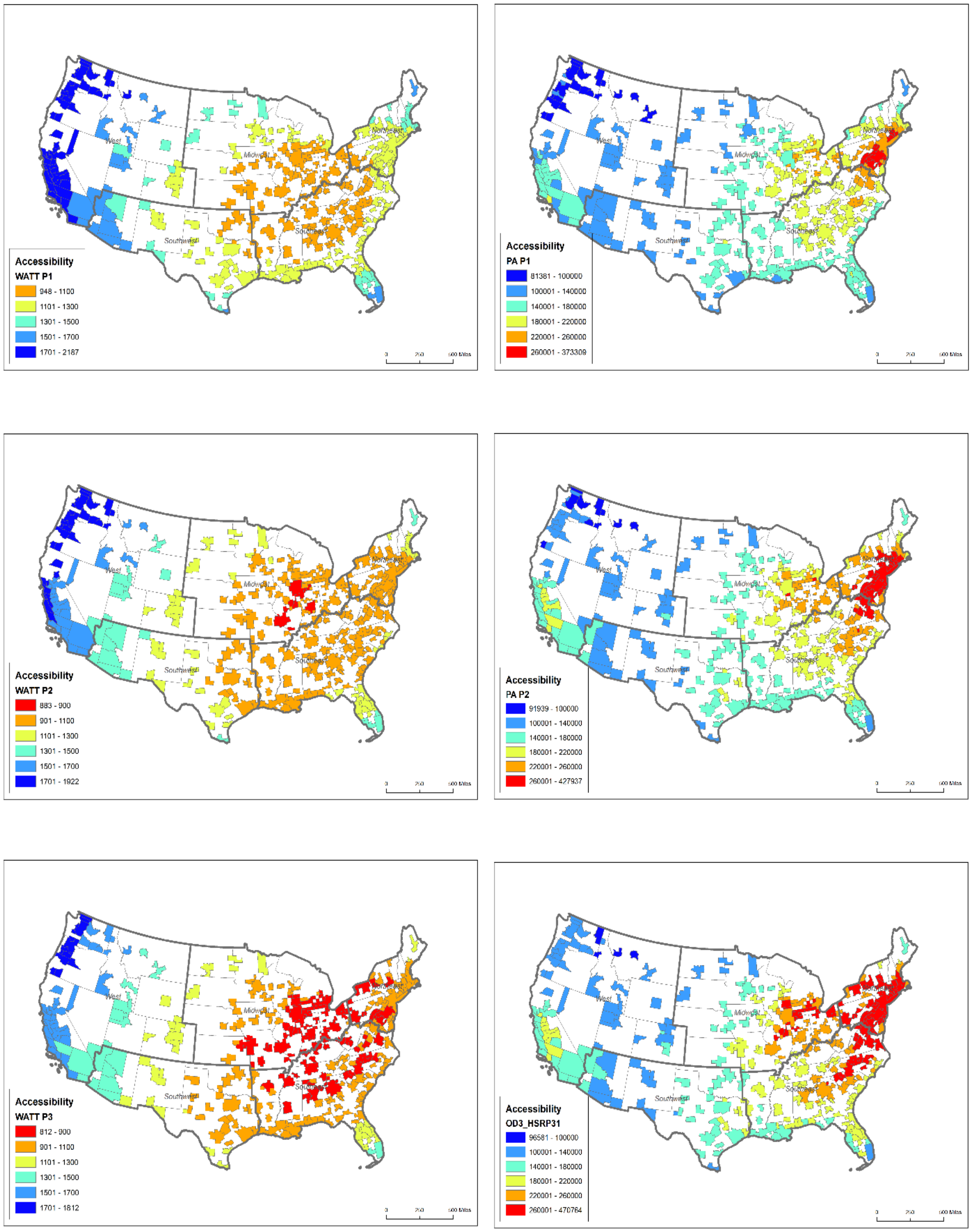
The improvement of potential accessibility (PA) has different spatial patterns compared to changes in WATT accessibility. High PA values are concentrated in the Northeast, particularly Boston and New York City, and MSAs adjacent to the Northeast Corridor in North Carolina are also expected to receive an increase in PA. Western MSAs are also expected to have an increase in PA values. The increase of PA in P3 shows the significant positive impact a true high-speed network would bring to the Northeast and southeast regions, while corridors connected to Chicago also show accessibility increases.

The distribution of potential accessibility in the full HSIPR scenario shows clusters of high or low potential accessibility. Clusters of high potential accessibility (e.g., higher accessibility on cities around Los Angeles) imply that the area in the clusters has a high chance of attracting economic activities leading to economic growth. Specifically, potential accessibility values are influenced by agglomerations, and hence, a region of dense cities has a high possibility of receiving increased potential accessibility.

For this reason, the Northeast region, which already has high potential accessibility, shows increased values in the HSR scenarios. Interestingly, cities in North Carolina along the Piedmont corridor also show relatively higher accessibility with high-speed trains, because this corridor is directly connected to the Northeast HSR corridor.

3.5.2 Spatial Equity in Accessibility

We also evaluated the spatial equity aspect of accessibility changes due to the railway upgrade scenarios. In this study, we use the coefficient of variance (CV) as an indicator of the degree of the disparity in accessibility values at different stages of railway improvement projects (Table 3.2). Lower CV values indicate reduced disparity in accessibility values. There is a slight decrease of CV of WATT from P1 to P2, but the increased (3.8%) CV value of WATT from P2 to P3 implies that the advantage of travel time reduction will be concentrated in specific locations rather than widely distributed. In addition, CV values of PA show a significant increase during both stages of railway improvement. The values of CV increased by 5% between P1 and P2 and increased again by 6.8% between P2 and P3, creating an overall 12.3% increase between P1 and P3. The results imply that the benefits of the current HSIPR are concentrated on MSAs along railway corridors with HSIPR. Thus, creating a high-speed train system in the U.S. is not expected to increase the spatial equity of accessibility.



(a) WATT by HSR

(b) PA by HSR

Figure 3.4 Changes of Accessibility by HSR Scenario

3.5.3 Regional Distribution of Accessibility

The results of accessibility changes show that the highest increases of accessibility are expected along major railway corridors, so it is necessary to investigate changes in reachable areas by train. Figure 3.5 shows the changes of railway's coverage areas by each MSA in each stage of HSR. We agglomerated the size of a train's service area for each origin and grouped this by travel time (travel times exceeding 5 hours were not considered here as it is not competitive). The figure shows that there is a significant expansion of service area in the range of 3- to 5 hours travel. The average 5-hour threshold area rises from 40,046 square miles to 53,783 square miles between P1 and P3, an increase of 34.3%. Interestingly, the increase of areas reachable by train between P1 and P2 (an increase of 15.6%) is significant while the coverage increases between P2 and P3 (an increase of 16.2%). This result shows that the accessibility gains are expected by the current HSIPR projects in P2 despite the limited improvement of train speed.

Based on Figure 3.5, we investigated the change of areas reachable by train in the regional perspective. Figure 3.6 and Table 3.3 shows that the increase of HSR's impact area is significant especially in Northeast and Midwest. Interestingly, the highest value of 48% increase in the HSR's coverage area is found in the Midwest despite the Northeast region have faster HSR network with more dense populations. That is because a number of railway routes cover the region and at the same time those routes converge on Chicago, which promotes the distribution of accessibility gains. Also, Northeast region show the increase the 5-hour threshold impact area by 86%, which indicates the significant impact of the train speed upgrade to 290 kph in P3.

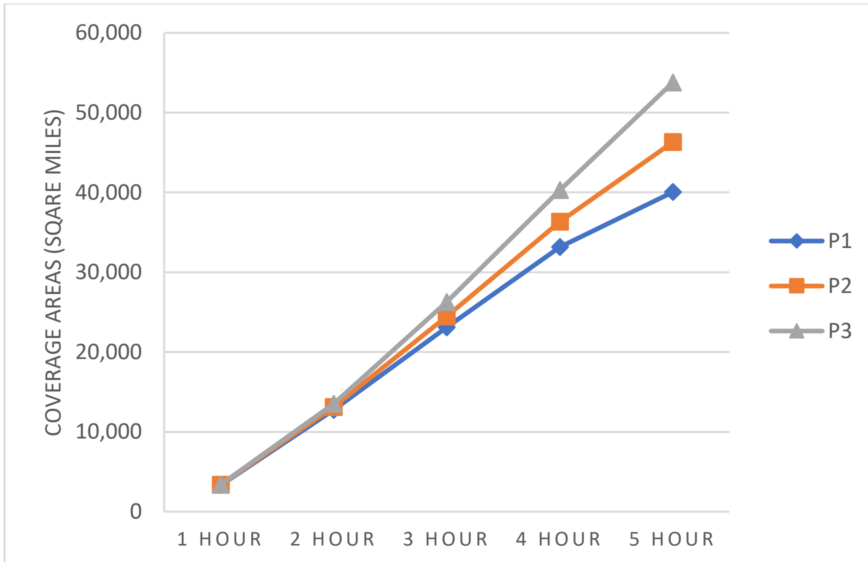


Figure 3.5 The Increase of Averaged Train Coverage Areas by HSR Stages

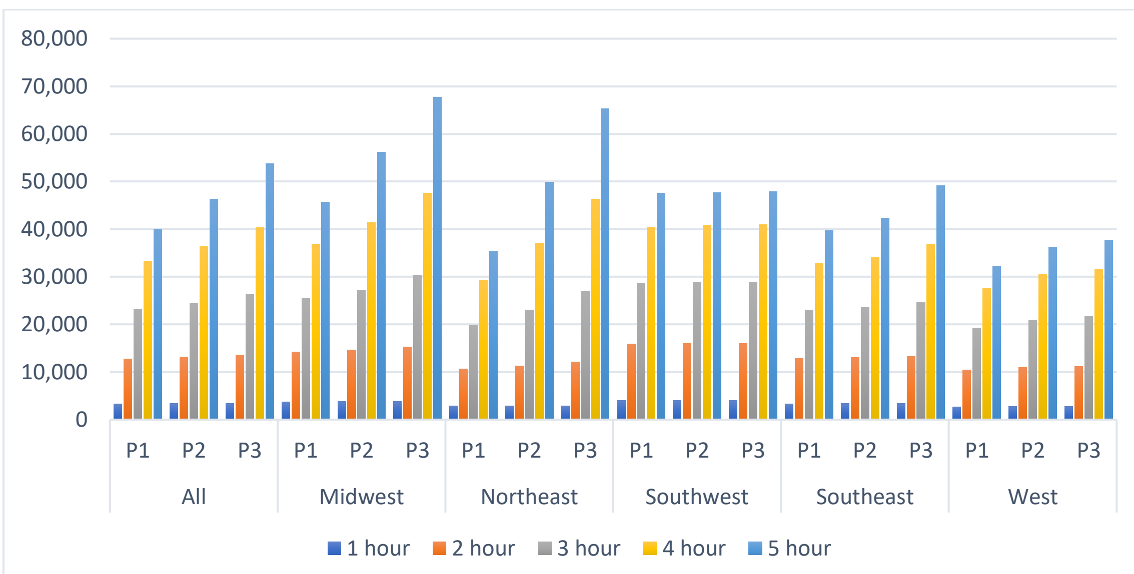


Figure 3.6 The Train's Averaged Reaching Area by MSA in the United States (unit: square miles)

Table 3.3 The Impact of HSR Plan in the United States on People's Inter-City Travel within Various Travel Time Threshold

Region	Stage	Travel time threshold				
		1-hour	2-hour	3-hour	4-hour	5-hour
All	P1	3,318	12,747	23,101	33,158	40,046
	P2	3,368	13,118	24,458	36,338	46,302
	P3	3,392	13,508	26,264	40,315	53,783
Midwest	P1	3,717	14,186	25,487	36,897	45,696
	P2	3,783	14,594	27,267	41,348	56,182
	P3	3,830	15,253	30,217	47,551	67,700
Northeast	P1	2,845	10,596	19,928	29,260	35,283
	P2	2,898	11,296	22,997	37,059	49,865
	P3	2,933	12,141	26,915	46,359	65,274
Southwest	P1	3,995	15,849	28,624	40,480	47,557
	P2	4,026	16,007	28,771	40,871	47,673
	P3	4,033	16,040	28,836	40,993	47,921
Southeast	P1	3,343	12,885	23,024	32,759	39,739
	P2	3,380	13,069	23,509	34,027	42,374
	P3	3,395	13,275	24,707	36,901	49,133
West	P1	2,708	10,434	19,279	27,588	32,298
	P2	2,768	10,947	20,952	30,436	36,288
	P3	2,782	11,150	21,660	31,484	37,714

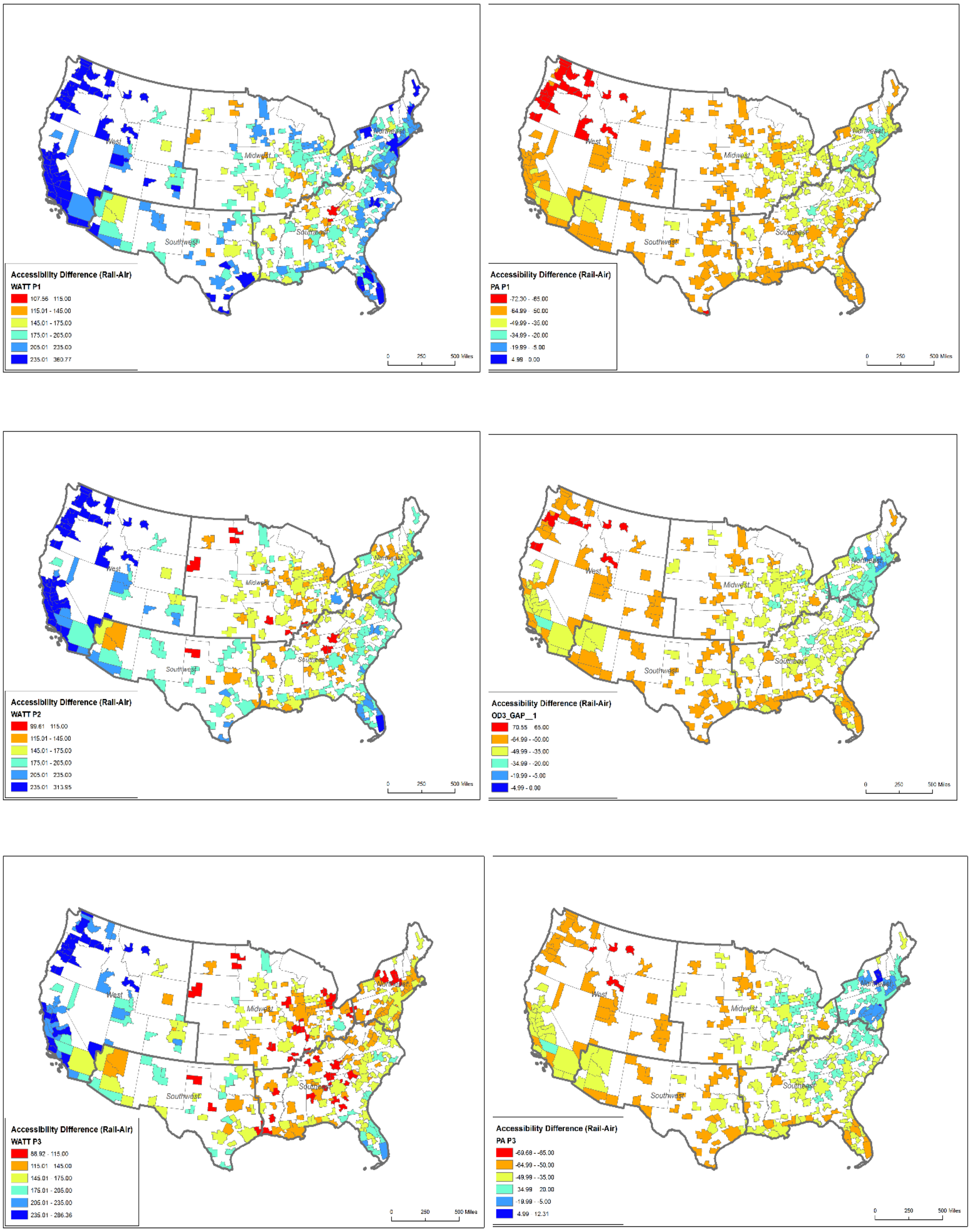
3.5.4 Modal Competition Perspective

The result of the expanded service area by train, especially within 3 to 5 hours travel time, implies the improvement of HSR's competitiveness relative to air services (see Figure 3.7). Additionally, high-speed rail has an advantage of connecting small- and mid-sized cities that have few direct connections within the hub-and-spoke system. Figure 3.6 shows the relative difference of WATT and PA accessibility of each MSA, calculated as Eqs. (3), which can be formulated as follows:

$$Diff_{A_i} = \frac{A_i^{Rail} - A_i^{Air}}{A_i^{Air}} * 100 \quad (4)$$

where A_i^{Rail} represents the accessibility of location *i* by rail while A_i^{Air} represents the accessibility by air. Lower value of WATT accessibility indicates a superior improvement of rail services over air services to MSA i. Figure 3.7a shows that more MSAs are expected to obtain benefits of HSR in travel time under the P2 and P3 scenarios. The results especially show that HSR can be competitive in many MSAs in the east coast and central regions of the United States including Detroit, Madison, Albany-Schenectady-Troy, Champaign-Urbana, Jefferson City, Tuscaloosa, Lake Charles, and Greenville, South Carolina, especially in the case of full speed trains in P3.

Similar to WATT, the relative difference of PA between high-speed trains and airplanes shows increasing competitiveness of HSR over air transport in P2 and P3 (Figure 3.7b). The higher value of the relative difference of PA indicate the decrease in the gap between HSR and air, although the relative growth of PA by rail mainly appears on MSAs in the northeastern region of the U.S., such as Albany-Schenectady-Troy, Philadelphia, Hartford, and New York City.



(a) Relative difference of

(b) Relative difference of PA

Figure 3.7 Modal Competition between Rail and Air Transportation

3.6. Discussion and Conclusion

The high-speed rail system is a form of mass transportation that emerged during the past half-century. Countries creating HSR systems have experienced changes in the spatial structure of their urban systems due to the impacts on flows (Sasaki, 1997; Perl and Goetz, 2014). Various studies have been conducted to evaluate the impact of a high-speed system or for a future network plan, along with their implications for regional economic development. Those studies have been popular in Europe (Gutiérrez et al., 1996; Vickerman, 1997) with the integration of European high-speed rail, and recently in China with the rapid construction of a high-speed rail system (Cao et al., 2013).

There has been little research on the potential impact of HSR in the United States. We have conducted an accessibility analysis, mainly focusing on plans to create a high-speed system, from the perspective of locational benefits of cities in the country. We used two location-based accessibility measures: WATT and PA, with a multi-modal transportation network that considers passengers' multiple uses of transportation for intercity traveling and includes waiting time, access/egress time, and transfer time. Based on this model, we examined intercity travel time in the case of rail services and air services to examine if HSR will be competitive with other modes.

The improvement of railway infrastructure shows that significant locational benefits by HSR will be expected in the United States, like that of other countries' systems (e.g., Gutiérrez, 2001; Cao et al., 2013; Kim and Sultana, 2015). We found that both WATT and PA will increase in the current progressing HSIPR (P2) and the planning process or proposed full HSR (P3). The current progressing HSIPRwill improve accessibility to the cities throughout the network. The spatial patterns of both WATT and PA are slightly different based on their different measurement process. Low WATT values, indicating lower average travel times, are found in the Midwest and east coast of the U.S., but would expand with a full high-speed system (P3). The high PA values are strongly concentrated in the Northeast region in the U.S.

We also found that the investment in HSIPR in the U.S. will improve the competitiveness of rail services relative to air services which dominate intercity travel. According to our accessibility analysis, some areas are expected to narrow the gap of accessibility between rail and air. This implies that HSR will reduce travel times between peripheral cities in a hub-and-spoke air system as well as between various core cities in the network. It is also supported by another result in this study that the reachable area by train within 5 hours travel time is expected to increase after the current and the future rail plans are completed.

The results of this study imply that the continuous investment in the construction and extension of the HSR network is essential to maximally distribute the benefits of HSR from the perspective of regional development at the national scale (Gutiérrez et al., 2010). In the case of the U.S., the significant improvement of accessibility in the future HSR (P3) is expected to relieve the disparity of accessibility benefits across the county. The results of this study are focused on changes in locational advantages to the city level, so accessibility analysis at the regional/local level would show HSR's implications for urban development. In future research, an analytical tool reflecting mode choice needs to be considered for improved multimodal accessibility.

CHAPTER IV

PREDICTING THE ROLE OF RAILROAD SPEED IN REGIONAL DEVELOPMENT: AN ACCESSIBILITY APPROACH IN THE SOUTHEAST CORRIDOR OF THE UNITED STATES[2]

4.1. Introduction

Over the past decade there has been a revolution in the speed of intercity traveling thanks to the emergence of high-speed rail (HSR) in Asia and Europe (Givoni, 2006). HSR generally reduces travel times between and within cities, resulting in dramatic shifts in land-use and travel patterns (Diao et al., 2016; Givoni, 2006; Marti-Hennenberg, 2015; Yin et al., 2015). These shifts will increase the accessibility of cities, regions, or even countries, which in turn will generate opportunities for regional economic growth and cohesion (Aschauer, 1989; Brinsma & Rietveld, 1993; Monson et al., 2019). Likewise, ambitious plans for an HSR system in the United States have been underway (Peterman, 2016), but there are few studies that have evaluated how such a system would impact regional or urban development.

Accessibility analysis has been used to investigate which cities gain or lose locational benefits after the construction of high-speed trains (Gutiérrez, 2001; Sánchez-Mateos & Givoni, 2012; Wang & Duan, 2019) and hence further concerns has been raised from the perspective of equity issues. When high-speed trains are in operation, an

[2] Kim, Hyojin, Sultana, Selima, and Weber, Joe. 2019. This manuscript is submitted to *Transportation Research Part A: Policy and Practice*.

accessibility gap may emerge because of the different location of cities on or off the system (Vickerman, 2015). With faster connections between selected cities, the distribution of HSR's benefits must needs to be considered. HSR research has already focused on this disparity between cities in Europe and Asia (Cao et al., 2013; Gutiérrez et al., 2001; Kim & Sultana, 2015; Monzón et al., 2013; Vickerman, 1997), yet few studies have focused on the disparity of accessibility gains within cities (Ureña et al., 2009).

The United States High-Speed Rail Strategic Plan (HSIPR) has been in development since 2009. The HSIPR aims to connect selected major cities via high-speed trains and improve the performance of regional rail networks. However, the plan is experiencing slow progress due to funding shortages and a lack of resources for railway planning (Peterman, 2016). The only portions of a true full-speed HSR will be found in California and the Northeast Corridor between Washington, D.C. and Boston soon. The Southeast Corridor between Washington, D.C. and Atlanta, Georgia, has seen upgrades, and there has also been research done on the benefits of a full high-speed upgrade in the future (Federal Railroad Administration [FRA], 2016; Levinson, 2012). The Southeast Region covers 11% of the area of the United States and had a population of 68 million in 2010, giving it 22% of the US population. Air services or personal vehicles are the main transportation options in the Southeast, as there is limited access to rail services. Given the distribution of population along the rail corridor it is likely that improved rail transport could become competitive with air travel. In 2010 the Northeast Rail Corridor carried 6% of travelers between Washington, D.C. and Boston, compared to 5% by air services (O'Tootle, 2011).

This paper focuses on the impact of high-speed trains from a perspective on equity, using the case of the Southeast HSR Corridor of the United States as an example. First, we evaluate the background and impact of high-speed services by measuring accessibility with different approaches, such as with multimodal networks or a multiscale unit of analysis. Second, the impact of the Southeast HSR plan is examined with accessibility calculations based on the multimodal transportation network. Third, we evaluate changes in accessibility within cities. Finally, we examine how the high-speed plan influences the degree of spatial equity within accessibility among cities in the study area.

4.2. Literature Review

4.2.1 Accessibility in High-Speed Rail Research

The term accessibility is generally defined as the potential opportunity for spatial interaction among spatially separated human activities promoted by transportation (Hansen, 1959). Accessibility has been used as an indicator of evaluating how high-speed rail improves the competitiveness of each city from the perspective of regional development (Martin, 1997; Vickerman, 1997; Gutiérrez, 2001; Givoni, 2006; Monzón et al., 2013; Cao et al., 2013; Kim and Sultana, 2015). The accessibility values typically indicate the attractiveness of each node within a transportation network (Bruinsma and Rietveld, 1998). The distribution of the accessibility values has been used to evaluate the impact of new transportation infrastructure, the location of facilities for welfare, and commuting convenience (Páez et al. 2012; Foth et al., 2013; Culver, 2016). This approach has been used in HSR studies as it easily determines cities that most benefit in terms of their accessibility impacts (Sánchez-Mateos, and Givoni, 2002; Wang and Duan, 2017).

Accessibility measures can be classified into four types: infrastructure-based, location-based, person-based, and utility-based measures (Geurs and van Wee, 2004; Páez et al., 2012). Among these various accessibility measures, location-based measures have been applied to HSR research by incorporating the distribution of spatial activities at different locations (Vickerman et al., 1999; Gutiérrez, 2001; Monzón et al., 2012; Kim and Sultana, 2015). Specifically, location-based measures include cumulative opportunities and gravity-based accessibility, using a distance decay function. Cumulative opportunities calculate the number of opportunities within either a given distance or travel time and gravity-based accessibility, and potential accessibility measures the adjacency of opportunities (Handy and Niemeier, 1997; van Wee et al., 2001; Geurs and van Wee, 2004). Because location-based accessibility calculates the cumulative opportunities and the adjacency of opportunities, this can be applied to evaluate the increased competitiveness of cities after HSR construction (Martin, 1997; Vickerman, 1997; Gutiérrez, 2001; Givoni, 2006; Monzón et al., 2013; Cao et al., 2013; Kim and Sultana, 2015; Jin et al., 2017). From this perspective, increased accessibility of cities served by HSR is assumed to have effects on changes in land use patterns and property values due to the improved locational attractiveness, which leads in turn to employment growth and greater social inclusion (Givoni, 2006; Marti-Hennenberg, 2015; Yin et al., 2015; Diao et al., 2016).

From the perspective of regional and urban development, the increase of accessibility values can be used to estimate the benefits of the expansion of the HSR network, which helps justify the construction of high-speed rail and the further expansion of the transport network (Vickerman, 1999; Martin et al., 2004). In this context, various studies on the impact of HSR have been conducted in Europe (Gutiérrez, 2001; Monzón et al., 2013) and East Asia (Cao et al., 2013; Jiao et al., 2014; Kim and Sultana, 2015). Jin et al. (2017) conducted accessibility analysis to measure the impact of high-speed trains due to an integrated network in East Asia. They expected this integrated network would significantly reduce travel time especially between core cities and those along the trunk lines such as Beijing-Shanghai and Beijing-Guangzhou in China, Seoul-Busan in South Korea, and Tokyo-Osaka in Japan.

4.2.2 Measuring the Impact of HSR

The growth of high-speed rail has brought attention to its advantages in the role of intercity transportation, and many studies have used accessibility measures to anticipate the benefits of new HSR plans (Chang & Lee, 2008; Gutiérrez, 2001). Among various concepts of accessibility, location-based measures have been used as an indicator of evaluating how HSR improves the competitiveness of a city in regard to regional development (Cao et al., 2013; Givoni, 2006; Gutiérrez, 2001; Kim & Sultana, 2015; Martin, 1997; Monzón et al., 2013; Vickerman, 1997).

With the expansion of high-speed networks in Europe, HSR research initially focused on the effect of regional integration and political and economic cohesion of provinces or countries (Gutiérrez et al., 1996; Gutiérrez, 2001; Vickerman, 1997). Likewise, studies of HSR and its emerging networks in East Asian countries have focused on changes of accessibility as an indirect measurement of expected economic benefits (Cao et al., 2013; Chang & Lee, 2008; Kim & Sultana, 2015). However, several studies have pointed out the uneven achievement in regional development due to high-speed systems between those cities on the network and those left off it. While HSR contributes to the overall efficiency of travel at the national level, the gaps between the absolute and relative accessibility of cities are widened between their connection and disconnection with HSR (Kim & Sultana, 2015; Monzón et al., 2013).

Location-based accessibility measures have been used to evaluate the benefit of HSR. Within this, two measures have generally been used: weighted averaged travel time and economic potential (Cao et al., 2013; Gutiérrez et al., 1996; Gutiérrez, 2001; Kim & Sultana, 2015; López et al., 2008; Monzón et al., 2013). Specifically, weighted average travel time (WATT) indicates the expected travel time benefits of a new HSR project, whereas potential accessibility (PA) focuses on how opportunities change economic activities based on a gravity model using distance decay functions. Gutiérrez (2001) used these three accessibility measures to evaluate the impact of a future HSR plan from Madrid to the French border and found that the planned line significantly reduced travel time. Cao et al. (2013) also calculated accessibility values by using the WATT and potential accessibility measures to evaluate changes of accessibility after the construction of an HSR network in China and found major cities in eastern China showed high attractiveness due to their locational advantage and dense population.

Previous studies have mainly focused on the impact of HSR on major cities with either efficiency or equity perspectives, but a lack of attention to small- and medium-sized cities has been noted by previous studies when assessing the benefits of HSR projects (Vickerman, 2015). For instance, regarding the inequality of HSR's locational benefits, a few studies focused on the location and size of cities along HSR routes. Generally, small- or medium-sized cities do not receive immediate benefits from high-speed lines because they have no direct connection with HSR. Also, their limited size does not attract as many passengers and therefore does not promote the desired social and economic interactions. Vickerman (2015) investigated the intermediate HSR stations of France and found limited economic growth within those cities. Kim and Sultana (2018) evaluated the performance of HSR stations in South Korea and found that there was a relatively low performance in the intermediate stations located in the small- or medium-sized cities.

4.2.3 Multiscale Accessibility Analysis

In spatial analysis, researchers generally weigh the scale of analysis because the choice of a boundary configuration will affect the degree of agglomeration, which then produces different conclusions. This situation is known as the "modifiable areal unit problem (MAUP)" (Fotheringham & Wong, 1991). The effect of the MAUP has been considered in urban and transportation research (Ortega et al., 2014; Taaffe et al., 1963, p. 517), including accessibility analysis (Kwan & Weber, 2008; Ortega et al., 2014; Pereira et al., 2019). The measurement of accessibility is commonly done using the centroid of vector-based areal units, such as cities or census units, or using raster-based grid cells with different spatial resolution. The results of such accessibility analysis by different areal units have been investigated to better understand the impact of accessibility in various perspectives of scale, as well as the effect of the MAUP (Gutiérrez et al., 2010; Gutiérrez et al., 2011; López et al., 2008; Ortega et al., 2014).

Previous HSR studies have two different approaches for choosing areal units for the accessibility analysis: the macro-scale and micro-scale. Some have conducted accessibility analysis at the macro-scale, such as cities or metropolitan areas (Chen & Haynes, 2017; Gutiérrez, 2001; Jiao et al., 2017; Kim & Sultana, 2015; Kotavaara et al., 2011; Ureña et al., 2009). This approach is necessary for evaluating the impact of a new HSR from the perspective of the entire urban system and regional development strategies, which can be essential for justifying the costly investment. Specifically, the distribution of accessibility to and around cities can be used to determine which cities will receive relative advantage or disadvantage from high-speed projects (Cao et al., 2013; Jiao et al., 2017; Kim & Sultana, 2015). However, the results of accessibility analysis at the macro-scale have limitations in explaining the impact of HSR in an urban context. This is because the accessibility results are commonly derived from the travel time calculation between centroids representing the core of a city, which results in the elimination of local variations in accessibility.

Considering this limitation, some studies have conducted accessibility analysis at a smaller scale, the so-called micro-scale, within cities. Interpolation is one method used to estimate the distribution of accessibility from the results of macro-scale analysis. For example, Monzón et al. (2013) used interpolation techniques to map accessibility values of Spanish cities to show the distribution of accessibility changes after high-speed service extensions in more detail. Beyond focusing on the visualization of details, some HSR studies have conducted accessibility analysis at the micro-scale, using census tracts, traffic analysis zones, or by rasterizing vector data layers at a fine resolution (Ortega et al., 2018; Wang & Duan, 2018). Results of this approach show detailed accessibility values or changes.

In addition, a few HSR studies have evaluated accessibility changes with a multiscale approach (Gutiérrez et al., 2010; López et al., 2008; Ortega et al., 2012; Wang & Duan, 2018). This approach conducts accessibility analysis at different scales, allowing researchers can find insights into the impact of faster trains when investigating various research proposals. For example, Wang and Duan (2018) evaluated the impact of HSR on cities in the Yangtze River Delta Region in China by analyzing the changes of accessibility and spatial equity at different scales. Specifically, they conducted accessibility analysis based on 100 m × 100 m grid cells, and the accessibility values were aggregated into administrative units to find which cities gained or lost accessibility. Additionally, the accessibility results from this small grid cell have been used for spatial equity analysis to investigate the disparity of accessibility considering intra-city accessibility to train stations (Ureña et al., 2009).

4.3. Methodology

4.3.1 Study Area: Southeast HSR Corridor

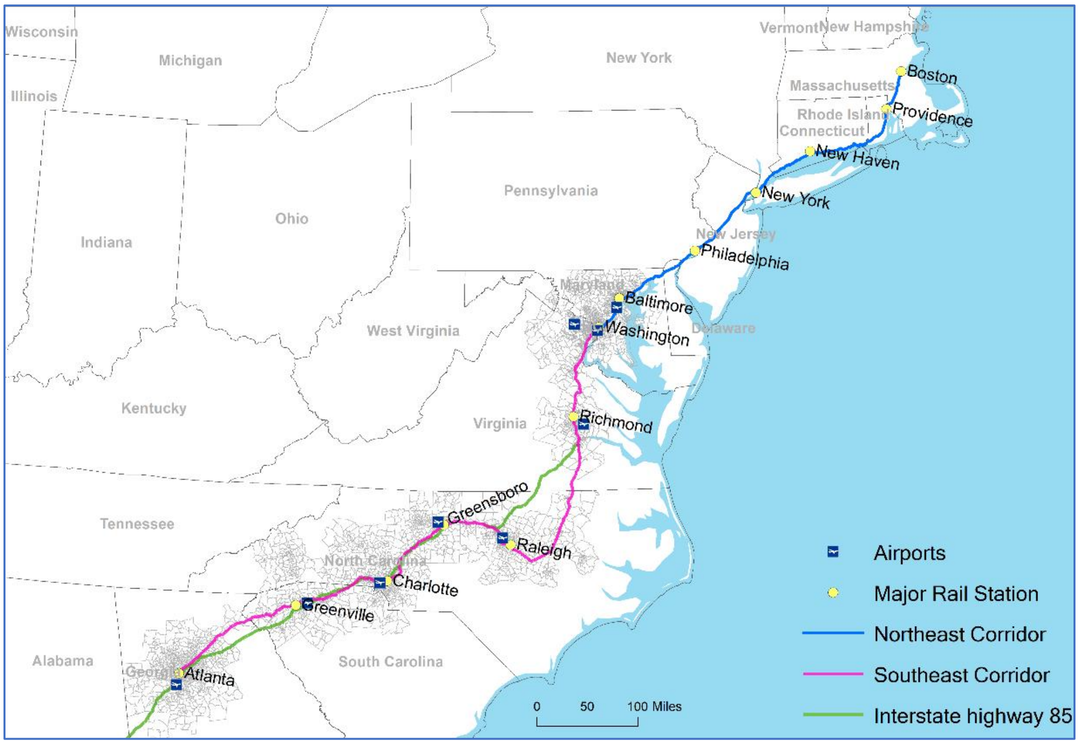


Figure 4.1 Study Area: Southeast HSR Corridor.

Since 2009, the High-Speed Rail Strategic Plan (HSIPR) program has provided a blueprint for upgrading intercity passenger rail services in the United States (FRA, 2016; Prum & Cats, 2012). The HSIPR program has two planning stages. The first refers to current investment that is focused on a new high-speed route between Los Angeles and San Francisco in California (cancelled in early 2019), the upgrade of conventional railway infrastructure for a minor speed upgrade and adding train capacity. The second stage of the HSIPR focuses on new construction to connect major cities with high-speed trains, capable of reaching speeds up to 289 kph. One of these new routes is the Southeast Corridor.

The Southeast Corridor stretches from Washington, D.C., to Atlanta, Georgia, through Richmond, Virginia, and south to Raleigh, Greensboro, and Charlotte in North Carolina along with Greenville, South Carolina (the pink line in Figure 4.1). It also has a branch route to Norfolk, Virginia. This route is connected with the Northeast Corridor that runs from Washington, D.C. to Boston, via Philadelphia, Pennsylvania and New York City (the blue line in Figure 4.1). The Southeast Corridor also connects to areas farther south, such as Florida and Alabama, but here we only focus on the corridor as it is defined by the Federal Railroad Administration, from Washington, D.C., to Atlanta.

The Southeast HSR Corridor passes through 20 urbanized areas in Virginia, North Carolina, South Carolina, and Georgia and reaches 22 million people, as of 2015. According to Amtrak in 2015, the ridership of rail services in the Southeast Corridor increased from 703,000 in 2005 to 1,339,000 in 2014, a jump of 90%. However, air travel is a major mode of long-distance transportation in this region. There are three major airports in Atlanta, Charlotte, and Raleigh, which served 156 million passengers in 2017. In addition, airports in Greenville, Greensboro, and Richmond also serve domestic travelers. The highway system is also a close competitor; the Southeast Corridor runs parallel to Interstate 85 (I-85) from Atlanta to Petersburg, Virginia. I-85 serves as the major transportation route for northeast Georgia, upstate South Carolina, and the three major metropolitan areas of North Carolina. To deal with the heavy traffic volume and congestion along I-85 massive projects are underway to add lanes in Georgia and South

Carolina. Adding more and faster train service could lighten the motor traffic burden along the Southeast Corridor as well as compete with air service.

4.3.2 Accessibility Measurement

This study mainly uses the two location-based accessibility measures, weighted average travel time (WATT) and potential accessibility (PA), to estimate the locational benefits of the two stages of high-speed rail planned for the Southeast Corridor (Figure 4.1). WATT focuses on the relationship between cities from a travel time perspective, as well as the relationship between cities in regard to the impact of HSR by reduced intercity travel time, which has been commonly used in research (Cao et al., 2013; Chang et al., 2008; Gutiérrez, 2001; Kim & Sultana, 2015; López et al., 2008). WATT measures travel time between a city to all destination cities and considers the total mass of destination cities. The mathematical expression is as follows:

$$T_i = \frac{\sum_j M_j \cdot t_j}{\sum_j M_j} \qquad (1)$$

where T_i is the accessibility of location i, t_j is the travel time to destination j, and M_j is the mass of j.

In conjunction, PA evaluates a city's location by considering its opportunities for economic activities and has been widely used in transportation research (Cao et al., 2013; Gutiérrez, 2001; Hansen, 1959; López et al., 2008; Martin et al., 2004). As a gravity-based measure, potential accessibility is determined by the volume of the mass of destinations divided by the travel time between them. The results of PA are interpreted as the degree of each city's attractiveness based on the theory that the mass of destinations, and the ease of travel from one location to another determines its economic potential (Cao et al., 2013; Gutiérrez et al., 2001; López et al., 2008; Monzón et al., 2013). The expression is as follows:

$$P_i = \sum_j \frac{D_j}{{t_{ij}}^{\alpha}} \tag{2}$$

where P_i is the potential accessibility of location i, t_{ij} is travel time between location *i* and j, D_j is the mass of destination *j* (in our case, it is total population by city), and α is the distance friction parameter.

4.3.3 Study Design and Data Sources

As mentioned above, we evaluated the impact of high-speed rail service by calculating accessibility changes based on WATT and PA measures. First, we computed changes in accessibility in the 20 urbanized areas (UAs) along the Southeast HSR Corridor. Then we conducted additional accessibility on the 2,132 census tracts in the intermediate urbanized areas in North Carolina and South Carolina along the Corridor. This was done to investigate the specific distribution of accessibility changes at the local perspective. Population data for 2015 was used and census tract data were collected from the Census Bureau.

Travel time is the main component of accessibility analysis, and we also considered multimodal travel when calculating intercity travel time. We developed a multimodal transportation network and calculated intercity travel time using ArcGIS

Network Analyst. The multimodal network acknowledges that most intercity travel happens through multiple modes of transportation, especially in the case of trains or airplanes. This model considers access/egress times during mode change and waiting time in rail stations. The access and egress times are 15 minutes while 20 minutes is assumed for waiting times. This transportation model also includes two different ways time may accumulates in airport: access/egress and passenger expenditure time. Passenger expenditure time in the airport includes check-in, security check-up, waiting, and boarding time. The Federal Aviation Administration and Transportation Security Administration have provided real processing times of security check-up, but that information is limited to select airports and varies by terminal, despite sometimes being in the same airport. Considering this limitation, the required physical check-in times listed by carriers and the average processing time have been used for allocating expected time for each airport. There are various conditions that influence time spent in airports, but it is difficult to include every condition in the model. To mitigate this limitation, we categorized three groups of airports based on their sizes: large, medium, and small, and allotted different time spent by the airport group. Based on this categorization, access and egress time is given as 25–35 minutes by airport groups in the model.

$$T_i = C_i + S_i + W_i + A_i + E_i \tag{3}$$

where *Ti* is total time expenditure in the airport, *i* and C_i is check-in time, S_i is security check time, W_i is waiting time for flight boarding, A_i is access time to the airport, and E_i is egress time from the airport.

4.4. Results and Discussion

4.4.1 Accessibility Changes at an Urbanized Area Level

Figure 4.2 shows the percentage of WATT change between the current rail network and future HSR. Lower WATT change for a city indicates a relatively high reduction of intercity travel time. Overall, the impact of travel time reduction by future rail construction concentrates on cities along the high-speed corridor. Rail cities in Virginia, such as Richmond and Harrisonburg, show a relatively high percentage of WATT reduction compared to other non-HSR cities in the state. Similarly, cities along high-speed routes in North Carolina, such as Raleigh, Greensboro, and Charlotte, show a relatively higher reduction of WATT after future service construction, but those cities are expected to receive less accessibility changes compared to cities along the Southeast HSR route in Virginia. A significantly high reduction of WATT is found in cities along the corridor in South Carolina and Georgia. Greenville in particular is expected to see the impact of reduced intercity travel time; this implies that Greenville and its adjacent urban areas will be an accessible and presumably economically attractive place. Also, Charleston shows the highest reduction in WATT, which might be a result of multimodal travel time calculation when considering the existing interstate highway.

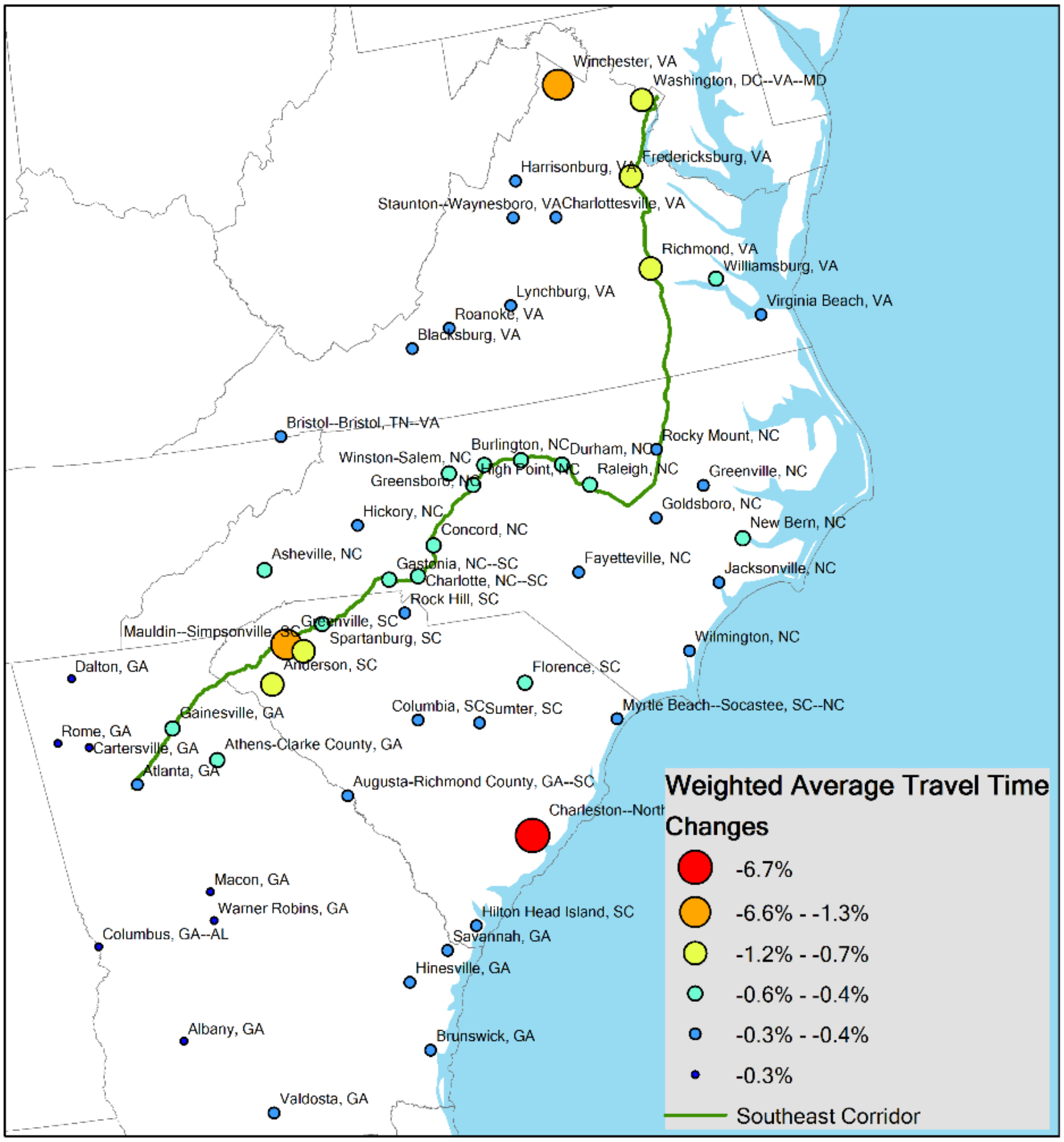


Figure 4.2 Weighted Average Travel Time (WATT) Changes.

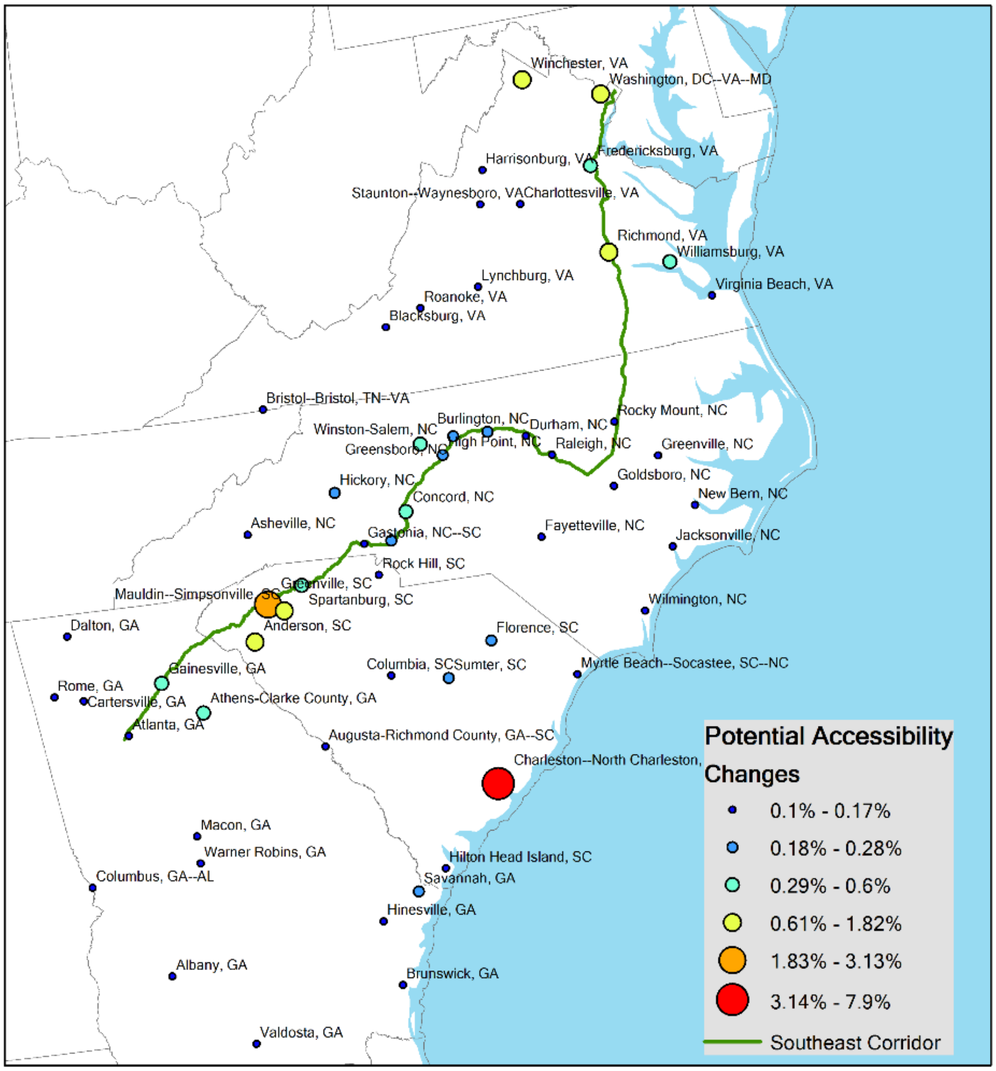


Figure 4.3 Potential Accessibility (PA) Changes.

Figure 4.3 illustrates the percentage of PA changes after future Southeast HSR construction. A higher percentage of PA value indicates that an increase in attractiveness can be expected. First, Greenville and its adjacent cities are expected to receive an increase in accessibility. Richmond also shows a relatively high increase in PA. The improvement of PA is also concentrated along the Southeast Corridor in North Carolina in cities such as Winston-Salem and Concord, but the impact is limited compared to cities in South Carolina and Virginia.

The result of the different PA prospects between North Carolina and South Carolina shows how the impact of reduced travel time by HSR will change the locational attractiveness of cities. Greenville is located between cities with populations over a million (Atlanta and Charlotte), and the one hour of travel time to both cities from Greenville is an advantage for increasing interactions between cities. Similarly, Richmond is expected to grow in economic potential with an improved locational advantage in travel time reduction to Washington, D.C., Williamsburg, and Virginia Beach. In North Carolina, intermediate cities between Charlotte and Raleigh, such as Concord, Greensboro, and Winston-Salem, have slightly more potential accessibility benefits compared to eastern cities in North Carolina. This demonstrates that the benefits of accessibility from high-speed passenger rail are not limited to the larger cities.

4.4.2 Accessibility Changes at the Census Tract Level

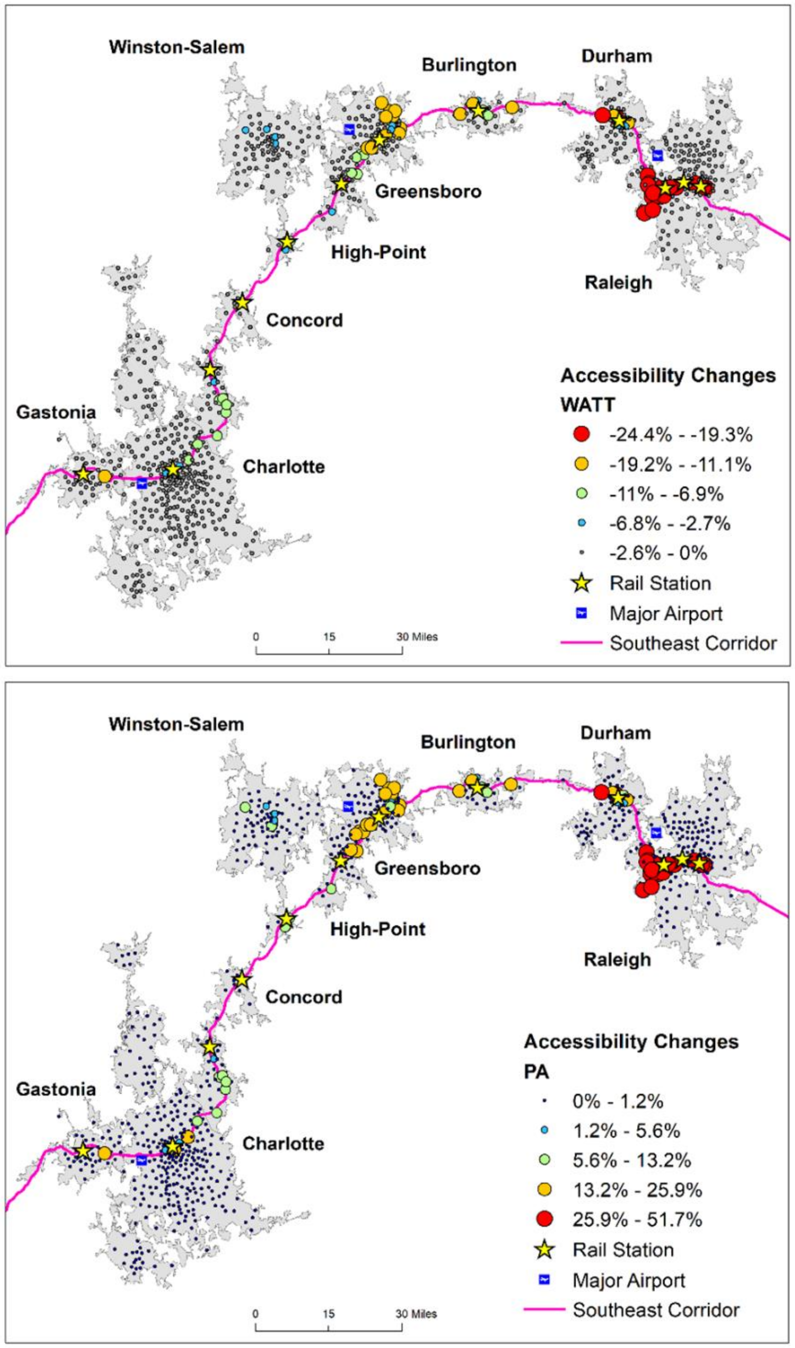


Figure 4.4 Accessibility Changes at the Census Tract Level in North Carolina (a. WATT, b. PA)

In this section, we will evaluate the accessibility changes facilitated by HSR from the local perspective. As discussed in Section 2, accessibility analysis at the city level simply shows locational benefits with simple values but has limitations when examining the disparity of accessibility gains within a city. According to this view, we calculate both WATT and PA at the census tract level for urbanized areas in North Carolina and South Carolina along the Southeast Corridor. We focus on intermediate cities in order to investigate whether those cities would have disadvantages in accessibility according to the findings of previous studies (e.g., Marti-Henneberg, 2015; Vickerman, 2015).

Figure 4.4 shows that there are significant disparities of accessibility gains in the urbanized areas of North Carolina after the construction of HSR. First, we found a decrease of WATT on those census tracts adjacent to the HSR corridor (Figure 4.4a), which means that those census tracts will receive increased accessibility thanks to the reduced travel time. Specifically, a high decrease of WATT, between -24.4% and -19.3%, is found for census tracts in Raleigh and Durham that are mostly concentrated near rail stations. These results indicate that cities that are close to the Northeast Corridor (Boston-Washington D.C.), such as Raleigh and Durham, would receive more benefits from travel time savings, and that the advantages mainly occur near rail stations. Similarly, a highly reduced WATT is shown in the east of Greensboro, which is adjacent to the rail line. In Charlotte, the largest urbanized area in North Carolina, however, there are only a few census tracts along the rail corridor that exhibit reduced WATT, as compared to the high reduction of WATT in other large urbanized areas such as Raleigh, Greensboro, and Durham. The PA result is similar with that of WATT, but it also illustrates high accessibility gains (Figure 4.4b). For example, a cluster of high accessibility in Raleigh has a much larger increase in the ratio of accessibility, between 51.8–96.3%, compared to the decrease ratio of WATT. This indicates that the impact of accessibility from the perspective of economic potential will be concentrated in limited areas within urbanized regions. This PA result implies that the benefits of economic development by HSR would be unequally distributed. Figure 4.5 shows that there are significant WATT and PA accessibility increase in Richmond; we found a decrease of WATT on the census tracts adjacent to the rail station. The PA result shows that many of the census tracts in Richmond are expected to see a significant accessibility increase by HSR. The result indicates the benefit of travel time will be concentrated near station area, but the entire city will have a potential to attract economic activities.

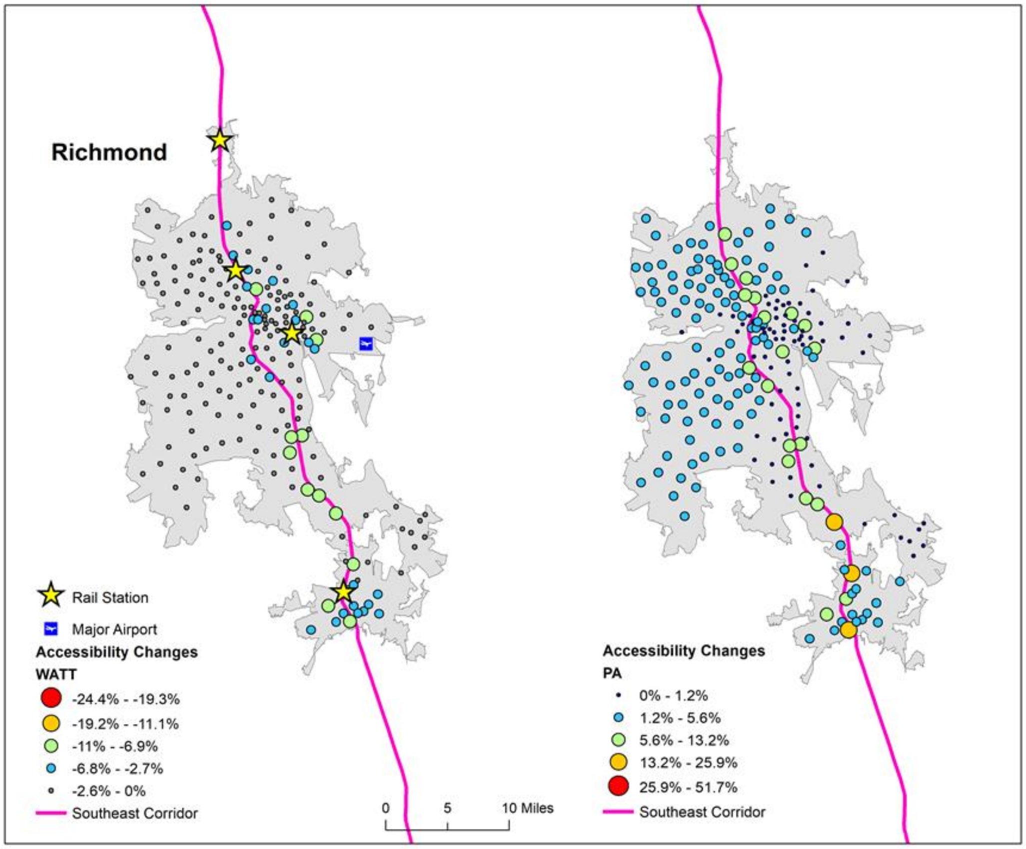


Figure 4.5 Accessibility Changes at the Census Tract Level in Richmond

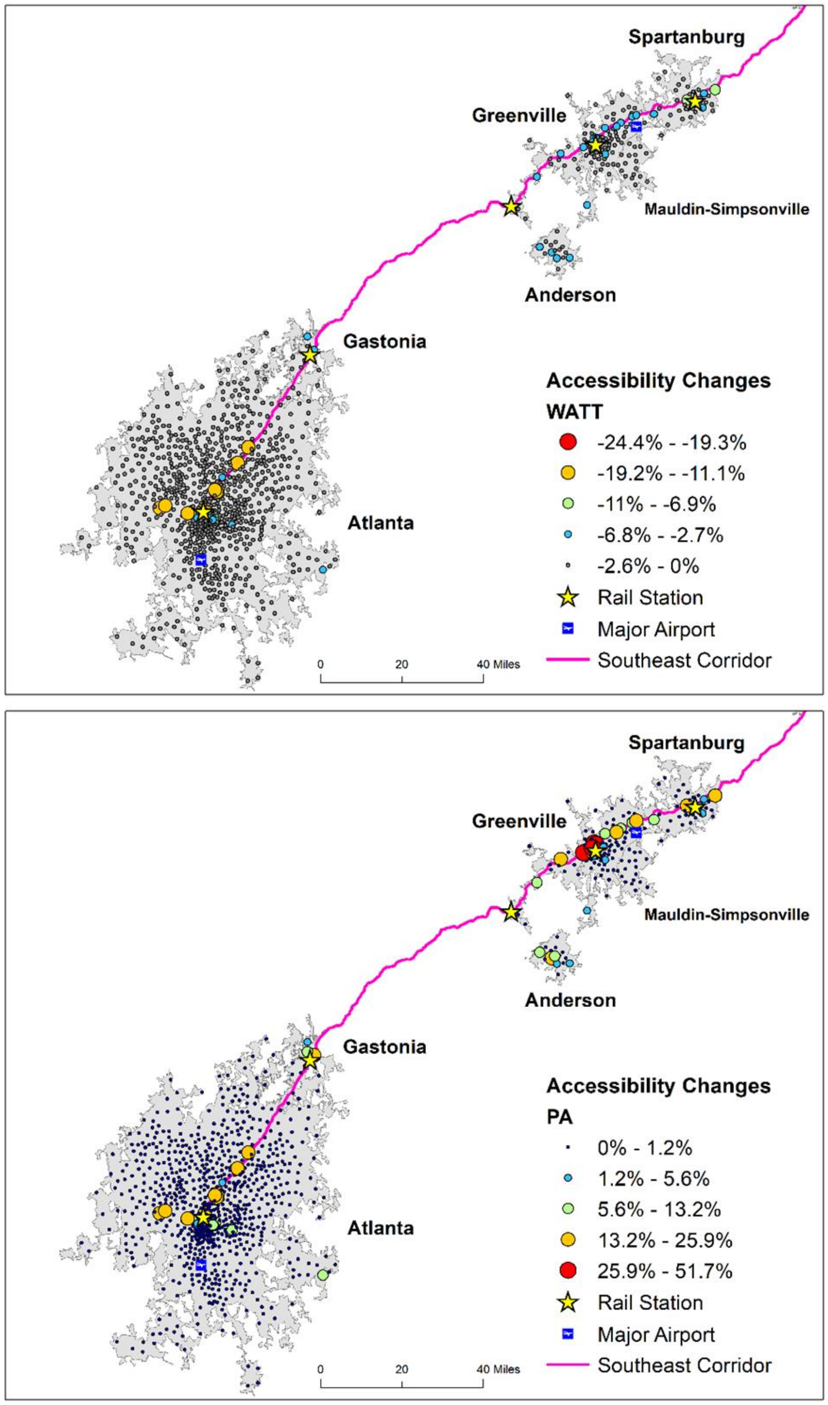


Figure 4.6 Accessibility Changes at the Census Tract Level in South Carolina and Georgia (a. WATT, b. PA)

Figure 4.6 illustrates the accessibility changes of both WATT and PA in the case of urbanized areas along the Southeast Corridor in South Carolina. The results show that few census tracts are expected to have accessibility gains, represented by the decrease of WATT and increase of PA. Specifically, Figure 4.6a demonstrates that a few census tracts in Greenville are concentrated near rail stations and show a high decrease of WATT, between -19.2% and -11.1%. Similarly, a high increase of PA is found near the rail station of Greenville (Figure 4.6b), and many of the census tracts around the station area are expected to show high accessibility gains. It indicates that Greenville will receive potential of attracting more economic activities in a wide range around the station area. Meanwhile, Anderson is also expected to see accessibility benefits, which means the city will also benefit from the impact of HSR by having the station connected to the interstate highway. It implies that a convenient and fast connection with high-speed service is a key for economic development for cities indirectly connected with a high-speed line.

We also measured weighted mean centers of a group of census tracts in each city, which were calculated in order to investigate the influence of HSR. These weighted mean centers of accessibility values were expected to move north of the urbanized area; this means a northern area of each urbanized region will have more improvement in accessibility. It clearly shows that census tracts close to the Northeast Corridor are expected to receive relatively more benefits of HSR and indicates a direct linkage to the Northeast Corridor will influence the accessibility increase of the urbanized areas along the Southeast Corridor.

4.4.3 Spatial Equity Analysis

Table 4.1 Spatial Equity Changes at Different Levels of Scale.

Accessibility	Urbanized Area Level			Census Tract Level		
	P1	P2	P3	P1	P2	P3
WATT	0.1320	0.1309	0.1306	0.1288	0.1212	0.1163
PA	0.1402	0.1387	0.1384	0.3472	0.3439	0.3469

Based on the HSIPR program, an accessibility analysis is conducted for the three stages of the railway network in the United States:

P1: current railway network

P2: minor upgrade of conventional railways including the Northeast Corridor, and the new HSR in California

P3: the full speed HSR in Southeast with upgraded convention railways

The results of accessibility show that HSR significantly increases the accessibility of cities, but most of the larger accessibility gains are concentrated along the HSR corridor and rail station areas. This suggests a disparity of accessibility gains, which has been an issue when evaluating the impact of a new or upgraded transportation infrastructure. Thus, we examined how the Southeast HSR plan changes the spatial equity of accessibility by calculating the coefficient of variance (CV) of WATT and PA accessibility values (Table 4.1). The spatial equity analysis was conducted for both urbanized area and census tract levels. The CV values of urbanized areas' WATT decrease in the process of HSR stages P1 to P3, which implies that the gap in travel time accessibility will be relieved after high-speed services are further developed in Virginia, North Carolina, South Carolina, and Georgia. Also, the CV values of PA decrease constantly in the process of HSR states P1 to P3, which indicates the accessibility benefits represented by locational attractiveness will be distributed more equally by HSR. Overall, we can expect that HSR will increase spatial equity by reducing the gap of intercity travel time between cities.

We also examined the spatial equity changes at the census tract level. The CV values of WATT decrease from 0.129 at P1 to 0.116 at P3, which indicates that the changes of WATT are reducing its disparity, while the high WATT changes are concentrated around rail station areas (see Figure 4.4 and Figure 4.5). It means that most of the census tract gain in reduced WATT (accessibility increase), but less accessible areas received more accessibility benefits. Meanwhile, the CV values increased between P1 and P2, and then decreased between P2 and P3. This suggests that the disparity between economic potential of areas at the census tract level will be relieved after future HSR plans, which implies the importance of the P3 stage of the rail plan.

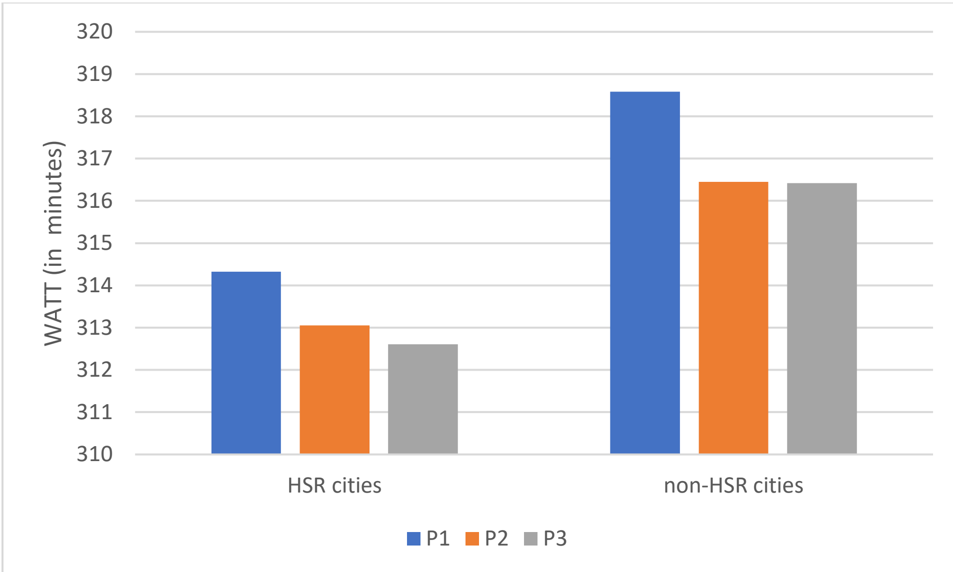


Figure 4.7 WATT Gap between HSR Cities and non-HSR Cities.

Despite the fact that HSR plans are expected to improve spatial equity, there remains the question of the accessibility gap between HSR cities and cities left off the system. Figure 4.7 demonstrates that there is a significant gap of WATT accessibility between cities with HSR and cities without it. A constant decrease of WATT is found in HSR cities, and the decrease of WATT in P2 is a noticeable result of a minor train speed upgrade expected in P2 of the HSIPR project in the Southeast Corridor. This is because of HSR projects in other corridors, such as the Northeast and California HSRs, as well as a small speed upgrade for the Southeast Corridor. Meanwhile, non-HSR cities are expected to see a decrease in WATT in P2, but no additional WATT reduction in P3. This indicates that the impact of the Southeast HSR, along with the full HSR standard, will be limited to cities directly connected with HSR due to the limitations of the quality of regional transportation networks. It suggests that the upgrade of regional transportation intrastate, at least a limited improvement, is necessary in order to more equally distribute the significant accessibility benefits from HSR cities to non-HSR cities.

4.5. Conclusion

This study evaluated how the HSIPR stages of the Southeast HSR Corridor in the U.S. may impact the accessibility of urbanized areas and how these results are distributed at the local scale, along with the spatial equity of these outcomes. The findings indicate that the speed upgrade will promote accessibility gains overall, and more benefits will be concentrated on cities where the high-speed trains will stop. The accessibility benefits are not limited to the large cities, but the impact of HSR is expected to increase accessibility for cities along the Southeast Corridor, even in the case of current investment levels, which are awaiting a minor upgrade of train speed.

The results also reveal the disparity of accessibility gains at the urban scale. A tract-level accessibility analysis reveals that the accessibility gains from HSR are concentrated only in specific parts of a city, with the highest concentration found near rail station areas. The results imply that urban planners and city governments need to consider both the efficiency and equity perspective when developing urban strategies related to high-speed rail such as station area development, landmark construction, upgrading local public transportation with sustainable transportation, and the improvement of attractions. In this case, locations expected to have high accessibility gains will be the best place to attract more economic activities. On the other hand, the concentration of accessibility benefits around the station area also indicates that an additional plan will need to be made for distributing the benefits of HSR to more people and places in the city. The equity issue may be relieved by upgrading the local public transportation or road network to improve access to station areas.

This kind of accessibility analysis prospecting the impact of a new transportation infrastructure related to land-use may also be effective when designing HSR routes and stations. High-speed routes need to be straighter compared to the conventional railways, so some HSR sections may require destroying housing within existing urbanized areas. Alternatively, HSR stations can be moved into suburban areas, but this may weaken the impact of high-speed service due to the increase of accessibility to city centers (Kim et al., 2018). Therefore, accessibility analysis that considers multi-mode transportation network at the local scale can be used to examine the advantages and disadvantages of moving station locations if there is no consensus between operators, planners, and citizens.

This study and its analysis have limitations because the plan (HSIPR) is still in the planning stage, so data is limited to past and future cases. If more concrete high-speed plans are established, we can evaluate the impact of the Southeast HSR Corridor in various conditions of operation, such as stop frequency, train stops patterns, or local economic development plans related to high-speed services.

CHAPTER V

TRANSPORTATION EQUITY AND HIGH-SPEED RAIL: A CRITICAL REVIEW AND AN APPLICATION[3]

5.1. Introduction

Urban and policy planners find it challenging to achieve a fair distribution of transport-related benefits across different communities in an urban area (Sultana et al., 2017). This is because costs and effects of transportation investment are hardly shared equally by different population segments and residential locations. The inequitable distribution of transport-related benefits is entangled with and affects the discrimination of transport access by different socioeconomic status (Bullard, 2003; Parks, 2016). Thus, transportation equity is considered an indicator of quality of life (QoL). Transportation equity is related to the fairness of transportation access as studied in the fields of geography and planning for decades (Hay, 1995; Van wee and Geurs, 2011; Tribby and Zandbergen, 2012). Fairness of transportation access is important in urban and policy planning from the viewpoint of social justice for ensuring the QoL of people without automobiles and the urban poor (Martens et al., 2012). Suburbanization resulted in separate residential and work locations and, in turn, disparities in transit funding distributions between existing urban and new suburban communities (Karner and Niemer, 2013; Grengs, 2002). This has been a critical issue for people in minority

[3] Kim, Hyojin. 2019. To be submitted to *Sustainability*.

communities who do not have automobiles (Hansen, 1959; Morris et al., 1978; Sultana, 2003; Páez et al., 2012).

Since the mid-twentieth century, the intercity travel time has been decreasing with technological improvements in transportation infrastructure (Warf, 2008). This has increased people's mobility and promoted spatial interactions. Simultaneously, concerns have been raised about inequalities in access to transportation services for intercity travel. One study of intercity travel by different communities based on 1995 American Community Survey (ACS) data showed that low-income households engaged in less intercity travel and were relatively more dependent on intercity buses (Mallett, 2001). This result raises questions about whether suitable investments have been made to give minority communities enough access to intercity travel (Park, 2016). The situation is worse in cities without access to intercity buses or trains because air fare may not be affordable to low-income households.

Recent years have seen the emergence of high-speed rail (HSR), and its benefits have been studied from the transportation equity perspective (i.e., Chen and Haynes, 2017; Kim and Sultana, 2015; Wang and Duan, 2018). Like major Highways, HSR projects are expensive, and they are developed around major corridors as well. HSR's transport-related benefits are thus also concentrated along these corridors, resulting in disparities-- people in developed areas enjoy more benefits whereas those in less-accessible areas enjoy fewer benefits (Foth at al., 2013). We argue that HSR can reduce disparities in transportation access for different communities by improving transportation service quality for intercity travel by competing with other transportation modes. If a city has only two options for mid- or long-distance travel, ticket price or airport access can be a barrier to faster travel using airplanes. In this case, HSR can be used as an alternative to improve transportation service quality. Therefore, HSR projects' potential benefits need to be considered from the viewpoint of transportation equity.

While the focus of transportation planning has shifted to "equity" or "social inclusion," there is no consensus on concepts and evaluation methods for the same (Tribby and Zandbergen, 2012). Accessibility is commonly measured for evaluating spatial variations in transportation services and transportation equity. Accessibility is defined as ease of access, and it can be shown as the spatial distribution of potential opportunities such as employment, recreation, or interaction with others (Hansen, 1959; van Wee and Geurs, 2011). It measures the opportunity or ease of access to a specific destination from the point of origin. Although it considers and measures disparities among potential opportunities to use transportation services, the methodologies for measuring equity are not well developed (Goetz et al., 2009; Golub et al., 2013). Despite various factors such as carload or assignment, transportation access in transportation equity analysis needs to be considered with a focus on car movement (Welch and Mishra, 2013). Accessibility measures have therefore been used in various studies on transportation equity (Monzón et al., 2013; van Wee and Geurs, 2011; Vickerman et al., 1997). However, few studies have investigated transportation equity disparities in minority communities (Sultana et al., 2017).

This study critically discusses transportation equity measurement in the fields of geography and planning. First, we present a historical background of transportation equity to understand how this concept has emerged and how it has been discussed in the field of geography. Second, we discuss the generally accepted definition of equity to understand its implications for measuring transportation equity. Third, we discuss the measurement of transportation equity and accessibility for examining the social effects of transportation. Finally, we conduct a simple transportation equity analysis for the Piedmont area of North Carolina, USA.

5.2. Theoretical Background of Transportation Equity

Historically, transportation equity has been influenced by the civil rights movement. This movement, which included bus boycotts sparked by segregated bus seating (Karner and Niemeier, 2013; Garrett and Taylor, 1999; Welch and Mishra, 2013). The civil rights movement, although a social movement, was related to transportation and ease of access to buses by different groups of people. The focus of transportation equity shifted to people's transportation access as a challenge in transportation planning (Bullard, 2003). Further, the civil rights movement highlighted the importance of transportation to people's QoL in relation to the equity of transportation investment distributions and segregation of specific communities in transportation infrastructure (Bullard, 2003; Golub et al., 2013). Another push was the construction of the Interstate Highway System, with urban construction often routed through minority neighborhoods (Mohl, 2004; Karner and Niemeier, 2013).

Transportation equity is considered an important aim of urban/transportation policy and is supported by legislation. Guided by Title VI of the Civil Rights Act of

1964, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 aimed to allocate funding to urban transportation services to increase the recognition of transportation equity issues and provide related guidance to Metropolitan Planning Organizations (MPOs). After ISTEA lapsed, the Transportation Equity Act for the 21st Century (TEA-21) was passed to promote public-friendly urban policy and planning so that transportation investment could benefit low-income/minority communities (Sanchez et al., 2003). Such laws led to increased focus on the transportation needs of different groups, especially low-income groups and minorities. The French Transport Act of 1982, known as LOTI, also considered transportation equity by increasing transportation access, supply, and quality (Bocarejo and Oviedo, 2012).

In the field of geography, examining transportation equity distribution from the perspective of spatial analysis has attracted increased interest. Equity and justice are interesting concepts topic that are directly connected to geographers' focus on social structures and problems. Hay (1995) introduced the concept of equity from the aspects of expectations, planning and policy, and spatial inequality to justify it and broaden its theoretical boundary. This study also dealt with geographical differences and problems such as inequity and injustice and noted the need for reducing disparities. In addition, with urbanization and development of transportation systems, studies have focused on disparities in different groups' urban mobility (Bocarejo and Oviedo, 2012; Di Ciommo and Shiftan, 2017).

Many studies have traditionally evaluated spatial mismatch between residential and work locations (i.e., Kain, 1968; Sultana, 2003; McLafferty & Preston, 2019). The concept of spatial mismatch was proposed to evaluate uneven job supply in places (Kain, 1968; Kain, 1992). Spatial mismatch postulates that Blacks suffer lower employment due to suburbanization and their lower accessibility to transportation modes (Kain, 1968; Gregs, 2010). This is an important issue for transportation equity. Geographers have evaluated different characteristics of residential areas, such as quality of neighbors, amenities, safety, and transportation (Levinson, 2010; Taylor and Ong, 1994; Blumenberg et al., 2015). Owing to rapid urbanization and sprawl, people routinely commute some distance from their residence to their workplace, making this an important issue in urban planning (Weber and Sultana, 2008). Therefore, the job-housing balance greatly influences transportation equity.

The need to commute between residential and work locations highlights the importance of public transportation to low-income households who cannot afford a car. People dependent on public transportation for commuting to work, shopping facilities, and social services suffer discriminative accessibility because of their residential location or socioeconomic status (Kwan, 1999; Delmelle and Casas, 2012; Karner and Niemeier, 2013), making this an important issue in urban planning (Kawabata and Shen, 2006). Accessibility has been used to examine unequal levels of public transportation services for traveling between residential and work locations for people without automobiles (Delmelle and Casas, 2012).

As suburbanization resulted in more residences being built far from central cities, the importance of public transportation decreased (Horner, 2004; Sultana, 2002). Many people preferred self-owned cars to public transportation services. However, public transportation services remained important because many people continued to use them as they could not purchase or use a car due to their income status, physical condition, or residential location. However, public transportation services require high passenger densities to remain feasible (Glaser et al., 2008). Reduced demand for these services results in reduced transportation funding; therefore, ensuring mobility for people who still need public transportation is now a complex problem (Karner and Niemeier, 2013; Welch and Mishra, 2013).

Transportation equity is related to social issues such as race, gender, and income, and quantitative research has been used for urban geography and urban planning (McLafferty & Preston, 2019). Women workers’ travel behaviors are influenced by household-related tasks such as pick-ups and drops and shopping (Goez et al., 2003; Monk and Hanson, 1982). Rosenbloom and Burns (1993) noted that women’s travel time and frequency differed from those of men because of their household-related tasks. Kwan (1998) analyzed differences in travel behavior by gender using space-time geography, which shows the combination of gender issues and spatial analysis.

5.3. Transportation Equity: Concepts vs Measures

Transportation equity is usually related to the fair distribution of transport-related benefits such as access to social and economic opportunities. It has the following elements:

- Ensuring opportunities in the planning process
- Public accountability and financial transparency: fair distribution of investment

- Fair distribution of benefits of transportation investment
- Improving the transportation quality and mobility for fair opportunities of economic activities
- Revitalize minority communities (equally prioritize efforts and consider minorities when investing in transportation)

Various concepts are used to define transportation equity. In general, transportation equity can be divided into two types: horizontal and vertical (Litman, 2018; Wench, 2013). Horizontal equity implies providing equal services to all target users. Vertical equity implies providing relatively equal services to disadvantaged target users (Delbosc and Currie, 2011; Foth et al., 2013). Some studies measuring transportation equity examined the spatial distribution of services with a focus on horizontal equity. Welch and Mishra (2013) treated households equally with potential riders to examine the distribution of transportation quality in the Washington-Baltimore region.

5.3.1 Transportation Equity in Geographical Analysis

The concept of transportation equity remains rather ambiguous, making it difficult to measure it from transportation benefits. In the geographical context, equity is used to evaluate the distribution of opportunities to economic activity or of certain services. Therefore, the concept of transportation equity deserves more discussion. It was categorized by the Transportation Equity Act for the 21st century as procedural inequity, geographic inequity, and social inequity. Geographical inequity is related to the spatial concept of transportation equity analysis. However, these categories are intertwined. For example, studies have focused on the mobility of socially disadvantaged people such as those without automobiles and the elderly, which has aspects of both geographical and social inequity.

Table 5.1 Issues Related to Transportation Equity

Category	Topics
Aspects of employment	Rate of automobile users by different socioeconomic status related to residential and work locations
Aspects of income status	Private automobile ownership Lack of automobile ownership and poor alternative public transportation services affect isolation of transit dependents like low-income households Road pricing and the constraints it imposes on mobility
Aspects of investment (traditional, mostly conducted in planning)	Transportation investment: evaluating costs-benefits
Emerging issues	Sustainable transportation (Litman, 2018)

Transportation geography deals with the following issues affecting transportation equity (Table 5.1). The concept of transportation equity incorporates both social and spatial aspects. It refers to the fairness and justice with which the impacts (benefits and costs) of transportation projects are distributed. Historically, when transport funding is allocated, wealthier regions enjoy more transport benefits because of demand and disadvantaged regions receive fewer benefits, resulting in a widening gap between the transportation services in different regions. Transportation equity analysis strongly relates to accessibility, such as discrete mobility and accessibility of low-income people who are socially excluded. Such analysis can be difficult because there are several types of equity, numerous impacts to consider, various ways to categorize people for analysis, and many ways of measuring impacts (Litman, 2018; Karner and Niemeier, 2013; Welch and Mishra, 2013). Considering this complexity, van Wee and Geurs (2011) presented two types of equity: social equity considers the disparity of accessibility by income, and spatial equity considers the disparity of accessibility by region. It supports the fact that equity analysis of quality and distribution is closely related with geography.

5.3.2 Equity and Job Accessibility

One popular transportation equity issue relates to job opportunities. This issue has been important since the passage of the Civil Rights Act of 1964. This act required the US federal government to equally distribute funding in a way that maintained citizens' QoL (Welch and Mishra, 2013). Later, transit dependents' employment access became a major focus from the perspective of their QoL (Gudmunsdsson et al., 2016). The Welfare Reform Act of 1996 in the US emphasizes transportation assistance by the state for needy people so that they have opportunities for seeking employment.

This approach to equity is related to the perspectives of neoclassical economics and critical geographies (Boschmann and Kwan, 2010). Neoclassical economics proposed an urban structure of residential and work locations using a bid-rend curve for land use. The clustering of low-income communities near downtown areas and manufacturing facilities offered employment opportunities (Kwan, 1999). Gregs (2010) addressed public transportation services should cover minorities' rights to mobility; however, the level of these services cannot be improved easily.

Previous empirical studies on spatial mismatch concluded that low-income communities live in the downtown area in inner cities because of their work locations and their lack of mobility is due to the very limited transportation services between essential destinations (Bauder, 2000; Blumenberg and Ong, 2001; Taylor and Ong, 1995; Welch, 2013). Some studies have focused on the discrimination of transportation opportunities for people, called a modal mismatch (Blumenberg and Manville, 2004; Taylor and Ong, 1995). These studies understand that most employment occurs in the central part of a city. This assumption criticized complex urban land uses (Boschmann and Kwan, 2010). To quantify spatial mismatch, various measures of transportation operations such as commuting time, distance, and speed have been used (Karner and Niemeier, 2013).

Urban structures changed to the dichotomy of a city and suburbs after the 1990s. A city did not have a single traditional center anymore due to the emergence of the edge city and the increasing poly-center in urban areas. The disparity distribution of people's socioeconomic condition became more complex. A highly localized scale is required for research (Boschmann and Kwan, 2010). Therefore, geographical factors were considered increasingly, and this resulted in studies focusing on a broader range of disadvantaged people and their job accessibility vulnerability by gender and minority group (Wyly, 1996; Sultana, 2003; Sultana, 2005). The increased factors of employment access must be combined with quantity-analytical discourse and used in multivariate regression analysis

(Preston and McLafferty, 1999) or spatial econometrics using a modeling spatial context (Boschmann and Kwan, 2010).

5.3.3 Measurement of Equity and its Distribution

Initial studies of transportation equity focused on the economic context, such as changes in economic welfare and maximization of profits (Hay, 1996); these refer to horizontal equity. The focus shifted toward examining the distribution of public transportation access among low-income riders (Garrett and Taylor, 1999). For example, a relation between vehicle ownership and income has been found, and it is closely related to the demand for public transportation (Welch, 2013).

Equity is generally measured using several methodologies from the perspective of demand for and supply of public transportation and the spatial distribution of accessibility. In this approach, the connectivity of a transportation network and nearby users can be evaluated. The connecting power of each node in the network is aggregated (Mishra et al., 2012; Tribby and Zandbergen, 2012). For measuring disparity, the distribution of accessibility values has been examined (López et al., 2008; Monzón et al., 2013). Lorenz curves were used to examine the distribution of public railway services by relative supply to people (Delbosc and Currie, 2012).

5.3.4 Accessibility Indicators for Transportation Equity

Mobility can also be an important indicator; however, it provides fragmentary information. It can show the rate of automobile or public transportation use or commute time. Accessibility is a more analytic concept. It can be applied to and modify different spatial variations. Accessibility refers to the opportunities of entities such as individuals or companies at certain locations using transportation as an indicator of the “spatial separation of human activities” (Hansen, 1959; Morris, 1979; Linneker and Spence, 1992).

Accessibility has been used in various fields such as location choices, travel demand forecasting, and land use (Song, 1996). It includes two types of opportunities: travel cost and quality/quantity of opportunities. In terms of accessibility, cost is based on the travel time or distance (Páez et al., 2012). Many measures exist for accessibility depending on the research topic or cost calculation. Travel cost is considered an effect of the friction of distance (Gutiérrez, 2001). Opportunities for a particular location can be measured by the distance. Some studies identified the components of accessibility. Geurs and van Wee (2004) suggested four types of components: land use, transportation, temporal, and individual. Páez et al. (2012) discussed the arrangement of accessibility from the origin or to the destination: cumulative opportunities, gravity, and mean travel cost to k nearest facilities. Accessibility has also been used to examine social exclusion with geographic information system (GIS) software in the spatial context (Prestion and Raje, 2007). An accessibility map contains a disparity of scores (Figure 5.1). Moreover, it is useful to compare different time periods (Figure 5.2), which shows relative disadvantages resulting from improvements in the transportation service.

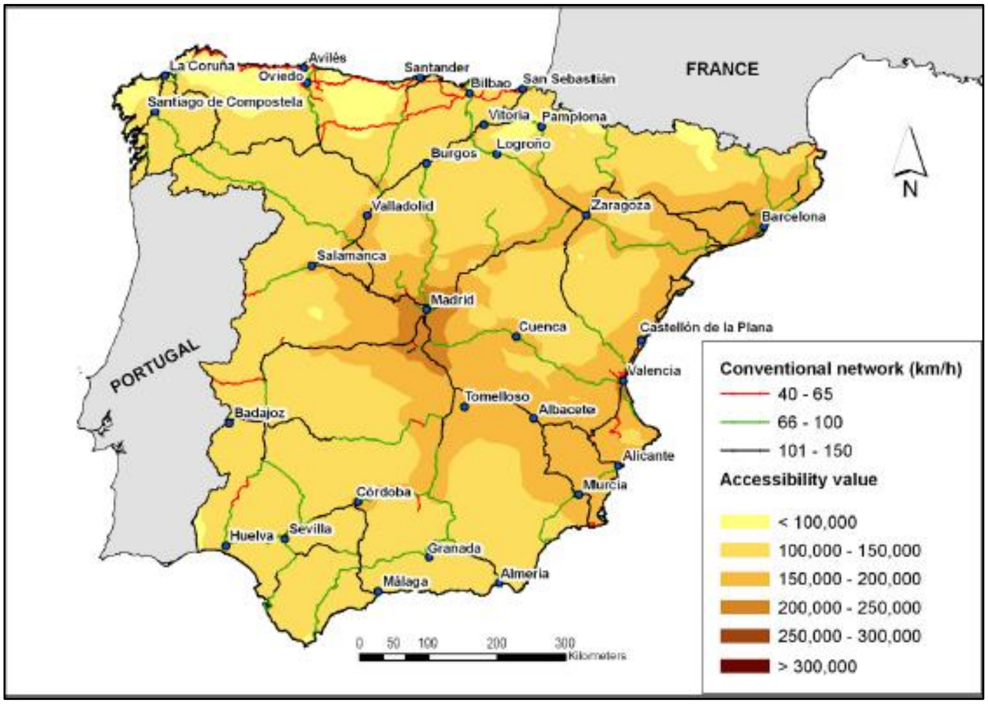


Figure 5.1 Distribution of Accessibility of Railway Network in Spain (Monzón et al., 2013)

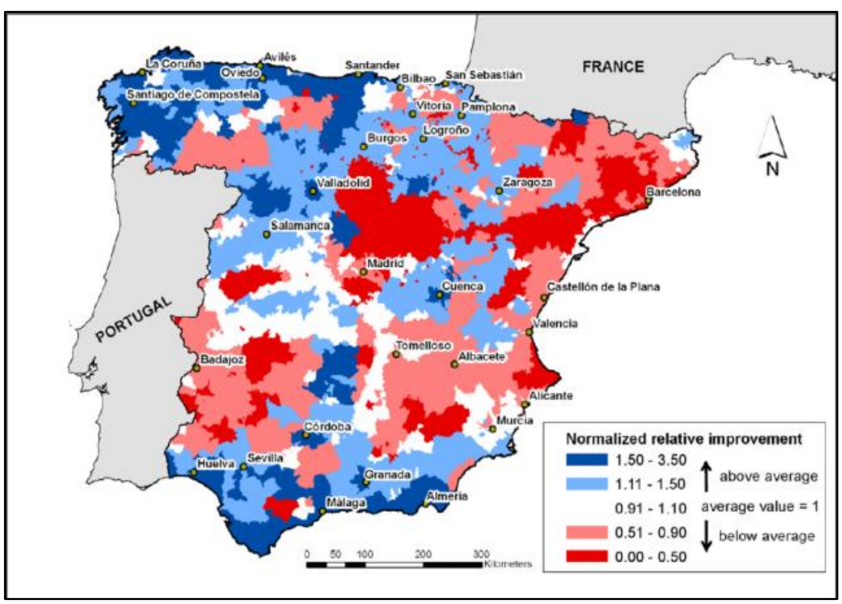


Figure 5.2 Normalized Change in Accessibility Score between Two Periods of High-Speed Rail Stage in Spain (Monzón et al., 2013)

5.3.5 Access to Transit: Catchment Area

For public transportation users, transit access points such as a bus stop and an urban rail station are important. This is significant for determining the location of stops to increase the accessibility of public transportation services (Welch and Mishra, 2013). The catchment area can be determined by just the travel time or distance or by the number of people in the given catchment area by travel time or distance (Figure 5.3). The catchment area can be calculated by the prorated connectivity ($\rho_{h_1,n}$) as follows:

$$\rho_{h_1,n} = a \times e^{-bt_{h_1,n}} \tag{1}$$

where a and b are parameters of prorated connectivity and $t_{h_1,n}$ is the walk time to travel from h_0 using unit h_1 to transit stop n (Kim et al., 2005; Welch, 2013; Welch and Mishra, 2013). This method indicates the different rates of connectivity as an equity measurement by the travel time to the transit station/stop.

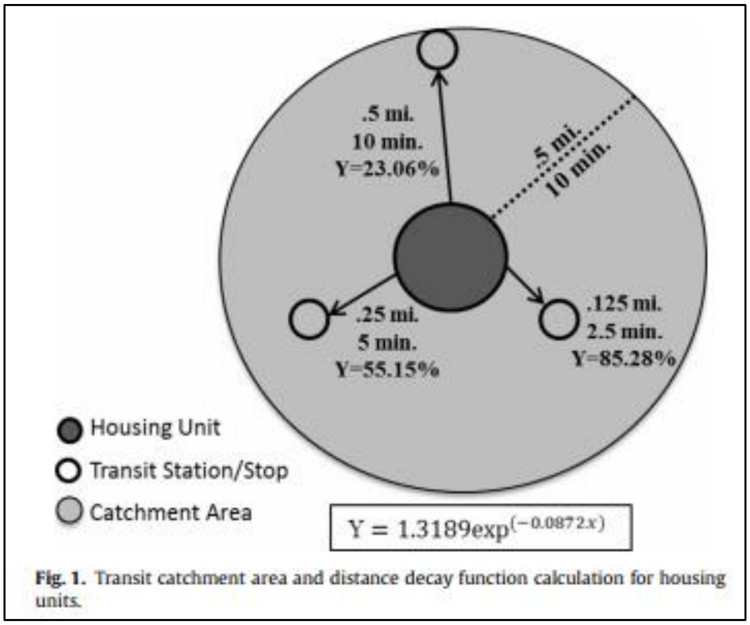


Figure 5.3 Concept of Catchment Area Calculation (Welch, 2013)

5.3.6 Evaluating Transportation Equity from Disparity of Accessibility

The distribution of accessibility indicates regional cohesion (López et al., 2008). There are several ways to analyze the degree of distribution of accessibility. As expressing and confirming accessibility are not sufficient to identify the disparity in accessibility improvement for equity analysis, the coefficient of variation (CV) has been used to evaluate the disparity of accessibility value of cities (Li and Shum, 2001; López et al., 2008; Martin et al., 2004; Monzón et al., 2013). The disparity of accessibility is represented by the absolute accessibility, its change rate, or its CV values between HSR service scenarios (López et al., 2008; Monzón et al., 2013). For evaluating the disparity of accessibility change, CV is calculated for equity analysis in this study. CV is expressed as follows:

$$\mathrm{CV} = \frac{\sigma^{P}}{\frac{\sum A_i \cdot P_i}{\sum P_i}} \tag{2}$$

where CV is the coefficient of variation of the whole area, σ^P is the standard deviation of accessibility values A_i, and P_i is the population, which is used as a weight. A high CV value indicates decreased inequity. It helps evaluate the degree of the balanced accessibility distribution. However, CV reflects the accessibility distribution of an entire study area. Thus, a normalized value of the accessibility improvement in each city is used for evaluating each city's accessibility change. This is useful for evaluating the benefits derived from the operation of new transportation services. Martin (1997) examined whether HSR fosters a tendency of polarization. From the standpoint of efficiency analysis of HSR, studies have evaluated the accomplishment of planned accessibility of cities. Monzón et al. (2013) noted that HSR reduced differences in accessibility in Spanish cities using CV values.

5.3.7 Inequity Index

Lorenz curves represent the cumulative distribution function of wealth across the population. They can be applied to the relation between a certain attribute and the population to indicate the equitable or inequitable distribution of the attribute. The Gini index is a measure of inequity, and it is generally used for calculating the wealth distribution. Delbosc and Currie (2011) used Lorenz curves and the Gini index to examine the distribution of public transportation services in Melbourne (Figure 5.4). The result indicated that 70% of the population in the city shared only 19% of public transit services, indicating the inequity of public transportation services. The Gini index was also used to evaluate the inequity of HSR's impact (Shi and Zhou, 2013; López et al., 2016; Chen and Haynes, 2017).

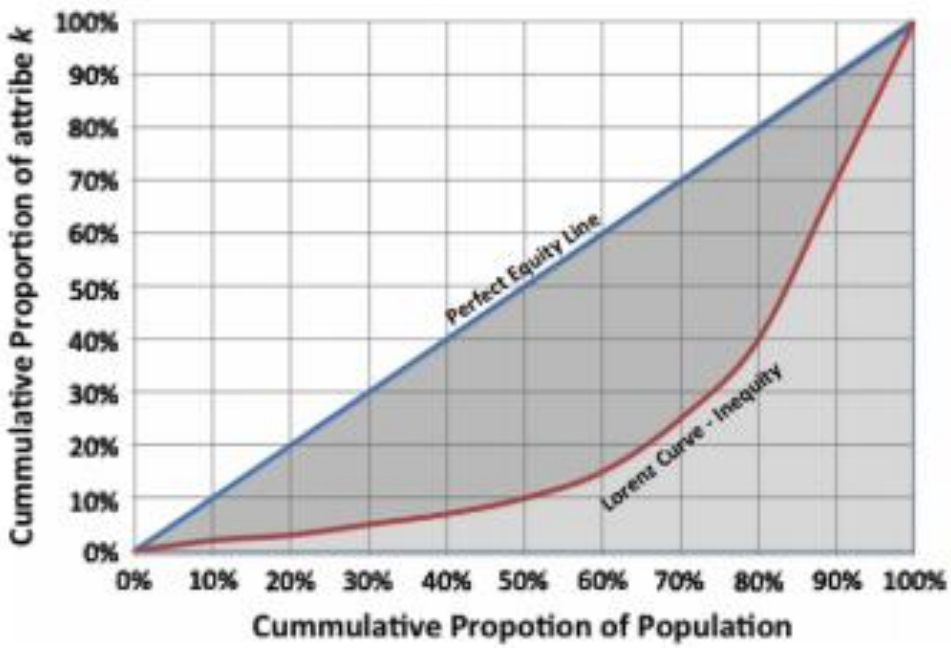


Figure 5.4 The Use of Gini Index to Evaluate Equity of Transportation Services in Melbourne (Delbosc and Currie, 2012).

5.4. Case Study: Equity Analysis from High-Speed Rail Project in North Carolina

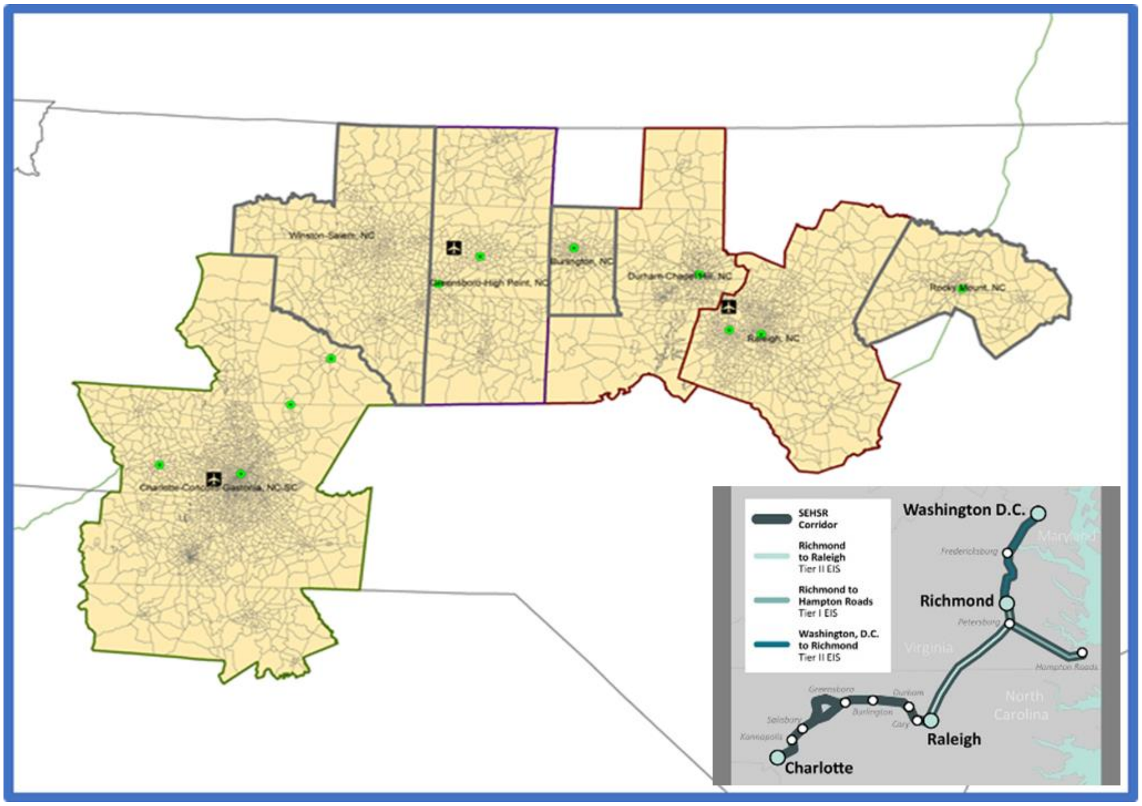


Figure 5.5 Study Area and Plan of Southeast HSR (source: NCDOT)

Figure 5.5 shows the current HSR plan that is part of the US High-Speed Rail Strategic Plan (HSIPR) being implemented in North Carolina and Virginia. The corridor between Raleigh and Charlotte is a part of the Southeast HSR corridor from Washington D.C. and Atlanta through Charlotte and Greenville. First, the conventional railway is receiving a minor speed upgrade. At the same time, the faster HSR has been proposed and studied for running high-speed trains in the Southeast Corridor. The Southeast Corridor contains three major metropolitan areas—Raleigh, Charlotte, and Greensboro—that are expected to receive the benefits of reduced intercity travel time by HSR.

This study evaluates the equity impact of HSR in the Piedmont Corridor in North Carolina, including Raleigh, Charlotte, and Greensboro. We select 4,660 traffic analysis zones (TAZs) in metropolitan statistical areas (MSAs) along the corridor. The population and median income of each TAZ is collected from the Census Bureau and CTPP websites. Accessibility is calculated based on a multimodal transportation network by combining road, railway, and air networks in ESRI's ArcGIS environment. Road data are collected from TIGER by the US Census Bureau, North Carolina Division of Motor Vehicles. Railway network data is collected from the Federal Railroad Administration. Passenger air service network data is collected from passenger boarding data of 2015 from the Federal Aviation Administration. All network data are modified for the travel cost calculation in the GIS analysis. We use the economic potential accessibility measure as a location-based accessibility indicator of the impact of HSR for each location. It is calculated as follows:

$$P_i = \sum_j \frac{D_j}{{t_{ij}}^{\alpha}} \tag{2}$$

where P_i is the potential accessibility of location *i*, t_{ij} is the travel time between locations *i* and *j*, D_j is the mass of destination *j* (in our case, total population by city), and α is the distance friction parameter. This accessibility measure shows how a location receives benefits of locational attractiveness owing to the transportation infrastructure upgrade. Economic potential accessibility is measured at the TAZ level of the study area, and changes in the accessibility values indicate transport-related benefits each TAZ along the

HSR corridor. The accessibility result is used for evaluating the degree of inequality of transport-related benefits by using the Gini coefficient and CV measures.

5.5. Result

5.5.1 Distribution of Low-Income Communities

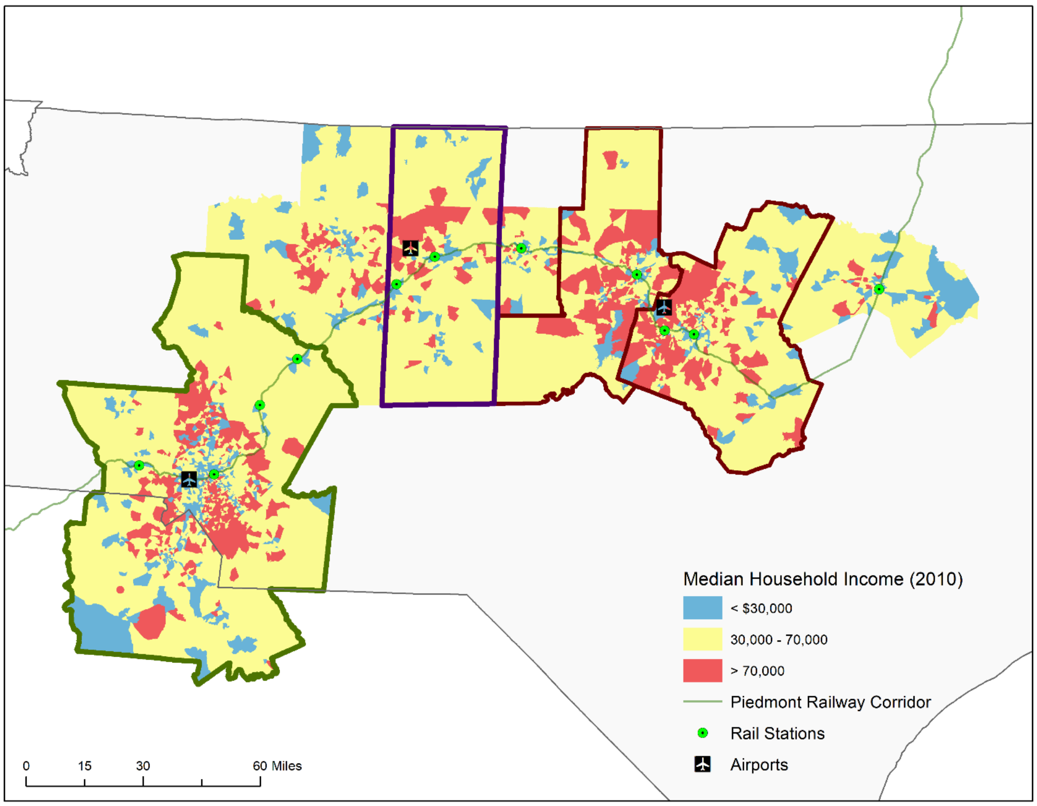
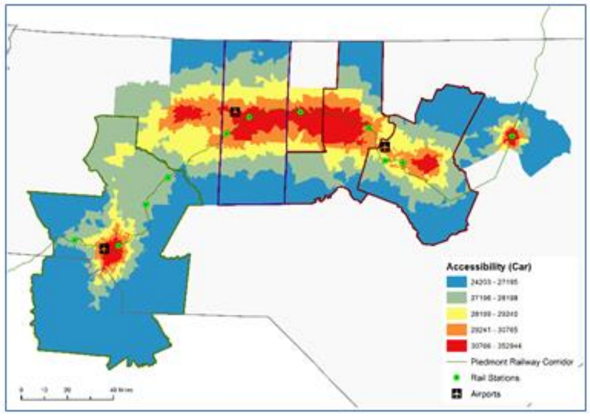


Figure 5.6 Income Distribution at the TAZ Level.

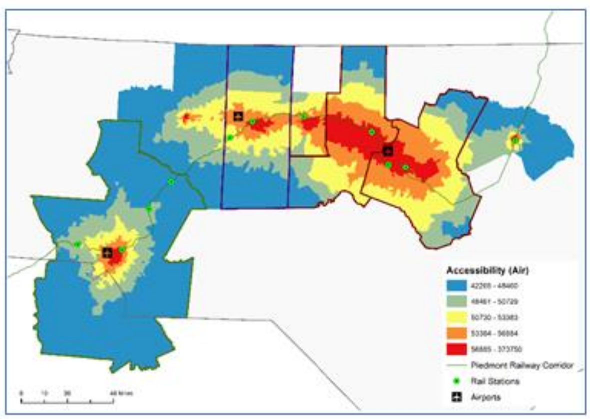
Figure 5.6 shows the distribution of median income as of 2010 at the TAZ level in the study area. This figure shows that the location of low-income communities varies depending on the characteristics of MSAs. For example, low-income areas are located at the city centers of both Raleigh and Durham; however, they are more scattered in

Charlotte except for a cluster in the uptown area. Specifically, we checked low-income TAZs' proximity to the city center. In Charlotte, 54% of TAZs are within 20-min network distance from the city center whereas 48% of high-income TAZs are in the same boundary. In Greensboro, only 34% of low-income TAZs are within 20-min distance from the city center, whereas 62% of high-income TAZs are in the same boundary.

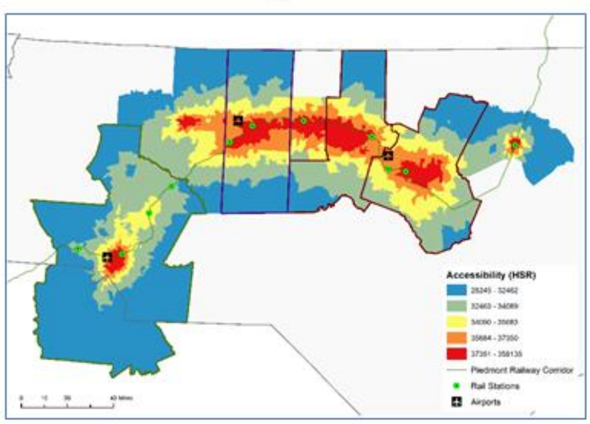
5.5.2 Distribution of Accessibility by Different Transportation Modes



(a) Car



(b) air



(c) HSR

Figure 5.7 Accessibility after HSR by Transportation Mode

The choice of transportation mode is an important factor in the mobility of minority communities. Thus, we conducted accessibility analysis for three different transportation modes: car, air, and HSR. Overall, the accessibility value of air transportation was 56%–67%; this was higher than the values for car and HSR (Figure 5.7). This result shows the dominance of airplanes in intercity travel; however, HSR shows relatively high accessibility compared to cars, implying that it can beat other ground transportation modes after it is introduced. We also checked the spatial equity of accessibility values for different transportation modes. Table 5.2 shows the Gini index and CV by transportation mode. Air shows the lowest CV and Gini, indicating that the effect of travel time savings is very high despite all TAZs having different ease of access to the airport. The concentration of high accessibility values by air in a wide range shows its impact. Meanwhile, HSR shows better Gini and CV compared to car, implying that its impact will be distributed over the entire study area.

Table 5.2 Spatial Equity of Accessibility by Transportation Mode.

Mode	Accessibility	CV	Gini
Car	29542	0.243	0.061
Air	52738	0.15	0.049
HSR	35419	0.207	0.060

5.5.3 Spatial Accessibility Distributions by Different Income Groups

It is necessary to evaluate whether the impact of HSR will be distributed equally for people from different income groups. Therefore, this study investigated the microscale accessibility distribution by different transportation modes. Table 5.3 and Figure 5.8 show the degree of accessibility distribution by different income groups. Air transportation shows the highest accessibility values owing to its high speed. The result shows that better equity is found in high-income TAZs, indicating that this group will have less disparity of accessibility for all transportation modes. It implies that high-income residences are concentrated in locations with relatively high accessibility. This result indicates that HSR is an attractive option for low-income communities from the viewpoint of accessibility considering its higher accessibility than cars.

Table 5.3 Equity of Accessibility by Income Group (all MSAs in Study Area)

	INCOME <30K			INCOME 30k-70k			INCOME > 70K		
	CAR	AIR	HSR	CAR	AIR	HSR	CAR	AIR	HSR
Mean	30300	53624	36212	29345	52085	35114	29274	53477	35379
Std	6228	6228	5531	8649	9313	4805	4117	5128	4254
CV	0.206	0.116	0.153	0.295	0.179	0.137	0.141	0.096	0.120

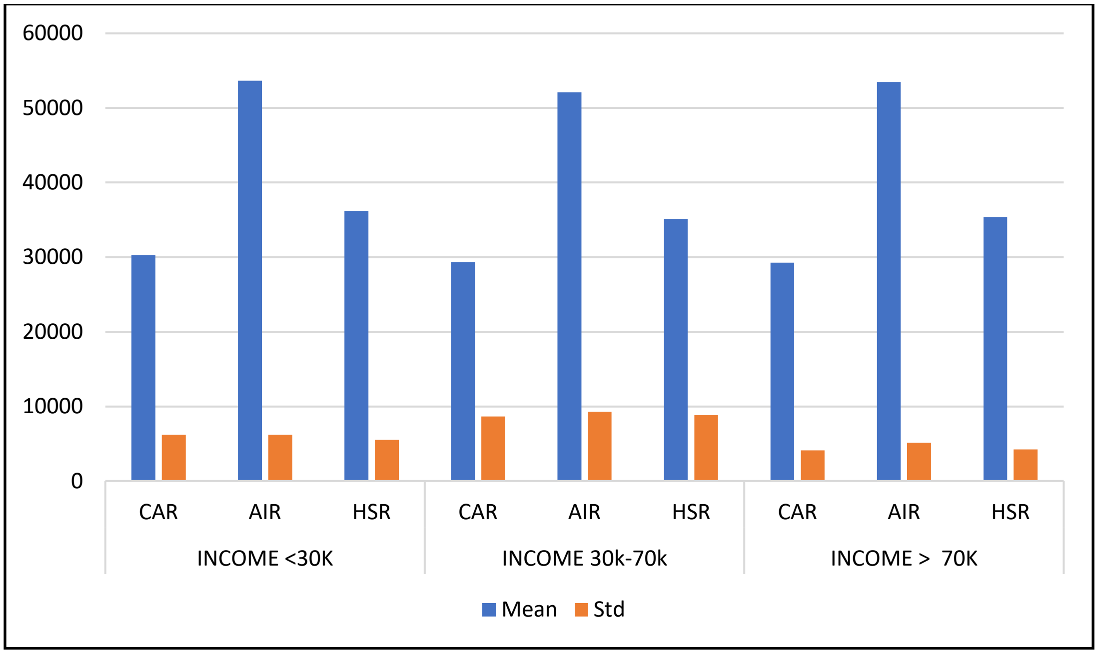


Figure 5.8 Equity of Accessibility by Income Group (all MSAs in Study Area)

Table 5.4 and Figure 5.9 show the equity evaluation of accessibility for the Southeast HSR by different income groups in Greensboro. Greensboro shows high disparity in spatial equity for different income groups. The high-income group has much better accessibility by air and HSR with less disparity of accessibility values. This result indicates that high-income residents in Greensboro are in very conveniently accessible locations to the airport or train station. The high accessibility of HSR could be influenced by the fact that some high-income residences are close to the rail station or inner-city highway to the rail station. However, the middle-income group shows relatively low accessibility with worse equity of accessibility for all transportation modes. This result is similar to the result for all study areas; however, the degree of disparity is much higher. This implies that middle-income communities are very scattered. The low-income group has better accessibility by car and HSR as well as better spatial equity compared to the middle-income group; this might be because low-income residences are close to the HSR station in the city.

Table 5.4 Equity of Accessibility by Income Group (Greensboro)

	INCOME <30K			INCOME 30k-70k			INCOME > 70K		
	CAR	AIR	HSR	CAR	AIR	HSR	CAR	AIR	HSR
Mean	30130.7	51614.5	35769.6	29798.1	51166.7	35345.6	30112.4	52836.4	36092.4
Std	3481.3	4591.8	3949.4	11462.9	11865.9	11617.3	1503	2178.1	1713.4
CV	0.116	0.089	0.11	0.385	0.232	0.329	0.05	0.041	0.047

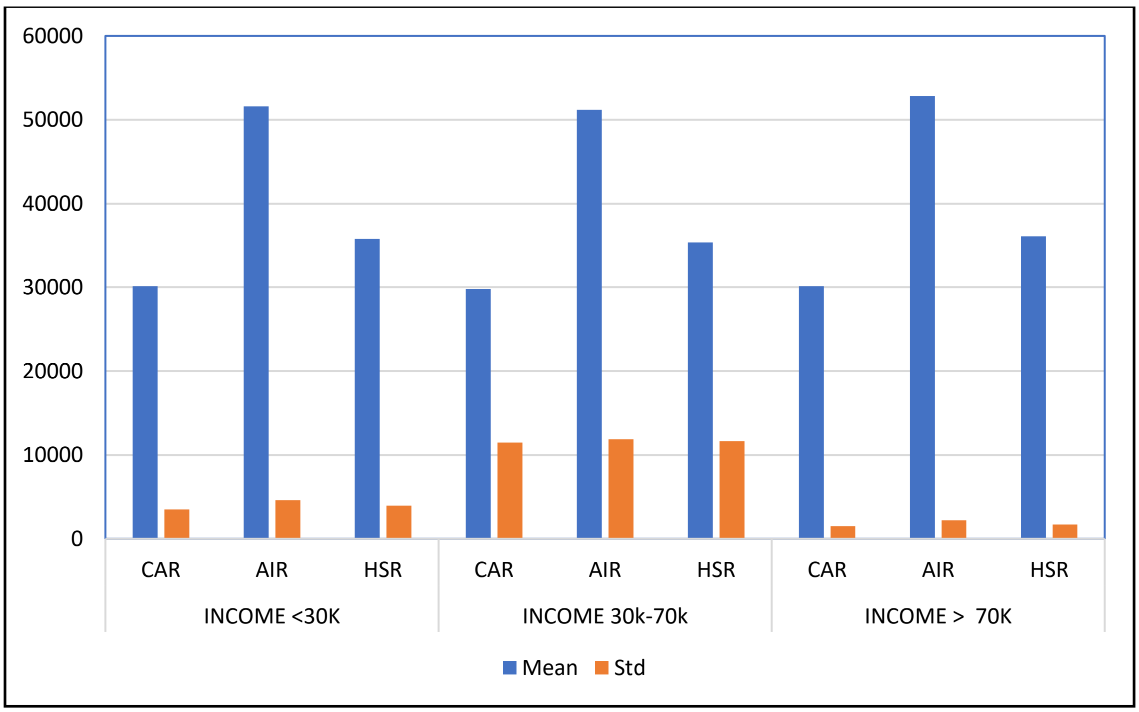


Figure 5.9 Equity of Accessibility by Income Group (Greensboro).

Interestingly, Charlotte shows different accessibility and equity results compared to Greensboro. Table 5.5 and Figure 5.10 indicate that low-income groups are expected to have relatively high accessibility for all transportation modes. They have high accessibility values for air transit and HSR because the main airport and rail station are located near the city center of Charlotte where some low-income communities are concentrated. Additionally, the CV values of the low-income group are lower than those of other income groups for all transportation modes. These results imply that low-income communities are located in areas with better accessibility to the highway, airport, and rail station. Similar to the result for Greensboro, middle-income communities show low accessibility for all transportation modes and worse spatial equity.

Table 5.5 Equity of Accessibility by Income Group (Charlotte)

	INCOME <30K			INCOME 30k-70k			INCOME > 70K		
	CAR	AIR	HSR	CAR	AIR	HSR	CAR	AIR	HSR
Mean	29437.6	51754.6	34845.7	28718.6	50628.4	34014.8	29025	51355.4	34508.6
Std	3613.7	4963.7	4094.2	6123.2	6883.9	6360.1	4449.4	5053.3	4663.3
CV	0.123	0.096	0.117	0.213	0.136	0.187	0.153	0.098	0.135

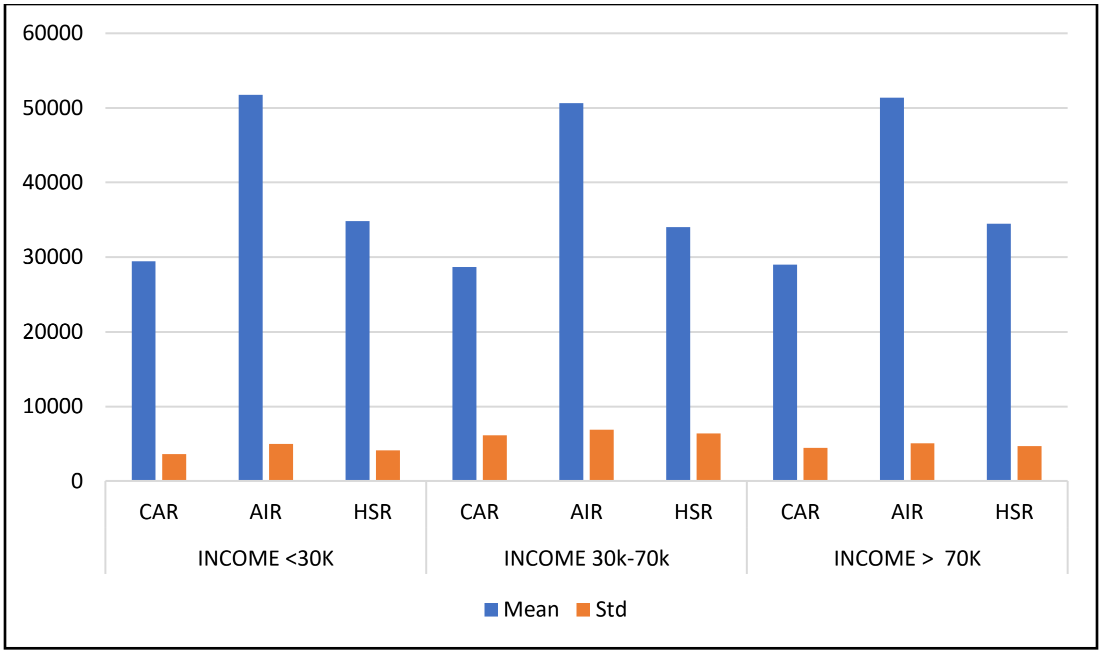


Figure 5.10 Equity of Accessibility by Income Group (Charlotte)

In addition, Figure 5.11 illustrates the distribution of accessibility values and the median household income values in Charlotte. There are high-accessibility clusters in between the rail station and the airport and central areas of Charlotte. As shown in the figure, the benefit of HSR is mostly concentrated on the low-income TAZs, but the high-income residence in the southern area of uptown Charlotte is also expected to have better accessibility by HSR. The result implies that the Southeast HSR will improve the accessibility of low-income communities in Charlotte.

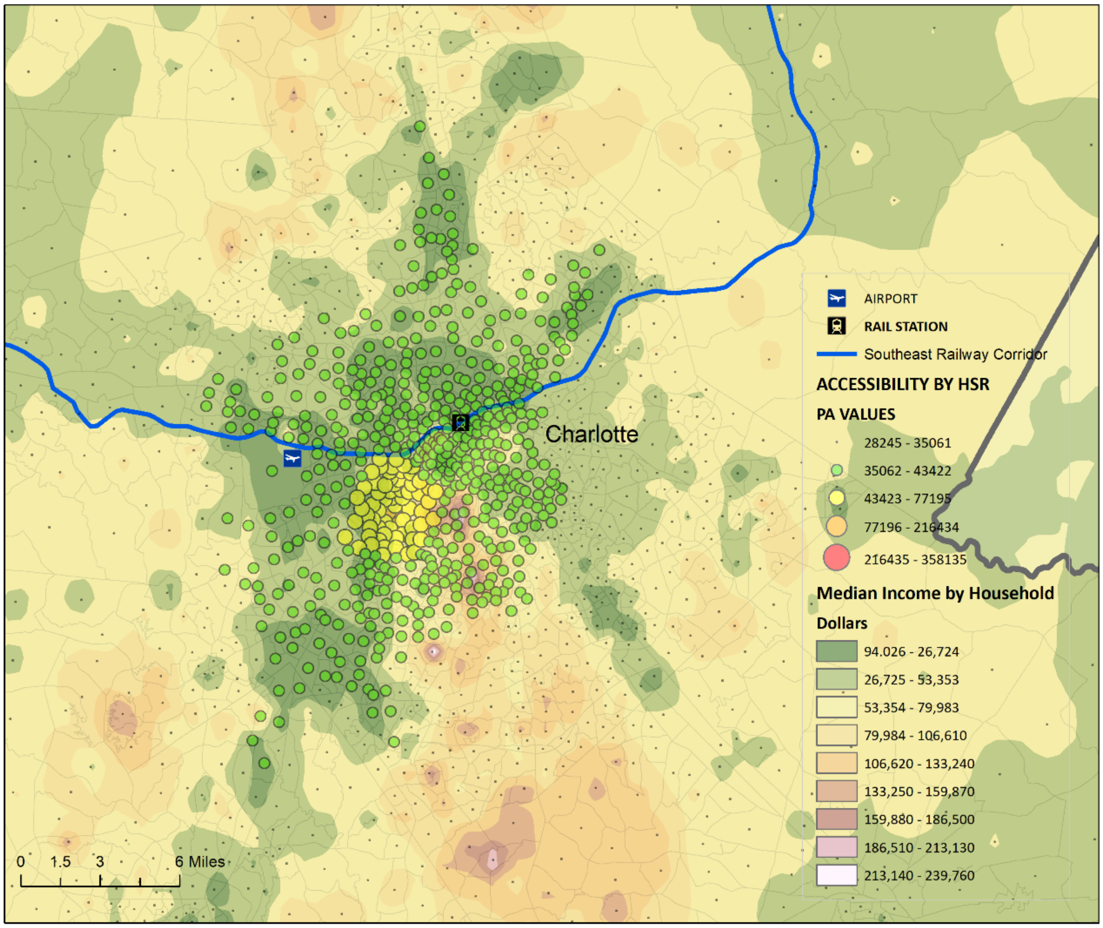


Figure 5.11 Locations of Low-Income TAZs/Accessibility by HSR (Charlotte)

Figure 5.12 also shows the distribution of accessibility values by HSR and the median household income values in Greensboro and High-Point. The result shows that high-accessibility values are found in the south of the train station in the downtown Greensboro. Similar with Charlotte, we also found that low-income communities are more likely to have better accessibility after HSR. Also, the high-income TAZs in the northwest of Greensboro shows the better accessibility. Similar patterns are found in High-Point, a city of Greensboro-High-Point MSA.

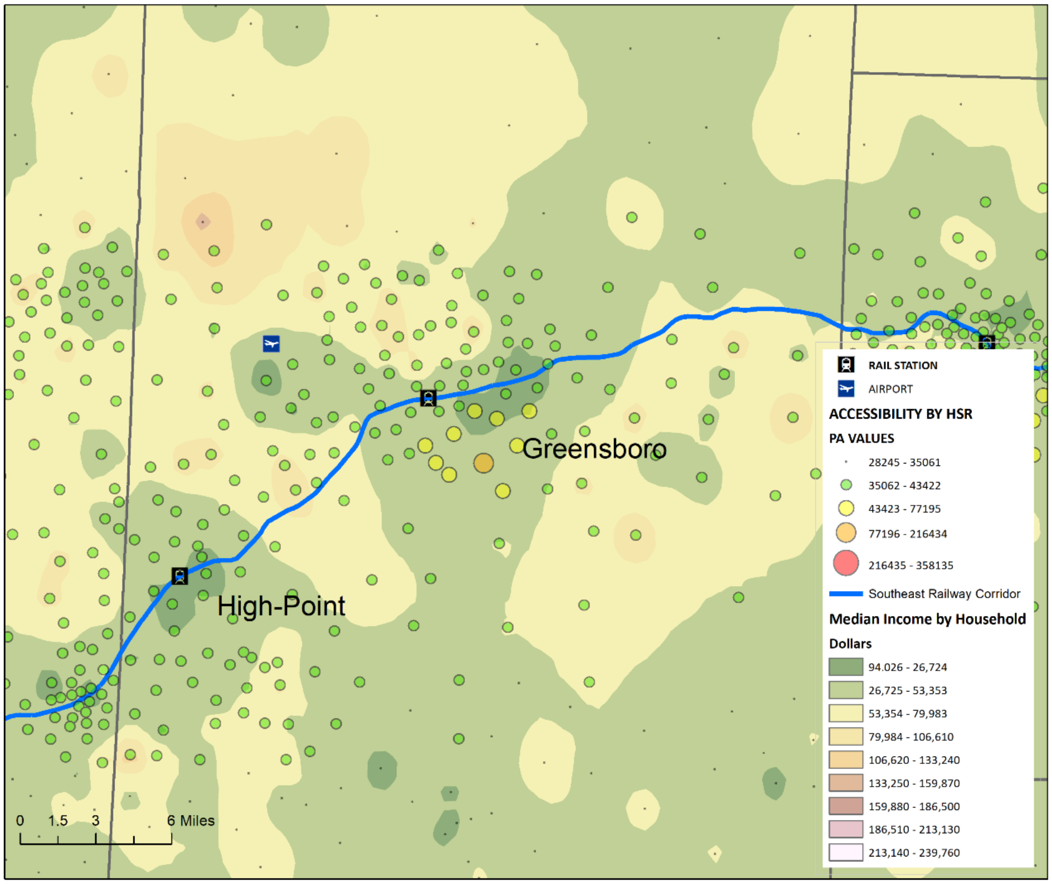


Figure 5.12 Locations of Low-Income Communities/Accessibility by HSR (Greensboro)

5.6. Discussion and Conclusions

This study investigated the distribution of accessibility benefits by different income groups. The findings clearly show that there is a discrete accessibility impact of the Southeast HSR by different communities. The fair distribution of HSR's benefits is becoming a significant issue related to transportation equity and is therefore a challenge in the decision-making process. HSR studies initially focused on the cost-efficiency of the investment during the initial planning stage of HSR; however, subsequent studies have focused on equal distribution of the benefits of HSR from the viewpoint of balanced development (Monzón et al., 2013; Kim and Sultana, 2015; Wang and Duan, 2018). Only a few HSR studies analyzed low-income or minority communities' accessibility within a city.

Therefore, this study suggests that researchers should consider how new transportation infrastructure improves the fairness of mobility/accessibility for low-income communities. Further, the accessibility gap between different transportation modes can be used for reflecting the different accessibilities of transportation modes and HSR's role in improving opportunities for intercity travel. We find that HSR shows relatively high accessibility in low-income communities whereas air transportation shows high accessibility in all income groups owing to its shorter travel time. This result implies that HSR can improve low-income communities' accessibility for intercity travel. Further, we find that middle-income communities have the lowest accessibility compared to low- and high-income communities. This might be because of scattered residences. However, HSR's benefit of improving accessibility is relatively moderate for all income groups.

The study results suggest that HSR and airlines can together improve transportation equity. In the Southeast United States, people mainly use cars or airlines for intercity travel, and trains are not popular owing to the limited routes and speed. Air transportation is the fastest transportation mode; however, it is conveniently accessible only in major cities, and air tickets are quite expensive for many people. In this case, HSR can be an alternative intercity travel option for people having less purchasing power for flight tickets. HSR can satisfy short-haul travel demands and promote the growth of low-cost airlines (Givoni and Banister, 2006). The integration of HSR and airlines has also been considered for the traditional hub-and-spoke system (Jiang and Zhang, 2014; Wu et al., 2014; Wang, et al. 2017). In brief, HSR can not only compete with other transportation modes but also serve as an alternative option for improving the quality of mobility and accessibility. Therefore, the multimodal transportation network used for equity analysis in this study affords the advantages of both competition and cooperation of all transportation modes for intercity travel.

This study also reviewed transportation equity evaluation methods and applied them to the case of the Southeast HSR in the United States to show the advantage of HSR for improving transportation equity. Areas with high-income communities have higher equitable accessibility values; this requires additional analysis from locational and socioeconomic perspectives. In addition, the different accessibility patterns of low-income groups in the Charlotte and Greensboro MSAs might be caused by the different locational characteristics of airports or proximity to the central business district; additional analysis using sociodemographic data needs to be continued. Overall, the current study data is limited. Therefore, future studies should test other sociodemographic factors affecting social exclusion of people’s mobility and accessibility and analyze intercity traffic patterns to predict those of minority communities.

CHAPTER VI

CONCLUSIONS

High-speed rail (HSR) systems have brought significant changes to interregional travel around the world and have begun to take a step forward in the United States. A catalyst for economic development and sustainable transportation, HSR alters urban forms and systems. It increases connectivity between cities and enhances interactions between their populations (Martin, 1997; Cao et al., 2013). For these reasons, many countries in Europe and Asia have introduced HSR and are extending its service network. HSR is an appealing method of travel between cities because passengers avoid check-ins, layovers, and driving-related stress. Passengers visiting cities traditionally serviced by hub-and-spoke air-traffic systems benefit from the reduced travel time HSR provides. Thus, the introduction of HSR in the United States would increase competitiveness of rail service among modes of transportation between cities.

Although the United States is lagging, there is renewed interest in developing HSR here. There is no single railway network that matches the speed of international systems, but railway improvement is the overall goal of the High-Speed Intercity Passenger Rail (HSIPR) project, which was launched in 2009 for major railway corridors, such as the Northeast and California. The HSR network plan in the United States focuses on fast connections between cities. An amount of $10.1 billion has been allocated for upgrading current railways to handle travel at speeds of 144–257 kph in 33 states and in the District of Columbia, which is close to semi-HSR standards in other countries. Even though air and car transportation are the principal modes of transportation in the United States, HSIPR could emerge as a competitive medium of intercity travel. While HSIPR aims to create faster intercity connections by upgrading existing railway infrastructure, the impact of this project for urban and regional development has not been widely examined. While Americans await a new era of HSR, infrastructure planners are focused on an essential process of evaluation and prospect its benefits before its operation for their regional development. Supported by transport-related development strategies intermodal transportation systems, the goal is to maximize HSR's impact when that era dawns.

My dissertation aimed to evaluate the potential impacts of HSR in the United States, especially investigate accessibility gaps between cities or income-disparate neighborhoods. The research evaluated HSR from efficiency and equity perspectives using accessibility measures. The evaluation process was conducted by modelling a multimodal transportation network that reflected the door-to-door trip experience. This dissertation had three broad goals: (a) to project the impact of HSR in the United States using location-based accessibility measures at a national scale, (b) evaluate the locational effect of both the current railway upgrade plans and the full HSIPR plan along the Southeast Corridor of the United States, and (c) assess the spatial patterns of multimodal accessibility via different intercity travel modes from a social-equity perspective in the context of seven metropolitan statistical areas along the Southeast Corridor in North Carolina.

Specifically, Chapter II evaluated the nationwide impact of HSIPR using two location-based accessibility measures: weighted average travel time (WATT) and potential accessibility (PA). These measures have been used in many HSR studies because their results concisely show which cities benefit the most. Another issue in HSR studies is setting origin and destination points. By developing a multimodal transportation network, this dissertation used the centroid of each city instead of a train station. This approach had the benefit of modeling the passengers' multiple uses of transit, including wait and transfer times. In the United States, WATT and PA were calculated for the 377 MSAs for current minor upgrade and the future major HSR scenarios. The research showed that HSIPR will improve accessibility in the United States, both in its early stages and when it is complete, but spatial distribution patterns will differ from region to region due to the characteristics of the accessibility measures. Low WATT values (an increase of accessibility) are concentrated in the Midwest and East Coast of the United States, but high PA values (an increase of accessibility) show a cluster in the Northeast.

Additionally, the findings explored various accessibility gaps between HSR and air and showed the potential for HSR to outperform air transportation. Specifically, HSR networks incorporating Detroit, Madison, Albany-Schenectady-Troy, Champaign-Urbana, Jefferson City, Tuscaloosa, Lake Charles, and Greenville, South Carolina, show HSR's WATT values are superior to those of air transportation. Similarly, the Northeast, including Albany-Schenectady-Troy, Philadelphia, Hartford, and New York City, boasts a relative growth in PA values thanks to HSR. Further, total trips of five-hours or less increased significantly since the introduction of HSR, with a 48% increase in the Midwest and an 86% increase in the Northeast.

Chapter III aimed to analyze the impact of HSR in the Southeast High-Speed Rail Corridor. The study conducted an accessibility analysis at the city and census tract levels. The findings indicated that HSR-related benefits are concentrated in the cities along the HSR corridor. There were significant differences in WATT values between HSR cities and non-HSR cities in 20 urbanized areas in the Southeast. Specifically, HSR cities showed a constant decrease of WATT values, while non-HSR cities did not. This research also considered the distribution of accessibility gains at the local level to investigate the nature of accessibility changes within city boundaries. The result showed that high accessibility gains are concentrated near rail stations. It implied that the potential for HSR-related economic development does not encompass a whole city but is concentrated in a small area. The research can be utilized when planning a new commercial facility in conjunction with an HSR-station development plan. Thus, the local scale accessibility analysis showed HSR's potential for successful urban development.

Chapter IV explored the spatial distribution of transport-related benefits, called transportation equity. Various evaluation measures of transportation equity were discussed, and the coefficient of variation (CV) and Gini index were applied to the Southeast. This study also considered the spatial distribution of household income to determine whether transportation equity is affected by income status. The findings showed that middle-income households have the lowest CV and Gini index while low-and high-income TAZs experience better transport equity. Further, high-income TAZs showed the highest degree of transportation equity, which implies high-income household are located near airports or train stations. This research investigated evaluation methods of spatial equity and applied it to the case of North Carolina's HSR plan, and the results indicated a significant difference in accessibility between different income neighborhoods. The results addressed the use of equity analysis with detail data of indicating minority groups is needed when evaluating the impact of the new or existing transportation infrastructure. However, the equity analysis relied on limited measures, so it is necessary to develop an improved tool to consider both spatial and vertical equity cases.

HSR planning in the United States is progressing, but its impacts remain vague to planners, rail operators, investors, and potential passengers. This dissertation attempted to determine whether current HSR planning represents a cost-effective and time-efficient improvement to intercity travel. The results clearly demonstrated HSR's significant travel-time savings, an overall increase of accessibility, and improved equity in accessibility. In addition, the Southeast has potential in achieving HSR benefits, especially in cities along the HSR corridor. Further, this dissertation showed that a multimodal transportation network can be used to calculate reliable travel time, as well spread HSR's benefits more widely throughout the country. The study is also useful for multiscale analysis because the model can set the origin in any place in the network supported by the integration of road, rail, and air transport. Therefore, our results can be convincing to Americans to understand the benefits of having a high-speed rail and for

HSIPR planners to identify the areas where improvement of the HSIPR infrastructure would be most efficient and would best close the spatial accessibility/equity gap. The construction and expansion of HSR should be continuous to optimize the distribution of related benefits for urban and regional development.

The scientific analysis of HSR has concentrated on the spatial impact from the perspective of urban/regional development influenced by changes of the transportation network connectivity and spatial proximity of cities (Garmendia et al., 2012; Urena et al., 2009). HSR changes the level of transportation network connectivity and spatial proximity, which results in the disparity of the benefits of HSR. Location-based accessibility has been used to evaluate the impact of HSR by indicating the level of spatial economic activities (Cao et al., 2013), which can be understood as a reference of HSR's potential of economic development. From this context, the relative accessibility of locations can be an essential approach to the socioeconomic implications of new HSR services for urban development. The result of accessibility analysis, therefore, can be directly used for planners to establish an urban development strategy related to HSR and can also be used for additional modeling analysis.

Nevertheless, the quantitative accessibility analysis of HSR has a limitation that the investment in social overhead capital has obstacles to the success of HSR as expected in accessibility analysis. The large-scale public projects such as a nationwide HSR network development can be influenced by political leverage. HSIPR was a federal project enforced by the federal government in Obama ministration announced in 2009, but HSIPR requires state funding as well as federal subsidy. Moreover, there have been conflicts of HSIPR due to political interests and politics. Specifically, there was the controversy of HSIPR at the state-level when the HSR projects in Florida, Ohio, and Wisconsin, were cancelled by newly-elected governors after the 2010 election (Culver, 2015). Also, there was a political struggle between the US federal government and California state government in 2019; the Trump administration canceled California's HSR funding (Vartabedian and Ormseth, 2019). HSR research and can help by highlighting the significance of HSR from economic and social justice perspectives. Meanwhile, there has been an alternative approach using private investment in Texas. This project has the advantage of financing stability but may result in higher fares or a lack of public interest in social equity.

This research also has a limitation that ticket price, a consideration factor of modal transfer to HSR, is not considered in accessibility analysis. The accessibility analysis focuses only on the condition of the transportation infrastructure and city-size. This approach relies on the premise that passengers will select HSR when the infrastructure is open to the public; however, ridership would be affected by HSR ticket prices related to modal competition. If the HSR fare is too high to purchase a ticket for every intercity traveling, the urban/regional development expected in accessibility analysis might not be realized. An insufficient number of HSR passengers will also result in the line not achieving break-even operation or construction cost recovery.

Finally, the findings in this dissertation will be continued in future research. Utility-based accessibility analysis can be used to investigate the detail of transportation-related benefits by changes in economic activities. The additional research on evaluating vertical equity measure will also be conducted to overcome the limitation of prospecting equity gaps by HSR. For example, the ability of ticket purchase and intercity traveling, social needs, and mode choices by different social status need to be analyzed.

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