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IMPROVING THE MOVEMENTS OF PEOPLE AND FREIGHT: A CASE STUDY OF THE PIEDMONT ATLANTIC MEGAREGION

Final Report

by

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DISCLAIMER

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EXECUTIVE SUMMARY

As a new geographic unit, megaregion interlocks economic systems, shares natural resources, and links people together. About three-quarters of national population and wealth are concentrated in the megaregional areas that occupy one-fourth of the land area in the United States. Projections indicate the continuing leading role of megaregions in future population and economic growth. Megaregions are playing an increasingly critical role in regional and global economic competition. In addition, businesses, policymakers, and community leaders are confronted by challenges which can be addressed at a mega-regional level. For example, one of the challenges is protecting public watersheds that span multiple state and regional boundaries. The emerging recognition of megaregions enables cooperation across jurisdictional borders to address specific challenges and presents an opportunity to reshape large federal system of infrastructure and funding.

The purpose of this research is to consider the Piedmont Atlantic Megaregion (PAM) with an emphasis on maintaining efficient future people and freight movements while offering multimodal solutions to moving people and freight to, between, and within the metropolitan economies of the megaregion. The needs, impacts, and benefits of high-speed intercity passenger rails are carefully examined and objectively quantified. The issues and themes that arise in the mega-region evolution and development context, including megaregional freight planning, social equity and health access issues, are discussed and addressed.

The future mobility demand in the PAM is estimated based on the projected gross domestic product and population data in 2050. The freight planning at a mega-regional level is studied. The opportunities and challenges faced by the PAM are discussed. In order to improve the movement of goods in the PAM, several recommendations are drawn. A geographic information system tool is used to conduct the accessibility assessment of high-speed rail in the PAM. The door-to-door approach is adopted to evaluate the multimodal (including roadways and high-speed rail) travel time. Three accessibility indicators are selected and compared, including the weighted average travel time, daily accessibility, and potential accessibility. Policy implications are drawn in terms of enhancing the megaregional accessibility.

Chapter 1. Introduction

1.1. Problem Statement

Over the past decades, the expansion of the metropolitan area has resulted in the integration of large polycentric urban agglomerations (Ducca et al., 2013). In addition, the United States 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 commonly known as megaregion.

As a new geographic unit, megaregion interlocks economic systems, shares natural resources, and links people together. About three- quarters of national population and wealth are concentrated in the megaregion areas that occupy one-fourth of the land area in the United States. Projections indicate the continuing leading role of megaregions in future population and economic growth. Megaregions are playing an increasingly critical role in regional and global economic competition. In addition, businesses, policymakers, and community leaders are confronted by challenges which can be addressed at a megaregion level. For example, one of the challenges is protecting public watersheds that span multiple state and regional boundaries. The emerging recognition of megaregions enables cooperation across jurisdictional borders to address specific challenges and presents an opportunity to reshape large federal system of infrastructure and funding.

Since megaregion is a group of geographic locations and regions that are combined due to similar characteristics and mutual interest, Federal Highway Administration (FHWA) encourages the need for a megaregional perspective influencing key transportation investments (Nelson, 2017). In the United States, roadway systems cross several jurisdictional boundaries. Problems, such as pollution, freight movement, and road safety, exist across boundaries as well. Thus, planning at a mega-regional level provides an approach to addressing new emerging challenges and taking advantage of the opportunities that arise around large metropolitan and their surrounding areas that are connected by existing environmental, economic, cultural and infrastructure relationships.

Typically, the geographic scale of a megaregion is consistent with its long-distance trips, which is appropriate for high-speed rails (Ross and Woo, 2012). High-speed rail corridor (and network) can be used to provide the fastest mean of mass ground transportation and alleviate congestion on roadway networks (Campos and de Rus, 2009). One way that megaregions can prepare for future population pressures is by marshalling resources to make bold investments in high-speed rails and other mobility infrastructure. High-speed rail can compete with air travel for its faster passenger loading and unloading times (Levinson, 2012). High-speed rail system planning studies at the megaregional level have been carried out by researchers (e.g., Ross and Woo, 2012) and organizations (e.g., American 2050, 2011) in the United States.

Compared with traditional transportation modes (such as cars, air, and conventional rails), high-speed rail (HSR) not only provides a shorter travel time, more safety, and lower cost but also reduces the emissions of greenhouse 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 the high-speed rail. Due to the benefits of high-speed rail services, the European counties, Korea, and China are continuing to support HSR projects. One of the most direct benefits of HSRs is increases 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).

1.2. Objectives

The purpose of this research is to consider the Piedmont Atlantic Megaregion (PAM) with an emphasis on maintaining efficient future people and freight movements while offering multimodal solutions to moving people and freight to, between, and within the metropolitan economies of the megaregion. The needs, impacts, and benefits of high-speed intercity passenger rails are carefully examined and objectively quantified. The issues and themes that arise in the mega-region evolution and development context, including megaregional freight planning, social equity and health access issues, are discussed and addressed.

1.3. Report Overview

The remainder of this report is organized as follows: Chapter 2 provides a review and synthesis of the state-of-the-art and state-of-the-practice literature on the megaregion planning problems and multimodal solutions to move people and freight between metropolitans, and issues as well as themes arise in the megaregion evolution and development. Chapter 3 presents a method that can be used to predict and estimate the future mobility demand in the PAM. The prediction results can be used to support future decision-makings on transportation investments that help transportation planning to be better prepared to accommodate the increasing travel demand. Chapter 4 is intended to explore the role of freight transportation in supporting and sustaining economic development in the PAM. Chapter 5 evaluates the accessibility impact of future high-speed rail corridor on the PAM. Finally, Chapter 6 concludes this report with a summary and a discussion of the directions for future research.

Chapter 2. Literature Review

2.1. Introduction

This chapter provides a review and synthesis of the state-of-the-art and state-of-the-practice literature on the megaregional planning problems and multimodal solutions to move people and freight between metropolitans, and issues as well as themes arise in the megaregion evolution and development. This should give a clear picture of the current situation in the movements of people and freight in megaregions.

The following sections are organized as follows. Section 2.2 presents definitions of megaregions in the United States. Section 2.3 discusses existing studies related to the megaregional planning. Particular attention will be given to commuter planning and freight planning in the megaregion. Section 2.4 reviews studies that aim to improve the mobility in a megaregion. Section 2.5 shows studies on high-speed rail accessibility. In addition, the high-speed freight rail planning is briefly reviewed. Section 2.6 presents the megaregion planning efforts made in the United States, including exiting megaregion planning reports and workshops. Finally, Section 2.7 concludes this chapter with a summary.

2.2. Megaregions Definitions in the United States

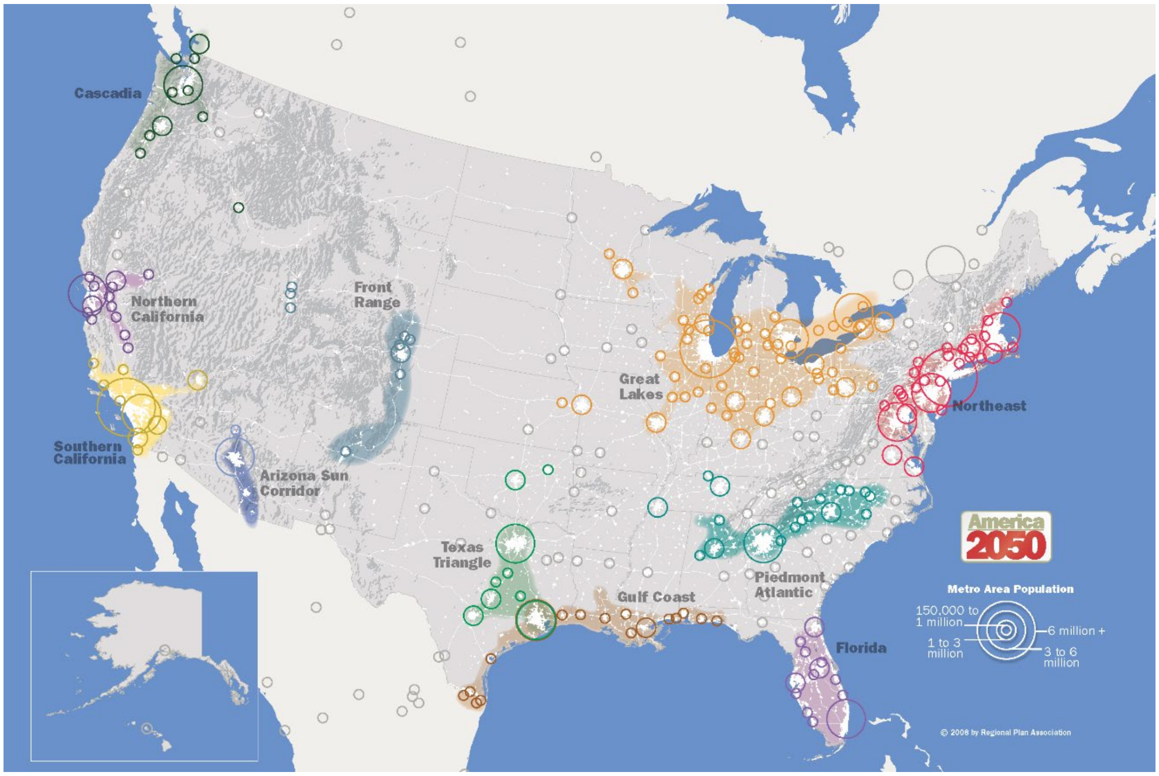
Metropolitan regions in the United States are expanding rapidly. As the metropolitan regions grow, the boundaries between the neighboring regions will become connected or overlapped. Finally, the boundaries of the regions might no longer be clear. For example, it is hard to draw a boundary line between the New York and Philadelphia metropolitan regions. Such new scale of geography is called or known as megaregions. Multiple urban cores, surrounding suburbs, and connected rural areas are encompassed by a megaregion. The economic, infrastructure, environmental, and other relationships between neighboring metropolitan regions can be connected and linked due to megaregions (Ross, 2008; Nelson and Rae, 2016).

Various organizations and researchers have defined megaregions in the United States (e.g., Lang and Dhavale, 2005; Ross et al., 2009; Hagler, 2009). The approximate delineation of megaregion boundaries was provided which might vary among different research studies. In the following sections, several definitions of megaregions in the United States are briefly summarized.

2.2.1. Megaregions Defined by American 2050

American 2050 is a Regional Plan Association's (RPA) national infrastructure planning and policy program. The main jobs of American 2050 are to provide leadership on a broad range of transportation, sustainability, and economic development issues impacting America's growth in the 21st century.

According to American 2050's definition, a megaregion is a large network of metropolitan regions that share several or all of the following criteria: environmental systems and topography, infrastructure systems, economic linkages, settlement patterns and land use, and shared culture and history. Figure 2.1 presents the map of megaregion defined by American 2050 (Hagler, 2009). The specific definition of megaregions given by American 2050 has been successfully used for increased funding for research and implementation of high-speed rail passenger systems in the United States.

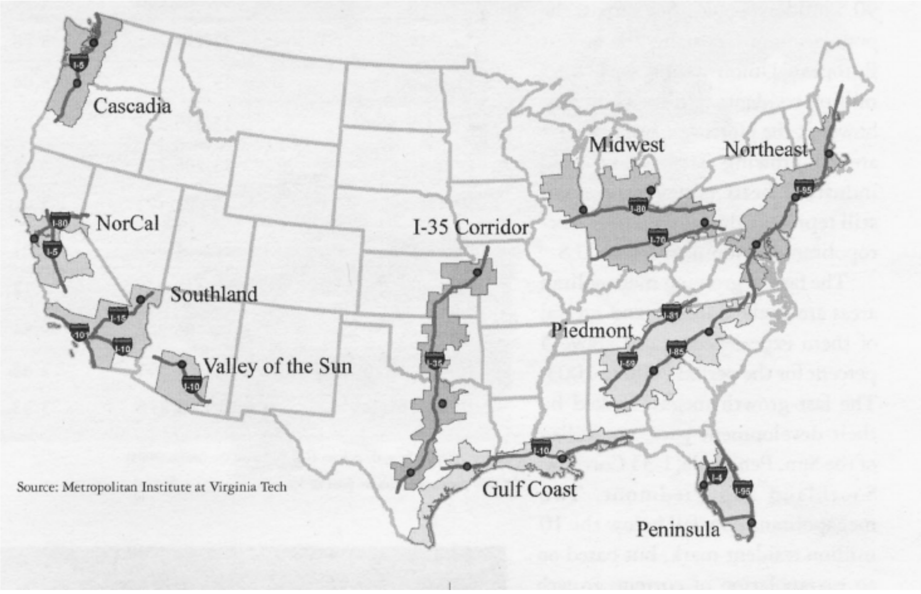


Source: http://www.america2050.org/assets_c/2014/02/2050_Map_Megaregions2008-3663.html

Figure 2.1: U.S. Megaregions Defined by America 2050

2.2.2. Megaregions Defined by Lang and Dhavale

In the study conducted by Lange and Dhavale (2005), the method for the delineation of megaregions was developed, which is presented in Figure 2.2. The method used by Lang and Dhavale is different from American 2050's. The criteria for defining megaregions include combining at least two metropolitan areas, having a projected population of at least 10 million by 2040, deriving from continuous metropolitan and metropolitan areas, constituting an organic cultural region with a distinct history and identity, occupying a roughly similar physical environment, linking large centers through major transportation infrastructure, forming a functional urban network via goods and service flows, creating a usable geography that is suitable for large-scale regional planning, lying within the United States, and consisting of counties as the most basic unit. The criteria used by Lang and Dhavale (2005) are more detailed than those used by American 2050. Thus some megaregion present in Figure 2.1 are absent in Figure 2.2.

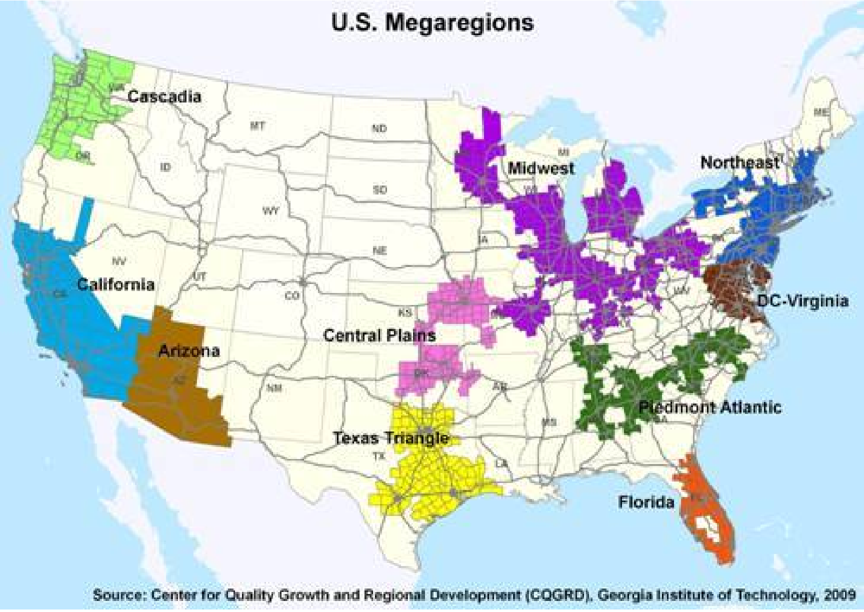


Source: Metropolitan Institute at Virginia Tech

Figure 2.2: Megaregions Defined by Lang and Dhavale (2005)

2.2.3. Megaregions Defined by Ross

Another commonly-used definition of megaregions is devised by Ross et al. (2009). Ross et al. (2009) identified ten emerging megaregions based on proximity, diverse interactions, and other uniting characteristics. The estimated population, gross domestic product (GDP), employment, CO_2 emission, and regional characteristics were used to delineate existing and emerging megaregions. The map of the megaregions is illustrated in Figure 2.3. This definition has been used in many studies (Ross, 2011a; Ross, 2011b; Ross, 2011c; Peckett et al., 2014).



Source: Center for Quality Growth and Regional Development (CQGRD), Georgia Institute of Technology, 2009

Figure 2.3: Megaregions Defined by Ross et al. (2009)

2.2.4. Megaregions Defined by Florida et al.

Florida et al. (2008) devised a definition of megaregions. The global data set of night-time light emission was used to produce an objectively consistent set of megaregions. The population within a megaregion was estimated. The authors combined the light data and national GDP to delineate the megaregions. Despite its simplicity as compared to other methods of megaregional delineation, megaregional borders defined by Florida et al. (2008) match up well with the megaregions defined by America 2050 (Harrison et al., 2012).

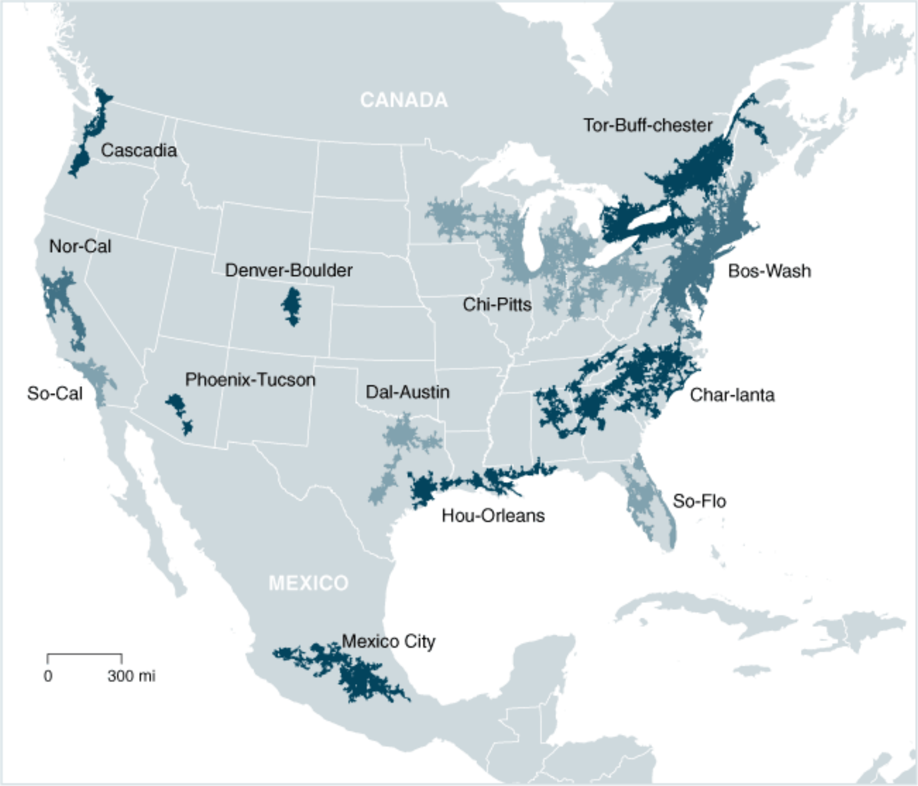


Figure 2.4: Megaregions Defined by Florida et al. (2008)

In this report, the research team uses the megaregion defined by American 2050, as shown in Figure 2.1. Currently, ten megaregions have been identified in the United States (see Figure 2.1). They include such diverse areas as the Northeast megaregion, spanning from Boston to Washington, D.C.; the I-35 Corridor in Texas and Oklahoma; and the Piedmont-Atlantic megaregion, centered on the I-85 Corridor and anchored by Birmingham, Atlanta, Charlotte, and Raleigh-Durham.

2.3. Megaregional Planning

Megaregions are networks of metropolitan areas that share economic, environment, and cultural features, as well as infrastructure and geographic connections. The megaregion concept is receiving more and more attention from the researchers and transitioning from planning theory to planning practice.

2.3.1. Existing Megaregional Planning Studies

This section reviews the existing literature and research on megaregions, intergovernmental cooperation, comprehensive planning, and state comprehensive planning enabling legislation located within megaregions.

2.3.1.1. Dewar and Epstein's research work

Dewar and Epstein (2007) discussed the state of current megaregion planning in the United States. The work of American 2050 planners was used as a case. In this study, an overview of current megaregion planning was provided. The authors presented resources and preliminary plans that addressed population characteristics, infrastructure, environment, land development, economy, socioeconomic patterns, and governance for the Northeast, Great Lakes, Southern California, Piedmont Atlantic, and Cascadia-Northwest megaregions. Several questions related to megaregional planning were raised and discussed.

2.3.1.2. Peckett et al.'s research work

To address transportation issues in the megaregions, Peckett et al. (2014) explored ways so that metropolitan planning organizations (MPOs) can collaborate with their partners to conduct planning efforts. A transportation planning framework for megaregions was proposed. In this study, the federal planning framework was first reviewed which offered insights on successful approaches to megaregion planning. MPO roles were identified and recommended. Two planning products were presented. The first product was a metropolitan transportation plan that includes strategies and actions to guide transportation system development over a 20-year planning horizon; and the second was a financially-constrained transportation improvement program that lists all capital and non-capital surface transportation projects along with total project costs and funding sources over a four-year period. Seven megaregions (including the Piedmont Atlantic Megaregion) were selected as case studies to develop frameworks that described how MPOs participated in initiatives to conduct megaregional planning.

2.3.1.3. Beiler et al.'s research

The term "resiliency" has been used in the planning fields, such as regional planning. Resiliency is an important input into the planning process. Due to the aging infrastructure, increased traffic congestion, environmental degradation, structural impairment, and social injustices, megaregions have been paid more attention from researchers. In this study, the authors focused on developing performance indicators for evaluating megaregional corridor resiliency and megaregional transportation planning. Among these performance measurements, a Geographic Information Systems (GIS) application was used to identify stresses effectively at the megaregional scale. Travel time index (TTI) and redundancy (reflecting the availability of alternate routes) were used to measure resiliency. The Bos-Wash megaregion was selected as a case study to examine the proposed method.

2.3.1.4. Ross's research work

Theoretical concepts of governing structures were provided in this study. The authors explored the evolution of the institutional structure so that a lesson can be learned to develop the megaregional governance. Three different concepts of governance were presented: reform consolidation, public market choice, and new regionalism. The historic structures and function of regional and statewide transportation planning, regional multi-modal transportation planning, and recent literature of megaregion planning were reviewed. The authors also reviewed case studies of multi-jurisdictional cooperation in multiple MPOs (e.g., transportation planning in Florida), multiple state MPOs (e.g., Augusta-Richmond County Planning Commission), and other multiple scale initiatives crossing states (e.g., Northwest Power Planning Council in the Northwestern of the United States). The opportunities and challenges in megaregional transportation planning were discussed in detail. The challenges included fragmented political boundaries in megaregions, passenger movement in megaregions, and freight movement in megaregions (in which major freight corridors in megaregions were presented). In the final part of this report, the authors developed an improved framework for megaregional planning to meet challenges.

2.3.1.5. Innes et al.'s research work

The megaregions have been emerging in the United States with linkages and interdependencies in the metropolitan areas' economies, infrastructure, water resources, environmental, and natural resources. However, the governance of megaregions has not been linked well yet. In this study, the authors intended to explore potential governance strategies among megaregions so that some successes in megaregional planning can be achieved. Five cases were selected, which include two major water planning cases (i.e., the Sacramento Area Water Forum and CALFED Bay-Delta Program), two cases of regional civic, voluntary organizations (i.e., Collaborative Regional Initiatives and Joint Venture), and the Sierra Business Council. The role of planners in megaregion governance, such as designing, creating, and supporting networks, was then discussed. In the last part of the study, the recommendations for planning education and research were proposed. For example, planning educations should be conducted to help planners prepare for megaregions.

2.3.1.6. Wheeler's research work

Wheeler (2009) explored the sustainability and governance difficulties at metropolitan and megaregional scales in the United States. Some successful regional sustainability planning initiatives were taken into account. Due to the rapid growth of the urban region, many issues, such as mobility, land and resource, equity, social and community, and economic development issues, have been faced and need to be resolved by the regional planners. The ongoing structure of regionalism was also discussed by the authors. The structural obstacles to regional planning were summarized, which included, but were not limited to, the fragmentation of jurisdictions, the sheer size of contemporary metropolitan areas, resistance to planning, deeply rooted institutional, and social capital deficits. The regional sustainability planning (including integrated environmental, economic, and social objectives) was discussed as well. The authors listed a number of considerations that should be taken into consideration in the sustainability regional planning theory, such as long-term time horizon, the implication of ecological, location and regional sense, and regional planner efforts to develop sustainability theory. A vision of a sustainable regionalism was provided in this study.

2.3.1.7. Lewis et al.'s research work

With the development of megaregions, Lewis et al. (2012) raised four key questions related to the megaregional planning, and the Texas Triangle was selected as an example.
"*Q1: Whether megaregional planning should be incorporated into regional transportation planning?"* Because the definition of megaregion does not fit existing federal laws and requirements, the leadership, regulatory environment, division of funding, scale, and data and information should be considered.
"*Q2: What planning activities should be included?*" The planning activities should include freight planning, education, air quality, transportation, land use, high-speed rail, water, economic development, etc.
"*Q3: What should be incorporated?*" Regional business, infrastructure, air quality issue, Texas Triangle Chamber of Commerce, Initiate a Texas Triangle Metropolitan Organization, Texas Triangle Infrastructure Commission, etc.
"*Q4: What should be the priority?*" Megaregional statewide LRP, (Education) Development and publish a research report, Pull in agencies/industries that have a statewide perspective to their business: HEB (Grocery Chain), CSX, Frito-Lay, and Follow through on whether there is interest in a Smart Growth Bill (Resurrection)."

2.3.1.8. Todorovich's research work

The purpose of this study was to consider the emerging of megaregions in the United States and address the planning challenges for transportation infrastructure, environmental resources, and economic growth. The existing research on megaregions was examined by Todorovich (2009), such as the origin of American megaregions since 1961 and ten identified megaregions in the United States. The benefits of megaregions included transportation infrastructure, curbing low-density sprawl and its impact on farmland, forests, and economic benefits. The "Blueprint" in California was selected as an example to explain megaregional planning for transportation investment. The city pair of New York and Philadelphia was used to test the economic benefits. The transportation issues (e.g., congestion and disrepair of infrastructure) in the Northeast were also studied. The authors suggested that improvement of intercity rail service was an immediate opportunity for megaregion cooperation. The coordination and cooperation efforts within the emerging megaregions (e.g., the existing National Committee for American 2050, the role of federal government, and voluntary collaborations among governors and majors), were discussed.

2.3.1.9. Transportation Planning Capacity Building (TPCB) Peer Program

In the report written by the TPCB peer program, key themes from a peer exchange on megaregion planning for MPOs and partners were summarized. Several examples of

MPO planning for megaregions were highlighted, including Atlanta Regional Commission, Delaware Valley Regional Planning Commission, Maricopa Association of Governments, Pikes Peak Area Council of Governments, and San Diego Association of Governments. The key themes that emerged from the peer exchange presentations, panel discussions, and breakout sessions were summarized as follows:

- "*Enhancing economic competitiveness is a key goal*
- *Improved transportation of freight is a key concern for megaregions*
- *Establishing new governance without creating a new government*
- *Partnerships develop out of necessity and opportunity*
- *Megaregion boundaries are flexible*
- *Identifying the important role of MPOs, but they may not be the most logical long-term leaders*
- *Megaregions need a champion*
- *Alternative transportation modes play an important role*
- *Linking megaregion planning to land use and transit*
- *Megaregion partnerships can address more than transportation*"

2.3.1.10. Teita and Barbour's research work

Since two megaregions are contained in California, it is necessary to consider the role of the state and local government in relation to megaregional development. Teita and Barbour (2007) examined the role of megaregions and megaregional policy within California. The study began with the definition of megaregions in California. The problems, such as the populous regions, the population, environmental issues, and the role of the state and local government, at the megaregional scale were discussed in detail. The growth issues faced in California's metropolitan regions since the 1990s were then analyzed. The growth issues included housing affordability, long commutes, inland-coastal development pattern, and fiscal and environmental constraint. However, most of the issues could not be resolved through existing regional planning frameworks. With the development of megaregions, more comprehensive megaregional issues have emerged, such as good movements, water quality and supply issues, planning issues, and air pollution. Planning institutions for megaregions should be established in order to resolve these issues. After learning lessons from the blueprint planning in the state's four largest metro areas, several concerns (e.g., how to nest planning effectively at different scales and what should be the state government's role in supporting blueprint planning) related to the megaregion planning were raised and discussed by the authors.

2.3.1.11. Zhang et al.'s research work

Zhang et al. (2007) discussed the megaregional planning in the Texas Triangle and the correlation between improving intercity transportation among metropolitan areas (i.e., Dallas-Fort Worth, Houston, San Antonio, and Austin) and the economic integration in Texas. The urbanization histories and backgrounds of the major Texas Triangle cities were depicted, such as highways, population, and environment. The economic structure including industrial specialization, comparison of freight flows, and air traffic was analyzed by the authors. Two ways (i.e., normative view and heuristic view) were proposed by the authors to understand future transportation demand in the Texas Triangle. Several challenges faced by the transportation planning in Texas were summarized in this study. In order to meet the future need, intercity passenger rail systems should be built to connect the Texas Triangle cities.

2.3.2. Freight Planning in Megaregions

Goods movement system has a direct connection to transportation investments. Goods movement plays a significant role in the megaregional economy development, both as a provider of jobs and as a facilitator of trade for businesses across the megaregion. It is also known that freight flows affect the productivity of economy. As such, ensuring the efficient movements of a commodity is essential in a megaregion (Jones, 2007). In this section, the megaregional freight planning efforts which have been made by other researchers and aimed to establish an efficient goods movement in megaregions are reviewed.

2.3.2.1. Harrison et al.'s research work

Harrison et al. (2012) studied freight planning in Texas. The current state of megaregional planning was discussed in detail. The authors conducted both domestic and international scans and gathered information on megaregional activities. The potential lessons learned from these megaregional activities were summarized. The authors analyzed federal and state rules that govern transportation planning to ascertain how these could be utilized for megaregional planning and to make recommendations. Megaregional freight planning enables cities to trade with outside. The role of international trade corridors, such as maritime corridors and rail corridors, in megaregional planning, were examined. Two megaregional planning examples in Texas were also analyzed, i.e., Tower 55 and Houston Rail Network. The authors utilized the data from the Freight Analysis Framework (FAF) 3.1, and divided freight flows into domestic, imports, and exports. Several recommendations which could be used to enhance the megaregional planning in Texas were drawn in the final part of this study.

2.3.2.2. Davis and Regan's research work

In the Mid-South Megaregion workshop held by the Federal Highway Administration (FHWA), Davis and Regan (2017) reviewed freight activities in the Mid-South Megaregion. The authors summarized the main freight challenges faced in the Mid-South Megaregion, such as freight funding, coordination among agencies, and truck parking. To address these issues, several potential solutions, such as increasing revenue sources and required plan review, were developed and discussed. The recommendations used to improve the freight movement in the Mid-South Megaregion were drawn: (1) inclusion of funding considerations in corridor planning; (2) participation in forums, programs, and other workshops; and (3) further consideration of truck parking and safety considerations.

2.3.2.3. Seedah and Harrison' research work

To maintain an efficient future freight movement and offer multimodal solutions to moving goods to, between, and within the metropolitan economies of megaregion in 2050, the Texas Triangle was selected as a case study (Seedah and Harrison, 2011). The current and future population, employment, and economic profiles in the metropolitan areas (i.e., Dallas/ Fort Worth, Austin, San Antonio, and Houston) of the Texas Triangle were presented. The road networks, rail networks, air infrastructure, marine infrastructure, and intermodal infrastructure were presented. Truck flows, rail flows, air flows and multiple mode flow including domestic, import, and export flows in the year 2007 and in the year 2040 were estimated. The authors presented three challenges of megaregional planning in the Texas Triangle. Several recommendations were developed in this study. For example, the current and future metropolitan transportation links that affect the movements of goods at a regional level should be identified; the bottlenecks on these links should be identified as well; and the future planning goals should be well set up. The challenges that summarized in this study were included the cooperation of the entire megaregion, connectivity within the megaregion, and the conservation and use of natural resources.

2.3.2.4. Bellisario et al.'s research work

Bellisario et al. (2016) studied goods movement in the Northern California Megaregion at a megaregional lens. In the Northern California Megaregion, trucking is the key mode for goods movement. The passenger rail and freight rail in the Northern California Megaregion occupy the same track which results in rail congestion problems. In order to solve these problems, the authors recommended creating a structure for passenger rail and freight rail to work together, supporting investment to limit environmental impacts, and coordinating advocacy for dedicated goods movement funding.

2.3.2.5. Transportation Capacity Building Program (TCBP)

In 2013, a peer exchange on megaregional freight planning was hosted (TCBP, 2013). Some key themes for megaregion planning were discussed, including the importance of economic competitiveness, establishing governance without new government, flexible megaregion boundaries, and alternative transportation modes. One of the major findings of this peer exchange was improving megaregion freight transportation performance which focused on the state of practice and research regarding freight planning and supply chain management in megaregions. The lessons learned from the current practice and research were described as follows: (1) continuing federal research on MPOs and megaregional planning; (2) reconsidering the term of "megaregion"; (3) looking for ways to incorporate megaregion planning into existing MPO planning processes; (4) leveraging existing government layers; and (5) building partnerships, starting conversations, and proactively planning for the freight planning in the megaregion.

2.3.2.6. Hylton's research work

Hylton (2014) developed methods which can be used to enhance freight distribution within megaregions. The supply chain management configurations were studied and examined using a megaregion framework. The relationship between the supply chain and megaregion was explored for transportation planners, policymakers, and supply chain managers.

2.4. Megaregion and Mobility

2.4.1. Zhang and Zhang's research work

An approach that utilized aggregate data to study megaregional mobility (passenger and freight) was presented in this study. The Gulf Coast Megaregion (GCM) was chosen as the case study, which contains coastal counties from five states (i.e., Texas, Louisiana, Mississippi, Alabama, and Florida). The travel characteristics (e.g., total passenger mile traveled (PMT), PMT per capita, travel time per capita, and mode split) in the United States megaregions were studied by utilizing National Household Travel Survey (NHTS) data. Zhang and Zhang (2013) also used the 2002 and 2007 Commodity Flow Survey (CFS) data to analyze freight flow in the GCM area. The characteristics of travel trends in freight flow in the GCM Area were studied as well. The results showed that an enormous amount of mobility growth would be experienced in the GCM area by the year 2050. For example, the total traffic volume would be four times higher than that in 2010. The results revealed that the share of high-speed travel (e.g., air and high-speed rail) would increase significantly. The high-speed rail should be seriously considered to accommodate the future travel demand.

2.4.2. Ross and Woo's research work

A cursory examination of spatial planning and transportation investment has shown that a lot of benefits of planning at the megaregion scale, such as improving the efficiency of freight and passenger movements. After reviewing the studies about megaregional transportation planning, Ross and Woo (2007) pointed out that "the planning at the scale of megaregion should ensure the inter-connectivity of major metropolitan areas and increase the economic competitiveness of the region." The current trends of car (longer average personal trips), truck (generating greenhouse gas and consuming energy), and air (increasing delays and high costs) were analyzed. All of these trends revealed that new investment in megaregional transportation infrastructure planning was needed. The high-speed rail projects were designated to relieve highway congestion. In the last part of the study, the authors gave federal governments three recommendations: encouraging the construction of HSR, improving and expanding the freight rail systems, and supporting collaborative efforts and initiatives by local, state, and regional bodies.

2.4.3. Bellisario et al.'s research work

In Bellisario et al.'s (2016) study, to improve the megaregional commuter and goods movement in the Northern California Megaregion, multimodal strategies were developed. The main issues in the Northern California Megaregion included highway congestion, transit systems providing limited alternatives to roadways, and shared system between passenger and freight rail limiting ability to improve service. Particular attention was given to the development of high-speed rails.

Based on the studies conducted by Zhang and Zhang (2013), Ross and Woo (2007), and Bellisario et al.'s (2016), the development of high-speed rail is a potentially promising way to improve megaregion mobility, and to relieve highway congestion. In the next section, the effectiveness of high-speed rail is reviewed. The accessibility benefit of high-speed rail at the regional and country levels is given more attention.

2.5. High-Speed Rail and Megaregion

High-speed rail projects have been proposed and constructed around the world. A high-speed passenger rail program has been developed to help address the transportation challenges in the United States by Federal Railroad Administration (FRA). The objective of building high-speed rails is to improve passenger transportation, reliability, speed, and frequency of existing services. The benefits of high-speed rail at a megaregion level have been evaluated by researchers. Such research efforts include identifying high-speed rail routes (American, 2050; Ross and Woo, 2012), environmental (Kamga and Yazici, 2014), economic, and mobility (Ross, 2011) benefits of the high-speed rail from a megaregion perspective. The challenges and issues of high-speed rail in the United States at a regional level (Chen, 2010) were also discussed.

Compared with traditional transportation modes, such as car, bus, and conventional rail, high-speed rail not only provides a shorter travel time, more safety, and lower cost but also reduces the emissions of greenhouse gases. Due to the benefits of high-speed rail services, the European, Korea, and China are supporting high-speed rail services. High-speed rail is a potential way to effectively improve the movements of people and freight within megaregions.

2.5.1. The Effectiveness of high-speed rail

2.5.1.1. American 2050's research work

American 2050 developed a method for assessing where potential high-speed rail corridors would have the greatest ridership/demand based on population size, economic activity, transit connections, existing travel markets and urban spatial form and density (2009). In 2011, American 2050 performed research on the design of high-speed rail lines in America. Serval research findings and recommendations were presented. The regional profiles of rail corridors were discussed (American 2050, 2011).

2.5.1.2. Ross's research work

Ross (2011) examined the status of high-speed rail in the United States within the context of emerging megaregions. The author assessed the current state of high-speed rail planning and its link to economic planning and enhanced mobility systems. The assessment of high-speed rail planning in the United States had a significant implication. The study suggested that high-speed rail was an attractive mode to consider in providing greater connectivity between and within megaregions as the United States considers reinvestment in its infrastructure and regional economy.

2.5.1.3. Ross and Woo's research work

Ross and Woo (2012) identified and assessed the potential high-speed rail routes from a megaregion perspective. By using the origination and destination data of commodity flows and air passenger travel, the potential high-speed rail routes with higher economic benefits were presented. The authors also compared the proposed high-speed rail routes with the high-speed rail corridors proposed by the U.S. Department of Transportation's Federal Railroad Administration. High-speed rail routes with higher investment priority were suggested. The results implied that the megaregion would be an appropriate scale for developing high-speed rail in terms of the benefits and effectiveness of implementation.

2.5.1.4. Chen's research work

Chen (2010) examined the high-speed rail development issues in the Northeast Megaregions of the United States. The only operational high-speed rail in the U.S., i.e., Amtrak's Acela Express was selected as the case study. The corresponding issue was summarized and compared to Japan's and other advanced high-speed rail systems in the world. The author adopted both regional and international perspectives to address the issues. The regional perspective conducted the passenger rail transportation deficiency analysis on the Northeast Corridor. The international perspective introduced the Japanese railway privatization process and its consequences. Based on the empirical research work, the recommendations made in this paper included: Partnership, Reform, Optimization, Multi-modalism, Interconnection, Sustainability, and Effectiveness.

2.5.1.5. Kamga and Yazici's research work

Transportation in the U.S. has been heavily depending on fossil fuel cars and planes, which has generated greenhouse gas emissions and contributed to the climate change. After examining the role of cars and planes in the U.S., Kamga and Yazici (2014) discussed the building of a high-speed rail system that might help U.S. advance towards environmental sustainability in transportation. In their study, the importance of cars in the U.S. economy and culture was presented, and the environmental and social costs of both automobiles and aviation were discussed. The potential roles of HSR in the transportation network in the U.S. were also discussed, such as improving transportation network resiliency, offering an alternative mode in a multimodal transportation network and a long-distance branch of public transportation, and satisfying future travel trends.

2.5.1.6. Chester and Horvath's research work

Chester and Horvath (2012) evaluated future automobiles, high-speed rail and aircraft long-distance travel, as well as considering emerging fuel-efficient vehicles, new train designs and the possibility that the region would meet renewable electricity goals. The California corridor was used in this study. The authors developed an attributional per passenger-kilometer-traveled (PKT) life-cycle inventory including vehicle, infrastructure, and energy production components. HSR has the potential to reduce passenger transportation impacts on people and the environment but must be deployed with the process, material and environmental reduction measures and in a configuration that will ensure a high level of adoption. The results showed that when using the life-cycle assessment framework, greenhouse gas footprints increased significantly, and human health and environmental damage potentials may be dominated. Also, a consequential assessment was developed, and compared a without HSR future where additional automobile and aircraft capacities were needed to meet growing demands to a with HSR future where the new rail system reduces the need to fully build this capacity.

2.5.1.7. Janic's research work

Even though many researchers have focused on studying the operational, economic, and environmental advantages of HSR compared to air, few researchers studied the potential benefits of HSR, such as mitigating airport airside congestion and delays, noise, and local and global emissions of greenhouse gases. Janic (2011) assessed the potential social and environmental benefits such as delays, noise, and emissions of greenhouse gases, which can be achieved by transforming some short-haul flights with equivalent HSR services at a large congested European airport.

2.5.2. HSR and Passenger Accessibility

With the increasing demand and rising fuel costs, both travel time and cost of current intercity passenger transportation modes are becoming increasingly relevant. Around the world, high-speed rail has been seen as a way to alleviate demand on highways and at airports. The large-scale implementation of the high-speed rail network is often considered to have a significant positive effect on the spatial distribution of accessibility. Accessibility has long been a central issue in transport geography and has been broadly used in various fields during the past few decades. Many studies have applied accessibility measures to determine the effects of roads and conventional railways in various countries (Wang et al., 2016; Cao et al., 2013; Jiao et al., 2014; Axhausen et al., 2011).

2.5.2.1. Wang et al.'s research work

Wang et al. (2016) quantified the accessibility impact of a HSR network proposed in the Jiangsu rail transport plan over the period from 2010-2030 in China. A layered cost distance (LCD) method was developed based on a door-to-door approach to calculating real travel time to evaluate the present and future accessibility at a geographical level. The results indicated that with the gradual development of the HSR network, accessibility levels across the province would be improved by about 9.6%, and the distribution of the gains will be uneven since the most significant improvements will occur in the more peripheral areas. The inequality in regional accessibility was decreased by an average of 25.7%. The policy measures were suggested to future enhance the competitiveness of the HSR network in the transportation market at a regional level which is presented as follows: (1) improving "feeder" transit facilities (e.g., light rail, bus services, or any other surface transportation system) to improve the first and last mile connectivity to and from HSR stations; (2) decreasing transfer time; and (3) increasing the designed speed of HSR.

2.5.2.2. Shaw et al.'s research work

In the study conducted by Shaw et al. (2014), detailed spatiotemporal accessibility patterns of cities affected by the operation of HSR in China were studied. Four scenarios were developed by authors: no HSR service in Stage 1 before August 2008, several HSR lines in Stage 2 between August 2008 and July 2011, reduced operating speed of HSR trains in Stage 3 between August 2011 and November 2012, and addition of new HSR lines and reduction of ticket fares in Stage 4 between December 2012 and January 2013. A timetable-based accessibility evaluation approach to analyzing the changes in travel time, travel cost and distance accessibility under the four scenarios was conducted. This study was useful for assessing HSR impacts on the accessibility of various cities in China as well as serving as decision-making support to policies related to adjustments of HSR operation and planning of future HSR routes by considering the existing HSR and future HSR railway lines.

2.5.2.3. Monzón et al.'s research work

Even though urban areas benefit from significant improvements in accessibility when a new HSR project is built, HSR extensions may contribute to an increase in spatial imbalance and lead to more polarized patterns of spatial development. In this regard, Monzón et al. (2013) carried out a research to study the efficiency and spatial equity impacts of HSR extensions on urban areas. The new HSR lines proposed by the Spanish Strategic Transport and Infrastructure Plan of 2005-2020 were selected as the case study. The accessibility and spatial equity evaluation were involved in this study.

2.5.2.4. Sánchez-Mateos and Givoni's research work

Sánchez-Mateos and Givoni's (2012) analyzed changes in accessibility that might result from a new HSR line in the UK. Using travel time to London as the main benchmark to measure the accessibility of a station on the current (conventional) and future (high-speed) rail networks, the authors examined the likely winners and losers from the construction of the new line. The results showed that the accessibility benefits from the proposed line are relatively limited in terms of geographic spread and that many cities close to it would not see any travel time reductions on journeys to London, thus will not see any accessibility benefits in this respect. The paper concluded by arguing that any examination of a high-speed rail line must consider a wider geographic area than just the cities, and especially the stations, on the line and it, therefore, must give due consideration to integration between transport networks, and especially between the high-speed and conventional rail networks.

2.5.2.5. Cao et al.'s research work

The large-scale implementation of a HSR network not only offers a new option for travelers' mode choice, but also may influence, or even generate, the redistribution of demographic and economic activities. Cao et al. (2013) used accessibility analysis for quantifying the impact of China's HSRs. Weighted average travel times and travel costs, contour measures, and potential accessibility were employed as indicators of evaluating accessibility at the macro or national level. Forty-nine major cities in the HSR network were selected in the accessibility analysis work. Accessibilities associated with varying availabilities of HSR, conventional rail, and airline were estimated and compared.

2.5.2.6. Chandra and Vadali's research work

Chandra and Vadali (2014) examined industry-specific 'attractiveness' due to changes in the transportation network for 23 counties in the Appalachian Region of the United States. The network improvements resulted from new highway construction and the proposed America 2050 high-speed rail plan for the Piedmont Atlantic Megaregion. The impacted counties that are proximate to five HSR stations (Birmingham, Atlanta, Greenville, Charlotte, and Greensboro) were studied for potential accessibility changes between the years from 2002 to 2035. The impacts were examined with respect to six key industry sectors found around the proposed HSR stations: manufacturing; retail; construction; mining, quarrying, oil and gas extraction; health-care services; and all other remaining industries combined. The results showed that, for transportation improvements with highways only (and no HSR), there would be a decrease in accessibility in all the impacted counties by using the six industry sectors in the future year of 2035. The HSR speed of 150 miles per hour was found to be adequate enough to cause positive changes in the potential accessibility of the directly impacted counties.

2.5.2.7. Chang and Lee's research work

Chang and Lee (2008) dealt with an accessibility analysis of Korean HSR. In this study, a systemized accessibility analysis with a case study of the Seoul metropolitan area was performed. A reduced form of a Hansen-type accessibility measure was proposed. An analysis of variance (ANOVA) test and a GIS-based mapping audit were used as tools for the assessment. The authors also identified the opportunity that could yield the greatest demand increase of HSR. In addition, some metropolitan railway expansions for improving the accessibility of the region were recommended.

2.5.2.8. Gutierrez's research work

Gutierrez (2001) evaluated the accessibility impact of the future Madrid-Barcelona-French border high-speed line. Accessibility impact of the new infrastructure was measured by three indicators: weighted average travel times, economic potential and daily accessibility. A GIS was used to carry out the research. The results were different by using different indicators. For example, by using daily accessibility indicator, the results were concentrated which was different from those by using economic potential.

2.5.2.9. Peters et al.'s research work

Peters et al. (2014) provided a systematic and consistent methodology for analyzing system wide modal ridership with and without a proposed HSR network and analyzed the potential for high-speed rail as part of the existing multimodal transportation system in a region in terms of ridership. The ridership prediction included considerations of modal accessibility and multimodal network performance. The HSR in the United States' Midwest corridor was selected as an example. Considerations of capital investment (e.g., network design and HSR speed), along with exogenous demographic, technological, economic, and policy trends in the long-term, were used to project ridership over time. The results of this study could provide planners and policymakers with a systematic methodology for analyzing the viability of the proposed HSR network over the long term.

2.5.2.10. Levinson's research work

Levinson (2012) analyzed the accessibility of HSR in the United States. In this study, the state of HSR planning in the United States was reviewed. Several points were raised by the authors, such as sharing the proposed high-speed passenger rail with the freight.

2.5.2.11. Zhang et al.'s research work

Zhang et al. analyzed HSR's influences on and contributions to accessibility changes around the Tanggu railway station in China. Four scenarios were designed: base scenario, hypothetical scenario 1, hypothetical scenario 2, and a real-world scenario. The shortest travel time, accessible regions, service populations, and population potential of one- to four-hour isochrones under four scenarios were compared. The results indicated that station accessibility was significantly improved from 2007 to 2012. HSR has not only brought a time-space contraction effect to the region from the station to the north-western area but also strengthened interactions among different regions. Road network improvement was identified as a key factor with balanced impacts on all four-hour isochrones. The results of this study generated supportive information for the planning and construction of HSR stations and networks and provided references for comprehensive transport policymaking.

Based on the literature review as presented above, Table 2.1 shows a summary of existing HSR accessibility analysis methods. Note that the following notations are introduced to facilitate the description.

* Weighted average travel times (WATT): computed as $WATT_i = \frac{\sum_{j=1}^{k}(T_{ij}^{k} M_j)}{\sum_{j=1}^{k} M_j}$;

* Daily accessibility (DA): computed as $DA_i = \sum_{j=1}^{m} P_j \delta_{ij}$;

* Potential accessibility (PA): computed as $PA_i = \sum_{j=1}^{n-1} \frac{M_j}{T_{ij}^{k}}$.

Note that M_j is the accessibility measures at destination j (e.g., population and/or GDP); P_j is the population of destination j; T_{ij}^{k} is the travel time between i and j by mode k; $\delta_{ij} = 1$ if $T_{ij} \leq 3$ hours, and 0 otherwise.

* Accessibility $A_i = \sum_j S_j f^{-1}(C_{ij})$, where A_i is the accessibility at origin i, which varies directly with the opportunity S of the socio-economic activities of destinations j and inversely with transport cost $f(C_{ij})$ between i and j.

Table 2.1: Summary of HSR Accessibility Analysis Methods

Year	Authors	Case Study	Country	Accessibility Factors	Tool	Study Period	Other
2001	Gutierrez	Madrid-Barcelona-French	Multi-counties	WATT, Economic Potential, and DA	GIS	/	NO
2008	Chang and Lee	Korean HSR	Korean	$A_i = \sum_j S_j f^{-1}(C_{ij})$	ANOVA and GIS	2004	NO
2012	Sánchez-Mateos and Givoni	Network Rail in UK	UK	Travel Time	GIS	2009	NO
2013	Cao et al.	HSR network in China	China	WATT, Travel Costs, Contour Measures, and PA	GIS	/	NO
2013	Monzón et al.	Spanish Strategic Transport and Infrastructure Plan	Spanish	PA	GIS	2005-2020	Efficiency and Equity
2014	Chandra and Vadali	HSR in Appalachian Region	United States	Travel Time	GIS	2002-2035	retail; construction; mining, quarrying, oil and gas extraction; health-care services; and all other remaining industries combined
2014	Peters et al.	Midwest Corridor	United States	Travel Time and Travel Cost	/	2010-2050	Multimodal Network Performance
2014	Shaw et al.	HSR network in China	China	Travel Time, Travel Cost, and Distance Accessibility	GIS	2008 - 2013	NO
2016	Wang et al.	HSR network in Jiangsu Province	China	WATT, DA, PA	GIS	2010-2030	NO
2016	Zhang et al.	Tanggu HSR Station	China	Travel Time, Accessible Regions, Service Population, and One- to Four- Isochrones	GIS	2007-2010	NO

2.5.3. HSR and Freight Movement

Based on the studies in section 2.5.2, the intercity high-speed passenger rail system can greatly improve the accessibility. The intercity high-speed passenger rail has also been recognized as an energy-efficient, environmentally-friendly, and safe mode, which holds the promise to mitigate highway congestion, achieve sustainable development and reduce foreign oil dependency. To achieve a cost-effective investment in HSR systems, a mixed traffic system which has been studied by the researchers is given in this section.

2.5.3.1. Ertem and Özcan's research work

Ertem and Özcan (2016) investigated the usage of HSR for freight (e.g., cargo and mail). A high-speed rail scheduling mode was developed to explore the effects of HSR system including freight and passenger system. A mixed-integer programming model was developed, and the Turkish State Railway HSR network was used to test the developed mathematical model. Two scenarios were examined (i.e., adding separate freight trains to the system and using passenger trains for freight transportation). The results indicated that using the same train for transporting both passengers and freight provides more time-saving in the system.

2.5.3.2. Song's research work

Song (2014) analyzed the impact of HSR express business in China. A case study of Wuhan-Guangzhou HSR corridor was selected. The loading capacity and economy performance of the selected HSR corridor were discussed. The result showed that HSR had advantages over air and highway in transporting express of medium- and long-distance.

2.5.3.3. Strale's research work

In a research conducted by Strale (2016), the experiences, literature, and prospects of HSR for freight were examined. The freight HSR services in European were evaluated. The author answered two question related to the high-speed freight rail system: why are there so few freight HSR services and the impact of a high-speed freight rail system on urban spaces. The potential effects on urban dynamics were analyzed. The location and potential relocations of the clients and of the terminals and their impacts on urban spaces were also identified. Finally, a threefold contribution was made: (1) the obstacles to the development of freight high-speed rail services were identified and demonstrated; (2) the effects of freight HSR on urban dynamics were analyzed; and (3) the related policy and recommendations in the European were made.

2.5.3.4. Troche's research work

Troche (2005) analyzed the efficient train system for freight projects carried out by the Centre for Research and Education in Railway Engineering at the Royal Institute of Technology Stockholm. Several examples of high-speed rail for freight were given and summarized in this study, including Sweden, Denmark, France, England, and Germany.

2.5.3.5. Zhang et al.'s research work

Zhang et al. (2015) carried out a research study to investigate the impact of high-speed passenger trains on freight train efficiency in shared railway corridors. In their study, a series of decision support tools which could help evaluate the impact of high-speed passenger rail on freight capacity were developed. The research was conducted from the following aspects: the carrying capacity of HSR system including HSPR and high-speed freight rail (HSFR), discussing the design factors of HSR (speeds, headways, and infrastructure design), and recommendations to support the development of proposed HSR system. The on-going Chicago-St. Louis HSR project was selected as the case study. This research project presented systems-level perspectives and added advanced train control technologies into the railway transportation context, and integrated them with theoretical models, optimization and simulation approach, policy analysis, and implementation framework.

2.5.3.6. Pazour et al.'s research work

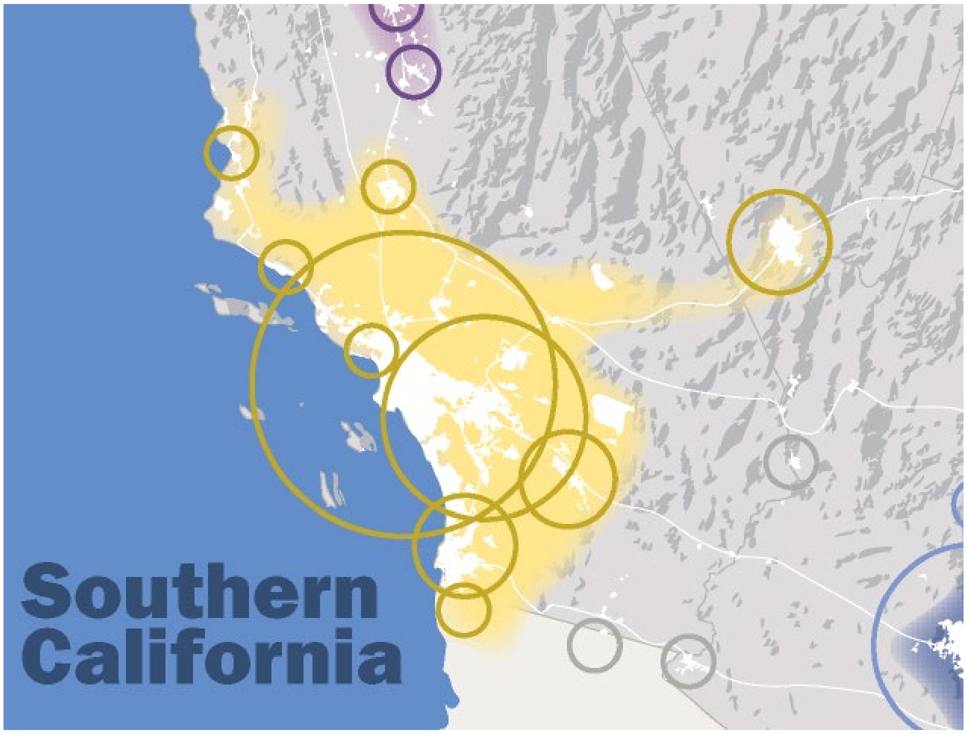
To reduce the amount of freight traffic on the highway network, Pazour et al. (2010) developed a potential national high-speed network for freight distribution. The potential network design model with a post-process step for the capacity constraint was developed while taking account in highway traffic and transit time. By using the preliminary data on high-speed rail operating parameters for freight application and from current data on shipments from a major truckload carrier and the U.S. Census Bureau, the modeling approach was illustrated. The results indicated that such an approach could be used by policymakers to evaluate the impacts of a high-speed rail network.

2.6. Megaregional Planning in the United States

Megaregions are networks of metropolitan areas that share economic, environmental, and cultural features, as well as infrastructure and geographic connections. Since its inception in the 1960s, the concept of the megaregion has been gradually transitioning from planning theory into planning practice. In this section, the practices of megaregional planning (including both freight and passenger planning) in the United States are reviewed, including the workshops held by FHWA, the planning collaboration among different MPOs, and the related megaregional planning reports.

2.6.1. Southern California Megaregion

The Southern California megaregion included six counties (i.e., Los Angeles, San Bernardino, Riverside, Imperial, San Diego, and Orange) and encompassed a population of approximately 21 million in 2000. The population is expected to grow to 28 million by 2030. The megaregion contains the largest ports in the United States and key international border crossings. The megaregion's GDP was $900 billion, representing the majority of California's economic activity and seven percent of the GDP in the United States. The position of Southern California megaregion defined by the American 2050 is shown in Figure 2.5. The development in the Southern California megaregion includes a growing and diverse population, denser development patterns, increasing congestion and limited transportation infrastructure, declining economic competitiveness, strains on public facilities and services, threats to the natural environment, and growing economic and social disparity (American 2050, 2005). The issues for the Southern California megaregion include (1) international borders and trade; (2) goods movement (regional, State, national, and international); (3) ability to leverage funds for transportation infrastructure; and (4) reduction of greenhouse gas emissions (Packett et al., 2014).



Source: http://www.america2050.org/southern_california.html

Figure 2.5: Southern California Megaregion

To address the problems faced by the Southern California Megaregion, both the American 2050 and Packett et al. (2014) proposed the solution strategies from a megaregional aspect. The detailed strategies are shown in Table 2.2.

Table 2.2: Issues and Potential Solution in the Southern California Megaregion

Source	Issues	Potential Solutions
American 2050 (2005)	- Population - Denser Development - Congestion - Declining Economic Competitiveness - Natural Environment - Growing Economic and Social Disparity	- Sustainability - Prosperity - Equity - Financing
Packett et al. (2014)	- International borders and trade - Goods movement - Ability to leverage funds for transportation infrastructure - Reduction of greenhouse gas emissions	- Identifying priority areas for coordination - Recognizing goods movement as inherently inter-regional - Coordinating local, regional, and State priorities - Inviting greater inter-regional collaboration - Integrating environmental sustainability into planning

2.6.2. Mid-South Megaregion

In Figure 2.6, a map of the Mid-South Megaregion outlined by the Federal Highway Administration is given. It shows the Mid-South Megaregion (peach), alongside the Piedmont Megaregion (orange), the Texas Triangle Megaregion (gold), and the Central Plains Megaregion (pink). The Mid-South Megaregion comprises critical highway infrastructure, passenger and freight rail, and seaports that go beyond state and agency boundaries to support the national economy. Effective transportation infrastructure, which links together neighborhoods, towns, cities to regions, and regions to megaregions, is essential to strong economic growth in a global economy.

The Mid-South Megaregion Workshop was held and sponsored by the FHWA office of planning, Environmental, and Realty on December 8, 2016 (Davis and Regan, 2017). The workshop examined shared regional issues of concern among transportation decision-makers and stakeholders in the Mid-Southern Megaregion. Five key issues were discussed in the workshop: (1). Economic; (2). Environment/Air Quality; (3). Freight; (4). Infrastructure/Congestion; and (5). Safety.

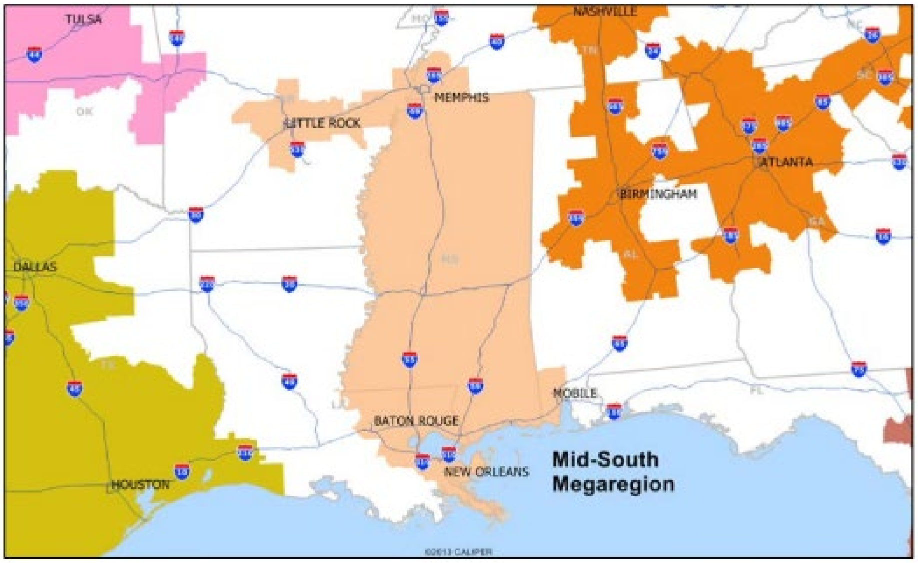


Figure 2.6: Mid-South Megaregion

2.6.3. Northern California Megaregion

The Northern California Megaregion is composed of 21 counties which can be grouped into four regions: Bay Area, Sacramento Area, Northern San Joaquin Valley, and Monterey Bay Area, as presented in Figure 2.7. It boasts one of the fastest growing economies in the country, joining the Texas Triangle and Gulf Coast as the only three megaregions to grow their gross regional product (GRP) at a compound annual rate greater than 5.0% since 2010 (Bellisario et al., 2016). The characteristics of the North California Megaregion include a population in the megaregion that is totaled 12.2 million in 2015, and three of the fastest growing counties in the state.

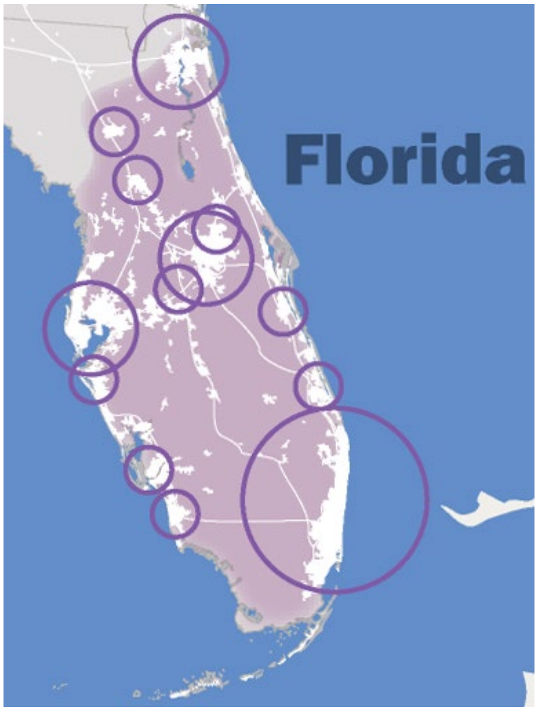
Source: https://en.wikipedia.org/wiki/California_megapolitan_areas

Figure 2.7: Northern California Megaregion

Recently, transportation inefficiencies are constraining megaregional movement, such as: increasing inter-regional commuters add to highway congestions, transit systems provide limited alternatives to roadways, and shared system between passenger and freight rail limits ability to improve service. To address the issues faced by the Northern California Megaregion, Bellisario et al. (2016) developed several recommendations which are given as follows: improving the level of services of Altamont Corridor Express and the San Joaquins Amtrak, promoting the construction of megaregional HSR project at the state level, and ensuring funding and infrastructure finance.

2.6.4. Florida Megaregion

The Florida megaregion is centered on its east and west coasts, and central and south Florida, as shown in Figure 2.8. The region is extremely diverse, with 6 out of every 10 residents who moved to Florida between 2000 and 2010 from foreign countries. The region is also well known for being a retirement hub and has a strong population of those over the age of 60. Florida has also recently promoted and developed a high-speed rail connection between Tampa and Orlando to begin the process of planning for the efficient movement of future larger populations. However, Governor Rick Scott returned federal funding for this endeavor in early 2011, jeopardizing the future of high-speed rail in the state.



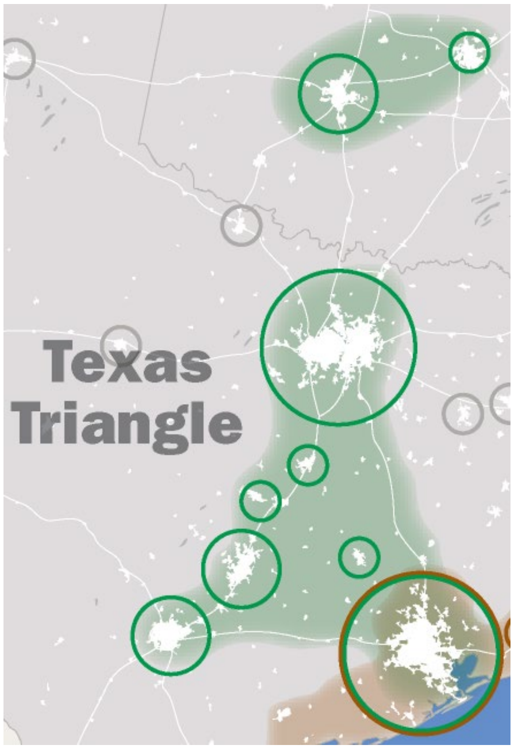
Source: http://www.america2050.org/florida.html

Figure 2.8: Florida Megaregion

In a “2060 Florida Transportation Plan” report, the emerging megaregions were taken into account. Transportation challenges faced by the Florida Megaregion were raised in the report. For example, the development of Florida’s megaregions requires connectivity between its economic regions. There are few choices for moving people or freight between many of Florida's regions today; and highways are the only option available. If current trends continue, most urban and interregional highway corridors will likely be heavily congested during peak periods by 2035. The rail capacity may not be sufficient for a significant increase in both passenger and freight demand. To solve the challenges, investing in transportation systems was proposed in the transportation plan.

2.6.5. Texas Triangle Megaregion

The Texas Triangle Megaregion is spatially delineated by the metropolitan areas of Dallas/Fort Worth, Austin, San Antonio, and Houston - the five most populated metropolitan areas in Texas and all within a 150-mile radius from their centroid (see Figure 2.9). It has a total land size of nearly 60,000 square miles. The Triangle had approximately 15 million inhabitants in the year 2000 (68% of the Texas population), which grew to 17 million (69% of the Texas population) in 2010. Of the top 50 fastest growing counties in Texas, 38 are in the Texas Triangle megaregion. Of this 38, 9 are among the top 10 fastest growing counties in Texas: Hays, Denton, Williamson, Collin, Bastrop, Montgomery, Rockwall, Fort Bend, and Waller (see Figure 2.10). Williamson, Hays, Collin, and Denton counties had population changes greater than 34% from 2000 to 2010.



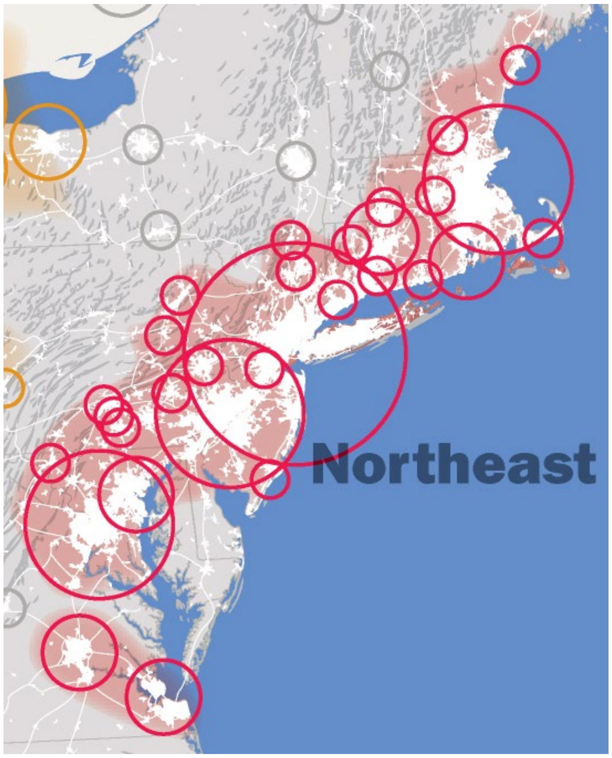
Source: http://www.america2050.org/texas_triangle.html

Figure 2.9: Texas Triangle Megaregion

Research work has been conducted to study the megaregional planning in the Texas Triangle Megaregion. For example, Seedah and Harrison (2011) studied the megaregional planning in the Texas Triangle, and the challenges faced by the Texas Triangle included: (1) current and future metropolitan transportation links that impact regional goods movements; (2) the current bottlenecks and future needs for these links, such as capacity constraints, community impacts, and environmental and permitting regulations; (3) setting up benchmarks and future planning goals for the links and cities; and (4) exploring alternative funding sources. Seedah and Harrison (2011) strongly suggested that the megaregion planning should include freight system and needs, the TxDOT should introduce elements of megaregional planning into statewide planning, and planners at MPOs and TxDOT should develop levels of integration.

2.6.6. Northeast Megaregion

The Northeast megaregion, as the largest of the commonly delineated megaregions, has a mixture of advantages as well as challenges to be faced in the near future. Situated on the Mid Atlantic seaboard from Northern Virginia to Southern Maine, the region is bounded by the Appalachian Mountains to the west. The major metropolitan cities of Boston, New York, Philadelphia, Baltimore, and Washington D.C. are all found within this megaregion, as presented in Figure 2.10. The deterioration of the environment due to the massive scale of urbanization in the region is a pervasive issue. The Northeast is also unique in that it has significant congestion across essentially all modes, including roadways, airports, and passenger and freight rail. Though growth between 2000 and 2025 is expected to be 18%, the existing large population means that this megaregion is expected to add roughly as many people in that timeframe as the Cascadia, Arizona Sun Corridor, and Gulf Coast megaregions combined. Several of the most populous metropolitan areas in the U.S. are located in this megaregion, aligned along Interstate 95 (I-95) from Boston, Massachusetts to Washington, D.C. In recent decades, urban sprawl has been a challenge for many of the metropolitan areas in the Northeast Megaregion.



Source: http://www.america2050.org/northeast.html

Figure 2.10: Northeast Megaregion

Delaware Valley Regional Planning Commission (DVRPC) is the MPO for the Philadelphia, Pennsylvania and Trenton, New Jersey metropolitan areas. DVRPC has always had a cross-jurisdictional perspective and has increasingly reached out to neighboring MPOs to coordinate transportation planning in the megaregion. Some examples of megaregions projected DVRPC has been involved in include: planning at the edge, i-95 corridor coalition, air quality partnership, Delaware valley goods movement task force, central jersey transportation forum, and megaregion aviation planning (TPCB, 2012; Ducca et al., 2013). The following insights were identified: (1) DVRPC defines different boundaries for each partnership, choosing the appropriate scale for the issues being addressed; (2) Many of DVRPC's early megaregion planning projects focused on specific corridors or projects. However, the focus has shifted somewhat to larger policy issues; (3) Limited staff resources are a major challenge for megaregion planning initiatives, particularly for smaller MPOs; and (4) Additional federal direction and support are needed.

2.7. Summary

A comprehensive review and synthesis of the current and historical researches related to megaregion definitions, megaregional planning, and megaregional freight planning experiences, high-speed rail accessibility, high-speed rail freight system design in the megaregion, and the megaregional planning in the United States have been discussed and presented in the preceding sections. This is intended to provide a solid reference and assistance in improving the movements of people and freight in the megaregions and developing effective strategies for future tasks.

Chapter 3. Future Mobility Demand in the Piedmont Atlantic Megaregion

3.1. Introduction

The Piedmont Atlantic Megaregion (PAM) is one of the ten emerging megaregions identified by American 2050. In the future, the PAM is expected to grow by an additional million of people in population. Tremendous pressure would be imposed on the transportation infrastructure. Thus, in order to support the future decision-making on transportation investments that help transportation planning to be better prepared to accommodate the increasing travel demand, this chapter adopts a method which can be used to predict and estimate the future mobility demand in the PAM.

The following sections are organized as follows. Section 3.2 presents the prediction method. Section 3.3 shows relevant information in the PAM, including the projected population and GDP. Section 3.4 discusses the prediction results by 2050. Finally, Section 3.5 concludes this chapter with a summary.

3.2. Method

The aggregated model developed by Schafer and Victor (2000) is used to predict the future mode share in the PAM in this chapter. Schafer and Victor found that the behavior of travelers was determined by two fundamental constraints: the budget of travel time and the cost devoted to travel. In the section, the prediction model is briefly introduced.

Typically, travelers spend a fixed amount of their daily time budget on traveling which is called the travel time budget. According to the traveling data collected from different cities and countries, Schafer and Victor (2000) suggested that the value of the travel time budget is approximately 1.1 hours per person per day.

There is a strong relationship between income and the demand for travel. As the traveler's income increases, spending on travel increases as well, which allows for longer mobility. By using the projected population and GDP, the projected per capita travel volume (TV) can be estimated. The future TV per capita can be calculated by (Schafer and Victor, 2000; Zhang and Zhang, 2013):

$$\frac{TV}{cap} = \mathbf{log}\left(\frac{GDP / cap}{g} - h\right) * \left(\frac{GDP}{cap}\right)^{e} * f \tag{3.1}$$

where cap is the projected population, and g, e, f, and h are the parameters which are calculated using the real world data, respectively.

The relationship between g, e, f, and h is

$$f = \frac{240{,}000^{1-e}}{\mathbf{log}\left(\frac{240{,}000}{g} - h\right)} \tag{3.2}$$

After achieving the future *TV*, the future mode split of existing or potential transportation mode *i* can be predicted. According to Zhang and Chen (2009), the share of the bus, railway, high-speed travel, and automobile will be estimated.

$$S_{rail} = i * \left(\frac{1}{(TV - j)^k} - \frac{1}{(240{,}000 - j)^k} \right) \tag{3.3}$$

$$S_{bus} = l * \left(\frac{1}{(TV - m)} - \frac{1}{(240{,}000 - j)} \right) - S_{rail} \tag{3.4}$$

$$S_{HST} = s * \mathbf{exp}\left(-\mathbf{exp}\left(-t * (TV / cap - u)\right)\right) + v \tag{3.5}$$

$$S_{car} = 1 - S_{rail} - S_{bus} - S_{HST} \tag{3.6}$$

where *i, j, k, l, m, t, u,* and *v* are parameters.

v is a parameter computed by $v = 1 - s * \mathbf{exp}\left(-\mathbf{exp}\left(-t * (240{,}000 - u)\right)\right)$.

s is a parameter which is calculated by using the following equation:

$$s = \frac{S_{HST,\ prediction-year} - 1}{\mathbf{exp}\left(-\mathbf{exp}\left(-t * (TV / cap - u)\right)\right) - \mathbf{exp}\left(-\mathbf{exp}\left(-t * (240{,}000 - u)\right)\right)} \tag{3.7}$$

$S_{HST,\ prediction-year}$ is the share for high-speed transportation in the studied year, affected by the speed of the other transportation modes;

$$S_{HST,\ prediction-year} = \frac{1 - S_{bus} * (1 - V_{car} / V_{bus}) - S_{rail} * (1 - V_{car} / V_{rail}) - V_{car} * TTB_{motorized} * 365 / TV}{1 - V_{auto} / V_{HST}} \tag{3.8}$$

where V_{car}, V_{bus}, V_{rail}, and V_{HST} are the speeds of the car, bus, rail, and high-speed travel mode (including HSR and air) respectively, and they are assumed to be 55 km/h, 20 km/h, 30 km/h, and 600 km/h (Schafer and Victor, 2000). $TTB_{motorized}$ is the fixed travel time budget, which is set as 1.1 hours.

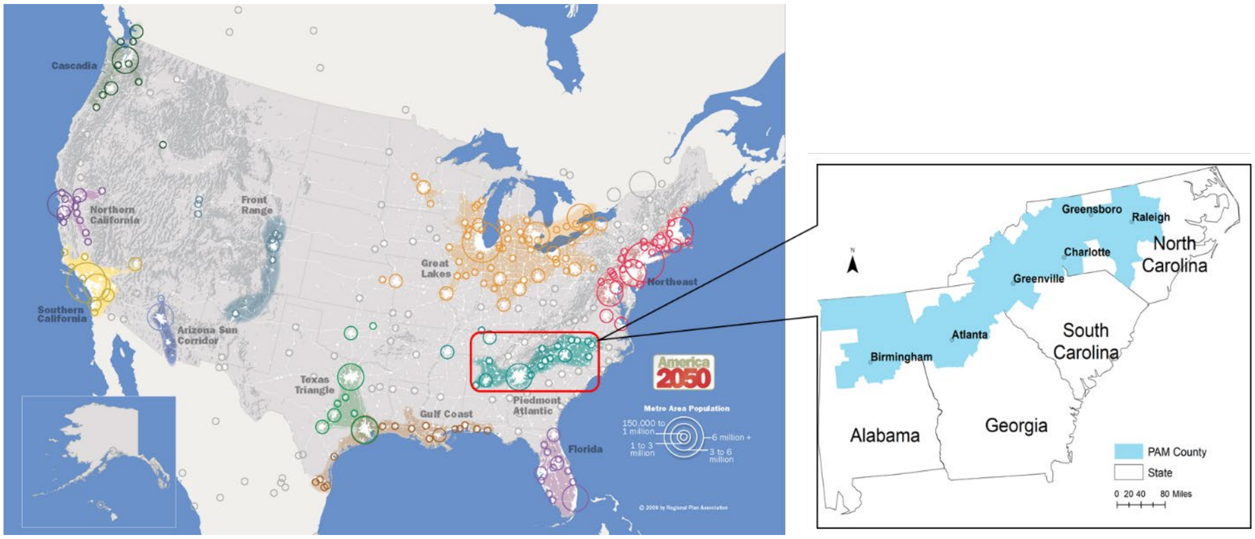
According to Schafer and Victor (2000), the value of parameters used in Eq. (3.1) – Eq. (3.8) are given in Table 3.1. It should be noted that these parameters are unitless (Zhang and Zhang 2013).

Table 3.1: Model Parameters

e	***g***	***h***	***i***	***j***	***k***	***l***	***m***	***t***	***u***
0.776	40.2	61.19	122.7	6262	1	1195	-3248	$4.82*10^{-5}$	35684

3.3. Data

The Piedmont Atlantic Megaregion (PAM) defined by the RPA is used to perform the study. The PAM is a megaregion in the area of the Southeast United States (American 2050, 2009. The PAM mainly includes Atlanta, Charlotte, Birmingham, Greenville, Raleigh–Durham, and Greensboro metropolitan areas. In Figure 3.1, the regions and counties included in the PAM are presented.



Source: http://www.america2050.org/assets_c/2014/02/2050_Map_Megaregions2008-3663.html

Figure 3.1: Piedmont Atlantic Megaregion

The PAM is characterized by a chain of loosely spaced, fast-growing regions, 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 city in the PAM with rail transit (along with Atlanta). The PAM generally follows the Interstate 85/20 corridor, as shown in Figure 3.2. In Table 3.2, the basic information (including megaregion population, gross regional product (GRP), and employment-population) about the PAM in 2015 and 2045 is given.

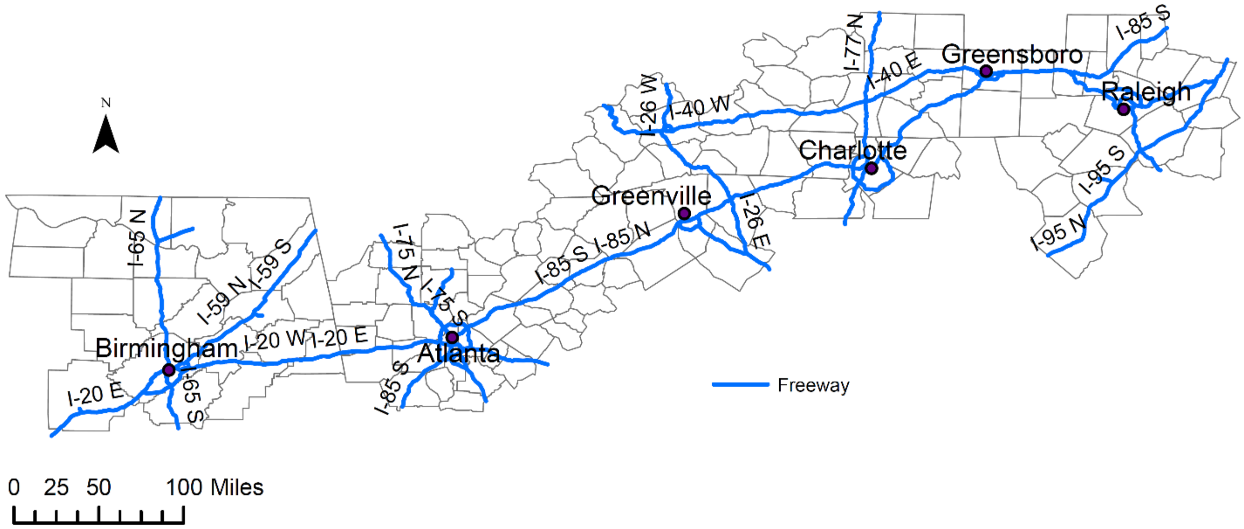


Figure 3.2: Freeway Layout in the PAM

Table 3.2: Population, GRP, and Employment Information in the PAM

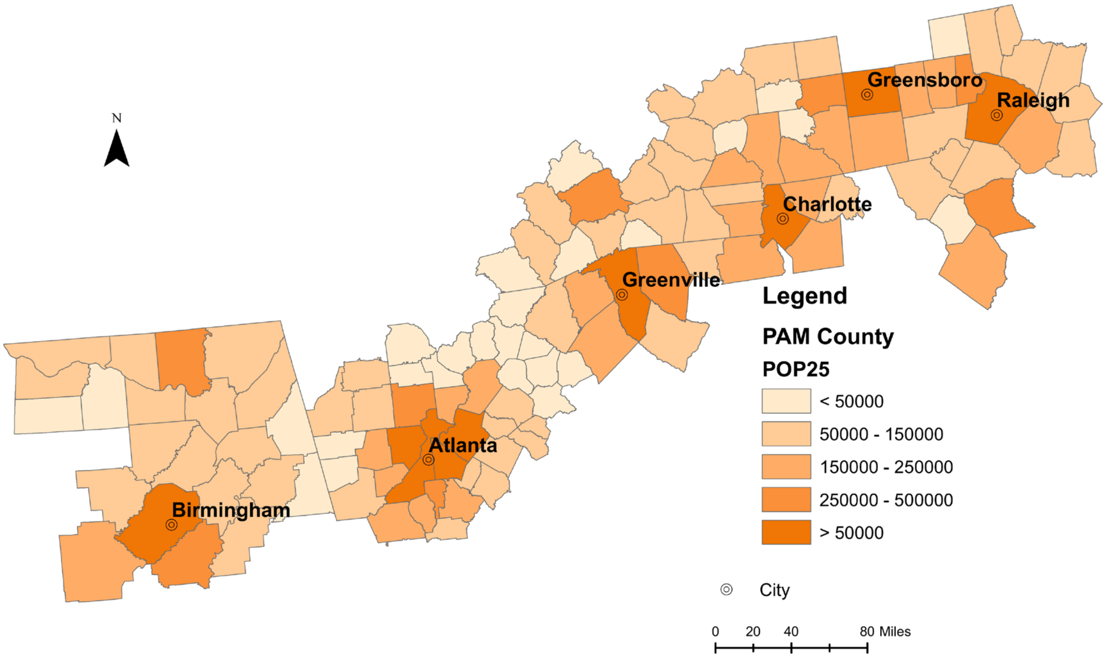
Information	2015[a]	2045[a]	Percentage change
GRP	1,088,374[b]	2,086,294[b]	91.69%
Population	23,127	33,365	44.27%
Total employment	13,439	20,769	54.54%
Natural Resources Employment	175	202	15.43%
Industrial Employment	2,068	2,177	5.27%
Retail and Services Employment	3,158	5,023	59.06%
Knowledge Employment	2,740	5,124	87.01%
Office Employment	5,063	8,048	58.96%

[a] Figures in thousands.

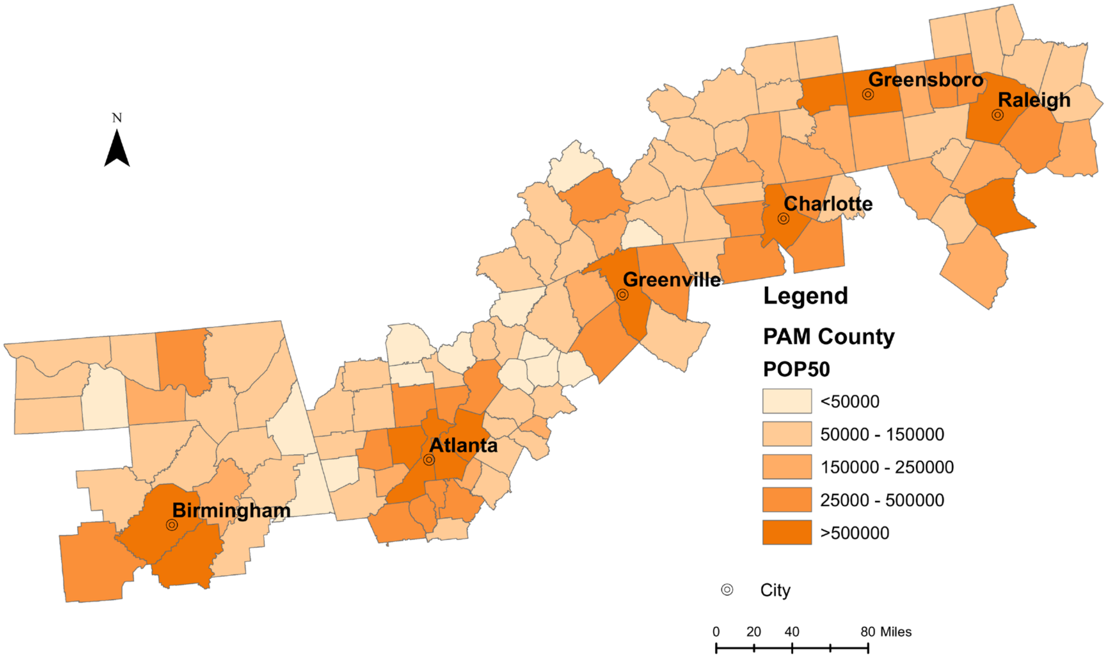
[b] Figures in millions of U.S. dollars.

3.4. Results

The projected population and GDP in the PAM in 2050 are estimated, which are used to estimate the future traveling demand. The population and GDP in 2025 and 2050 projected by the American 2050 are directly used in this study. The projected population by American 2050 in each county is depicted in Figure 3.3. The GDP in 2025 and 2050 in each county is shown in Figure 3.4.

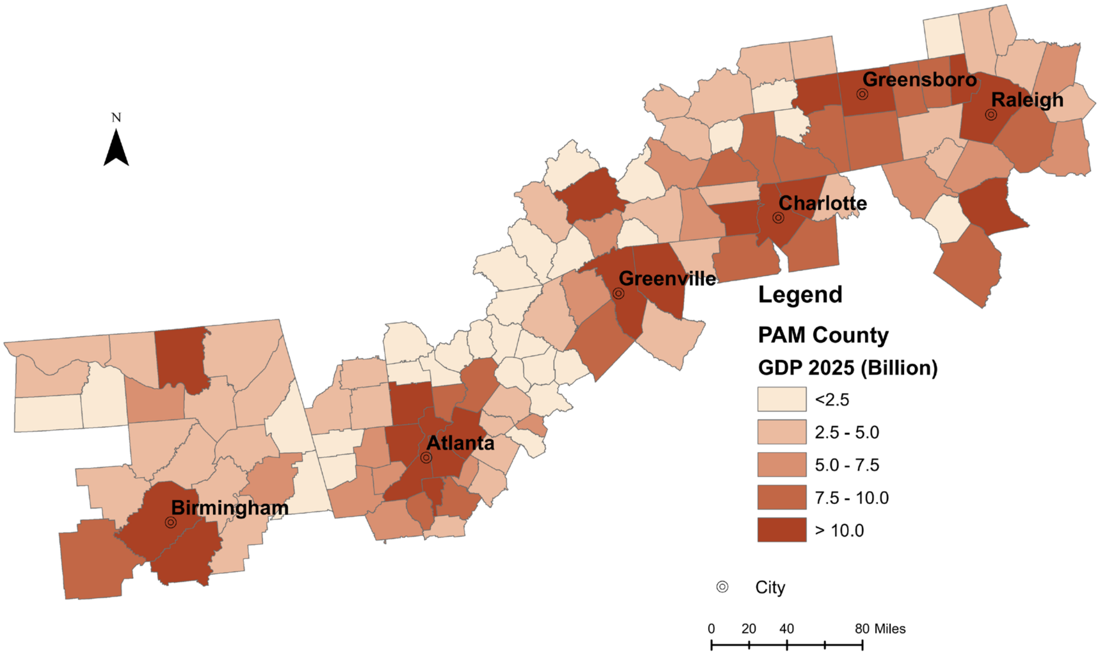


3.3.a Projected Population in PAM in 2025

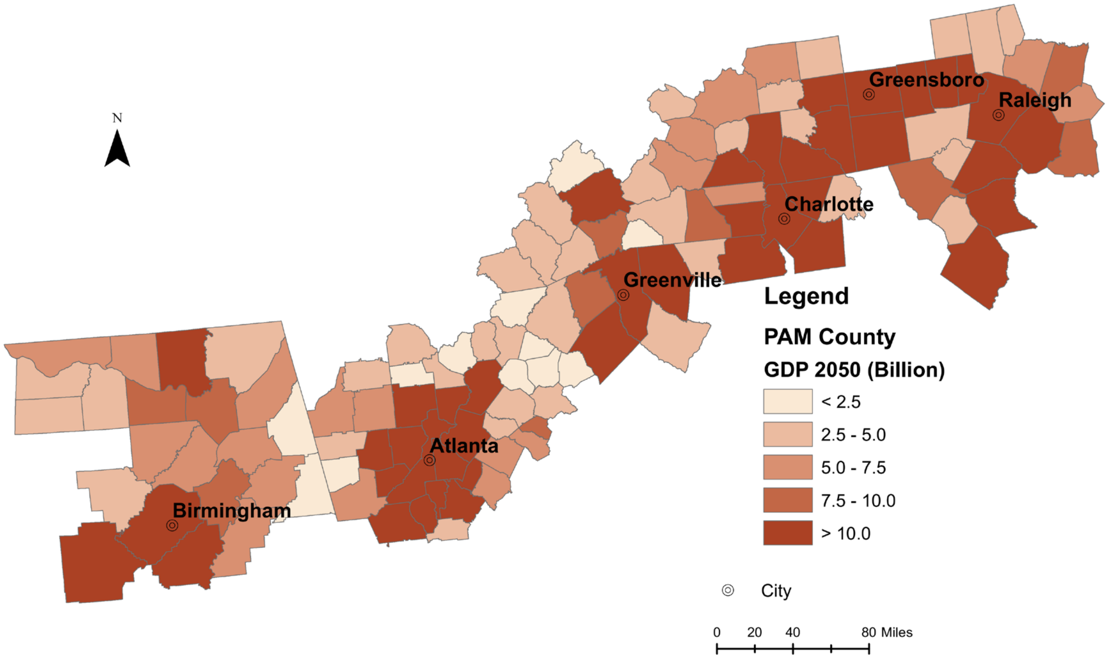


3.3.b Projected Population in PAM in 2050

Figure 3.3: Projected Population in 2025 And 2050 in Each County in the PAM



3.4.a Projected GDP in PAM in 2025



3.4.b Projected GDP in PAM in 2050

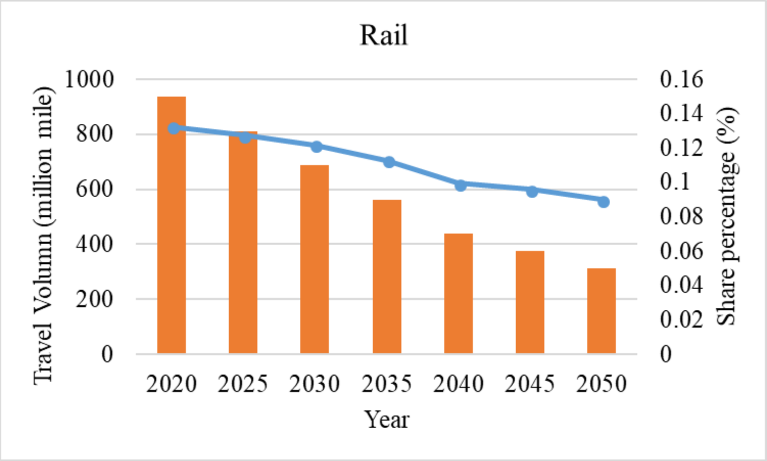
Figure 3.4: Projected GDP in 2025 And 2050 in Each County in the PAM

As mentioned in the model section (see section 3.2), based on the future projection of per capita GDP (GDP/population), a region's future mobility can be estimated. Table 3.3 presents the detailed projection of mobility by different modes, including car, rail, bus, and high-speed travel model (including HSR and airplane). The year varies from 2020 to 2050. The prediction results in Table 3.3 suggest that there is an increasing trend by HST. By the year 2050, the share for high-speed travel mode would be 68.87%. The usage of rail, bus, and car has a decreasing trend. For example, the percentage of the car in 2020 is 89.48%. However, by the year 2050, the projected share of the car will drop to 30.57%.

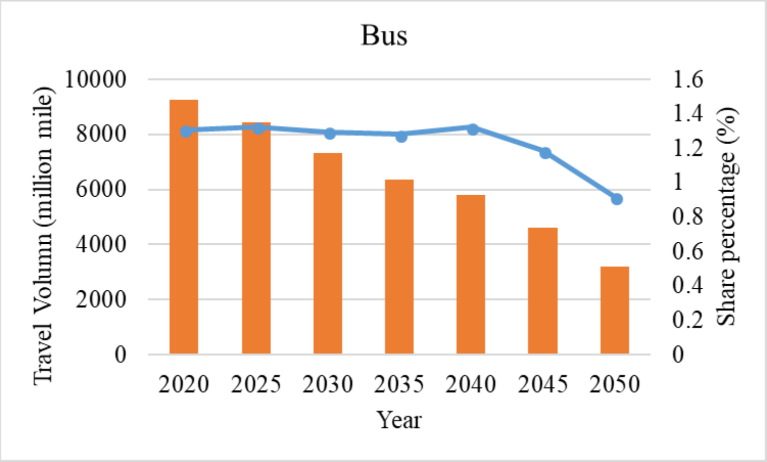
Table 3.3: Estimated Mode Share in the PAM

Year	Rail (%)	Bus (%)	Car (%)	High-speed travel (%)
2020	0.15	1.48	89.48	8.89
2025	0.13	1.35	76.31	22.21
2030	0.11	1.27	68.64	29.98
2035	0.09	1.12	57.3	41.49
2040	0.08	1.03	50.46	48.43
2045	0.06	0.94	45.67	53.33
2050	0.05	0.51	30.57	68.87

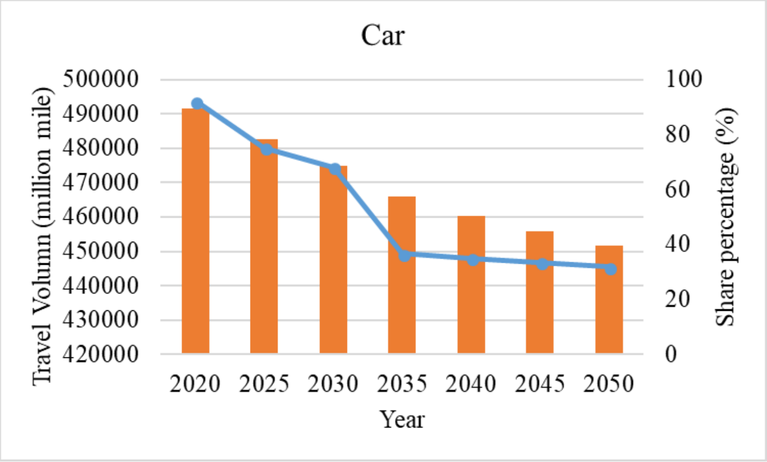
Figure 3.5 presents the travel volume and percentage of rail, bus, car, and high-speed travel mode over years. As one can clearly see from Figure 3.5e, the total travel volume will greatly increase by the year 2050. The total travel volume in the PAM is projected to increase nearly two times compared to 2020. Such increased travel volume will impose great pressure on the transportation systems in the PAM. As shown in Figure 3.5, the travel volume of some travel modes, such as rail and car, has a decreasing trend. However, as shown in Figure 3.5(d), by 2050, the total estimated travel volume by high-speed travel mode will considerably grow to 673914.08 million mile, which is about 13.74 times of that in 2020.



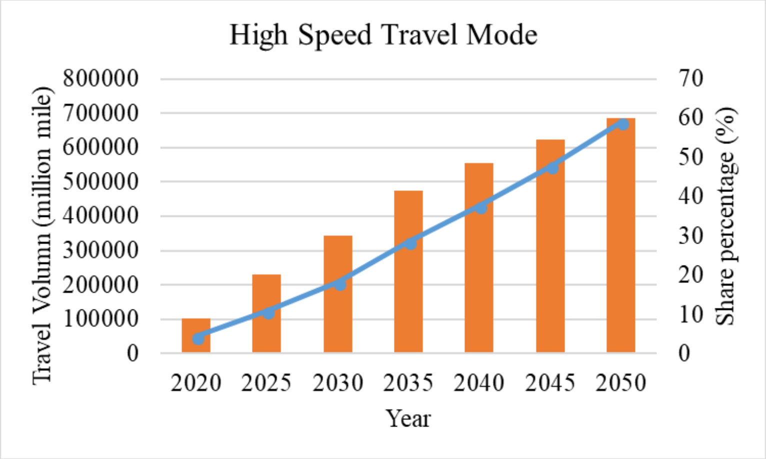
3.5.a Travel Volume and Percentage of Rail vs. Year



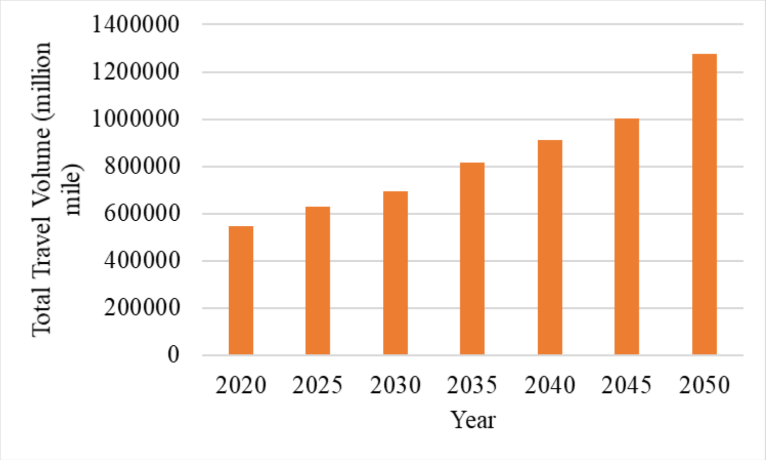
3.5.b Travel Volume and Percentage of Bus vs. Year



3.5.c Travel Volume and Percentage of Car vs. Year



3.5.d Travel Volume and Percentage of High-speed Travel Mode vs. Year



3.5.e Total Travel Volume vs. Year

Figure 3.5: Travel Volume and Percentage vs. Year

According to the results in Figure 3.5, the share for high-speed travel model will increase considerably in the next 30 years. By the year 2050, high-speed travel demand will rise to more than 10 times that of the demand in year 2020. However, only air transportation offers the high-speed mode of inter-city travel in the PAM currently. It is unlikely that the demand for high-speed travel can be met by air travel only because of the capacity constraints in airway network, gate and runway, and airport operations. Accordingly, planning for megaregional transportation should seriously consider high-speed travel in the form of high-speed rail to accommodate the future travel demand in the PAM. The sooner the HSR is incorporated in the regional transportation plan, the better the PAM would be prepared for the future.

3.5. Summary

This chapter adopts a method which utilizes aggregate population and GDP for mobility study at a mega-regional level. The future mobility demand in the PAM is predicted and estimated. The prediction results show that the PAM will experience an enormous amount of mobility growth by the year 2050. The projection of mode split in the PAM reveals a general trend that the share of high-speed travel model will increase while those of all other conventional low-speed modes, including rail, bus, and car, will decrease. The implementation of high-speed rail should be encouraged to satisfy the increasing demand for high-speed travel mode.

Chapter 4. Megaregional Freight Planning in the Piedmont Atlantic Megaregion

4.1. Introduction

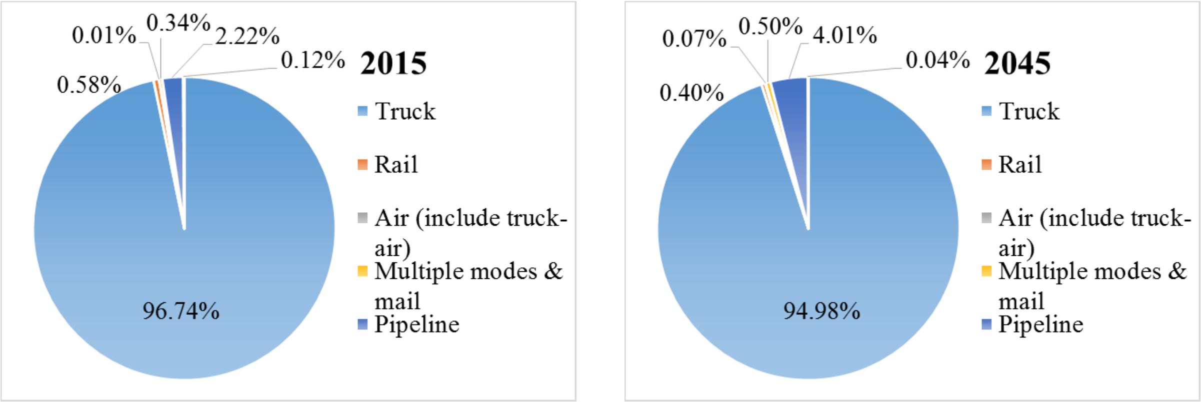
Economic globalization is promoting a new geographical scale in the United States – megaregion, in which people, jobs, and capital are concentrated. A megaregion consists of several metropolitans linked with similar environmental systems, transportation systems, and complementary economics (Zhang et al., 2007). The freight planning at a mega-regional level enhances the metropolitan and city level planning for economic development, infrastructure investment, environment protection, and land uses. In addition, megaregion offers provocative answers to regional problems, such as congestion, air pollution, and development disparity. This chapter is intended to explore the role of freight in supporting and sustaining economic development in the PAM. The opportunities and challenges faced by the PAM are studied. According to the analysis results, some recommendations that aim to improve the freight movement in the PAM are drawn.

The following sections are organized as follows. Section 4.2 presents the freight patterns in 2015 and 2045 in the PAM. In Section 4.3, the opportunities and challenges of implementing megaregional freight planning in the PAM are discussed. Section 4.4 presents suggestions and recommendations for future megaregional freight planning initiatives. Finally, Section 4.5 concludes this chapter with a summary.

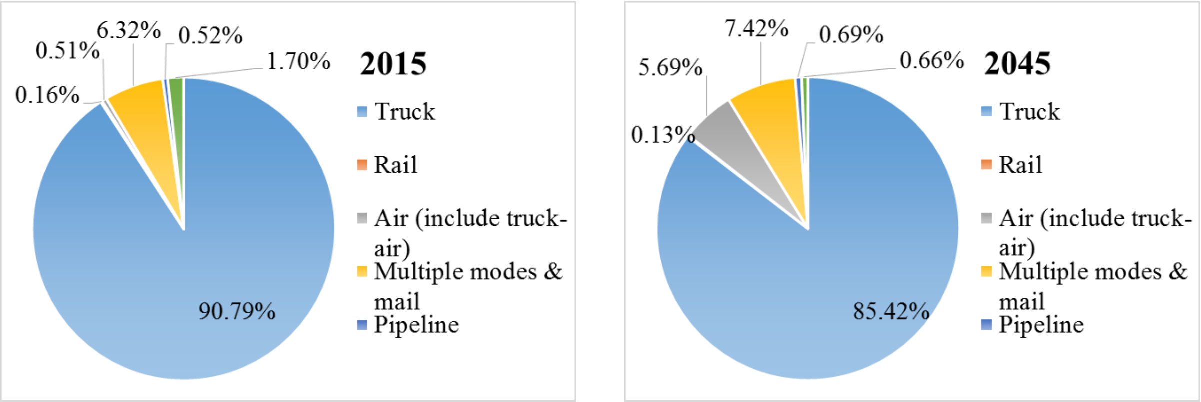
4.2. Freight Patterns in the PAM

4.2.1. Freight Movement in the PAM

Goods movement plays a significant role in the megaregional economy, both as a provider of jobs and as a facilitator of trade for businesses across the megaregion. According to the data collected from the Freight Analysis Framework Data Tabulation Tool (FAF4), freight flows between the major cities in the PAM by mode and commodity in 2015 and 2045 are presented in Figure 4.1.



4.1.a Measured by Weight



4.1.b Measured by Value

Figure 4.1: PAM Freight Flows by Mode between Major Cities in 2015 and 2045

As presented in Figure 4.1, the freight mode between major cities in the PAM mainly includes air, pipeline, rail, truck, water, multiple modes, among others. As can be seen in Figure 4.1(a) and Figure 4.1(b), truck is the key mode for goods movement. When measured by weight, among these modes, truck accounts for 96.74% of all PAM freight flows in 2015. In 2045, truck will still account for more than 90% in the PAM. The share of the other modes, such as rail and air, is very low in both the year 2015 and 2045. For instance, the percentage of rail in 2015 is only about 0.58%. In 2045, the freight transportation mode split is expected to change slightly, with the pipeline increasing in share from 2.22% to 4.01%.

When measured by value, as shown in Figure 4.1(b), truck still plays an important role in goods movement. In 2045, it is estimated that about 480,572.04 million dollars of freight will be moved to, from, or within the PAM, and truck will account for 85.42% of all megaregional freight flows (measured by value).

Figure 4.2 depicts the megaregional freight flows by commodity in 2015. The commodity in the PAM includes coal, sands, gravel, logs, etc. Among the commodity, the percentage of natural sands is about 27.87% which is the highest.

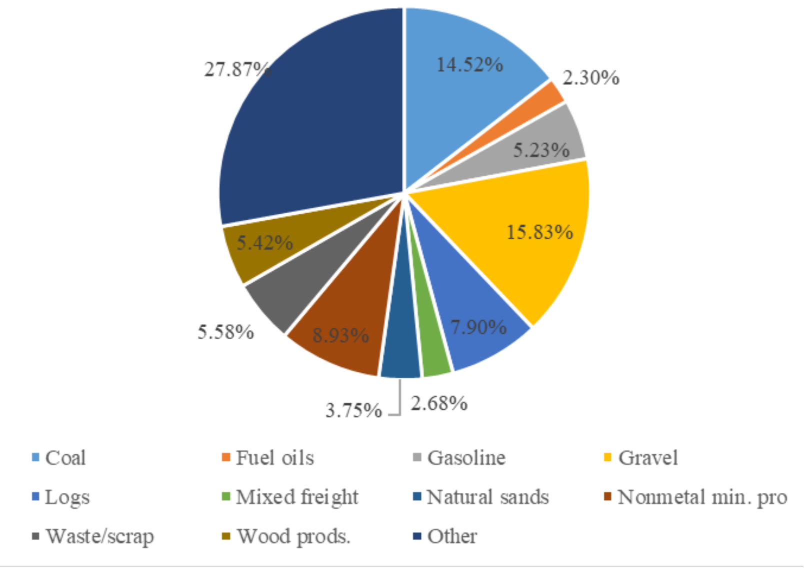
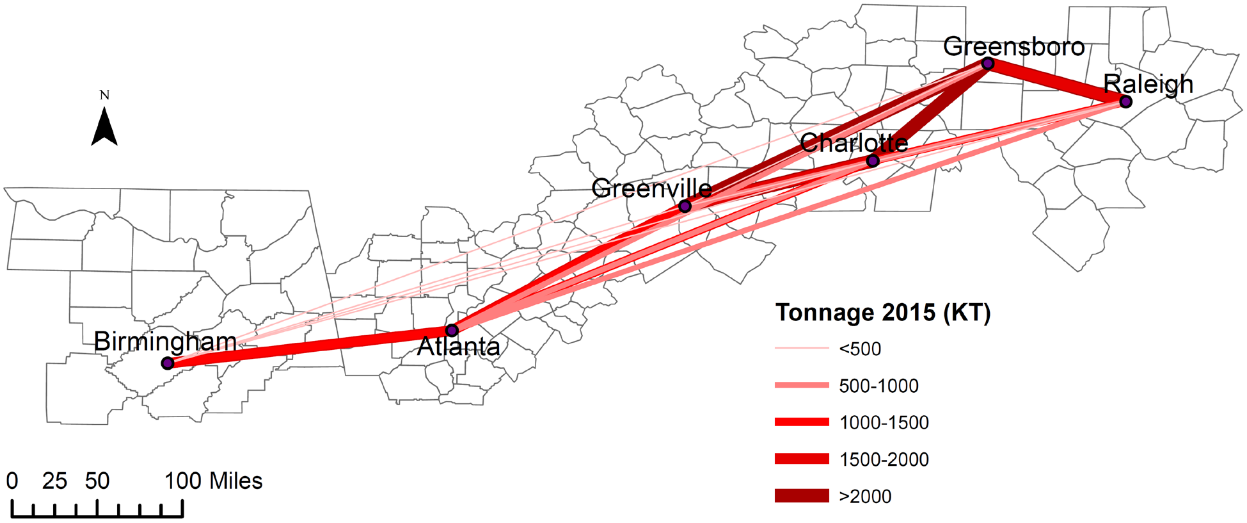
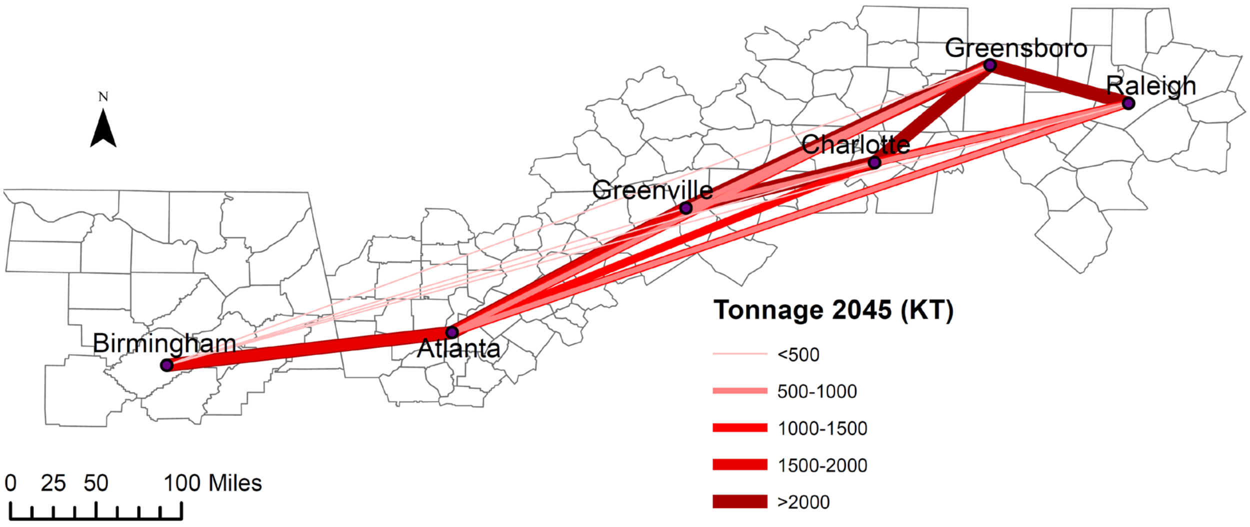


Figure 4.2: Megaregion Freight Flows by Commodity - 2015 Estimates Based on Weight

Freight flows between major cities both in terms of tonnage and value help to illustrate freight linkages in the PAM. Figure 4.3 presents the freight volume of goods movements between major cities in the PAM in 2015 and 2045 respectively. In Figure 4.4, the value of freight flows in the PAM in 2015 and 2045 is presented. As can be seen in Figure 4.3 and Figure 4.4, in 2045, both the tonnage and value of the goods movements in the PAM will be increased considerably. All these figures (Figure 4.3 and Figure 4.4) illustrate that linkage along I-85 and I-20, from Raleigh-Greensboro-Charlotte-Greenville-Atlanta and Atlanta-Birmingham. The freeways serve as the backbone of commerce in the PAM. Interstate 85/20 is and will be one of the most heavily truck corridors in the PAM (see Figure 4.1, Figure 4.3, and Figure 4.4). From Birmingham to Raleigh, huge number of trucks travel per day in 2045. As the largest city in the PAM, Atlanta accounts for most of the weight and the value.

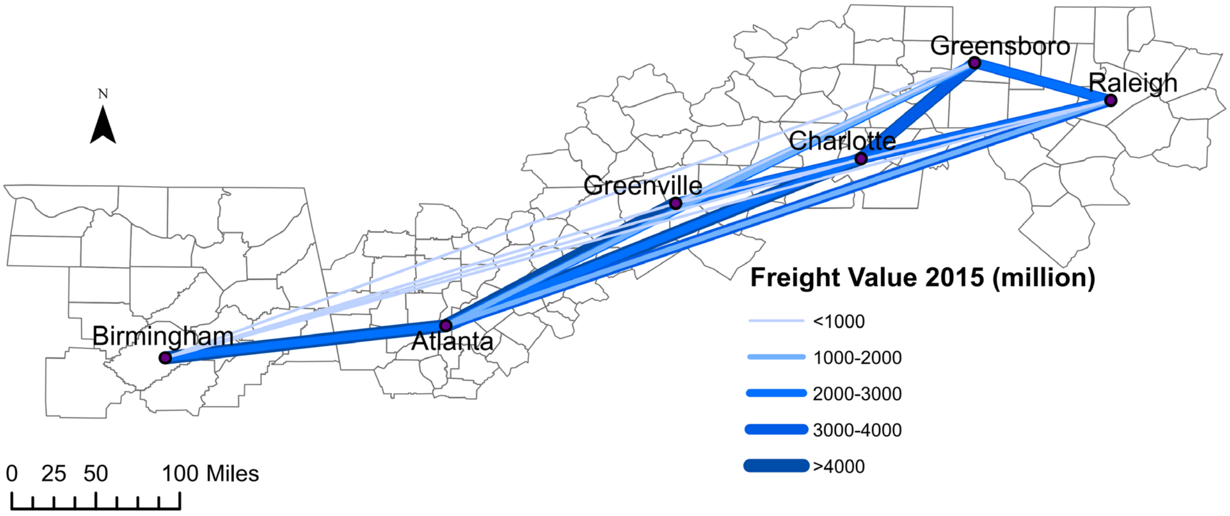


4.3.a Freight Volume between Major Cities in 2015 in The PAM

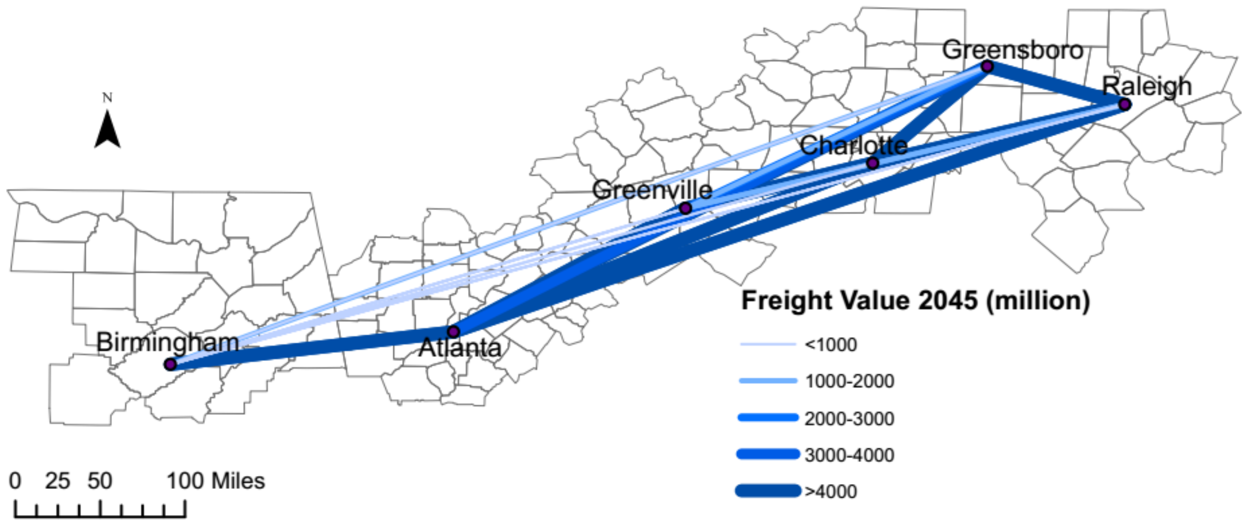


4.3.b Project Freight Volume between Major Cities in 2045 in The PAM

Figure 4.3: Volume of Freight Flows in the PAM



4.4.a Freight Value between Major Cities in 2015 in the PAM



4.4.b Freight Value between Major Cities in 2045 in the PAM

Figure 4.4: Value of Freight Flows in the PAM

4.2.2. Road Network

As presented in the previous section, truck plays an important role in moving goods in the PAM. In 2015, average daily long-haul truck traffic on the national highway system in the PAM was between 12,500 to 25,000 movements a day, as shown in Figure 4.5. The highway around the Atlanta accounted for the highest truck volumes in the PAM. The average daily long-haul truck traffic is expected to double to between 25,000 and 40,000 movements a day by 2045, as presented in Figure 4.6. Most of the highways in the PAM are expected to have significant increases in truck volume in 2045.

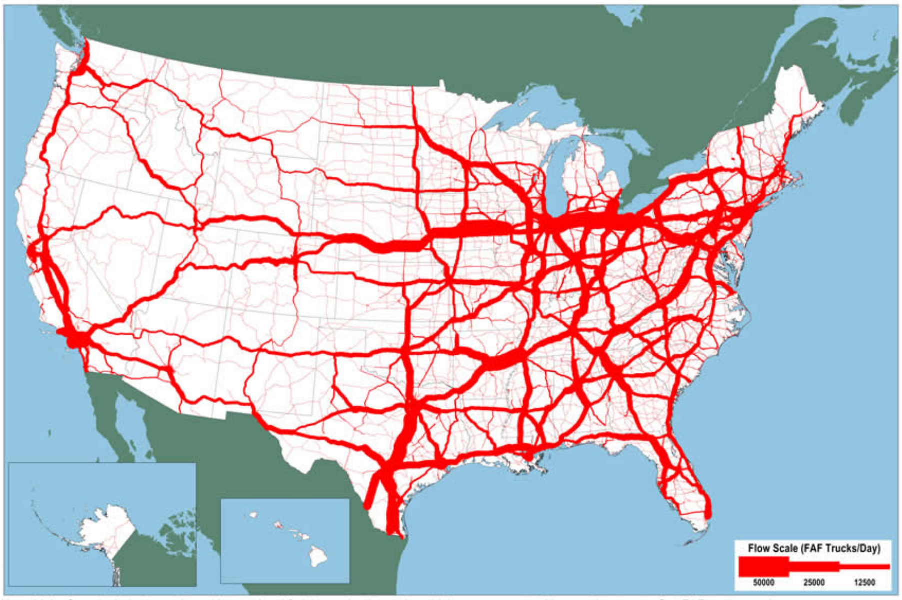
Average Daily Long-Haul Truck Traffic on the National Highway System: 2015

Note: Major flows include domestic and international freight moving by truck on highway segments with more than twenty five FAF trucks per day and between places typically more than fifty miles apart.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 4.3, 2017.

Source: https://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/nhsavglhft2015.htm

Figure 4.5: Average Daily Long-Haul Truck Traffic on the National Highway System, 2015

Average Daily Long-Haul Truck Traffic on the National Highway System: 2045

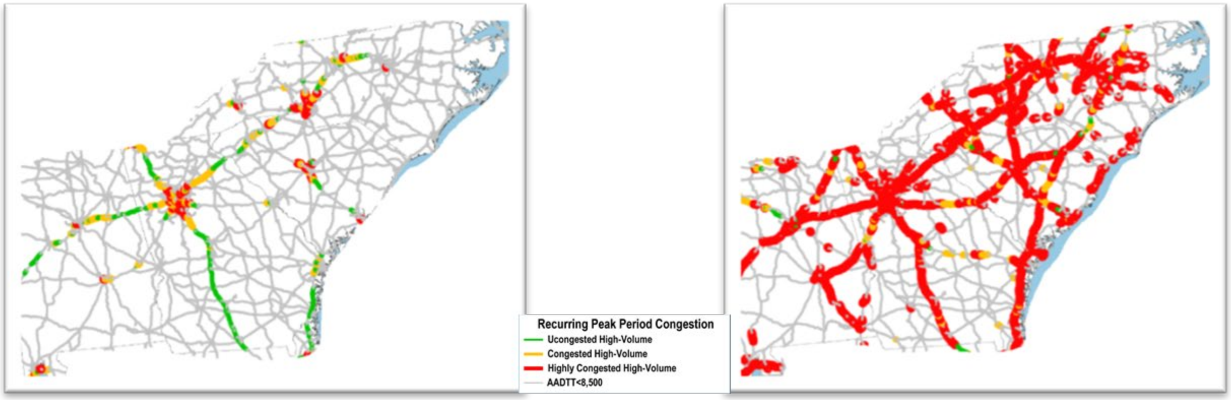


Note: Major flows include domestic and international freight moving by truck on highway segments with more than twenty five FAF trucks per day and between places typically more than fifty miles apart.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 4.3, 2017.

Source: https://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/nhsavglhft2045.htm

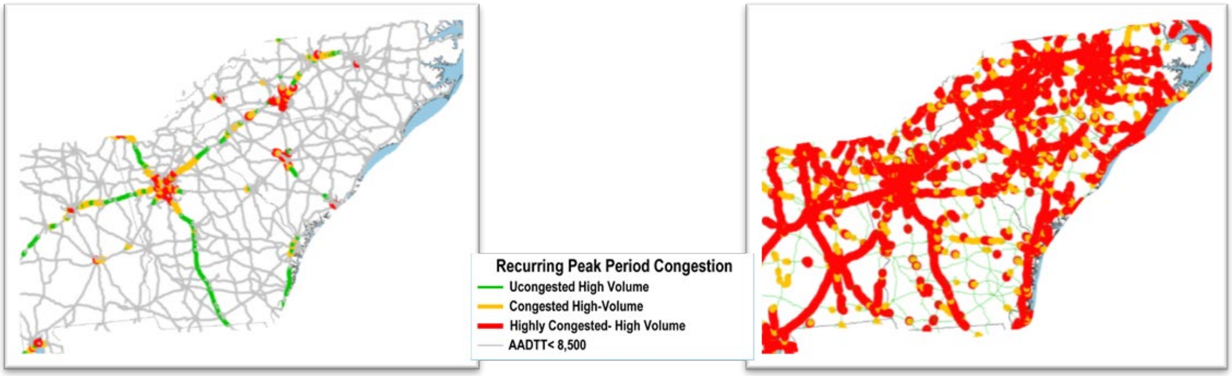
Figure 4.6: Average Daily Long-Haul Truck Traffic on the National Highway System, 2045

As illustrated in Figure 4.7 and Figure 4.8, peak period congestion on all the national highway system entering or exiting major cities of Atlanta and Charlotte experienced highly congested traffic conditions in 2012, and this is expected to spread further into the system interconnecting these cities by 2045. With truck traffic being a large percentage of movements on these corridors, these highly congested conditions are expected to negatively impact intercity truck freight movements in the PAM.



Source: https://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/nhspperiodcong2045.htm

Figure 4.7: Peak-Period Congestion on the National Highway System



Source: https://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/nhsconghvtrk2045.htm

Figure 4.8: Peak-Period Congestion on Highway Volume Truck Portions of The National Highway System

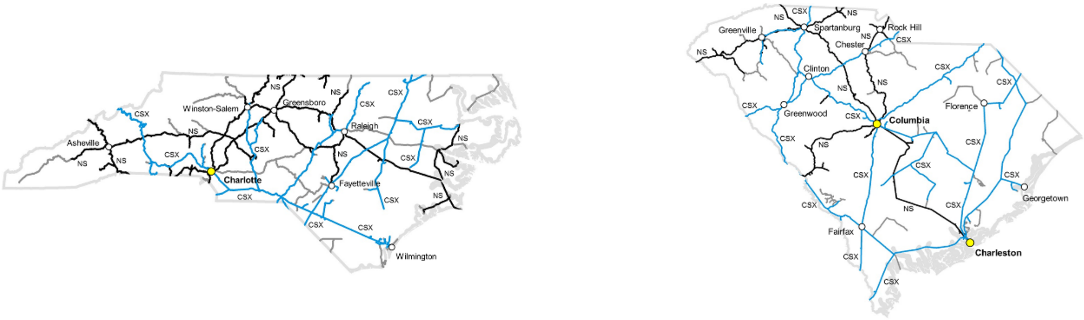
4.2.3. Rail Network

Table 4.1 shows the number of freight railroads and miles in the PAM. The PAM has 90 freight railroad and 12,789 miles of railroad in 2015. Figure 4.9 and Figure 4.10 show Rail Lines and Networks in each States in the PAM, respectively.

Table 4.1: Number of Freight Railroads and Miles in the Piedmont Atlanta Megaregion (2015)

State	Number of freight railroads	Freight Railroad Miles	Starting[1]	Ending[2]
North Carolina	23	2879	342285	656484
South Carolina	13	2277	319684	521884
Georgia	28	4422	1222063	1504652
Alabama	26	3211	518718	517003
Total	90	12789	2,402,750	3,200,023

Note: **1.** Starting: goods starting in the state;
2. Ending: goods ending in the state.



4.9.a North Carolina **4.9.b South Carolina**

4.9.c Georgia **4.9.d Alabama**

Source: U.S. Freight Railroad Industry Snapshot, 2015, https://www.aar.org/data-center/railroads-states#US

Figure 4.9: Rail Lines in the States in the Piedmont Atlanta Megaregion

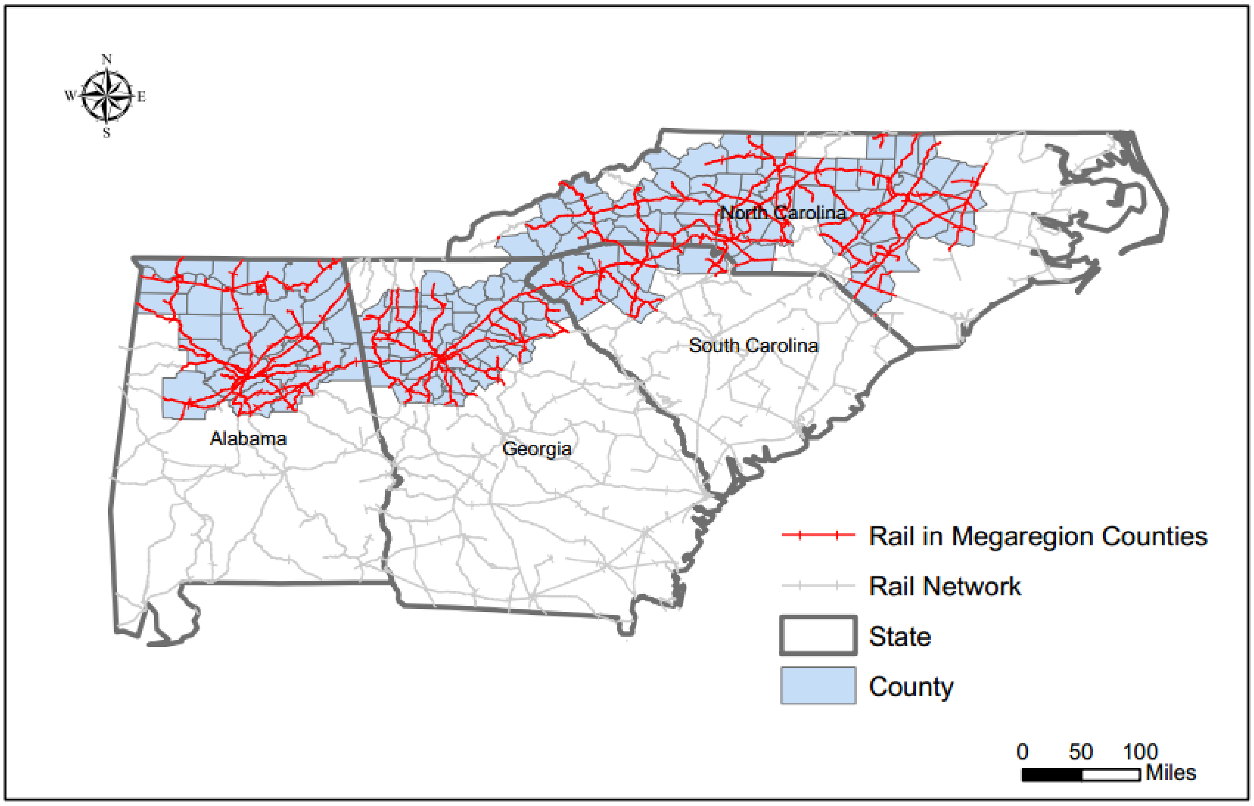


Figure 4.10: Rail Network in The Piedmont Atlanta Megaregion

Table 4.2 presents freight rail flows including domestic, import, and export flows in the PAM. In Table 4.2, it can be seen that rail is not widely used in the PAM. The freight weights from Raleigh-Durham and Greenville to Atlanta are 61.48 and 148.28 (Thousand Tons) in 2015, respectively. However, the freight weight and value start from and end at the other cities are very low.

Table 4.2: Freight Rail Flows including Domestic, Import, and Export Flows in The PAM

Origin	Destination	2015				2045		
		Tonnage (KT)	Ton Mile (Million)	Value $ (Million)	Total Current Value in 2015	Tonnage (KT)	Ton Mile (Million)	Value $ (Million)
Birmingham AL	Atlanta GA	0.1631	0.0321	0.0030	0.0033	0.2049	0.0403	0.0038
Birmingham AL	Charlotte NC-SC	1.2015	0.6102	1.4325	1.5759	1.4745	0.7489	1.7581
Birmingham AL	Raleigh-Durham	2.7107	1.6360	2.4028	2.6433	3.2739	1.9758	2.9020
Birmingham AL	Greenville SC	0.2127	0.0767	0.0820	0.0902	0.3052	0.1101	0.1177
Atlanta GA	Birmingham AL	0	0	0	0	0	0	0
Atlanta GA	Charlotte NC-SC	2.1997	0.7587	6.1495	6.0706	2.7455	0.9469	7.6758
Atlanta GA	Raleigh-Durham	0	0	0	0	0	0	0
Atlanta GA	Greenville SC	0	0	0	0	0	0	0
Charlotte NC-SC	Birmingham AL	0	0	0	0	0	0	0
Charlotte NC-SC	Atlanta GA	0	0	0	0	0	0	0
Charlotte NC-SC	Raleigh-Durham	0	0	0	0	0	0	0
Charlotte NC-SC	Greenville SC	0	0	0	0	0	0	0
Raleigh-Durham	Birmingham AL	0	0	0	0	0	0	0
Raleigh-Durham	Atlanta GA	61.4844	25.4536	65.6722	66.0643	80.6221	33.3764	86.1135
Raleigh-Durham	Charlotte NC-SC	0	0	0	0	0	0	0
Raleigh-Durham	Greenville SC	0	0	0	0	0	0	0
Greenville SC	Birmingham AL	0	0	0	0	0	0	0
Greenville SC	Atlanta GA	148.2766	26.3545	60.0521	47.6584	135.8782	24.1853	54.4277
Greenville SC	Charlotte NC-SC	0	0	0	0	0	0	0
Greenville SC	Raleigh-Durham	0	0	0	0	0	0	0

Source: Freight Analysis Framework Data Tabulation Tool

4.2.4. Air Infrastructure

The five major cities in the PAM have international airports: the Hartsfield–Jackson Atlanta International Airport, Charlotte Douglas International Airport, Raleigh–Durham International Airport, Greenville–Spartanburg International Airport, and Birmingham-Shuttlesworth International Airport International Airport. In Table 4.3, freight air flows including domestic, import, and export flow in the PAM are presented.

Table 4.3: Freight Air Flows including Domestic, Import, and Export Flows in The PAM

Origin	Destination	2015		2045	
		Tonnage (KT)	Value $ (Million)	Tonnage (KT)	Value (Million)
Birmingham AL	Atlanta GA	1.537	112.17	2.195	147.483
Birmingham AL	Charlotte NC-SC	0.086	4.014	0.124	5.915
Birmingham AL	Raleigh-Durham	0.004	0.747	0.005	0.99
Birmingham AL	Greenville SC	0.002	0.017	0.003	0.025
Atlanta GA	Birmingham AL	3.26	124.65	4.857	186.611
Atlanta GA	Charlotte NC-SC	12.157	1163.453	19.322	1869.228
Atlanta GA	Raleigh-Durham	4.223	311.333	6.725	511.262
Atlanta GA	Greenville SC	10.575	500.863	16.101	768.494
Charlotte NC-SC	Birmingham AL	0.078	0.89	0.09	1.296
Charlotte NC-SC	Atlanta GA	7.741	598.874	13.067	1039.837
Charlotte NC-SC	Raleigh-Durham	2.679	207.149	4.297	361.246
Charlotte NC-SC	Greenville SC	4.078	171.899	6.197	262.148
Raleigh-Durham	Birmingham AL	0.0003	0.0589	0.0004	0.0795
Raleigh-Durham	Atlanta GA	7.603	612.085	12.997	1059.989
Raleigh-Durham	Charlotte NC-SC	1.188	1078.621	1.892	1718.055
Raleigh-Durham	Greenville SC	0.012	1.204	0.017	1.919
Greenville SC	Birmingham AL	0.006	0.091	0.008	0.132
Greenville SC	Atlanta GA	6.396	384.364	9.733	561.297
Greenville SC	Charlotte NC-SC	0.875	57.312	1.341	90.252
Greenville SC	Raleigh-Durham	0.163	14.179	0.292	26.308

Source: Freight Analysis Framework Data Tabulation Tool

4.3. Opportunities and Challenges

Megaregional planning, including both freight and passenger planning, theoretically provides benefits better than the traditional planning schemes of MPOs. According to Ross (2009), the current system where states or local governments compete for funds can be replaced by inter-jurisdictional cooperation: “planning at an inter-jurisdictional level, with an emphasis on how economic and network interactions are set in a spatial context which could lead to more efficient public investments resulting in increased global economic competitiveness” (Ross et al., 2008). In addition to the above, megaregional planning presents a new perspective on defining regionalism that captures the economic, political and spatial level at which planning should be conducted in order to respond to the challenges of agglomerations of economic activity and population. It also recognizes the new context in which large-scale regions exist - one of global economic and environmental issues taking place on a larger scale (Ross, 2009). Megaregional planning presents a new way of approaching large-scale transportation systems, green infrastructure, and economic development (Zhang, 2007). In summary, megaregions provide an effective strategy for researchers, planners, engineers, politicians, and decision-makers to tackle regional issues, economic development planning, and transportation planning.

Despite the benefits of megaregional freight planning, a number of challenges still exist. The main challenges include, but are not limited to, boundaries and borders, funding and financing, environment and partnerships and competition. In the following section, these challenges are discussed in detail.

4.3.1. Boundaries and borders

There is a complex and nuanced relationship with boundaries and borders in the megaregions. Megaregions are bounded differently in their operationalization depending on the spatial extent of the issue to maximize local and regional dividends. One of the advantages of the megaregions is the ability to cross local and state boundaries to align with commodity movement and economic conditions, which has been pointed out by many researchers. Unlike the Texas Triangle and Southern California, the PAM comprises four states (i.e., North Carolina, South Carolina, Georgia, and Alabama) and 121 counties. One of the challenges faced in the PAM is the interactions across boundaries and borders which are important and critical to the freight planning in the PAM.

4.3.2. Funding and financing

Revenue is used to support all kinds of transportation infrastructure planning at the city, metropolitan, and regional level. Currently, revenue is coming from fuel taxes or tolls for roads, landing fees for airports, or many other options depending on the modes of freight transportation. These fees are usually perceived as a hindrance to growth and a burden to shippers. However, it is often possible to structure revenue such that it supports efficient infrastructure usage. At a megaregional level, the revenue is very important as well. PAM is facing challenges with its rapidly growing population and inadequate infrastructure (e.g., rail infrastructure). The funding is essential to implement megaregion planning and perform megaregional projects in the PAM. Funding sources might vary according to different freight infrastructure and projects, which will also be a challenge faced by the PAM.

4.3.3. Environment

Another challenge in the PAM is how to address the issues related to the conservation and usage of natural resources, environmental pollution, and highway congestion in the PAM. As cities grow and population increases rapidly, natural resource (e.g., water and fuel) and environmental pollution (e.g., noise and air pollution) are problems which have to be taken into account. In addition, the freight demand in 2045 in the PAM will be increased considerably. For example, as presented in Figure 4 and Figure 5, both the weight and value of freight flow between major cities in the PAM will dramatically increase, especially around

Atlanta and Charlotte. The increased demand will lead to increased greenhouse gas emission, environmental pollution, and traffic congestion problem.

4.3.4. Partnerships across geographic scales

Several researchers pointed out that it is necessary to establish partnerships within and across cities, regional, and metropolitans in the megaregions. The analysis of spatial patterns within and between megaregions can reveal the primary, large-scale relationships among regions. Typically, major cities within a megaregion, as well as the areas between major nodes, are deeply interconnected, and a better understanding of these relationships is necessary to best plan for economic development and protection of natural resources. Due to the huge number of counties and MPOs in the PAM, a successful freight planning effort will need more close cooperation and organizational skills among MPOs

4.3.5. Competition and partnerships

Typically, partnerships build on the idea of complementarity, which may be a complementarity of size, scale, level of government, function, mode, commodity, or industry. Partners bring different abilities that when combined increase their effectiveness. However, along with partnership, competition may also occur due to market forces without any regulatory or governmental action. Due to the multi-states, multiple jurisdictions, organizations, and sectors included in the PAM, the relationships between competition and complementarity in economic functions of megaregion, which will require additional future attention.

4.4. Recommendations on Freight Movement in the PAM

The PAM is a megaregion with multi-states and multiple jurisdictions, which carries both opportunities and challenges. Multi-states' projects, when capable of promoting economic growth, are supported by a large number of politicians, industries, and voters. However, they can be more complex and expensive to plan and administer and thus are vulnerable to revenue shortfalls at the megaregional level. The PAM requires the ability to coordinate goods movement policies at a megaregional scale. The MPOs in the PAM also need to meet frequently to discuss common challenges and opportunities so that an efficient movement of goods in the PAM can be established and achieved. The following recommendations can also be taken into consideration when carrying out the freight planning in the PAM.

4.4.1. Encouraging the implementation of high-speed freight rail corridor

As discussed in the previous section, due to the increasing weight of goods and a more expansive goods movement, more trucks will travel on the roadways in the PAM which will increase the congestion on the highways. As such, in order to satisfy the increasing weight and value of the goods in the PAM, relieve/mitigate the congestion on the highways, achieve sustainable development, and reduce foreign oil dependency, besides optimizing and updating existing rail lines, it is necessary to promote the building of high-speed freight rail corridors. Moreover, to achieve a cost-effective investment in high-speed rail systems, a mixed rail system (including both passenger and freight) should be well considered and implemented.

4.4.2. Enhancing partnerships across geographic scales

Megaregional freight planning cannot be the responsibility of a single entity because of the complexity presented by the engagement of multiple jurisdictions, organizations, and interests within each other. Enhancing partnership across geographic scales help overcome these issues. Partnerships can also help overcome financial obstacles and move ideas from planning to implementation.

In addition, due to MPOs' experience in working across local, state, and even at international boundaries, MPOs can be early leaders when performing megaregional freight planning. MPOs specialize in bringing relevant partners (including freight companies, policymakers, logistics companies, and public sectors) together to work for common benefits, which will be an essential skill in freight planning as well. However, MPOs are not the only potential lead for this initiative, implementing freight planning will require building partnerships across boundaries and at multiple scales.

4.4.3. Building a megaregional dataset

Currently, planners must resort to developing and using hybrid datasets to build a megaregion picture because complete datasets at a megaregional level often do not exist. Complete and high-quality data is essential to perform freight planning for megaregions effectively. Thus, the dataset (such as private sector economic data) must be available in the PAM at the scale of the megaregion to solve multi-jurisdictional issues.

4.4.4. Ensuring Dedicated Goods Movement Funding

As the term of "megaregion" is receiving more and more attention, megaregional freight planning projects that ensure the effective movement of goods and improve transportation corridor mobility should receive priority. Coordination among multiple jurisdictions in resolving transportation and freight movement issues in the PAM can be organized to get federal funding. Decisionmakers should ensure the funding and financing are organized in ways that encourage partners to address megaregion-scale freight transportation problems. The policymakers in the PAM should also help the state designate freight corridors. These designated freight corridors in the PAM are able to access funding when available.

4.4.5. Paying attention to the environmental problem

The most congested freeway in the PAM is and will be Interstate I-85 and I-20. Vehicles on the freeways are contributors to greenhouse gas emissions. Regions in the PAM need to work together to determine how to address environmental issues. There might be a need for memorandums of understanding or compromises by all parties involved in the PAM. To resolve environmental problems, a megaregional approach calls for new ideas, methods, and tools for planning beyond the current toolbox of MPOs because of the geographical scale of the megaregion. MPOs will need to work together to develop common standards and policies to ensure uniformity among the planning organizations.

It should be noted that megaregional freight planning has much to recommend and should be pursued at the state, multi-state, and federal levels. For example, the PAM's policymakers need to help the state to treat competition and cooperation correctly. The other challenges do exist and need to be addressed as well. For example, segments of the interstate highway system face severe congestion that will not be relieved by additional capacity investment in the next decade. Thus, detailed research needs to be conducted in the future to address all the issues related to megaregional freight planning.

4.5. Summary

In this chapter, current and future freight movements in the PAM are discussed, which include four sections: economic profile, freight pattern, megaregional freight planning's challenges and opportunities. Finally, some recommendations on megaregional freight planning are made.

Chapter 5. Accessibility Impact of Future High-Speed Rail Corridor on the Piedmont Atlantic Megaregion

5.1. Introduction

This chapter evaluates the accessibility impact of future HSR corridor on the PAM. A GIS tool is used to conduct the accessibility assessment. The door-to-door approach is adopted to evaluate the multimodal (including roadways and HSR) travel time. Three accessibility indicators are selected, including the weighted average travel time (WATT), daily accessibility (DA), and potential accessibility (PA). The selected accessibility indicators are calculated using the estimated travel time at the geographical level. The average accessibility scores of the counties in the PAM during peak and off-peak hours are estimated and compared. The relationships between megaregional accessibility scores (i.e., WATT) and HSR services (such as headway and speed) are explored. Several policy implications are drawn in terms of enhancing the megaregional accessibility.

The remainder of this chapter is organized as follows. Section 5.2 describes the methodology used in this study. Section 5.3 provides an overview of the PAM. Section 5.4 presents the methods used to estimate the multimodal travel times and calculate the accessibility impact. The numerical results (including the validation of the travel time, comparisons of the accessibility indicators, and drawing policy implications) are discussed in Section 5.5. Section 5.6 presents the conclusions and outlook for future research.

5.2. Methodology

5.2.1. Approach for Travel Time Measurement

As a common performance indicator for measuring accessibility, travel time has frequently been used (Salonen and Toivonen, 2013; Wang et al., 2016). In some studies, travel time at every stage of a journey between origin and destination is taken into account when calculating the total travel time from origin to destination (Lei and Church, 2010; Benenson et al., 2011). The door-to-door approach, which was initially 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 5.1. Two scenarios are presented: one traveling by car and the other by HSR. Under the first scenario, in which one chooses car, the travel time includes (1) walking from origin to parking space; (2) driving from the parking space to the destination point; (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) total transferring time 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). It should be pointed out that the waiting time is highly relevant to the HSR headway. In this study, the average waiting time at the HSR station is assumed to be half the headway (Lei and Church, 2010); (3) Traveling from origin HSR station to destination HSR station; (4) driving (or taking transit) from HSR station to destination.

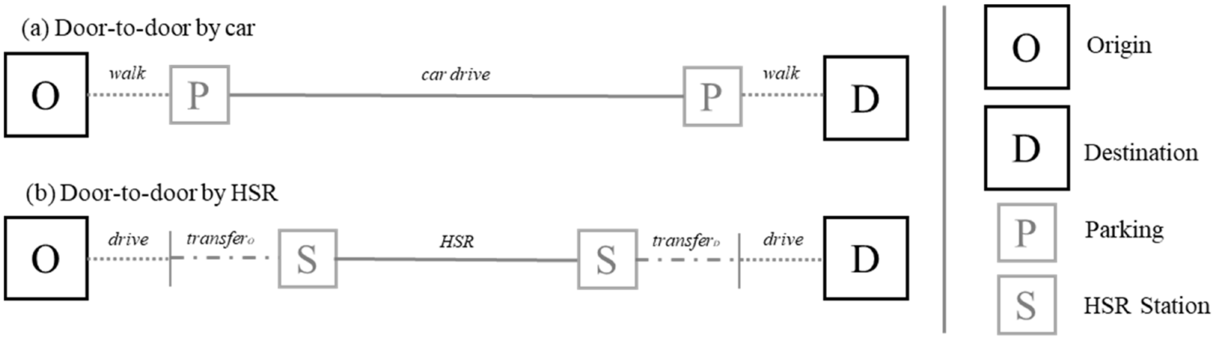


Figure 5.1: Schematic Diagram of The Door-To-Door Approach

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

Traveling by car: $T_{od}^{car} = T_{OP} + T_{PP} + T_{PD}$ (5.1)

Traveling by HSR: $T_{od}^{HSR} = T_{OS} + T_{SS} + T_{SD} + T_{transfer}$ (5.2)

Where $T_{tranfer}$ is the total transfer time at the HSR stations, which can be calculated by $T_{tranfer} = T_{walking} + T_{waiting} + T_{other}$. $T_{walking}$ is the total walking time at the stations, $T_{waiting}$ is the average waiting time at the HSR station, and T_{other} is other penalty time. Note that it is assumed that the penalty time is not involved in this study, i.e., $T_{other} = 0$.

Based on Eq. (5.1) and Eq. (5.2), 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:

$$T_{od} = \mathbf{min}\left(T_{od}^{car}, \ldots, T_{od}^{HSR}\right) \tag{5.3}$$

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

5.2.2. Accessibility Indicators

Accessibility is defined as the potential to reach 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 and van Wee, 2004; Holl, 2007; Cao et al., 2013). Accessibility analyses have 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), which include evaluating the accessibility at a HSR station (Zhang et al., 2016), corridor (Gutiérrez, 2001; Sánchez-Mateos and Givoni, 2012), and network (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 by the 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 at Tanggu Railway Station in China.

To evaluate the accessibility impact of a new infrastructure, different indicators have been selected by different researchers. Typically, the accessibility indicators can be divided into three categories: cumulative opportunities, gravity-based, and utility-based (Wang et al., 2016; Zhang et al., 2016). Each indicator highlights different effects, and each one provides a different point of view for the impact of accessibility. According to López et al.'s (2008) suggestion, more than one indicators should be computed. 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 WATT, DA, and PA.

5.2.2.1. 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:

$$WATT_i = \frac{\sum_{j=1}^{n} T_{ij} M_j}{\sum_{j=1}^{n} M_j} \tag{5.4}$$

where $WATT_i$ is the weighted average travel time of location *i*, T_{ij} is the travel time between locations from location *i* to city *j* (i.e., the physical address of the city government), *n* is the number of selected 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. (5.5) (Wang et al., 2016).

$$M_j = \sqrt{P_j \times GDP_j} \tag{5.5}$$

where P_j is the population of city *j*, and GDP_j is the gross domestic product (*GDP*) of city *j*.

5.2.2.2. 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 (Martín et al., 2004). For the DA measurement, the limit of the 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 location, the number of inhabitants that can be reached in less than 3 hours is computed by using Eq. (5.6):

$$DA_i = \sum_{j=1}^{n} \delta_{ij} P_j \tag{5.6}$$

where DA_i is the daily accessibility of location *i*. $\delta_{ij} = 1$ if $T_{ij} \le 3$ hours, and 0 otherwise.

5.2.2.3. PA Indicator

The PA indicator is a gravity-based measure. Eq. (5.7) gives the formulation of the PA.

$$PA_i = \sum_{j=1, i \neq j}^{n} \frac{M_j}{T_{ij}^{\alpha}} \tag{5.7}$$

where PA_i is the potential accessibility of raster *i*, α is a gravity parameter, and the rest of terms are same as those in Eq. (5.5). According to existing studies (López et al., 2008; Cao et al. 2013), α represents the efficiency of a travel mode and traveller's momentum for traveling, which needs to be calibrated through empirical data. Typically, in a national- and international-scale analyses. α is assumed to be 1. While at a local or regional level, a higher value of α is always adopted. But in most of the studies, the value of α was always set as 1 (Wang et al. 2016). In this study, due to the lack of empirical data, the value is also assumed to equal 1. As can be seen from Eq. (5.7), the level of accessibility by using PA indicator between location *i* and a city *j* is positively related to the population or *GDP* of a city and inversely proportional to the travel time between location *i* and city *j* (López et al., 2008).

5.3. HSR Planning in the PAM

Currently, there is no HSR line in the PAM. The American Recovery and Reinvestment Act authorize 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, 2011). The "Southeaster Corridor" is developed for the PAM under the phase 2 and phase 3 plan, which will finally connect Birmingham to Raleigh (Chandra and Vadali, 2014). Under the phase 2 plan, the Southeast Corridor which runs from Atlanta to Washington, D.C. via Charlotte and Raleigh in the PAM is shown in Figure 5.2.a. The Southeast Corridor will be extended under phase 3 plan, see Figure 5.2.b (American 2050, 2011). Due to the HSR corridor, the major cities in the PAM will be connected in the future, as presented in Figure 5.2.b. Figure 5.2.c depicts the spatial distribution of the future HSR line in the PAM.

5.2.a Phase 2 Plan

5.2.b Phase 3 Plan

5.2.c Spatial Distribution of the Future HSR in The PAM

Figure 5.2: A Phasing Plan for HSR in the PAM (a) Phase 2 Plan; (b) Phase 3 Plan; and (c) Spatial Distribution of the Future HSR in The PAM

Data on roads are collected from the FHWA highway dataset, which is presented in Figure 5.3.

Figure 5.3: Road Network in the PAM in 2012

5.4. Travel Time Estimation

A spatial analysis tool – "Cost Distance" in ArcGIS is adopted to estimate the travel time, which can efficiently measure the total travel time from a location 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.

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 an impediment which indicates that travelers cannot get access to the HSR service except through those HSR stations;
(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 using the "Cost Distance" tool;
(4) Combining these cost distance results to produce a minimum cost raster map for multimodal travels.

The PAM is divided into 5,958,103 raster grid cells with a spatial resolution of 0.1 mile*0.1 mile (about 160 m). The travel time cost of each cell is attached as an attribute to each route *k* (e.g., freeway, arterial, or HSR), which is computed by:

$$\text{cost}_k = \frac{0.1}{v_k} \times 60 \tag{5.8}$$

where cost_k is the travel time on route *k* (min), and v_k is the average travel speed on route *k*.

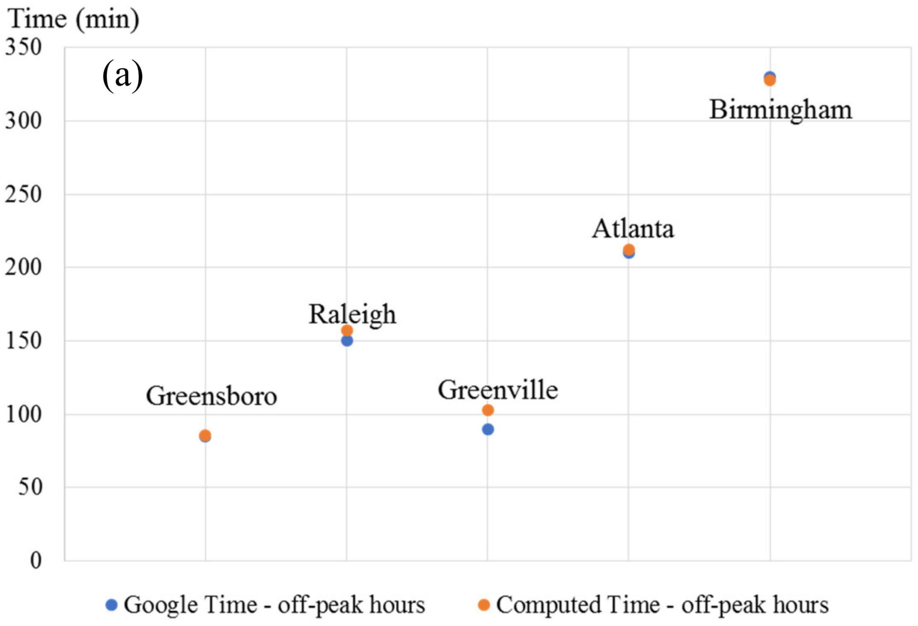
The following hypothetical speeds are used in this study: During off-peak hours, the speeds of freeway, arterial, secondary road, local connecting road, and important local road are 65 mph, 50 mph, 45mph, 35mph, and 25 mph, respectively. During peak hours (i.e., 6 am to 9 am in the morning and 6 pm to 8 pm in the evening), it is assumed that the speeds of freeway, arterial, secondary road, local connecting road, and important local road are 55 mph, 40 mph, 35mph, 25mph, and 15 mph, respectively. The average speed of HSR is set as 100 mph in terms of the design speeds of 90~120mph for the future HSR corridor program in the PAM, which refers to the Federal Railway Administration (FRA) High Speed Intercity Passenger Rail (HSIPR) Program (2010). To model transfer time at the HSR stations, five grid cells are created to surround the stations. For example, if the walking time at the rail station is 10 minutes and the HSR headway is 40 minutes, according to the assumption made in section 2.1, the average waiting time at the station would be 20 minutes (Lei and Church, 2010). As a result, the total transfer time $T_{tranfer}$ =20+10*2=40 minutes. It should be noted that there is no waiting time at the destination station. However, when implementing in ArcGIS for a trip by HSR, the waiting time is divided equally between the origin and destination HSR station. Thus, for a trip, the transfer time at each station (origin station and destination station) is 20 minutes. To realize the average 20min's transfer time, a speed of 1.5mph is set to each cell surrounding the HSR stations (0.1/1.5*60*5=20min).

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, arterial, 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.

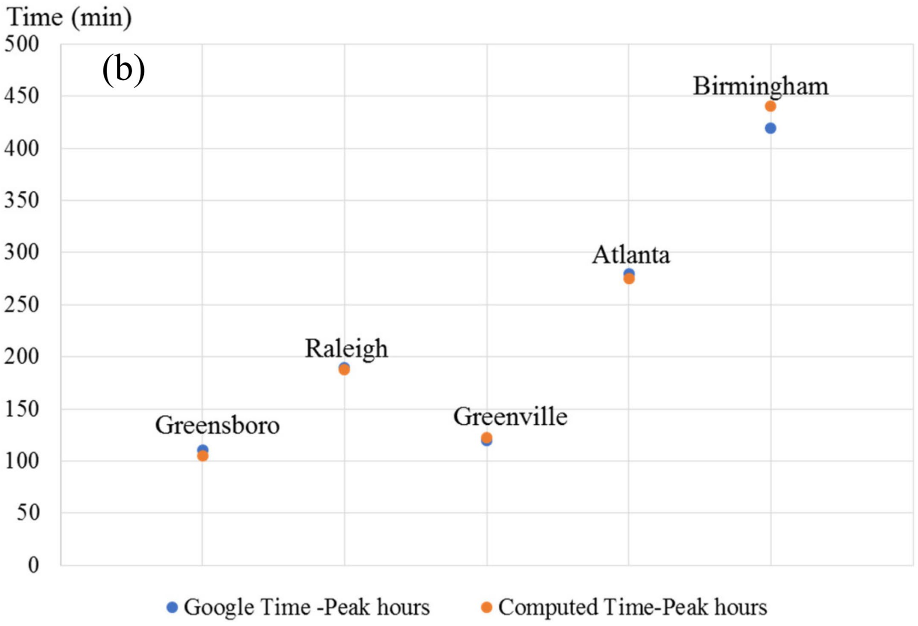
5.5. Results

5.5.1. 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 5.4, travel times from Charlotte to the other cities in the PAM which are estimated by using Google Maps and LCD method during both the peak and off-peak hours are presented. As one can see from Figure 5.4, both the peak and off-peak period's travel times using the developed travel time estimation method are consistent with those obtained by using Google Maps.



5.4.a Off-peak Hours



5.4.b Peak Hours

Figure 5.4: Comparison of the Travel Times Estimated by Google Maps and the Developed Method (a) Off-Peak Hours; and (b) Peak Hours

5.5.2. Accessibility Analysis

According to American 2050's HSR phrase plan, three scenarios are designed: Scenario 1 - there are no HSRs in 2025; Scenario 2 – the phase 2 plan, i.e. HSR corridor from Atlanta to

Raleigh via Greenville, Charlotte, and Greensboro; and Scenario 3 – the phase 3 plan, i.e. the Southeast Corridor is built and major cities in the PAM are connected. It should be noted that the roadway networks are assumed to be the same under all the scenarios (Jiao et al., 2014; Wang et al., 2016). The travel time used for accessibility evaluation is estimated based on the current networks. The projected population and GDP in 2025 in each county predicted by American 2050 is used. A 40-minute headway is assigned to the HSRs. The total transfer time at the HSR stations is set as 40 min. In the following sections, the accessibility results are discussed.

5.5.2.1. Accessibility during peak and off-peak hours

Table 1 lists the statistical accessibility scores of the WATT, DA, and PA indicator in which the average scores of the PAM and the counties where the six major cities are located are presented. Note that for the WATT, a lower value indicates more accessibility, and for the DA and PA, a higher value indicates greater accessibility (Wang et al., 2016).

Under scenario 2, the average WATT of the PAM during off-peak period decreases from 266.81 min to 203.52 min, giving a reduction of 63.29 min (i.e., 23.72%). The PAM's average WATT during peak hours decreases from 322.29 min to 229.31 min, and the improvement percentage is 28.85%. Under scenario 3, the average WATTs during peak and off-peak period are 207.96 min and 189.74 min, and the reduction percentages are 35.47% and 28.89%, respectively. One can also see from table 1 that the accessibility improvement percentages of the six counties measured by the WATT at peak hours are greater than those during off-peak periods. The reason is that the travel times between any pairs of cities in the PAM are reduced more by the HSR corridor during peak period than off-peak hours. Furthermore, the WATTs of the selected counties are all reduced under scenario 2 and scenario 3, and the improvement percentage under scenario 3 is greater than that under scenario 2.

When using the DA indicator, under scenario 3, the average accessibility population in the PAM within 3-hour limit during peak and off-peak hours is increased by 56.38% and 40.53%, respectively. In addition, it can be seen from table 1 that the Greenville County's accessibility population during peak hours is increased by 108.24% and 123.63% under scenario 2 and scenario 3. The reason is that the Greenville County is located between Atlanta and Charlotte which are the top 2 largest metropolitans in the PAM (see Figure 5.2(c)). Because of the HSR corridor, more travelers living in Atlanta and Charlotte can be reached by the Greenville County within 3 hours during peak period. In addition, the Jefferson County's DA scores are greatly increased under scenario 3, particularly during peak hours, and the improvement percentage is 113.79%. The average percentage increases of the PA in the PAM under scenario 2 during peak and off-peak period are 16.91% and 13.79%, respectively. For the DA and PA indicators, the accessibility improvement percentages during peak period are greater than those during off-peak period as well.

Table 5.1: Statistical Accessibility Scores of the WATT, DA, and PA Indicator

County, City	Hours	WATT (unit: minute)					DA ($\times 10^6$)					PA ($\times 10^6$)				
		Scenario					Scenario					Scenario				
		1	2	3	2/1 (%)	3/1 (%)	1	2	3	2/1 (%)	3/1 (%)	1	2	3	2/1 (%)	3/1 (%)
Average score of the PAM	Peak hours	322.29	229.31	207.96	28.85	35.47	1.37	2.00	2.14	46.13	56.38	5.44	6.36	6.51	16.91	19.67
	Off-peak hours	266.81	203.52	189.74	23.72	28.89	1.77	2.36	2.49	33.27	40.53	6.6	7.51	7.69	13.79	16.52
Mecklenburg, Charlotte	Peak hours	195.67	118	104.5	39.69	46.59	2.16	4.11	4.12	90.28	90.74	16.84	17.48	17.87	3.80	6.12
	Off-peak hours	163.09	109.19	100.01	33.05	38.68	3.06	4.14	4.14	35.29	35.29	20.98	21.15	21.39	0.81	1.95
Guilford, Greensboro	Peak hours	234.35	138.38	125.64	40.95	46.39	2.68	3.37	3.37	25.75	25.75	9.87	13.39	13.39	35.66	35.66
	Off-peak hours	195.23	129.49	120.48	33.67	38.29	2.73	3.45	3.46	26.37	26.74	12.21	15.39	15.44	26.04	26.45
Wake, Raleigh	Peak hours	281.11	161.06	147.39	42.71	47.57	1.62	3.11	3.11	91.98	91.98	8.9	13.96	14.14	56.85	58.88
	Off-peak hours	233.5	151.24	142.06	35.23	39.16	2.45	3.14	3.14	28.16	28.16	11.83	16.62	16.79	40.49	41.93
Greenville, Greenville	Peak hours	226.77	139.81	126.92	38.35	44.03	1.82	3.79	4.07	108.24	123.63	7.47	10.22	10.48	36.81	40.29
	Off-peak hours	188.88	129.67	120.46	31.35	36.22	2.42	3.93	4.31	62.40	78.10	10.74	11.75	12.04	9.40	12.10
Fulton, Atlanta	Peak hours	269.83	152.45	141.78	43.50	47.46	1.59	2.93	3.28	84.28	106.29	11.37	13.83	14.25	21.64	25.33
	Off-peak hours	223.61	142.21	135.37	36.40	39.46	2.08	3.36	3.41	61.54	63.94	13.6	16.55	16.82	21.69	23.68
Jefferson, Birmingham	Peak hours	406.01	283.31	205.77	30.22	49.32	0.87	0.88	1.86	1.15	113.79	7.2	7.74	9.19	7.50	27.64
	Off-peak hours	337.88	251.69	199	25.51	41.10	1.3	1.31	1.92	0.77	47.69	9.97	9.98	10.86	0.10	8.93

5.5.2.2. Comparison of the indicators

Different accessibility indicators are calculated using different measurements, which might result in different rankings of 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 travel cost or time that the travelers spend from origin to destination, and the PA indicator measures the potential of a new mode which will change the accessibility in a region or city (Wang et al., 2016). In addition, the WATT indicator aims to express the accessibility for any locations in the study area, while the DA and PA indicators describe nodal accessibility (Gutiérrez, 2001). According to the accessibility results in table 1, the future HSR corridor in the PAM contributes to more accessibility at peak hours than off-peak hours, and therefore, the comparison among the three indicators at rush hours is discussed in this section.

To compare different accessibility indicators, Figure 5.5 presents each county's average accessibility scores during peak hours using the WATT, DA, and PA under scenario 2 and scenario 3. The WATT results show that the counties around the HSR stations achieve higher accessibility scores (i.e., lower WATT). With the expansion of the HSR corridor from scenario 2 to scenario 3, more counties achieve a lower WATTs. For example, the average WATT of the Jefferson County where city Birmingham is located decreases from 4.7 hours to 3.4 hours. The DA indicator indicates the counties around Charlotte, Greensboro, and Greenville get higher accessibility scores. Under scenario 3, the average DAs of the counties around Atlanta and Birmingham are increased compared with scenario 2. The PA indicator shows results in a similar pattern as the WATT indicator. Due to the spatial distribution of population and GDP, compared to the WATT and PA, the DA shows that the counties with higher accessibility score are mainly concentrated along the HSR corridor in North Carolina (NC) and South Carolina (SC). In addition, when using the WATT and PA, the most accessible counties are usually located in the central region of the PAM (e.g., Mecklenburg, Greenville, and Fulton), and the least counties are located in the peripheral region (e.g., Tuscaloosa in Alabama (AL) and Nash in NC).

Figure 5.5 illustrates the spatial distribution of accessibility percentage increases by using the WATT, DA, and PA. If the WATT is used, counties around Atlanta and Raleigh have the greatest improvement (≥40%) under scenario 2. Under scenario 3, besides Atlanta and Raleigh, the accessibility of the counties near Birmingham are also greatly improved due to the phase 3 HSR plan (see Figure 5.5.b). When using the DA indicator, the accessibility of the counties that are concentrated around Greenville is greatly increased under scenario 2. The reason is that the HSR make these counties accessible within 3 hours from counties with large population size, such as the Mecklenburg and Fulton County. Also, scenario 3 results in significant increases in DAs in the counties around Atlanta and Birmingham. The counties around Birmingham see greater accessibility increases under scenario 3 if the PA is used which is similar to the WATT results. Some significant improvements in accessibility appear in the peripheral counties as measured by the PA. Another finding from Figure 5.5 is that the counties with high improvement in accessibility are mainly concentrated around the railway stations (Jiao et al., 2014; Shaw et al., 2014; Wang et al., 2016). The relationship between the accessibility improvement and travel time to the nearest stations can be clearly seen in Figure 5.6. Typically, as the travel time to the nearest HSR stations increases, the average accessibility improvement percentage has a decreasing trend. Such relationship is called “travel time (or travel distance) decay rule” (Jiao et al., 2014).

Figure 5.5: Spatial Distribution of Accessibility under Scenario 2 and Scenario 3 during Peak Hours

Figure 5.6: Spatial Distribution of Accessibility Increase by Using the WATT, DA, and PA

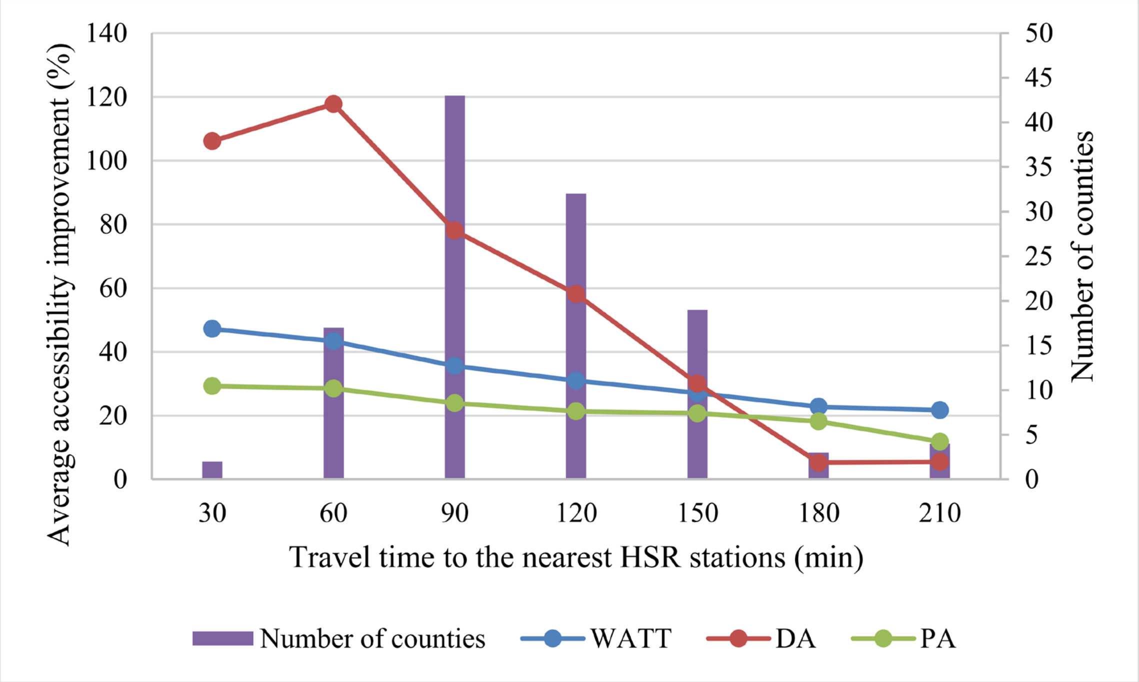


Figure 5.7: Average Accessibility Improvement vs. Travel Time to the Nearest HSR Stations (Scenario 3/1)

Table 5.2 presents the top 10 most accessible counties based on the WATT, DA, and PA under scenario 3. In table 5.2, 5 counties are in the top 10 (Mecklenburg, NC; Greenville, SC; Gaston, NC; Cabarrus, NC; and DeKalb, GA (Georgia)) using the three indicators. Mecklenburg County in NC has the highest accessibility scores based on all three indicators. No counties in AL appear in the top 10 list. As shown in Eq. (5.5), the population and GDP are selected as the weight to compute the WATT and PA. The spatial distribution of population and GDP might result in AL's exclusion using the WATT and PA. In addition, as shown in Figure 5.7, because of the position in the PAM, counties in AL are not in the top 10 list for the DA. The top 10 counties with the highest accessibility increases are also included in table 5.2. The counties with the highest increases in accessibility are different using the three indicators. For example, Jefferson, AL; Transylvania, NC, and Greenville, SC are the counties with the highest accessibility improvement percentage on the basis of the WATT, DA, and PA, respectively. No counties in AL appear in the list using the DA. However, the PA indicator shows that the accessibility of 5 counties in AL is greatly improved. Some counties not only have high accessibility score but also have great accessibility improvement percentage, such as the Greenville County and Guilford County (see Figure 5.5, Figure 5.6, and table 5.2). The reason is that these counties are located near the counties where the population size is large and the GDP is high. For example, the Guilford County is located very close to two large cities in North Carolina (i.e., Raleigh, Charlotte). Furthermore, the travel time is reduced due to the HSR line. Thus, both the accessibility scores and the improvement percentages in such counties are high.

Table 5.2: 10 Counties with Highest Accessibility and Greatest Increase in Accessibility under Scenario 3

Rank	Accessibility			Increase in accessibility		
	WATT	DA	PA	WATT	DA	PA
1	Mecklenburg, NC	Mecklenburg, NC	Mecklenburg, NC	Jefferson, AL	Transylvania, NC	Greenville, SC
2	Guilford, NC	Greenville, SC	DeKalb, GA	Clayton, GA	Rockdale, GA	Pickens, SC
3	Greenville, SC	Gaston, NC	Fulton, GA	DeKalb, GA	Pickens, SC	Guilford, NC
4	Gaston, NC	Cabarrus, NC	Wake, NC	Cobb, GA	Fayette, GA	Walker, AL
5	Cabarrus, NC	Anderson, SC	Guilford, NC	Wake, NC	Henry, GA	Tuscaloosa, AL
6	DeKalb, GA	York, SC	Clayton, GA	Fulton, GA	Clayton, GA	Anderson, SC
7	Cobb, GA	Union, NC	Cobb, GA	Mecklenburg, NC	Cherokee, GA	Limestone, AL
8	Forsyth, NC	Iredell, NC	Greenville, SC	Guilford, NC	Newton, GA	Lawrence, AL
9	Clayton, GA	Spartanburg, SC	Cabarrus, NC	Johnston, NC	Haywood, NC	Laurens, SC
10	Fulton, GA	DeKalb, GA	Gaston, NC	Fayette, GA	Cobb, GA	Cullman, AL

The correlation coefficient (CC) has been widely used in statistics to measure how strong a relationship is between two variables. The CCs between the WATT, DA, and PA are presented in Table 5.3. There is a negative relationship between WATT and DA and PA. The reason is that the more accessible counties are inclined to have lower WATTs and greater DA and PA values. The relation between the DA and PA is positive which indicates that the future HSR corridor enables more counties to be accessible in 3 hours in the PAM and achieve a higher potential accessibility value. Under scenario 3, the absolute values of the three CCs are close to 1, especially the CC of the WATT-DA, which indicates the WATT-DA, WATT-PA, and DA-PA are closely related to each other. In these three indicators, the projected population is included as the weight which plays an important role in evaluating the accessibility impact. Thus, the PAM counties with larger accessible populations are inclined to have lower WATTs and higher PAs and DAs, which is a little different from the conclusion in Jiao et al.'s (2014) study.

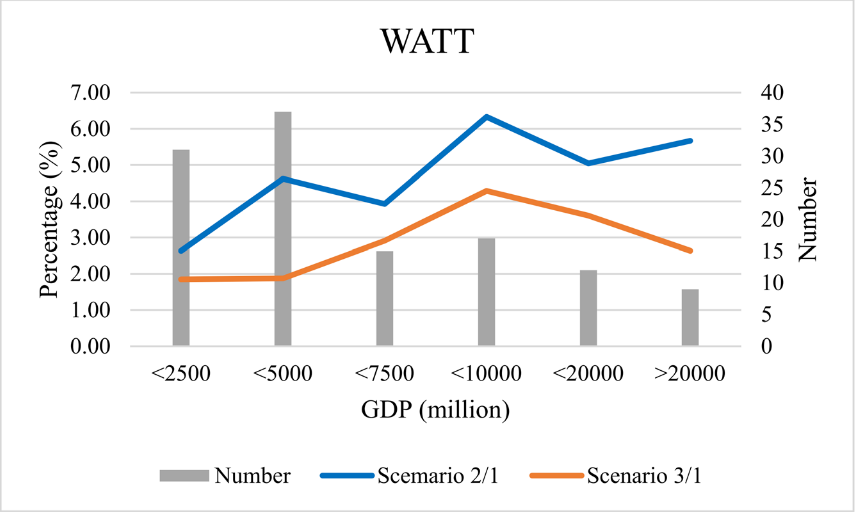
Table5.3: CC between the WATT, DA, and PA and CV of The WATT, DA, and PA

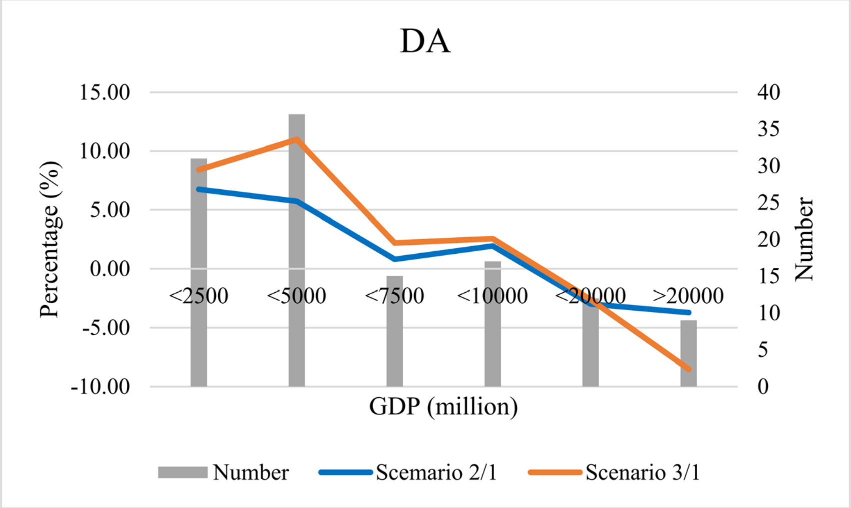
CC between the WATT, DA, and PA			
Scenario	**WATT-DA**	**WATT-PA**	**DA-PA**
Scenario 1	-0.8635	-0.7276	0.7447
Scenario 2	-0.8557	-0.7362	0.7661
Scenario 3	-0.9436	-0.7815	0.8063
CV of the WATT, DA, and PA			
Scenario	**WATT**	**DA**	**PA**
Scenario 1	29.03%	51.47%	55.15%
Scenario 2	33.22%	57.47%	56.60%
Scenario 3	29.38%	52.33%	55.30%

It is necessary to examine whether the new HSR line will contribute to increasing inequities in terms of accessibility in the PAM. As a measure of relative variability in statistics, the coefficient of variation (CV) has always been adopted to measure the increase or decrease in disparities among regions or cities after building a new infrastructure in the existing studies (Gutiérrez, 2001; López et al., 2008; Wang et al., 2016) . The CVs of the WATT, DA, and PA are given in table 5.3, which increase with the building of the HSR corridor in the PAM. The CV increases under scenario 2 and decreases with the expansion of HSR corridor under scenario 3. But the overall CV still increases. For example, the CV of the WATT increases from 29.03% to 33.22% and then drops to 29.38%. The difference between scenario 3 and scenario 1 is 0.35%. Although the megaregional accessibility is improved, the future HSR corridor increases inequalities in terms of the accessibility in the PAM.

In Figure 5.8, the relationship between the CVs of the WATT, DA, and PA indicator under scenario 2/1 and 3/1 vs. the population size in each county are presented. Under scenario 3/1, all the CV percentages are less than those under scenario 2/1 which is in line with the result in table 5.3, and the percentages are all greater than zero. Figure 5.8(a) indicates that the HSR increases inequalities in all the counties if the WATT indicator is used. The CVs of the DA demonstrate that the HSR corridor reduces the inequalities in the counties with large population size (>500,000), but the inequalities of small population size counties are increased. The PA indicator shows that the building of HSR (scenario 2) increases inequalities, but the expansion of HSR (under scenario 3) improves equalities in counties where the number of the population is greater than 500,000. In Figure 5.9, the CV of the WATT, DA, and PA vs. GDP is presented. As shown in Figure 5.9, the inequalities effects on the counties with low and high GDP by using the three indicators are similar to the results in Figure 5.9. For example, the PA (see Figure 5.9(c)) demonstrates that the equalities in high GDP counties where the GDP is greater than 10,000 (million) are improved under scenario 3.

Figure 5.8: CV of The WATT, DA, and PA vs. Population





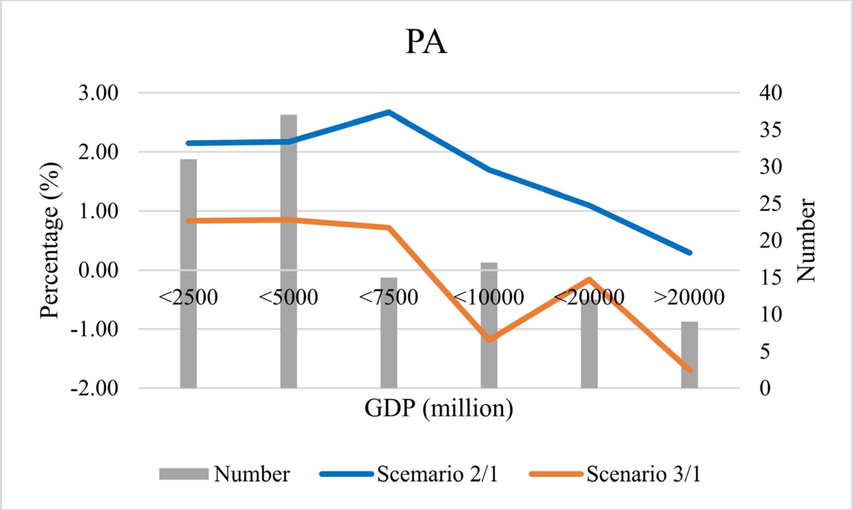


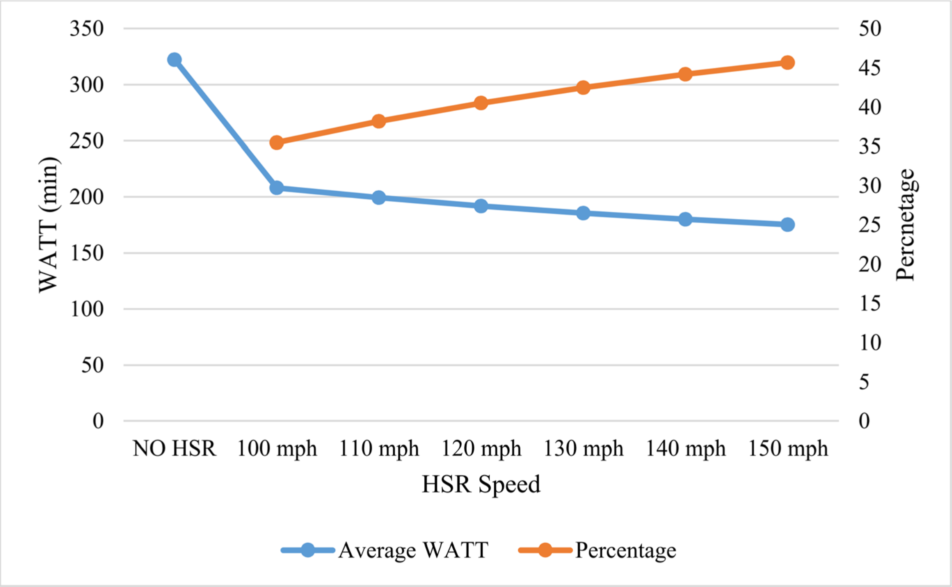
Figure 5.9: CV of the WATT, DA, and PA vs. GDP

5.5.3. Policy Implications

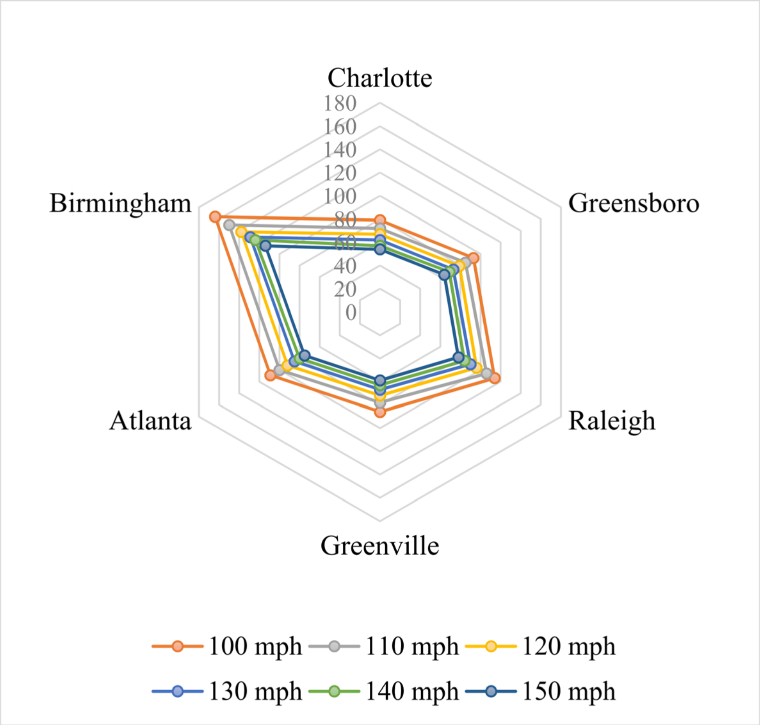
Better accessibility within a megaregion helps achieve considerable economic efficiency gains. According to the results in section 5.5, HSR is a potential travel mode that could significantly improve the megaregional accessibility (Yin et al., 2015). However, the U.S. is facing considerable challenges when developing the HSR. For example, Lane (2012) discussed the challenges of developing HSR in the U.S. from different perspectives, such as engineering, service provision, and "last-mile" problem of HSR. In this section, the corresponding policy suggestions on HSR are drawn in terms of improving accessibility.

One of the most obvious benefits of HSR is significantly reduced travel time between two cities. The total travel time of HSR in this study is divided into four-stage on the basis of the door-to-door approach (see Figure 5.1). Thus, to maximize the benefits of HSR, particular attention should be paid to reducing the travel time at each stage, as shown in Figure 5.1.

The first suggestion is increasing HSR operating speed which can decrease the travel time from origin station to destination station. The effects of speeding up are investigated during peak hours by varying it from 100 to 150 mph. The average WATTs vs. HSR speed are shown in Figure 5.10.a. In Figure 5.10.b, the WATT values with different HSR speeds in the six major cities are presented. As the speed of HSR increases by 10 mph, the average WATT in the PAM will be reduced by about 6 minutes. As can be seen from Figure 5.10.b, the WATT in each city is reduced as well, particularly in Birmingham.



5.10.a Average WATT (minutes) Values in The PAM vs. HSR Speed



5.10.b WATT Values for The Six Cities with HSR Speeding Up

Figure 5.10: (a) Average WATT (minutes) Values in The PAM vs. HSR Speed; and (b) WATT Values for The Six Cities with HSR Speeding Up

Decreasing the total transfer time at the HSR stations is another way to enhance accessibility. Increasing (higher) HSR frequency or decreasing (lower) headway can decrease the average waiting time at the stations. The effect of reducing headway is qualified by varying the headway from 20 to 90 min, and the corresponding WATTs are presented in Figure 5.11. As the HSR headway decreases by 10 minutes, the average WATT in the PAM is reduced by about 3 minutes. The results in Figure 5.10 and Figure 5.11 indicate that increasing HSR speed results in more WATT reduction. However, to achieve more accessibility enhancement, the two strategies can be implemented at the same time, especially during peak hours. Besides high-frequency trains, some other strategies can also be employed to reduce the total transfer time, such as good access to the station for transit and cars, convenient ticketing services, and clear spatial orientation at the stations (Garmendia et al., 2012; Wang et al., 2016).

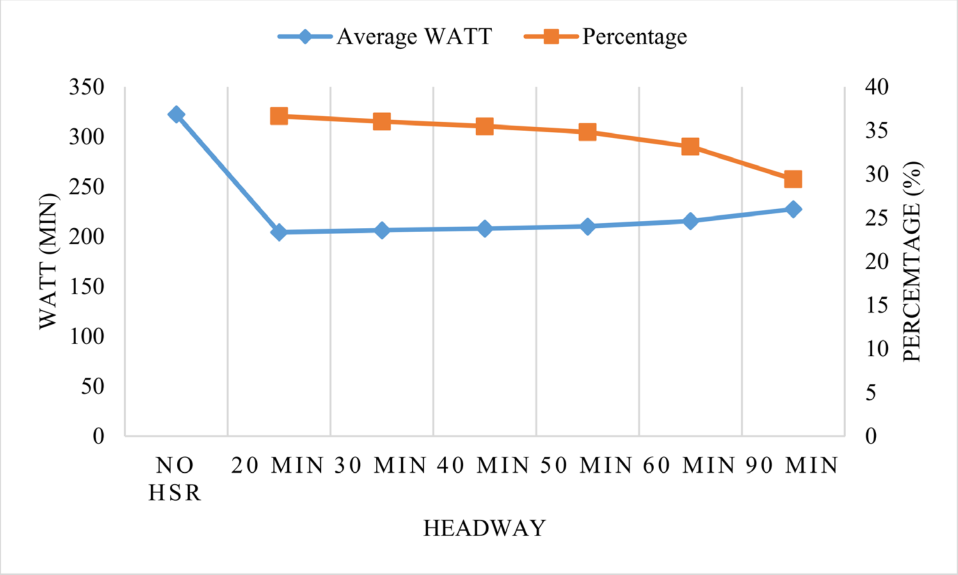


Figure 5.11: Average WATT (Minutes) Values in The PAM vs. Headway

The third suggestion is improving the highway infrastructure around the HSR stations. The PAM is and will still be an auto-oriented megaregion, and most of the travelers will still drive cars as the "feeder" mode to HSR. In this regard, the traffic demand on the roadway systems connecting to the HSR stations will increase, which will result in an increase in congestion and travel time. The congestion on the roadway system around the HSR stations will reduce the accessibility impact of HSR at a megaregional level. Thus, the accessibility of the HSR station area should be enhanced (Zhang et al., 2016). The construction and expansion of highway networks will play an important role in accessibility enhancement in the PAM.

The last suggestion is that an efficient feeder transit system (e.g., light rail, bus services, or taxi services) for the commuters should be provided so that the "last-mile" problem to and from the HSR station can be addressed (Lane, 2012; Chandra and Vadali, 2014). The "last-mile" problem, as mentioned in Lane's (2012) study, is a potential stumbling block for the development of HSR in the U.S. How to efficiently connect HSR commuters to the rest of the city's transport network should be paid more attention by policymakers. Most cities in the PAM lack of the efficient transit system, especially outside of the downtown areas. For example, only Atlanta and Charlotte have a rail transit system in the PAM. An efficient and convenient public transportation system should be provided in the cities where HSR stations are located. The strategies to build efficient feeder transit systems include, but are not limited to, building high-occupancy vehicle (HOV) lanes for buses (Chandra and Vadali, 2014) and deploying monorail, metro, trams, or light-rail transit.

5.6. Summary

To estimate the accessibility impact of the future HSR corridor on the PAM in the United States, the study adopts a GIS tool. The door-to-door approach is developed and used to estimate the multimodal travel times. Three accessibility indicators are employed to evaluate the megaregional accessibility, which include the WATT, DA, and PA. To understand the overall accessibility impact of the new HSR line during peak and off-peak periods, accessibility performances at the county level are discussed on the basis of the calculated results. Different indicators result in different accessibility performances. The comparisons among the three indicators are undertaken. The results indicate that the future HSR corridor will significantly improve the megaregional accessibility, especially during peak period. Furthermore, the HSR increases the inequities in terms of accessibility in the PAM based on the CV statistical results. To enhance the accessibility, several policy suggestions, such as increasing HSR frequency and operating speed, are made on the basis of the door-to-door approach.

Chapter 6. Summary and Conclusions

6.1. Introduction

As specifically addressed in the 2016 Southeast Rail Forum by Mr. Anthony Foxx, U.S. Secretary of Transportation, a wave of population growth is going to hit the Southeast. Another 13 million people and a significant increase in the movement of freight can be expected by 2045. As such, local and state leaders shall act promptly to develop a comprehensive blueprint for the Region's rail network and establish a Southeast Rail Commission to advance it or risk being stuck in traffic for a very long time. Although the progress over the years has been steady, future work remains. Meanwhile, from Boston to Washington DC to Charlotte to Atlanta, the term, "megaregions", has been used to re-envision the economic and social fabric of America. Megaregions have been defined as networks of metropolitan areas linked by economic and trade relationships, transportation infrastructure, linked ecosystems, and growth concerns. Megaregions, supported by improved transportation networks, have the potential to evolve as integrated economic units. Megaregions are playing an important role in regional and global economic competition.

The primary objective of this research is to consider the PAM with an emphasis on maintaining efficient future people and freight movements. Multimodal solutions to move people and freight to, between, and within the metropolitan economies of the megaregion in 2050 are explored. The future mobility demand in the PAM is estimated. The freight planning at a megaregional level is studied, and the accessibility impact of future high-speed rail on the PAM is examined and evaluated.

The rest of this chapter is organized as follows. Section 6.2 provides a brief review of the methods used to predict the mobility demand and evaluate the accessibility impact of HSR. Section 6.3 details the directions that should be taken in future research in order to improve the movement of people and freight in megaregions.

6.2. Summary and Conclusions

An extensive review of the current and historical research studies related to megaregional planning, megaregional freight planning experiences, and high-speed rail accessibility assessment, have been performed.

To support future megaregional planning efforts, a method using an aggregate model to estimate future mobility demand in the PAM is developed. The projected population and GDP data in 2050 is used. The modeling framework is based on the assumptions of fixed travel time budget and cost budget. The results demonstrate that the high-speed travel will rise dramatically in the PAM. Planning for megaregional transportation should seriously consider HSR to accommodate the future travel demand.

The role of freight in supporting and sustaining economic development in the PAM is explored as well. The opportunities and challenges faced by the PAM are discussed. The challenges include but are not limited to, funding and financing, coordination, and truck management. Some recommendations that aim to improve the freight movement are proposed, such as continuing participation among MPOs and encouraging the high-speed freight rail corridor.

Finally, in order to evaluate the accessibility impact of future HSR corridor on the PAM, a GIS tool is used to conduct the accessibility assessment. The door-to-door approach is adopted to evaluate the multimodal (including roadways and HSR) travel time. Three accessibility indicators are selected, including the weighted average travel time, daily accessibility, and potential accessibility. The selected accessibility indicators are calculated using the estimated travel time at the geographical level. The average accessibility scores of the counties in the PAM during peak and off-peak hours are estimated and compared. The results indicate that the building of the HSR corridor within the PAM will improve the accessibility at the megaregional level. However, the coefficient of variation results indicates that the inequality will also increase due to the introduction of the new HSR corridor. Several policy implications (including increasing HSR frequency and operating speed, decreasing the total transfer time at the HSR stations, improving the highway infrastructure around the HSR stations, and building efficient feeder transit system) are drawn in terms of enhancing the megaregional accessibility.

6.3. Directions for Future Research

In the future, high-speed rail systems that integrate freight and passengers will need to be explored and designed. In addition, as mentioned in most of the existing studies, the travel cost is also an important factor which is worth being considered when evaluating the accessibility impact of HSR. Methods that can be used to improve the accessibility around the HSR stations will also need to be developed, and corresponding guidance will be provided.

References

1. American 2050. *Where High-Speed Rail Works Best*. 2009. http://www.america2050.org/pdf/Where-HSR-Works-Best.pdf
2. Hagler, Y. *Defining U.S. Megaregions*. 2009. http://www.america2050.org/upload/2010/09/2050_Defining_US_Megaregions.pdf
3. American 2050. *High-Speed Rail in American*. January 2011. http://www.america2050.org/pdf/HSR-in-America-Complete.pdf
4. American 2050. The Southern California Megaregion A Case Study of Global Regions: America's Third Century Strategy. September 2005. http://www.america2050.org/pdf/socalmegaregion.pdf
5. Alexandra, M., and M. Kevin. *Freight Planning and Regional Cooperation in the Piedmont Atlantic Megaregion: A Regional Models of Cooperation Peer Exchange Summary Report*. FHWA-HEP-17-101, Office of Planning U.S. Department of Transportation, Washington D.C. September 2017. https://ntl.bts.gov/lib/62000/62500/62548/RMOC_Atlanta_PeerExchangeReport.pdf
6. Beiler, M.O., S. McNeil, D. Ames, and R. Gayley. (2013) "Identifying Resiliency Performance Measures for Megaregional Planning: Case Study of the Transportation Corridor Between Boston, Massachusetts, and Washington, DC." *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2397*, Transportation Research Board of the National Academies, Washington, D.C., pp. 153-160.
7. Bellisario, J., M. Weinberg, and C. Mena. The Northern California Megaregion: Innovative, Connected, and Growing. Bay Area Council Economic Institute, June 2016. http://www.bayareaeconomy.org/files/pdf/The_Northern_California_Megaregion_2016c.pdf
8. Benenson, I., K, Martens, Y. Rofé, and A. Kwartler. (2011). "Public Transport Versus Private Car GIS-Based Estimation of Accessibility Applied to The Tel Aviv Metropolitan Area." *The Annuals of Regional Science*, 47, pp. 499 – 515.
9. Campos, J., and G. de Rus. (2009) "Some Stylized Facts about High-Speed Rail: A Review of HSR Experiences around The World." *Transport Policy*, 16, pp. 19-28.
10. Chandra, S., and S. Vadali. (2014). "Evaluating Accessibility Impacts of the Proposed America 2050 High-Speed Rail Corridor for the Appalachian Region." *Journal of Transport Geography*, 37, pp. 28-46.
11. Chang, J. S., and J. H. Lee. (2008). "Accessibility Analysis of Korean High-speed Rail: A Case Study of the Seoul Metropolitan Area." *Transportation Reviews*, 28(1), pp. 87-103.
12. Cao, J., X. C. Liu, Y. Wang, and Q. Li. (2013) "Accessibility Impacts of China's High-Speed Rail Network." *Journal of Transport Geography*, 28, pp. 12-21.
13. Chen, X. (2010). "The High-speed Rail Development in the Northeast Megaregion of the United States: A Conceptual Analysis." *Theoretical and Empirical Researches in Urban Management*, 8(17), 2010.

14. Chester, M., and A. Horvath. (2012). “High-Speed Rail with Emerging Automobiles and Aircraft Can Reduce Environmental Impacts in California’s Future.” *Environmental Research Letter*, 7, pp. 1-11.
15. Davis, J., and T. Regan. Mid-South Megaregion Freight Planning Meeting and Workshop; Memphis, Tennessee. U.S. Department of Transportation, Washington, D.C., December 2016. https://planning.dot.gov/Peer/Tennessee/Memphis_midSouth_12-8-16.pdf
16. Dewar M., and D. Epstein.(2007). “Planning for “Megaregions” in the United States.” *Journal of Planning Literature*, 22(2), pp. 108-124.
17. Ducca, F.W., T. Ma, S. Mishra, T. Welch, R. Donnelly, T. Weidner, R. Moeckel, T. Moore, R. Pozdena, B. Deal, A. Chakraborty, D. Simmonds, and S. Yoder. *A Framework for Megaregion Analysis: Development and Proof of Concept*. May 2013. http://smartgrowth.umd.edu/assets/tprg/full_report_megaregion_ncsg_20130528.pdf
18. Ertem, M. A., and M. K. Özcan. (2016). “Freight Transportation Using High-speed Train Systems.” *Transportation Letters: The International Journal of Transportation Research*, 8(8), pp. 250-258.
19. FRA (Federal Railroad Administration), 2010. High Speed Intercity Passenger Rail (HSIPR) Program. https://www.fra.dot.gov/Page/P0134
20. Florida, R., T. Gulden, and C. Mellander. (2008). “The Rise of Megaregion.” *Cambridge Journal of Regions, Economy and Society*, 1, pp. 459-476.
21. Freight Analysis Framework Data Tabulation Tool (FAF4). https://faf.ornl.gov/faf4/Extraction1.aspx
22. Garmendia, M., C. Ribalaygua, and J.M. Ureña. (2012). “High Speed Rail: Implication for Cities.” *Cities*, 29, pp. 526-531.
23. Geurs, K.T., and B. van Wee. (2004). “Accessibility Evaluation of Land-Use and Transport Strategies: Review and Research Directions.” *Journal of Transport Geography*, 12, pp. 127-140.
24. Gutierrez, J. (2001). “Locations, Economic Potential and Daily Accessibility: An Analysis of the Accessibility Impact of the High-Speed Line Madrid-Barcelona- French Border.” *Journal of Transport Geography*, 9, 229-242.
25. Gutiérrez, J., A. Condeço–Melhorado, E. López, A. Monzón. (2011). “Evaluating the European added value of TEN-T projects: a methodological proposal based on spatial spillovers, accessibility and GIS.” *Journal of Transport Geography*, 19, pp. 840–850.
26. Harrison, R., D. Johnson, L. Loftus-Otway, N. Hutson, D. Seedah, M. Zhang, and C. Lewis. *Megaregions Freight Planning: A Synopsis*. FHWA/TX-11/0-6627-1, Texas Department of Transportation, Austin, TX, March 2012. http://ctr.utexas.edu/wp-content/uploads/pubs/0_6627_1.pdf
27. Holl, A. (2007). “Twenty Years of Accessibility Improvements: The Case of the Spanish Motorway Building Program.” *Journal of Transport Geography*, 15, pp. 286 – 297.

28. Hou, Q., and S.M. Li. (2011). "Transport Infrastructure Development and Changing Spatial Accessibility in the Greater Pearl River Delta, China, 1990-2020." *Journal of Transport Geography*, 19, pp. 1350 – 1360.
29. Horizon 2060. *2060 Florida Transportation Plan*. http://www.fdot.gov/planning/ftp/2060FTP.pdf
30. Hylton, P. *Megaregions as a Framework for Integrating Supply Chain Dynamic and Freight Planning*. Georgia Institute of Technology, May 2014. https://smartech.gatech.edu/bitstream/handle/1853/52905/PeterHylton_Megaregions+as+a+Framework+for+Integrating+Supply+Chain+Dynamics+and+Freight+Planning.pdf;jsessionid=1095ECC8A7B11D77FCD1A33D617B8573.smartech?sequence=1
31. Innes, J. E., D. E. Booher, and S. Vittorio. (2010). "Strategies for Megaregion Governance: Collaborative Dialogue, Networks, and Self-Organization." *Journal of the American Planning Association*, 77(1), pp. 55-67.
32. Janic, M. (2011). "Assessing Some Social and Environmental Effects of Transforming an Airport into a Real Multimodal Transport Node." *Transportation Research Part D*, 16, pp.137-149.
33. Jiao, J., J. Wang, F. Jin, and M. Dunford. (2014). "Impacts on Accessibility of China's Present and Future Network." *Journal of Transport Geography*, 40, pp. 123-132.
34. Jones, C. (2007). "Economic and Equity Frameworks for Megaregions." *Regional Plan Association, New York*, 2007. http://www.america2050.org/2007/07/economic-and-equity-frameworks-for-megaregions-1.html
35. Kamga, C. and M. A. Yazici. (2014). "Achieving Environmental Sustainability beyond Technological Improvements: Potential Role of High-Speed Rail in the United States of America." *Transportation Research Part D*, 31, pp. 148-164.
36. Kotavaara, O., H. Antikainen, and J. Rusanen. (2011). "Population Change and Accessibility by Road and Rail Networks: GIS and Statistical Approach to Finland 1970–2007." *Journal of Transport Geography*, 19, pp. 926 – 935.
37. Koopmans, C., P. Rietveld, and A. Huijg. (2012). "An Accessibility Approach to Railways and Municipal Population Growth, 1840–1930." *Journal of Transport Geography*, 25, pp. 98-104.
38. Lang, R. E. and D. Dhavale. *Beyond Megalopolis: Exploring America's New "Megapolitan" Geography*. In Metropolitan Institute Census Report Series, 2005. https://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=1038&context=brookings_pubs
39. Lakshmanan, T.R. (2011). "The Broader Economic Consequences of Transport Infrastructure Investments." *Journal of Transport Geography*, 19, pp. 1-12.
40. Lane, B.W. (2012). "On The Utility and Challenges of High-Speed Rail in the United States." *Journal of Transport Geography*, 22, pp. 282-284.

41. Lei, T.L., and R.L. Church. (2010). “Mapping Transit-Based Access: Integrating GIS, Routes and Schedules.” *International Journal of Geographical Information Science*, 24, pp. 283 – 304.
42. Levinson, D. M. (2012). “Viewpoint: Accessibility Impacts of High-Speed Rail.” *Journal of Transport Geography*, 22, pp. 288-291.
43. Lewis, C.A., S. Land, and B. Afefayane. *Moving the Concept of Megaregions into Transportation Planning: Workshop Processing*. SWUTC/12/47/6660-00051-1, Center for Transportation Training and Research, Houston, Texas, August 2012. https://texashistory.unt.edu/ark:/67531/metapth542145/m2/1/high_res_d/txcs-0913.pdf
44. López, E., J. Gutiérrez, and G. Gómez. (2008). “Measuring Regional Cohesion Effects of Largescale Transport Infrastructure Investments: An Accessibility Approach.” *European Planning Studies*, 16, pp. 277 – 301.
45. Maricopa Association of Governments (MAG). *Megaregions Planning for MPOs and Partners: A TPCB Peer Exchange.* Transportation Planning Capacity Building (TPCB) Peer Program, Phoenix, Arizona, May 2012.
46. Martín, J.C., J. Gutiérrez, and C. Román. (2004). “Data Envelopment Analysis (DEA) Index to Measure the Accessibility Impacts of New Infrastructure Investments: The Case of the High-Speed Train Corridor Madrid–Barcelona– French Border.” *Regional Studies*, 38, pp. 697 – 712.
47. Monzón, A., E. Monzón, and E. López. (2013). “Efficiency and Spatial Equity Impacts of High-Speed Rail Extensions in Urban Areas.” *Cities*, 30, pp. 18-30.
48. Nelson, A.C. (2017). “Megaregion Projections 2015 to 2045 with Transportation Policy Implications.” *Transportation Research Record: Journal of the Transportation Research Board*, 2654, pp. 11–19.
49. Nelson, G. D., and A. Rae. (2016). “An Economic Geography of the United States: From Commutes to Megaregions.” *PLoS ONE*, 11(11), e0166083.
50. Páez, A., D.M. Scott, and C. Morency. (2012). “Measuring Accessibility: Positive and Normative Implementations of Various Accessibility Indicators.” *Journal of Transport Geography*, 25, pp. 141 – 153.
51. Pérez, E.O., S.M. Quintana, and I.O. Pastor. (2011). “Road and Railway Accessibility Atlas of Spain.” *Journal of Maps*, 7, pp. 31 – 41.
52. Pazour, J. A., R. D. Meller, and L. M. Pohl. (2010). “A Model to Design A National High-Speed Rail Network for Freight Distribution.” *Transportation Research Part A*, 44, pp. 119-135.
53. Peckett, H., M.L. William, and D. David. *Metropolitan Planning Organization and Transportation Planning for Megaregions*. FHWA-HEP-15-010, Prepared for U.S. Department of Transportation, Washington D.C., December 2014. https://ntl.bts.gov/lib/54000/54600/54607/fhwahep15010.pdf
54. Peckett, H., W. M. Lyons, and D. Daddio. *Metropolitan Planning, Organization and Transportation Planning for Megaregions*. FHWA-HEP-15-010, U.S. Department of

Transportation Office of Planning, Environment, and Realty Federal Highway Administration, Washington, D. C., December 2014.https://www.fhwa.dot.gov/planning/megaregions/reports/mpo_and_transportation_planning/fhwahep15010.pdf

55. Peters, J. C., E. P. Han, S. Peeta, and D. DeLaurentis. (2014). "Analyzing the Potential for High-speed Rail as Part of the Multimodal Transportation System in the United States' Midwest Corridor." *International Journal of Transportation Science and Technology*, 3(2), pp. 129-148.
56. Read, A., and D. Morley. *Multimodal Planning at the Megaregional Scale*. FHWA-HEP-17-091, United States Department of Transportation, Washington, DC, June 2017. https://www.fhwa.dot.gov/planning/megaregions/reports/megaregions_report_2017/fhwahep17091.pdf
57. Ross, C.L. *Literature Review of the Implications for U.S. Infrastructure Investment and Transportation Planning*. FHWA-BAA-HEPP-02-2007. U.S. Department of Transportation, Washington D.C., September 2008. https://www.fhwa.dot.gov/planning/megaregions/reports/megaregions_report_2008/megaregions.pdf
58. Ross, C.L., J. Barringer, J. Yang, M. Woo, A. Danner, H. West, A. Amekudzi, and M. Meyer. *Megaregions: Delineating Existing and Emerging Megaregions.* Center for Quality Growth and Regional Development (CQGRD) of Georgia Institute of Technology. Prepared for the U.S. Department of Transportation, Federal Highway Administration, 2009.
59. Ross, C.L. (2011a). "Transport and Megaregions: High-Speed Rail in the United States." *The Town Planning Review*, 82, pp. 341 – 348.
60. Ross, C. L., and M. Woo. (2012). "Identification and Assessment of Potential High-Speed Rail Routes from Megaregion Perspective." *Transportation Research Record: Journal of the Transportation Research Board, No. 2307*, Transportation Research Board of the National Academies, Washington, D.C., pp. 31–42.
61. Ross, C. L. *Megaregions: Literature Review of Organizational Structures and Finance of Multijurisdictional Initiatives and the Implications for Megaregions Transportation Planning in the U.S.* DTFH61-11-C-00003, U.S. Department of Transportation, Washington, D.C., October 2011b. https://www.fhwa.dot.gov/planning/megaregions/reports/megaregions_report_2011/megaregions2011.pdf
62. Ross, C.L., and M. Woo. *Megaregions and Mobility*. The BRIDGE, 2011c, pp. 27-34. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.679.3816&rep=rep1&type=pdf#page=29
63. Schafer, A., and D.G. Victor. (2000). "The Future Mobility of the World Population." *Transportation Research Part A*, 34, pp. 171 – 205.
64. Salonen, M., and T. Toivonen. (2013). "Modeling Travel Time in Urban Network: Comparable Measures for Private Car and Public Transport." *Journal of Transport Geography*, 31, pp. 143-153.

65. Sánchez-Mateos, H. S. M., and M. Givoni. (2012). "The Accessibility Impact of A New High-Speed Rail Line in the UK – A Preliminary Analysis of Winners and Losers." *Journal of Transport Geography,* 25, pp. 105-114.
66. Seedah, D., and R. Harrison. Megaregion Freight Movements: A Case Study of the Texas Triangle. SWUTC/11/476660-00075-1, Southwest Region University Transportation Center, Texas, September 2011. https://ntl.bts.gov/lib/45000/45400/45420/476660-00075-1.pdf
67. Shaw, S. L., Z. Fang, S. Lu, and R. Tao. (2014). "Impacts of High Speed Rail on Railroad Network Accessibility in China." *Journal of Transport Geography,* 40, pp. 112-122.
68. Song, F. (2014). "Analysis of Conducting High-Speed Rail Express Business in China." *CICTP 2014: Safe, Smart, and Sustainable Multimodal Transportation Systems*, 2014.
69. Strale, M. (2016). "High-Speed Rail for Freight: Potential Developments and Impacts on Urban Dynamic." *The Open Transportation Journal*, 10, pp. 57-66.
70. Teita, M .B., and E. Barbour. (2007). "Megaregions in California: Challenges to Planning and Policy." *The Healdsburg Research Seminar on Megaregions, Healdsburg, California, United States, April 4–6*, pp. 7-19.
71. Tierney, S. (2012). "High-Speed Rail, the Knowledge Economy and the Next Growth Wave." *Journal of Transport Geography*, 22, pp. 285-287.
72. Transportation Planning Capacity Building (TPCB) Peer Program. *Megaregions Planning for MPOs and Partners: A TPCB Peer Exchange*. Hosed by Maricopa Association of Governments (MAG), Phoenix, Arizona, May 2012. https://www.planning.dot.gov/documents/MAG_Megaregions_Planning_for_MPOs_TPCB_Peer_Report_May%202012.pdf
73. Transportation Capacity Building Program. *Megaregions Freight Movement Peer Exchange*. Metro Atlanta Chamber, Atlanta, Georgia, November 2013. https://www.fhwa.dot.gov/planning/megaregions/reports/freight_movement/atlantapeer.pdf
74. Todorovich, P. (2009). "America's Emerging Megaregions and Implications for A National Growth Strategy." *International Journal of Public Sector*, 22, pp. 221-234.
75. Troche, G. *High-speed Rail Freight*. KTH Railway Group, Report 0512, Stockholm, Sweden, 2005. https://www.kth.se/polopoly_fs/1.87134!/Menu/general/column-content/attachment/0512_inlaga.pdf
76. Troche, G. *High-speed Rail Freight*. KTH Railway Group, Report 0512, Stockholm, Sweden, 2005. https://www.planning.dot.gov/documents/MAG_Megaregions_Planning_for_MPOs_TPCB_Peer_Report_May%202012.pdf
77. Wang, L., Y. Liu, C. Sun, and Y. Liu. (2016). "Accessibility Impact of the Present and Future High-Speed Rail Network: A Case Study of Jiangsu Province, China." *Journal of Transport Geography*, 54, pp. 161-172.
78. Wheeler, S. (2009). "Regions, Megaregions, and Sustainability." *Regional Studies*, 43, pp. 863-876.

79. Yin, M., L. Bertolini, and J. Duan. (2015). “The Effects of the High-Speed Railway on Urban Development: International Experience and Potential Implications for China.” *Progress in Planning*, 98, pp. 1-52.
80. Zhang, M., and W. Zhang. (2013). *Future Mobility Demand in Megaregions: A National Study with a Focus on the Gulf Coast*. SWUTC/13/600451-00074-1, Center for Transportation Research, Austin, Texas, September 2013. https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/600451-00074-1.pdf
81. Zhang W., P. Nian, and G. Lyu. (2016). “A Multimodal Approach to Assessing Accessibility of A High-Speed Railway Station.” *Journal of Transport Geography*, 54, pp. 91-101.
82. Zhang, M., F. Steiner, and K. Butler. (2007). Connecting the Texas Triangle: Economic Integration and Transportation Coordination. *The Healdsburg Research Seminar on Megaregion, Healdsburg, California, United States, April 4-6*, pp. 21-36.
83. Zhang, K., M. R. Saat, Y. Ouyang, and C. P. L. Barkan. (2015). *Impact of High-speed Passenger Trains on Freight Train Efficiency in Shared Railway Corridors*. NEXTRANS Project No. 100IY04, USDOT Region V Regional University Transportation Center Final Report. http://www.purdue.edu/discoverypark/nextrans/assets/pdfs/Final%20Report%20100IY04.pdf