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Accessibility's Influence on Population Location near Light Rail in the Denver Region

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Accessibility's Influence on Population Location near Light Rail in the Denver Region

by

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DEDICATION

This thesis is dedicated to my father, Theodore C. Zuppa, who committed his professional and personal life to education. A humble librarian, dad and (and mom) sacrificed personal wants to put my sister and me through college debt-free. Like all good parents, he always believed in me. He also believed that a good education unlocked doors leading to new opportunities in life. I miss you dad. Others deserve credit for helping me along the way, too. My mother, Evon R. Zuppa, and mother-in-law, Joan Conner, provided financial assistance for this degree. More importantly, my wife, Kristin Zuppa, deserves eternal thanks. She listened to my worry, gripes, and doubt. She stood by me during my worst moments of frustration and stress, she herself not once complaining about my failing to chip in to do my part around the house. Indeed, Kristin kept the Zuppa household going. To her and our boys, Eli and Simon, I love you. They say it takes a village to raise a child. It certainly took a village to get this middle-aged dad through graduate school.

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ABSTRACT

Accessibility is the most important concept in transportation planning because it describes the ease of travel to opportunities vital for everyday needs. Theoretically, people locate closer to transit corridors if accessibility improves. One desired benefit from light rail is denser land use patterns in the form of Transit Oriented Development (TOD) that captures population growth. In October 1994, the City of Denver, CO, joined the list of American cities that have implemented light rail within the last 33 years. Since then, five corridors have opened there, and planners are retooling their zoning codes to allow TOD near light rail. The hope is to mitigate road-centric policies that enabled sprawl during the second half of the 20th Century. This thesis investigates light rail in the Denver region in the context of accessibility. It asks the following research question: What land use and transportation conditions must exist to encourage the general population to locate near light rail? Five linear regression models test a range of accessibility variables. Evidence suggests that accessibility to jobs and housing near station areas is important for facilitating population growth near light rail. Specifically, land use policy needs to allow residential and non-residential mixed uses near station areas for population growth to occur. It is too early to draw any definitive conclusions for the Denver region. Anecdotal evidence indicates that planners are achieving land use goals of growth, even though many of the region's TOD-supportive policies were recently adopted.

CHAPTER ONE:

INTRODUCTION

On October 7, 1994, the City of Denver, Colorado, joined the list of American cities that have implemented light rail within the last 33 years (Sutherland, 2010; Kuby, Barranda, & Upchurch, 2004; Boorse, Tennyson, & Schumann, 2000; Obmascik, 1994). The mood that day was mostly celebratory. In the *New York Times*, Johnson (1994) described the inaugural run as a "civic celebration" complete with "bands, balloons [*sic*] and clowns" (p 7). Booth (1994) reported in the *Denver Post* that hundreds waited in line to ride the 5.3 mile line, the first of a handful planned for the region.

Not all believe that light rail is worth the investment, and the debate between proponents and opponents of light rail can result in hyperboles from both sides. For example, in Pinellas County, Florida, No Tax for Tracks received a "False Claim" from *Politifact* for saying that the transit improvement plan, Greenlight Pinellas, would raise taxes 300 percent (Gillin, 2014). If approved in a voter referendum, the proposed sales tax for funding light rail and bus improvements replaces the property tax, and the amount depends on a variety of factors (Greenlight Pinellas Means, 2014; Marrero, 2014; The Greenlight Pinellas Plan, n.d.). These types of debates mean that credible research is invaluable for guiding the planning process.

Projects such as Denver's light rail are good urban laboratories because over time, transportation planners can use established performance measures to evaluate a transportation project. Some measures include cost-effectiveness, ridership growth, and fare box recovery

(Transportation Research Board, 2003). Improved accessibility is another performance measure (Handy, 2005). Often defined as the ease of movement to opportunities, accessibility is an important concept that describes how well society can meet its needs via a transportation system (Litman, 2012; Handy, 2005; Koenig, 1980). Theoretically, once a transportation project is implemented, accessibility should improve followed by the population locating closer to the system out of convenience (Huang, 1996).

This quantitative study investigates accessibility's influence on population growth near light rail in the Denver region. The study uses a simple but practical methodology that can be duplicated by planning organizations. It tackles this research question: What transportation and land use conditions encourage the general population to locate near light rail? The first chapter of this study defines light rail, tells its history, discusses transportation's and public policy's roles in suburbanization, and contrasts transit-oriented development (TOD) to suburban development. The second chapter defines accessibility, discusses the roles of suburbanization and transportation technology to accessibility, and explains methods for measuring accessibility. The third chapter reviews existing literature on rail transit, light rail, and their relationship to land use. The fourth chapter describes the study area, methodology, hypotheses, and variables. The final chapter is a discussion of the results and a look ahead to additional research possibilities.

Defining Light Rail Transit

Light rail (Figure 1.1) is easily confused with other rail modes including commuter, heavy, and high speed rail. That is because some organizations use the terms light rail, modern streetcar, and trolley interchangeably whereas other organizations differentiate between them. In addition, the literature does not consistently present a universal definition for light rail and other

rail modes. For example, Reconnecting America (n.d.) defined light rail, commuter rail, heavy rail, high speed rail, modern streetcar, and trolley individually. On the other hand, American Public Transportation Association (2014) and Garrett (2004) defined light rail as trams, streetcars, or multicar trains that operate in mixed traffic or within their own right of way (Fact Book Glossary, 2014). Another definition is that light rail is "a metropolitan electric railway system" (Boorse, Tennyson, & Schumann, 2000, p. 3) that both weighs and costs less than the other rail modes and can operate on streets, freeway medians, elevated structures, and even underground (Boorse, Tennyson, & Schumann, 2000). This definition is too broad. Heavy rail systems such as New York City's subway operate on elevated structures and underground, and it is not considered light rail.

In reality, the differences are more noticeable between light rail and heavy rail. Heavy, commuter, and high-speed rail carry more passengers over longer distances at faster speeds and operate with longer service frequencies and station spacing farther apart. Light rail is generally cheaper to implement and operate, and it can maneuver tight turns and steep slopes (Garrett, 2004). It is more difficult to compare light rail and the modern streetcar because they essentially use the same technology (Walker, 2010). For example, the Regional Transportation District (RTD) in the Denver region defined light rail as carrying 12,000 to 15,000 passengers per hour and the modern streetcar 1,440 passengers per hour; yet, the carrying capacity of each is 125 and 120 passengers per car, respectively. RTD's definition continues: light rail operates within its own right of way; the modern streetcar operates in mixed traffic and its own right of way. Light rail's maximum speed is 55 miles per hour; the modern streetcar's is 45 miles per hour (Regional Transportation District, n.d).

Figure 1.1. D Line Light Rail, Denver, CO.

By Regional Transportation District Photo Library, n.d., retrieved from http://www.rtd-denver.com/images/MediaCenter/mineral-crowd.jpg, Copyright Regional Transportation District. Used with permission (Appendix A).

Walker (2010) suggested that the best way to differentiate between light rail and the modern streetcar is the distance between stations. Specifically, light rail stations are located farther apart than the modern streetcar, and light rail is a longer-distance transit service that serves suburban communities. This definition is not universal, though. Station spacing for light rail can likewise be spaced close together. To avoid confusion, this study does not distinguish between light rail and the modern streetcar. Instead, it uses the National Transit Database's (2013) broad definition found in its glossary of terms, which follows:

- Light rail is not heavy rail

- Light rail operates mostly in exclusive right of ways

- Light rail is powered by electricity

A Brief History of Light Rail

Light rail is a descendent of the late 19th and early 20th century streetcar (Xie & Levinson, 2009; Jackson, 1985). Transit's beginning in the United States dates to 1829 when an entrepreneur named Abraham Brower started running an omnibus service in New York City. The omnibus opened in other major cities soon afterward, including Philadelphia, Boston, and Baltimore (Jackson, 1985). The omnibus, a short-haul stage coach pulled by a horse, originated in France three or four years earlier (The date depends on the source.) when Stanislas Baudry developed the service to transport customers from Nantes to his bathhouse outside the city (Belenky, 2007; Jackson, 1985).

Figure 1.2. Horse-Drawn Streetcar in Covington, GA.[1]

By Unknown Author, 1888-1917, retrieved from the United States Library of Congress, http://www.loc.gov/pictures/item/2012646773/

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[1]The Library of Congress officially does not grant or deny usage. Its policy is "no known-restrictions on publication of this photograph."

By 1832, American entrepreneur John Martin had adapted the omnibus to a horse-drawn streetcar on railroad tracks in New York City. Twenty years later, horse-drawn streetcars (Figure 1.2) were carrying 30 to 40 passengers at six to seven miles an hour in New York City, Philadelphia, Pittsburgh, Chicago, Cincinnati, and Boston (Jackson, 1985). It took a little longer for horse-drawn streetcars to reach the City of Denver. The first one began operation there in December 1871, just before the advent of the electric streetcar era in the 1880s (City of Denver, n.d.).

A number of famous Americans tried to be the first to successfully develop an electric streetcar during the 1880s. Thomas Edison dabbled in building an electric streetcar with no success, along with Leon Daft, Edward Bentley, Walter Knight, and Charles J. Van Depoele (Jackson, 1985). Frank Julian Sprague was the one who invented the widely-used model for the electric-powered streetcar by the end of the decade in Richmond, VA (Jackson; 1985). The new technology resulted in faster travel times over longer distances. Streetcars operated at 20 miles per hour in the city and transported people to suburban communities at faster speeds. By the early 20th century, almost all of the streetcar systems in the United States used Sprague's technology (Figure 1.3), and a little less than 30,000 miles of electric streetcar lines operated in cities across the country (Jones, 2008; Jackson, 1985).

Streetcars were at first a profitable investment, in part because of backroom deals and no other viable competition existed. Businessmen wanting to monopolize a route bribed municipal officials for exclusive operating rights. Other companies unable to compete merged or folded (Jackson, 1985). At the same time, the streetcar expanded the walkable city. The working class afforded the nickel fare and explored other parts of the city (Jones, 2008, Jackson, 1985; Warner, 1978). Annual ridership grew year after year until it peaked at more than 15 billion in 1923.

After that, the streetcar ridership fell and never recovered. Ridership declined more than 40 percent by1940 (Jones, 2008; Jackson, 1985). In 1970, only three percent of all transit riders rode on streetcars in the United States (Thompson, 2003). Most streetcar lines went out of business, although a few cities such as New Orleans kept their streetcar lines by the end of the 20th century (Jones, 2008; Jackson, 1985). Denver's streetcar service ceased operation on June 3, 1950 (City of Denver, n.d.).

Figure 1.3. Streetcar Surrounded by Horse and Buggies, and Cars in Downtown Des Moines, IA.[2]

By A. O. Harpel, 1910, retrieved from the United States Library of Congress
http://www.loc.gov/pictures/item/2012646332/

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[2]The Library of Congress officially does not grant or deny usage. Its policy is "no known-restrictions on publication of this photograph."

Contemporary local, regional, and federal support of light rail is ironic considering early public policy largely ignored mass transportation and supported mass motorization (Jackson, 1985; Barrett, 1975). Streetcar fares were regulated, so transit companies were not allowed to raise rates as profits diminished (Jones, 2008; Jackson, 1985). Meantime, public officials promulgated car-centric policies as streetcar use diminished. Consider the following from Jackson (1985):

- New York City Mayor Fiorello LaGuardia believed that the car "represented the best of modern civilization [and] the trolley was simply an old-fashioned obstacle to progress" (Jackson, 1985, p. 170);

- "In 1940 the Denver Planning Commission suggested that streetcars be removed from major thoroughfares 'because (they) delay the faster vehicular traffic'" (Jackson, 1985, p. 170-171); and

- "In Detroit the chairman of the rapid transit commission himself spoke of the automobile as 'the magic carpet of transportation for all mankind" (Jackson, 1985, p. 171).

Streetcar owners deserve some blame. Historians have characterized them as greedy transit barons who mismanaged profits and did not reinvest in their systems when profits were good (Jones, 2008; Jackson, 1985). Still, greed was not the only factor contributing to the decline. Rising wages, mass production of cars, and supportive public policies made personal travel easier and affordable. Between 1909 and 1924, Henry Ford's Model T sales increased from 100,000 to more than three million. In 1925, the United States accounted for approximately six percent of the world's population. Yet, the nation accounted for 81 percent of the world's motor vehicle registrations, with approximately 90 percent of all American households owning at

least one car (Jones, 2008). American mobility was improving, and the personal automobile had become the preferred choice for weekend leisure travel (Jones, 2008; Jackson, 1985).

The effects of the Great Depression further compounded the streetcar dilemma. High unemployment resulted in less people taking streetcars to work and back home (Jackson, 1985). A federal mandate for a 40 hour, five-day work week contributed to a decline in Saturday ridership. New Deal policies designed to bolster the foundering economy focused on road development, not transit. The Pennsylvania Turnpike, Arroyo Seco Parkway in Los Angeles, and the Merritt Parkway in Connecticut were built as a part of the New Deal's emergency Public Works Administration. Like LaGuardia, President Franklin D. Roosevelt pushed highway policies because he believed the car was an important part of the nation's mobility and economy (Foster, 1981). Ten years after the stock market crash, the Federal Government and state highway departments devised much of the interstate highway system. The Bureau of Public Roads prepared two plans for interregional highways — one in 1939 and another in 1944. Congress approved the Defense Highway Acts in the early 1940s, which funded a highway system modeled after Germany's Autobahn (Jones, 2008). The 1956 Federal Aid Highway Act committed the Federal Government to paying 90 percent of all highway construction costs for a 41,000-mile interstate system. By 1990, more than 43,000 miles had been built (Baum-Snow, 2007).

Reaction from the planning community was mixed. Many planners welcomed the Age of the Automobile. But in 1940, the Highway and Transportation Committee of the American Society of Planning Officials predicted a decline in mass transit, suburban growth, urban decentralization, growing urban blight, greater parking demand, and business relocation to the suburbs (Jones, 2008). Anticipating those issues, writer and planner Lewis Mumford

sarcastically praised Americans for electing the congressmen who voted for the 1956 Federal Aid Highway Act (Hayden, 2003). Until the 1974 Federal-Aid Highway Act allowed differently, the Federal Highway Trust Fund could only be used for highway projects (Hess & Lombardi, 2005).

The 1960s marked a shift in public policy to support transit, albeit too little too late for streetcars. Congress recognized that federal intervention was important to transit's survival. It passed a litany of transit-supportive legislation beginning with the Housing Act of 1961. The law provided "modest loans" to help troubled commuter rail systems. More funding came from the following:

- Urban Mass Transportation Act in 1964.

- Urban Mass Transportation Assistance Act in 1970

- Federal-Aid Highway Act in 1974

- Surface Transportation Assistance in 1978 and 1982

- Intermodal Surface Transportation Efficiency Act in 1991

- Transportation Equity Act for the 21st Century in 1998

- Safe, Accountable, Flexible, Efficient Transportation Equity Act in 2005 (Hess & Lombardi, 2005)

- Moving Ahead for Progress in the 21st Century in 2012 (Federal Highway Administration, 2014)

Between 1964 and 2005, federal transit funding grew by more than 2,200 percent (Hess & Lombardi, 2005). By the 1970s, transportation planners sought to improve mass transit and reverse the decline. Attitudes changed, too. Suburbia was no longer romanticized as a solution to the problems associated with city life. During the late 19th and much the 20th centuries, the

prevalent view was a better life was accomplished by moving away from the city. The Garden City movement that Ebenezer Howard founded was based on this planning philosophy (Hall, 2002). At the end of the 20th century, many blamed highway expansion, suburban sprawl, and a decline in mass transit for creating a lack of accessibility to opportunities and hurting central cities' economies. Impressed with European intra-urban rail systems, the Urban Mass Transit Administration (now the Federal Highway Administration) "coined" the name light rail to describe its interest in reviving the moribund American streetcar. Its belief was that rail transit could help reverse urban decline (Thompson, 2003). The City of Edmonton in Canada opened the first North American light rail line in 1979. San Diego was the first city in the United States to open a light rail line in 1981 (Thompson, 2003). Since then, more than 30 American cities have implemented light rail in some form, and more than a dozen systems are planned nationwide (Sutherland, 2010).

American Suburbanization and Transportation

Suburban development began before the post-World War II housing boom. Indeed, it was the streetcar, not highways, which first enabled suburbanization (Xie & Levinson, 2009; Jackson, 1985). Mentioned previously, the suburbs were considered a solution to the social ills associated with city life: overcrowding, poverty, and disease. Streetcars were a first step towards connecting the opportunities in urban centers to the countryside where the working man could metaphorically "convalesce" from those urban ills (Hall, 2002). After streetcar systems peaked in ridership then declined, mid-20th century public policies and highway expansion further spurred outward, low-density growth and urban decentralization. Today, important goals of light rail are to mitigate sprawl and facilitate denser development near transit stations.

Walking was the primary means for travel before the streetcar grew in popularity; many necessities were accessible by foot. For example, the majority of Boston's citizens lived within two miles of city hall before 1850 (Warner, 1978). Current planning policies in places such as Denver harken to that walkable era. At the turn of the century, a combination of streetcar infrastructure, inexpensive land, and a desire to move facilitated some resettlement outside cities (Young, 1998; Warner, 1978). Named streetcar suburbs, new communities formed near rail lines and homeownership grew on the outskirts of cities including Boston, MA; Chicago, IL; Minneapolis, MN; and Cleveland, OH (Xie & Levinson, 2009; Chew, 2009; Harwood, 2003; Young, 1998; Warner, 1978).

The Van Sweringin brothers founded the well-known streetcar suburb of Shaker Heights, OH, and built their own streetcar line from there to downtown Cleveland during the early 1900s (Harwood, 2009). The Shaker Heights line exemplifies how transit connects new development to opportunities in the city. Many contemporary urban planners believe that denser development near transit, or Transit Oriented Development (TOD), can bring people closer to opportunities. In turn, proximity to transit encourages its use, reduces traffic congestion, improves air quality, and conserves energy (Cervero, 2007). Unlike TOD, Shaker Heights was a low-density suburban community characterized by wide, curvilinear streets; large houses on large tracts; well-to-do schools; and exclusive country clubs. Zoning regulation precluded commercial development or any semblance of contemporary mixed-use development (Harwood, 2009).

Shaker Heights was incorporated with a population of about 250 in 1911. Eight years later, the population swelled to 1,900, and the Shaker Heights streetcar moved commuters approximately six miles to the city and back. The streetcar line did well, too. It carried 1.5 million passengers in 1924 and three million in 1930. Ridership and revenue eventually fell. The

City of Shaker Heights took over the line in the 1940s. Unable to afford its continual operation, the city sold the line to the Greater Cleveland Regional Transit Authority for $1.3 million in 1975 (Harwood, 2009).

Other streetcar suburbs were established, and some can be described as legacies in greed and conniving. A business consortium purchased land tracts in Oakland, CA, anticipating growth at the turn of the century, and then arranged for the streetcar lines to bypass the competition's real estate for their own to raise the consortium's land values. In Los Angeles, CA, Henry E. Huntington developed an interurban rail system for the sole purpose of suburban land development and speculation in the early 1900s (Jackson, 1985). Senator Francis G. Newlands used his political influence for an unsuccessful attempt to build an affluent suburb linked to Washington, DC, by a streetcar system (Jackson, 1985).

Housing growth was not rapid during the streetcar era. Those years did set the stage for the quicker pace of urban decentralization after World War II. Between 1950 and 1990, city jobs declined 35 percent and urban populations shrunk 20 percent. One explanation for the urban exodus is natural evolution theory. It states that the middle class will chose to live farther away from the Central Business District (CBD), sacrificing higher commute costs and distances for cheaper housing and more space. An important element to this theory is that mass motorization facilitated the choice to move. Another explanation is the fiscal-social problems theory. It states that people who can afford to move from the city want to trade the social and fiscal problems associated with central cities with predictable suburban life. In this scenario, people seek out communities with like-minded neighbors of similar demographic composition, such as the one depicted in the 1998 movie, *The Truman Show* (Ewing, 1997; Mieszkowski & Mills, 1993).

Evidence supports both theories. For example, early zoning policies were designed to maintain socially and racially stratified cities and codify the existence of homogenous neighborhoods (Hall, 2006), and transportation arguably enabled decentralization. Urban decentralization may have slowed within recent years. Nationwide suburban population growth was three times more than urban growth from 2000 to 2010. Between 2011 and 2013 though, the urban population growth outpaced the suburbs by 0.24 percent (Sanburn, 2014).

Transit Oriented Development and Suburbia

The difficult task ahead for planners is to know how to best use light rail as a planning tool to improve transit and counteract current sprawling patterns — the outward, low-density growth that dominated built environment policies and household preferences in the second half of the 20th century (Ewing, 2008; Ewing, 1997; Mieszkowski & Mills, 1993). Lang, Blakely, and Gough (2005) reported that 50% of Americans were living in the suburbs where public transit is generally absent. Gordon and Richardson (1997) argued that public transit in the United States could not adequately service the suburbs where 5% of commuters used it, and TOD could not realistically accommodate suburban population booms. Frielich (1998) countered the skeptics by writing that public transit has more capacity to carry more people per hour than highway lanes.

TOD and sprawl share a couple of similarities. For example, both have been ambiguously defined in the literature. In addition, TOD and the suburbs have been romanticized as the "strengthening [of] the bond between people and the communities in which they live, work, socialize, and recreate" (Cervero et al., 2004, p. 8; Jackson, 1985). That said, sprawl and TOD mean different things. Ewing (2008) found that sprawl is usually characterized as low-density, strip, scattered, and leap-frog development. Sprawling land uses evoke images of commuters

driving longer distances to reach their destinations, stuck in congestion with car fumes polluting the atmosphere (Black, 2010; Flint, 2006).

A problem with these descriptions is that they do not always recognize the nuance and complexity in measuring sprawl. Leapfrog development does not mean the same thing as economically efficient, discontinuous development that supports intense land uses (Ewing, 1997; Heikkila & Peiser, 1993). Likewise, commercial strip development is not the same as an activity corridor that supports multi-modal transportation (Ewing, 1997; Beimborn, Rabinowitz, Gugliotta, Mrotek, & Yan, 1991). Ewing (1997) wrote that two qualities are important to consider when defining sprawl. First, the differences between sprawl and other land uses need to be quantifiable. Second, measuring the choice to live in a suburban or urban place is based on the development pattern's impacts. The impacts make the development pattern undesirable, not the pattern itself, and one such impact is poor accessibility (Ewing, Pendall, & Chen, 2003; Ewing, 1997; Handy, 1993).

Accessibility over the years has been defined as the ease of reaching opportunities (Litman, 2012; Handy, 2005; Koenig, 1980). Ease can be determined by distances, financial costs, or travel times incurred to reach a destination. The best method for measuring it is debatable, and results can vary depending on the method used. A simple explanation is that TOD and accompanying transit will not improve accessibility if transit travel times are no better than that from driving personal vehicles.

Theoretically and by definition, TOD should facilitate good accessibility. Opportunities will be closer and better connected via a multimodal system that provides more travel choices. As a land use tool, it should capture inward growth and facilitate more biking, walking, and

transit use. Specifically, its ability to improve accessibility is determined by the following "D"

principles that define TOD:

- Density of land use

- Design that encourages walking

- Diversity of land uses

- Distance from the transit stop to residential, employment, shopping, and entertainment

   opportunities (Cervero, 2004).

The general attitude is that TOD enables people to drive less and use transit more. Research

supports this premise (Kockelman, 1997).

TOD cannot be built without supportive local policies, though. For example, New

Urbanists have argued that Euclidean zoning that allows sprawl by segregating land uses

prevents TOD (Elliott, 2008; Duany, Plater-Zyberk, & Speck, J., 2001). Thus, planners working

in communities with multimodal systems have designed transit-related land use policies. The

City of Denver adopted *Blueprint Denver: An Integrated Land Use and Transportation Plan* in

2002 as a planning supplement to the city's 2000 comprehensive plan to recognize the

importance of coordinating land use and transportation planning. *Blueprint Denver*

acknowledged that the city's 1956 zoning code was outdated (City of Denver, 2002). The city

adopted a revamped zoning code that enables TOD eight years after *Blueprint Denver* was

adopted (approximately 16 years after RTD started operating light rail). Other municipalities

have adopted zoning ordinances to support TOD (Regional Transportation District, 2013). Some

research already indicates a good start for new development near light rail, despite the policy lag

(Bhattacharjee, 2013; Ratner & Goetz, 2013), while other research has not (Shen, 2013). It may

be that it is too early to know for certain how the new policy is performing along with light rail.

Conclusion

Throughout transportation history, one theme is evident: Evolving transportation technology enabled more people to travel longer distances. Prior to the streetcar, the working class was limited in their ability to move beyond city centers where necessities were located. The electric streetcar was faster, cheaper, and convenient to use than the omnibus. It connected cities to new suburbs that developed along streetcar corridors. Those streetcar suburbs were a precursor to the explosion of low-density, suburban growth that occurred in the second-half of the 20th century. The streetcar era was relatively short-lived, and policymakers were complicit in its decline. Streetcars could not compete with federal support for building a vast highway network across the United States. Rising wages and mass production of the automobile helped the middleclass afford car ownership. Meanwhile, streetcar ridership declined, and most of the systems in the United States folded (Jackson, 1985).

Recognizing that transit was neglected, Congress began passing transit-supportive legislation in the 1960s. Since then, funding allocation to transit has increased, and awareness of the effects of transportation on land use has led to the revival of urban rail transit (Jones, 2008). More than 30 cities have implemented light rail, and others are planned (Sutherland, 2010). The belief is that light rail facilitates denser, mixed-use development, or Transit Oriented Development (TOD), that will in turn encourage transit use and reduce dependency on driving. Theoretically, people will locate in TOD if light rail improves accessibility by reducing the costs for travel to reach opportunities. The answer to how best to define those costs depends on the method of measuring accessibility, which is discussed in the next chapter.

CHAPTER TWO:

ACCESSIBILITY: THEORY AND PRACTICE

Throughout the years, transportation planners have wondered how best to measure accessibility (Handy, 2005). One well-articulated definition is that accessibility is a relationship between transportation and land use (Primerano & Taylor, 2005). For example, Hansen (1959) defined accessibility as "the potential of opportunities for interaction" (p. 73) linked by transportation systems. Dalvi and Martin (1976), Koenig (1980), and Litman (2012) defined accessibility as the ease of reaching a land-use activity from a specific location. Handy (2005) defined accessibility as the ability to reach one's needs. The number, quality, and types of opportunities define accessibility; as does the cost in terms of money, time, or distance for reaching those activities (Handy & Niemeier, 1997).

In transportation planning, accessibility is "perhaps the most important concept" (Wachs & Kumagai, 1973, p. 438). Accessibility is an indicator of the quality of life and a predictor of location choice (Hanson, 1995; Wachs & Kumagai, 1973). The middle and upper class can afford to be selective on where to live based on accessibility to activities (Primerano & Taylor, 2005). On the other hand, transit dependent populations have limited accessibility to opportunities (Cox, 2014; Bhattacharya, Brown, Jaroszynski, & Batuhan, 2013; Scott & Horner, 2008; Wachs & Kumagai, 1973). In addition, accessibility theoretically influences land use (Wachs & Kumagai, 1973) and vice versa (Scott & Horner, 2008). These reasons make accessibility a good performance measure for studying the effectiveness of a transportation

system's ability to link travelers to jobs, schools, leisure activities, and more (Scott & Horner, 2008).

Considering its importance, a question is to what extent has accessibility been incorporated into transportation planning practice. The Transportation Equity Act for the 21st Century (TEA-21) codified accessibility as a planning factor; therefore, long range transportation plans have included the improvement of accessibility as a goal (Federal Highway Administration, 2014; Handy, 2005). An issue, though, is that the planning practice does not always accurately incorporate accessibility (Handy & Niemeier, 1997). Specifically, evidence suggests that planners do not understand what accessibility really means (Handy, 2005). This chapter reviews the theoretical and practical application of accessibility. The first section traces the history of how land use and transportation systems have influenced accessibility. The second section discusses the differences in theoretical perspectives on accessibility, reviews the mathematical formulas used in practice, then concludes with a brief discussion of the theoretical strengths and weaknesses of the measures.

Accessibility: Social Context

Accessibility's history can be traced through the evolution of transportation technology. The narrative is that transportation evolved from horse-driven cars to electric street cars to automobiles and an interstate system, with the latter two enabling Americans to travel longer distances in shorter times (Muller, 1995; Warner, 1978; Wachs and Kumagai, 1973). That storyline may be too simplistic (Knaap & Song, 2005). American urbanization was not necessarily a two-stage process of first urban densification of opportunities, then decanting them with roads and cars. Industry and housing began locating on city edges in the early 1800s,

streetcars facilitated early suburbanization, and cultural values that shaped American attitudes attributed to outward growth (Walker & Lewis, 2001; Jackson, 1985).

Indeed, suburbia was not thought of as a planning boondoggle in the 19th and early20[th] centuries like it is today. Movers and shakers viewed life in the suburbs as a better alternative to life in the cities. Single-family housing was symbolic of the working class rising to middle-class ranks, and transit connecting the suburbs to the city was considered essential for making it happen. In 1912, Cincinnati Mayor Henry T. Hunt supported improving streetcar lines to support the development of the suburbs (Jackson, 1985). Hunt believed that single-family housing was a panacea to disease, high death rates, and poverty associated with urban life. In contrast, the suburbs supported American ideals of "family stability, peace of mind, patriotism, and moral character" (Jackson, 1985, p. 117).

Suburbanization was at first steady and slow. Streetcar lines originally connected suburban clusters only the wealthy could afford (Hayden, 2003; Muller, 1995; Warner, 1978). Cities still outpaced suburbs in population growth by more than seven percent between 1910 and 1920 (Muller, 1995). That changed during the post-World War II era when a confluence of policies and market trends sped up suburban growth and urban decline. Federally-backed mortgages and highway construction, higher wages, and the affordability of automobiles contributed to that shift (Muller, 1995; Jackson, 1985). As evidence, between 1950 and 2007, Detroit lost nearly 50 percent of its residents, Cleveland 56 percent, St. Louis 59 percent, Philadelphia 30 percent, and so on (Mallach, 2010).

During those decades, the suburbs and highways represented both the realization of a middleclass dream and class divisions. Disinvestment from cities and new highways resulted in the dispersion of opportunities difficult to reach by the urban poor, many of whom were non-

whites (Grengs, 2004; Grengs, 2002; Garrett & Taylor, 1999; Wilson, 1996). In the 1930s, the

Home Owners Loan Corporation practice of coloring urban neighborhoods considered high-risk

investments on maps red enabled banks to refuse to invest there in a practice called "redlining"

(Hillier, 2003; Bissinger, 1997; Jackson, 1985). Highways that destroyed vibrant African

American neighborhoods compounded the problem (Bissinger, 1997). In one example, the

McCone Commission found that a lack of accessibility to employment and health care was an

"underlying cause" of the Watts riots that occurred in Los Angeles during the 1960s (Wachs &

Kumagai, 1973).

The middleclass experienced a different problem. With low-density growth came longer

commutes between home and work, more time spent in the car, and more money spent on travel

(Black, 2010). In1979, the average distance between home and work for 54 million households

in the United States was almost 31 miles. Commute distances would shrink for some households

as jobs relocated from cities to the suburbs, but overall commute distances and times continued

to rise (Janelle, 1995). Of course, not all is bad. Transportation technologies have in fact

benefited society in numerous ways (Miller, 2007). It took 74 hours to travel by stagecoach from

Boston to New York City in the early 19th century. One could make the trip by car in five hours

in 1995 (Janelle, 1995). Nonetheless, the automobile and the development of the highway

created new challenges in transportation. An evolution of accessibility measures designed to

understand how to connect opportunities to better meet people's daily needs followed.

Measuring Accessibility: Perspectives on Theory and Practice

Pirie (1980) wrote, "If the literature is any guide, a great deal of effort has been and

continues to be spent on formulating a meaningful and operational measure of accessibility" (p.

377). More than twenty years later, no "best" measure has been identified (Krizek, 2005) —

especially considering that the literature is inconsistent. For example, Geurs and van Wee (2004)

identified four classes of accessibility measures: infrastructure-based, location-based, person-

based, and utility-based measures. Krizek (2005) and Handy and Niemeier (1997) identified only

three types of models: the gravity, cumulative opportunities, and utility-based models. Miller

(1999) identified three. Miller (2005) later identified a different set of measures, which are

displayed in Table 2.1 at the end of this chapter.

The measurement of accessibility is therefore difficult to understand because the

literature is inconsistent. Location-based and person-based measures in some articles refer to

scale (Miller, 2005) and in others to the type of measure (Geurs & van Wee, 2004). Handy and

Niemeier (1997) credited Igram (1971) with developing gravity-based measures, whereas Geurs

and van Wee (2004) credited Ingram (1971) for being the first to develop cumulative

opportunities measures under the name integral accessibility. (Both mean the same thing.) Pooler

(1995) argued that accessibility measures have a longer history than Allen, Liu, and Singer

(1993) documented. The literature on the whole better supports the former. These differences

highlight the variations and make understanding accessibility challenging for practice. For

example, Handy (2005) found that planners did not correctly distinguish between the meaning of

accessibility and mobility in transportation plans. For the record, mobility is defined as the

ability for movement (Handy, 2005).

Understanding accessibility begins with a discussion of travel demand (Handy &

Niemeier, 1997; Hanson, 1995). Travel is theoretically derived from a desire to meet basic needs

by reaching various opportunities (Koenig, 1980). For example, Hanson (1995) reported that less

than one percent of all trips made in the United States were for leisure. The remaining trips were made to work, shop, or attend school (Koenig, 1980).

Measuring accessibility is dependent on the scale of measurement. The most widely-used scale is place-based, which is grounded in traditional geographic theory of distance measures (Miller, 2007). A simple explanation for distance measures is that opportunities nearby are likely to be substituted for similar opportunities farther away out of convenience (Krizek, 2005; Levinson, 1998; Handy, 1993; Gur, 1971). Over time, the complex relationships with people and their activities have resulted in place-based measures being thought of as "incomplete" (Miller, 1999; Miller, 2005; Miller, 2007). Technology allows people to participate in activities without physically being present, or "telepresent." Home-schooling, telecommuting to work, and online shopping are telepresent activities (Miller, 2005). Person-based measures are theoretically suited for measuring "telepresent" activities (Miller, 2005; Miller 2007) because they account for the individual's movement in "space and time" (Miller, 2005, p. 73) in both the "real and virtual world" (Miller, 2007, p. 504). They are not necessarily viewed as a replacement of place-based measures. Instead, person-based measures complement place-based measures (Miller, 2005; Miller 2007).

No matter the method used to measure accessibility, Miller (1999) wrote that accessibility measures should theoretically be "rigorous, realistic, and easily computed" (p. 2). Geurs and van Wee (2004) created a rubric for evaluating accessibility measures that is useful for comparing their strengths and weaknesses, shown in Table 2.2 at the end of this chapter. In practice, accessibility measures do not fulfill all of the evaluation requirements. In cases where the models are simple, they may not realistically measure temporal constraints or a transportation project's true impact on accessibility. Complex measures may better model behavior and new

technology; however, they require extensive data and technical expertise to understand and communicate the results (Geurs & van Wee, 2004). The complexity of accessibility analysis is even more evident in the range of variables used over the years. Accessibility has been measured as travel outcomes, such as mode choice and trip generation. It has also been measured in terms of land use, such as land use density and sidewalk connectivity (Krizek, 2005).

Despite the semantic differences, the mathematical formulas have consistently remained the basic DNA of accessibility analysis. Each evolution in a formula has been designed to better account for the complexity of travel (Miller, 2005; Geurs and van Wee, 2004). Of course, critics continue to argue that the changes are not adequate enough to accurately model travel behavior and technology advances (Krizek, 2005; Miller, 2005; Primerano & Taylor, 2005; Miller, 2007). It may be that the best takeaway in all of this is that the method used to measure accessibility is dependent upon the research objective and constraints.

Four primary types of measures are discussed: gravity measures, cumulative opportunities, utility-based measures, and time-space geography. Another name for cumulative opportunities is integral accessibility and contour measures (Geurs and van Wee, 2004; Ingram, 1971). Cumulative opportunities are typically gravity-based, mathematical formulas. Gravity and cumulative opportunities are calculated on a place-based scale. Conversely, utility-based and time-space geography measures are calculated on a person-based scale.

Gravity Measures

The gravity model for calculating accessibility is derived from Newtonian Gravitation. Gravity-based accessibility measures the potential attraction between an origin and destination (Geurs & van Wee, 2004). It assumes that the number of opportunities is directly proportional to

accessibility, and the cost to travel is inversely proportional to accessibility (Miller, 2005). The earliest known accessibility measure comes from William J. Reilly's Law of Retail Gravitation (Stewart, 1948) on the flow of goods and services between towns. The automobile was a new technology, and Reilly (1931) wondered if "Mrs. Blank, who buys her staple groceries at a neighborhood store, may be willing to motor 100 miles or more if she thinks she can find a hat that she likes" (Reilly, 1931, p.3). The law, a result of three-years of study, is comprised of two rules. Trade growth is directly proportional to population growth, and trade is inversely proportional to the squared distance of a town to a city (Stewart, 1948; Reilly, 1931).

Subsequent development of theory and application continued to be adapted from Newtonian Gravitation. For example, Stewart (1948) derived "The Formal Laws of Demographic Gravitation" (p. 34) from Newton's formulas. Newtonian Gravitation defines the force between two masses mathematically by equation (1). In social science, Stewart (1948) called the attraction between two groups "demographic force" and equation (1) became equation (2). Stewart (1948) made other adaptations from Newton's work. Mutual energy between two masses was named demographic energy. Equation (3) then became equation (4). Gravitational potential essentially remained unchanged but was renamed demographic potential, which is illustrated by equation (5) (Stewart, 1948).

$$F=G(M_1*M_2)/d^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

$$F=(N_1*N_2)/d^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

$$E=G(M_1*M_2)/d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

$$E=G(N_1*N_2)/d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(4)$$

$$V_n=G*M_n/d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots....(5)$$

Where, G is the gravitational constant, M is mass, d is distance, and N is a population group.

Hansen (1959) may have specified the first operational definition for accessibility: the "potential [number] of opportunities for interaction" (p. 73). At this point, the measurement of accessibility became more nuanced. Prior, the exponent value was defined as *unity* (Stewart, 1948), but newer research found that the exponent value is dependent on trip types (Hansen, 1959). For example, the exponent value was higher for social trips than for work trips because people were willing to travel farther to work than to socialize (Hansen, 1959). Another important adjustment made to the model was that geographic separation was no longer thought of as the only impendence. Travel time and later monetary costs to travel would later be incorporated into future measures (Scott & Horner, 2008; Krizek, 2005; Handy, 1993; Dalvi & Martin, 1976; Ingram, 1971; Hansen, 1959).

Cumulative Opportunities

Cumulative opportunities measure has also been called contour measures and integral accessibility (Geurs & van Wee, 2004; Ingram, 1971). It is a summation of accessibility measures from one origin to all possible destinations, as illustrated in equation (6) (Handy & Niemeier, 1997; Ingram, 1971).

$$A_i = {}_i\sum_{j=1}^{n} a_{ij} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(6)$$

Where, A_i is the sum of accessibility measures, and a_{ij} is the relative accessibility of point *j* to *i* derived from the gravity model's basic principles of attractiveness (Ingram, 1971).

Several methods for calculating a_{ij} include (but are not limited to) the straight line distance between two points (7), the reciprocal function (8), and the negative exponential function (9).

$$a_{ij}= (\textstyle\sum_{j=1}^{n} d_{ij})/n \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(7)$$

$$a_{ij}=100*d_{ij}^{-k}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(8)$$

$$a_{ij}=100*e_{ij}^{-d}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(9)$$

Where, d is distance between point i and j and k is a parameter measure (Ingram, 1971).

Cumulative opportunities measures were first used by Ingram (1971) and Wickstrom (1971) (Geurs & van Wee, 2004; Handy & Niemeier, 1997). Another early use is Wachs and Kumagai (1973), who studied regional employment accessibility in Los Angeles County. In addition, Black and Conroy (1977) calculated an accessibility index for male and female employment opportunities in Sydney, Australia. Guy (1983) compared results of cumulative opportunities measures to other methods to analyze local shopping convenience in Reading, England. A more recent use is from Kuby, Barranda, and Upchurch (2004), who tested the influence travel times from one light rail station to all other stations on ridership.

Cumulative opportunities and gravity measures share strengths and weaknesses. Both are easy to calculate, interpret, communicate, and operationalize. On the other hand, they do not account for barriers between points that impede movement. Neither measure explains individual perceptions and preferences for travel, capacity restrictions to reach opportunities, the interaction between land use and a transportation system, and temporal constraints (Geurs & van Wee, 2004; Ingram, 1971).

Utility-Based Measures

Utility-based measures theoretically complement gravity-based models. As the name suggests, the measure assumes people maximize their utility when making travel decisions. Geurs and van Wee (2004) identified two types of utility-based accessibility models: logit and entropy models. Pertaining to the first, mode choice is calculated using a binomial or multinomial logit model (10). The logsum of the mode choice model's denominator is considered a summary measure describing desirability of all the choices available to a transportation user. It is the formula for measuring accessibility (11) (Krizek, 2005; Geurs & van Wee, 2004; Handy & Niemeier, 1997).

$$P(\text{mode}|C_n) = e^{Vk}/[\ \textstyle\sum_{k=1}^{n} e^{Vk}]\dots\dots\dots\dots\dots\dots\dots\dots(10)$$

$$A_i = \text{logsum}[\textstyle\sum_{k=1}^{n} e^{Vk}]\dots\dots\dots\dots\dots\dots\dots\dots(11)$$

Like the logit model, the entropy model has not been widely used. Martinez (1995) and Martinez and Araya (2000) derived a doubly-constrained entropy model based on work by Williams (1976) (Geurs & van Wee, 2004). Gravity and cumulative opportunities measures summarize accessibility between origins and destinations. The doubly constrained entropy model measures the transportation system's user's benefits per trip generated (12), trip attracted (13), and trip between the origin and destination (14). The benefits calculated are similar between the logsum model. The primary difference is the balancing parameter in the front portion of the equation (Geurs & van Wee, 2004).

$$A_i = (-1/\beta)\ln(a_i)\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(12)$$

$$A_j = (-1/\beta)\ln(b_j)\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(13)$$

$$A_i = (-1/\beta)\ln(a_i b_j)\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(14)$$

Time-Space Geography

Time-space geography incorporates temporal and geographic context on a person-based scale. Hägerstrand (1970) first discussed space-time geography to account for how individual identity influences decisions and make up for the deficiencies in traditional econometric models (Yu & Shaw, 2007; Hägerstrand, 1970). Time-space geography operates on a three-dimensional coordinate system comprised of two spatial dimensions and a third temporal dimension (Yu & Shaw, 2007). Two concepts derived from time-space geography are the time-space path and time-space prism. Time-space path traces individuals' movements as a linear trajectory on a three-dimensional coordinate system. Time-space prism operates within continuous space on a three-dimensional coordinate system. Both assume that individuals' movements have a beginning (birth) and end (death) and are limited by three types of constraints: capability, authority, and coupling (Yu & Shaw, 2007; Miller, 1999; Hägerstrand, 1970).

Capability constraints are physical limitations, barriers, needs, and the availability of resources. Sleeping, eating, and car ownership are examples of capability constraints. Authority constraints are societal and institutional rules that preclude participation in an activity or prevent movement. Examples are the hours in which a business is open and a military base that limits access. Coupling constraints are social interactions with established rules for movement, such as athletic events and professional conferences. In summation, capability and authority constraints determine if an individual can participate in an activity, and coupling constraints specify the requirements needed for the interaction. All three types of constraints operate within a spatial and temporal context (Yu & Shaw, 2007; Golledge & Stimson, 1997; Hägerstrand, 1970)

Miller (1999) derived a set of time-space geography measures from the axiomatic framework for formulating attraction-based accessibility measures (15) developed by Weibull

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(1976) and Weibull (1980). Miller (1999) then argued that the methodology was "rigorous, realistic, and easily computed" (Miller, 1999, p. 23). Geurs and van Wee (2004), who summarized the theoretical strengths and weaknesses of each measure (Table 2.3), countered that a couple of problems arise with Miller (1999). First, the methodology is not easily operationalized. Second, the model is difficult to interpret and communicate to policymakers and citizens. Those two problems limit time-space geography's practical application in transportation planning (Geurs & van Wee, 2004).

$$AM_3(\mathrm{x}_i, \mathrm{x}_k, \mathrm{x}_j) =$$

$$\max\{k|a_{k.}>0, T_K>0\}[0, \mathrm{EXP}[\lambda((\boldsymbol{\alpha}/\lambda)\ln a_k + (\beta/\lambda)\ln(t_j - t_i - t(\mathrm{x}_i, \mathrm{x}_k, \mathrm{x}_j)) - t(\mathrm{x}_i, \mathrm{x}_k, \mathrm{x}_j))] \quad (15)$$

Where, AM_3 is the attraction-based accessibility measure of an individual's accessibility to maximum location benefit, with the transformed distance function defined by $t(\mathrm{x}_i, \mathrm{x}_k, \mathrm{x}_j)$ (Miller, 1999).

Conclusion

Beginning with Reilly (1931), accessibility has evolved to become an important but underutilized concept in transportation planning (Wachs & Kumagai, 1973). A widely-used definition of accessibility is that it is relationship between transportation and land use. Thus, a transportation system's ability to facilitate the ease of movement between opportunities for all travelers has implications. The middle class can afford to locate where they want to, but they spend more time commuting. On the other hand, transit dependent populations have limited accessibility to opportunities.

If the published literature is any indication, an issue with accessibility analysis is that varying perspectives make it difficult to clearly communicate a best practice. Traditional models

are not adequate for measuring contemporary changes in transportation technology. More recent, complex measures have limited practical application. For example, gravity and cumulative opportunities measures are easier to operationalize, interpret, and communicate than utility-based and time-space geography measures. At the same time, utility-based measures account for travel behavior and preferences, and time-space geography is theoretically best for measuring individual and temporal constraints. Time-space geography is limited in practice because it is data intensive and complex (Geurs and &van Wee, 2004). Ultimately, an ideal measurement may never exist. The takeaway may be that the measurement used is what best fits the research problem and need. No matter which method is used, researchers must clearly communicate results in a language easily understood for mass consumption to best serve the general public (Koenig, 1980; Pirie, 1980).

Table 2.1. Accessibility Measures Identified in the Literature.

Literature	Accessibility Measures
Handy and Niemeier (1997) **Krizek (2005)**	Gravity Cumulative opportunities Utility-based
Miller (1999)	Constraints-oriented Attraction Benefit

Geurs and van Wee (2004)	Infrastructure-based
	Location-based
	    • Contour measure
	    • Potential measure
	    • Adapted potential measure
	    • Balancing factor
	Person-based
	Utility-based
	    • Logsum benefit measure
	    • Time-Space measure
	    • Balancing factor measure

Miller (2005)	Distance-based Topological Attraction Benefit Time geography

Note: Adapted from the sources cited in the table.

Table 2.2. Criteria for Evaluating Accessibility Measures.

Theoretical Criteria	Definition of Theoretical Criteria
Transportation	The measurement is responsive to system changes.
Land Use	The measurement is sensitive to the land use, including the availability of opportunities.
Temporal	The measurement "is sensitive to temporal constraints" (Geurs & van Wee, 2004, p. 130).
Individual	The measurement considers individual needs.
Operationalization	Data are easily available, financially affordable, and practical for use.
Interpretation	The results are easy to understand and communicate.
Economic	There are two types of economic impacts: direct and indirect. Direct economic impacts are travel-cost savings. Indirect economic impacts are productivity gains for private firms.
Social	Social impacts are the degree of accessibility to jobs, food, health care, recreation, etc.

Note: Adapted from "Accessibility and evaluation of Land-use and Transport Strategies: Review and Research Directions," by Geurs, K. T., and van Wee, B., 2004, *Journal of Transport Geography*, 12(2), 127-140.

Table 2.3. Theoretical Strengths and Weaknesses of Accessibility Measures.

Measure	Theoretical Strengths	Theoretical Weaknesses
Gravity Model	• Moderately sensitive to changes in the transport systems and nearby land uses • Easy to operationalize • Can analyze social and economic impacts • Easy to interpret and communicate	• Does not account for individual preferences and temporal constraints
Cumulative Opportunities	• Moderately sensitive to changes in the transport system and nearby land uses • Moderately easy to operationalize • Can analyze social and economic impacts • Moderately easy to interpret and communicate	• Does not account for individual preferences and temporal constraints
Utility-based	• Sensitive to changes in the transport systems and nearby land uses • Moderately easy to operationalized • Can analyze social and economic impacts • Moderately sensitive to individual preferences	• Moderately difficult to understand and communicate • Not sensitive to temporal constraints
Time-space geography	• Sensitive to changes in the transport system and nearby land uses • Sensitive to individual preferences and temporal constraints • Can analyze social and economic impacts	• Difficult to understand and communicate • Difficult to operationalize

Note: Adapted from "Accessibility and evaluation of Land-use and Transport Strategies: Review and Research Directions," by Geurs, K. T., and van Wee, B., 2004, *Journal of Transport Geography*, 12(2), 127-140.

CHAPTER 3:

LITERATURE REVIEW

Research is a Catch-22. It is vital for disentangling propaganda from evidence, but definitive

conclusions can be elusive for intricate topics. For example, Handy (2005) summarized the

complexity of the transportation and land use relationship with this statement: "[T]he more we

know, the less we seem to know" (p. 149). Specifically, the research on rail transit has produced

a range of results; some favorable to implementing rail transit, some not. Meanwhile, many have

criticized planners for overstating light rail's benefits (O'Toole, 2010; Bartholomew, 2007;

Flyvberg, Holm, & Buhl, 2005; Pickrell, 1992; Gomez-Ibanez, 1985). In one example,

economist Don Pickrell (1992) censured the planning profession for overestimating the ridership

benefits and underestimating the capital costs for light rail. Proponents have countered with

range of benefits based on research. Several are that light rail can help reduce congestion

(Versalli, 1996); contribute to improving public health (MacDonald, Stokes, Cohen, Kofner, &

Ridgeway, 2010) and air quality (Versalli, 1996); lower health care costs (MacDonald, Stokes,

Cohen, Kofner, & Ridgeway, 2010); and spur economic development (Landis, Cervero, & Hall,

1991). The debate makes credible research invaluable for guiding the planning process so

planners, policymakers, and citizens can make informed decisions (Bartholomew, 2007).

This chapter reviews existing relevant literature. The first section explores the range of

questions and debates that have been covered in the literature. The second section focuses on the

relationship between rail transit and land use. It summarizes the research questions, hypotheses,

methodologies, and results from relevant studies. Two important themes emerge. One is that land use impacts rail ridership. The other is that rail transit induces land use changes in conjunction with other variables. Both are interrelated to accessibility because rail ridership indicates supportive land uses, and land use characteristics describe the types of opportunities available in a particular area. The final section of this chapter draws basic conclusions using existing evidence.

Rail Transit and Accessibility: Debates within the Literature

Accessibility was defined in Chapter Two as the ease of reaching opportunities. Transportation and land use are related in that the former facilitates movement to the latter where opportunities are located (Handy, 2005; Primerano & Taylor, 2005; Handy & Niemeier, 1997; Huang, 1996; Koenig, 1980; Dalvi & Martin, 1976). The number, quality, and types of opportunities define accessibility; as does the cost in terms of money, time, or distance for reaching those activities (Handy & Niemeier, 1997). A question repeatedly asked in the literature in various forms is if improved accessibility from rail transit will induce land use changes.

Theoretically, the answer is circular (Figure 3.1). After the transportation project is built, "activities should shift toward stations along the rail corridors" (Huang, 1996, p. 19) because accessibility has improved (Huang, 1996; Vesalli, 1996). In turn, the increase in the number of activities near a transportation system creates more demand for the system itself. Good accessibility maintains demand for the system, which transports commuters to activities supported by the appropriate land uses. The cycle continues.
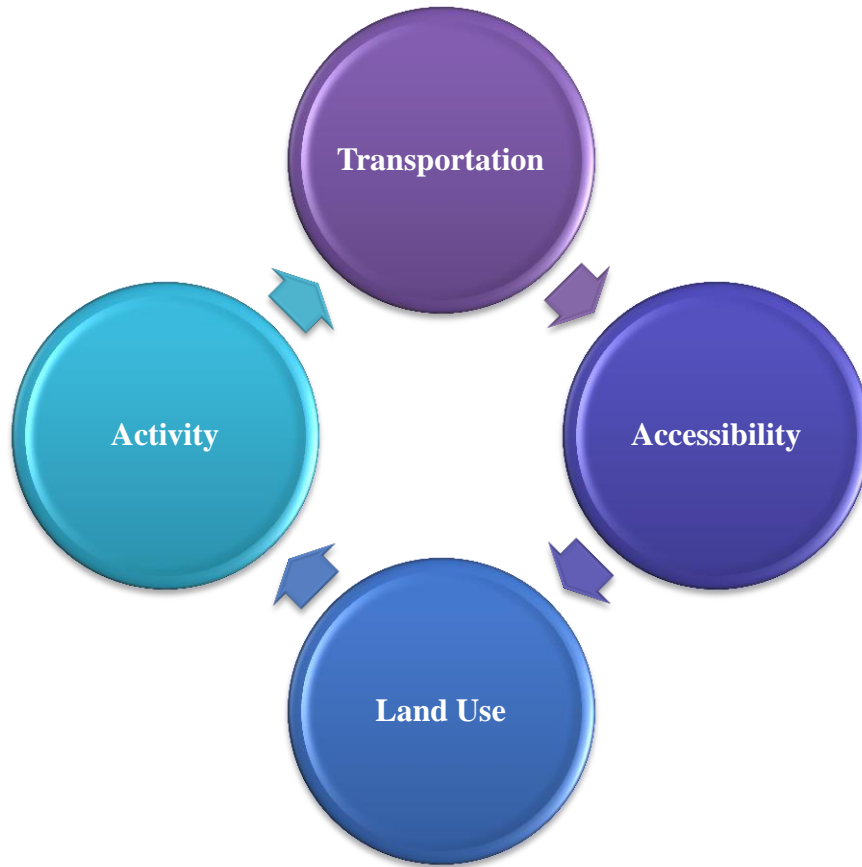
Figure 3.1. The Circular Relationship between Transportation and Subsequent Impacts.

Adapted from " Light Rail and Land Use Change: Rail Transit's Role in Reshaping and Revitalizing Cities," by Higgins, C. D., Ferguson, M. R., and Kanaroglou P. S., 2014, *Journal of Public Transportation,* 17(2), p. 96.

In reality, any shift may be more complex than accessibility theory indicates (Higgins, Ferguson, Kanaroglou, 2014). On one hand, light rail is a tool well-suited for redirecting development to denser patterns such as Transit Oriented Development (TOD), which was defined in Chapter One (Higgins, Ferguson, Kanaroglou, 2014; Cervero, 1984; Knight & Trygg, 1977). Yet the literature indicates that additional conditions need to be present, such as a strong regional growth, positive social conditions along corridors, and supportive land use policies (Higgins, Ferguson, Kanaroglou, 2014). Other considerations are what works in one place may not be applicable to another (Huang, 1996), communities interested in building light rail may

mistake pent up demand for transit use when none exists (Polzin, 1999), and transit alone is not enough to influence urban form (Higgins, Ferguson, Kanaroglou, 2014; Vesalli, 1996; Meyer & Gomez-Ibanez, 1981; Dewees, 1975). To date, numerous questions have been studied, and still it is difficult draw a consistent conclusion on the land use and transportation relationship (Table 3.1) — especially in the context of accessibility (Handy, 2005; Huang, 1996; Vesalli, 1996; Knight & Trygg, 1977). This makes Handy's (2005) aforementioned statement relevant.

Table 3.1. Research Questions asked over the Years.

Prior Literature Reviews	Research Questions Reviewed
Knight and Trygg (1977)	Will transit attract wealth, population, and density? What is necessary to make this happen? What time frame will changes occur within?
Huang (1996)	Can rail transit impact urban development? Why do some rail stations have more development than others?
Vesalli (1996)	To what extent have rapid transit systems actually affected land use? Under what conditions? How can these impacts be characterized?
Handy (2005)	Do highways cause sprawl and higher automobile use? Will light rail facilitate denser development? Can New Urbanism design principles facilitate less automobile dependency?

Note: Compiled from sources identified in the table.

Consider Handy (2005), who summarized research from four transportation relationships: highways cause sprawl; highways result in more driving; light rail facilitates higher urban densities; and the adoption of new urbanism reduces automobile use. The findings were not always simple. For the first relationship, Handy (2005) found that literature generally shows that

highways redistribute growth, not cause it (Handy, 2005; Cervero, 2003; Hartgen & Curley, 1999; Boarnet, 1998). Evidence suggests that while new highway construction facilitated more driving, new highway construction does not create the demand in itself (Handy, 2005; Cervero, 2002; Noland & Lem, 2002). When it comes to light rail, urban densities will increase near the system, but only in conjunction with local land use policies, public support, and strong regional growth (Handy, 2005; Cervero & Duncan, 2002; Knaap, Ding, & Hopkins, 2001). Finally, New Urbanism design principles that characterize TOD impacted driving demand (Handy, 2005; Ewing & Cervero, 2001; Cervero & Kockelman, 1997; Newman & Kenworthy, 1989; Pushkarev & Zupan, 1977). How much the driving reduction was a result of self-selection was still an unanswered question (Handy, 2005).

Rail Transit's Influence on Accessibility

Relevant transit research has mostly been confined to three relationships: rail transit and real estate values, rail transit and ridership prediction, and rail transit and congestion (Table 3.2). Many of the conclusions are typically one of two things. The first is that land values increase after a new transit line is introduced to a place in anticipation of better accessibility. The second is that ridership is highest in denser urban areas and lowest in sprawling suburban areas, presumably because accessibility to transit is better in the former setting. As discussed in Chapter One, the literature does not always do a good job of differentiating between the types of rail modes. For example, light rail, high speed rail, and commuter rail are not the same. Capacity across distances varies for each, so an assumption is that their impacts differ too (Kuby, Barranda, & Upchurch, 2004). Thus, this literature review summarizes the research on rail transit and specifically light rail when possible.

Table 3.2. Research in Chronological Order.

Authors	Study Type	Findings
Pushkarev and Zupan (1977)	Cross-sectional	Transit use increases as residential and employment densities increase.
Newman and Kenworthy (1989)	Cross-sectional	Gasoline consumption decreases as land use density increases.
Kockelman (1997)	Cross-sectional	Variables such as gender, distance, and employment status are better predictors of mode choice than accessibility.
Cervero and Kockelman (1997)	Cross-sectional	Density, diversity, and distance influence mode choice.
Cervero and Landis (1997)	Longitudinal	Land use changes around BART are not uniform.
Cervero (1994)	Longitudinal	Property values increase near light rail with the presence of public-private partnerships.
Knaap, Ding and Hopkins (2001)	Longitudinal	Property values increase within half mile of light rail station after TOD is announced.
Cervero and Duncan (2002)	Longitudinal	Property values increase near light rail.
Cervero et al. (2004)	Cross-sectional	Land use density, diversity, and design influence rail ridership.
Kuby, Barranda, and Upchurch (2004)	Cross-sectional	Employment and accessibility influence average weekday boardings for light rail.
Joshi, Subhrajit, Goran, Crittenden, and Ke (2006).	Longitudinal	Population growth was limited or declined in the build light rail scenario.
Xie and Levinson (2009)	Longitudinal	Streetcar preceded land development.
Atkinson-Palombo (2010)	Longitudinal	Supportive overlay zoning influences land values near light rail stations.

Table 3.2 (Continued). Research in Chronological Order.

Authors	Study Type	Findings
King (2011)	Longitudinal	Developers built New York City subway where they perceived ridership demand to be strongest.
Golub, Guhathakurta, and Sollapuram (2012)	Longitudinal	Property values rose near light rail.
Ratner and Goetz (2013)	Longitudinal	Land use changes are apparent near light rail stations.
Bhattacharjee (2013)	Longitudinal	Congestion did not improve, but higher land use densities occurred near light rail corridors.
Shen (2013)	Longitudinal	Commuter rail induced land use changes more so than light rail.
Hurst and West (2014)	Longitudinal	Proximity to light rail stations was not related to land use changes.

Note: This table was compiled from the sources cited in the table.

Historical Evidence

Mentioned earlier, the relationship between land use and transportation is fundamental to accessibility. The latter facilitates movement to the former where opportunities are located. Accessibility is therefore important to the regional distribution of population and employment opportunities (Xie and Levinson, 2009). Historical studies are a window into changing land use patterns as transportation technology evolved. As discussed in Chapter One, light rail is a descendent of the streetcar, which peaked in United States at 72,911 in 1917. By 1948, the number of lines fell 75 percent to 17,911 (Jackson, 1985). The streetcar era peaked in the Twin Cities of Minneapolis and St. Paul between 1919 and 1925, with more than 200 million annual passengers. By 1931, 523 miles of track had been built (Xie & Levinson, 2009).

Xie and Levinson (2009) studied spatial distribution near streetcar lines during that era in the Twin Cities. They tested two hypotheses. First, streetcar lines preceded residential density growth in places served by the streetcar. Second, residential density was highest within walking distance to stations where accessibility to the line was best. Historic residential and streetcar network data and residential parcel data was collected for the time period of 1900 to 1930 from the Metropolitan Council. Xie and Levinson (2009) used Granger causality analysis to test their hypotheses. Two time-series regression models were estimated. The dependent variables were residential and streetcar line density. Independent variables included residential density, streetcar line density, total residential area, distance to the nearest downtown, and the lagged change in streetcar line density. The results showed that streetcar lines in the Twin Cities preceded residential development, and residential densities declined as the distance from streetcar lines increased. Xie and Levinson (2009) also speculated that other "forces" affected land development. Among them, streetcar technology was the "superior" technology and a monopoly during its peak, and a good real estate market most likely supported new development (Xie & Levinson, 2009).

King (2011) wrote that transportation infrastructure improves accessibility, and as it improves, "land becomes more desirable for development or redevelopment" (King, 2011, p. 19). Admittedly, New York City's subway is not the same as the streetcar, and New York City developed at higher densities than other American cities. However, both transit modes have similarities. Namely, rail transit competed with growing automobile use and highway-supportive policies. For example, Robert Moses notoriety can in part be credited for his ability to develop the region's road system while not supporting transit (Caro, 1974). Between 1915 and 1937,

New York City's automobile registrations increased approximately 1,464 percent from more than 39,000 to more than 610,000 (King, 2011).

That is where the similarities end for King's (2011) study did not yield similar results. To test the theoretical aspects of accessibility he wrote about, King (2011) posed two contradictory hypotheses. First, New York City's subway expansion came before residential growth. Second, land growth took place before subway development. If the first hypothesis proved statically significant, then it could be argued that New York City's land use was dependent upon a transportation system. If second was statistically significant, then evidence better supports the premise that land use determines transit demand.

Parcel data from the New York City Primary Land Use Tax Output (PLUTO) were combined with subway station and line data. The study area was defined by a half mile radius around subway stations. This distance is based on conventional TOD planning (Dittmar & Poticha, 2004). A set of time-series data was used to estimate Granger causality models. Dependent variables included residential, commercial, and overall station area densities. Independent variables included distance from city hall, and changes in city population, residential, commercial, and station area densities. King (2009) also conducted Spearman's rank correlationship tests to determine if subway expansion came before land use changes. The study found that commercial densities were correlated to increased station densities but not the subway itself.

Accessibility: Land Use Influence over Transportation

Research on contemporary rail transit is also mixed in its results. One early study is Pushkarev and Zupan (1977), who have been cited more than 409 times. Their book, *Public*

Transportation and Land Use Policy, is comprised of several studies, including one on the relationship between transit demand and land use. Using linear regression and United States Decennial Census Data, they found that transit demand in New York City rose with increasing residential densities beginning at seven units per acre. At 50 units per acre, transit became the preferred choice over the car. At 85 units per acre, car use was almost non-existent. In addition, they found that transit use was highest in cities where the downtown commercial development was densest (Pushkarev & Zupan, 1977).

Newman and Kenworthy (1989) sparked a debate that gasoline consumption is correlated to urban density (Handy, 2005). They compared data on per capita fuel consumption and population and employment densities from 32 cities in North America, Australia, Europe, and Asia in 1980. The primary finding from Newman and Kenworthy (1989) was that gasoline consumption decreases as population and employment densities rose. Their conclusion was that land use density is a predictor for transportation demand. The study's results has provided a strong defense for New Urbanism principles that promulgate policies for denser land use to encourage more walking, bicycling, and transit use (Handy, 2005). An important criticism, though, is that the Newman and Kenworthy (1989) study was too simplistic, and vital relationships were ignored. Their study did not include household incomes' and gasoline prices' effect on consumption and income's relationship to land use (Breheny, 1995). For example, poor urban areas defined by high densities and pedestrian-centric environments are necessary because its residents cannot afford to drive.

While Newman and Kenworthy (1989) drew valid criticisms, other substantive studies have supported the belief that New Urbanism design principles facilitate multimodal travel. In a study on the San Francisco Bay area, Cervero and Kockelman (1997) tested hypotheses that

density, design, and diversity of land uses influence household trip rates, mode choice (i.e., walking, bicycling, public transit, or car), and trip choice. Land use and 1990 travel survey data came from the Association of Bay Area Governments. Dependent variables included personal vehicle miles of travel and mode choice. Density was measured as an accessibility index, diversity of land uses in part as a proportion of residential and commercial units per acre, and design as neighborhood characteristics. Cervero and Kockelman (1997) used multiple regression analysis to estimate independent variables' influence on personal vehicle miles of travel and binomial logit analysis to predict vehicle and non-vehicle travel. Their findings were that pedestrian-friendly environments affected travel decisions and outcomes. For example, people living in mixed-use residences characterized by land use density drove 11.2 fewer personal VMT per household, *ceteris paribus* (Cervero & Kockelman, 1997).

Kockelman (1997) posed two hypotheses. The first is relevant to this study. It states that land use intensities, balance, and mix explain travel behavior. The second is that they reduce vehicle kilometers traveled (VKT). Data from the 1990 San Francisco Bay Area travel surveys were used to estimate multiple regression and logit models. Dependent variables included household VKT, car ownership, and mode choice. Independent variables included household size; car ownership; income; land use mix; trip distance; employment; gender; and accessibility, calculated as a gravity model (Wachs & Kumagai, 1973). The explanatory power for accessibility was highly significant at the 0.01 level in predicting mode choice within a thirty-minute travel time radius. Accessibility's explanatory power was not as strong as socioeconomic variables such as gender, geographic variables such as distance, and employment status (Kockelman, 1997).

Cervero et al. (2004) tested the hypotheses that density, diversity, and design influence

ridership demand. Data came from the 2000 Decennial United States Census. They used

Geographic Information Systems (GIS) and bivariate regression analysis to estimate residential

and employment densities' influence on ridership within one mile of 129 San Francisco Bay area

rail stations for heavy rail (BART), commuter rail (Caltrain and Altamount Commuter Express),

and light rail (Valley Transportation Authority). The following summarizes their findings:

- Density was measured as residential density. Ten units per acre resulted in a 24.3 percent

  probability that rail would be the preferred transportation mode, 20 units per acre was a

  43.4 percent, and 40 units per acre was 66.6 percent.

- Diversity was measured as employment density. Five retail/service jobs per acre resulted

  in an 11 percent probability that rail would be the mode choice, 20 jobs per acre was 26.5

  percent, and 60 jobs per acre was 52.1 percent. However, after 80 jobs per acre, rail's

  share as mode choice peaks.

- Design was measured as block size. Six acres yielded a probability of 11.2 percent that

  rail was used for a work commute. A block size of three acres resulted in a probability of

  48.2 percent (Cervero et al., 2 004).

Kuby, Barranda, and Upchurch (2004) estimated a multiple regression model to test

variables that influence light rail ridership in the United States. They collected data from a

variety of national and local agencies for 268 stations in nine cities across the United States for

the year 2000. Ridership measured as average weekday boardings was the dependent variable.

Seventeen independent variables were placed into five categories: traffic generation, land use,

intermodal connection, citywide, network infrastructure, and socioeconomic. Total population

within walking distance of a light rail station is an example of a traffic generation/land use

variable. Accessibility, measured as average travel times from one station to all other stations, is an example of network infrastructure. It is also an example of a cumulative opportunities accessibility measures. The findings were that ridership decreased by 1,872 as travel time increased, *ceteris paribus*. Bus and airport connections were best for improving ridership, with it increasing by 123 and 915 respectively, *ceteris paribus*. Line access to employment opportunities also influenced ridership, with average weekday boardings increasing by 1,301, *ceteris paribus* (Kuby, Barranda, & Upchurch, 2004).

Accessibility: Rail Transit Influence on Land Use

The evidence on transit's ability to induce land use changes is not a clear cut as it is for land use's impact on transit use. Numerous studies have found that rail transit can have a positive effect on land use when accessibility to rail transit improves (Chatman, Tulach, & Kim, 2011; Atkinson-Palombo, 2010; Hess & Almeida, 2007; Knaap, Ding, & Hopkins, 2001; Cervero, 1994), while other studies have found that land use or building growth stays the same (Hurst & West, 2014; Shen, 2013; Hess & Almeida, 2007; Joshi, Himanshu, Subhrajit, Goran, Crittenden, & Ke, 2006). Cervero (1994) tested the public-private partnership relationship to commercial real estate at station locations. Independent variables included ridership, unemployment, and the existence of a public-private partnership in developing five stations from Atlanta's Metropolitan Atlanta Rapid Transit Authority and Washington, D.C.'s, Metrorail between 1978 and 1989. The dependent variable was average office rent. Cervero (1994) found that average rent rose approximately 3.17 dollars per square foot in places where public-private partnerships existed, *ceteris paribus*.

Knaap, Ding and Hopkins (2001) studied property value changes within walking distance (measured as half a mile) of light rail stations after planned TOD was announced in Washington County, OR. No one hypothesis was posed. Data from the Regional Land Information System from Metro, the Washington County Tax Assessor's files, and the Oregon Department of Education was used to estimate hedonic regression models. The dependent variable was residential parcel data on sales price per acre between January 1992 and August 1996. Twenty-two independent variables were tested. Distance to the transit station impacted land values the most. Land prices increased 36 percent per acre within half a mile of a station after TOD was announced, *ceteris paribus* (Knaap, Ding, & Hopkins, 2001).

Atkinson-Palombo (2010) investigated overlay zoning's impact on single-family housing and condominium values near light rail stations in Phoeniz, Arizona. The study posed the following four hypotheses:

1) Various types of land use will exist along the rail corridor.

2) Some communities will resist overlay zoning more so than others.

3) Parking will not be present in already dense, mixed land uses.

4) Land values will increase more at Walk-and-Ride stations) than Park-and-Ride stations.

Data came from a variety of sources. Land parcel sales between 1995 and 2007 were from the Maricopa County Assessor's Office. Municipal overlay zoning were from the Cities of Phoenix and Tempe and the transit agency Valley Metro. Atkinson-Palombo (2010) estimated a hedonic pricing model. The dependent variable was sales price. Her independent variables ranged from neighborhood characteristics, such as lot size and living space, and light rail characteristics, such as Walk-and-Ride or Park-and-Ride stations. The findings suggested that the existing land use mix influences land values near stations. For example, single-family housing and condominium

values increased by six percent and 20 percent respectively at Walk-and-Ride stations, *ceteris paribus*. In the presence of overlay zoning supportive of TOD, condominium prices increased by about 37 percent, *ceteris paribus*. In other words, communities where land values are most likely to increase are ones that "evolve" into TOD or take on qualities of TOD (Atkinson-Palombo, 2010).

Golub, Guhathakurta, and Sollapuram (2012) also studied Phoenix's light rail. They asked the question of how property values are influenced by location to light rail. Property sales price data came from W.P. Cary School's repeat sales database. They estimated four hedonic regression models for four different property types: single-family homes, multifamily homes, commercial, and vacant properties. The parcel's sales price was the dependent variable. Independent variables included building characteristics, such as living space; proximity to light rail; and implementation phase, such as National Environmental Protection Act review period. Their findings on the whole supported the previous two studies: property values rose near light rail.

Cervero and Landis (1997) studied residential and commercial changes during the first 20-year period of the Bay Area Rapid Transit (BART) commuter rail. Using matched-pairs descriptive statistics, their study compared land use changes at BART stations to nearby freeway interchanges. They also estimated a binomial logit model and linear regression analysis to test variables that potentially explained land use changes. Data came from a variety of sources including the United States Census Bureau, property-tax records, and travel surveys (Cervero & Landis, 1997). Ultimately, BART's influence on land use was not what planners had envisioned (Cervero & Landis, 1997). Some stations areas experienced modest increases in commercial and residential densities, others none.

For example, the Cities of Oakland and San Francisco had the largest commercial growth increases at 28 million square feet and 1.6 million square feet, respectively. On the other hand, commercial and residential growth along the Dale City corridor rose less than one percent while growth was the strongest along the highway corridor. Cervero and Landis (1997) wrote that a variety of variables could have contributed to the findings. One is the lack of land availability near rail. Another is allowable land-use mixture. BART moves across different municipalities that have separate zoning codes. In some cases, citizen opposition and local policy may not have allowed development to occur at higher densities (Cervero & Landis, 1997).

Joshi, Subhrajit, Goran, Crittenden, and Ke (2006) modeled future land use impacts from the City of Phoenix's new light rail system using UrbanSim. A hypothesis was not formally posed, but the fundamental question under study was if improved accessibility to transit would influence household location. Research had consistently found that land values rise near rail transit in anticipation of better accessibility (Hess & Almeida, 2007; Knapp, Ding, & Hopkins, 2001; Cervero, 1994). A caveat is that rising land values may indicate gentrification because as land values increase, low-income residents who cannot afford to live there must relocate. UrbanSim is comprised of multiple models: economic and demographic transition model, employment and household location choice model, employment and household mobility model, and a real estate model. Parcel data from the Maricopa County assessor's office, employment data from the Maricopa Association of Governments (MAG) and United States Census data were used to predict future scenarios. Boundary layers came from the Maricopa Association of Governments (MAG). ArcGIS and MySQL were used to parse the data and build a model database (Joshi, Himanshu, Subhrajit, Goran, Crittenden, & Ke, 2006).

The study's authors divided the study area into three zones. Each one had a build and no-build light rail scenario between 2008 and 2015 (Joshi, Subhrajit, Goran, Crittenden, & Ke, 2006). In the three study areas, population increased by about 19 percent, 15 percent, and six percent respectively for the no-build light rail scenarios. The results were mixed for the build light rail scenarios. Population remained essentially unchanged in the first study area. Population increased by approximately 12 percent in the second study area. Population decreased by more than 50 percent in the third study area. The question of light rail and gentrification remained unanswered, though. The third study area is comprised mostly of college students, who are not the typical demographic impacted (Joshi, Subhrajit, Goran, Crittenden, & Ke, 2006).

In contrast, Ratner and Goetz (2013) and Bhattacharjee (2013) found land use changes to be evident near light rail in the Denver region. Ratner and Goetz (2013) did not formally state a hypothesis. Their research investigated land use changes from the late 1990s through 2012. It used Geographic Information Systems (GIS) to measure the amount of changes in terms of population and new building development along light rail corridors and at station areas. In addition, they compared population density in TOD to regional population density and new TOD to regional growth. Data came from multiple sources: Regional Transportation District (RTD), the Denver Regional Council of Governments (DRCOG), and the Center for Transit-Oriented Development Population and Household Density. While the Ratner and Goetz (2013) study is couched theoretically in accessibility, it is unclear how accessibility ties into their results. They calculated a wide range of descriptive statistics to show growth in varying degrees along some corridors and at specific stations. Their results do show that the Denver region has experienced building growth near light rail corridors, but no relationships were tested.

Divided into two parts, Bhattacharjee's (2013) study mostly supports Ratner and Goetz (2013). The first part was a temporal analysis of vehicle miles traveled (VMT) and volume/capacity changes near the light rail corridors. VMT is considered one measure of sprawl, and a reduction in VMT can indicate that light rail is facilitating inward growth. In addition, both measures are useful for evaluating how light rail impacts nearby highways and roads. Bhattacharjee (2013) used data from the Annual Average Daily Traffic and Colorado Department of Transportation between 1992 and 2008 and GIS to quantify changes. It was found that VMT and volume/capacity remained relatively the same. Bhattacharjee's (2013) noted that long-term reductions could still be seen as more extensions are built and the system matures.

In the second part, Bhattacharjee (2013) used city and county data on population, employment, and total building square footage between 1990 and 2010. GIS was also used to analyze land use changes. Bhattacharjee's (2013) hypotheses were that overall growth and commercial, multi-family, and single-family housing grew along the light rail corridors under study (Bhattacharjee, 2013). Using inferential statistics, Bhattacharjee (2013) confirmed the first, second, and third hypotheses but not the fourth. Growth occurred most in mixed developments and remained the same for suburban development (Bhattacharjee, 2013).

Shen (2013) studied four different rail transit systems in the United States that included commuter and light rail: the Orange Line in the Chicago; the Green Line in Washington, D.C.; the D Line in the Denver region; and the Blue, Green, and Red/Purple lines in Los Angeles. The study asked four research questions that examined what internal and external factors influence land use near transit stations. The hypotheses were that rail transit is likely to induce land use changes in neighborhoods with strong economies, and transit impacts vary across cities. Using American Community Survey Census data and employment data from the private vendor

Claritas, Shen (2013) utilized spatial statistics and estimated a series of difference-in-differences (DID) regression models with socioeconomic variables and an accessibility variable. Accessibility was defined as transit access to the total jobs in the metropolitan area.

The findings suggested that commuter rail is more likely than light rail to induce land use changes, and those changes take place in urban areas. Shen (2013) appears to contradict Ratner and Goetz (2013) and Bhattacharjee (2013) because light rail was not statistically related to new development in the Denver Region. It is important to note that the three studies approached their investigations using different methodologies. In addition, Shen (2013) was limited to one suburban corridor whereas the other two included urban corridors. When accounting for these differences, it could be argued that the studies are closer in their findings than realized. Specifically, Bhattacharjee (2013) found that single-family housing that typifies suburban growth was not strong along light rail corridors, and Shen's (2013) results arrived at the conclusion.

More recently, Hurst and West (2014) studied land use changes prior to and after the City of Minneapolis' METRO Blue line was built. Their study asked two questions. First, does the implementation of light rail stimulate significant land use changes; and second, how does it vary spatially? To test the relationship between light rail and new development between 1997 and 2010, they examined 7,635 properties that were within a half mile radius of 12 stations on the corridor divided into three sub-periods. Property data from The Metropolitan Council's Generalized Land Use Survey (GLUS) and the City of Minneapolis' parcel data set was used to estimate four logit models. The dependent variable was growth and no growth, and the independent variables ranged from land use types, such as industrial, to socioeconomic, such as race. They found that proximity to light rail stations was not related to land use changes. At the

same time, Hurst and West (2014) cautioned against a definitive conclusion: "Indeed, casual observation of activity along the line in 2012 and 2013 suggests that substantial changes are taking place now that market outlooks have improved" (p. 70).

Conclusion

This literature review covers a number of evidence-based patterns in the land use and transportation relationship relevant to this thesis. One is that land use density and mixtures influence transit ridership (Kuby, Barranda, & Upchurch, 2004). A second is that desirable land use changes, such as TOD, will not take place without supportive policies that allow for higher densities (Atkinson-Palombo, 2010). A third is that land values near light rail increase in anticipation of better accessibility to transit (Knaap, Ding, & Hopkins, 2001). By definition, an increasing number of jobs and residential units linked together means better accessibility (Dalvi and Martin, 1976; Koenig, 1980; Huang, 1996; Handy & Niemeier, 1997; Handy, 2005; Primerano & Taylor, 2005; Litman, 2012). These patterns indicate that light rail can be a tool for facilitating growth to denser land use patterns and inherently improving accessibility. That said, more research is required to better know how light rail relates to the entire transportation network and if land use changes over time will continue to attract jobs and residents. It is simply not enough to measure the number of building units and floor space built (Ratner & Goetz, 2013) or the responsiveness of the real estate market to light rail's regional introduction (Knaap, Ding, & Hopkins, 2001). Such measures are a good stepping off point for future studies that can explore these questions:

- Can light rail effectively compete with highway projects to induce development?
- What conditions must exist for highways and transit to complement one another?

- What transportation and land use conditions encourage population and job growth?

- How does light rail compare to bus rapid transit in facilitating land use changes?

- What is light rail's explanatory effect on any land use changes that do occur?

- What is the explanatory effect of public policy in conjunction with light rail on population location?

- What household types live near light rail?

- How much does accessibility influence population location near light rail?

With so many questions, it may be that Handy's (2005) statement will always remain true: "[T]he more we know, the less we seem to know" (p. 149) about the transportation and land use relationship. This much is certain: Continual evaluation of light rail systems will undoubtedly be necessary. That is because transportation systems have evolved and changed over the years and will continue to do so to meet society's varying needs. The early 20$^{\text{th}}$ century saw the rise and fall of the streetcar. The automobile grew in popularity, and supportive policies subsidized its use. More people settled outside city centers in suburbs and exurbs as a seemingly endless network of roads were built that connected opportunities over longer distances. New technology now includes autonomous vehicles and hybrid cars and information and communication technologies used for telecommuting as well as light rail, high speed rail, and BRT. Indeed, transportation and the theory of accessibility is becoming more complex and nuanced, making its study a worthwhile endeavor. The next chapter describes a methodology for continual investigation.

CHAPTER FOUR:

METHODOLOGY

This study investigates light rail's relationship to population growth through the prism of accessibility. Specifically, it asks: What transportation and land use conditions encourage the general population to locate near light rail? In addition, this study is an extension of Bhattacharjee (2013), Ratner and Goetz (2013), and Shen (2013) — all studied portions of Denver's light rail. The purpose of this chapter is to explain the study's methodology. The first part describes the study area, poses the research question and hypotheses; and presents the data sources. The second part describes the independent and dependent variables and the statistical models employed to analyze the data. Note that the study is conducted in two parts. The first is a preliminary step that estimates contingency tables and chi-square tests to study population and employment growth as a function of the transportation project. The second part uses linear regression analysis to test the relationship between accessibility and population growth near light rail stations.

Study Area

Like many American metropolises, the Denver region grew outward and not inward during the second half of the 20th century. Seventy-two percent of the population lived in the City of Denver prior to World War II. The highway system was developed and the middleclass moved to the suburbs. The result is a sprawling, automobile-dependent region. By the 21st

Century, only 23 percent of the region's population lived within the City of Denver's boundaries (*BluePrint Denver*, 2002). Today, local policy and political attitudes support a different archetype. Interagency collaboration among the Denver Regional Council of Governments (DRCOG), the Regional Transportation District (RTD), and local governments has resulted in multimodal projects — particularly light rail — garnering national attention. Former Tampa mayor Pam Iorio praised the Denver region in 2007 for its "marriage of land use to rail" (Gedalius, 2007, p. 2), and officials in other places such as Charlotte, NC, and Milwaukee, WI, have called Denver a model of excellence (Gedalius, 2007).

In all, Regional Transportation District serves 2.8 million people and 40 local governments covering 2,340 square miles (Facts and Figures, 2014). RTD built four light rail corridors using a variety of funding sources from federal, local, and private organizations. In 2004, voters from RTD's eight-county service area approved a sales tax increase of 0.4 cents 58 to 42 percent to fund RTD's multimodal program, named FasTracks. In the end, there will be 122 miles of new commuter rail service, three light rail extensions, 60 new rail stations, and 18 miles of bus rapid transit (BRT) (Regional Transportation District, 2013; Gedalius, 2007).

The marriage of land use policy and transit is difficult to accomplish. Planners and policymakers encounter this issue during the planning process and even afterwards when plans and policy are in place. Citizen and/or political opposition can prevent developers with good intentions towards building denser, mixed-use developments such as TOD. For example, the Buckhead Neighborhood Planning Unit in the Atlanta region rejected a proposal for a mixed-use development near a Metropolitan Atlanta Rapid Transit Authority station; a smaller version was built. In Albuquerque, NM, the city council passed a resolution enabling higher density growth

along transportation corridors, only to later reject a new mixed-use development (Levin, Inam, & Torng, 2000).

The Denver region appears to have reconciled those problems — especially when accounting for the size of the region and jurisdictional complexity. The Denver Regional Council of Governments (DRCOG) has nine member counties (Figure 4.1) and 47 participating cities covering approximately 3,608 square miles (Table 4-1). In areas directly impacted by light rail, local policy support has been strong. A good example is *BluePrint Denver: An Integrated Land Use and Transportation Plan* that the Denver City Council adopted as a supplement to the city's 2000 Comprehensive Plan. *BluePrint* (2002) laid out a plan for redirecting growth to urban areas while supporting the expansion of region's transportation choices. The city updated its zoning code in 2010 to allow land use supportive of transit. Meanwhile, suburban cities that include Englewood, Littleton, and Greenwood Village adopted station area plans intended to guide TOD. As of 2013, 27,172 residential units and approximately 12.4 million square feet of commercial property had been built or were under construction along current and future rail corridors (Regional Transportation District, 2013).

New construction near light rail is only one indicator of a land use and transportation relationship, and new development alone does not guarantee that people will live and work there. States such as Florida struggled during the recent recession when housing supply outpaced demand, and news reports told stories of newly-built neighborhoods and condominiums that were ghost towns (Van Sickler, Sokol, & Martin, 2009; Montgomery, 2008). In addition, rail transit does not mean that building growth will occur over the short and medium time periods (Cervero & Landis, 1997). Property values close to light rail corridors have tended to increase after it is built or plans to build it are announced (Chatman, Tulach, & Kim, 2011; Atkinson-

Palombo, 2010; Hess & Almeida, 2007; Knapp, Ding, & Hopkins, 2001; Cervero, 1994). While

rising land values are good for local governments that can benefit from the property taxes, an

issue may be gentrification, or the pricing out of low-to-middle income families (Joshi,

Himanshu, Subhrajit, Goran, Crittenden, & Ke, 2006). If population declines near transit, an

unintended consequence is likely to be declining ridership (Pushkarev & Zupan, 1977). Thus, the

new construction growth may not be the best indicator of population growth.
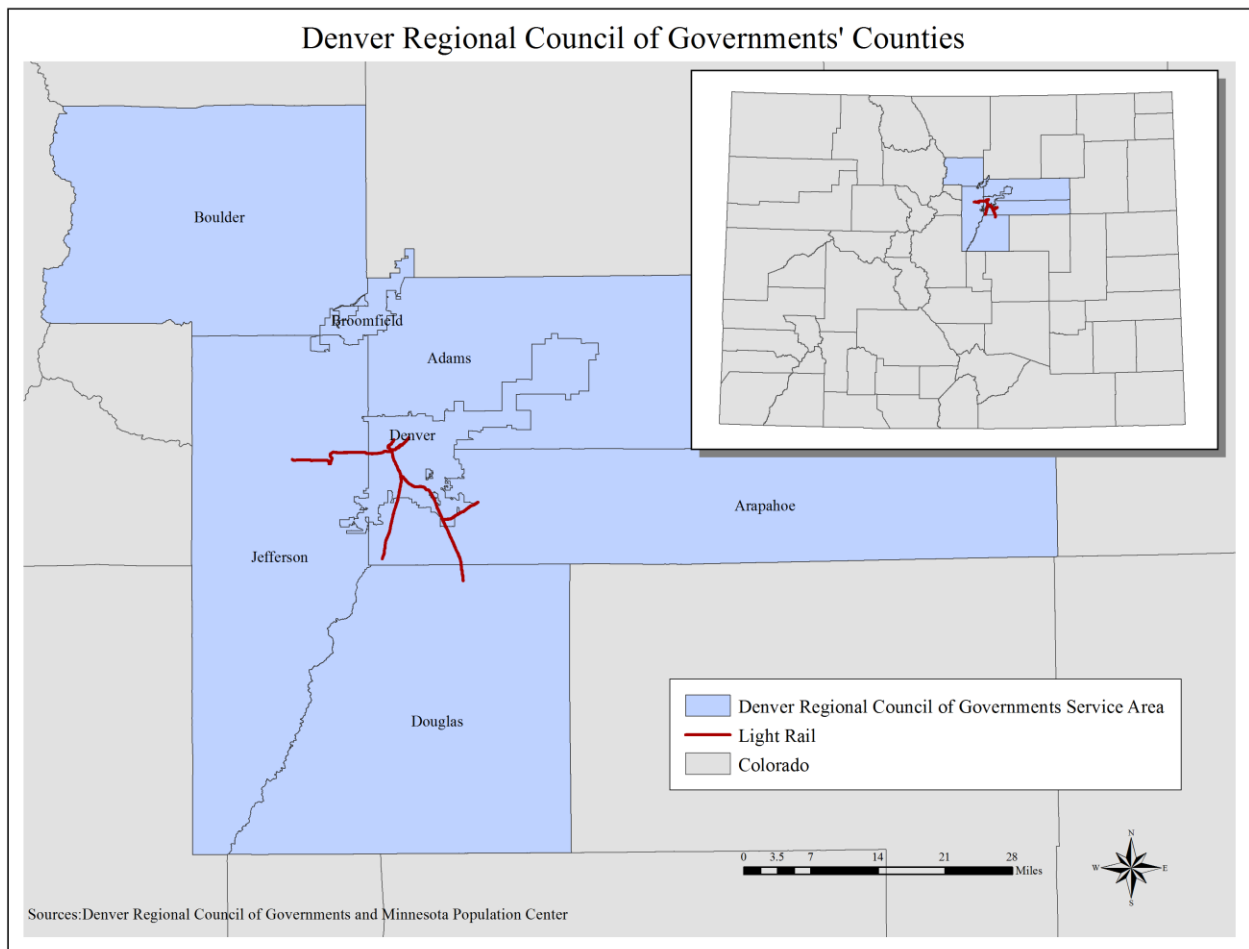

Figure 4.1. Denver Regional Council of Governments Coverage Area.

Map created by author using data from the Denver Regional Council of Governments, 2014,
Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population
Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN:
University of Minnesota 2011.

Table 4.1. Denver Regional Council of Governments Member County Populations per Year.

County	1990	2000	2010	Difference (1990-2010)
Adams	265,038	363,857	441,603	66.62%
Arapahoe	391,511	487,967	572,003	46.10%
Boulder	225,339	291,288	294,567	30.72%
Broomfield	24,638	38,272	54,889	122.78%
Clear Creak	7,619	9,322	9,088	19.28%
Denver	467,610	544,636	600,158	28.35%
Douglas	60,391	175,766	285,465	372.69%
Gilpin	3,070	4,757	5,441	77.23%
Jefferson	438,430	527,056	534,543	21.92%

Note: Adapted from *Colorado: 2010 Summary Population and Housing Characteristics*, by United States Census Bureau, 2012, retrieved from https://www.census.gov/prod/cen2010/cph-1-7.pdf; *Colorado: 2000 Summary Population and Housing Characteristics*, by United States Census Bureau, 2003, retrieved from http://www.census.gov/prod/cen2000/phc-1-7.pdf

Study Corridors

Even though five light rail corridors have opened in the Denver region since 1996, four of the five corridors opened between 1996 and 2010. The fifth is the West Corridor. It opened in 2014 and is beyond the scope of this study. An interstate corridor, I-25, that carries traffic north and south through the Denver region was also incorporated into part of this study. The corridors are described in the following sections.

Central Corridor

The Central Corridor is an urban corridor. It was the region's first light rail corridor to open on October 7, 1994. Light rail on the 5.3 mile corridor operates in Denver County (Figure 4.2). It serves 14 stations and 1,248 Park-and-Ride spaces between the I-25 and Broadway Station and Denver's Five Points north of the Central Business District (CBD). Part of the route operates parallel to I-25 in the City of Denver. Service frequencies range from 7.5 minute headways during off-peak periods to three minute headways during peak periods. RTD used funding comprised of voter-approved bonds, capital reserves, and an existing use tax to build it (Central Corridor Light Rail Line, 2013).

Central Platte Valley Corridor

The Central Platte Valley Corridor is an urban corridor. It opened on April 5, 2002. It operates for 1.8 miles in Denver County (Figure 4.2) and connects Union Station to the Central Corridor near Colfax Avenue in the City of Denver. Light rail along this corridor serves four stations. Service frequencies are 15 minute headways during weekday peak and off-peak periods and more frequent headways during special events. A combination of public and private funding paid for the extension. Sources included the DRCOG, City of Denver, the Denver Broncos and Rockies, and Six Flags/Elitch Gardens (Central Platte Valley Light Rail Line, 2013).

Southwest Corridor

The Southwest Corridor is a suburban corridor. It began operation on July 17, 2000. Light rail operates in Denver and Arapahoe Counties. It extends 8.7 miles from the Central Corridor in the City of Denver to three different suburban cities: Englewood, Greenwood

Village, and Littleton (Figure 4.3). Light rail on this corridor serves five stations, 2,600 Park-and-Ride stations, and a variety of land use typologies. Headways on average range from 7.5 minutes during weekdays and 15 minutes during week nights, weekends, and holidays. The Federal Transit Administration (FTA) funded approximately 67.3 percent of the project. The Federal Government also allowed additional flexible highway-to-transit funding to contribute to the corridor's construction (Southwest Corridor Light Rail Line, 2013).

Southeast Corridor

The Southeast Corridor is a suburban corridor. It was the last of the four corridors in this study to open on November 17, 2006. It operates in Denver, Arapahoe, and Douglas Counties. The corridor is unique because it was a part of an I-25 and I-225 widening project named The Transportation Expansion, or T-REX. Light rail along the corridor extends 19 miles from the City of Denver into five suburban cities: Englewood, Aurora, Greenwood Village, Sheridan, and Lone Tree (Figure 4.3). Fifteen miles of the corridor operates along I-25, and four miles of the corridor operates along I-225. The route serves 13 stations and more than 7,000 Park-and-Ride spaces. Service frequencies range from ten minute headways during week-day peak travel periods to 15 minute headways during off-peak weekday and weekend travel periods. Project funding came from a 1999 voter-approved bond issue and FTA (Southeast Corridor Light Rail Line, 2013).

I-25

I-25 is a control variable for the first part of this study. The interstate dates back to 1958 when an 11.2 mile segment first opened between 48th Avenue and Evans Avenue south of

Denver's CBD. The remaining 289 miles of I-25 was completed eleven years later. The highway

carries travelers through Colorado from the New Mexico/Colorado border in the south to the

Wyoming/Colorado border in the north. The section of I-25 that is the control variable runs north

and south for approximately 20 miles between Denver's Central Business District (CBD) to the

northern boundary of Adams County. It connects suburban cities such as Thornton, Westminster,

and Northglenn to Denver's urban areas. A 6.6 mile section of I-25 that is a part of the study area

was converted over two phases into tolled bus/High Occupancy Vehicle (HOV) lanes in 2001

and 2004. The HOV lanes operate between Downtown Denver and to just north of U.S. 36

(Downtown Express I-25, 2013; Colorado Department of Transportation, 2009).

Table 4.2. Cost to Build Light Rail and Average Weekly Ridership

Corridor	Total Cost	Ridership	Lines
Central	$116.5 million	67,630	C, D, E, F, & H
Central Platte Valley	$47.8 million	12,486[a]	C & E
Southwest	$177 million	26,829	C & D
Southeast	$879 million[b]	41,427	E, F, & H

Note: [a] Ridership number is for 2012, all others are for 2011; [b] only for the light rail transit portion, the T-REX improvement costs that included I-25 improvements totaled $1.67 billion. Adapted from "Central Corridor Light Rail Line: Facts & Figures," by Regional Transportation District, 2013, *RTD*, retrieved from http://www.rtd-denver.com/FF-CentralCorridorLRT.shtml; "Central Platte Valley Light Rail Line: Facts & Figures," by Regional Transportation District, 2013, *RTD*, retrieved from http://www.rtd-denver.com/FF-CentralPlatteValleyLRT.shtml; "Southwest Corridor Light Rail Line: Facts & Figures," by Regional Transportation District, 2013, *RTD*, retrieved from http://www.rtd-denver.com/FF-SouthwestCorridorLRT.shtml; and "Southeast Corridor Light Rail Line: Facts & Figures," by Regional Transportation District, 2013, *RTD*, retrieved from http://www.rtd-denver.com/FF-SoutheastCorridor.shtml.

Figure 4.2. Existing Regional Transportation District Light Rail Transit Corridors.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.

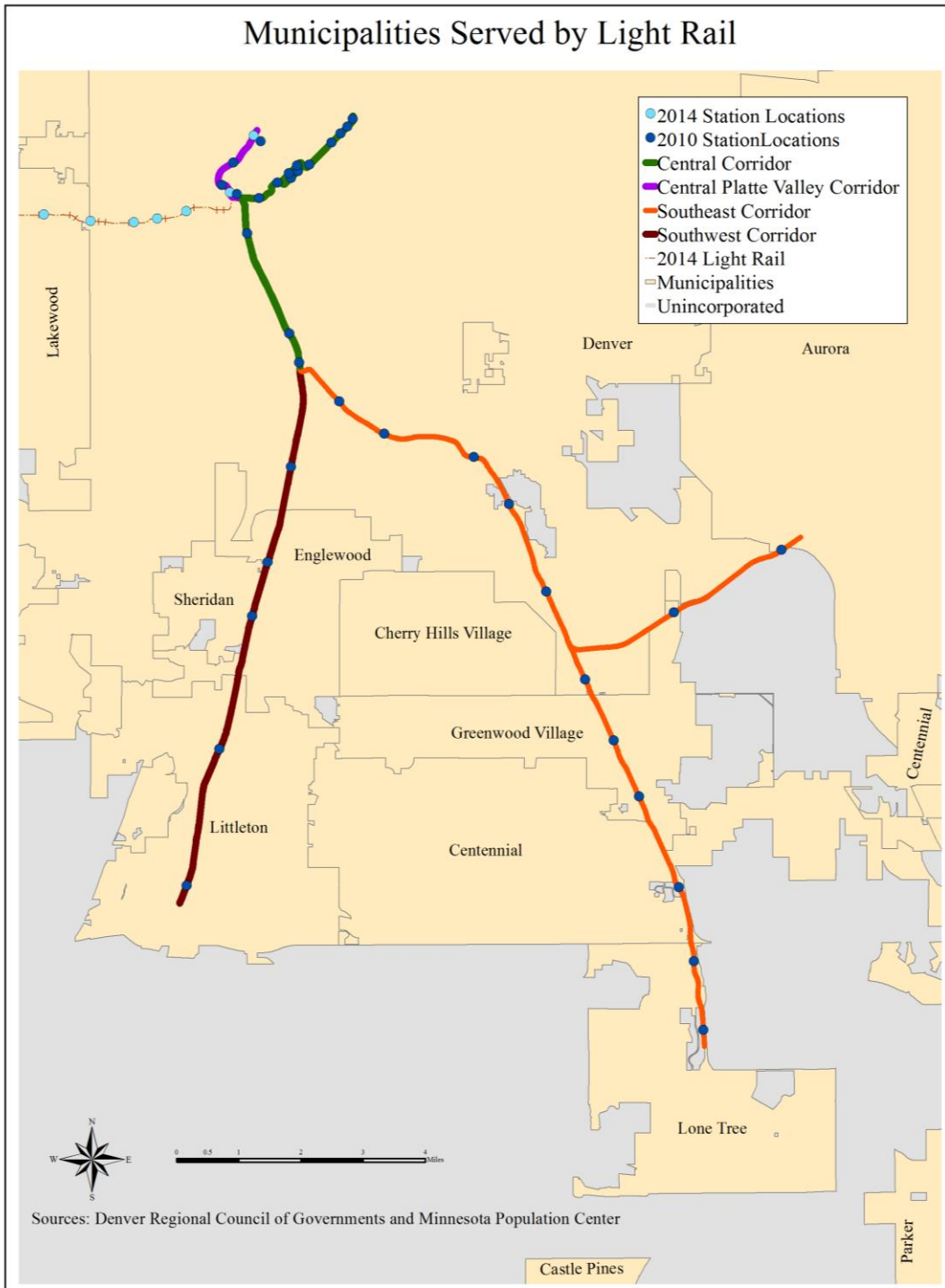**Figure 4.3**. Municipalities Served by Light Rail.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.

Research Question, Hypothesis, and Operational Definition

   This study investigates transportation and land use relationship through the prism of accessibility. Prior research has found population to be correlated to ridership demand. In an era when planners want to mitigate sprawling land use patterns using light rail as a tool, it is important to know if the transportation investment will induce changes over time. Theoretically, better accessibility should enable growth near transit corridors, and growth should result in more people using a transit system (Huang, 1996). All individual hypotheses and null hypotheses are listed in table form in Appendix B for each model estimated.

The research question follows:

Q: What land use and transportation conditions must exist to encourage the general population to locate near light rail?

The null and alternative hypotheses for the research question follow:

H_{01}: Accessibility does not influence population growth near light rail in urban and suburban areas.

H_{a1}: Accessibility influences population growth near light rail in urban and suburban areas.

H_{02}: Accessibility does not influence population growth near light rail in suburban areas.

H_{a2}: Accessibility influences population growth near light rail in suburban areas.

   As discussed in Chapter 2, accessibility can be defined as a choice based on travel preferences, or it can be defined by the interconnected nature of land uses (Geurs & van Wee, 2004). The operational definition of accessibility for this study is the ease of movement to opportunities that are important for meeting society's daily needs. In this case, opportunities are defined as jobs and housing units. Three reasons explain why that definition of accessibility is applied in this study. First, it is relatively easy to operationalize. Second, data are available;

therefore, this study can be duplicated by other researchers and planning organizations with limited resources at minimal additional cost. Third, this definition of accessibility describes how land use and transportation are related. Admittedly, the definition has limitations. It potentially oversimplifies accessibility. The definition does not account for personal preferences; behavior; and *some* socio-economic variables such as age, gender, and car-ownership. Finally, it ignores the influence of new technology and innovation on future travel demand.

Data Sources and Management

The data sources are the National Historical Geographic Information Systems (NHGIS) database that is produced by the Minnesota Population Center at the University of Minnesota and the Denver Regional Council of Governments (DRCOG). This study used, population, housing, socioeconomic, and travel time data that include the following:

- United States Census decennial population data from the years 1990, 2000, and 2010 stored in the NHGIS database and measured on the block scale.

- The number of housing units from 2010 and 2000 stored in the DRCOG's data catalog, also measured on the block scale.

- The number of housing units from 1990 stored in the NHGIS, measured on the block group scale.

- The number of jobs for 2005 and 2010 from the DRCOG, measured within the travel analysis zone (TAZ).

- Origin-destination transit skims that are a part of DRCOG's Focus travel demand model containing travel costs; i.e., zone-to-zone travel times, travel distances, and monetary costs.

- The number of Park-and-Ride spaces at each light rail station obtained from DRCOG's and RTD's Web sites.

- The number of low-income households in a travel analysis zone (TAZ). DRCOG measures income as the following: low income households are in the bottom third percent the region's income bracket, middle income households are in the middle third percent, and high income earners are in the top third percent.

The NHGIS database provides census data at no cost to researchers and not readily available from the United States Census Bureau. For example, decennial census data measured on the block scale for 1990 are no longer available from the United States Census Bureau's Web site. The DRCOG was also an invaluable resource for providing employment data and data on highway, transit, bicycle, and pedestrian travel skims. The data included estimated travel times and costs for morning and evening peak periods and a midday off-peak period. The census block is the highest geographic resolution available for measuring population. Employment data are not available on the block scale. Employment was measured as the total number of jobs within TAZs. Shapefiles for Colorado on the block and county scale came from the NHGIS database. Shapefiles for major roads, light rail lines and stations, and TAZs were from the DRCOG data catalog.

Microsoft Access was used to manage and organize data from the origin-destination skims, which contained nearly six million origin and destination possibilities. ArcGIS was used to conduct spatial analyses to extract and store the appropriate data sets. Statistical Package for the Social Sciences (SPSS) was utilized to estimate contingency tables and multiple regression models that tested the hypotheses discussed in this chapter and Appendix A.

Study Design and Limitations

While this study has some similarities to Shen's (2013) excellent study, an important

difference is the data sources, variable definitions, and study design. Shen (2013) in part used

American Community Survey data, which are forecast data based on a sample. This study uses

United States Census decennial data, which are measured data. In addition, Shen (2013)

measured accessibility on the regional scale as the total jobs within a metropolitan area reached

by transit. This study measures accessibility at the station area and TAZ scale. Shen (2013) used

a difference-in-differences (DID) methodology. His study design adopts elements of the

"BART@20: Land Use and Development Impacts" study (Cervero & Landis, 1997). The first

part of that study used matched-pairs combined with descriptive statistics to compare new

development between a treated and control areas: BART stations and highway nodes,

respectively. The second part of "BART@20" study used two model forms. The first was a

linear regression analysis to investigate non-residential and multi-residential family growth near

BART stations between 1973 and 1993. The second was a binomial logit analysis to investigate

predictors of land use changes between 1965 and 1990. The model analysis did not lag variables,

and it was not a DID study (Cervero & Landis, 1997).

Other studies have tested before-and-after implementation relationships using linear

regression analysis that is not true DID and could not account for variability between years. For

example, Baum-Snow and Kahn (2000) used 1980 and 1990 census tract data and a regression

analysis methodology to study the construction of rail transit's effect on ridership, comparing the

pre-and-post construction period. In addition, hedonic pricing models in some studies are

estimated as a simple pre-and-post treatment analysis (Atkinson-Palombo, 2010). There are

weaknesses to this methodology. As mentioned, it cannot account for the variability that occurs

over long periods of time. Further, it assumes that the effects of the transportation improvement are evenly spread across a time.

The first part of this study estimates three contingency tables. Two test population growth as a function of light rail along the five corridors — Central, Central Platte, Southwest, Southeast, and I-25 — over two time periods: 1990 to 2010 and 2000 to 2010. The third contingency table tests employment growth as a function of light rail along the Southeast Corridor and I-25 for the period of 2005 to 2010. I-25 was selected as a control variable because, unlike other interstate corridors that operate in the region, travel on I-25 between the DRCOG's planning boundary and Denver's Central Business District (CBD) is generally uninterrupted. In other words, travel does not require exiting to another interstate or major roadway to reach the CBD.

The second part of this study uses linear regression analysis. Note that data limitations preclude a true DID methodology. This is because measured employment data are limited to the years 2005 and 2010, and other databases that provide employment data do not necessarily coincide with decennial count years. For example, the National Transit Oriented Development Database stores employment for transit stations from the Local Employment Dynamics between 2002 and 2009. Another issue is that employment data collection methods vary among organizations. Employment data are available for the year 2000 from the United States Census Bureau, but it is not comparable to DRCOG's data. The 2000 Census counted approximately 20,000 jobs within Denver's CBD, and DRCOG's 2010 estimates that approximately 87,000 jobs are within the CBD. It is unlikely that the CBD grew by 67,000 jobs. DRCOG's employment data are the best available source for this level of analysis.

Spatial Analysis: Contingency Tables

A spatial analysis was conducted using Geographic Information Systems (GIS). The phrase "near light rail stations" is defined as a half mile radius from stations throughout the entire study. This distance is considered the acceptable maximum comfortable walking distance TOD planning (Dittmar & Poticha, 2004).

This study used GIS to create half mile buffers around light rail stations and highway interchanges (Figure 4.4). Stations that were located within each other's half mile buffer zones were treated as one station area. The contingency tables used population data contained within census blocks and employment data contained within TAZs. An assumption is that population and jobs are evenly distributed within the respective geographic zones. Census block boundaries changed between 1990 and 2000, so population data were aggregated to station and interchange areas to make comparisons over the 20-year period. Only census blocks and TAZs with centroids inside the half mile buffer were included in the analysis. However, employment data were not aggregated to station areas. This was possible because TAZ boundaries between 2005 and 2010 did not change.

The independent variable for all three contingency tables is categorical: light rail and I-25. Light rail was coded 1, and I-25 was coded 0. The dependent variables are 20-year population changes, ten-year population changes, and five-year employment changes near light rail stations. Population and job growth were coded 1. Population and job stagnation and decline were coded as 0. Stagnation is defined as no growth.
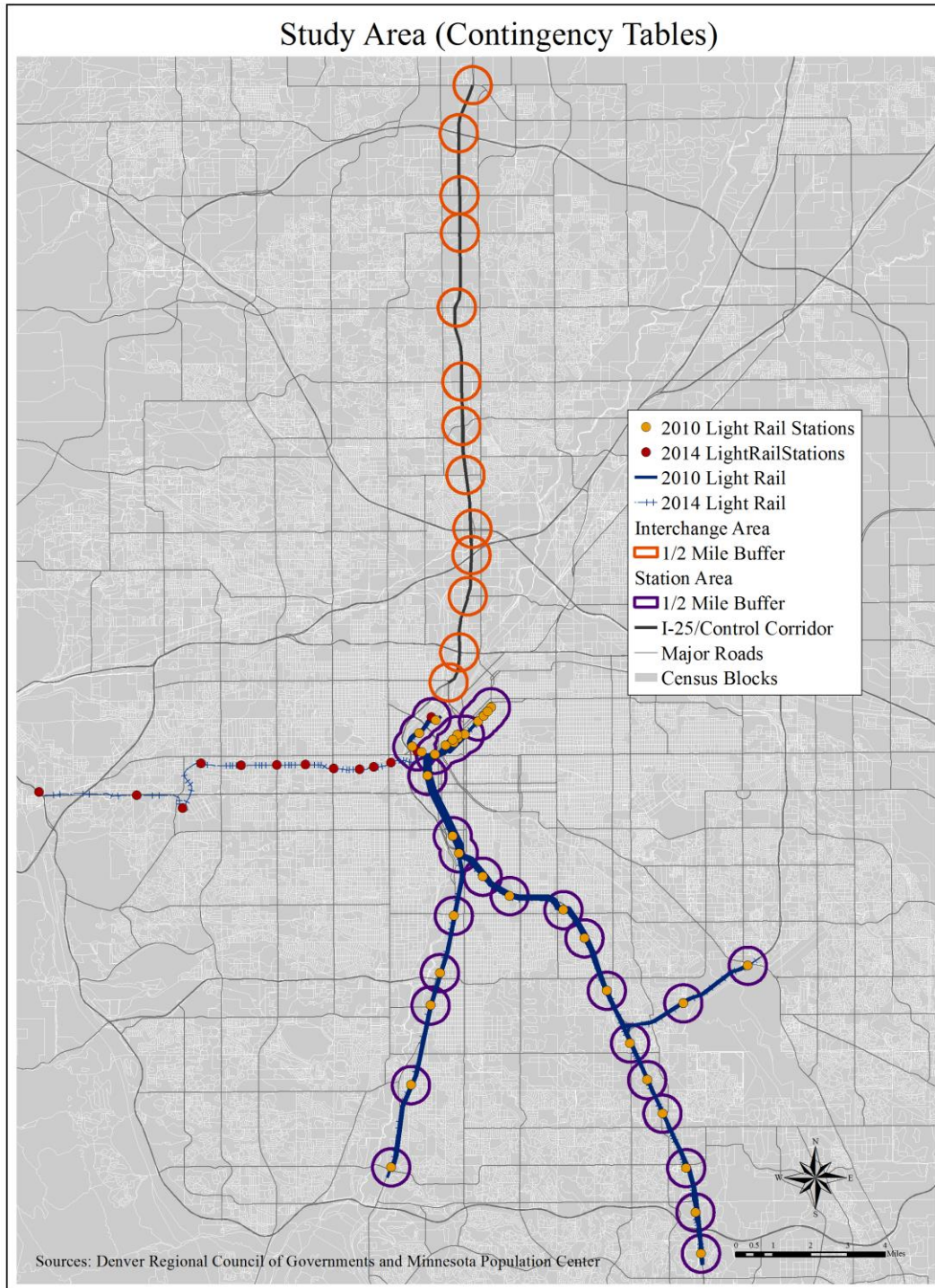
Figure 4.4. Study Area Corridors including I-25.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.

Spatial Analysis: Linear Regression

To conduct the second part of the study, five linear regression models are estimated, as defined by the following base equation (17):

$$Y=\beta_0+ \beta_1X_1+ \beta_2X_2\dots \beta_{n+1}X_{n+1}\dots\dots\dots\dots\dots\dots.(17)$$

Where, Y is the dependent variable, X_n is the independent variable, and β_n is the model coefficient.

Table 4.3 defines each independent variable. Table 4.4 defines each accessibility variable.

Two approaches were taken. To test the first hypothesis, population, employment, housing, household income, and Park-and-Ride data were aggregated within half mile buffers around stations along the four light rail study corridors. Only blocks, block groups, and TAZs with centroids inside the buffer were selected using GIS. The one exception was the Littleton-Mineral station because its TAZs were too large for their centroids to fit inside the half mile buffer. Four TAZs were manually selected. Equation (18) illustrates a longitudinal specification, and equation (19) illustrates a cross-sectional specification.

Population difference ALLCORRIDORS 1990-2010=β_0+ β_1(ΔActive Accessibility)+ β_2(Δ Accessibility CBD) + β_3(Housing Growth)…………………………………………………………………....(18)

Population 2010 ALLCORRIDORS = a_0 + a_1(Park-and-Ride) + a_2(Total Station Accessibility) + a_3(Accessibility CBD) + a_4 (%LI HH) …………………………………………....(19)

To test the second hypothesis, two suburban corridors were analyzed: Southeast and Southwest Corridors. Using GIS, Travel Analysis Zones (TAZs) were overlaid on top of census blocks to measure population and housing units for each TAZ (Figure 4.5 and Figure 4.6). Total jobs and the number of low, medium, and high income households were already stored in a database for TAZs. Only TAZs with their centroids inside the half mile buffer were selected for

analysis, as illustrated in Figure 4.6. Mentioned in the previous section, the one exception was the Littleton-Mineral station. Equations (20) and (21) illustrate a longitudinal specification, and equation (22) illustrates a cross sectional specification.

Population density change *2000-2010SESW*=b_0+ b_1(Δ Active Accessibility) + b_2(ΔAccessibility CBD) + b_3(Housing Growth) +b_4(T-REX) ……………………………………… (20)

Population Density Change *2000*-2010SE=c_0+ c_1(Δ Active Accessibility)+ c_2(ΔAccessibility CBD) + c_3(Housing Difference) …………………………………… …………(21)

Population Density *2010SESE*= α_0+ α_1(Active Accessibility) + α_2(Passive Accessibility) + α_3(Accessibility CBD) + α_4 (T-REX) + α_5 (LI HH) ………………………………(22)

In summary, the dependent variables follow:

1. Difference in population near light rail stations between 1990 and 2010

2. Difference in population density near light rail between 2000 and 2010

3. Population near light rail stations in 2010

4. Population density near light rail stations in 2010

The independent variables follow:

1. Accessibility to the Central Business District (CBD)

2. Active accessibility to the light rail station

3. Passive accessibility to the light rail station

4. Station accessibility (the sum of active and passive accessibility)

5. The number of Park-and-Ride parking spaces

6. Percent change in housing

7. Change in housing ratio

8. Percentage of low-income families living near light rail stations

9. Light rail running parallel to the T-REX corridor (1=Yes, 0=No)

Figure 4.5. Travel Analysis Zones overlaid on Census Blocks.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.

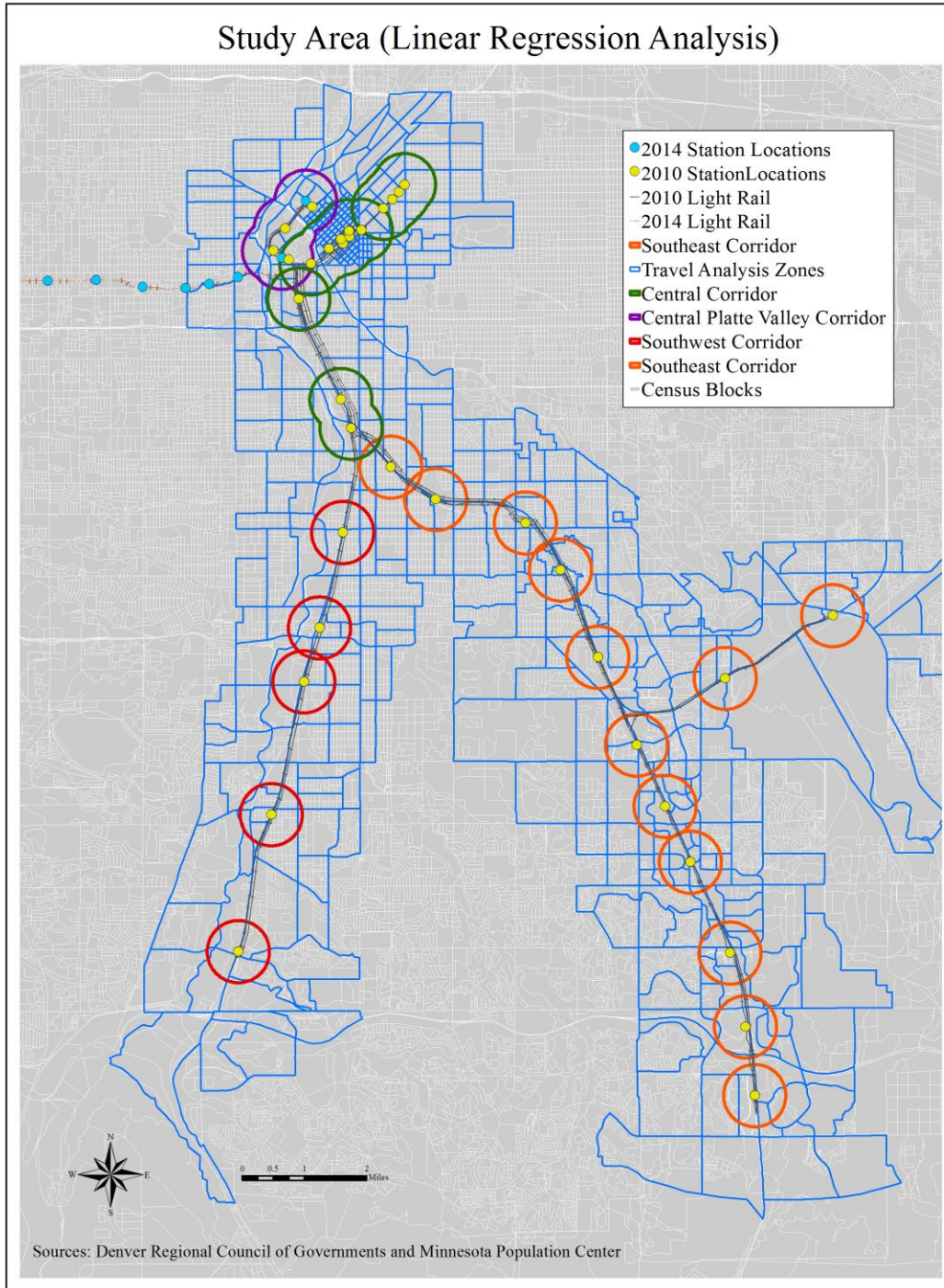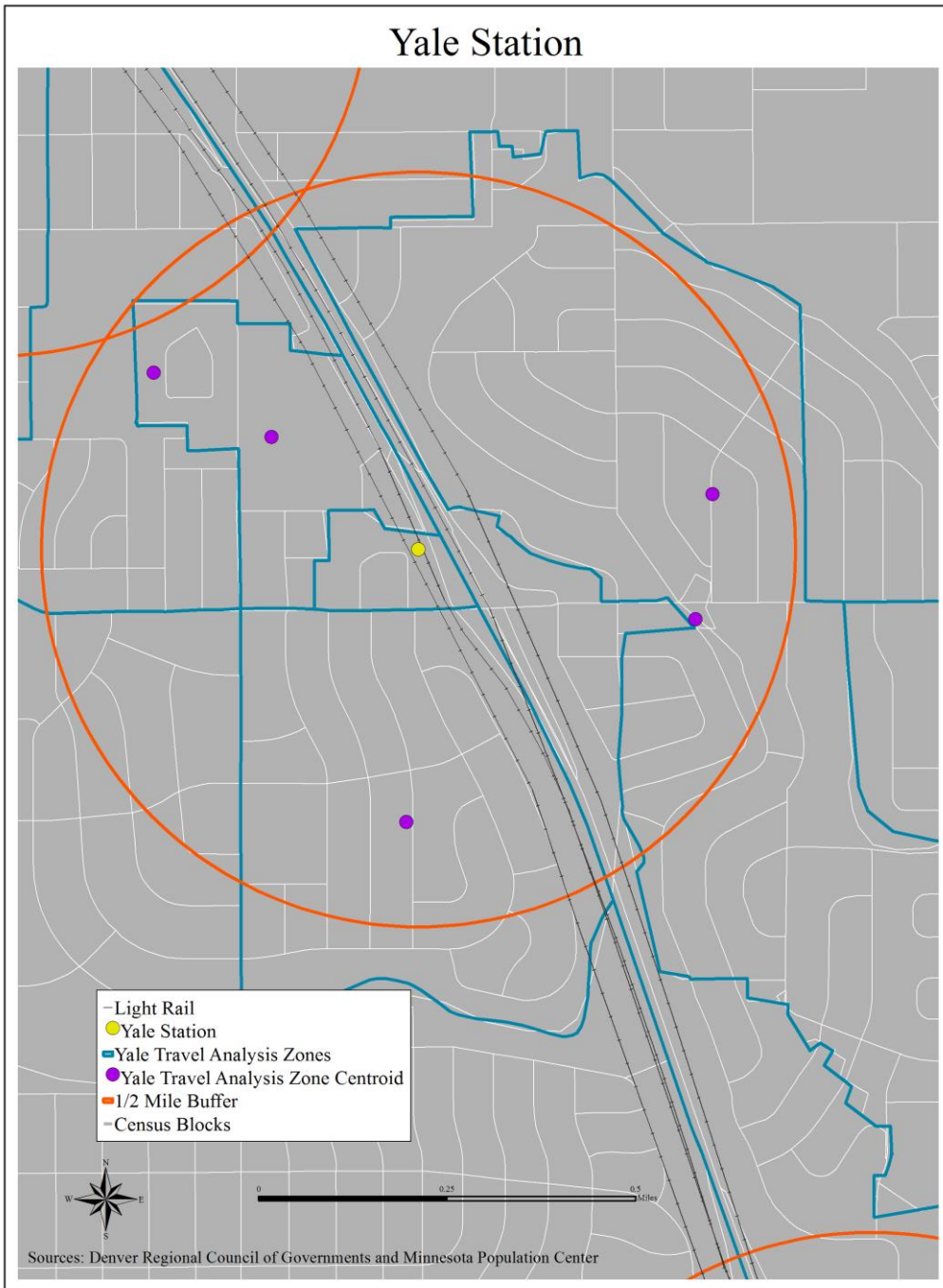**Figure 4.6.** Example of How Travel Analysis Zones were Selected.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.

Table 4.3. Independent and Dependent Variables Defined.

Variable	Definition
Model 1 / Linear Regression Equation (18)	
Population Difference 1990-2010	Difference in population between 1990 and 2010 within a half mile distance of station j
ΔActive Accessibility	Difference in accessibility t jobs from station j; equals 0 prior to implementation
ΔAccessibility CBD	Difference in accessibility to jobs at the CBD to station j; equals 0 prior to implementation
Housing Growth	Percent change in housing units
Model 2/ Linear Regression Equation (19)	
Population 2010 ALLCORRIDORS	The estimated number of persons living within half a mile of light rail station j along all study corridors in 2010
Park-and-Ride	The number of Park-and-Ride spaces near light rail station j
Total Station Accessibility	Sum of active and passive accessibility measures
Accessibility CBD	Accessibility from station j to the CBD
% LI HH	Percentage of low-income households living near station j
Model 3 / Linear Regression Equation (20)	
Population Density Change 2000-2010 *SESW*	The estimated difference in the number of persons per acre living in Travel Analysis Zone i within half a mile of light rail station j along the Southeast and Southwest Corridors between 2000 to 2010.
ΔActive Accessibility	Change in accessibility to jobs from Travel Analysis Zone i to light rail station j; equals 0 prior to implementation
ΔAccessibility CBD	Change in accessibility from station j to CBD; equals 0 prior to implementation
Housing Growth	Ratio of change in housing units divided by the original number of housing units
T-REX	Dummy variable for light rail running parallel to I-25 and I-225 highway expansion project; 1=yes, 0=no

Table 4.3 (Continued). Independent and Dependent Variables Defined.

Variable	Definition
Model 4 / Linear Regression Equation (21)	
Population Density Change *2000-*2010SE	The estimated difference in the number of persons per acre living in Travel Analysis Zone *i* within half a mile of light rail station *j* along the Southeast Corridor between 2000 to 2010.
ΔTotal Station Accessibility	Difference in accessibility to jobs from Travel Analysis Zone *i* to light rail station *j*; equals 0 prior to implementation
ΔAccessibility CBD	Difference in accessibility from station *j* to CBD; equals 0 prior to implementation
Housing Growth	Ratio of change in housing units divided by the original number of housing units
Model 5 / Linear Regression Equation (22)	
Population Density *2010SESE*	The estimated number of persons per acre living in Travel Analysis Zone *i* within half a mile of light rail station *j* along the Southeast and Southwest Corridors
Active Accessibility	Accessibility to total jobs in Travel Analysis Zone *i* to light rail station *j*
Passive Accessibility	Accessibility to total housing units in Travel Analysis Zone *i* to light rail station *j*
Accessibility CBD	Accessibility from station *j* to CBD
TREX	Dummy variable for light rail running parallel to I-25 and I-225 highway expansion project; 1= yes, 0=no
LI HH	Percentage of low-income households living near the Southwest and Southeast light rail stations

Table 4.4. Accessibility Variables Defined.

Accessibility	Definition	Equation
Active	The ease of reaching the total number of jobs from a nearby light rail station	$A_j = \sum_{j=station}^{n} O(jobs)j /(100*e_{ij}^d)$, $O(jobs)_i$ =total jobs near station j d=distance to station j $A_{ij} = \sum_{j=station}^{n} O(jobs)i /(100*e_{ij}^d)$, $O(jobs)_i$ =total jobs in Travel Analysis Zone i d=distance to station j
Passive	The ease of reaching housing from a nearby light rail station.	$A_j = \sum_{j=station}^{n} O(HU)j /(100*e_{ij}^d)$, $O(HU)_i$ =total housing units near station j d=distance to station j $A_{ij} = \sum_{j=station}^{n} O(jobs)i /(100*e_{ij}^d)$, $O(jobs)_i$ =total housing units in Travel Analysis Zone i d=distance to station j
Central Business District	The ease of reaching opportunities in the Central Business District from a light rail station	$A_{jCBD} = \sum_{j=station}^{n} O(CBD) /(TT^2)$, $O(CBD)$ =total jobs near CBD light rail stations TT=total travel time to travel between station j to the CBD TT = walk time + wait time + in-vehicle travel time
Total Station	The sum of active and passive accessibility measures	$A_j = \sum_{j=station}^{n} [O(jobs)j + O(HU)j] /(100*e_{ij}^d)$, $O(jobs)_j$ =total jobs near station j d=distance to the station j $O(HU)_j$ =total housing units near station j d=distance to station j

Note: Adapted from "Gravity-Based Accessibility Measures for Integrated Transport-Land Use Planning (GraBAM)," by E. Papa and P. Coppola, 2012, *Accessibility Instruments for Planning Practice*, 117-124.

Travel Time Assumptions

Four travel time assumptions are important for defining the independent variables. The first assumption deals with peak travel time. Travel time data for both AM and PM peak travel periods were compared. DRCOG defines AM peak transit travel time as 6:30 a.m. to 8:59 a.m. and PM transit travel time as 3:00 p.m. to 6:59 p.m. Travel times did not differ much, if at all. This study assumes one-way travel during AM peak travel time. The selection of AM peak travel time is based on McKenzie and Rapino (2011), who found that 52.6 percent of travel in the United States took place between 6:30 a.m. and 8:59 a.m. The assumption does not account for activity-based travel. This study therefore stops short of examining travel behavior's and activity-based travel's influence on location choice.

The second assumption involves walk time. DRCOG's focus travel demand model assumes that walk time is three miles per hour. The maximum walk time that it takes to walk from a station area half mile buffer's border to the station itself was calculated as ten minutes using this formula (16):

Maximum Walk Time $=60$ minutes per hour/ $[(3$ miles per hour)/0.5 miles$] = 10$ minutes (16)

The third assumption uses DRCOG definition of wait time of half the headway. The fourth assumption is that accessibility to opportunities improves via light rail in the post-implementation phase. Accessibility is 0 in the pre-implementation phase since light rail stations and corridors did not exist prior to the implementation.

Conclusion

This chapter describes in detail this study's methodology. It discusses the research question, variables under study, assumptions made to conduct the analysis, and statistical

techniques. Limited data makes the best analysis impossible, but this study is based on past studies using similar methodologies, such as Cervero and Landis (1997). A specific strength of this study is how it defines accessibility and aggressively tests accessibility. While these accessibility measures are not new, other studies that have examined light rail's role in inducing land use changes have not tested them to the extent that they are tested here. Looking ahead, the next chapter will discuss the findings and takeaways from this research. It will also make recommendations for future research that can contribute to understanding the transportation and land use relationship.

CHAPTER FIVE:

DISCUSSION AND RESULTS

So far, his thesis has explained the evolution of transportation and land use beginning from the mid-19th century to present-day. It has also defined light rail, Transit Oriented Development (TOD), sprawl, and accessibility; reviewed relevant literature; and presented a methodology for investigating the relationship between light rail and land use in the Denver region. This chapter explains the results, draws conclusions, and proposes a framework for future research. The methodology is based on previous work (Cervero & Landis, 1997), and it is important to note that data limitations prevent a complete analysis. Such issues are not new, and studies generally acknowledge them. For example, Cervero and Landis (1997) wrote, "We, like others, have been forced to draw inferences by looking at a handful of time slices using less-than-complete data, thus the results of our work should be interpreted accordingly"(p. 311). Educated conclusions must be made based on the best available data.

Many of the studies reviewed in Chapter 3 have encountered these same research quandaries. For example, Shen's (2013) measurement of accessibility was on a regional scale because employment data were not available on a smaller geographic scale. In addition, historical population data for the appropriate scale did not exist for the Xie and Levinson (2009) study. Their solution was to use historical parcel data from the regional planning agency as a proxy for population (Xie and Levinson, 2009). Most of the studies that test the relationship between land use and light rail use this methodology. This study takes a different approach

because recent history provides anecdotal evidence that housing growth does not automatically result in population growth (Van Sickler, Sokol, & Martin, 2009; Montgomery, 2008).

Results: Contingency Tables

Tables 5.1 through 5.3 summarize the results for the contingency tables and chi-square tests. In addition, Figures 5.1, 5.2, and 5.3 visualize where growth occurred. Note that Figure 5.3 shows job growth and loss along the four corridors even though only the Southeast Corridor relative to the control corridor, I-25, was tested.

Also note that contingency tables and chi-square tests are descriptive and limited in their ability to test the types of relationships between dependent and independent variables. Certainly, one cannot draw any conclusions on causation and correlationship between two variables using this methodology. On the other hand, contingency tables and chi-square tests are a good step in establishing if there is an association between two categorical variables. If the answer is yes, contingency tables are useful for determining the direction of the relationship (Berman, 2007).

Table 5.1. Population Growth as a Function of the Transportation Improvement: 20-Year Period

	Station Area	Interchange Area	Total
Growth	78.3% (18)	46.2% (6)	65.7% (23)
No Growth	21.7% (5)	53.8% (7)	35.3% (12)
Total	100% (23)	100% (13)	100% (35)

Note: X^2=3.853>3.841, p<0.05

Table 5.2. Population Growth as a Function of the Transportation Improvement: 10-Year Period

	Station Area	Interchange Area	Total
Growth	73.9% (16)	30.8% (4)	42.9% 20
No Growth	26.1% (6)	69.2% (9)	57.1% (15)
Total	100% (23)	100% (13)	100% (35)

Note: X²=6.361>3.841, p<0.05

Table 5.3. Job Growth as a Function of the Transportation Improvement, 5-Year Period (2005-2010)

	Station Area	Interchange Area	Total
Growth	49.1% (28)	11.4% (4)	34.8% (32)
No Growth	50.9% (29)	88.6% (31)	65.2% (60)
Total	100% (57)	100% (35)	100% (92)

Note: X²=13.582>3.841, p<0.05

That said, all three chi-square tests are significant at the 0.05 level. Statistical evidence suggests that a relationship exists between the post-and-pre-implementation periods for the periods of 1990 to 2010 and 2000 to 2010. The relationship is positive in both cases. Approximately 78 percent and 74 percent of all station areas experienced population growth over 20 and ten year periods, respectively. In comparison, approximately 54 percent and 69 percent of highway interchanges experienced no growth over the 20 and ten-year periods, respectively.

The contingency table testing employment along the Southeast Corridor relative to highway interchanges is a different narrative. Approximately 49 percent of all station areas along the Southeast Corridor experienced job growth, whereas approximately 89 percent of all highway interchanges experienced job loss. The former percentage makes it difficult to conclude with certainty that a positive relationship exists between the treatment corridor and job growth. Unfortunately, data limitations preclude a level of analysis similar to the one for population growth, and the Southeast Corridor began operation shortly before the worst economic recession since the Great Depression. Local and state economies were still recovering when 2010 job data were collected. Considering the context, the job growth remained steady near the Southeast Corridor.

Also consider Sadler and Wampler (2013), who tracked job growth using a different data set between 2002 and 2009 along the Southeast Corridor. They found that total jobs along the corridor grew 10.5 percent from 79,249 in 2002 to 87,559 in 2009, or 9.85 percent faster than the metropolitan region. Between 2003 and 2008, job growth was steady, with the largest increase between 2007 and 2008 after the Southeast Corridor began operation. On the other hand, jobs declined by approximately 5,000 between 2008 and 2009, which was the start of the recession (Sadler & Wampler, 2013). The takeaways from Sadler and Wampler (2013) study are this:

- Their findings are consistent with research from this thesis

- It can be inferred that economic collapse limited job growth near light rail

- Researchers should continue to measure and evaluate job growth near light rail

Figure 5.1. 20-Year Growth near Light Rail Stations and Highway Interchanges.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.
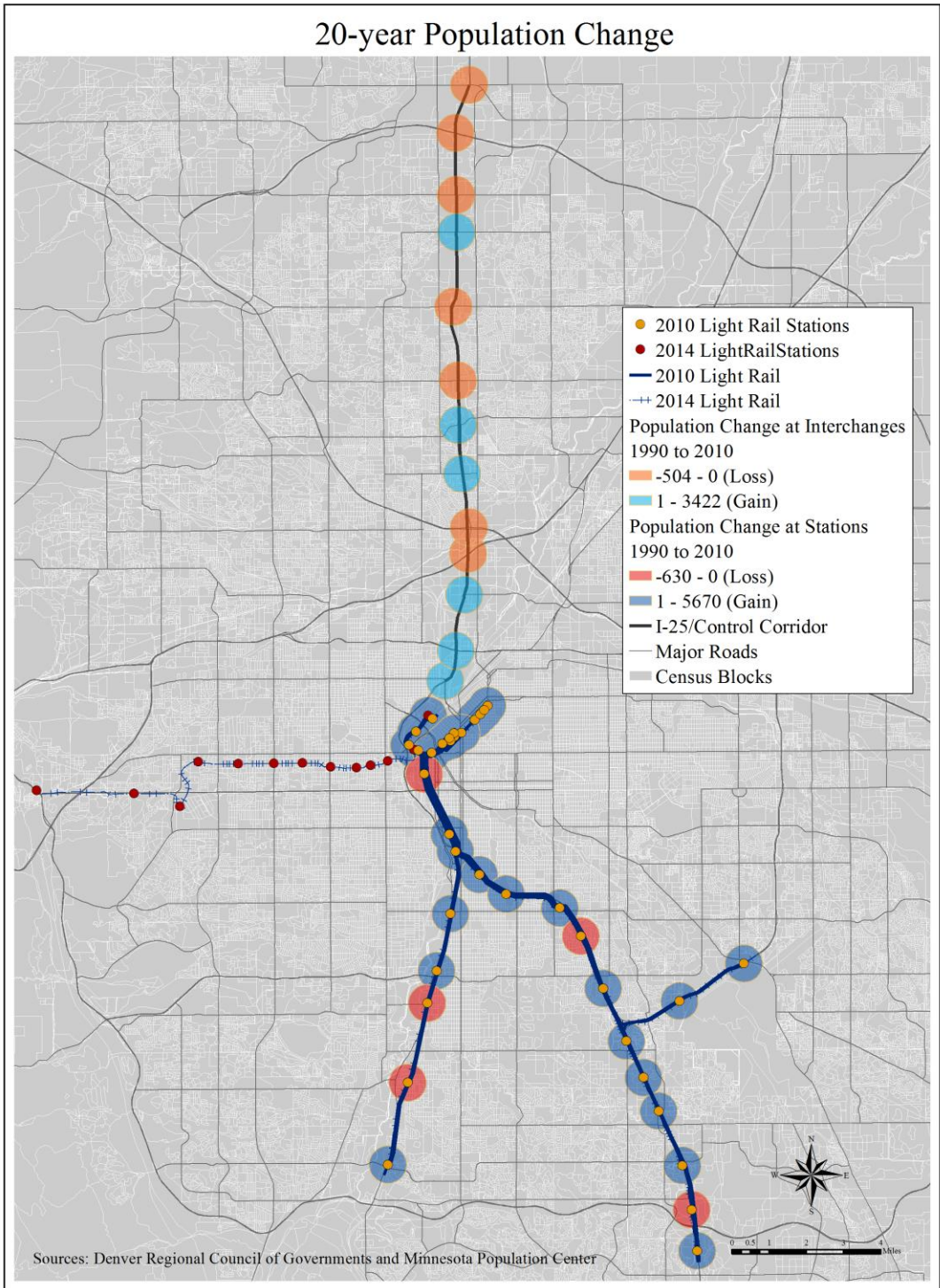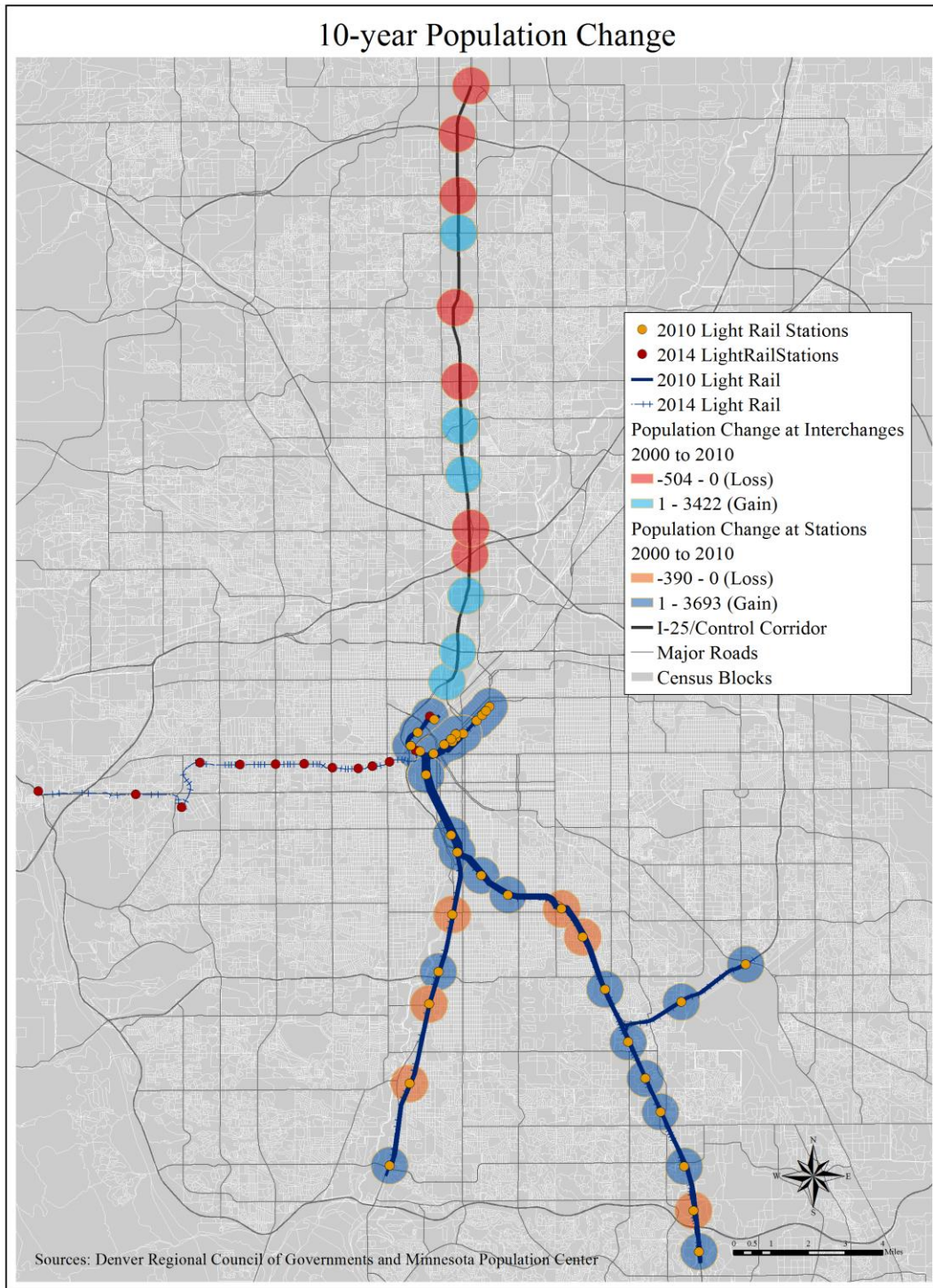
Figure 5.2. 20-Year Growth near Light Rail Stations and Highway Interchanges.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.

Figure 5.3. Five-Year Employment Growth near Light Rail Stations and Highway Interchanges.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.
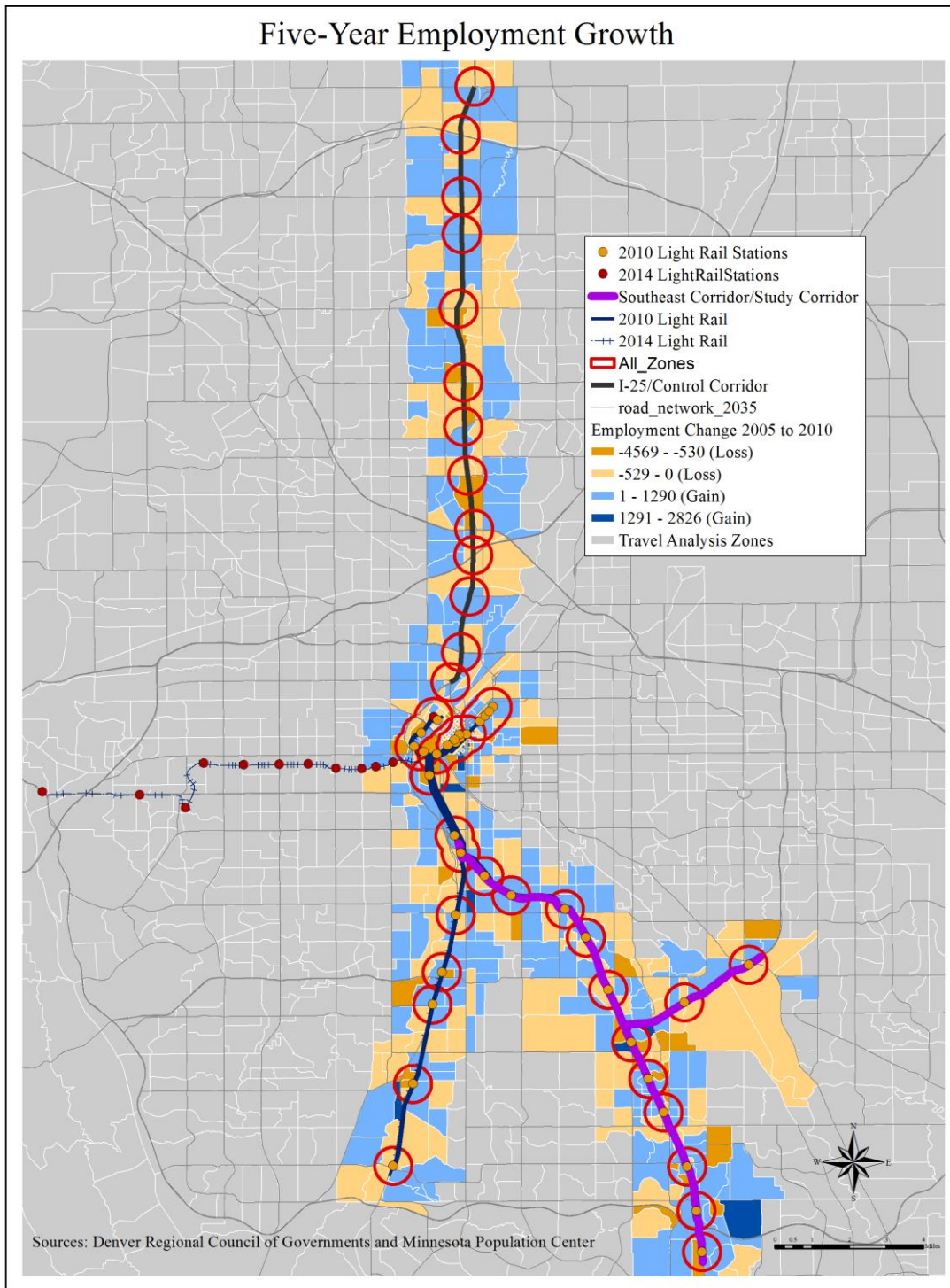
Results: Linear Regression

As discussed in Chapter 4, this study is limited by data. For example, employment data are inconsistent across organizations that provide it. In addition, statistical modeling is inherently flawed by the ability to account for the variability between time periods (Shen, 2013; Cervero & Landis, 1997). Any interpretations of the results must consider these weaknesses. On the other hand, this methodology has strengths. First, it establishes a simple and practical model for evaluating policy goals supportive of denser development near light rail. Second, this methodology does not require additional data collection than what is generally required for planning purposes. Third, this study is unique because it tests accessibility on the station area scale using measured employment data. Fourth, the methodology is flexible enough to adapt to changing evaluation needs. For example, a policy variable can be added as more time passes between TOD-policies being adopted and the post-treatment period. Accessibility variables can also be expanded to better account for the types of jobs and travel choices that dictate mode choice. Table 5.4 summarizes the results for each model.

Model 1 Interpretation

Longitudinal model 1's explanatory power is good. It indicates that accessibility near light rail facilitates population growth. Job accessibility near light rail is significant at a 0.01 level, and housing growth is statistically significant at a 0.05 level. Accessibility to the CBD is not statistically significant. Station area population increased by 7.03 as accessibility to jobs improved by one, *ceteris paribus*. It also increased by 5.63 for each percent increase in housing, *ceteris paribus*. In other words, a strong housing economy and job proximity to light rail is correlated to population growth near stations.

Table 5.4. Linear Regression Model Results.

Predictors	Coefficient	SE	t	sig.	VIF
Model 1** (20-year Population Growth, Urban and Suburban Corridors)					
Constant	-266.57	415.90	-.641	.529	N/A
Δ Active Accessibility	7.03**	2.44	2.885	.009	1.694
Δ Accessibility CBD	12.13	7.46	1.626	.121	1.626
% HU Difference	5.63*	2.11	2.671	.015	1.158
R = 0.820 Adjusted R squared = 0.622.					
Model 2** (2010 Population, Urban and Suburban Corridors)					
Constant	219.60	1274.65	.172	.865	N/A
Parking	-0.33	.95	-.35	.731	1.149
Station Accessibility	14.34*	5.75	2.49	.023	1.548
Accessibility CBD	22.39	21.92	1.025	.321	2.127
% LI Households	99.30	52.77	1.88	.076	1.536
R = 0.807. Adjusted R squared = 0.574.					
Model 3** (10-year Population Growth, Suburban Corridors)					
Constant	-10.04	4.30	-2.36	0.02	N/A
Δ Active Accessibility	0.03	0.13	0.211	0.83	1.14
Δ Accessibility CBD	0.05	0.40	1.2	0.24	1.14
HU Growth	0.20	0.16	1.24	0.22	1.06
T-REX	7.68*	5.25	2.36	0.02	1.18
R = 0.327. Adjusted R squared = 0.057.					
Model 4** (10-year Population Growth, Suburban Corridor)					
Constant	2.07	0.996	2.08	0.04	N/A
Δ Active Accessibility	-0.03	0.03	-0.93	0.36	1.03
Δ Accessibility CBD	-0.12	0.01	-0.96	0.34	1.08
HU Growth	0.13**	0.44	0.38	0.004	1.06
R = 0.439. Adjusted R squared = 0.147.					
Model 5** (2010 Population Density, Suburban Corridors)					
Constant	-0.035	1.06	-0.03	0.97	N/A
Active Accessibility	-0.07*	0.0.3	-2.15	0.035	1.19
Passive Accessibility	0.98**	0.16	6.34	0.000	1.86
Accessibility CBD	0.02*	0.01	2.26	0.027	1.23
T-REX	1.29	0.82	0.21	0.12	1.21
LI Households (Ratio)	0.01	0.01	0.14	0.14	1.94
R = 0.812. Adjusted R squared = 0.636.					

Note: SE=Standard Error; VIF = Variance Inflation Factor. *p<0.05; **p<0.01.

Model 2 Interpretation

The explanatory power of cross sectional Model 2 is good. The model specification indicates that Park-and-Rides and accessibility to jobs located in the Central Business District (CBD) has no effect on the general population locating near light rail. Station area accessibility is significant at the 0.05 level. Defined in Chapter 4, station area accessibility for this particular model is the number of jobs and housing units divided by the cost to reach them from the light rail station. Cost is defined as distance. Multicollinearity was a problem when controlling for passive and active accessibility. Thus, jobs and housing were incorporated into the same accessibility variable. The model specification suggests that population near light rail stations increases by 14.34 when accessibility to station area jobs and housing increases by one, *ceteris paribus*. Income is significant at the 0.10 level.

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Model 3 Interpretation

The narrative changes when the study controls for suburban areas: specifically the Southwest and Southeast Corridors. Longitudinal Model 3's explanatory power is weak. These results mirror Shen's (2013) findings, which found that light rail along Denver's Southwest corridor has had a limited effect on inducing new growth. Both this study and Shen (2013) arrived at the same conclusion using a different methodology and variable definitions. The T-REX variable is significant at the 0.05 level. The model's specification indicates that population density increased 7.68 along the Southeast Corridor relative to the Southwest Corridor, *ceteris paribus.* Model 4 tests the Southeast Corridor.

Model 4 Interpretation

The explanatory power of longitudinal Model 4 is not much better than Model 3. Both job accessibility and accessibility to the Central Business District (CBD) are not significant. Unlike the previous model, this one suggests that a strong housing economy is important to population growth. This variable is significant at the 0.01 level. The model specification indicates that population density increased by 0.13 for every percent increase in housing, *ceteris paribus.* The model does not control for the type of housing; i.e., renter versus ownership. In comparing Models 3 and 4, it is evident that the Southeast Corridor experienced more growth than the Southwest Corridor.

Model 5 Interpretation

The explanatory power of cross sectional Model 5 is strong. All three accessibility variables are significant at the 0.05 or 0.01 level. The model specification indicates that there is no relationship between population density and income. The T-REX variable is not statistically significant. Population density increases by 0.98 when accessibility to station area housing improves by one, *ceteris paribus.* It also increases 0.02 when job accessibility to the CBD increases by one, *ceteris paribus.* On the other hand, population density decreases 0.07 when accessibility to jobs located near stations improves by one, *ceteris paribus.*

Discussion of Findings

This study asked the question: What land use and transportation conditions must exist to foster population location near light rail transit? The discussion in this section attempts to answer

it using the study's findings. To summarize, evidence is mixed on if implementing light rail is related to population growth for Models 3, and 4. Models 1, 2, and 5 allow for the first null hypotheses from Chapter 4 to be rejected. Station area accessibility influences population growth near light rail stations in urban and suburban areas. The following sections discuss accessibility variables, economic indicators, the research question and hypotheses, and policy implications. Figures 5.4 and 5.5 illustrate the findings.

Accessibility to the Central Business District

Two reasons may explain why accessibility to the CBD was not significant in Model 2. First, it may be that population location is more dependent on community characteristics. For example, Podobnik (2011) found that TOD did not necessarily guarantee transit would become the preferred mode choice over single-occupancy vehicle commute to work trips. Among the findings, those who lived near the Orenco Station in Portland, OR, were more likely to walk to nearby destinations, but residents were still more likely to drive to work than take light rail. However, Orenco Station area residents were 84 percent more likely to use transit, particularly for non-work trips, than residents living in three separate neighborhoods with no access to light rail. The Orenco station area was not a failure in inducing transit use, but residents viewed light rail as an amenity and not a necessity for commute trips to work (Pobobnik, 2011).

Another explanation is that travel times to the CBD may not be competitive with the car. Higgins, Ferguson, and Kanaroglou (2014) wrote that the decision for choice riders to live near light rail stations is determined in part by transit service being competitive with other modes. If travel costs for transit are no better than driving, then theoretically only those who self-select or have no other options will locate near light rail.

It should be noted that the dissimilarity in the results for the accessibility to the CBD variable between Models 2 and 5 raises a question of why. The two models differ in variable specifications, so a comparison is not possible. Model 5's result is intuitive because stations located in suburban cities do not have the density found in urban stations. Further, population is measured in Model 5 as a normalized variable (population density) as opposed to an aggregate sum (total population). Thus, the two models simply tell different stories.

Accessibility to Jobs

At first, Model 5's results appear to contradict evidence showing many of the suburban stations experiencing population growth (Figure 5.6). For example, the Bellville, Orchard, Dry Creek, and Lincoln Stations along the Southeast Corridor grew considerably between 1990 and 2010. Belleville grew by 1,968 persons living within half a mile of the station. Orchard grew by 1,136 persons, Dry Creek grew by 1,631 persons, and Lincoln grew by 2,251.

Good market conditions enabled population growth at those station areas, as indicated by Models 1, 3, and 5. Aggregate population and population density was highest in urban areas. It is possible that urban station areas had maximized their growth potential, or new development land was not available relative to the suburban corridors. Model 4's results are useful for transit oriented development (TOD) planning. Population density decreased by 0.07 as job accessibility improved by one, *ceteris paribus*. For station areas to grow in population in conjunction with job growth, land use regulations need to codify the appropriate mix of jobs and residential housing through TOD-supportive land use policies (Higgins, Ferguson, & Kanaroglou, 2014).

Figure 5.4. 20-Year Population Growth Near Light Rail Transit Stations.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.
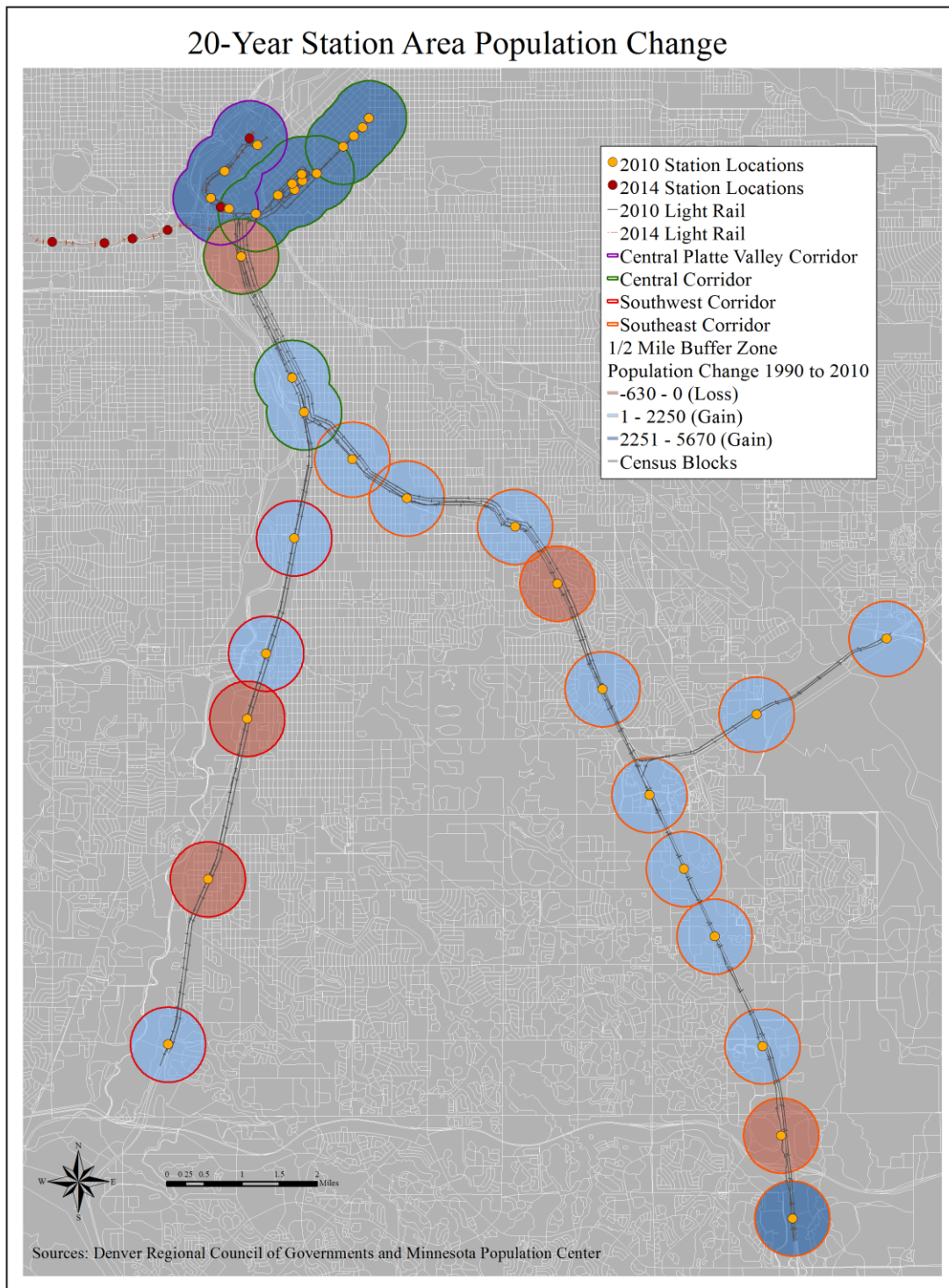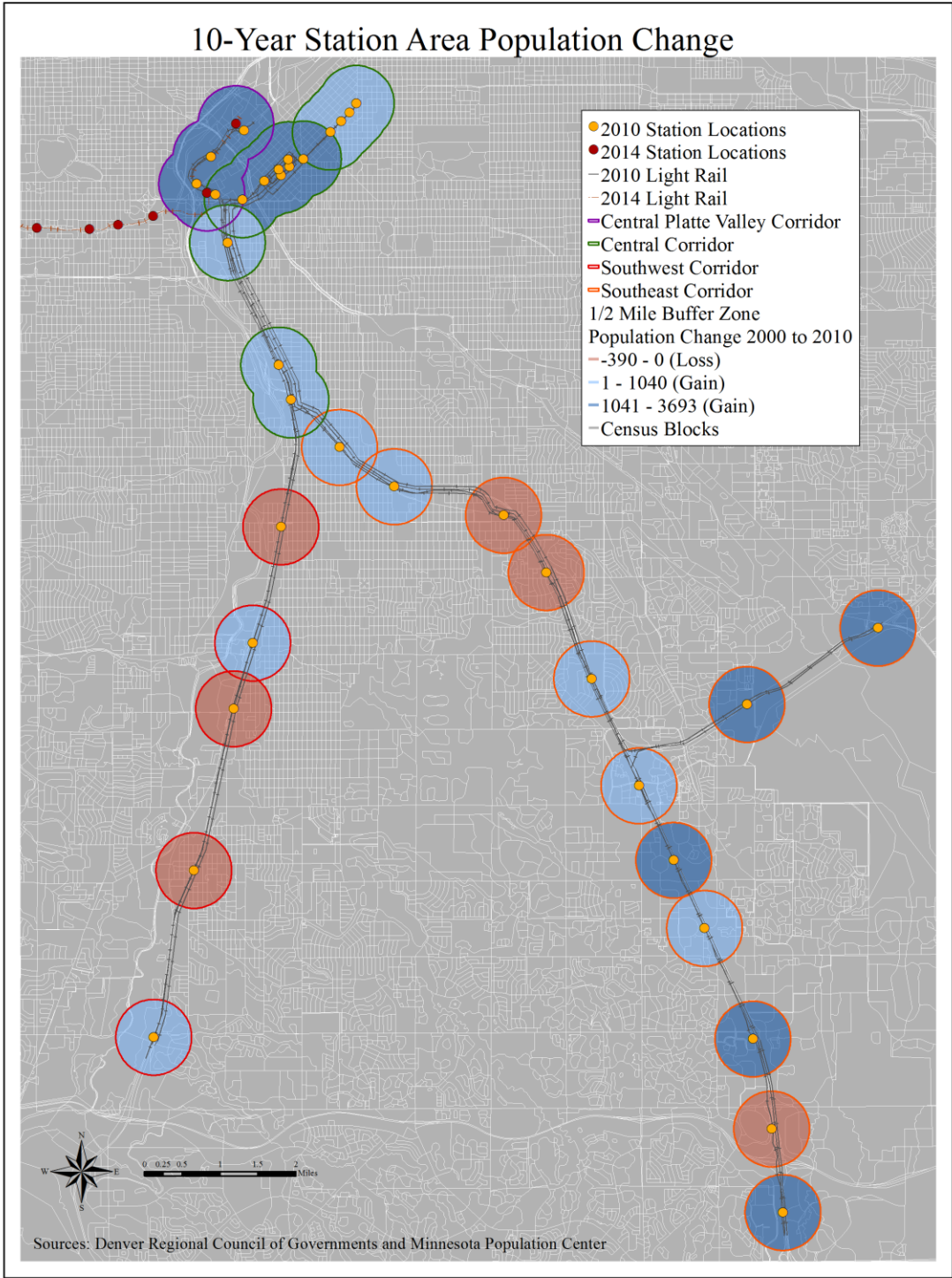
Figure 5.5. 10-Year Population Growth Near Light Rail Transit Stations.

Map created by author using data from the Denver Regional Council of Governments, 2014,
Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population
Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN:
University of Minnesota 2011.

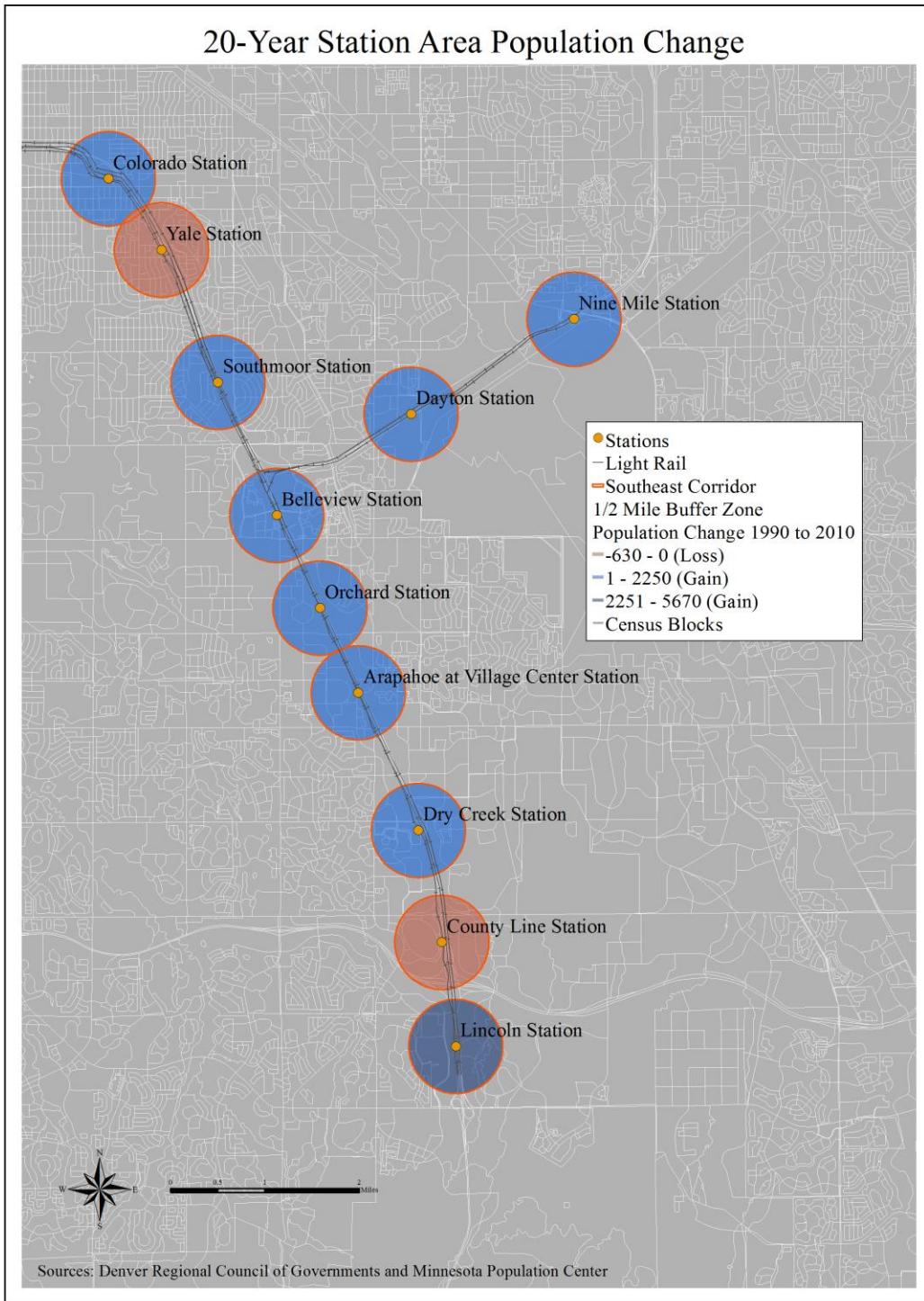**Figure 5.6.** 20-Year Population Growth Near Light Rail Transit Stations, Southeast Corridor.

Map created by author using data from the Denver Regional Council of Governments, 2014, Regional Data Catalog, retrieved from http://gis.drcog.org/datacatalog/; Minnesota Population Center, *National Historical Geographic Information System: Version 2.0*, Minneapolis, MN: University of Minnesota 2011.

The results should not be interpreted to mean that the Denver region is not emphasizing

TOD. In fact, municipalities along the light rail corridor are adopting station area plans and

zoning policy intended to guide TOD planning. For example, Greenwood Village zoned the

Arapahoe Village Station as mixed use and the Orchard Station as a town center (Regional

Transportation District, 2013). Most of the plans were adopted shortly before or after 2010,

thereby making it impossible to test their effect on population. It also takes time for a plan's

vision and objectives to become reality. In addition, this study did not control for types of jobs,

and it was unable to test policy effects on land use.

Economic Indicators

The ratio of low income households and housing growth was the study's proxy for

economic indicators. While the chicken and the egg argument regarding housing and population

location is a concern, the study found that new housing construction does not automatically

guarantee population growth. Housing growth had no effect on population growth in Model 3

whereas it did for Model 4. Neither model explains why housing growth was correlated to

population growth along the Southeast Corridor but not the Southwest Corridor. One reason may

be that the latter corridor experienced a market surplus in housing, indicative of the recent

recession, and the former did not. It is also unclear if social equity is an issue. The income

variable was not significant.

Research Question, Hypotheses, and Policy Implications

What transportation and land use conditions encourage the general population to locate

near light rail? The evidence is mixed. Three conclusions are drawn from the statistical evidence

from this study. First, accessibility is directly related to population growth near light rail, as

evident in Models 1, 2, and 5. Specifically, job proximity to transit is an important indicator of population growth and population density. A caveat is that accessibility is negatively correlated to population density, as shown in Model 5. One possible explanation is that land use mix within the Travel Analysis Zones (TAZs) along suburban corridors may not be diverse enough to allow for the general population to grow in conjunction with jobs. It may too early to draw a conclusion with certainty, though. As discussed previously, the City of Denver adopted its zoning ordinance in 2010, and suburban cities served by light rail such as Greenwood Village and Englewood have only recently adopted supportive of TOD policy (Regional Transportation District, 2013).

A second conclusion is that accessibility to the Central Business District (CBD) did not influence people's decisions to locate near light rail. Accessibility to the CBD was not significant in four of the five models tested. This is further supported by Podobnik (2011), who found that residents of the Orenco TOD lived there as a lifestyle choice. Finally, a third conclusion is that a good housing economy is vital to growth. Mentioned in the previous section, housing growth does not automatically guarantee that people will move near light rail. For example, housing growth was not statistically linked to population growth along the Southwest corridor. Models 2, 4, and 5 support the third conclusion. Models 2 and 4 found housing growth to be correlated to population growth. Multicollinearity was not a problem with those models. In addition, Model 5 found that accessibility to housing was correlated to population density. Thus, the following conclusions answer the research question:

- Job and housing near stations influence population growth
- Population growth near light rail requires a good housing economy

In the end, this study supports the first hypothesis, or that accessibility encourages population growth near light rail in urban and suburban areas. On the other hand, the second hypothesis is not confirmed. Evidence does show that accessibility encourages population growth near light rail when controlling for suburban areas. Based on these conclusions, what are the policy implications for the Denver region and elsewhere? Any policy discussion may be premature for reasons already discussed. The primary explanation for this answer is that many of the TOD-supportive policies in the region have only recently been adopted. It is therefore impossible to test their impact using existing data.

Still, enough research exists to make educated inferences. Higgins, Ferguson, and Kanaroglou (2014) found in a review of the literature that a number of conditions must be present for land use to change near light rail. Among them are improved accessibility, a strong regional economy, and supportive government planning and land use policy. The first two of the three were well-tested by this study. From a broader perspective, this study's conclusions and others discussed in Chapter 3 — the literature review — supports the third condition. If planners in the Denver region and other places want population to grow near light rail, then planning and land use policies must allow it. A concern is that TOD-supportive policies will not permit land use densities high enough to facilitate population growth that will in turn encourage ridership growth as opposed to ridership plateaus or declines.

Evidence for the third condition can mostly be drawn from Models 1 and 5, although all five models can be used as a justification. In Model 5, as housing accessibility improved by one in a TAZ, population density in suburban areas increased by 0.98, *ceteris paribus*. On the other hand, as job accessibility improved by one, population density in suburban areas decreased by 0.07, *ceteris paribus*. Stated another way, population density essentially did not change in TAZs

that experienced improved job accessibility. For Model 1, as job accessibility improved by one in urban and suburban station areas, the general population grew by 7.03 persons, *ceteris paribus*. In comparing the two models, it appears that land use mix supports population growth in the urban areas more so than suburban areas.

Model Improvement

This study is only the beginning. Future research could improve upon it by doing the following:

- Purchase and geocode employment data from the Colorado Department of Labor and Employment for the years 1990 and 2000, assuming it is available

- Use the data to add a control variable for a true DID analysis for Models 1, Model 3, and Model 4

- Expand the study area to include areas outside the half mile buffer zone

- Incorporate the accessibility variables to include a utility-based accessibility variable

- Include recently-adopted land use policy for station areas

- Differentiate between the types of jobs near light rail stations to isolate each's effect on population growth

- Control for the type of housing growth; i.e., renter versus ownership

- Measure social conditions near light rail, such as crime rates

- Calculate a land use entropy index to test the land use policy's influence on population growth

Conclusion

In some ways, the United States has come full circle in transportation and land use during the last 130-plus years. Prior to the 1880s, cities were blamed for social problems, so politicians and planners believed outward growth could alleviate disease, poverty, and crime. Most people were still confined to urban areas until the streetcar emerged as a new technology. It moved people faster and farther at an affordable nickel fare than previous transportation technologies. Streetcar suburbs formed along corridors while ridership grew year after year. Eventually mass motorization disrupted mass transit, and a litany of policies supporting new road development subsidized the automobile while the streetcar was left to market forces (Mallach, 2010; Jackson, 1985).

The streetcar all but disappeared after World War II when the suburban housing pace quickened, which was helped by highways connecting cities to the periphery. Many American cities lost populations as the middleclass left them for the suburbs (Jackson, 1985). The tradeoff was that households drove to work farther to live in larger homes (Janelle, 1995). Americans were more mobile, but urban planners wondered if the external costs were too high.

To mitigate sprawl, planners began envisioning American cities with European-like urban rail: light rail. The goal was to encourage compact development along its corridors. San Diego was the first city to open a line, and more than 30 cities followed (Sutherland, 2010; Thompson, 2003). Since then, critics and supporters have debated its merits. This means that as other regions plan to implement light rail, its study will continue to be a worthwhile endeavor — especially in places such as Denver that have invested in multimodal projects and land use policy. They are good urban laboratories.

One issue is that current data do not enable the best analysis. Past studies have traded off research aims with what is realistic from data collection. This study is no different. It is unique in how it rigorously tested accessibility as a land use and transportation variable. The models developed here are easy to communicate and practical for planning practice. They do not require data collection beyond what is required for long range transportation planning. The models can be expanded and used to evaluate light rail systems as they mature. The results can also help guide future policy and planning. For example, evidence clearly suggests that mixed uses are important for encouraging population growth.

It may too early to determine what is truly happening in the Denver region using the most recent data. Anecdotal evidence shows that new development is occurring along the light rail corridors. An important question for future research is if the population will continue to grow near station areas. A concern is that TOD-supportive policies will not allow land use densities high enough to facilitate population growth that will in turn enable ridership growth as opposed to ridership plateaus or declines. In addition, as local governments adopt new land use policies, it is important that researchers revisit the area to continue to evaluate policies. Meantime, planners, policymakers, and the general public should strive to use existing research to disentangle sound evidence from opinion-based propaganda to ensure a rational planning process.

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APPENDIX A:

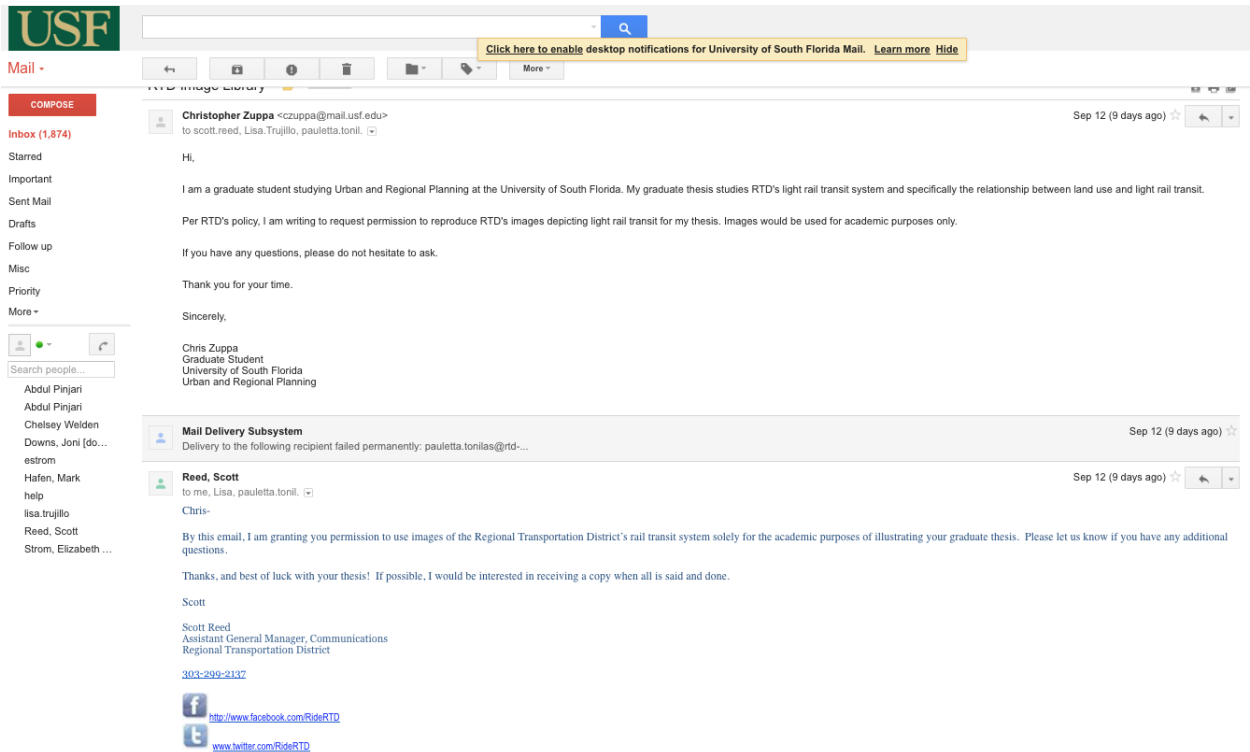# REGIONAL TRANSPORTATION DISTRICT CORRESPONDENCE

Figure A1. E-mail Correspondence with Regional Transportation District

APPENDIX B:

HYPOTHESES

Table B1. Contingency Tables and Coefficent Hypotheses.

Equation	Hypotheses Tested	Result
Contingency Tables	H_{01}: Twenty year population growth is not a function of the transportation project. H_{a1}: Twenty year population growth is a function of the transportation project.	Null Rejected
	H_{02}: Ten year population growth is not a function of the transportation project. H_{a2}: Ten year population growth is a function of the transportation project.	Null Rejected
	H_{03}: Five year job growth is not a function of the transportation project. H_{a3}: Five year job growth is a function of the transportation project.	Null Rejected
Model 1	H_0: Accessibility to jobs does not influence population growth near light rail, *ceteris paribus*. $\beta_1=0$ H_A: Accessibility to jobs influences population growth near light rail, *ceteris paribus*. $\beta_1\neq0$	$\beta_1\neq0$
	H_0: Accessibility to the CBD via light rail does not influence population growth near light rail, *ceteris paribus*. $\beta_2=0$ H_A: Accessibility to the CBD via light rail influences population growth near light rail, *ceteris paribus*. $\beta_2\neq0$	$\beta_2=0$
	H_0: Housing growth does not influence population growth near light rail, *ceteris paribus*. $\beta_2=0$ H_A: Housing growth influences population growth near light rail, *ceteris paribus*. $\beta_3\neq0$	$\beta_3\neq0$

Table B1 (Continued). Contingency Tables and Coefficent Hypotheses.

Equation	Hypotheses Tested	Results
Model 2	H_0: The number of Park-and-Ride spaces does not influence the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_1=0$ H_A: The number of Park-and-Ride spaces influences the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_1\neq0$	$a_1=0$
	H_0: Accessibility to jobs and housing does not influence the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_2=0$ H_A: Accessibility to jobs and housing influences the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_2\neq0$	$a_2\neq0$
	H_0: Accessibility to the CBD via light rail does not influence the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_3=0$ H_1: Accessibility to the CBD via light rail influences the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_3\neq0$	$a_3=0$
	H_0: Income does not influence the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_4=0$ H_1: Income influences the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $a_4\neq0$	$a_4=0$

Table B1 (Continued). Contingency Tables and Coefficent Hypotheses.

Equation	Hypotheses Tested	Results
Model 3	H_0: Accessibility to jobs does not influence population density growth near light rail in suburban areas, *ceteris paribus.* $b_1=0$ H_A: Accessibility to jobs influences population density growth near light rail in suburban areas, *ceteris paribus.* $b_1 \neq 0$	$b_1=0$
	H_0: Accessibility to the CBD via light rail does not influence population density growth near light rail in suburban areas, *ceteris paribus.* $b_2=0$ H_A: Accessibility to the CBD via LRT influences density growth near light rail in suburban areas, *ceteris paribus.* $b_2 \neq 0$	$b_2= 0$
	H_0= Housing growth does not influence population density growth near light rail in suburban areas, *ceteris paribus.* $b_3=0$ H_A: Housing growth influences population density growth near light rail in suburban areas, *ceteris paribus.* $b_3 \neq 0$	$b_3= 0$
	H_0: The presence of the T-REX corridor does not influence population density growth near light rail in suburban areas, *ceteris paribus.* $b_4=0$ H_A: The presence of the T-REX corridor influences population density growth near light rail in suburban areas, *ceteris paribus.* $b_4 \neq 0$	$b_4 \neq 0$
Model 4	H_0: Accessibility to jobs does not influence population density growth near the Southwest Corridor, *ceteris paribus.* $c_1=0$ H_A: Accessibility to jobs influences population density growth near the Southwest Corridor, *ceteris paribus.* $c_1 \neq 0$	$c_1=0$
	H_0: Accessibility to the CBD via light rail does not influence population density growth near the Southwest Corridor, *ceteris paribus.* $c_2=0$ H_A: Accessibility to the CBD via light rail influences population density growth near the Southwest Corridor, *ceteris paribus.* $c_2 \neq 0$	$c_2=0$
	H_0= Housing growth does not influence population density growth near the Southwest Corridor, *ceteris paribus.* $c_3=0$ H_A: Housing growth influences population density growth near the Southwest Corridor, *ceteris paribus.* $c_3 \neq 0$	$c_3 \neq 0$

Table A1 (Continued). Contingency Tables and Coefficent Hypotheses.

Equation	Hypotheses Tested	Results
Model 5	H_0: Accessibility to jobs does not influence population density near light rail in suburban areas, *ceteris paribus*. $\alpha_1=0$ H_A: Station area accessibility to jobs influences population density near light rail in suburban areas, *ceteris paribus*. $\alpha_1\neq0$	$\alpha_1\neq0$
	H_0: Accessibility to housing does not influence population density near light rail in suburban areas, *ceteris paribus*. $\alpha_2=0$ H_A: Station area accessibility to housing influences population density near light rail in suburban areas, *ceteris paribus*. $\alpha_2\neq0$	$\alpha_2\neq0$
	H_0: Accessibility to the CBD via light rail does not influence population density near light rail in suburban areas, *ceteris paribus*. $\alpha_3=0$ H_A: Accessibility to the CBD via light rail influences population density near light rail in suburban areas, *ceteris paribus*. $\alpha_3\neq0$	$\alpha_3\neq0$
	H_0: The presence of the T-REX corridor does not influence population density near light rail in suburban areas, *ceteris paribus*. $\alpha_4=0$ H_A: The presence of the T-REX corridor influences population density near light rail in suburban areas, *ceteris paribus*. $\alpha_4\neq0$	$\alpha_4=0$
	H_0: Income does not influence the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $\alpha_5=0$ H_1: Income influences the number of people living near light rail in urban and suburban areas, *ceteris paribus*. $\alpha_5\neq0$	$\alpha_5=0$