Accessibility Impact of Future High Speed Rail Corridor on the Piedmont Atlanta Megaregion

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ABSTRACT

This study evaluates accessibility impact of future high speed rail (HSR) corridor on the Piedmont Atlanta Megaregion (PAM) in the United States. A geographic information system (GIS) tool is used to conduct the accessibility study. The door-to-door approach is adopted to evaluate the multimodal (including roadways and HSR) travel time. Three accessibility indicators are selected: weighted average travel time (WATT), daily accessibility (DA), and potential accessibility (PA). The selected accessibility indicators are calculated by using the estimated travel time at a geographical level. The results indicate that the building of the HSR corridor within the PAM will improve the accessibility at a megaregional level. Different indicators result in different rankings for cities in the PAM. The inequality in megaregional accessibility is decreased due to the new HSR corridor.

KEYWORDS: Accessibility, high speed rail, Piedmont Atlanta Megaregion, geographic information system

1 INTRODUCTION

The U.S. population is projected to reach 400 million in 2050 (Ross and Woo, 2011). The increasing population and the continually expanding metropolitan regions create a new scale of geography which is known as megaregion. As a new geographic unit, megaregion plays an important role in interlocking economic systems, sharing natural resources, and linking people together. Typically, the geographic scale of megaregion is consistent with the longer distance trips appropriate for High-speed rail (HSR) (Ross and Woo, 2012). HSR corridor (and network) can be used to provide a fastest mean of mass ground transportation and alleviate congestion on roadway networks (Campos and de Rus, 2009). In addition, HSR can compete with air travel for its faster passenger loading and unloading times (Levinson, 2012). HSR system planning studies at the megaregion level have been carried out by researchers (e.g., Ross and Woo, 2012) and organizations (e.g., American 2050) in the United States.

Compared with traditional transportation modes (such as cars, air, and conventional railway), HSR not only provides a shorter travel time, more safety, and lower cost, but also reduces the emission of green-house gases. The mobility and interactions among people in different regions and different economic activities can be promoted since the space-time distance is shorted by HSR. Due to the benefits of HSR services, the European counties, Korea, and China are continuing to support HSR projects. One of the most direct benefits of HSR is the improvement in accessibility (Sánchez-Mateos and Givoni, 2012; Wang et al., 2016; Zhang et al., 2016). The improved accessibility results in
numerical benefits among different regions, including the expansion of markets and spatial agglomeration of industries (Lakshmanan, 2011; Chandra and Vadali, 2014), inducing shifts in the travel dynamics of householders, and restructuring new economic patterns (Tierney, 2012).

Accessibility is defined as the potential for reaching spatially distributed opportunities for employment, recreational, and social interactions (Páez et al., 2012). The concept of accessibility has been widely adopted in the fields of land-use, transportation planning, and geography (Geurs, 2004; Holl, 2007; Cao et al., 2013). Accessibility analysis has also been used in HSR planning during the past decades (Hou and Li, 2011; Kotavaara et al., 2011; Gutiérrez et al., 2011; Pérez et al., 2011; Koopmans et al., 2012; Cao et al., 2013; Jiao et al., 2014; Wang et al., 2016), including evaluating the accessibility at a HSR station (Zhang et al., 2016), corridor (Gutiérrez, 2001; Sánchez-Mateos and Givoni, 2012), and networks (Cao et al., 2013; Monzón et al., 2013; Chandra and Vadali, 2014). For example, Gutiérrez (2001) evaluated the accessibility impact of the high speed Madrid–Barcelona–French border train line. By using different accessibility indicators, the European value-added of TEN-T projects was appraised by Gutiérrez et al. (2011). Cao et al. (2013) conducted accessibility analysis for quantifying the impact of HSR network in China. Chandra and Vadali (2014) analyzed the potential accessibility changes from 2002 to 2035 with respect to six key industry sectors around the HSR stations in the Appalachian Region in the United States. Zhang et al. (2016) employed accessibility analysis to compare the shortest travel times, accessible regions, and service populations in Tanggu Railway Station.

The purpose of this research is to evaluate the accessibility impact of the future HSR corridor proposed on the Piedmont Atlanta Megaregion (PAM). By using the door-to-door approach, the travel time between any pair of cities is estimated. Three accessibility indicators are employed to measure the accessibility impact. Such evaluation results will provide support for decision-making on the operation and planning of future HSR corridor in the PAM. The reminder of this chapter is organized as follows. Section 2 describes the methodology used in this study. Section 3 provides an overview of the PAM. Section 4 presents the methods used to estimate the travel time and to calculate the accessibility impact. The results, including the validation of the travel time and comparisons of the accessibility indicators, are discussed in Section 5. Section 6 presents the conclusions and outlook for future research.

2 METHODOLOGY

2.1 Approach for Travel Time Measurement

As a common performance indicator for measuring accessibility, travel time has been frequently used (Wang et al., 2016). In some studies, travel time of every stage of a journey between origin and destination is taken into account when calculating the total travel time from origin and destination (Lei and Church, 2010; Benenson et al., 2011). The door-to-door approach, which was developed by Salonen and Toivonen (2013), is adopted to estimate every stage’s travel time in a journey in this study. The door-to-door approach is illustrated by Figure 1. Two scenarios are presented: one travels by car and the other by HSR. Under the first scenario, one chooses car, and travel time includes (1) walking from origin to parking space; (2) driving from the parking space to destination; (3) looking for a parking space at the destination point; (4) walking from the parking space to destination (Benenson et al., 2011). By HSR, the total travel time is also divided into four parts: (1) driving (or taking transit) from origin to HSR station; (2) transferring at the HSR station, including the walking time to the station, waiting time at the station, and relevant transfer penalties in travel time (if any); (3) Traveling from origin station to destination station; (4) driving (or taking transit) from HSR station to destination.
Figure 1: Schematic Diagram of the Door-to-Door Approach

The total travel time taken in the two scenarios by using door-to-door approach can be estimated by the following two equations:

Traveling by car: \( T_{od}^{car} = T_{op} + T_{pp} + T_{pd} \)  
(1)

Traveling by HSR: \( T_{od}^{HSR} = T_{os} + T_{ss} + T_{sd} + T_{transfer} \)  
(2)

Where \( T_{transfer} \) is the total transfer time at the HSR stations.

Based on Equation (1) and Equation (2), the travel time \( T_{od} \) of the journey from origin \( o \) to destination \( d \) is the shortest travel time among different modes (e.g. car, HSR, air, and conventional rail), which is defined as:

\[ T_{od} = \min\left(T_{od}^{car}, ..., T_{od}^{HSR}\right) \]  
(3)

Where \( T_{od}^{car} \) and \( T_{od}^{HSR} \) are the travel time by car and HSR, respectively.

2.2 Accessibility Indicators

After estimating the travel time from origin to destination by using the door-to-door approach, three classical accessibility indicators which are computed on the basis of travel time are used in this study, including the weighted average travel time (WATT), daily accessibility (DA), and potential accessibility (PA).

2.2.1 WATT Indicator

WATT is the average weighted travel time from a given location \( i \) to other locations that are connected to location \( i \). The mathematical expression of WATT is presented as follows:

\[ WATT_i = \frac{\sum_{j=1}^{n} T_{ij} M_j}{\sum_{j=1}^{n} M_j} \]  
(4)

Where \( WATT_i \) is the weighted average travel time of place \( i \), \( T_{ij} \) is the travel time between the locations from place \( i \) to city \( j \) (i.e., the physical address of the city government), \( n \) is the number of cities in the study area, and \( M_j \) refers to the value of accessibility measurement of destination city \( j \), which can be computed by Eq. (5) (Wang et al., 2016).

\[ M_j = \sqrt{P_j \times GDP_j} \]  
(5)

Where \( P_j \) is the population of city \( j \), and \( GDP_j \) is the GDP of city \( j \).

2.2.2 DA Indicator

The DA indicator calculates the population or economic activities that can be reached from each place within a limit amount of travel time (Martin et al., 2004). For the DA measurement, the limited amount of time is usually set up to be between 3 and 4 hours, enabling a traveller get to a certain city, conduct an activity at the city, and return within the same day (López et al., 2008). In this study, from each place, the number of inhabitants that can be reached in less than 3 hours is computed by using Equation (6):

\[ DA_i = \sum_{j=1}^{n} \delta_{ij} P_j \]  
(6)
Where $DA_i$ is the daily accessibility of a place $i$. $\delta_{ij} = 1$ if $T_{ij} \leq 3$ hours, and 0 otherwise.

### 2.2.3 PA Indicator

The PA indicator is a gravity-based measure. Equation (7) gives the formulation of the PA.

$$PA_i = \sum_{j=1}^{n} \frac{M_{ij} \alpha}{T_{ij}}$$

(7)

Where $PA_i$ is the potential accessibility of raster $i$, $\alpha$ is a gravity parameter which is assumed to equal 1, and the rest of terms are the same as those in Equation (5). As can be seen from Equation (7), the level of accessibility by using PA indicator between a place $i$ and a city $j$ is positively related to the population or GDP of a city and inversely proportional to the travel time between place $i$ and city $j$ (López et al., 2008).

### 3 STUDY AREA

The Piedmont Atlanta Megaregion (PAM) (as presented in Figure 2) is a megaregion defined by the Regional Plan Association (RPA) in an area of the Southeast United States (American 2050). The PAM mainly includes Atlanta, Charlotte, Birmingham, Greenville, Raleigh–Durham, and Greensboro metropolitan areas. The location of the PAM in the United States is illustrated in Figure 2. Figure 2(a) presents the megaregions delineated by American 2050. In Figure 2(b), the counties that are included in the PAM are shown and such counties are selected as the study area.

![Figure 2: Location Map of the PAM in the United States (a). Megaregions Defined by American 2050; (b) The Counties and States in the PAM](image)

The PAM is characterized by a chain of loosely spaced, fast-growing regions in the Southeastern United States, with auto-oriented development patterns. Atlanta is the largest metropolitan area in the Southeastern, home to the nation’s busiest airport and some of the worst traffic congestion (Ross and Woo, 2011). Charlotte is the second largest city and the only city in the PAM with rail transit (along with Atlanta). The PAM generally follows the Interstate 85/20 corridor. Data on roads is collected from the FHWA highway dataset, which is presented in Figure 3(a). Currently, there is no HSR line on the PAM. The American Recovery and Reinvestment Act authorizes a distribution of $8 billion for HSR projects, and American 2050 developed a three-phase plan for the development of the HSR in the United States (American 2050). Due to the HSR corridor, the major cities in the PAM will be connected in the future, as presented in Figure 3(b).
4 TRAVEL TIME ESTIMATION

A spatial analysis tool – “Cost Distance” in ArcGIS is adopted to estimate the travel time and accessibility indicators, which can efficiently measure the total travel time from a place to any target cities based on raster datasets. It should be noted that the “Cost Distance” tool cannot be directly used to calculate the travel time of HSR. Unlike roadway networks in which travelers can enter at any section, HSR lines are closed except at the railway stations. As such, this study adopts the layered cost distance (LCD) method which was developed by Wang et al. (2016) so that the tool can be used for HSR.

The basic steps of LCD method are illustrated as follows:

1. Creating buffer zones on both sides of the HSR line and stations. The buffer zones along the HSR line work as impediment which indicates that travelers cannot get access to the HSR service except through those HSR stations. An example of raters map by roadway and HSR is presented in Figure 4;

2. Assigning a travel time cost to each cell, including both roadway cells and HSR cells;

3. Calculating the travel time of different travel modes from origin to destination (such as travelling by car or by HSR), in different layers, in which the “Cost Distance” tool is used;

4. Combining these cost distance results to produce a minimum cost raster map for multimodal travels.

Figure 4: An Example of Raster Map by HSR and Roadway
The PAM is divided into 1,489,546 raster grid cells with a spatial resolution of 0.2 mile * 0.2 mile (about 320 m). The travel time cost of each cell is attached as an attribute to each route \( k \) (e.g., freeway, arteria, or HSR), which is computed by:

\[
\text{cost}_k = \frac{0.2}{v_k} \times 60
\]  

(8)

Where \( \text{cost}_k \) is the travel time on route \( k \) (min), and \( v_k \) is the average travel speed on route \( k \).

The following hypothetical speeds are used in this study: the speeds of freeway, arteria, secondary road, local connecting road, and important local road are 65 mph, 50 mph, 45mph, 35mph, and 25 mph, respectively. The average speed of HSR is set as 100 mph in terms of the design speeds of 90~120 mph for the future HSR corridor program on the PAM, which refers to the Federal Railway Administration (FRA) High Speed Intercity Passenger Rail (HSIPR) Program (FRA, 2018). To model transfer time at the HSR stations, three grid cells are created to surround the stations. For example, if the transfer time at the HSR station is 30 min, to realize the average 30 min’s transfer time, a speed of 1.2 mph is set to each cell surrounding the HSR stations \( (0.2/1.2/60*3=30\text{ min}) \).

By using the developed travel time estimation method, the cost surface and accessibility are calculated as follows. First, cost raster maps of each city are estimated separately for HSR, freeway, arteria, secondary road, local connecting road, and important local road. Then, the “Mosaic to New Raster” tool (“MINIMUM” mosaic operator) is employed to produce the multimodal cost raster. Finally, regional accessibility maps are generated using the “Raster Calculator” tool based on the three accessibility indicators, i.e., WATT, DA, and PA.

5 RESULTS

5.1 Validation of Travel Time

To validate the developed travel time estimation method, Google Maps is employed (https://www.google.com/maps). The travel time of a pair of city is collected by using Google online maps. In Figure 5, travel times from Charlotte to the other cities in the PAM which are estimated by using Google Maps and LCD method are presented. As one can see from Figure 5, travel times using the developed travel time estimation method are consistent with those obtained by using Google Maps.

![Figure 5: Comparison of the Travel Times Estimated by Google Maps and the Developed Method](image)

5.2 Accessibility Analysis

Two scenarios are designed to evaluate the accessibility impact of future HSR corridor on the PAM: Scenario 1 - there are no HSRs in 2025; and Scenario 2 - the HSR line is built and major cities in the PAM are connected in 2025. It should be noted that the roadway networks are assumed to be the same under both scenarios (Jiao et al., 2014; Wang et al., 2016). The projected population and GDP in 2025 in each county by American 2050 is used. The total transfer times at the HSR stations are set as 30 min. In the following sections, the WATT, DA, and PA results are discussed.
5.2.1 **WATT Results**

Accessibility maps for the PAM using the WATT indicator without and with HSR are shown in Figure 6 (in which a lower value means more accessibility). It can be seen from the accessibility maps that accessibility is higher near the city and lower at the edges under the two scenarios. Without HSR service, as shown in Figure 6(a), the region where the WATT is less than 3 hours comprises 29.93% of the total area of the PAM. The WATT value of the Birmingham area is greater than 5 hours. With the introduction of HSR service, the percentage of regions where the WATT is less than 3 hours is increased to 45.97%. The WATTs of Birmingham, Atlanta, Greensboro, and Raleigh are all greatly improved. Table 1 lists the WATT results for the six cities. The improvement percentage of Raleigh is the greatest among these six cities, which is about 79.36%.

![Figure 6: Accessibility Maps Using WATT. (a) WATTs without HSR; (b) WATTs with HSR; (c) Percentage Changes](image)

<table>
<thead>
<tr>
<th>Cities</th>
<th>Scenario Without HSR</th>
<th>Scenario With HSR</th>
<th>Absolute Difference</th>
<th>Percentage Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charlotte</td>
<td>151</td>
<td>45</td>
<td>106</td>
<td>70.11%</td>
</tr>
<tr>
<td>Greensboro</td>
<td>183</td>
<td>53</td>
<td>130</td>
<td>71.00%</td>
</tr>
<tr>
<td>Raleigh</td>
<td>226</td>
<td>47</td>
<td>179</td>
<td>79.36%</td>
</tr>
<tr>
<td>Greenville</td>
<td>164</td>
<td>49</td>
<td>116</td>
<td>70.48%</td>
</tr>
<tr>
<td>Atlanta</td>
<td>202</td>
<td>60</td>
<td>141</td>
<td>70.04%</td>
</tr>
<tr>
<td>Birmingham</td>
<td>301</td>
<td>89</td>
<td>212</td>
<td>70.33%</td>
</tr>
</tbody>
</table>
5.2.2 DA Results

With the building of HSR line, the average accessibility population within the 3-hour limit is increased by 117.03%. Table 2 lists the accessibility results on the basis of the DA indicator for the six cities. In Figure 7, changes in DA indicators are presented. As can be seen in Figure 7, the most improvement percentages are mainly located in the counties around Atlanta and Birmingham. The increase in accessible population is very important in Atlanta due to its size, and the improvement percentage is about 125.72% compared to the scenario without HSR. Atlanta is one of the chief metropolises in the PAM, and it will be accessible within 3-hours from the megaregion counties in Alabama and Georgia with HSR.

Birmingham gains about 3.2 million (194.42%) with the new HSR lines, and the improvement is the greatest in the PAM. In other words, with the new HSR line, inhabitants around Birmingham can reach Birmingham within 3 hours. The improvement percentage of Charlotte, Greensboro, and Raleigh is about 52.5%, 81.81%, and 81.68%, respectively.

Table 2 DA indicator: Reachable Population (Thousands of Inhabitants) in a Limit of 3 Hours

<table>
<thead>
<tr>
<th>Cities</th>
<th>Without HSR</th>
<th>With HSR</th>
<th>Absolute</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charlotte</td>
<td>3206</td>
<td>4889</td>
<td>1683</td>
<td>52.50%</td>
</tr>
<tr>
<td>Greensboro</td>
<td>2689</td>
<td>4889</td>
<td>2200</td>
<td>81.81%</td>
</tr>
<tr>
<td>Raleigh</td>
<td>2691</td>
<td>4889</td>
<td>2198</td>
<td>81.68%</td>
</tr>
<tr>
<td>Greenville</td>
<td>2593</td>
<td>4889</td>
<td>2296</td>
<td>88.55%</td>
</tr>
<tr>
<td>Atlanta</td>
<td>2166</td>
<td>4889</td>
<td>2723</td>
<td>125.72%</td>
</tr>
<tr>
<td>Birmingham</td>
<td>1649</td>
<td>4855</td>
<td>3206</td>
<td>194.42%</td>
</tr>
</tbody>
</table>

Figure 7: Changes in DA Indicator

5.2.3 PA Results

Table 3 lists the PA changes for the six major cities in the PAM. The new HSR line increases the PA by 82.1%. Figure 8 presents the changes in PA indicator for all regions in the PAM. One can see from Figure 8 that regions located near the HSR corridor are improved significantly in their PA values. The reason is that the PA indicator is a gravity-based measurement, which is positively related to the population and GDP and inversely proportional to the travel time. As shown in Table 3, the most benefits received from the HSR line is Greensboro (40.60%) and Atlanta receives the second most benefits from the building of HSR line. Because Greensboro is located very close to two large cities in North Carolina, i.e. Raleigh and Charlotte, the travel time will be greatly reduced due to the introduction of HSR.
Table 3 PA: Potential Values (million) Indicator for the Selected Cities

<table>
<thead>
<tr>
<th>Cities</th>
<th>Scenario</th>
<th>Difference</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without HSR</td>
<td>With HSR</td>
<td>Absolute</td>
<td>Percentage</td>
</tr>
<tr>
<td>Charlotte</td>
<td>55.86</td>
<td>57.29</td>
<td>1.43</td>
<td>2.56%</td>
</tr>
<tr>
<td>Greensboro</td>
<td>33.91</td>
<td>47.67</td>
<td>13.77</td>
<td>40.60%</td>
</tr>
<tr>
<td>Raleigh</td>
<td>48.03</td>
<td>50.85</td>
<td>2.82</td>
<td>5.88%</td>
</tr>
<tr>
<td>Greenville</td>
<td>31.95</td>
<td>39.95</td>
<td>7.99</td>
<td>25.02%</td>
</tr>
<tr>
<td>Atlanta</td>
<td>41.61</td>
<td>50.80</td>
<td>16.19</td>
<td>22.09%</td>
</tr>
<tr>
<td>Birmingham</td>
<td>36.45</td>
<td>36.58</td>
<td>0.12</td>
<td>0.34%</td>
</tr>
</tbody>
</table>

Figure 8: Changes in PA Indicator

5.3 Comparison of the Indicators

Different accessibility indicators are calculated using different measurements, which might result in different rankings for regions or cities. Moreover, different accessibility indicators have different meanings. For example, the results of the WATT and DA indicators imply a certain amount of savings in terms of time that inhabitants spend from origin to destination, and the PA indicator measures the potential of a new travel mode which will change the accessibility of a city (Wang et al., 2016). In addition, the WATT indicator aims to express the accessibility for any places in the study area, while the DA and PA indicators describe nodal accessibility (Gutiérrez, 2001).

Through comparing the accessibility results of different indicators (See Tables 1~3), the following conclusions can be drawn. Typically, the most accessible cities are usually located in the central region of the PAM (e.g., Charlotte), the least accessible cities are located in the peripheral region of the PAM (e.g., Birmingham). For example, the accessibility of Charlotte is always ranked in the top on the basis of all three indicators. Birmingham is usually the least accessible city. However, with the building of HSR corridor, the difference between the most and the least accessible cities is greatly reduced, and some significant improvements appear on the peripheral cities. For example, the improvement percentage of Birmingham in terms of the DA indictor is about 194.42% (See Table 2) which is the greatest among the six cities.

Moreover, it is necessary to examine whether the new HSR line will contribute to increasing inequities in terms of accessibility among the cities in the PAM. The coefficient of variation is always adopted to measure the increases or decreases in disparities among cities after building a new infrastructure in the existing studies (Gutiérrez, 2001; López et al., 2008; Wang et al., 2016). Table 4 presents the changes in the coefficient of variation for the selected three accessibility indicators. It can be seen from Table 4 that the new HSR line will decrease the disparities by -0.72% in WATT, by 11.61% in DA, and by 33.40% in PA. From the megaregional perspective, the changes in the coefficient of variation are in line with the spatial accessibility of the effects of the new HSR line. Typical, during the initial stage of the development of HSR, the new HSR corridor will result in an increasing equity in the megaregion.
Table 4 Changes in the Coefficient of Variation

<table>
<thead>
<tr>
<th>Accessibility Indicators</th>
<th>Without HSR</th>
<th>With HSR</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATT</td>
<td>28.50%</td>
<td>27.78%</td>
<td>-0.72%</td>
</tr>
<tr>
<td>DA</td>
<td>42.88%</td>
<td>31.28%</td>
<td>-11.61%</td>
</tr>
<tr>
<td>PA</td>
<td>89.71%</td>
<td>56.31%</td>
<td>-33.40%</td>
</tr>
</tbody>
</table>

6 CONCLUSIONS

To estimate the accessibility impact of the future HSR corridor on the Piedmont Atlanta Megaregion (PAM) in the United States, the study adopts a geographic information system (GIS) tool. The door-to-door approach is used to estimate the multimodal travel times. Three accessibility indicators are employed to evaluate the megaregional accessibility: weighted average travel time (WATT), daily accessibility (DA), and potential accessibility (PA). To understand the overall accessibility impact of the new HSR line, the accessibility performances in the major cities (i.e., Charlotte, Raleigh, Greensboro, Greenville, Atlanta, and Birmingham) are discussed on the basis of the calculated results. Different indicators result in different accessibility performance. The comparison among the three indicators are undertaken. Moreover, the HSR reduces the inequities in terms of accessibility among the cities in the PAM based on the analysis results.

In this study, the total transfer time is set as 30min. According to the existing studies, transfer time is highly related to the HSR headway. In the future, a sensitivity analysis on the transfer time will be conducted. In addition, the total travel cost will also be taken into account.

7 ACKNOWLEDGEMENTS

The authors want to express their deepest gratitude to the United States Department of Transportation (USDOT), University Transportation Centers (UTC) Grants Program through the Center for Advanced Multimodal Mobility Solutions and Education (CAMMSE) at the University of North Carolina at Charlotte for sponsoring this research (Grant Number: 69A3551747133).

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