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Economic and Traffic Impacts Following the Installation of New Bicycle Facilities: A Denver Case Study

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ECONOMIC AND TRAFFIC IMPACTS FOLLOWING THE INSTALLATION OF NEW BICYCLE FACILITIES: A DENVER CASE STUDY

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by

Stephen Antonio Rijo

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Third, protected bike lanes (PBLs) improve overall safety for all users and encourage more "types" of bicyclists to use the facility. Lastly, PBLs increase overall bicycle traffic, while simultaneously decreasing the number of traffic violations and sidewalk riding counts. It represents a next step towards cultivating a method to provide an unbiased view of the direct economic impacts of cycling infrastructure improvements.

Acknowledgements

"If you want to go fast, go alone. If you want to go far, go together." ~ *African Proverb*

I want to make sure to thank some of the key individuals who helped make my Masters' thesis a reality. First of all, I thank Dr. Andy Goetz and Dr. Eric Boschmann from DU's Geography Department for encouraging me to explore new research topics. I also want to thank all of my other colleagues from DU, and my entire thesis committee, for assisting my research and providing invaluable feedback along the way. I am also grateful for Parry Burnap, Chad King, and Kevin Williams for always making themselves available to help with my research. I would like to acknowledge Rachael Bronson, for taking me on as a research intern, and everyone else at Public Works, who were always open to sit down and brainstorm. Next, I need to make sure to thank my managers and colleagues at my other two jobs, namely Genevieve Hutchison and the planning department at RTD and Molly North and the other staff at BikeDenver, who participated in countless thought exercises that guided my research. I am also grateful for PeopleforBikes for funding my position at BikeDenver. I must express gratitude to Mike Aleksick from the Office of the Controller, who provided invaluable help with my research and was there for every step of the sales tax data collection. In addition, I would like to thank Councilmen Nevitt's Office and the Old South Pearl Merchants Association for their help on South Pearl Street. Most importantly, I need to thank my understanding family, friends, and girlfriend, who were encouraging while I spent long hours in the office. I will close by thanking the city of Denver and all of its component parts for allowing a dynamic bike culture to flourish.

Table of Contents

List of Figures

List of Tables

Personal Background

"Life is like riding a bicycle. To keep your balance you must keep moving."

Albert Einstein, Letter to his son Eduard, 1930

I want to start with a brief personal background to help contextualize my thesis for the reader. I grew up in Basking Ridge, NJ, a medium sized suburban town approximately 30 miles west of New York City. My undergraduate degree is in Environmental Policy from Colorado College (CC), where I focused on the human environment interaction through a policy, economic, and anthropologic lens. After CC, I came to The University of Denver (DU) to study human geography as a Graduate Teaching Assistant. My initial explorations at DU highlighted an interest in alternative transportation modes, namely the bicycle and transit, which encouraged me to take more transportation, sustainability, planning and Geographic Information Systems (GIS) courses.

After my first year at DU, I was hired by the Regional Transportation District (RTD) as the Planning Coordination Annual Intern for the Planning Department. This position provided excellent exposure to the regional components of alternative transportation planning and allowed me to focus on the intersection of bicycles and transit. Around the same time, I also received an unpaid Research Internship with the City and County of Denver's Department of Public Works. The research internship allowed me to conduct counts on the newly constructed 15th Street Protected Bike Lane (PBL) and gain exposure to the city-level planning processes related to bikes.

Around the start of my second year at DU, I was approached by BikeDenver about a new Business Network Coordinator position. I knew this was too good an opportunity to pass up and accepted their offer. My time at BikeDenver has exposed me to grassroots advocacy and allowed me to interact with many of Denver's bike-minded individuals and businesses.

The aforementioned positions I've held over the past two years helped support my academic interests and allowed me to get compensated for some of my research. I hope this helps to contextualize my research, and I would like to take this opportunity to thank you for picking up my thesis.

Introduction

"When I see an adult on a bicycle, I do not despair for the future of the human race"

H.G. Wells

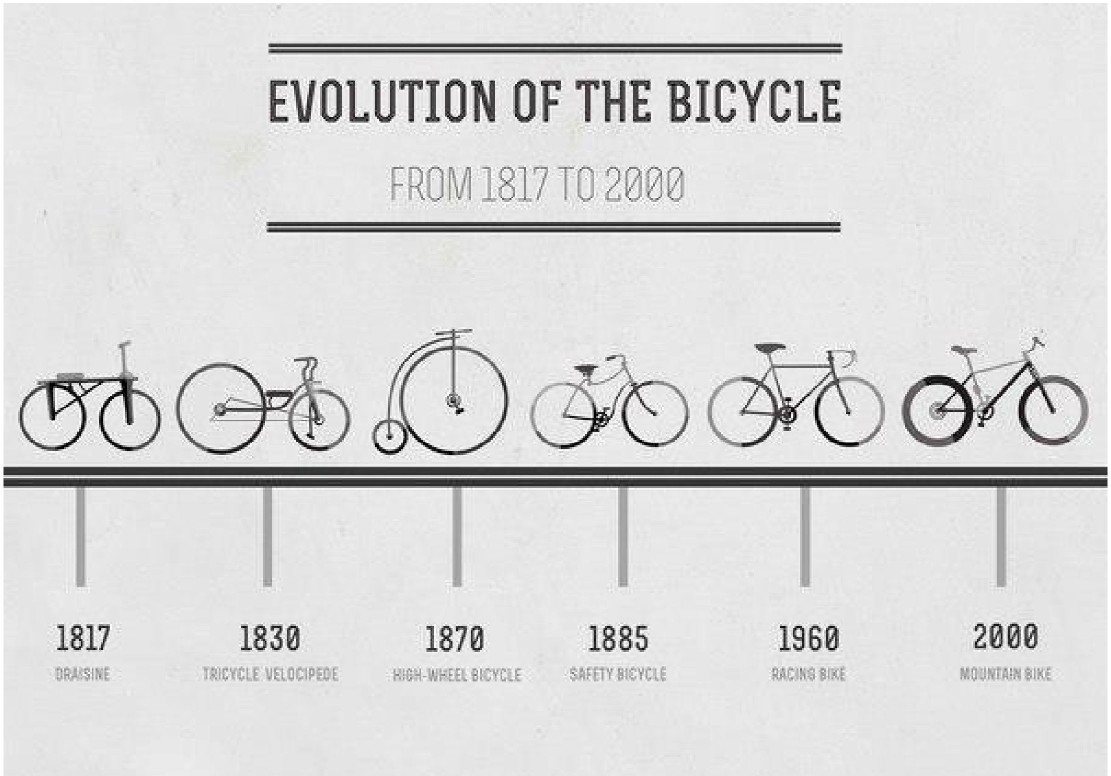
H.G. Wells' kind words for the bicycle are as relevant today as they were during the past bicycling renaissance in the late 19th century. Humans are an impressively mobile species, and our drive to go further and faster than past generations has led to some tremendous transportation innovations. Humans have access to cars that can take us across the country, high-speed trains that can zip us anywhere we can build tracks, massive ocean liners that can take us across the seas, commercial planes that can circle the globe in 12-24 hours, and rockets that can send men beyond our atmosphere into outer space. The aforementioned transportation innovations have spurred economic development and created a truly global economy (Rodrigue et al. 2013). Unfortunately, the excessive energy, land use, and monetary requirements of these high-speed and long-distance modes have led researchers to question whether this development pattern is sustainable, or equitable, for all of humankind (Black 2010). America has an overwhelmingly auto-centric system where car ownership is a prerequisite to full mobility (Newman and Kenworthy 1999; Newman and Kenworthy 2011; Cohen 2012). While the US' auto-centric system introduced unprecedented levels of mobility, the current level of driving worsens our health, degrades our environment, fragments our cities, and kills approximately 37,000 people each year (ASIRT 2015). America's current transportation system poses unique challenges for decision makers because it is a broad reaching issue that requires changing current practices. The current externalities of America's auto-centric system suggest that the bicycle might be the best mobility tool, especially for shorter distance trips (Black 2010).

This research aims to uncover the economic and traffic impacts of new bicycle facilities in Denver, CO. I conducted a mixed-methods analysis on two local urban neighborhoods to uncover the impacts of newly added bike facilities. The research is informed by the US' recent departure from the historical vehicle miles traveled (VMT) trends, often referred to as "peak travel". While there is weak consensus surrounding the exact cause of the decline in VMT, Americans are driving less and therefore opting to use alternative transportation methods instead (Polzin 2006; Puentes and Tomer 2008; Lucas and Jones 2009; Millard-Ball and Schipper 2011; Miller 2012). The following research calls on the need to understand the importance of alternative transportation infrastructure improvements and how they impact local communities and businesses. I address the overarching question, "What are the impacts of new cycling facilities?" and also suggest how to employ these findings in future transportation projects. The research uses a geographic analysis of monthly sales tax, traffic counts, transit access, and land use data to highlight economic impacts following the installation of new bike facilities. I conducted over 100 hours of observational research and counts on Denver's first protected bike lane (PBL) on 15th Street to supplement my geographic analysis and uncover general usage levels, safety conflicts, and other miscellaneous observations. A comprehensive analysis of Park-n-Ride utilization across the RTD jurisdiction, allowed me to assess the viability of encouraging patrons to access transit by bike instead of by car. I conclude with an integration of my findings from the preceding three methods to suggest how planners, policy makers, and other relevant stakeholders can build the best transportation network for Denver's future.

A Brief History of Bicycling in the US

Bicycles have been around for centuries, but the past decade has experienced a renaissance of publications related to cycling and the benefits of this ultra-efficient transportation mode (Rosen et al. 2007; Mapes 2009; Byrne 2010; Heinen et al. 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Henderson 2013). In order to understand the current state of bicycle affairs, it is beneficial to have a brief understanding of bicycle history. Scholars still debate the exact timing of the first bicycles, but they generally agree that the first two-wheeled vehicles, the draisine and velocipede, were introduced in the early 19th century. Fast forward through a half-century of experimental design, and we start to see the high-wheeled "penny farthing" bicycles. In the 1880s we begin to see the first bicycles to resemble modern bicycles, called safety bicycles. A simplified timeline of bicycle evolution is included in Figure 1 below for reference. Cycling was regarded as a counterculture activity for the majority of the 19th century, but the advent of the safety bicycle changed this (Herlihy 2004).

Figure 1: Evolution of the Bicycle



Source: Rose 2014

Safety bicycles sparked the first cycling renaissance of the 1890s and helped make cycling more accessible to the general public (Horton et al. 2007). The newfound popularity of biking pushed planners to pave roads and even influenced the creation of entire towns (Reid 2014). One example is the town of Valley Stream, Long Island, on the border of Queens, in Nassau County, New York. Valley Stream was built to service the "throngs of cyclists" that would come to Merrick Road every weekend. The very first hotels and businesses were built for the sole purpose of catering to the large number of cyclists that would visit Valley Stream from the city. Some say that the bicycle created Valley Stream in a similar way that gambling created Las Vegas and that car racing created Daytona Beach (BikeSnobNYC 2010). While Merrick Road is a far cry from the biker's paradise it used to be, the fact that bicycles influenced the entire development pattern of a town is significant.

This discussion of bicycle oriented development (BOD) and current lack of facilities often leads one to wonder what happened next. History tells a story of territoriality, private interests, and social forces combining to overshadow the bicycle. After the turn of the century, more US citizens began to desire cars, and the car companies wanted more space for consumers to use their products (Hanson and Giuliano 2004). The following decades began to see the bicycle, and pedestrian for that matter, slowly squeezed off of the roads until they were completely pushed off. Streets that were designed as communal space were converted over to thoroughfares, and we began to see policy take similar shifts (Jacobs 1961). Concepts like sidewalks, crosswalks, and jaywalking were introduced by the auto lobby during this time to speed up car traffic and further remove the pedestrian from the road. Before long, most American roads were an exclusively automobile space, and the paved street networks created by-cyclists-for-cyclists became inhospitable to the bicycle (Herlihy 2004; Rosen et al. 2007).

Fast forward to the post World War II (WWII) era in the US, and the bicycle was an afterthought in most transportation discussions. In sharp contrast, several progressive European countries objected to the auto-dominant design patterns, but this was certainly not the case in the US (Martens 2007). The federal government decided that they wanted to provide returning veterans with the "American Dream" of owning one's own house, yard, and car. This fueled the GI Bill and the creation of the interstate highway system that incentivized car use above all else (Gallagher 2013). Planners also adopted the automobile level of service (LOS) metric that completely overlooked pedestrian mobility (Henderson 2013). As if things could not get any worse, the introduction of the "vehicular cycling" concept by John Foster in the 1970s further limited the attractiveness of bicycle transportation for the masses. Foster's book, titled *Effective Cycling*, affirmed that the safest way to ride a bicycle was to do so like a vehicle (Foster 1993). While his concept sounds good in theory, it encourages high-stress riding with traffic that is obviously unappealing for most people. Despite good intentions, the impacts of *Effective Cycling* are still felt today with the layout of shared roadways and traffic laws that treat the bicycle user as a car. All of the aforementioned factors created a hostile bicycle environment that is still present in most US cities.

The preceding discussion of the bicycle helps to contextualize it in the broader land use and transportation framework, while also helping to explain why we do not need new roads. New roads and more lanes sound good in theory, but the concept of induced demand explains why new car infrastructure only spurs increased car ownership that eventually leads to the same traffic problems from before the lanes were added. Induced demand is an accepted economic concept, yet many Americans are still hesitant to get out of their cars as showcased by one famous blogger's take on a proposed bike facility in Boston, MA. In his article, titled "Boston's Plan to Replace Parking Spots with Bike Paths is Idiotic", Jerry Thornton goes on to criticize plans to improve cyclist safety, improve mobility, and activate a retail corridor by saying, "There's not a smarmier, more self-satisfied and righteously indignant subset of the culture than bike riders" (Thornton 2015). He then disputes findings from a widely accepted Portland study on spending habits by saying, “Assuming that’s even true, which I am not…I’ll suggest people in cars spend a lot more on food than some neckbeard squeezed into spandex bike shorts” (Clifton et al. 2012; Thornton 2015). Thornton’s disdain for bicyclists oozing off the page serves as an unfortunate reminder that, while the bike mode share is growing, there are still many who believe that people on bikes do not deserve to use the road.

The seas of change are rarely swift, but progressive thinkers are demanding increased alternative transportation options that are starting to influence policy. These discussions frequently highlight the bicycle as an inexpensive, efficient, cost-effective, healthy, low impact, local, sustainable, equitable, accessible, and enjoyable transportation mode that exhibits unparalleled benefits to other modes for shorter distance trips (Rosen et al. 2007; Mapes 2009; Byrne 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Henderson 2013). Despite its recent praise, the bicycle is still slow to catch on as a legitimate transportation option. One reason for this is that bicycle groups historically advocated for the “feel good” benefits of cycling and have struggled to enact major change when framed this way. In light of these past shortcomings, it is time to frame the argument so that it resonates with policy makers and other local stake holders. What better way to do this than by framing the discussion with language they understand–dollars and cents? The benefits of increased bicycle transport have been quantified in many ways, ranging from health benefits to environmental benefits, but there has been less attention paid to the economic impacts of the bicycle (Krizek 2007; Heinen et al. 2010; Meisel 2010; Cheng et al. 2011; Denver Moves 2011; Buehler and Pucher 2012; Clifton et al. 2013; Blue 2013; Handy et al. 2014; Rybarczyk 2014). The US is at a crucial time, where the bicycle is experiencing a renaissance of similar magnitude to the turn of the 20th century, but the bicycle needs a considerable push to jump from counterculture back into the mainstream. While there are numerous ways to advocate for improved bicycle facilities, I assert that the most effective method is to highlight the economic benefits of increased cycling for local neighborhoods and business districts. This forces decision makers to acknowledge studies that quantify the impacts of increased bicycle use into directly tangible economic benefits. The bicycle may not be a silver bullet that will solve all transportation issues, but it is safe to say that many US cities will experience major benefits if they prioritize the installation of low-stress bicycle facilities. Roads were not built for cars, and now is an excellent time to highlight the cost effectiveness of assigning US road space back to bicycle uses in an effort to create low-stress networks that encourage people to pedal more (Reid 2014).

Theoretical Background Problem Statement

A brief history of American biking highlights several shortcomings of bicycle transport. The US currently exhibits a suppressed need to conduct research on how to improve the current state of affairs. For many decades, transportation planning rested on the assumption that automobile use, measured in VMT, increased in a lockstep fashion with overall Gross Domestic Product (GDP) growth (Battelle 2007). The decade between 2002 and 2012 saw an extraordinary departure from the historical trend, where per-capita VMT was lower at the end of the decade than at the start. The year 2007 was another remarkable year for American transportation planning, as it marked peak VMT, also known as “peak travel”, despite continued US population growth (Millard-Ball and

Schipper 2011). Several studies indicate that individuals are driving less, yet there are fewer studies targeting the alternative modes of transportation being substituted (Cohen 2012; Piatkowski et al. 2014). The preceding statistics highlight the need for increased research on the impacts of alternative transportation improvements, namely the bicycle.

Bicycling is a growing topic of discussion within urban and transportation geography circles, especially with the recent emphasis society places on sustainability (Keeley 2001; Culley 2002; Rosen et al. 2007; Krizek 2007; Mapes 2009; Pucher and Buehler 2009; BikeSnobNYC 2010; Byrne 2010; Heinen et al. 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Blue 2013; Henderson 2013; Rybarczyk 2014). Unfortunately, the bicycle remains an underutilized mode of transportation in the majority of American cities. Low bicycle mode share numbers are largely due to gaps in the historical planning process that caused the lack of infrastructure visible today (Handy et al. 2014). Numerous Americans still ride their bikes for transport despite this lack of infrastructure, but the bicycle's true potential remains untapped due to these shortcomings. The urban transportation literature highlights the multifaceted nature of this issue, as it contains everything from basic urban design to social equity and policy dimensions (Hanson and Giuliano 2004; Rybarczyk 2014). While there has been an increase in bicycle research and ridership, it still accounts for less than 10% of commuters in all large US cities (US Census ACS 2012). A recent report from The Bureau of Labor Statistics (BLS) states that the average American spends $9,104 on annual transportation costs while the average income before taxes is $64,432. This means that average individuals spend about 14% of their income on transportation, which is second only to housing and $2,439 more than they spend on food (BLS 2015). These statistics ought to instill a sense of humility for transportation planners, as the auto-centric system is one of the chief contributors to humankind's currently unsustainable lifestyle.

My research emphasizes the impacts of improved bicycle facilities in economic terms by analyzing sales tax, traffic count, transit access, land use, and other data. This project also highlights how improvements to Denver's bicycle network will encourage individuals to cycle for transport and can foster a host of benefits at the local and regional scale. I also assert that we must improve alternative transportation offerings in order to maintain similar levels of mobility without compromising humankind's future. While this study explicitly targets the bicycle as a means of transport, it also touches on the interplay of bicycles and transit because a geographic transportation analysis that fails to mention complementary modes is incomplete. A mixed-methods analysis on the benefits of improved bicycle facilities adds to the discourse of why we ought to expand Denver's bicycle network in the peak travel context. I will shed light on the best scales of implementation for Denver's current transportation network, as a diverse system is more resilient than a singularly auto-centric model.

Planners in large metropolitan areas, especially those located in the western US, have noticed that they need to rethink their current transportation networks if they hope to see continued growth. The car-centric planning of the past few decades has created unsustainable land and water uses across the Denver metropolitan area. Peak travel and shifting transportation interests among younger generations have motivated Denver to change its focus from being a car-oriented metropolis to a transit-oriented, bike- and pedestrian friendly city. Denver has reacted by improving many of the local transportation networks. These improvements range from unprecedented transit improvements with the help of the FasTracks transit expansion to Bike and Pedestrian improvements informed by the Denver Moves Bicycle and Pedestrian plan. The recent interest in improving the bicycle network is highlighted by the installation of Denver's first PBL on 15th Street in Downtown Denver and the installation of Denver's first on-street bike corrals along South Pearl Street. Environmental and health concerns have made alternative transportation a real topic of interest for cities that want to ensure a trajectory of future growth. While many agree that transit, biking, and walking amenities are important, there is less understanding of the nuances of how these modes impact local economic performance.

This research targets the economic impacts of improved bicycle facilities on local communities and their businesses. Increased knowledge of the impacts of improved bicycle facilities will arm US planners and policy makers with more information on how to encourage people to drive less and use alternative transportation modes instead. A study on the impacts of bicycle facilities is timely in light of the city's updates to the Denver Moves Plan, a relatively supportive political climate, PeopleForBikes' Green Lane Project, and an exploding bike culture, all of which increase the focus on bicycles in Denver. Ultimately, the findings from this research will inform the broader bicycle discourse and assist other cities dealing with similar transportation challenges.

Importance of Study

The bicycle is an extremely useful transportation tool with many benefits. Studies show that the bicycle is an inexpensive, efficient, cost-effective, healthy, low impact, local, sustainable, equitable, accessible, and enjoyable transportation mode that exhibits unparalleled benefits to other modes for shorter distance trips (Rosen et al. 2007; Mapes 2009; Byrne 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Henderson 2013). The following research adds to the transportation literature on the bicycle and the impacts of infrastructure improvements. The approach combines a sales tax and GIS analysis of other related data with observational research and user counts to increase knowledge on the impacts of bicycle facility improvements. Historical transportation analyses often focus too heavily on the statistical components of transportation, which is inherently problematic, considering that the real world does not follow statistical laws (Hanson and Giuliano 2004). This mixed-methods research suggests the economic impacts of improving pedestrian-scale transportation infrastructure in light of the US' currently unsustainable auto-centric system. Denver is an interesting case city because it exhibits progressive cycling initiatives, yet still has significant room for future improvement. This research will uncover how local communities and businesses are impacted by cycling facility improvements and may also suggest how to improve cycling geographies at other scales.

More broadly, this research project contributes to the discourse surrounding alternative modes of transportation. Transportation experts suggest that peak travel will have major implications for the future of American urban and transportation planning:

therefore we must explore non-auto forms of transportation to meet shifting demands (Polzin 2006; Puentes and Tomer 2008; Lucas and Jones 2009; Millard-Ball and Schipper 2011; Miller 2012). This research suggests why planners and policy makers must increase non-auto transportation modes and the economic benefits of doing so. Denver is also a noteworthy case city because it is one of the leading bicycle cities in the US, based on various factors, and recently ranked sixth in commuter bicycling rates among large US cities in 2012 (US Census ACS 2012). Denver is currently pushing numerous bicycling initiatives, such as updates to the Denver Moves plan, the PeopleForBikes Green Lanes Project, and many smaller initiatives. Consequently, this research will directly impact planning and implementation efforts in Denver and may also speak to national-scale issues. We are at a unique place in American history, where improvements to bicycle facilities can foster mutually beneficial outcomes for all transportation modes. The US' current transportation climate exhibits a need for the proposed research to inform relevant decision makers as they attempt to sculpt an equitable and sustainable transportation system in light of peak travel. The aforementioned claim that the bicycle is an inexpensive, efficient, cost-effective, healthy, low impact, local, sustainable, equitable, accessible, and enjoyable transportation mode, helps to inform my research (Rosen et al. 2007; Mapes 2009; Byrne 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Henderson 2013).

Limitations

Several key limitations occurred while conducting this original research project. First, I experienced technical difficulties and time delays while working with sales tax data that had to be aggregated. The five-year timelines for sales tax data also greatly narrowed the sites that were available for analysis. Additionally, extensive data cleaning constrained the number of study sites I was able to analyze. The low resolution of the traffic camera used for observational research and counts on 15th Street also limited the level of detail I was able to analyze. Institutional Review Board (IRB) requirements presented another key limitation that prevented me from conducting a brief survey near the end of my research. While many of the aforementioned limitations were from necessary safeguards to protect the city and its residents, their impact is worth noting.

Literature Review

> *It is by riding a bicycle that you learn the contours of a country best, since you have to sweat up the hills and coast down them. Thus you remember them as they actually are, while in a motor car only a high hill impresses you, and you have no such accurate remembrance of country you have driven through as you gain by riding a bicycle.*
>
> *Ernest Hemingway*

Overview

VMT, an essential statistic for transportation planners, has guided infrastructure developments since the advent of the personal automobile. Historically, VMT rates have been a direct indicator of national prosperity (when tied to GDP) and individual affluence (when tied to household income) (Carlson and Howard 2010; Ecola and Wachs 2012; McMullen and Eckstein 2012). The historical fluctuations of VMT and Gross Domestic Product (GDP) were described as exhibiting a lockstep relationship, where they saw simultaneous increases and decreases. One example of this relationship is how VMT increased 3.6%, while disposable income increased 3.2%, over the same 18-year period prior to peak travel (Battelle 2007). While the causal relationship of VMT and economic activity is still up for debate, the recent decoupling of both indicators helps to highlight numerous questions for planners and policy makers alike. New questions on the causes of this historic reversal, implications for future transportation planning, and demand for infrastructure development are hot topics in transportation circles (Polzin 2006; Puentes and Tomer 2008; Lucas and Jones 2009; Millard-Ball and Schipper 2011; Miller 2012).

Certain scholars claim society is approaching a new normal (Ewing et al. 2008; McMullen and Eckstein 2012), while others believe this is an abnormally long dip, and that VMT and GDP will soon return to their historical relationship (Pozdena 2009). The peak travel phenomenon is a topic for contentious debate with serious implications for the US' transportation industry. While several scholars are focused on the causes of recent VMT trends, others have switched to study the impact of peak travel on modal switching and increased use of alternative forms of transportation (Jensen 1999; Hensher and Reyes 2000; Marshall and Banister 2000; Cherry and Cervero 2007; Tilahun et al. 2007; Hante et al. 2009). A reduction in overall VMT, coupled with continued population growth and similar levels of mobility, indicate that more individuals are using alternative modes of transportation than we have experienced historically. We must focus on the need to address modal switching and its relevant value-based components in order to shed light on the potential for non-auto transportation in the future (Hensher and Reyes 2000).

Empirical studies on the geography of urban transportation highlight various failures of the US' auto-centric transportation system to maximize utility for users, especially in densely populated urban areas (Hanson and Giuliano 2004; Transportation Solutions 2013). The US' auto-centric system has also fostered sedentary lifestyles as people no longer need to exert any physical energy to get from point A to point B. Nearly two-thirds of Americans now lead sedentary lifestyles, and the healthcare costs associated with this lack of exertion exceed $24 billion. Public health studies suggest that one solution to the lack of exercise in the US is to encourage cycling for transport (Rybarczyk 2010). Americans ought to reevaluate our transportation system that fails to maximize utility for urban users, and also encourages an unhealthy lifestyle that is costly for all.

In light of the aforementioned findings, urban and transportation planners often advocate for use of alternative modes of transportation, such as bus, train, walking, or biking. Denver specifically targeted active transportation in the most recent Denver Moves Plan that increases priority for projects to improve cycling and multi-use connections (Denver Moves 2011). Specific alternative modes of transportation experience varying levels of success, depending on local factors, including but not limited to density, zoning codes, and urban design (Cervero et al. 2002). One alternative mode of transportation that has received increased consideration from varying disciplines, industries, non-governmental organizations (NGOs), and levels of government is the bicycle (Rosen et al. 2007; Mapes 2009; Byrne 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Henderson 2013). While the car is still the ideal transportation method for long distance trips in the current system, cycling provides copious advantages, including health, cost, congestion, and environmental benefits (Krizek 2007; Heinen et a. 2010; Meisel 2010; Cheng et al. 2011; Buehler and Pucher 2012; Clifton et al. 2013; Blue 2013; Handy et al. 2014; Rybarczyk 2014). In light of the economic, social, and environmental benefits of cycling for transport, scholars must increase knowledge surrounding the role of improved cycling facilities, especially when close to transit, so that planners and policy makers can appropriately structure the transportation networks of the future.

Possible Explanations of Peak Travel

Saturation of Driving Demand Encourages Modal Switching

Elementary economic theory suggests that as the utility of a good or service diminishes, consumers turn to other goods or services to maximize their overall utility. The current peak travel phenomenon indicates that utility for personal auto use has reached saturation, with the negatives outweighing the benefits of driving and owning an automobile (Crozet 2009; Millard-Ball and Schipper 2011; Cohen 2012; Metz 2012). Diminishing utility for car use suggests that individuals have turned to alternative modes of transportation such as walking, biking, or transit use, and/or have reduced the number of trips overall (Polzin et al. 2004; Litman 2006; Lucas and Jones 2009; Madre et al. 2012). In response to this modal shift, scholars have identified the transit leverage effect, wherein there is a direct relationship between increases in transit ridership, leading to decreases in VMT (Newman and Kenworthy 2011). While the preceding paragraph discusses the market forces that influence modal switching, there is growing interest surrounding the value-based factors of driving less.

In contrast to the saturated personal auto market, the bicycle is currently experiencing a renaissance in the developed world (Rosen et al. 2007; Mapes 2009; Byrne 2010; Heinen et al. 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Henderson 2013). Increasing numbers of individuals have dusted off their bicycles and taken to the streets, in spite of an impressive lack of infrastructure. The lack of infrastructure highlights a need for increased scholarly inquiry on the economic, social, and environmental impacts of improved cycling facilities and how to integrate them with the current system. Additionally, an increased literature on the value-based components of modal choice will add to the discourse (Tilahun et al. 2007). Studies must target the impacts of improved cycling facilities and their role in bolstering transportation and mobility options for all.

“New” Urban Layout – Urbanism, Densification, and Equity Concerns

In addition to the saturation of driving demand, new patterns of urban layout appear to be responsible for peak travel and the increased use of alternative modes of transportation. Cities often function as economic hubs, but recently there has been a shift towards cities designed to maximize livability factors as well (Congress for the New Urbanism 2001; Fishman 2005). Many Americans have grown discontent with suburban sprawl, which is represented by a “fifth” in-migration back to urban cores (Fishman 2005). A rejuvenated interest in urban living, with mixed use, higher densities, and better access to alternative modes of transportation, allows for more individuals to live auto free and influence the VMT reductions (Ewing and Cervero 2010). Scholars also note several relationships between residential density and transportation choices. Density often suggests diversity of land uses and accessibility to destinations, which also imply transportation connectivity (Cervero et al. 2002; Cervero and Murakami 2009; Ewing and Cervero 2010). Others also cite that higher residential densities are associated with lower levels of car ownership, which ultimately leads to lower VMT in dense neighborhoods (Schimek 1996; Cervero and Kockelman 1997).

Studies also note that there are numerous transportation and mobility benefits from urban forms that cater to the agglomeration effects of bike-transit integration in Transit Oriented Developments (TODs) (Cervero et al. 2002; Pucher and Buehler 2009). One North American study focused on cities that had large cycling and transit mode-shares with efforts to target bike-transit integration. The study found the most important aspects of built environment design and public policy to be: secure bike parking at transit stops and stations, bike racks on busses, provisions for bikes on trains, and bike routes to and from transit stops (Pucher and Buehler 2009). These findings suggest that coordination between regional transit agencies, politicians, and local planners is necessary in order to create a built environment that encourages the use of alternative modes of transportation, namely bike-transit integration.

Pucher and Buehler's study also suggests that planners and policy makers ought to facilitate multi-use zoning in urban areas, namely surrounding transit, if they hope to further TOD and bikeability initiatives (Cervero et al. 2002; Pucher and Buehler 2008, Denver Moves 2011). However, planners must remain aware of the local and regional scales of implementation, which are best suited to TOD and bikeability. Additionally, the built environment provides an excellent avenue towards aligning TOD and bikeability initiatives. TODs inherently require some level of new development. In the interest of maximizing overall utility, developers need to create separate pedestrian infrastructure, including bike lanes and storage, to increase connectivity and incentivize bike use

(Calthorpe 2008). Finally, studies suggest that a population of pedestrians and motorists who possess a strong understanding of traffic laws will also improve overall safety, especially in high traffic transit nodes (Pucher and Buehler 2008; Mapes 2009). Creation of safe, convenient, and community-oriented environments around transit nodes, through the use of Public Private Partnerships (PPPs), mixed-use zoning, alterations to the auto-centric built environment, and educational programs will ultimately facilitate both TOD and bikeability objectives.

The final, and frequently overlooked, component of the new urban layout is concern for equity and fairness (Viegas 2001; Litman 2002; Fishman 2005; Sanchez and Wolf 2005). Fishman discusses a recent in-migration into urban areas by the creative class, while noting that low-income individuals are often displaced during this gentrification process (2005). Scholars, who focus on the equity component of displacement, found that market forces, such as increasing rents and property values, have forced an increasing number of low-income individuals into the suburbs (Lin 2002). Planners and policy makers must prioritize the creation of equitable TODs so that low-income families have access to transportation and mobility options, as they are often more reliant on transit than their wealthier counterparts. In light of these findings, scholars must not overlook the underserved populations such as need-based, female, juvenile, and elderly cyclists.

Recession and Rising Oil Prices

The economic recession coupled with rising oil prices are two more elements of peak travel. Basic economics suggests that rising oil prices will lead to a decrease in disposable income, and therefore a decrease in economic activity, thus highlighting the role of market forces in transportation choice. There is a vast body of literature on the role of gas prices and transportation mode choice. While the specifics vary slightly, every study noted an increase in transit ridership when gas prices were high (Litman 2004; Stern 2006; Currie and Phung 2007; Currie and Phung 2008; Mattson 2008; Budger and Kaffine 2009). A similar study, focused on cycling, found that, “the prevalence of cycling is higher in less sprawling areas and areas with higher gasoline prices” (Rashad 2009 pg. 1). These findings are not surprising but suggest the need for further study into the economic, social, and environmental impacts of improved non-auto transportation infrastructure, in light of peak travel.

Shifting Environmental Values

A final factor to help explain the peak VMT phenomenon is widespread shifting of environmental values. US environmental values are steadily increasing, since the green revolution, when many environmental statutes were passed in the 1960s and 1970s. Recent decades witnessed a significant increase in sensitivity to environmental and sustainability initiatives, thus bolstering overall environmental values (Dietz et al. 2005). Another similar study on energy use found a connection between education level, expressed by attainment of graduate degrees, and owning fewer cars (Goetzke and Weinberger 2012). Goetzke and Weinberger suggest that as one reaches a higher level of education, a car becomes less of a status symbol (2012). The aforementioned findings suggest that environmental values directly impact transportation mode choice, and therefore peak travel.

Impacts of Improved Cycling Facilities

An analysis of the peak travel literature highlights how planners and policy makers must rethink the fundamental assumption of historical transportation planning, that car use will always increase. Peak travel suggests that individuals now opt to drive less and use alternative modes of transportation more. While peak travel has positive externalities for environmental and urban sustainability, the general lack of non-auto transportation infrastructure is reason for concern. Scholars and planners have responded to this gap with studies on the benefits of improved non-auto transportation infrastructure (Krizek 2007; Heinen et al. 2010; Meisel 2010; Cheng et al. 2011; Denver Moves 2011; Buehler and Pucher 2012; Clifton et al. 2013; Blue 2013; Handy et al. 2014; Rybarczyk 2014). The aforementioned studies often cite impacts in economic, social, health, land use, and/or environmental terms, as discussed in the following section of this review.

Transit, biking, and walking are three alternative modes of transportation, often discussed in tandem. Studies indicate that the agglomeration effects of locating all three modes near one another leads to mutually beneficial outcomes, especially in TODs (Cervero et al. 2002; Martens 2007; Pucher and Buehler 2009). This research focuses on the impacts of cycling facilities, yet mentions transit infrastructure at the same time, because the two are not mutually exclusive. While the increased focus on cycling research is a relatively recent phenomenon, transportation scholars have studied the impacts of transit infrastructure for a long time (Wedderburn et al. 2013). There is a strong understanding of the long term benefits of multi-modal transportation networks, and cycling is a component of this. I believe it is important to contextualize a cycling study within the broader transportation literature so that my findings speak to those from other modes.

Economic Impacts

The economic, social, health, and environmental impacts of improved cycling facilities are multifaceted and are studied by scholars from varying disciplines (Spinney 2011; Dill 2013; Rybarczyk 2014). A book titled *Bikenomics* was recently published to dispense these concepts to the masses (Blue 2013). One Portland study found that cyclists spend more money overall at supermarkets than their car-driving counterparts (Clifton et al. 2012). There are also various publications that focus on specific components of the economic impacts of improved cycling facilities research.

Two recent studies examined local sales tax data as an indicator of neighborhood vitality in New York and Washington State (NYCDOT 2013; Rowe 2013). These studies used aggregated retail sales tax data from several fiscal years to pinpoint how the local businesses, whose sales are most likely to be impacted by street improvements, fared in comparison to similar businesses in areas with no street improvements. The NY and WA studies employed a unique mixture of methods to uncover local scale economic performance before and after the improved bicycle and pedestrian facilities were added. Both of the WA and NY studies found that streets with pedestrian improvements generally performed better than streets with no improvements, which suggests the importance of human-centric streetscapes for business success. Two studies from opposite ends of the country came up with interesting findings after using these methods, which motivated me to sculpt a similar method for this study.

Another growing area of research is the economic impacts of increased cycling in personal health and environmental terms. The Netherlands conducted a famous study to estimate the value of each human life after a devastating flood (Jonkman 2003). While it focused on flood risk, this research reinforced the premium on human life in the Netherlands. The impacts of this study are still apparent with the Netherlands' focus on preventative traffic safety, in part due to the high cost of losing a human life (Jonkman et al. 2003). Shifting back to the US, one study found the personal health benefits from increased activity and reduced greenhouse gas emissions to rank in the hundreds of millions of dollars (Guo and Gandavarapu 2010). Another study, which analyzed user fatality rates to highlight the benefits of a shift from auto travel to active transport, found major benefits due to increased exercise (Rabl and Nazelle 2012). The growing number of publications on the economic impacts of active transport in environmental and health terms highlights increased interest in future studies.

An increasing number of academic studies, and countless more white papers, attempt to quantify the economic impacts of cycling, cycling tourism, and the cycling industry (Krizek 2007; Meisel 2010; Cheng et al. 2011; Buehler and Pucher 2012; ADOT 2013; Clifton et al. 2013; Blue 2013; Handy et al. 2014; Rybarczyk 2014). Research on the economic impact of cycling facilities in North Carolina's Outer Banks indicated a conservative estimate of "$60 million, with 1,400 jobs created/ supported per year" (Meletiou et al. 2005).

Initial economic-impact analyses highlight that the cycling industry is significantly larger than previously predicted, but these analyses can be unreliable due to the large extrapolations, inconsistent methods, and potential for ulterior motives (Krizek 2007; Flusche 2012). Another phenomenon termed “the substitution effect”, or the rate at which users substitute an improved bicycle facility for another one, also complicates economic evaluation of cycling projects. Current research on the substitution effect asserts that it is extremely difficult to calculate, due to a high sensitivity to distance and other mode offerings (Hu and Schneider 2014). Scholars assert this can lead to problematic over calculations for the benefits of an infrastructure improvement, which is why the substitution effect is a noteworthy phenomenon (Piatkowski et al. 2014). The economic-impacts literature reveals a need for more transparent methods that target local scales of analysis.

Social, Equity, and Health Impacts

Another area with growing attention is the social impact of improved cycling facilities. Americans’ are slowly killing themselves, with their sedentary lifestyles, which has negative externalities in terms of social costs (Rybarczyk 2014). There is also increased attention to the actual experience of transportation and the social utility gained from non-auto commutes (Krizek 2007; Dill and McNeil 2012). The social impacts discourse also mentions, yet frequently overlooks, the equity component of alternative transportation modes. Low-income households are often the most reliant on transit, yet they rarely have a say in the planning process (Soursourian 2010). One can see how this is an unjust system, and that there is significant room for addressing the social concerns that transportation planning historically overlooks.

Research also indicates that there are numerous health benefits, in addition to the social benefits, of increased cycling. The health benefits of increased cycling levels are relatively straightforward, and they represent one of the largest positive impacts of improved cycling facilities. A comprehensive literature review found that there are major health benefits related to increased cycling and that cycling is currently an underutilized transportation mode (Nazelle et al. 2011). Transportation-related health improvements are also noteworthy in light of America's expensive healthcare system, and increased efforts to quantify the health related benefits of increased cycling are necessary (Guo and Gandavarapu 2010; Rabl and Nazelle 2012). There is also a relevant connection between the environmental benefits of greenhouse gas reductions and human health, which suggests that human and environmental health are closely related (Grabow et al. 2012; Maizlish et al. 2013).

Environmental Impacts

The environmental impact of improved alternative transportation infrastructure is another topic of growing interest. Several environmental benefits of alternative transportation include decreased noise and air pollution from reduced traffic congestion (Lee 1986; Litman 1994), reduced energy costs (Komanoff and Roelofs 1993), and overall improved environmental health (Newman and Kenworthy, 1999). Several other studies also found that there are billions of dollars in potential savings from reduced greenhouse gas emissions as a result of substituting the emission free bicycle for auto travel (Grabow et al. 2012; Rabl and Nazell 2012). An increased environmental focus also motivated scholars to reassess the sustainability of our transportation system with rather grim conclusions (Black 2010). While the specific level of environmental inquiry can vary across fields, many of the alternative transportation studies include environmental benefits of auto reduction.

An analysis of the relevant cycling literature highlights the need for a study on the impacts of improved cycling facilities at a local scale. Existing studies have quantified these impacts in economic, social, health, and environmental terms with a great deal of overlap between the different types of analysis. All of the preceding points showcase the need for a mixed-methods study that targets the benefits of infrastructure improvements. Such a study is especially relevant in Denver, where there are ambitious plans to expand the alternative transportation networks.

Land Use Impacts

Land Use is another key component of research on the impacts of new bike facilities. There is a long standing tradition of research on the land use impacts of highways and transit systems (Knight and Trygg 1977; Lee 1989; Guhathakurta et al. 1995; Huang 1996; Guiliano 2004; Ratner & Goetz 2012; Chakraborty et al. 2013). Stores carry textbooks on the land use impacts of highways and transit, yet historically, there has been less attention paid to the specific land use impacts of the bicycle (Guiliano 2004; Handy et al. 2013).

There are publications that discuss “livable streets” and the importance of planning neighborhoods that appeal to the pedestrian scale, but there are very few that solely target the bicycle (Appleyard et al. 1981; Ewing et al. 1996; Cervero 1996; Handy 2002; Dannenberg et al. 2003; Zhang 2004; Gregory 2006; Handy 2013). One study on land use and mode choice found that “residential densities exerted a stronger influence on commuting mode choices than levels of land-use mixture, except for walking and bicycle commutes.” (Cervero 1996 1) The need to sculpt inviting land uses to encourage people to use pedestrian modes is essential, especially with the relative gaps in the literature.

Integration of Literature

Peak travel is now a national phenomenon, yet there is still little consensus as to its root cause (Millard-Ball and Schipper 2011; Cohen 2012). Several scholars assert that this is the indication of a new normal, where VMT is no longer tied to economic growth, (Litman 2006) yet others assert it is an abnormal lag of little concern (Madre et al. 2012; Miller 2012). While there are numerous explanations for the peak travel phenomenon, none of the theories is accepted as universally true. Despite the uncertainties of peak travel, there is need for increased scholarship on the alternative modes of transportation that individuals can choose. This is especially true of bicycle-related topics, where more literature on the impacts of improved alternative transportation infrastructure is required (Keeley 2001; Culley 2002; Rosen et al. 2007; Krizek 2007; Mapes 2009; Pucher and Buehler 2009; BikeSnobNYC 2010; Byrne 2010; Heinen et al. 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Blue 2013; Henderson 2013; Rybarczyk 2014).

Several studies explore the impacts of improved cycling facilities in economic, social, health, land use, and/or environmental terms (Appleyard et al. 1981; Meletiou et al. 2005; Guo and Gandavarapu 2010; Nazzelle et al. 2011; Grabow et al. 2012; Rabl and Nazelle 2012; ADOT 2013; Handy et al. 2013; Maizlish et al 2013; NYCDOT 2013; Rowe 2013; Hu and Schneider 2014; Piatkowski et al. 2014). While there is reasonable overlap between these subtopics, the current literature has minimal consensus about the best methods for assessment. The preceding literature review suggests a need for increased cycling scholarship, especially on the impacts of infrastructure improvements, which directly inform this research.

Research Questions & Hypotheses

"I thought of that while riding my bike."

Albert Einstein, On the Theory of Relativity

The following research is driven by the peak travel phenomenon and its implications for America's auto-centric transportation system. My study sheds light on the impacts of bicycle facility improvements in Denver in order to suggest how planners and policy makers can maximize user utility and efficiency of future transportation projects. I set out to answer the following three research questions:

1. Based on a multiscalar analysis of sales tax and other relevant data, what are the local-scale economic impacts of bicycle facility improvements, and what are the implications for similar corridors in the region and planners across the US?
2. Based on observational research and counts, how does bicycle use change within the corridor before and after the implementation of new bicycle facilities?
3. Based on a GIS and statistical analysis of transit access data, how far do most RTD transit patrons drive to access transit facilities, in Denver, and the entire RTD district?

Original Hypothesis & Expected Findings

Before conducting any research, I prepared several key hypotheses and expected findings outlined below. I hypothesized that my sales tax and geographic analysis would uncover more benefits than drawbacks of bicycle facility improvements. Another central hypothesis was that my sales tax analysis would produce similarly positive results as the NY and WA studies. I also expected businesses situated in densely populated areas to experience more benefits from the new bike facilities than their counterparts in less dense areas or the city of Denver as a whole. Another hypothesis was that “creative” businesses as well as food and retail establishments heavily impacted by people traffic would fare better than others in the corridor (Fishman 2005). I also predicted that new bicycle and pedestrian facilities would effectively pull business types that rely on pedestrian traffic towards the facility. Another hypothesis was that businesses with close proximity to transit or bike infrastructure would experience increased benefits due to the agglomeration effects from increased mobility.

I also hypothesized that my observational research and counting efforts would show a shift from right side bicycle traffic to the PBL on the left. This would likely pair with an increase in total utilization and overall safety. I expected that the preceding increases in bicycle traffic would pair with reductions in traffic violations and illegal use, including cyclists disobeying traffic laws on 15th Street and illegally locked bikes on South Pearl Street. My final hypothesis was that impacts will vary greatly based on the exact location of the infrastructure and its proximity to the business, which is why I included comparisons for all of the improvement sites. This means that facility placement will greatly impact utilization and that facilities in more active spaces will fare better than others in less active ones. The aforementioned hypotheses represent my initial predictions, but I also hoped to reveal unexpected findings as well.

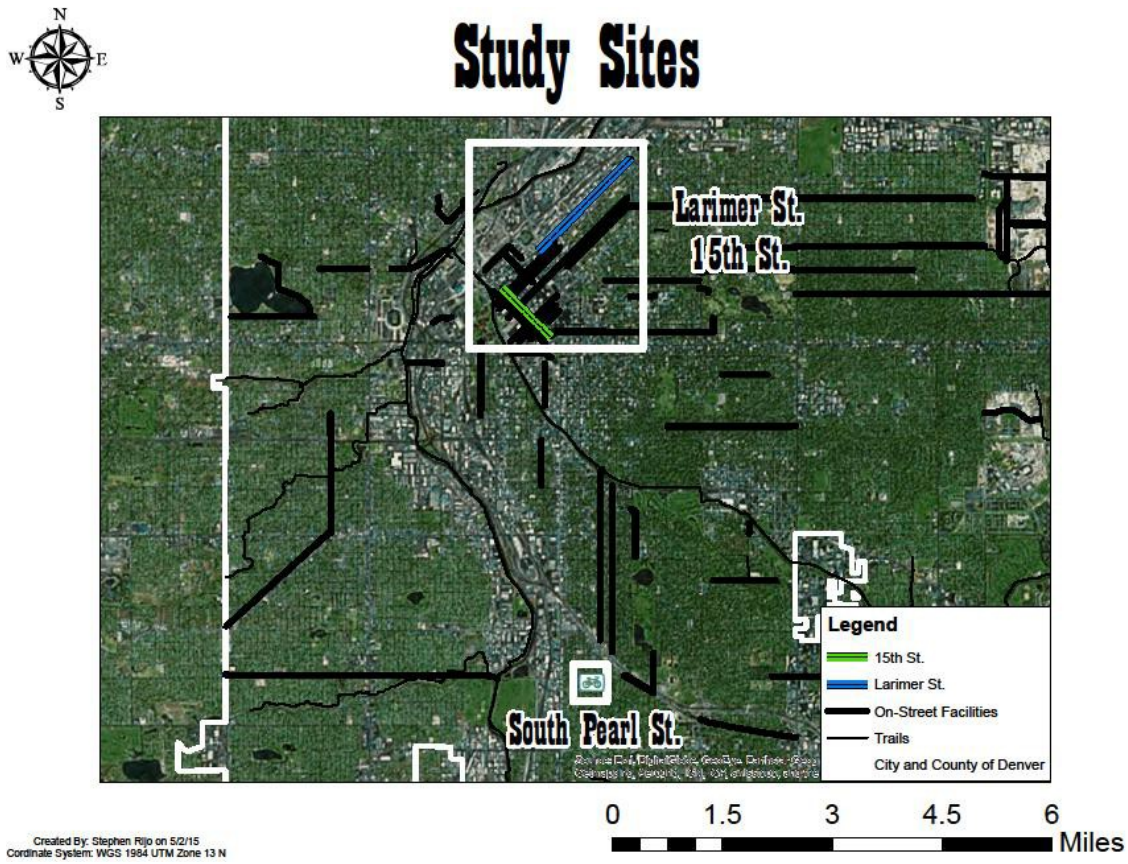
Study Sites, Data, and Methods

> *The future does not belong to those who are content with today, apathetic toward common problems and their fellow man alike, timid and fearful in the face of bold projects and new ideas. Rather, it will belong to those who can blend passion, reason and courage in a personal commitment to the ideals of American society.*
>
> *Robert Francis Kennedy*

Study Sites

I focused my analysis on the neighborhood, or local scale in order to provide suggestions for larger-scale planning efforts. I carefully selected the study and comparison sites to ensure that they would help me accomplish my research goals. After analyzing numerous neighborhoods and corridors, a myriad of factors led me to choose 15th Street in Downtown Denver and Larimer Street in Five Points as the study sites, shown in Figure 2 below. Both of these sites represent notably different urban corridors, which provided me with interesting findings on the economic impacts following the installation of new bicycling facilities in Denver. I also conducted a brief pilot study on newly installed on-street bike corrals on South Pearl Street. The following section outlines the site selection process for the improvement and comparison site corridors.

Figure 2: Study Sites



Denver

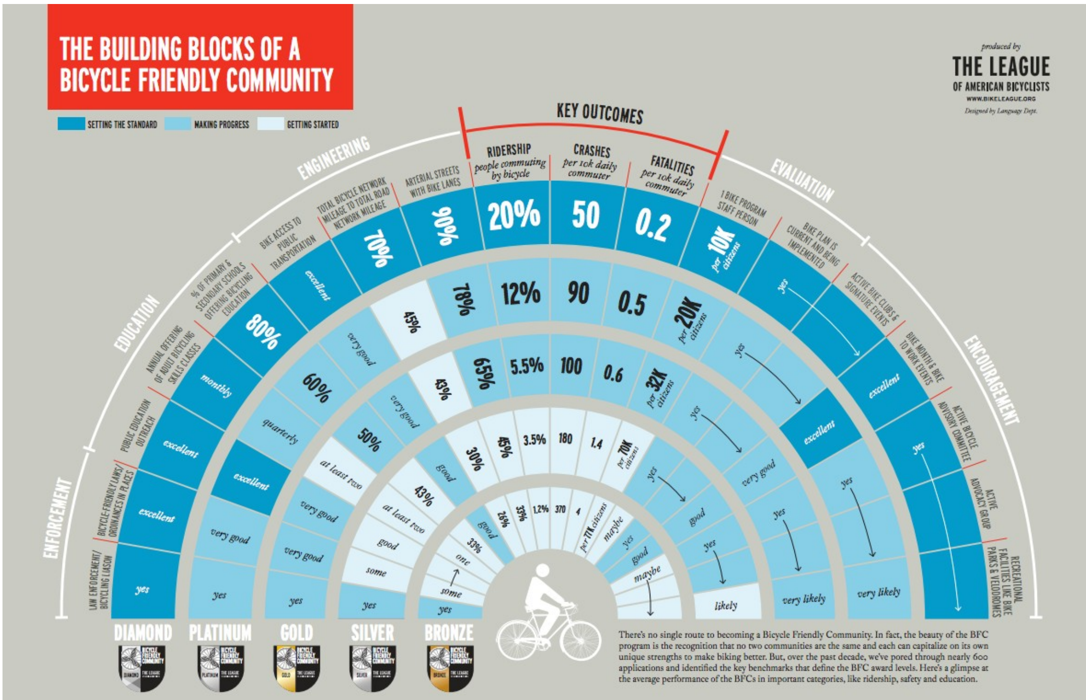
It is difficult to understand the study site selection process without a discussion of the current state of cycling in Denver as a whole. First and foremost, Denver has an excellent climate for bicycling and receives the Colorado average of nearly 300 days of sunshine a year. There are very few rainy days in Denver, and the rain storms typically only last a few hours when they occur. Denver’s dry climate and sunshine pair nicely with a flat topography to make the city even more inviting for the bicycle from an environmental perspective. The relatively flat topography, mild climate, and lack of rain suggest that Denver is poised to be an excellent bike city if the human elements catch up.

Denver has also been awarded a rating of Silver by the League of American Bicyclists (LAB). LAB is one of the nation's premier cycling advocacy organizations, and they employ a rigorous ranking system to classify bike-friendly communities, cities, and businesses across the US, based on "The 5 E's" of "Engineering, Education, Encouragement, Enforcement, and Evaluation & Planning" (League of American Bicyclists 2015). The 5 E's, shown in Figure 3, represent the essential elements consistent in making great places for bicycling. Denver has been stuck on the Silver rating for a few years and hopes to make the leap to Gold in the next cycle.

Denver is also experiencing changing VMT trends. The DRCOG's Metro Vision 2035 Plan lays out goals to "Reduce the daily per capita vehicle miles traveled (VMT) by 10 percent by 2035… (dropping daily per capita) VMT 22.27 in 2035" (DRCOG 2011). The Denver Metro region is doing well and has had a decreasing daily per capita VMT trend for the past 5 years, despite rapid population growth in the region. These minor decreases suggest that the region is off to a promising start and that stakeholders must begin to focus on alternative transportation offerings if they want to meet their VMT reduction goal by 2035.

The US Census Bureau recently released data on the bicycle mode share in US cities with populations greater than 200,000, and Denver ranked eleventh on this list, with a mode share of 2.3% (Census ACS 2013). The mode share is considerably higher for residents commuting to Downtown Denver, as highlighted by the Downtown Denver Partnership's (DDP) Commuter Survey of 4,962 commuters in September of 2014. "When asked how they commuted to work on the day of the survey, 43% reported using transit, 38% drove alone, 7% bicycled, 5% carpooled, 5% walked and smaller numbers teleworked, vanpooled, or used a motorcycle, scooter or moped" (DDP 2014). This report also highlighted several promising statistics for bicycle commuting in Downtown Denver. Downtown Denver bicycle mode share increased 43% from last year's commuter survey, and these commuters were 11 times more likely to bike to work than the average US commuter. One can see how Downtown Denver already displays increased levels of cycling from the entire city, and metropolitan region as a whole, which suggests that downtown is likely the most cost-effective location to add new bicycle facilities. Denver's mode share of bicycle commuting has witnessed promising growth, from 1.6% in 2007 to 2.3% in 2013 (US Census ACS 2013). Denver is trending in the right direction, as shown by Figure 4, but also experienced a drop of .6% from the 2.9% mode share in 2012. This surprised the local community, as cycling rates appear to be growing in Denver, but closer inspection revealed that many cities across the country saw a similar blip from 2012 to 2013 (Census ACS 2013). This highlights how the census has a large margin of error and is not the ideal method for collecting data on small changes in travel behavior and has led many to consider a more effective way to track bicycle use. Denver has pieced together bike facilities that led to increased levels of cycling for transport, yet many feel that the current on-street network, shown in Figure 5 below falls short of the demand to provide low-stress connectivity to all parts of the city. Figure 6 highlights the connectivity differences between Denver's bicycle and street networks. Thousands of advocates recently signed a petition asking Mayor Hancock to reconsider Denver's bike network, especially major streets such as Broadway that have the potential to improve bicycle access for the entire city. This is not to say that Denver completely lacks facilities, but that the current number of PBLs, trails, lanes, and secure parking offerings do not constitute a fully functioning network.

Figure 3: Bicycle Friendly Community Infographic



Source: League of American Bicyclists 2013

Figure 4: Denver Bicycle to Work Mode Share

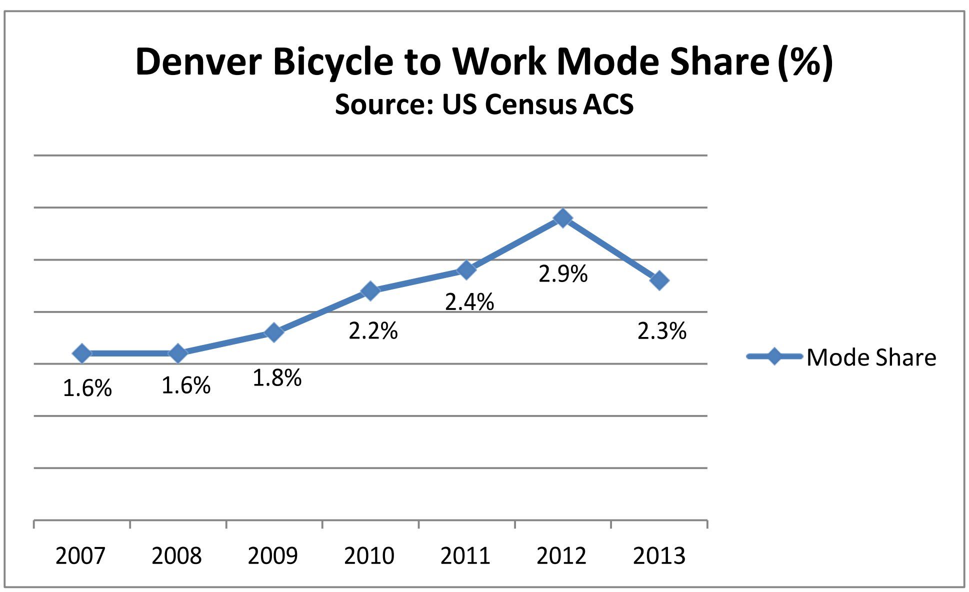


Figure 5: Denver On-Street Bicycle Facilities

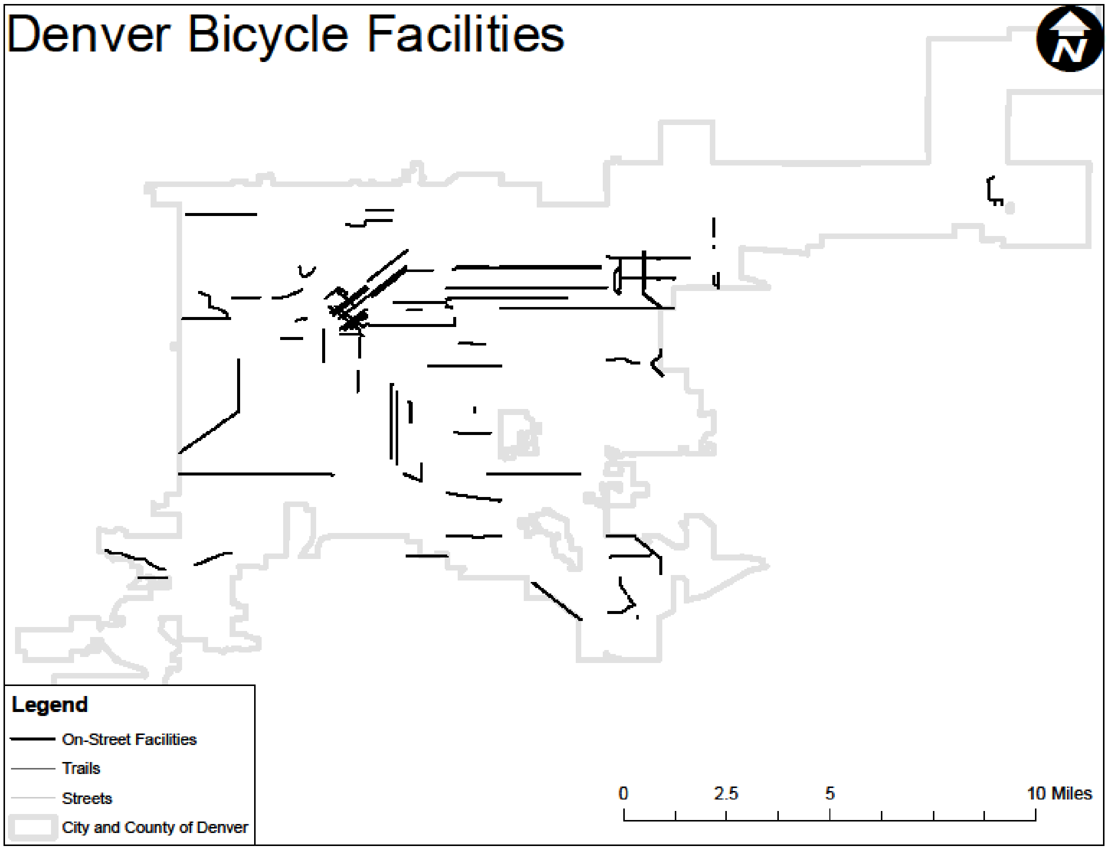
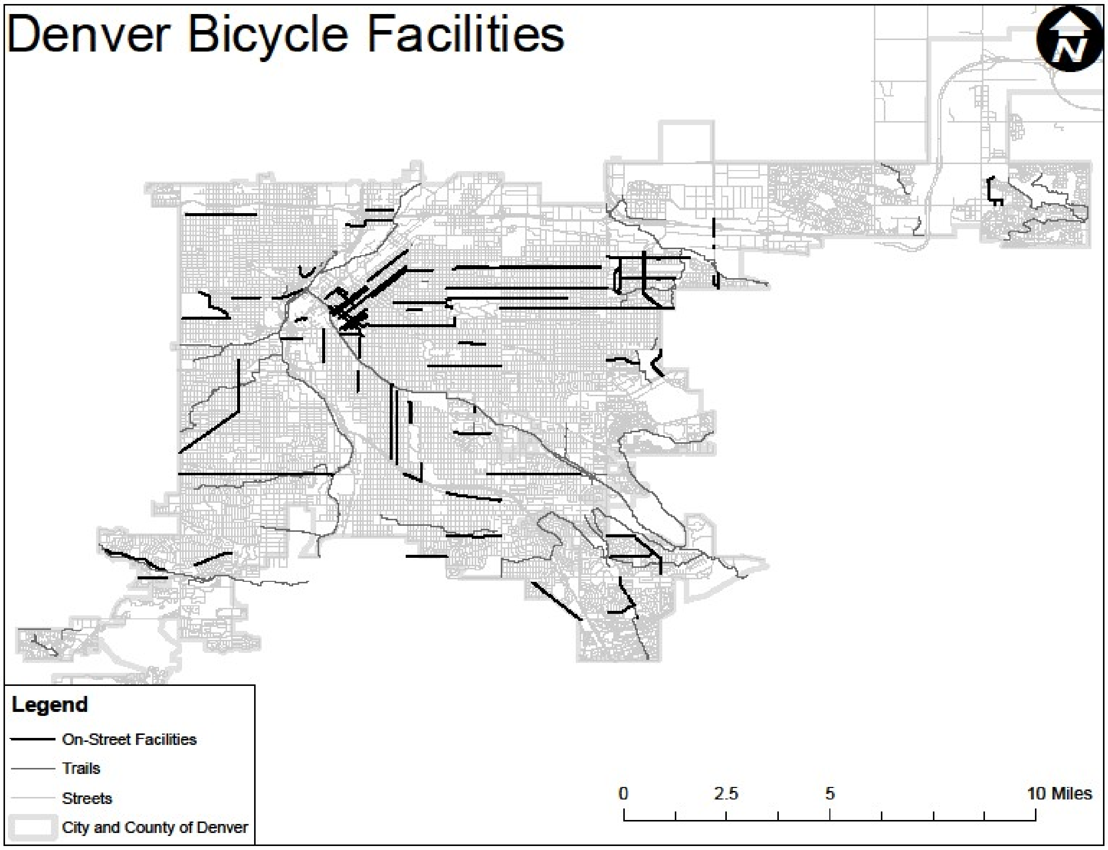


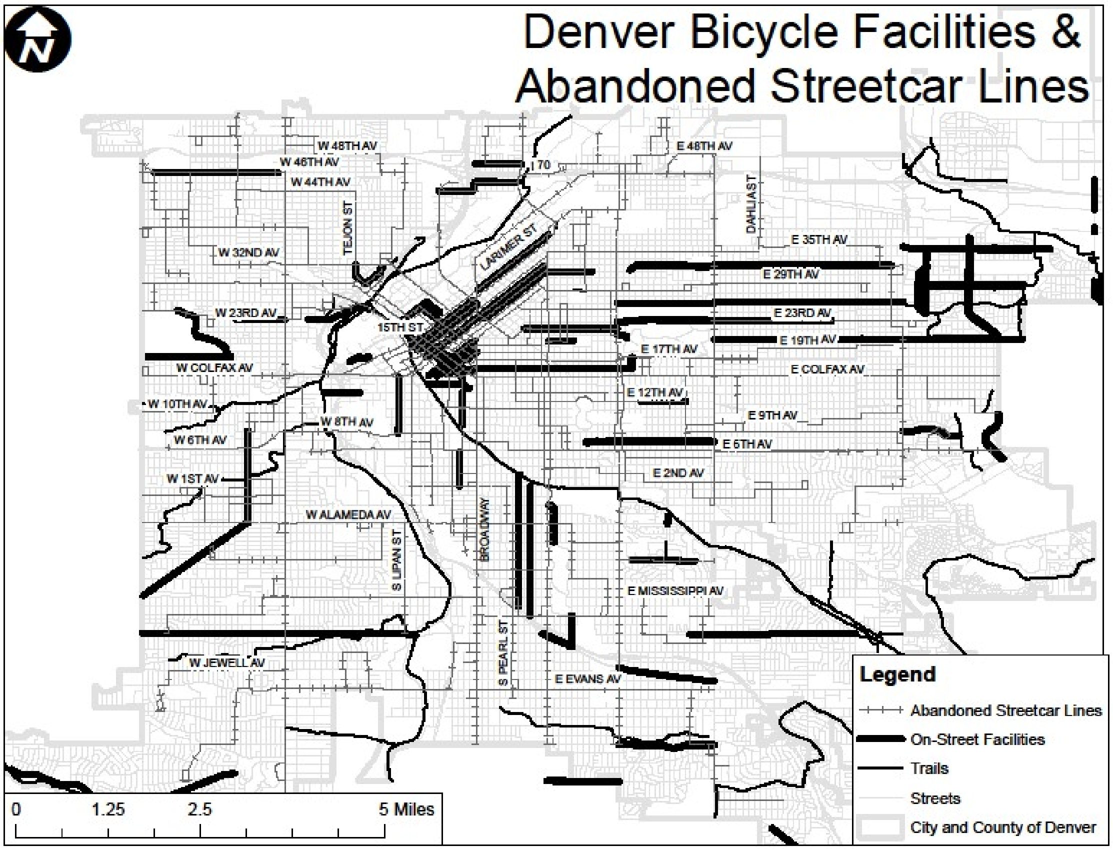
Figure 6: Denver On-Street Bicycle Facilities and Trails vs. Street Network



In addition to the promising increase in cycling for transport, Denver currently exhibits several other pro-bicycle initiatives. Denver is in the process of updating its bicycle and pedestrian plan, titled "Denver Moves," that lays out proposed improvements to cycling and pedestrian infrastructure across the city. The plan has several substantive requirements for future bike infrastructure implementation, which is progressive for an American bike and pedestrian plan. The two main goals of the plan are to create "A biking and walking network where every household is within a quarter mile (5-minute walk or 2-minute bicycle ride) of a high ease of use facility" and to "achieve a 15% bicycling and walking commute mode share by 2020." (Denver Moves 2011) Denver was also selected for PeopleForBikes' Green Lane Project this past year. PeopleforBikes is one of the US' leading bicycle advocacy and lobbying organizations, and their Green Lane Project aims to help "U.S. cities build better bike lanes to create low-stress streets." (PFB 2015) The Green Lane Project brings together six hand-picked cities from across the country to encourage collaboration, while also providing a host of resources. In sum, The Green Lane Project acts like a bike think tank and adds Denver to a network of peer cities, which are interested in improving cycling infrastructure. The aforementioned factors combine to make Denver a relatively hospitable city for cycling initiatives with hopes to create a fully functional and interconnected network of low-stress bicycle facilities. While there is growing interest in cycling in Denver, one can see why we need more research to highlight the impacts of cycling facility improvements in Denver.

I must also mention that both of the study sites were originally serviced by Denver's historic streetcar network, and therefore display relatively dense and mixed-use urban layouts. Historic streetcar access was not a selection criterion but happened by coincidence. Figure 7 suggests that these original streetcar suburbs, or TODs from long ago, exhibit an ideal urban layout with the appropriate densities to promote bicycle use. More specifically, Denver's historical streetcar suburbs are great places to add bicycle facilities because they have flatter grades, wider streets, more businesses, and increased residential densities that can support local businesses while also encouraging bicycle transport. Both sites also fall within current RTD TOD ½ mile buffers where there are benefits to the agglomeration effects of transportation. The provided discussion of the current state of cycling in Denver helps contextualize my neighborhood choices in the following section.

Figure 7: Denver Bicycle Facilities and Abandoned Streetcar Lines



Selecting Improvement & Comparison Sites

The first step of this research was to select the study sites. I used publicly available information from Denver's Open Data Catalog, Google Maps Street View, DRCOG's traffic counts, and personal observations from 2 years of Denver bicycle commuting to narrow down potential study sites. I selected Larimer and 15th Streets because both corridors had new bike facilities constructed in the past five years. In 2011, the city added new bike lanes to Larimer Street, and in 2013, 15th Street received a PBL installation. The city only maintains monthly sales tax data five years into the past, and therefore I was limited by having to select improvements that fell within this timeframe. I should note that 15th Street's installation was too recent to discern major post-installation trends, but I still wanted to include 15th Street because it is Denver's first PBL (NYCDOT 2013).

The following step was to select comparison sites for the improvement sites. I used the comparison sites to test sales tax performance across the study sites and control for local variations. The first comparison site was Denver as a whole, which I used as a basic control for all the sales tax data. Next I selected three smaller comparison sites that were in relatively close proximity to the improvement sites. These smaller comparison sites displayed a similar, although not necessarily identical, level of business activity, building type, street make up, traffic levels, and proximity to transit as the improvement sites. All of the comparison sites are remarkably similar to the improvement sites in all ways except for the presence of bicycle facilities, which guided all of my study site selections.

Larimer Street in Five Points

I chose Larimer Street as a study site because the city performed a major street improvement, often referred to as a road diet, and added bike lanes between Broadway and Downing Street in 2011, which is shown in Figure 8 below. This segment of Larimer Street is within the Curtis Park neighborhood and displays an interesting mix of retail, commercial, and residential land uses. This study site is also an "area of change" delineated in the 2011 Blueprint Denver integrated land use and transportation plan

(Blueprint Denver 2011). Five Points was Denver's historically African American neighborhood, and this area has witnessed waves of change from predominantly African American, to Latino, and to the current state of change with many ethnic groups living in close proximity to one another (Mauck 2001). Larimer Street had three lanes of one-way car traffic heading south into downtown and was relatively inhospitable to pedestrians before the street improvement. The street improvement increased pedestrian access by removing a car travel lane, switching car traffic to two-way, and adding bike lanes in both directions. One would expect this road reconfiguration to impact business activity in the corridor, which is why I chose Larimer Street as an improvement site. I was interested to see how this active corridor with mixed land uses performed after the street improvement completely changed the streetscape.

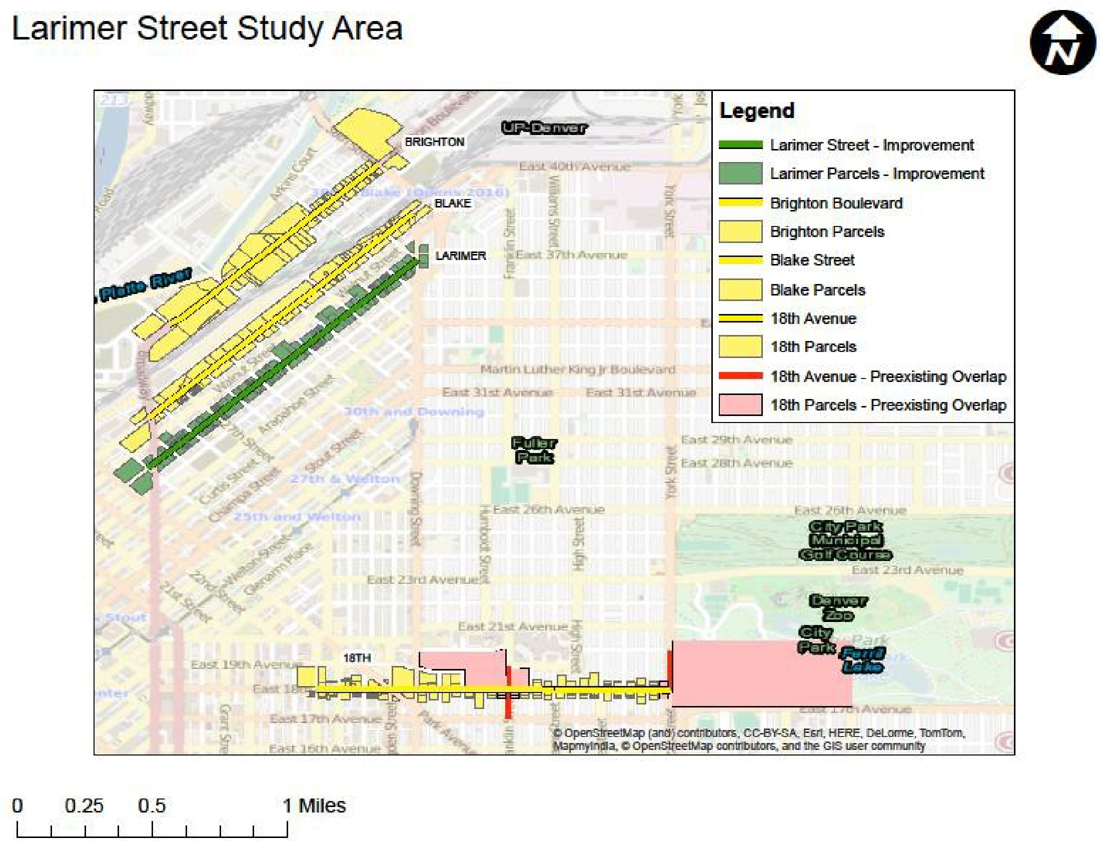
Figure 8: Larimer Street

Larimer Street was also a logical improvement site choice because there are several similar streets in the area to use as comparison sites, outlined in Table 1 below. I selected Brighton Boulevard, between Broadway and 38th Street, as one of the Larimer Street comparison sites because it is a similar corridor three blocks north of Larimer St, but exhibits a very different level of pedestrian accessibility. The flow of car traffic on Brighton resembles the high-speed, high-volume, and high-stress conditions that existed on Larimer prior to the street improvement. Brighton also completely lacks sidewalks, which exemplifies how inhospitable this corridor is for bikes and pedestrians. I also selected Blake Street, between Broadway and Downing Street, in Five Points as one of the Larimer Comparison sites for similar reasons to Brighton. Blake Street is geographically close to Larimer Street and displays extremely similar characteristics in many ways, except for the presence of bike facilitates. It is worth noting Blake Street is only 2 blocks north of Larimer Street, and I paid close attention to the similarities and differences between both sites for spillover effects. The final comparison site was 18th Avenue, between Washington Street and York Street. 18th Avenue has a similar land use and business character as Larimer Street but exhibits an auto-centric road layout. A map of the Larimer Street improvement and comparison sites is displayed in Figure 9 for reference. The preceding discussion of the Larimer Street improvement and comparison site selection process helps contextualize the results for this site. My analysis of Larimer Street also highlighted unexpected factors of this unique corridor adjacent to the central business district.

Table 1: Larimer Area Study Sites

Improvement Site	Comparison Sites
Larimer St. (Broadway to Downing St.)	Brighton Blvd. (Broadway to 38th St.)
	Blake St. (Broadway to Downing St.)
	18th Ave. (Washington St. to York St.)

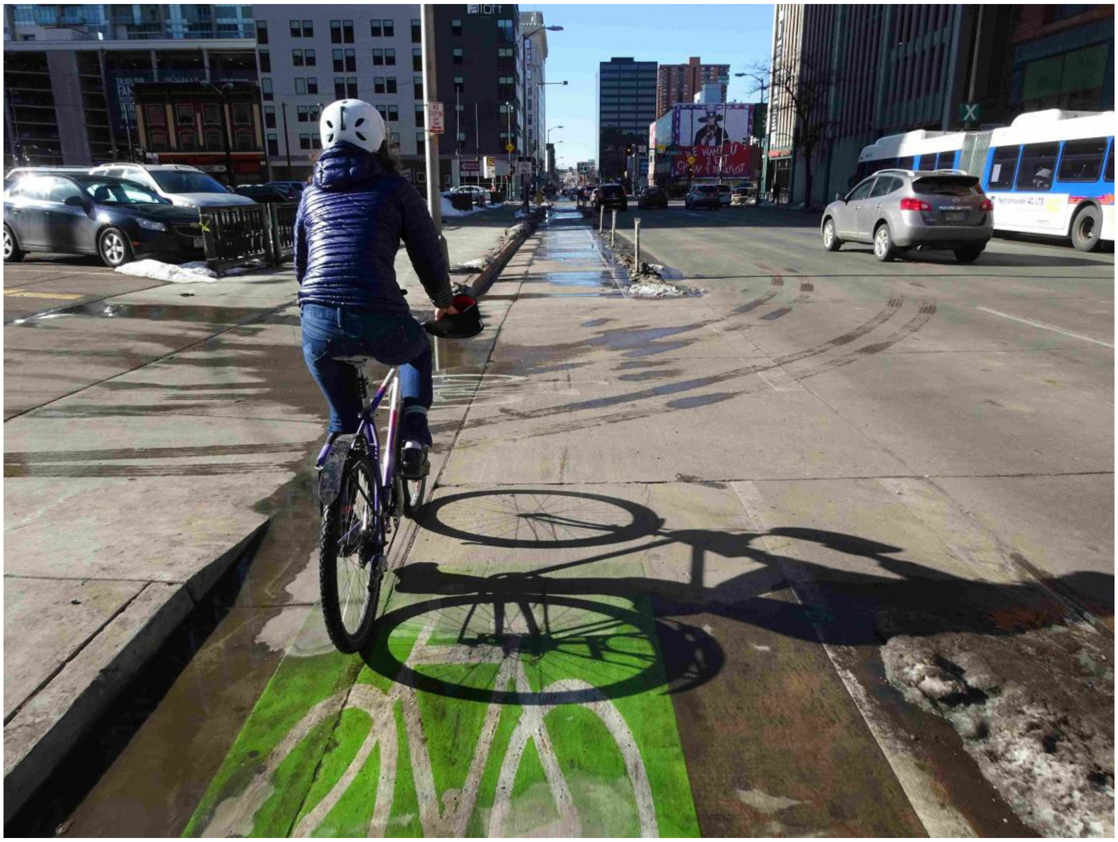
Figure 9: Larimer Street Study Area



15th Street in Downtown Denver

I chose 15th Street, between Cleveland Place and Wynkoop Street, in Downtown Denver as the other improvement site because it is the location of Denver's first PBL, which is shown in Figure 10 below. 15th Street is also within the most densely developed part of the city, which is where cycling infrastructure works best. Downtown Denver has numerous bike lanes and other infrastructure and recently installed the first vertically separated PBL in Denver on 15th Street. Construction on 15th Street began with a buffered bike lane during August of 2013 that remained in place until vertical separation was added in May of 2014. This area exhibits a dense, mixed-use development pattern with a large number of employers and destination centers. There are several apartment high-rises, but the residential densities are not as high as the other land uses adjacent to 15th Street. My research targeted the 15th Street corridor, which I split into PBL and Sharrow to see if different types of bicycle facilities have different impacts. I also focused on Larimer Square, where the PBL ends and encourages people on bikes to stop at one of the many shops on this block. 15th Street also provides a nice comparison to the 16th Street Mall, where non-auto infrastructure revitalized the corridor several decades ago. This corridor contains numerous RTD transit offerings, from bus to rail, which was another reason for selection. My over-100 hours of observational research and counts on 15th Street also increased my momentum in this area and introduced me to the Department of Public Works. I ultimately chose to study the bike lane on 15th Street as it is the first-of-its-kind in Denver and runs through a high-profile, dense urban corridor.

Figure 10: 15th Street PBL

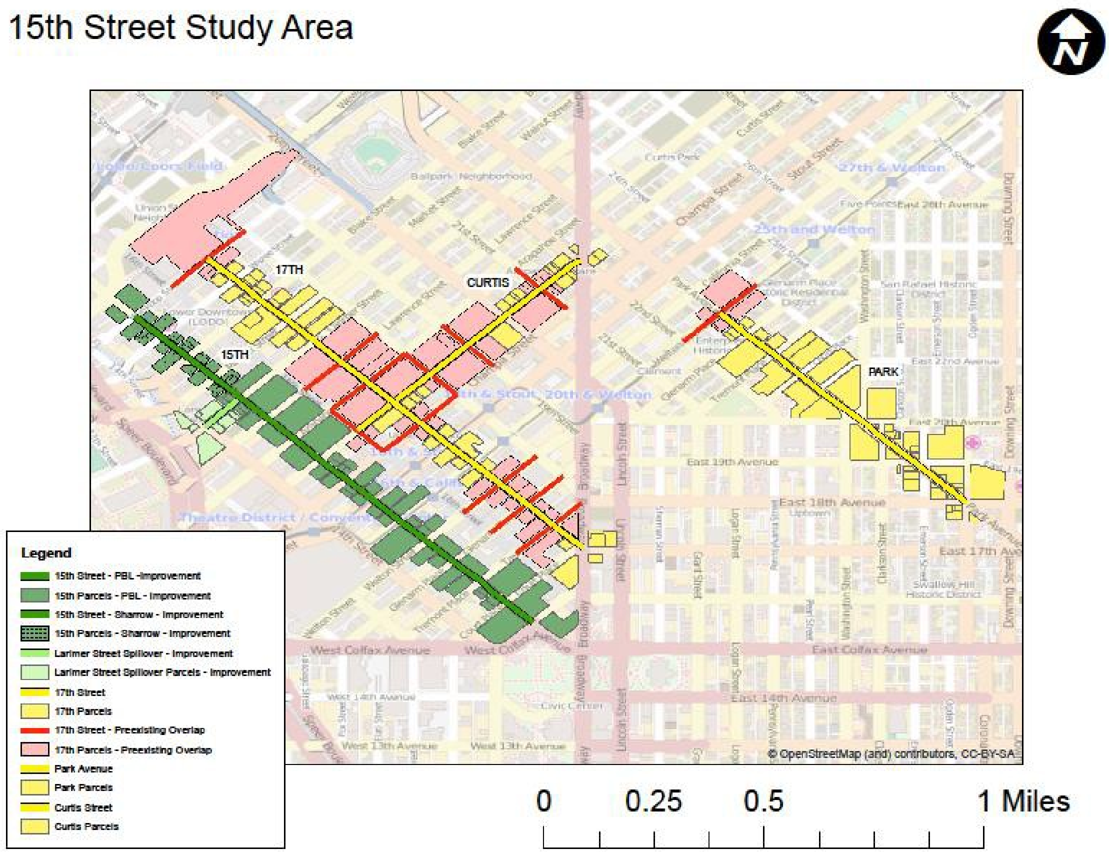


15th Street's new PBL made it a clear choice for study, but selecting comparison sites, included in Table 2 below, was not as obvious. Downtown Denver has the largest quantity of bicycle facilities in the city, and avoiding comparison sites with preexisting bicycle facilities was a noteworthy challenge. I chose 17th Street, between Wynkoop Street and Court Place, as the first comparison site because it has a similar composition of businesses, buildings, and street layout, except for the presence of bicycle facilities. Neither 17th Street nor 15th Street has a large amount of ground floor retail, which is also interesting. Next, I selected Curtis Street, between 16th Street and Broadway, as the second comparison site. Curtis and 15th Street both have a large number of high-rises and are remarkably similar in most ways, except for the presence of bicycle facilities. The final comparison site for 15th Street was Park Avenue, between Welton Street and 18th Avenue. Park Avenue is on the other side of Broadway and is slightly removed from downtown. Besides geographic proximity and the presence of bicycle facilities, Park Avenue has a lot in common with 15th Street. A map of the 15th Street improvement and comparison sites is included in Figure 11 for reference. These comparison sites, with similar levels of business activity, building stock, street make up, traffic levels, and proximity to transit, provided interesting comparisons to the improvement corridor with the new PBL.

Table 2: 15th Area Study Sites

Improvement Site	Individual Improvement Site Sections	Comparison Sites
15th St. (Cleveland Pl. to Wynkoop St.)	15th St. - PBL (Cleveland Pl. to Larimer St.)	17th St. (Wynkoop St to Court Pl.)
	15th St. - Sharrow (Larimer St. to Wynkoop St.)	Curtis St. (16th St. to Broadway)
	Larimer St. - Spillover (15th St. to 14th St.)	Park Ave. (Welton St. to 18th Ave.)

Figure 11: 15th Street Study Area



South Pearl Street

South Pearl Street was not the focus of my thesis, but I conducted a pilot study of on-street bike corrals that I mention later. South Pearl Street was an interesting area for research due to a host of physical and social factors. The city and county of Denver's choice to focus its bike corral pilot program on South Pearl Street was the main reason for conducting research in the area. I also chose South Pearl Street because it has a motivated organization, the Old South Pearl Merchants Association (OSPMA), which puts on numerous events during the year. Some of their money-making events draw tens of thousands of visitors and provide unique transportation challenges for the residential area. Resource limitations forced me to sideline my work at this site, but the aforementioned points highlight why South Pearl Street is relevant to my larger focus on the impact of new bicycle facilities.

Summary of Site Choices

My choice to study Larimer Street in Five Points and 15th Street in Downtown Denver as improvement sites for this project significantly influenced my findings. The range of urban neighborhood types selected as improvement and comparison sites allowed for robust analysis of the impacts of improved cycling facilities in different neighborhoods. I was happy to find that Larimer Street has a wide range of socioeconomic groups, but it still does not completely speak to low-income sites because it is further along in the gentrification process.

Despite frustrations from not having the scope to include a low-income site, I am very pleased with my overall results. Larimer Street is a great improvement site because the diverse corridor underwent a major street improvement and is still thriving. I also enjoyed researching 15th Street because of the PBL's central and iconic status for bicycling in the city of Denver. These study sites assisted my local scale analysis and helped uncover the economic and traffic impacts following the installation of new bicycle facilities in Denver, CO.

Data

This research project was largely data driven, and therefore a brief discussion of the data will assist comprehension in the methods section. My data types fit into the two main categories of geographic statistical data and observational research and counts.

Geographic statistical Analysis

The geographic statistical data included sales tax, transit access, land use, and census data. I used monthly sales tax data from 2010-2014 for each of the study sites in addition to city-wide reports for the same timeframes. The sales tax data came as GIS shapefiles and required numerous iterations of data cleaning by me, and the city, before it was ready for analysis. I analyzed various North American Industry Classification System codes (NAICS) and ultimately chose to look at the codes related to retail, food, and creative businesses (Fishman 2005).

Next, I downloaded the land use data from Denver's Open Data catalog. I separated this data by the provided classification types of: assessor tax classification, community planning and development land use level 1, and community planning and development land use level 2. These land use data helped to compliment my sales tax analysis and discern general trends but was not the central focus of my statistical analysis. I also used Park-n-Ride (PnR) utilization numbers to get an idea of what transit stations have the most car access. Following this step, I briefly reviewed census data provided by the US Census to guide my initial site selection (ACS 2009-2013).

Observational Research and Counts

I conducted observational research and counts along the 15th Street study site in Downtown Denver. The use of traffic camera recordings allowed me to conduct counts after an observation day. The observational research and count data were collected by watching over 100 hours of video recordings from nine observation days in addition to 2 other days that city staffer Rachael Bronson had already analyzed. I followed Rachael's counting process and used her forms to ensure that my observations were consistent with hers. I also took detailed notes on the counts that I used to assemble the observational research data afterwards. The preceding discussion of the data types will help contextualize the specific methods I employed to analyze the data.

Research Methods

The following thesis research employs a mixed-methods approach to target the inherently multi-faceted topic of economic impacts of improved bicycle facilities. I combined quantitative and qualitative methods to uncover the intricacies of the economic and traffic impacts following the installation of new bicycle facilities. I analyzed the sales tax data as an indicator of local prosperity and was in frequent contact with Denver's Department of Finance over the course of my research. The subsequent section presents an outline of each method in their general order of importance.

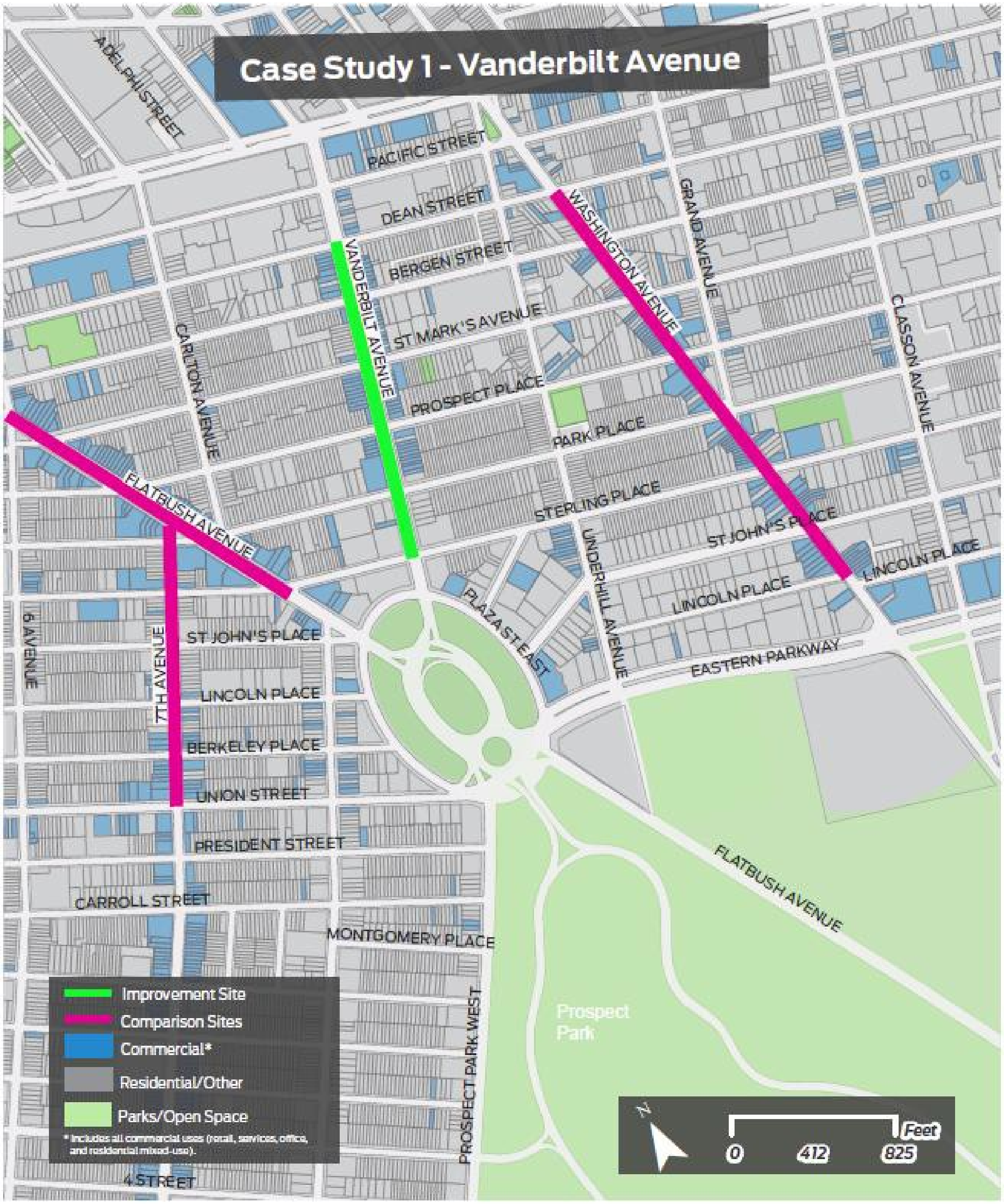
Sales Tax Data Analysis

The central focus of my research was to uncover the economic impacts of new bicycle facilities, which proved to be a challenging feat. Economic analysis was a major component of the study, and I employed a new method to assess the impacts of improved cycling infrastructure and answer RQ1; *Based on a multiscalar analysis of sales tax and other relevant data, what are the local-scale economic impacts of bicycle facility improvements, and what are the implications for similar corridors in the region and planners across the US?* It is often difficult to assign the causality of an economic benefit to bike facility improvements due to the multifaceted nature of transportation projects (Krizek 2007).

In light of this fact, I based my methods off of two recent studies that simultaneously employed a similar method that uses local sales tax data as an indicator of local economic prosperity (NYCDOT 2013; Rowe 2013). Current research on the economic impacts of cycling facilities is difficult to replicate due to the high level of subjectivity of volunteered information projects (NYCDOT 2013; Rowe 2013). My method was developed in direct response to the aforementioned point because sales tax analysis is unbiased. I worked closely with Mike Aleksick from the Denver Department of Finance's Office of the Controller to pull the North American Industry Classification System (NAICS) codes for retail trade, accommodation & food services, and arts, entertainment, and recreation as these industries are heavily reliant on people traffic, and therefore I think they are most likely to be affected by local street improvements. My initial plan was to include "creative" industries in addition to food and retail, but these businesses artificially inflated my results, and I eliminated them before conducting final analysis. I also eliminated auto-centric industry codes that included gas stations and car repair shops as they are less related to cycling facility improvements. Both studies that pioneered this general method assert that the ideal study site should have one year of baseline data available before the infrastructure project and two years of data available after the project to showcase the effects. I should note that the 15th Street study site was only a year and a half old when I performed my analysis. While this falls on the younger side for producing usable results, I had to include 15th Street in my study because it is Denver's premier on-street bicycle facility and its first PBL.

The major steps to perform this method involve selecting study or "improvement" sites, selecting three "comparison" sites for each improvement site, mapping and defining the sites, generating data sets with the city's help, and various iterations of data cleaning to focus analysis and streamline results (NYCDOT 2013; Rowe 2013). First, I selected the improvement study sites of 15th Street and Larimer Street because they received cycling infrastructure improvements in the past few years. Sales tax data are only maintained in monthly increments for 5 years, and therefore I had to pick projects that were built between 2010 and 2013. The next step was to select the local and regional comparison sites. I selected comparison sites with similar levels of business activity, building stock, street make up, traffic levels, and proximity to transit as controls to showcase how a comparable area performed in the absence of street improvements. Both of the aforementioned studies compared the improvement sites to three similar local-scale sites and one city-wide site to see what the sales tax trends were for areas without improvements and to control for city-wide fluctuations. Figure 12 and Figure 13 include maps from the NYCDOT and Rowe studies to provide insight into their comparison site selection process. I used all of Denver for the city-wide control. For Larimer Street, I chose Brighton Boulevard, Blake Street, and 18th Avenue as the comparison sites, and for 15th Street, I used 17th Street, Curtis Street, and Park Avenue as the comparison sites. The following section outlines the process to generate the site-specific datasets, which was the most time-consuming component of this project due to the large amount of back and forth required between Mike and me. I cannot overstress the importance of staying ahead of the curve with this step as the time requirements for Mike and myself were often larger than expected.

Figure 12: Vanderbilt Avenue: Case Study and Comparison Sites



NYCDOT 2013

Figure 13: Project Overview Map for Greenwood Ave. N Study Site

Rowe 2013

There are laws that forbid taxation agencies to provide raw sales tax data to the public. While this is a necessary safeguard for protecting private information, it significantly impedes the data collection process. In order to protect the privacy of local businesses, the Denver Department of Finance had to aggregate all data before sharing it. This step required a fair bit of back and forth between the Department of Finance and me.

I found that cultivating strong relationships with city staff in the early stages was imperative to my overall success (NYCDOT 2013; Rowe 2013).

Next, I provided city staff with the study sites as a collection of tax parcels in a GIS layer, and they returned a list of businesses that were within the target area. I sorted this list of businesses by NAICS code and selected the relevant codes for all of Retail Trade (44-45) and Accommodations and Food Services (72). After this, I went through and manually selected relevant businesses from Manufacturing (31-33), Professional, Scientific, and Technical Services (54), Arts, Entertainment, and Recreation (71), and Other Services (81). Several examples of businesses I individually selected for were NAICS code 312120 for Breweries that also serve food, NAICS code 541430 for Graphic Design Services, NAICS code 712110 for Museums, and NAICS code 812111 for Barber Shops. I should note that I ultimately eliminated all of the businesses from NAICS code 54 that contain Professional, Scientific, and Technical Services. These businesses were initially added to capture growth from "creative" industries that moved to the improvement site, but they artificially inflated my results with their high returns, so I removed them before conducting the final analysis (Fishman 2005). The Department of Finance historically used NAICS code 453998 for all tax returns submitted without a code so I decided to remove all of these businesses. I also asked Mike to keep the tax from retail marijuana (RMJ) sales separate so as to not artificially inflate the data collected after the laws changed. Once I selected all of the businesses to include, I went on bike rides through the corridors and used Google Maps street view to make sure the businesses were physically located within the study sites (NYCDOT 2013). Next, I sent my business lists back to Mike for him to pull and aggregate the sales tax data. Both of the pioneering studies noted that the selection codes are not set in stone, and researchers must pay close attention to select for businesses that make sense in their geographic and temporal research context. This was also the most subjective step in my research, and others should pay close attention to the businesses they select to include while using this method.

Mike then returned lists that contained monthly sales tax split into “gross sales” prior to any deductions for non-taxable sales, “food and beverage tax” for the sale of prepared food and drink, “RMJ” for retail marijuana, and “other sales tax” for sales which don't fall into any of the other four categories. There were several instances where there were too few businesses to provide separate totals for “food and beverage tax” and “other sales tax,” so Mike had to combine them into the “total sales tax” category to protect privacy. This was unfortunate for my initial goal to keep things separate, but a necessary tradeoff for working with highly confidential sales tax information. Next, I used sales indexing, with the baseline set at the start of 2010, to organize these data and conducted several levels of inquiry. I then conducted an Analysis of Variance (ANOVA) to uncover general trends and test the statistical significance of my findings (Flowerdew and Martin 1997; Burt et al. 2009; Clifford et al. 2010; Gomez and Jones III 2010; NYCDOT 2013; Rowe 2013). The baseline period selected has a noteworthy impact on sales index calculations, and therefore I paid close attention to this value. I initially used a standard baseline of one year before the improvement, but found that this exacerbated several outliers in the improvement and comparison sites (NYCDOT 2013). I proceeded to test several different baseline periods with mixed results and decided to use February 2010 as my baseline month. One can argue for using various different baseline months, but February 2010 was the first data point for all sites, which helped to standardize the indices. My statistical analyses highlighted significant trends and also showcased similar challenges as the NY and WA studies that found it difficult to prove exact causality due to modeling limitations and multicollinearity (NYCDOT 2013; Rowe 2013). The NY study summarized this point well when they stated:

> This study's methodology does not ultimately prove causality between the street improvement projects and any resulting economic changes. However, for those locations that had positive results as compared to their borough and their comparison sites, it is reasonable to conclude that their gain in retail sales can at least in part be attributed to changes stemming from the higher quality street environment (NYCDOT 2013).

While this method falls short of proving causality between the new bicycle facilities and the economic changes, it still produced significant findings and represents the logical first step towards drilling down the exact economic impacts of improved bicycle facilities.

The aforementioned method provides the most accurate measure for assessing the economic impact of cycling infrastructure improvements on local businesses (NYCDOT 2013; Rowe 2013). One of the negatives of using this method was that I was at the mercy of the Department of Finance for data acquisition. While things generally went smoothly, I did experience several unexpected setbacks throughout the course of this research. I also supplemented my sales tax analysis with several other methods.

Analysis of Other Available Data: Land Use, Census, and RTD

In addition to my sales tax analysis, I also employed methods to conduct geographic analyses of several existing datasets. I began by conducting a low-level analysis of land use data from 2003 and 2012 that I acquired from Denver's Open Data Catalog. After that, I selected for land use data from the improvement and comparison study sites. Next, I separated the data by the provided classification types: assessor tax classification, community planning and development land use level 1, and community planning and development land use level 2. Once all of the data was sorted, I conducted simple percent change calculations to see how the land use changed during the same time period as the economic changes. Unfortunately, I was unable to use these 2012 land use data on 15th Street because the new bicycle facilities were not added until 2013 and 2014. I walked both corridors to note current conditions but decided not to use these data as they were not directly comparable to the data from Denver's Open Data Catalog. The land use analysis was a productive exercise that helped me visualize shifting uses within both of the study sites and provided insight into my hypothesis that new bike facilities will pull pedestrian land uses towards the improvement site.

Once I completed my analysis of the land use data, I employed a method to conduct a brief spatial analysis of a few demographic indicators from the US Census. I began my efforts with traditional US census data from their website but then learned about an interactive mapping application from the Colorado State Demography Office in the Colorado Department of Local Affairs that suited my needs (DOLA 2015). This tremendous map allowed for on-the-fly analysis of census data without the hassle of downloading and cleaning everything, which was welcomed for this auxiliary component of my research. Street improvements suggest an inherent level of change, which is why I employed a GIS analysis to uncover unexpected impacts to local demographics following new bicycle facilities in Denver. I also looked at census data on income, race and ethnicity, and transportation preference to suggest how the street improvement influenced the fabric of the study sites. I ended up using this analysis to inform other parts of my research, but that was the extent of my land use analysis.

Working for RTD has provided me with access to a wealth of data related to Denver's alternative transportation networks. My manager at RTD always encouraged me to pursue my personal interests, which allowed me to work on numerous projects related to bike-transit integration. I worked on RTD's new Bike Parking and Accessibility Plan and was able to access a bicycle survey of approximately 1,300 respondents. I also worked on RTD's license plate survey and made hundreds of maps of RTD's many Park-n-Rides around the Denver Region. The License plate survey employed several methods by consultants and me to track where RTD's transit patrons are driving from to access transit. More specifically, consultants went to every Park-n-Ride and wrote down all of the license plate numbers. We sent the license plate numbers into the Federal Highway Administration (FHA) who sent back the registration addresses. Next, I created an address locator to geocode all of the addresses and used the network analyst tool to create a network with ½ mile, 2 miles, 2-5 miles, 5-10 miles, and 10-20 miles breaks. After creating the maps, I conducted a statistical analysis of the data to assign values to my visual representation. I was able to take this analysis one step further and conduct a pedestrian scale analysis of the license plate survey data, where I adjusted the network to represent pedestrian relevant distances of ½ mile, 1 mile, 3 miles, and 5 miles breaks. I conducted all of the same statistical analyses as the car scale license plate survey for this project. This was the first time anyone at RTD had displayed the license plate survey data at a pedestrian scale, which sparked internal conversations about the "low hanging fruit" for bike and pedestrian access to RTD's transit facilities. The aforementioned methods I used to analyze these other datasets complemented my sales tax analysis and helped inform my central RQ1 *Based on a multiscalar analysis of sales tax and other relevant data, what are the local-scale economic impacts of bicycle facility improvements, and what are the implications for similar corridors in the region and planners across the US?*

Observational Research and Counts

After I conducted my geographic analyses of provided data, I began to analyze data from previous observational research and counting efforts. I began conducting focused observational research over the summer months, when there were increased numbers of people riding bicycles. Experts cite observational research and counts as helpful methods to enhance human geography research, which is why I employed them in my thesis (Flowerdew and Martin 1997; Clifford et al. 2010; Gomez and Jones III 2010). I began my observational research with bike parking counts and general usage notes around Denver's first on-street bike corrals on South Pearl Street. Next, I conducted two days of counts, before the bike corrals were added, and four days of counts, after the bike corrals were added. I was also able to interview Mark Gill, the head of OSPMA, and drafted a questionnaire for business owners. Much to my regret, I had to pull the plug on my questionnaire due to shifting research interests. The elimination of my questionnaire reduced the statistical significance of my findings for South Pearl Street, but I discuss my efforts as they are still relevant for discussions about new bicycle facilities and business.

A joint project with the City and County of Denver allowed me to assess the usage impacts following the installation of Denver's first PBL in the 15th Street corridor, which is the same stretch as the sales tax improvement site. I adopted a method, developed by Rachael Bronson of the Department of Public Works (DPW), of capturing video from a traffic camera on Glenarm Place and 15th Street and saving it to a hard drive for future analysis. We captured 12 hours of video from 7:00am – 7:00pm each day to ensure that we included both peak periods. I then used these video recordings to perform covert observational research and counts (Gomez and Jones III 2010). This was one of the best parts of this method because I did not need to stand on a corner for hours on end like traditional counting methods, but instead was able to conduct counts remotely from a climate controlled desk. We captured over 100 hours of video observation that I used to document how bicycle traffic changed after the installation of this one-of-a-kind PBL in Downtown Denver. I personally conducted nine days of video observation and was given access to two other days, which provided me with 132 hours of counts from 11 separate observation days. The specific breakdown was: two days of observations before any bike facilities, two days of buffered bike lane observations, and seven days of PBL observations. I produced quantitative counts and qualitative notes during my observational research, both of which were the basis of my analysis that follows. An overview of the counting form that Rachael and I used is included in Table 3 below. While this was not the central focus of my research, it produced interesting results about bicycle traffic and usage in the newly improved 15th Street corridor that complemented my sales tax analysis. The observational research I conducted along 15th Street exceeded my initial expectations, and the results helped answer RQ2 *Based on observational research and counts, how does bicycle use change within the corridor before and after the implementation of new bicycle facilities?*

Table 3: Counting Form Used for 15th Street Observations

XX/XX/14 7-8a 15th/Glenarm											
Bike count: 0											
Bike lane cl	**# bikes**	**Bike la**	**# bikes**	**Bike turn m**	**# bikes**	**Ped/Bike***	**# occur**	**Bus/bike**	**# occur**	**Car/bike***	**# occur**
Left SW		Disobeying traffic signals		Rt from rt lane		Encounter on SW/CW		Bike pinch		Car aggressive	
Bikeway		Riding against traffic		Rt from middle lanes		Encounter on road		Bike to/from bus		Bike aggressive	
2		Sidewalk riding w/traffic		Rt from Bikeway		@ Bike traffic light violation				SW encounter	
3		SW riding against traffic		Left from Bikeway						Car pinch	
Right		No stop at rt/left turn		Left from middle lanes						Bike exit bikeway (turning car)	
Right SW				Rt from SW						Car overtaking encounter	
Road then SW				Left from SW							
SW then road				Mid-block crossing against traffic							
Changing lanes											
Road-SW-road											
SW-Road-SW											

Synthesis of Methods

The previous section outlined the methods I employed to complete this research project. I assert that my selected blend of sales tax data analysis, analysis of RTD, land use, and census data, and my observations and counts were the best combination of geographic methods to answer both of my research questions. Sales tax data analysis was the central tenet of my research methods, and the other types of analysis helped suggest the economic impacts following the installation of new bicycle facilities in Denver.

Results

"It is the unknown around the corner that turns my wheels."

Heinz Stucke, Bicycle touring for over 50 years and still going

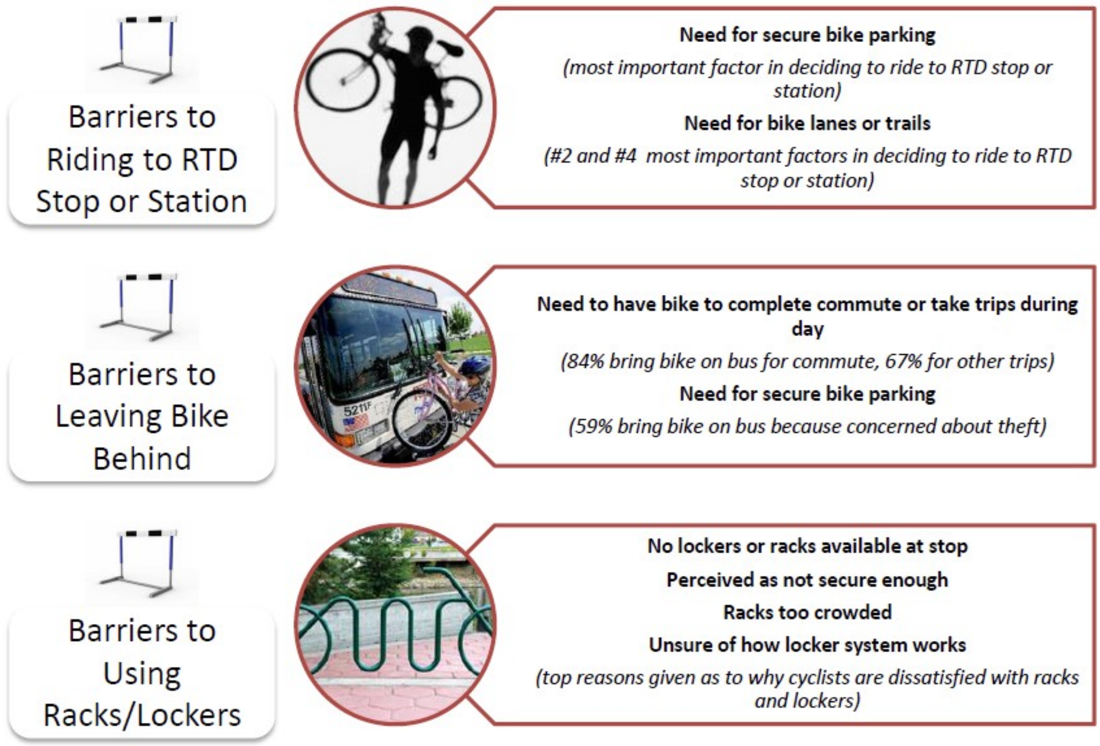
Introduction

The following section contains a detailed discussion of all the findings from this research. It begins with brief discussion of RTD data, followed by an in-depth discussion of my sales tax results, and ends with a detailed discussion of the findings from my mixed-methods observational research and counts on 15th Street. The results discussed in this section highlight the economic and traffic impacts following the installation of new bicycle facilities in Denver and the implications of these impacts for other cities.

Analysis of Existing Data: RTD License Plate Survey

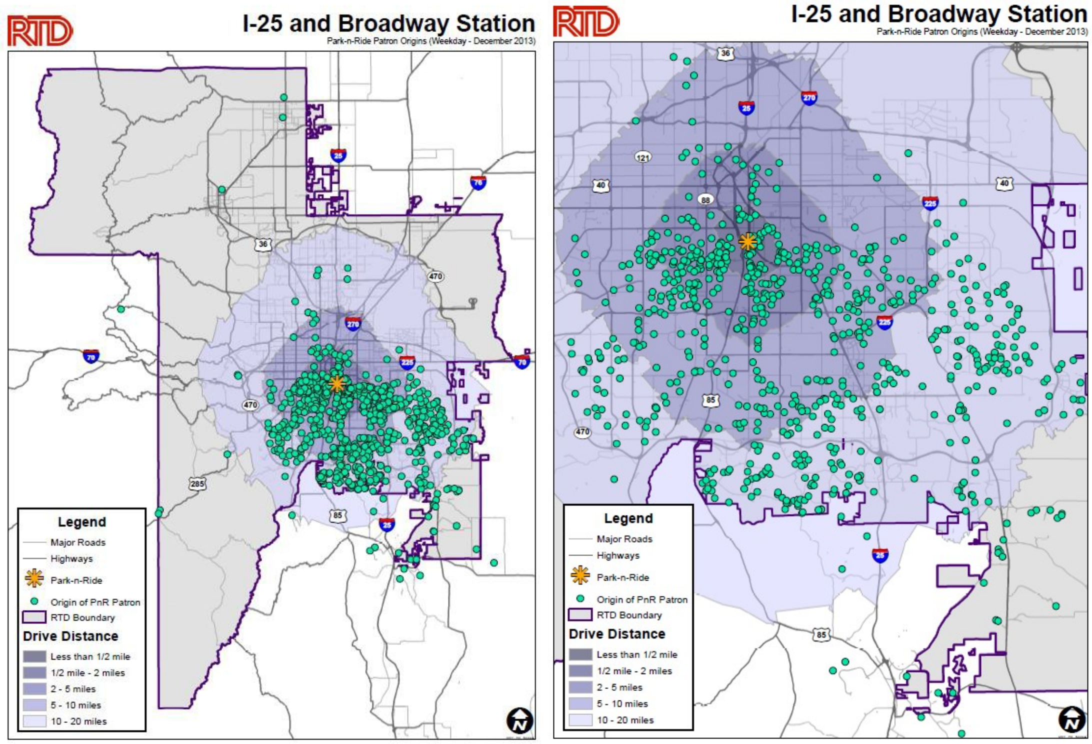
My position with RTD allowed me to analyze a large amount of geographic data, and provided access to numerous bike and transit reports. I was able to read the Bike on Bus Report, Bike Survey, and also worked directly on the Bike Parking and Accessibility Plan. The Bike Survey was conducted in 2014 and polled approximately 1,300 local transit patrons who used bikes to access transit. This survey highlighted aspects of RTD's Bike-n-Ride program that worked and others that needed improvement. Several key findings from the survey are outlined in Figure 14 below (RTD 2014). One can see that the majority of RTD patrons demand better bicycle facilities, and that many patrons needed to use their bike for other trips throughout the day. The Bike Survey helped to contextualize the suggestions put forth in the Bike Parking and Accessibility Plan that is currently being updated.

Figure 14: High-Level Findings from RTD Bike Survey (2014)



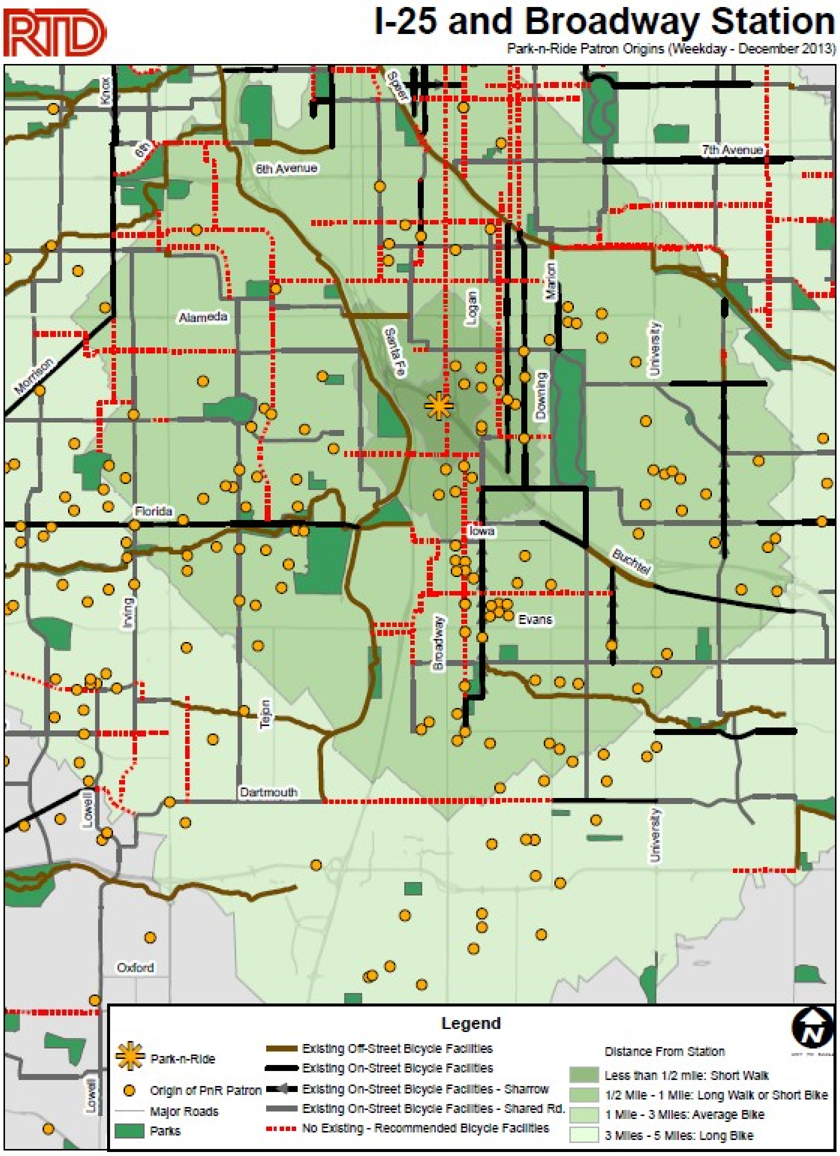
I also conducted the license plate survey to analyze the origins of RTD patrons who drive to access transit facilities. I created small scale and large scale maps for RTD uses, included in Figure 15 below, and used the network analyst tool to perform a statistical analysis of the data. I found that district-wide Park-n-Ride utilization was at 47%, that 57% of the 14,137 vehicles inventoried drove less than five miles to access transit facilities, and that 17% of those vehicles drove less than two miles. This means that nearly 2,500 patrons drove less than two miles to access transit across the RTD district, which motivated me to take a look at these data from a more pedestrian scale.

Figure 15: RTD License Plate Survey Car Scale: I-25 and Broadway Station



Next, I chose to conduct the pedestrian scale analysis for the City and County of Denver, displayed in Figure 16 below, because Denver displays the densest land uses in the region, which is where biking and transit work best. Denver's Park-n-Ride utilization was 40%, which is slightly lower than the entire district's rate. The pedestrian scale analysis also found that 33% of vehicles inventoried drove less than 3 miles to the station, and that 5% of those vehicles drove less than 1 mile to access the RTD transit facility. That is approximately 1,200 Denver residents who drove less than 3 miles, which is the FTA's acceptable distance for bike access. This suggests that thousands of transit patrons in the Denver Metro Area can easily substitute bike trips for car trips to access their local transit facility. My colleagues at RTD were intrigued by the large number of individuals driving short distances to access transit and remarked how this bicycle access potentially represents “low hanging fruit” for increasing transit ridership and improving mobility for all residents. The findings from the license plate survey help to contextualize my research and suggest that bicycle facilities are a cost-effective method for improving mobility.

Figure 16: RTD License Plate Survey Pedestrian Scale: I-25 and Broadway Station



Analysis of Individual Study Sites

Larimer Street Area Study Site: Sales Tax Analysis

A geographic statistical analysis of the Larimer Street improvement site delineated in Figure 9 above shows a sustained trend of increasing economic performance following the street improvement. Figure 17 shows Larimer Street's gross sales performance, while Figure 18 displays the food and beverage, other, and total sales tax categories. The green column corresponds with the construction of the new bicycle facilities in October of 2011, and there appears to be an increasing trend immediately following the street improvement. Both of these figures highlight how Larimer Street performed well in the 3-year period following the street improvement, and experienced a $1,570,440 increase in gross sales, a $36,129 increase in food and beverage tax, and a $29,937 increase in other tax. The last two figures combine for a $66,066 increase in total sales tax during this timeframe. Larimer Street witnessed economic growth after the street improvement, which suggests that the removal of a car travel lane and addition of bicycle facilities did not hurt business activity within this improvement site and may have contributed to the increase. The next step was to compare Larimer Street's economic performance to the Larimer Area comparison sites.

Figure 17: Larimer Street Economic Performance – Gross Sales

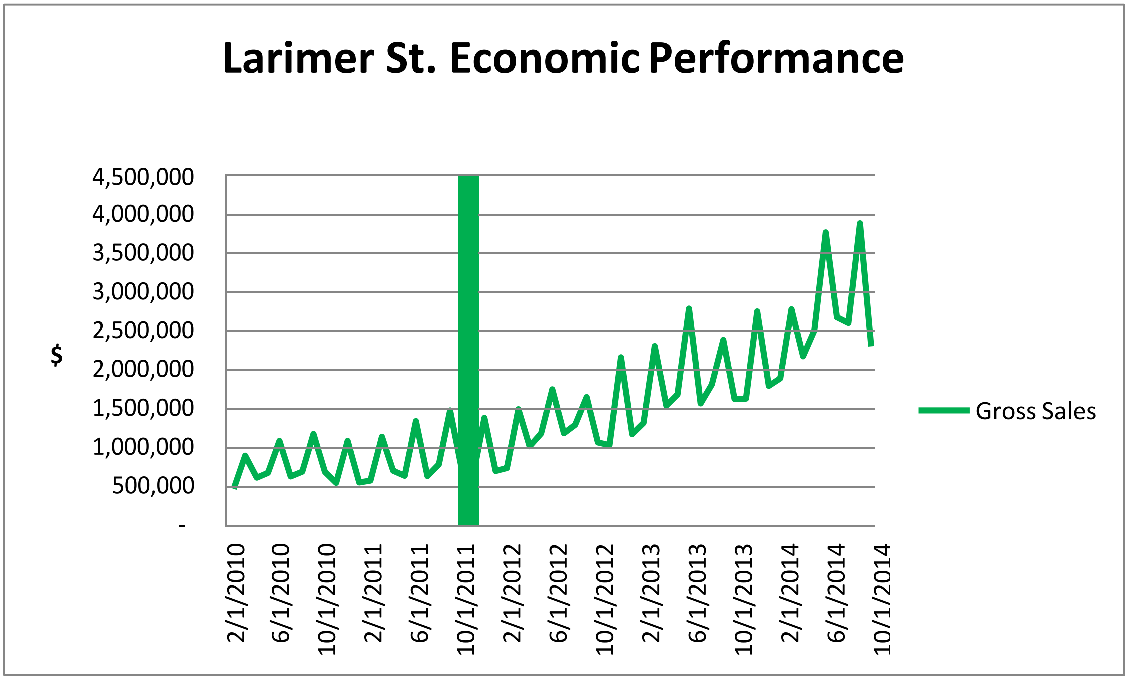
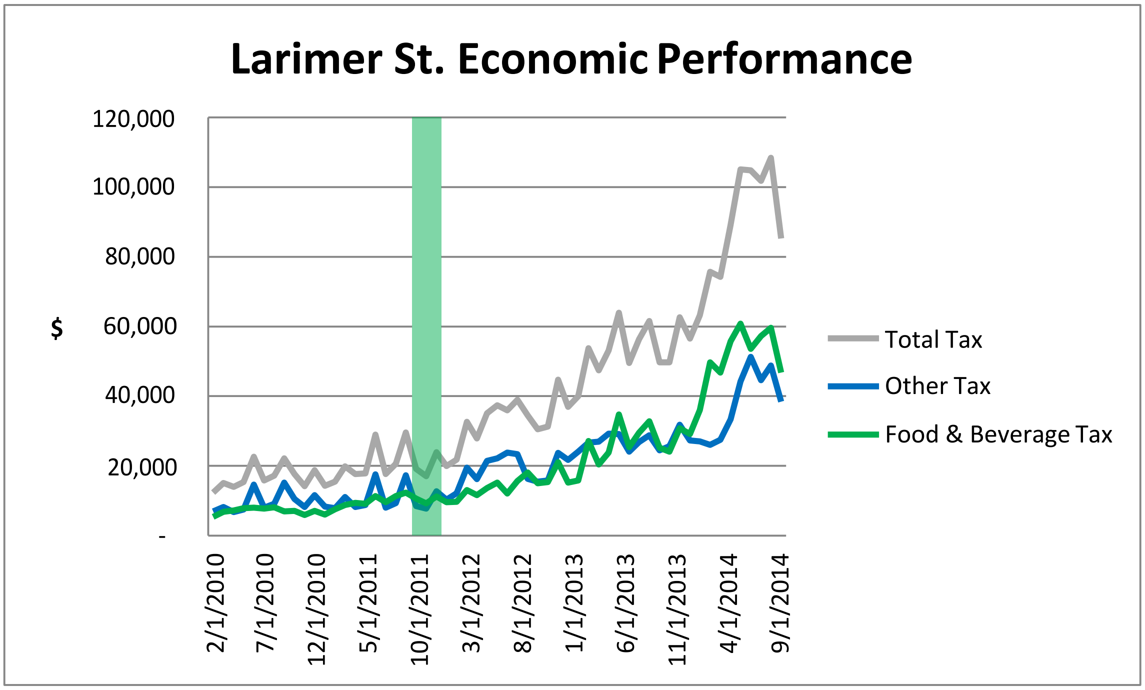


Figure 18: Larimer Street Economic Performance – Food & Beverage, Other, & Total Sales (Sum) Taxes



An analysis of Larimer Street, Brighton Boulevard, Blake Street, and 18th Avenue's sales tax data reveals several interesting trends and unexpected findings for the Larimer study area. Table 4 below highlights the overall economic performance for gross sales and total sales tax for all of the Larimer area improvement and comparison sites. This table shows the baseline monthly gross sales and total sales tax level along with the percent change for each year following the improvement. A brief overview of the table highlights how the gross sales for Larimer Street and 18th Avenue are similar, while Blake Street's is lower, and Brighton's is more than four times higher. The total sales tax tells a different story with Larimer Street as the largest, followed closely by 18th Avenue, and then Brighton Boulevard and Blake Street, displaying minute baseline tax levels. Brighton Boulevard's total sales tax baseline and Blake Street's baseline for both tax categories were relatively low, which caught my attention, since low starting values have the potential to impact the indices.

Table 4: Larimer Street Overall Economic Performance

Area	Baseline Monthly Gross Sales ($)	% Change in Sales Post-Improvement		
Improvement Site		**1st Year**	**2nd Year**	**3rd Year**
Larimer St.	729,930	46.27%	52.49%	41.29%
Comparison Sites				
Brighton Blvd.	4,085,896	-1.12%	-3.27%	7.08%
Blake St.	146,153	18.99%	364.84%	-14.67%
18th Ave.	863,980	7.07%	-3.55%	-40.32%
All Comparisons	5,096,029	0.85%	9.13%	-3.59%
Denver	44,974,696	6.80%	10.59%	11.94%

Area	Baseline Monthly Total Sales Tax ($)	% Change in Sales Post-Improvement		
Improvement Site		**1st Year**	**2nd Year**	**3rd Year**
Larimer St.	19,185	59.14%	62.74%	71.58%
Comparison Sites				
Brighton Blvd.	4,233	-52.11%	502.12%	77.17%
Blake St.	1,390	54.46%	974.80%	7.27%
18th Ave.	16,822	6.12%	-1.49%	-63.08%
All Comparisons	22,445	-1.87%	140.02%	0.01%
Denver (Gross Sales)	44,974,696	6.80%	10.59%	11.94%

Closer inspection of Table 4 above shows that the Larimer Street improvement was the only site to experience growth for all three years in both tax categories. Larimer

Street also outperformed all of the comparison sites in the first year following the street improvement, which suggests that the street improvement may have jumpstarted economic performance along the improvement site before the impacts spilled over to the comparison sites around Five Points. Brighton Boulevard and Blake Street experienced uncharacteristically large boosts in sales during the second year following the improvement, but these increases were not sustained into the third year. While the data in this table are slightly erratic, Larimer Street still appears to have performed well, and the street improvement certainly did not have a negative impact on its economic performance. I found it difficult to ascertain other trends from this table, which led me to conduct further analyses.

The uncharacteristically large increases in sales for Brighton Boulevard and Blake Street encouraged me to plot gross sales and total sales tax performance for both sites individually, which are displayed in Figure 19 and Figure 20 below. Both figures highlight how Brighton Boulevard and Blake Street experienced massive increases during the study period and how neither of the increases aligned with the street improvement. Unfortunately, I did not have access to the individual data points, and therefore reached out to Mike to see what he saw in the individual data. Mike found two noteworthy trends in the data. First, he noted how several businesses along the Brighton improvement site changed the way they reported gross sales and exempt sales on their tax return in June of 2011. He provided the example that a business can report $4.5 million in gross sales with a $4 million deduction to arrive at $500,000, or they can report $500,000 with zero deduction to arrive at the same amount. This remarkable change in reporting methods highlighted Brighton Boulevard as an artificially inflated outlier that required extra attention throughout the analysis.

Mike's second observation was that the sharp increase in total sales tax for Blake Street was due to a couple of businesses reporting large sales during this time, which changed the general trend afterwards. The drastic increase in total sales tax for Blake Street proves it to be a statistical outlier, but this is due to a relative increase in sales as opposed to completely different methods. Mike's notes on these two outliers were invaluable and highlighted the importance of cultivating close working relationships with city staff. I was tempted to smooth the outliers with averages, in a similar fashion as the NY and WA studies, but decided against it to avoid masking results (NYCDOT 2013; Rowe 2013). Once I understood the reasons for these drastic increases I proceeded to my sales index analysis.

Figure 19: Brighton Boulevard and Blake Street's Gross Sales Performance

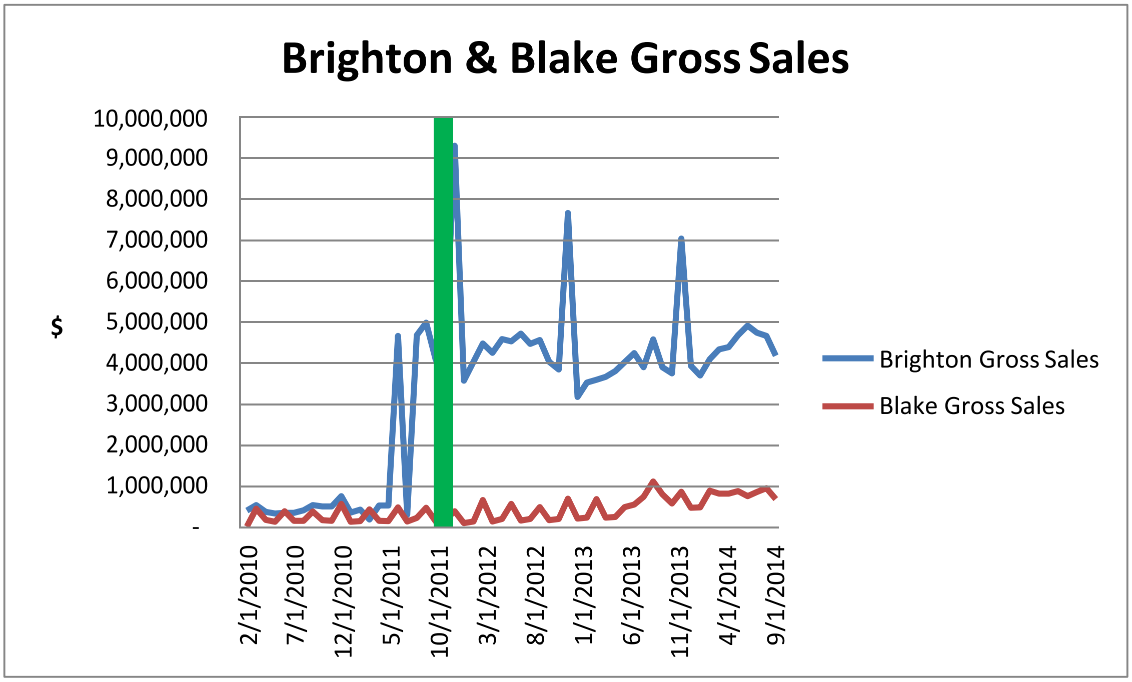
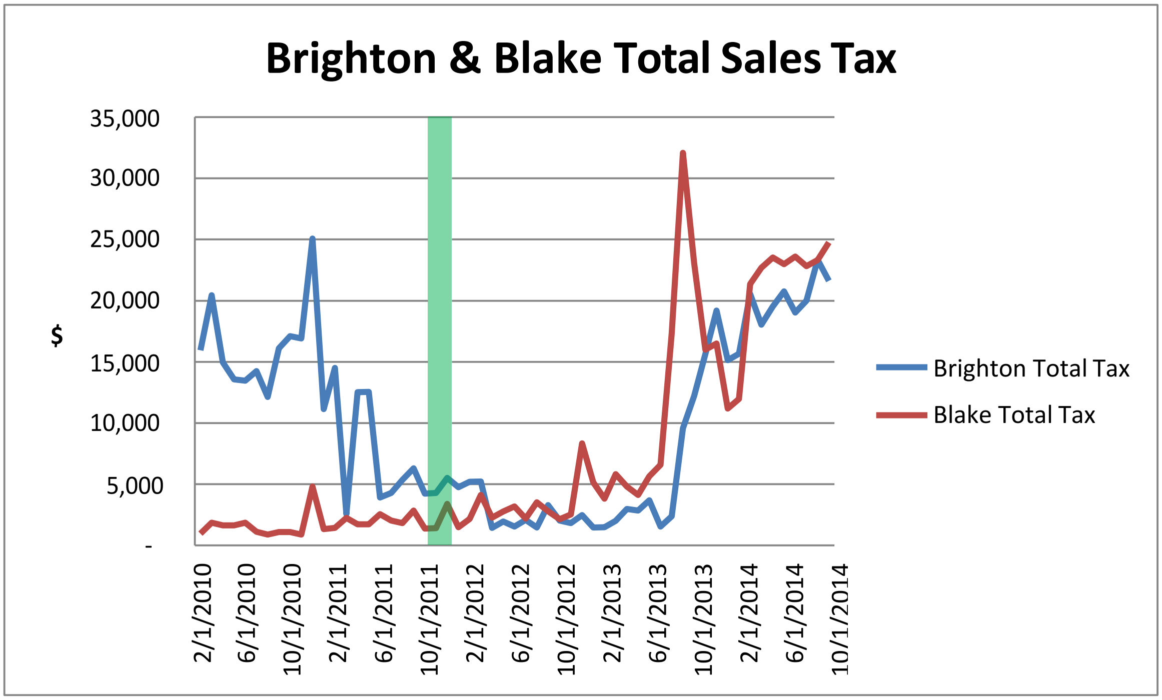


Figure 20: Brighton Boulevard and Blake Street's Total Sales Tax Performance



The next step in my analysis was to create sales indices for all of the Larimer area sites in order to compare performance across all sites. Figure 21 and Figure 22 display the sales indices for Larimer Street, the average of all three comparison sites, and the Denver city-wide comparison for gross sales and total sales tax, respectively. The gross sales index in Figure 21 below shows that all of the improvement and average comparison sites experienced growth during the study period. Denver's gross sales index experienced minimal growth, which makes sense for a city-wide statistic. Both Larimer Street and the comparison sites experienced increasing economic performance during the study period, and the timing of these increases is noteworthy. Larimer Street displayed a horizontal gross sales index trend until the street improvement, when the trajectory changed, and a new trend of increasing economic performance emerged. The comparison sites also began with a generally horizontal gross sales index until they exhibit a major spike in June of 2011. This spike corresponds directly to the aforementioned change in reporting methods for the Brighton Boulevard businesses. One can also see how the comparison site average follows a nearly identical trend as the Brighton Boulevard gross sales in Figure 19 above. The similarities between the Brighton Boulevard trend line and the average of all Larimer area comparison sites highlights the influence outliers have on general trends. I discuss the role of outliers in more detail below. Despite the skewed data from Brighton Boulevard's methods change, Larimer Street's sustained growth still helped it outperform the comparison sites.

Figure 21: Larimer Street and Comparison Sites – Gross Sales Indices

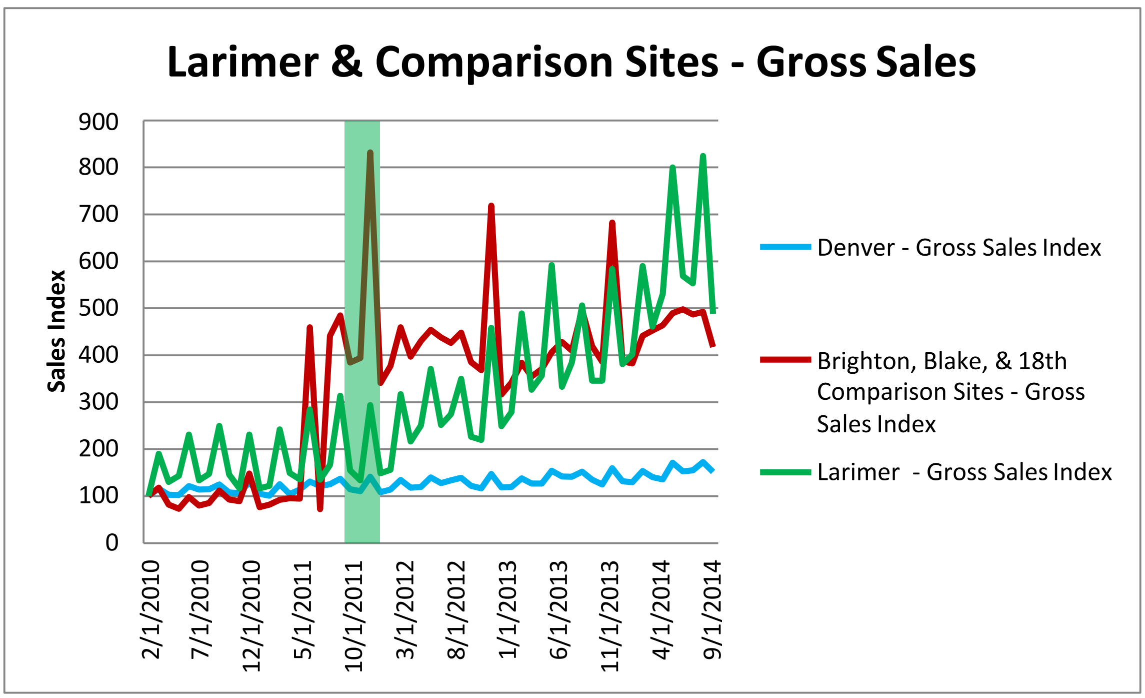
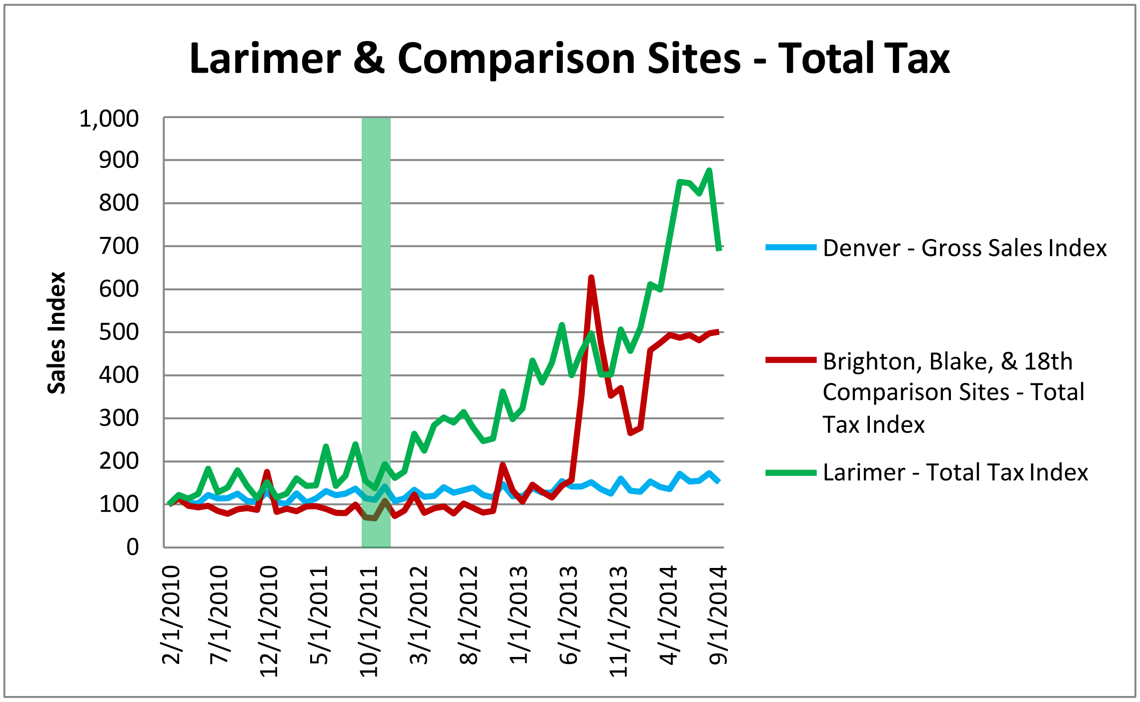


Figure 22: Larimer Street and Comparison Sites – Total Sales Tax Indices



The total sales tax index in Figure 22 displays similar findings as the gross sales index and shows how all of the improvement and average comparison sites experienced growth during the study timeframe. Denver did not provide a total sales tax for the entire city, and therefore I use the same gross sales index in Figure 21 as a general city-wide comparison site. Both Larimer Street and the comparison sites witnessed increasing economic performance during the study period, and the timing and severity of these increases is noteworthy. Larimer Street's total tax index displayed a similarly horizontal gross sales index trend until the street improvement, when the trajectory also changed to follow a new trend of increasing economic performance. The comparison sites also began with a generally horizontal gross sales index, but they did not exhibit the same trajectory of increasing economic performance that Larimer Street did, immediately following the street improvement. One can see how the economic growth of the comparison sites does not appear until long after the street improvement. The delay in growth might be due to spillover effects from the Larimer Street improvement, but may also be related to other factors. Closer inspection also revealed how the total tax index followed a similar trajectory as the Blake Street comparison site, which suggested that the Blake Street outlier skewed the entire average. Despite the large spike in the data from Blake Street's positive outlier, Larimer Street still outperformed the comparison sites at the end of the study period due to a sustained growth trend. Figure 21 and Figure 22 showcase how the Larimer Street improvement site outperformed the comparison site averages for gross sales and total sales tax, while also suggesting that the Brighton and Blake Street outliers had a major impact on the comparison street trends.

The large influence of outliers on the sales indices motivated me to plot the same data as Figure 21 and Figure 22 above, but without the Brighton Boulevard gross sales, and Blake Street total tax data included. Figure 23 and Figure 24 plot the same improvement site and city-wide data, but they do not include the Brighton Boulevard and Blake Street outliers in the comparison site averages. Removing the outliers highlights how largely they influence the averages, while also showcasing that Larimer Street experienced significant increases in economic performance for both gross sales and total sales tax. Figure 23 and Figure 24 also indicate that the comparison sites performed worse than the Denver city-wide comparison, which was unexpected. I also believe the relatively low starting total sales tax values for Brighton Boulevard and Blake Street help to explain why the sales index increase is so large. Sales index calculations require a baseline value for comparison against future economic performance. Low starting values can influence a major spike in the sales index for that site because the fractional growth, or decrease, is remarkably different than the starting value. The best example of this from my data is Blake Street. Blake Street begins with $1,390 in total sales tax during the improvement year and grows to $24,754, a $23,364 increase, by October of 2013. This increase is dwarfed by the increase of $89,232 that Larimer Street experienced during the same timeframe, but the low starting point caused Blake Street's sales index to jump into the thousands, while Larimer Street's index remained in the hundreds.

Figure 23: Larimer Street and Comparison Sites (No Brighton) – Gross Sales Indices

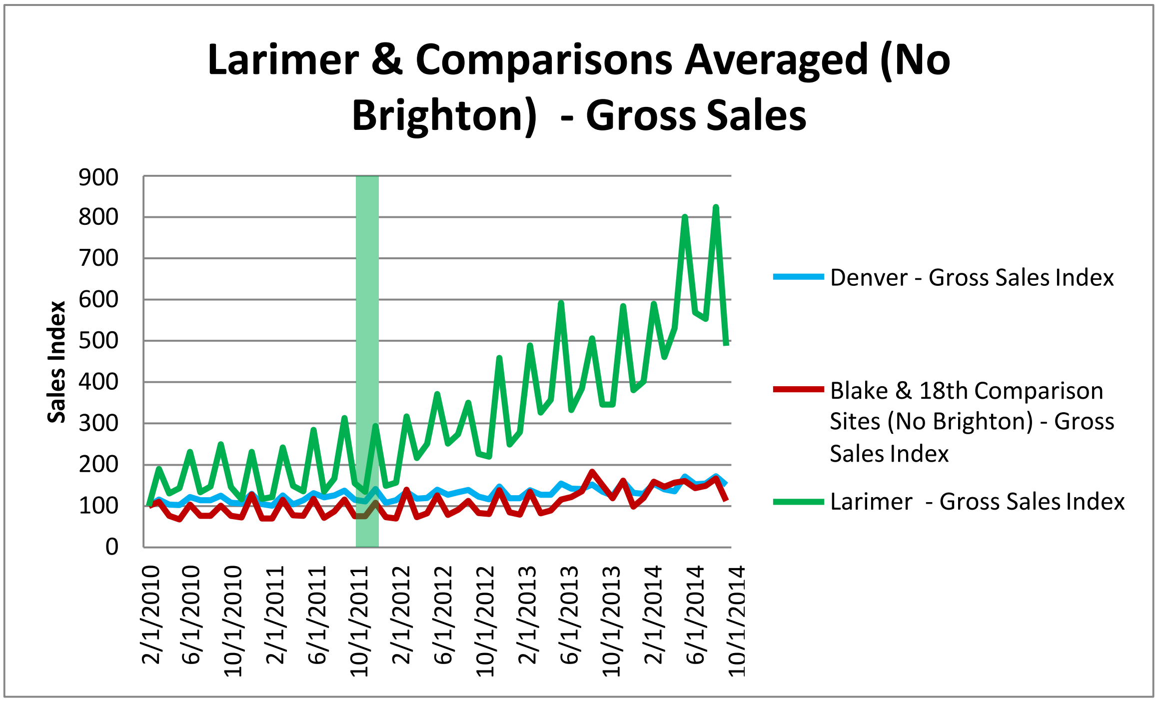
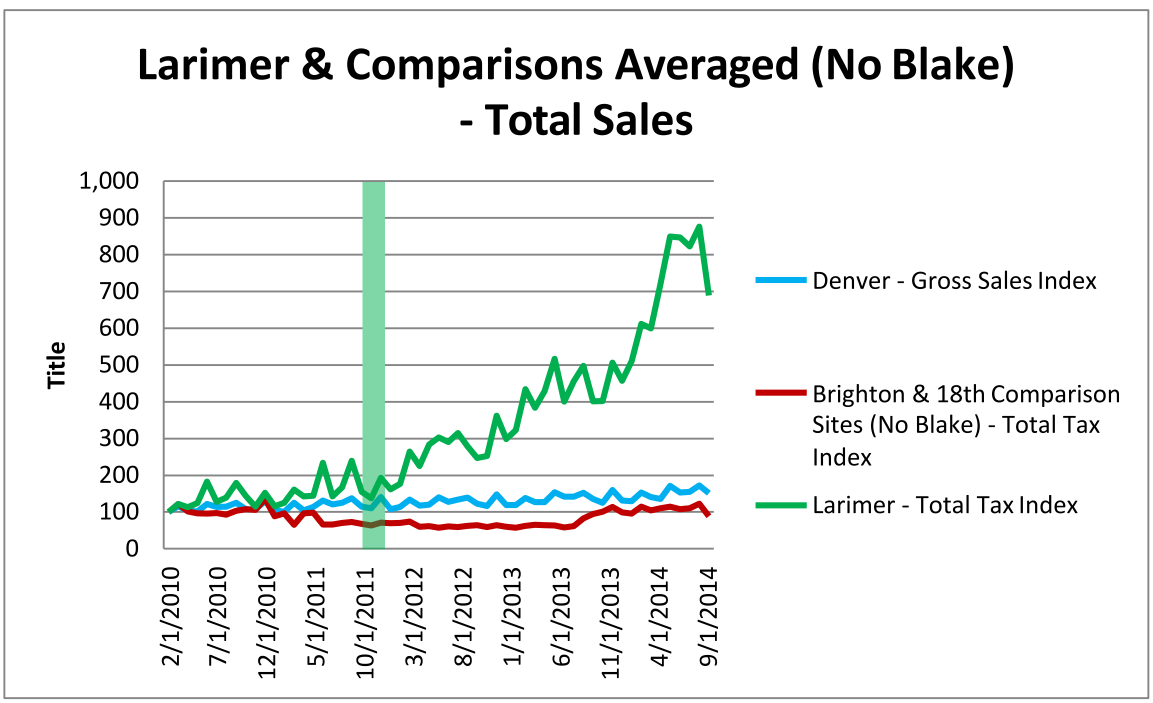


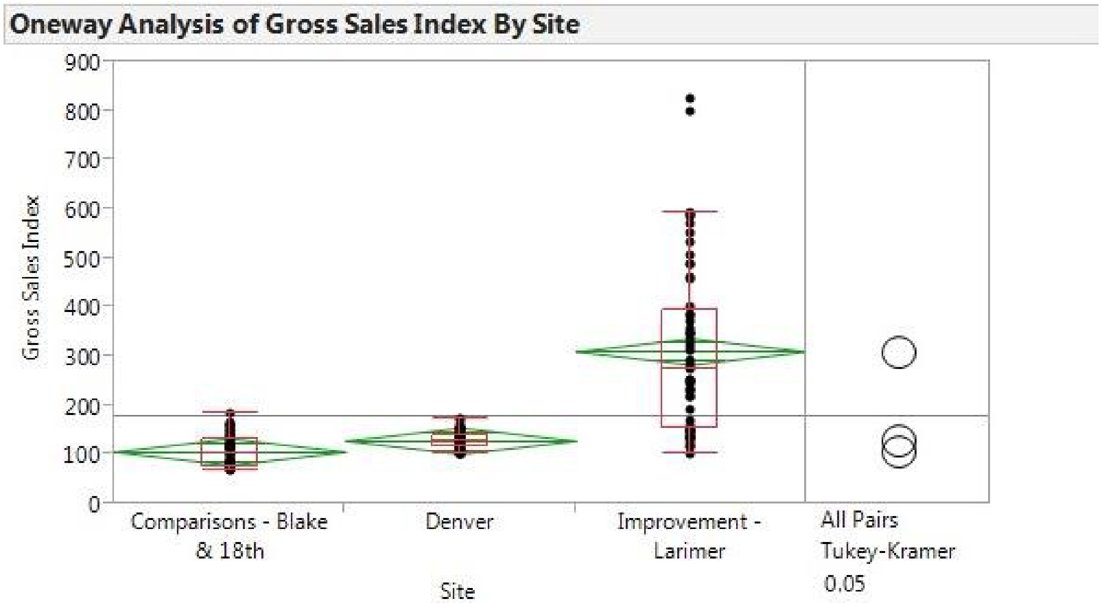
Figure 24: Larimer Street and Comparison Sites (No Blake) – Total Sales Indices



This discussion of outliers highlights several key points. The Brighton Boulevard comparison site is a true outlier based on the reporting methods change for gross sales discussed earlier, and therefore must be removed from the data set to show the actual economic performance for this area. The elimination of Brighton Boulevard's data in Figure 23 helps to provide a more representative portrayal of the actual gross sales economic performance for this area. Blake Street's large spike in total sales tax after September 2013 also represents a statistical outlier. This outlier is not related to a method change or other anomaly, but instead growth from a very low starting point that influences the trajectory of its total tax index. While Figure 24 tells a clean cut story about the total sales tax performance at the Larimer Street area study site, Figure 22 still provides a representative portrayal of the actual economic performance along Blake Street. The removal of Brighton Boulevard was justified due to that anomalous spike in data before the improvement. Deleting Brighton Boulevard's gross sales outlier further highlights how the Larimer Street improvement site outperformed all of the comparison sites in both indices.

The aforementioned analysis of visible trends and outliers suggested where to focus the statistics component of this research. I performed one-way ANOVA tests on all of the sites to test for statistically significant differences between each study site, and began by conducting a one-way ANOVA on the gross sales indices for the Larimer Street improvement site, the average of the Blake Street and 18th Avenue comparison sites, and the Denver city-wide comparison site displayed in Figure 23 above. The ANOVA, displayed in Figure 25 below, shows there to be a significant difference in means across the Larimer study area sites, $F(2, 168) = 68.78$, $p = .0001$. This highlighted the statistically significant difference between the means of Larimer Street ($M = 310.46$) and the neighborhood comparison ($M = 106.3$) and city-wide sites ($M = 128.51$). I conducted a Tukey-Kramer HSD with an $\alpha = .05$, which provided the output included in Figure 26 that corresponds with the circles on the far right of Figure 25. This display visualizes the statistically significant differences within the data using letters and asserts that the Larimer improvement site is significantly different from the other two comparisons, but that these comparisons do not display statistically significant differences between one another. These results emphasize that the difference in gross sales performance between the Larimer area improvement site and the neighborhood and city-wide comparisons is statistically significant. The results of the preceding significance test make sense when viewed alongside the data it tests in Figure 23.

Figure 25: Basic Output for Larimer Study Area Gross Sales Index Analysis (Brighton Outlier Removed)



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Comparisons - Blake & 18th	67	71.8	76	101	131	157.4	183
Denver	100	104.8	114.5	127	140.5	153.2	172
Improvement - Larimer	100	133.2	152	274	393	572	824

Figure 26: Connecting Letters Report from Tukey-Kramer HSD for Larimer Study Area Gross Sales Index Analysis (Brighton Outlier Removed)

Connecting Letters Report

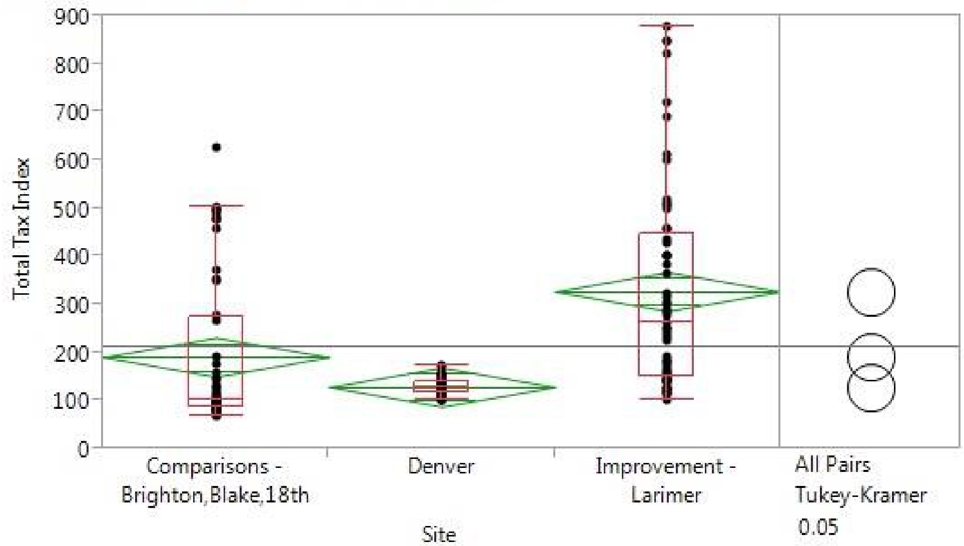
Level			Mean
Improvement - Larimer	A		310.45614
Denver		B	128.50877
Comparisons - Blake & 18th		B	106.29825

Levels not connected by same letter are significantly different.

The following step was to conduct another one-way ANOVA to test the significance of the total sales tax indices for the Larimer Street improvement site, the average of the neighborhood comparison sites, and the Denver city-wide comparison site, displayed in Figure 22 above. The ANOVA, displayed in Figure 27 below, shows there to be a significant difference in means across the Larimer study area sites, $F(2, 168) = 24.57$, $p = .0001$. This highlighted the statistically significant difference between the means of Larimer Street ($M = 327.11$) and the comparison ($M = 190.65$) and city wide sites ($M = 128.51$). I conducted a Tukey-Kramer HSD with an $\alpha = .05$, which provided the output included in Figure 28 that corresponds with the circles on the far right of Figure 27. This display visualizes the statistically significant differences within the data (using letters) and asserts that the Larimer improvement site is significantly different from the other two comparisons, but these comparisons do not display statistically significant differences between one another. These results emphasize that the difference in total sales tax performance between the Larimer area improvement site and the neighborhood and city-wide comparisons is statistically significant. The results of the preceding significance test make sense when viewed alongside the data it tests in Figure 22.

Figure 27: Basic Output for Larimer Study Area Total Sales Tax Index Analysis

Oneway Analysis of Total Tax Index By Site



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Comparisons - Brighton,Blake,18th	68	79.8	86.5	100	272	488.4	628
Denver	100	104.8	114.5	127	140.5	153.2	172
Improvement - Larimer	100	123.6	148.5	264	445.5	695.4	876

Figure 28: Connecting Letters Report from Tukey-Kramer HSD for Larimer Study Area Total Sales Tax Index Analysis

Connecting Letters Report

Level		Mean
Improvement - Larimer	A	327.10526
Comparisons - Brighton,Blake,18th	B	190.64912
Denver	B	128.50877

Levels not connected by same letter are significantly different.

Larimer Street Area Study Site: Other Analysis

The statistically significant findings, discussed in the preceding paragraphs, outline how there is a difference between the economic performance of the Larimer area improvement and comparison sites. Larimer Street’s unique differences led me to take a brief look at land use and census data to see if I could uncover other discernible trends corresponding with the street improvement. Brief analysis of the 2009-2013 US Census American Community Survey (ACS) data revealed that all of the Larimer area study sites fell below the $50,000 median household income mark, and one of the Five Points block groups had nearly 60% of its residents below the poverty line. An analysis of transportation indicators also revealed that Five Points had an uncharacteristically large percentage of residents who biked to work, with a 10% mode share in two census tracts (DOLA 2015). The aforementioned factors highlight how the Larimer Area study site displays promise for increased cycling rates, while also serving the need-based bike commuter category.

A brief analysis of land use change over time also helps to contextualize the findings from my sales tax analysis of economic performance. Table 5 below displays the most recent land use data for the Larimer area study site, sorted by Larimer Street's largest to smallest values. This chart reveals several interesting findings about the land uses at the sites. Larimer Street exhibits the largest amount of mixed-use and commercial/retail land uses, and the lowest vacancy rate for all of the sites in Five Points. We also see that 18th Avenue has the second largest amount of commercial/retail land uses, yet still performed relatively poorly in this category. A quick comparison of the 2012 and 2003 land uses also uncovers several interesting trends. Larimer Street begins to trade out vacant land for more pedestrian focused land uses of retail, housing, and mixed land uses, while many of the other sites experienced increased vacancy, especially Brighton, which climbed from 14.49% vacancy in 2003 to 29.58% in 2012. These are the easily discernible trends, and I do not want to belabor the discussion of land use change here as the nine year gap between land use data does not correspond exactly to my four year sales tax analysis.

Table 5: 2012 Land Use for Larimer Area Study Sites

Land Use Category	Larimer LandUse%	Brighton LandUse%	Blake LandUse%	18th LandUse %
Industrial	27.39%	54.93%	25.44%	0.00%
Multi-Family Low Rise	18.47%	0.00%	47.37%	32.06%
Commercial/Retail	15.29%	2.82%	0.00%	13.74%
Vacant	10.19%	29.58%	10.53%	2.29%
Single Family	8.28%	5.63%	0.88%	8.40%
Office	6.37%	0.00%	3.51%	23.66%
Parking	6.37%	1.41%	4.39%	6.87%
Mixed-Use	5.10%	1.41%	1.75%	3.82%
Multi-Family Mid Rise	1.27%	1.41%	3.51%	2.29%
Public/Quasi-Public	1.27%	0.00%	0.00%	2.29%
Entertainment-Cultural	0.00%	0.00%	0.00%	0.00%
Multi-Family High Rise	0.00%	0.00%	0.00%	0.76%
Other/Unknown	0.00%	1.41%	0.00%	0.00%
Park-Open Space-Recreation	0.00%	0.00%	0.00%	3.82%
ROW/Road	0.00%	0.00%	1.75%	0.00%
Surface Water	0.00%	0.00%	0.00%	0.00%
TCU	0.00%	1.41%	0.88%	0.00%

The preceding discussion of the Larimer area study sites showcases how Larimer Street's economic performance was not at all hindered by the street improvement and removal of an auto travel lane. After removing the Brighton Boulevard outlier for gross sales, the trends all suggest that Larimer Street outperformed all of the comparison and city-wide sites. The timing of the increase in economic performance was also noteworthy because it occurred immediately following the street improvement. Larimer Street's amplified economic performance was proven to be statistically significant after an

ANOVA test. A brief overview of US Census and land use data also highlights the unique demographic factors at play and shows that this is a rapidly changing area. The Larimer area study site confirmed many of my original hypotheses, while also uncovering several interesting findings.

15th Street Area Study Sites: Sales Tax Analysis

A geographic statistical analysis of the 15th Street improvement site, displayed in Figure 11 above, shows a trend of increasing economic performance after the installation of the buffered bike lane and PBL that was less pronounced than the Larimer area site. Figure 29 shows 15th Street's gross sales performance, while Figure 30 displays the food and beverage, other, and total sales tax categories. These figures display the data for all three improvement sites on the same chart. The light green column indicates the addition of the buffered bike lane in August of 2013, and the darker green line indicates the addition of the PBL in May 2014. It is difficult to call out discernible trends from a 14 month post improvement period because the facilities are still new. Simple calculations reveal that 15th Street's PBL segment performed well economically and experienced a $2,322,123 increase in gross sales, $48,420 increase in food and beverage tax, and a $5,934 increase in other tax. The last two PBL figures combine for a $54,354 increase in total sales tax during this timeframe. 15th Street's sharrow segment experienced a $343,108 increase in gross sales, $724 decrease in food and beverage tax, and a $1,322 increase in other tax. The last two sharrow figures combine for a $598 increase in total sales tax during this timeframe. The Larimer Street spillover block experienced a $386,140 increase in gross sales, $11,325 increase in food and beverage tax, and a $1,429 increase in other tax. The last two Larimer Street spillover figures combine for a $12,754 increase in total sales tax during this timeframe. Nearly all of 15th Street's improvement segments experienced growth after the new bicycle facilities were added, which suggests that the substitution of a bicycle travel lane for a car travel lane did not hurt business activity along this improvement site and may have helped. I want to make it clear that the findings from 15th Street's sales tax economic performance are less conclusive than Larimer Street's. 15th Street still displays significant trends and findings, but the PBL is relatively new, and therefore we shouldn't over ascribe the sales tax increases to be the results of the PBL. This highlights the need for future research on 15th Street's PBL once the facility has been in use for more than two years after the 2014 installation date. The following step was to compare the economic performance between the improvement and comparison sites.

Figure 29: 15th Street Economic Performance – Gross Sales

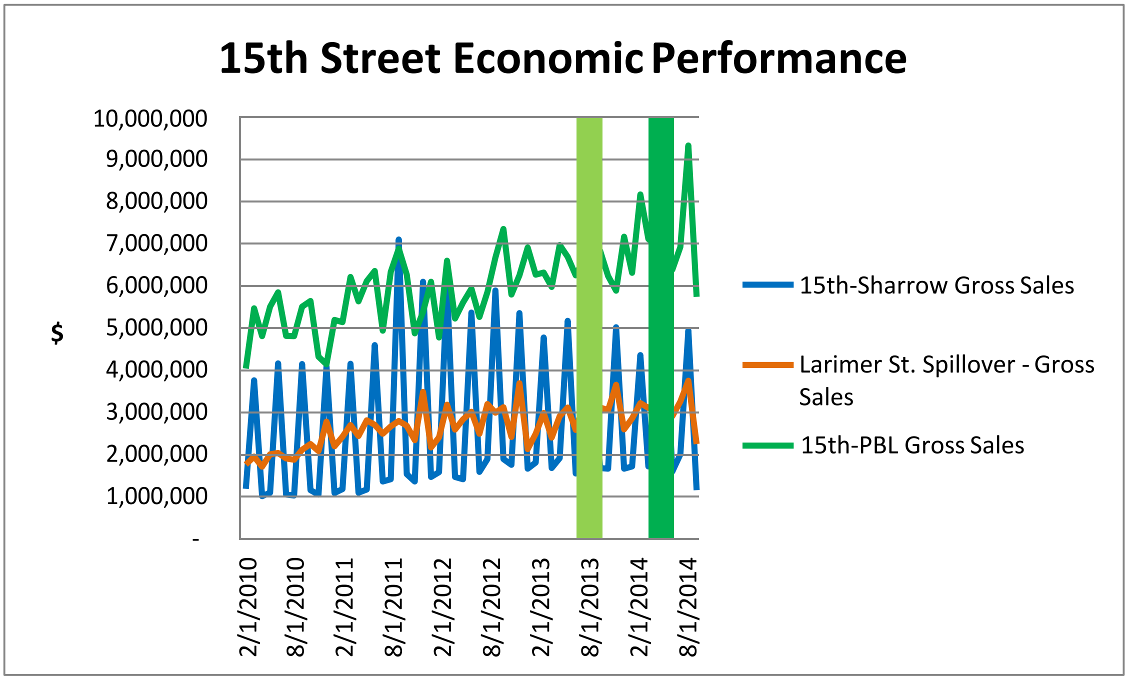
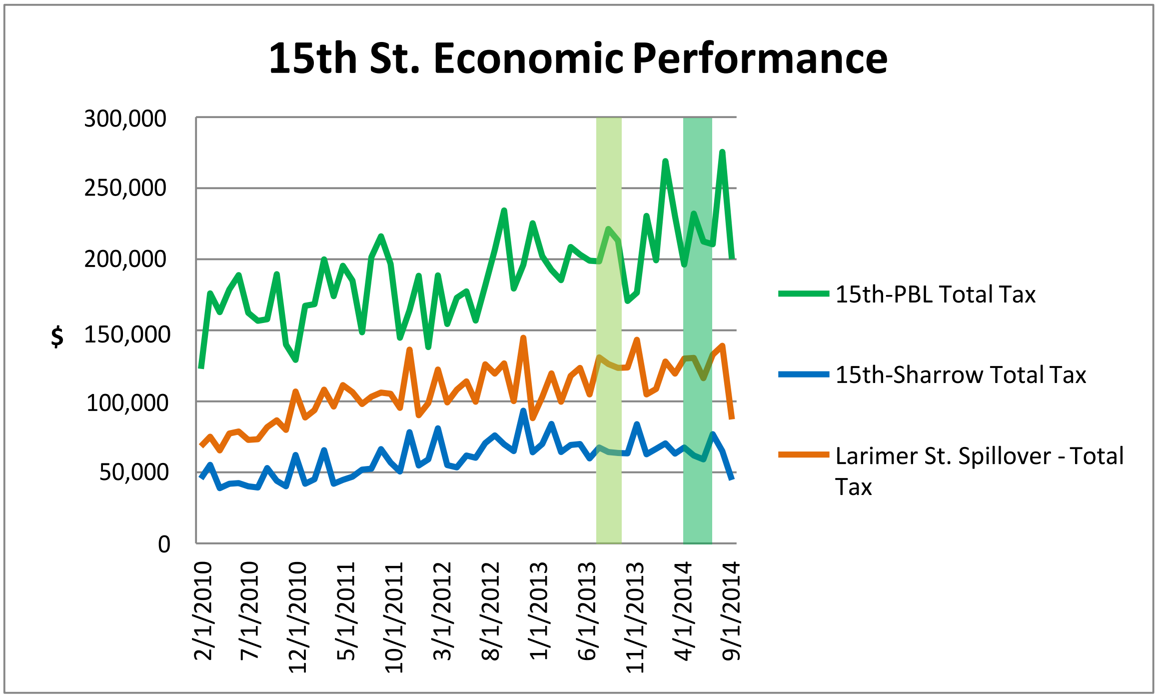


Figure 30: 15th Street Economic Performance –Total Sales Tax



An analysis of sales tax performance for the 15th Street improvement segments, 17th Street, Curtis Street, and Park Avenue sites reveals several notable trends and unexpected findings for the 15th Street study area. Table 6 below highlights the overall economic performance for gross sales and total sales tax for all of the 15th area improvement and comparison sites. This table shows the baseline monthly gross sales and total sales tax level along with the percent change for each year following the improvement. A brief overview of the table highlights how the gross sales for all improvement and comparison sites are in the millions, except for Park Avenue, which is lower. The total sales differ slightly with 17th Street having the highest total tax returns, and Park Avenue still rounding out the bottom. Park Avenue's low gross sales and total tax values also caught my attention due to their low baseline values. 15th Street does not appear to outperform the other sites in this initial analysis, which was the motivation for the statistical analyses that follow.

Table 6: 15th Street Overall Economic Performance

Area		**% Δ Sales Post-Improvement**
Improvement Site	**Baseline Monthly Gross Sales ($)**	**Observation Period (Buffered Lane - 8 Months & PBL - 7 Months)**
15th St. - PBL	6,652,847	40.19%
15th St. - Sharrow	1,769,120	179.48%
Larimer St. - Spillover	3,246,923	15.58%
All Improvements	11,668,890	54.46%
Comparison Sites		
17th St.	9,680,783	57.70%
Curtis St.	4,409,356	114.11%
Park Ave.	421,032	57.24%
All Comparisons	14,511,171	114.11%
Denver	55,520,390	21.94%

Area		**% Δ Sales Post-Improvement**
Improvement Site	**Baseline Monthly Total Sales Tax ($)**	**1st Year (Buffered Lane - 8 Months & PBL - 4 Months)**
15th St. - PBL	198,502	38.87%
15th St. - Sharrow	67,524	-3.87%
Larimer St. - Spillover	130,999	6.16%
All Improvements	397,025	20.81%
Comparison Sites		
17th St.	335,353	42.78%
Curtis St.	124,624	12.94%
Park Ave.	15,539	33.95%

All Comparisons	475,516	34.67%
Denver (Gross Sales Tax)	55,520,390	21.94%

An analysis of general trends did not reveal any major outliers to control for. The following step was to create sales indices, using the 2010 baseline data, for all of the 15th area sites to contrast with the comparison sites. Figure 31 and Figure 32 display the sales indices for the average of the 15th Street improvement sites, all three comparison sites, and the Denver city-wide comparison for gross sales and total sales tax, respectively. The gross sales index in Figure 31 below demonstrates how all of the improvement and comparison sites experienced growth during the study period. Denver's gross sales index experienced minimal growth, which makes sense for a city-wide statistic. Both 15th Street and the comparison sites experienced increasing economic performance during the study period, and the improvement site appears to outperform the comparisons too. The economic growth within the 15th Street study area was only slightly higher than the city-wide comparison. This suggests that businesses downtown serve as barometers for Denver's economic performance. Unlike the Larimer area sites, there is no noticeable difference in gross sales following the street improvement, which may be due to the recent installation date.

Figure 31: 15th Street Improvements and Comparison Sites – Gross Sales Indices

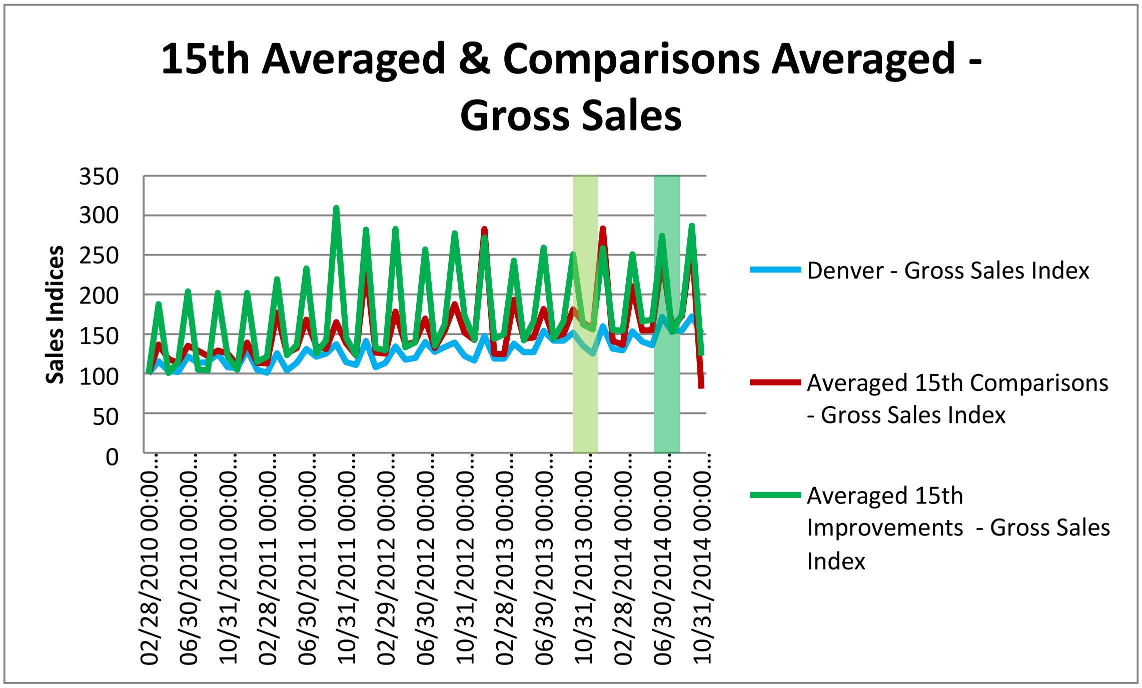
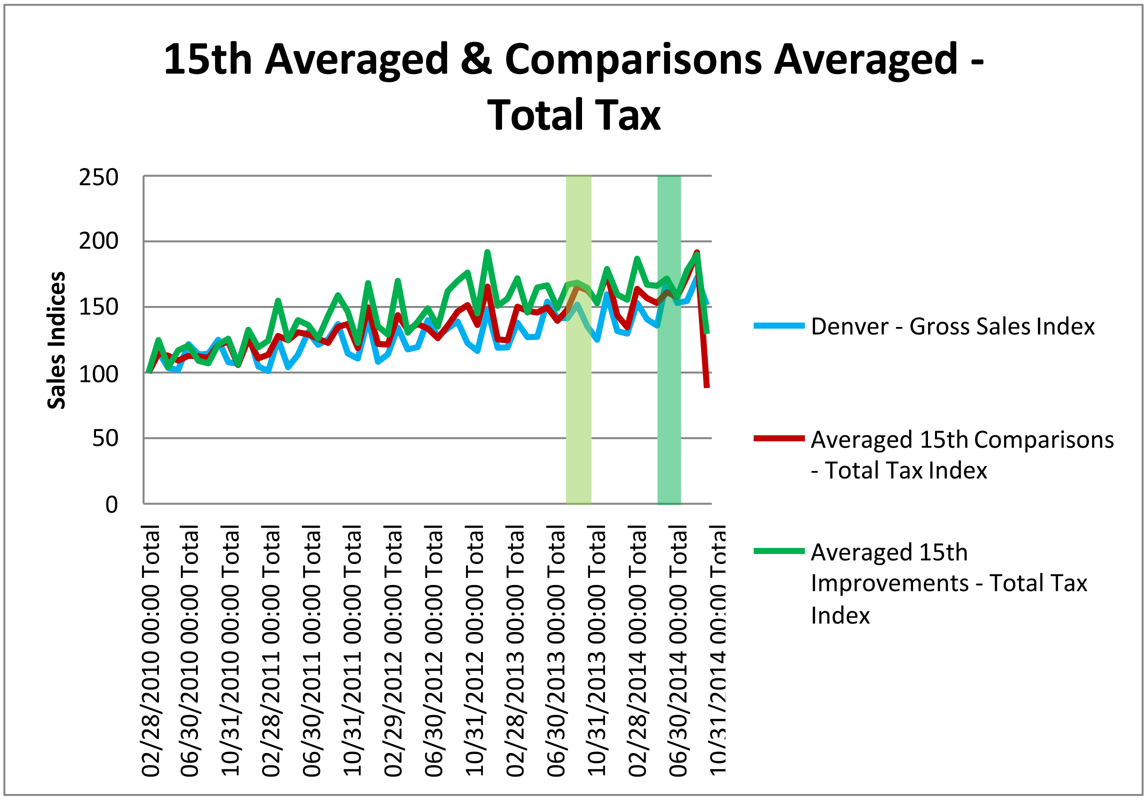


Figure 32: 15th Street Improvements and Comparison Sites – Total Tax Indices

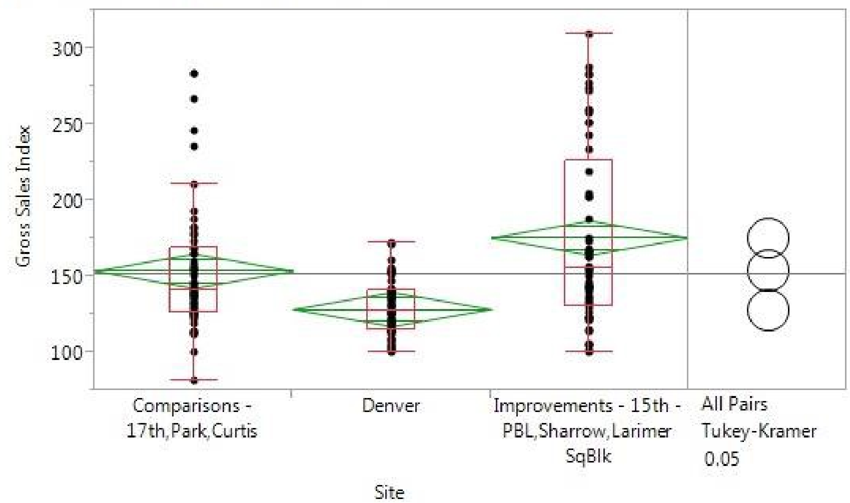


Total sales tax tells a different story and appears to increase after the street improvement. Figure 32 shows how all sites experienced growth following the street improvement. Denver did not provide a total sales tax for the entire city, and therefore I use the same gross sales index in Figure 31 as a general city-wide comparison site. All of the sites closely follow the city-wide trajectory, yet the improvement site also appears to slightly outperform the comparisons. There is an initial increase following the buffered bike lane, but the timeframe is too short to allow the trend to stabilize following the PBL installation, which highlights the need for future research.

The aforementioned analysis of visible trends and outliers suggested where to focus the statistical component of this research. I performed one-way ANOVA tests on all of the sites to test for statistically significant differences between each study site and began by conducting a one-way ANOVA on the gross sales indices for the improvement sites, comparison sites, and the Denver city-wide comparison displayed in Figure 31 above. The ANOVA, displayed in Figure 33 below, shows there to be a significant difference in means across the 15th Street study area sites, $F(2, 168) = 16.92$, $p = .0001$. This highlighted the statistically significant difference between the means of the 15th Street improvement site average ($M = 175.53$) and the neighborhood comparisons ($M = 153.72$) and city-wide sites ($M = 128.51$). Next, I conducted a Tukey-Kramer HSD with an $\alpha = .05$, which provided the output included in Figure 34 that corresponds with the circles on the far right of Figure 33. This display visualizes statistically significant differences using letters, and shows that the 15th Street improvement sites are significantly different from the other two comparisons, and that these comparisons are also statistically significantly different from one another. These results emphasize that the differences in gross sales performance between the 15th Street improvement sites and the neighborhood and city-wide comparisons are statistically significant. These statistically significant differences are important but require further analysis with 2017 data to uncover conclusive trends after the improvement. The results of the preceding significance test look correct when viewed alongside the data it tests in Figure 31.

Figure 33: Basic Output for 15th Study Area Gross Sales Index Analysis

Oneway Analysis of Gross Sales Index By Site



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Comparisons - 17th,Park,Curtis	81	114	126.5	141	168.5	215	283
Denver	100	104.8	114.5	127	140.5	153.2	172
Improvements - 15th - PBL,Sharrow,Larimer SqBlk	100	112.2	130.5	155	226	274.6	309

Figure 34: Connecting Letters Report from Tukey-Kramer HSD for 15th Study Area Gross Sales Index Analysis

Connecting Letters Report

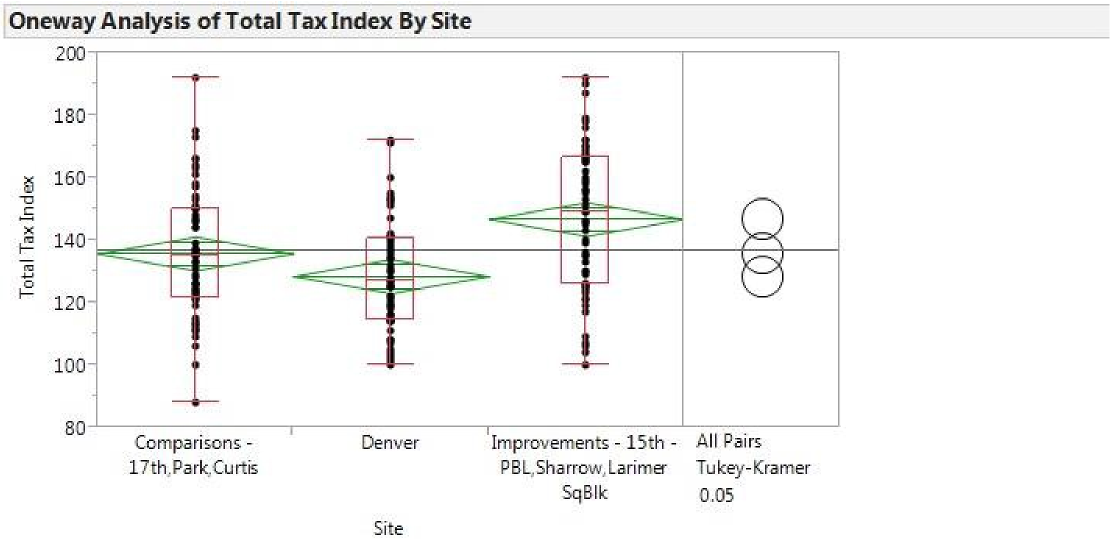
Level				Mean
Improvements - 15th - PBL,Sharrow,Larimer SqBlk	A			175.52632
Comparisons - 17th,Park,Curtis		B		153.71930
Denver			C	128.50877

Levels not connected by same letter are significantly different.

The following step was to conduct another one-way ANOVA to test the significance of the total sales tax indices for the average 15th Street improvement sites, the average of the neighborhood comparison sites, and the Denver city-wide comparison site displayed in Figure 32 above. The ANOVA, displayed in Figure 35 below, shows there to be a significant difference in means across the 15th Street study area sites, F(2,

168) = 11.17, p = .0001. This highlighted the statistically significant difference between the means of the 15th Street improvements (M = 135.77) and the comparison (M = 146.79) and city wide sites (M = 128.51). Next, I conducted a Tukey-Kramer HSD with an $\alpha = .05$, which provided the output included in Figure 36 that corresponds to the circles on the far right of Figure 35. This display highlights the statistically significant differences within the data using letters, and asserts that the 15th Street improvement sites are significantly different from the other two comparisons, but that these comparisons do not display statistically significant differences between one another. These results emphasize that the differences in total sales tax performance between the 15th area improvement sites, and the neighborhood and city-wide comparisons, are statistically significant. These statistically significant differences are noteworthy, but require further analysis with 2017 data to uncover conclusive trends following the improvement. It helps to view the results of the significance test alongside the data in Figure 32.

Figure 35: Basic Output for 15th Study Area Total Tax Index Analysis



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Comparisons - 17th,Park,Curtis	88	111	121.5	135	150	164.4	192
Denver	100	104.8	114.5	127	140.5	153.2	172
Improvements - 15th - PBL,Sharrow,Larimer SqBlk	100	115.4	126	149	166.5	176.4	192

Figure 36: Connecting Letter Report from Tukey-Kramer HSD for 15th Study Area Total Tax Index Analysis

Connecting Letters Report

Level			Mean
Improvements - 15th - PBL,Sharrow,Larimer SqBlk	A		146.78947
Comparisons - 17th,Park,Curtis		B	135.77193
Denver		B	128.50877

Levels not connected by same letter are significantly different.

The preceding analysis uncovered several interesting trends and motivated me to test the significance of the total tax economic performance of each individual improvement segment compared to the average of the comparisons sites, and the city-wide performance shown in Figure 37. The ANOVA, displayed in Figure 38, shows there to be a significant difference in means across the 15th Street study area sites, $F(2, 168) = 15.56$, $p = .0001$. This highlighted the statistically significant difference between the means of the 15th Street PBL (M = 153.67), Larimer Street spillover (M = 155.67), and the 15th Street sharrow (M = 130.98) comparison (M = 135.77) and city wide sites (M = 128.51). Next, I conducted a Tukey-Kramer HSD with an $\alpha = .05$, which provided the output included in Figure 39 that corresponds with the circles on the far right of Figure 38. This display visualizes the statistically significant differences within the data by letter and shows that the 15th Street PBL and Larimer Street spillover improvement sites are significantly different from the 15th Street sharrow and the other two comparisons. The test also showcases that these last three levels do not display statistically significant differences between one another. These results emphasize statistically significant differences in total sales tax performance between the 15th Street PBL and Larimer Street spillover block improvement sites and the 15th Street sharrow, neighborhood, and city-wide comparisons. The results of the preceding significance test make sense when viewed alongside the data it tests in Figure 37. They also suggest that there is a differing level of impact for different facility types, as the PBL performed much better than the sharrow segment. 15th Street is still too young to notice conclusive changes in economic performance, but these findings suggest that there was not a negative impact.

Figure 37: 15th Street Individual Improvement Sites and Averaged Comparison Sites – Total Tax Indices

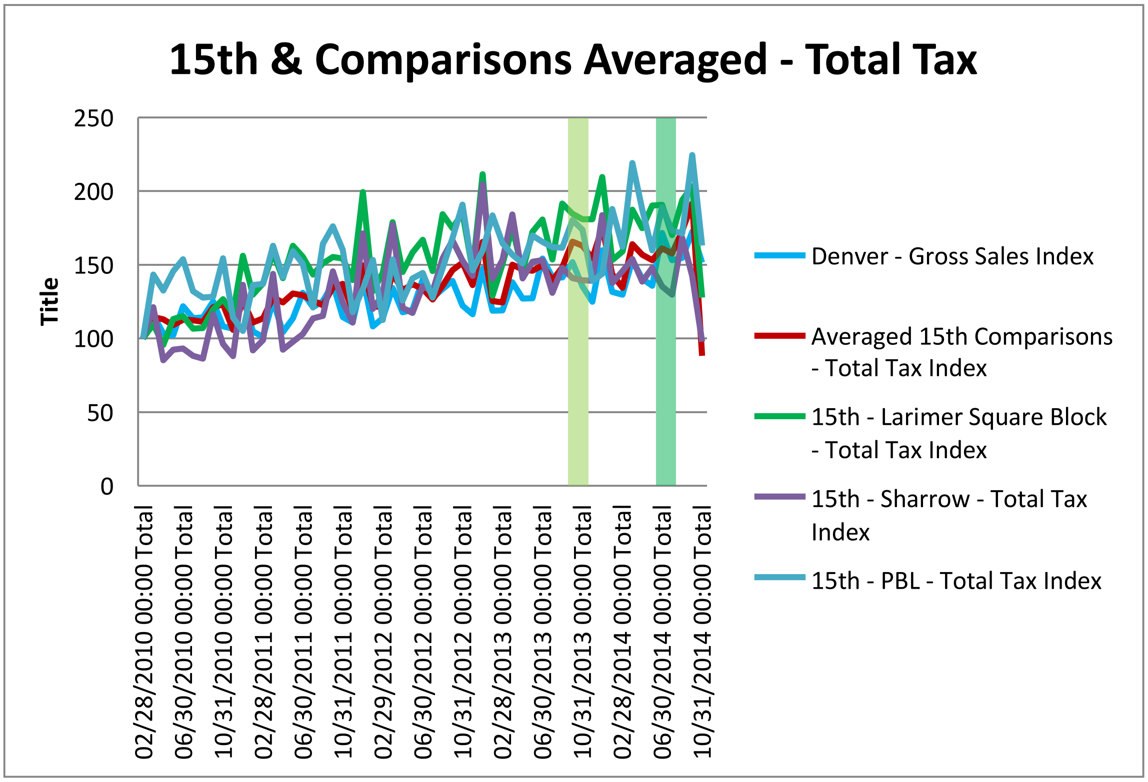
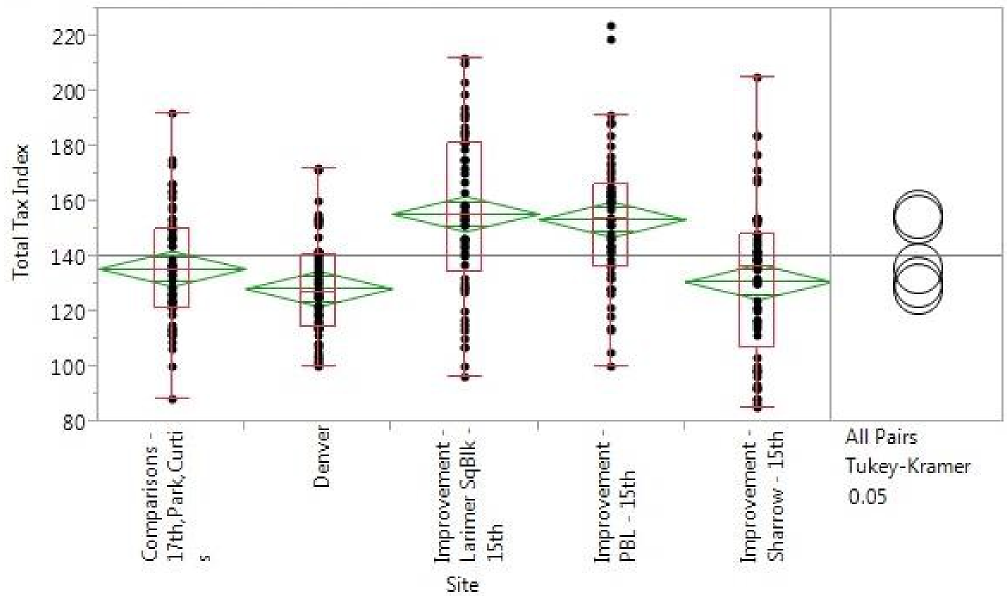


Figure 38: Basic Output for 15th Study Area Individual Total Tax Index Analysis

Oneway Analysis of Total Tax Index By Site



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Comparisons - 17th,Park,Curtis	88	111	121.5	135	150	164.4	192
Denver	100	104.8	114.5	127	140.5	153.2	172
Improvement - Larimer SqBlk - 15th	96	112.4	134.5	155	181	192.4	212
Improvement - PBL - 15th	100	120.4	136.5	154	166.5	188	224
Improvement - Sharrow - 15th	85	92	107	136	148	168.6	205

Figure 39: Connecting Letter Report from Tukey-Kramer HSD for 15th Study Area Individual Total Index Analysis

Connecting Letters Report

Level			Mean
Improvement - Larimer SqBlk - 15th	A		155.66667
Improvement - PBL - 15th	A		153.66667
Comparisons - 17th,Park,Curtis		B	135.77193
Improvement - Sharrow - 15th		B	130.98246
Denver		B	128.50877

Levels not connected by same letter are significantly different.

15th Street Area Study Site: Other Analysis

The preceding paragraphs outline how there is a statistically significant difference between the economic performance of the 15th Street area improvement and comparison sites. 15th Street's unique differences influenced me to take a brief look at land use and census data to see if I could uncover other discernible trends corresponding with the street improvement. Brief analysis of the 2009-2013 US Census ACS data revealed that 15th Street and the surrounding downtown neighborhood are not as uniform as the Five Points area that contains the Larimer area study sites. The downtown block groups represent a dynamic urban neighborhood and have median household incomes ranging from \$12,000 – \$157,000, and anywhere from 38% – 11% of the residents living below the poverty line. Downtown Denver has fewer residents biking to work than the Larimer area study site but has 45% of residents walking to work in the downtown tract, which represents the largest value for the entire City and County of Denver (DOLA 2015). The aforementioned factors highlight how the 15th Street area study site has potential to increase the use of active transportation, while also serving the need-based bike commuter category for several block groups.

A brief analysis of land use change over time also helps contextualize the findings from my sales tax analysis. The most recent land use layers available are from 2012, which falls before the street improvement. There is a brief discussion of pre-improvement land uses included below, but it makes sense to reanalyze these land uses at a later date when newer data become available. Table 7 below displays the most recent land use data for the 15th Street area study site sorted by largest to smallest for 15th

Street's PBL values. The main land use along 15th Street is car parking, followed by commercial/retail, and then office uses. These categories represent the top three land uses for all sites, except for the 15th Street's sharrow segment that had a large percentage of mixed-uses and the Park Avenue segment that has a large percent of parks and vacant land uses. I do not want to belabor my discussion of land use because we only have pre-improvement values.

Table 7: 2012 Land Use for 15th Area Study Sites

Land Use Category (CPD_LU_I)	15th PBL LandUse %	15th Sharrows LandUse %	Larimer Street Spillover LandUse%	17th LandUse %	Curtis LandUse %	Park LandUse%
Parking	35.42%	7.41%	7.69%	9.68%	28.95%	7.41%
Commercial/ Retail	31.25%	25.93%	38.46%	16.13%	15.79%	7.41%
Office	12.50%	29.63%	30.77%	51.61%	26.32%	11.11%
Industrial	4.17%	3.70%	0.00%	0.00%	13.16%	1.85%
Multi-Family High Rise	4.17%	0.00%	0.00%	1.61%	0.00%	1.85%
Agriculture	2.08%	0.00%	0.00%	0.00%	0.00%	0.00%
Mixed-Use	2.08%	29.63%	7.69%	8.06%	0.00%	5.56%
Multi-Family Low Rise	2.08%	3.70%	0.00%	1.61%	10.53%	9.26%
Multi-Family Mid Rise	2.08%	0.00%	0.00%	0.00%	0.00%	7.41%
Public/Quasi-Public	2.08%	0.00%	7.69%	0.00%	0.00%	1.85%
Vacant	2.08%	0.00%	0.00%	4.84%	0.00%	18.52%
Entertainment-Cultural	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Other/Unknown	0.00%	0.00%	0.00%	0.00%	0.00%	3.70%
Park-Open Space-Recreation	0.00%	0.00%	7.69%	3.23%	5.26%	18.52%
ROW/Road	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Single Family	0.00%	0.00%	0.00%	1.61%	0.00%	5.56%
Surface Water	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

TCU	0.00%	0.00%	0.00%	1.61%	0.00%	0.00%

The preceding discussion of the 15th Street area study sites showcases how the economic performance of the improvement sites was not noticeably hindered by the substitution of a PBL for a car travel lane. 15th Street is also a unique corridor because it has limited first floor retail and serves more as a throughway to get people out of Downtown Denver and to the river trails, Highlands neighborhood, or to Interstate 25. An ANOVA test revealed statistically significant differences between the sales tax performances with the improvement sites slightly outperforming the comparisons. While these sites outperformed the comparisons in the short-run, one should be careful not to make faulty assumptions about what will happen in the coming years. This method requires several years of post-improvement data to uncover definite trends (NYCDOT 2013; Rowe 2013). The findings from the 15th Street areas study site are still relevant but must not be taken as final because this study area is young.

15th Street Area Study Sites: Observational Research and Count Analyses

A sales tax analysis of 15th Street uncovered interesting findings, but the recent 2014 installation date encouraged me to expand my analysis to focus on more tangible findings from Denver’s first PBL. My counting project with the Department of Public Works revealed many interesting and unexpected findings about how bicycle use changed throughout the corridor after the new facility was installed. These data are showing a 37% increase in the number of bicyclists using the corridor and a 54% reduction in sidewalk riding. The largest increase is during the PM peak when commuters are leaving Downtown Denver, and we’re seeing a 100% increase in users on the PBL from the pre-improvement period. This project included a tallied list of my qualitative observations and detailed quantitative counting sheets. The next section starts with a general outline of my qualitative notes that are supported by over 100 hours of observations, followed by statistical analyses to support the qualitative observations where necessary.

Qualitative Observations

One obvious observation was how the PBL funneled bicycle traffic to the left lane. Prior to the installation of the buffered lane and PBL, bicyclists were all over the road, and most bicyclists used the right lane or sidewalk to access 15th Street. Figure 40 highlights this as we see bicyclists in the left lane, right lane, and crossing against traffic signals. This changed significantly afterwards, and now nearly all bicyclists use the PBL, except for when they need to turn right, displayed in Figure 41. Another general observation was how 15th Street saw higher use in the afternoon, when people were leaving the city. One last general observation was that the majority of dangerous encounters occurred during the AM, lunch, and PM peak periods, when there were more cars on the road. The unique mixing zones on 15th Street lead to an unfortunately high number of conflicts between cars and bikes, and this was frightening when oblivious drivers would enter the mixing zones without checking the PBL first. This often led to dangerous conflicts where the bicyclists were forced to brake aggressively, or swerve, to avoid colliding with the vehicle that cut them off.

Figure 40: Pre-Improvement Period – Bikes Everywhere

Figure 41: After PBL – Safe Passage and Consistency During PM Peak

Conflicts between bikes and other modes of transportation pose the largest risks to all users, and therefore I carefully documented the situations that led to close encounters. The most frightening conflicts were not a product of disobeying laws, but instead seemed to occur in the mixing zones, where cars and bikes are expected to share space. Drivers rarely acknowledged the presence of bikes in the mixing zones that were unmarked when I conducted this study. This was especially bad in the AM and PM peak periods, when cars would rush to and from the parking garage shown in Figure 42 below. I should note that the Department of Public Works responded swiftly to these concerns about mid-block mixing zones with green paint markings to indicate to cars that the PBL is a unique space. While the green pavement markings have helped, they have not eliminated the issue. Just yesterday, I ran into a bike industry colleague, who was “left hooked” by an oblivious driver in a mid-block mixing zone. This individual is a capable bicyclist and said the collision was completely the driver’s fault. I find it discouraging to think that Denver’s premier protected bike lane can be unsafe for regular users. I hope not to belabor this point, but I want to highlight the inconsistencies of how Denver’s premier PBL puts cars and bikes at conflict multiple times each block and doesn’t feel truly protected. 15th Street’s PBL is a major step in the right direction, but it is certainly too soon to ring the victory bells.

Figure 42: Screenshot of 15th with Car in Mid-Block Mixing Zone

Another conflict occurs when cyclists try to turn right from the PBL or merge into the PBL from the right lane. This is a major conflict because there is no turn signal prioritization for cyclists, with the exception of Lawrence Street, where the PBL ends abruptly. This forces bikes to choose between turning on the pedestrian signal, which is safer but technically illegal, and aggressively merging across four lanes of traffic, which often made me cringe. This conflict highlights how the 15th Street PBL functions well to get people out of downtown in a straight line, but that it offers less connectivity for bikes trying to turn north off of 15th Street. The final noteworthy conflict was how many of the most dangerous encounters occurred when the cyclist surprised a driver. I found it difficult to assign blame for this type of encounter, as it was very case-specific, but I think the take home point is that eliminating room for surprises can largely improve safety. It appears that eliminating the mixing zones, slowing down all types of traffic, and prioritizing signals to eliminate conflict are the best options for reducing this type of encounter.

I also made sure to observe the types of bicyclists using the PBL. Initially I wanted to document the specifics of gender, bicycle type, age, etc., but quickly realized the granular recordings would not allow for this level of analysis. While I was unable to accurately count all types of users, I was able to make notes when someone obviously fit into a category. One observation was that the vast majority of bicyclists riding on 15th Street during the pre-improvement period were either traveling at a high rate of speed, in order to keep up with car traffic, or opting to ride slow on the sidewalk. After the new facilities were added, there were a wider variety of people riding bikes along 15th Street. I witnessed far more women, children, and b-cycle users on 15th Street after the new facilities were added, in addition to the commuters, messengers, and Pedi-cabs, who were already using the space. This is consistent with research on the topic about how better facilities encourage new riders from the “interested, but concerned” group to get on their bikes as is shown in Figure 43 below (Dill and McNeil 2013). There were also many more Pedi-cabs, recreational riders, and non-commuters accessing the PBL on Sundays, which was showcased by far more low-speed and paired riding than on weekdays, when most people appeared to be commuting alone. The last observation about types of users surprised me. I found that a remarkable number of skateboarders and longboarders used the PBL to avoid pedestrians on the sidewalk. PBLs are technically for bikes, but I think planners need to consider the discussion about allowing other pedestrian modes that travel at a similar speed as bikes. I am not saying we need to muddy the waters with this discussion in the short term, but boarders are using the space so it is worthy of consideration.

Figure 43: Family Use on a Sunday

One of the final observations worthy of close attention was the change in obedience of traffic signals after the new facilities were installed. A representative example was that traffic violations decreased 33% after the new facilities were added, during the same timeframe that overall use increased by 37%. This highlights how building better facilities will immediately have an impact on raising ridership, lowering the number of traffic violations, and thus improving safety for all, which is a major win-win. New bicycle facilities encourage everyone to follow the laws and seem to facilitate teaching moments about safe cycling. I mentioned earlier how the mixing zones can lead to unwanted car-bike conflicts, but I also found they can encourage cyclists to try to make risky passes and/or ride on the sidewalk, when they are filled with turning cars at peak periods. The final observation was that people on bikes will often go to great lengths to avoid coming to a complete stop and losing their momentum. Many times this involves the "Idaho stop," where a bicyclist will roll through an empty intersection once they see they are clear. While there were many different instances of bicycle traffic violations, the majority of them were caused by cyclists apparently wanting to maintain their momentum and avoid a complete stop. It seems that coordinated signal timing can help to solve this issue, while also improving safety in the PBL. This brief discussion of my qualitative observations of the new bicycle facilities outlined all aspects of PBL use, from traffic violations to conflicts, and provides a nice lead in to the following section, where I perform statistical analyses on the quantitative count data.

Quantitative Observations and Statistical Analyses

A statistical analysis of the count data reveals a dramatic trend of increasing bicycle traffic following the installation of new bicycle facilities on 15th Street. Figure 44, Figure 45, Figure 46, and Figure 47 respectively display the total counts in: a table with the weekday observations, a table with the Sunday observations, a bar chart of daily totals, and a line graph of hourly totals. The 37% increase in bicycle traffic was also coupled with a 33% reduction in the number of traffic violations and a 54% reduction in sidewalk riding. Increased bicycle counts combined with decreased traffic violations suggest that the new bicycle facilities have simultaneously drawn more people to the area, while also encouraging them to obey the laws. These unique trends in the 15th Street count data encouraged me to conduct further analysis. I also want to make two disclaimers about my count data before proceeding. First, while it was not the focus of this research, the counts appear to have a close correlation to weather, only second to facility type. Second, I only conducted significance tests on the total count values. My observational research tallied numerous types of encounters and violations, but I only tested the total counts and other clear-cut examples to avoid introducing judgment calls. The following section will discuss the statistical findings from the total counts and several key types of traffic violations I observed on 15th Street.

Figure 44: All Weekday Observations

Weekday Analysis									
Lane Choice	**R - Before (6/5/13)**	**Before (7/11/13)**	**R - Buffered Bike Lane (11/13/13)**	**Buffered Bike Lane (4/15/14)**	**PBL (8/6/14)**	**PBL (8/27/14)**	**PBL (9/10/14)**	**PBL (9/17/14)**	**PBL (11/19/14)**
Left	62	56	358	392	666	654	605	727	415
Lane #2	17	24	7	5	3	6	4	7	2
Lane #3	15	24	9	8	8	7	5	6	5
Right	255	355	59	73	69	83	67	88	35
Sidewalk	145	192	56	60	108	91	74	89	47
Changing Lanes	41	17	34	14	26	21	11	9	13
TOTAL	538	678	512	553	895	876	771	930	524
Notes	Before any bike facility in place; 0" precip, H77 o	Before any bike facility in place; 0.02" precip, H96	After the installation of buffered bike lane (no vertical); 0" precip, H67 o	After the installation of buffered bike lane (no	After the installation of the vertical protection; 0"	After the installation of the vertical protection; 0.05"	After the installation of the vertical protection; 0.13" precip,	After the installation of the vertical protection; 0.00" precip,	After the installation of the vertical protection; 0.00"

	F/L44 ^{o} F	^{o} F/L62 ^{o} F	F/L30 ^{o} F	vertica l); 0" precip , H62 ^{o} F/L32 ^{o} F	precip , H86 ^{o} F/L56 ^{o} F	precip, H77 ^{o} F/L54 ^{o} F	H73 ^{o} F/L49 ^{o} F	H86 ^{o} F/L56 ^{o} F	precip , H48 ^{o} F/L26 ^{o} F

Figure 45: All Sunday Observations

Sunday Analysis		
Bike Lane Choice	**PBL (9/14/14)**	**PBL (9/21/14)**
Left	334	254
Lane #2	3	0
Lane #3	1	2
Right	72	49
Sidewalk	61	60
Changing Lanes	10	3
TOTAL	485	368
Notes	After the installation of the vertical protection; 0.00" precip, 846 ^{o} F/L48 ^{o} F	After the installation of the vertical protection; 0.17" precip, 76 ^{o} F/L55 ^{o} F

Figure 46: Daily Totals

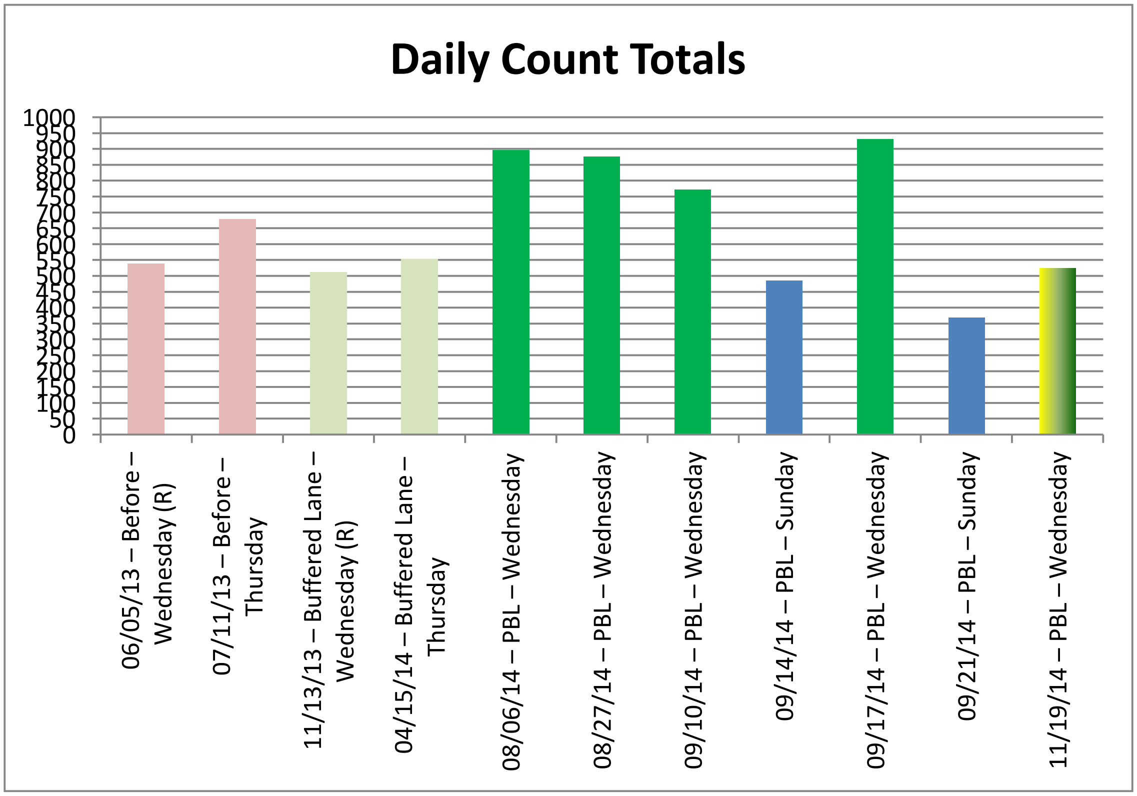
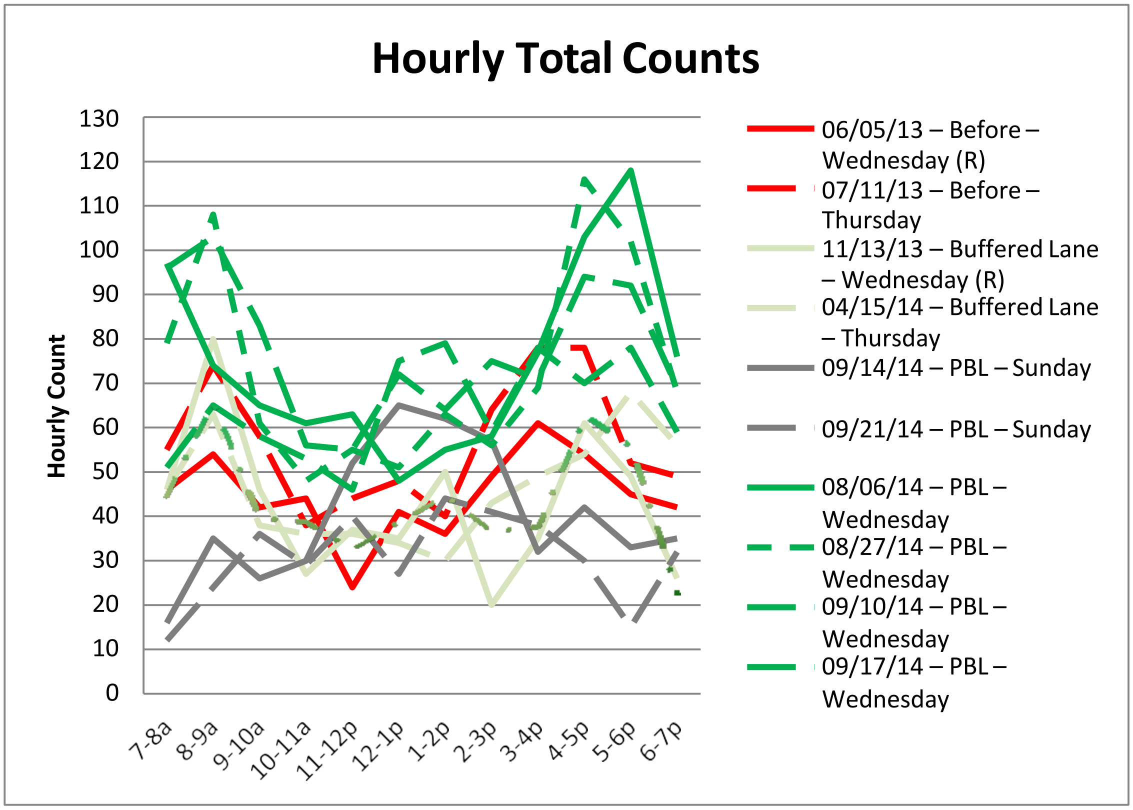
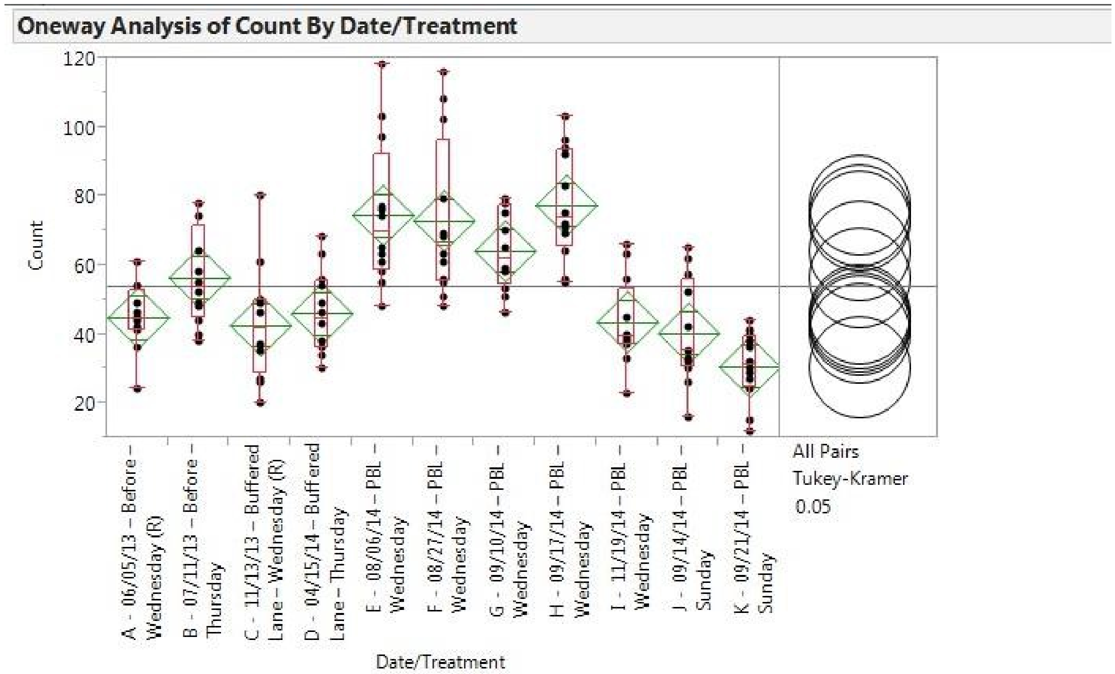


Figure 47: Hourly Totals



An analysis of the total counts from Figure 44, Figure 45, Figure 46, and Figure 47 reveals that the new bicycle facilities on 15th Street increased bicycle traffic within the corridor. Figure 46 displays the total counts for each individual observation day color coded by facility type and highlights 15th Street's steadily increasing total bicycle traffic trends. The ANOVA, displayed in Figure 48, showcases a statistically significant difference in means across the 15th Street study area sites, $F(10, 121) = 13.05$, $p = .0001$. This highlights the statistically significant difference between the means of my observations days. After this step, I conducted a Tukey-Kramer HSD with an $\alpha = .05$, which provided the output in Figure 49 that corresponds with the circles on the far right of Figure 48. This display visualizes the statistically significant differences within the data by letter, and the hierarchy appears to follow the facility type and general weather patterns. All of the after PBL days from warmer months fall into the top “A” category in Figure 49 and are all significantly different than the other observations. The “B” category slightly complicates things as there is some overlap between the before bicycle improvement period (hereafter referred to as “before” observations) and after bicycle improvement period (hereafter referred to as “after” observations), yet the two days still show statistically significant differences. I don’t want to belabor my discussion of the minute differences, but the general trend is certainly noteworthy. This trend uncovers how the PBL observation days from warm months display the highest values on the list, followed by the warmer before observations and colder after ones, and the Sunday observations that were lowest. The preceding trends make sense considering that people prefer to bike in the warmer months and also prefer to ride on better bicycle facilities.

Figure 48: Basic Output for 15th Street Total Counts Analysis



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
A - 06/05/13 – Before – Wednesday (R)	24	27.6	41.25	44.5	52.75	58.9	61
B - 07/11/13 – Before – Thursday	38	38.6	45	53.5	71.5	78	78
C - 11/13/13 – Buffered Lane – Wednesday (R)	20	21.8	29	41.5	49.75	74.3	80
D - 04/15/14 – Buffered Lane – Thursday	30	31.2	36	44.5	55.5	66.5	68
E - 08/06/14 – PBL – Wednesday	48	50.1	58.75	69.5	92	113.5	118
F - 08/27/14 – PBL – Wednesday	48	48.9	55.25	65.5	96.25	113.6	116
G - 09/10/14 – PBL – Wednesday	46	47.5	54.25	62	77.25	78.7	79
H - 09/17/14 – PBL – Wednesday	55	55.3	65.25	73.5	93.5	100.9	103
I - 11/19/14 – PBL – Wednesday	23	26	37.25	39.5	53.25	65.1	66
J - 09/14/14 – PBL – Sunday	16	19	30.5	35	55.75	64.1	65
K - 09/21/14 – PBL – Sunday	12	12.9	24.75	31	39.5	43.1	44

Figure 49: Connecting Letters Report from Tukey-Kramer HSD for 15th Street Total Counts Analysis

Connecting Letters Report

Level						Mean
H - 09/17/14 – PBL – Wednesday	A					77.500000
E - 08/06/14 – PBL – Wednesday	A	B				74.583333
F - 08/27/14 – PBL – Wednesday	A	B				73.000000
G - 09/10/14 – PBL – Wednesday	A	B	C			64.250000
B - 07/11/13 – Before – Thursday		B	C	D		56.500000
D - 04/15/14 – Buffered Lane – Thursday			C	D	E	46.083333
A - 06/05/13 – Before – Wednesday (R)			C	D	E	44.833333
I - 11/19/14 – PBL – Wednesday				D	E	43.666667
C - 11/13/13 – Buffered Lane – Wednesday (R)				D	E	42.666667
J - 09/14/14 – PBL – Sunday				D	E	40.416667
K - 09/21/14 – PBL – Sunday					E	30.666667

Levels not connected by same letter are significantly different.

I mentioned earlier how 15th Street witnessed a 37% increase in bicycle traffic during the same time that it experienced a 33% reduction in the number of traffic violations and a 54% reduction in sidewalk riding. The large increase in total bicycle traffic, the decrease in sidewalk riding and traffic violations, and the statistically significant differences in my observation days, motivated me to plot these three indicators next to one another. Figure 50, Figure 51, and Figure 52 plot these indicators for the before, after, and Sunday highest totals on the same scale, respectively. An analysis of these figures highlights several important trends in the data. First, we see that weekends and weekdays experience opposite peak periods, with Sunday peaks around 12 noon, and weekday peeks around 9am and 5pm. These findings briefly confirm that 15th Street is a unique corridor that acts more like a peak period throughway than a destination corridor. Figure 50 highlights that the majority of bicyclists used to disobey traffic laws along 15th Street. The larger gap between the trend lines of the after counts in Figure 51 suggests that more bicyclists obey traffic laws on 15th Street after the PBL was added. I also noticed a decoupling of the total count and traffic violation totals, which I think is one of the most noteworthy findings from the total count analysis. The count and traffic violation values follow a nearly identical trend during the before counts, which highlights that most bicyclists used to disobey traffic laws along 15th Street prior to the PBL. After the PBL is installed, counts and traffic violations decouple and begin to follow different trends, which suggest that more bicyclists follow traffic laws on the improved facilities. This decoupling is important because it displays the importance of bicycle facilities in encouraging safe use. After the PBL, the traffic violations are no longer a product of total counts, and instead, become a product of sidewalk riding. My analysis of the interplay between total counts, traffic violations, and sidewalk riding indicators motivated me to conduct ANOVA for several of the traffic violation component categories.

Figure 50: Before PBL: Counts, Traffic Violations, and Sidewalk Riding Hourly Totals

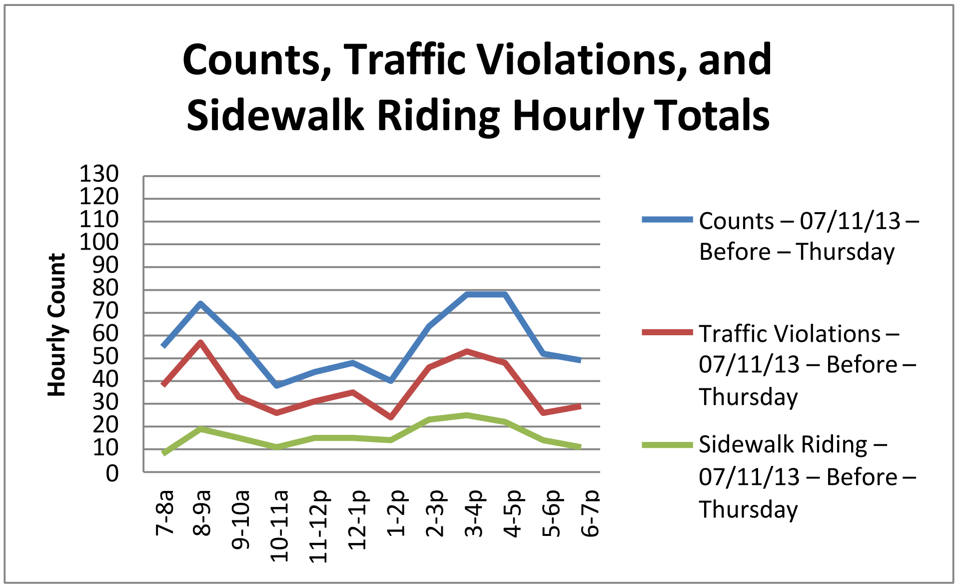


Figure 51: After PBL: Counts, Traffic Violations, and Sidewalk Riding Hourly Totals

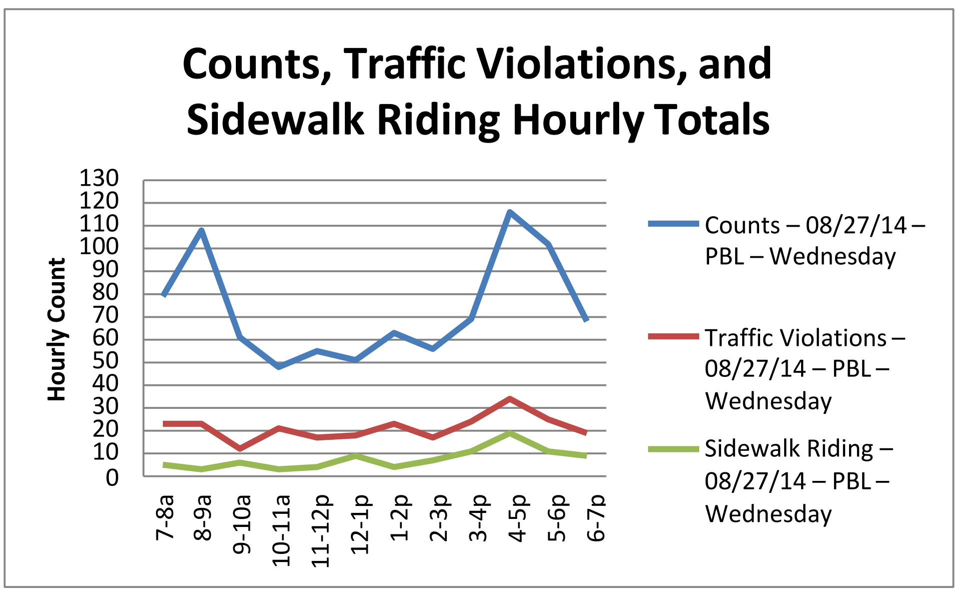
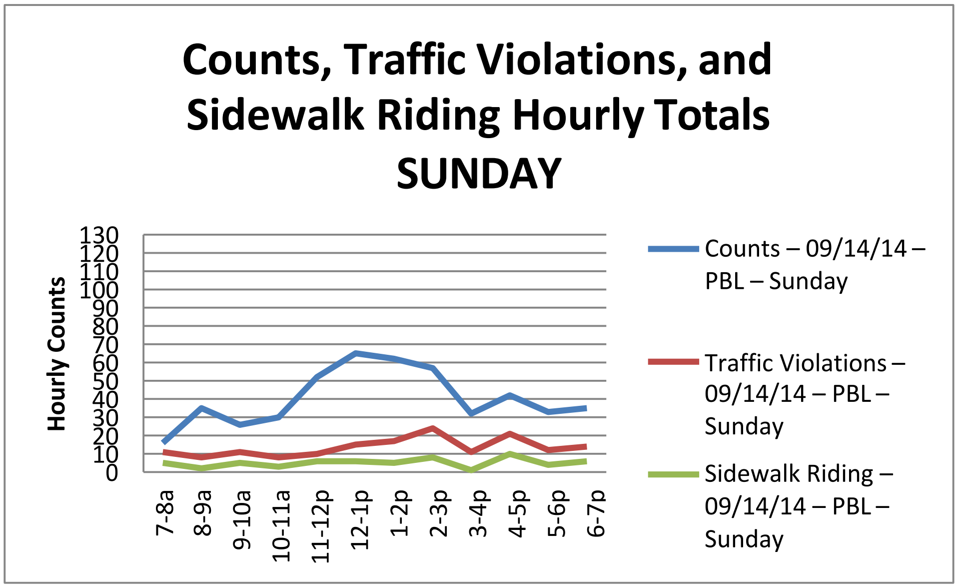


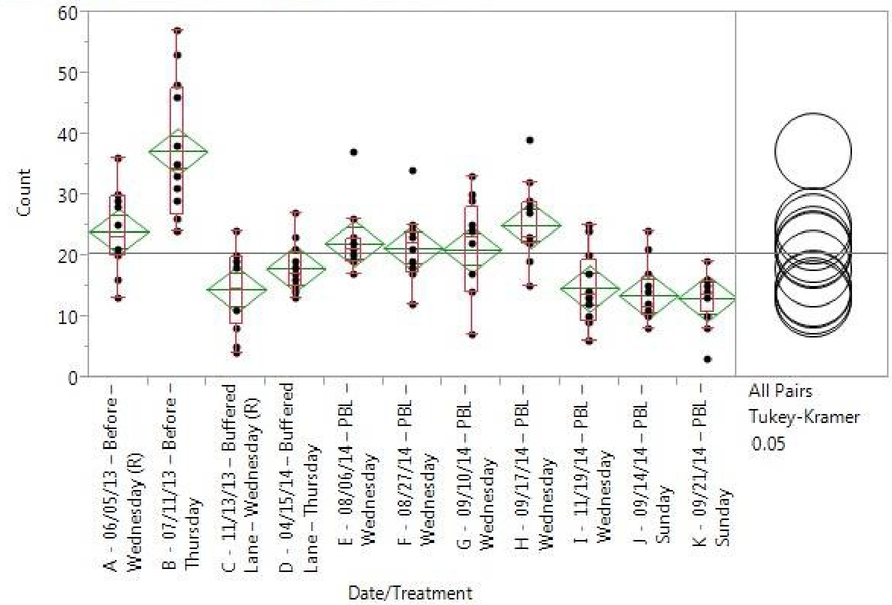
Figure 52: Sunday After PBL: Counts, Traffic Violations, and Sidewalk Riding Hourly Totals



A statistical analysis of total traffic violations (the sum of individual values for disobeying traffic signals, riding against traffic, sidewalk riding with/against traffic, and failure to stop at right or left turn on red) is displayed in Figure 53 and Figure 54 below. This figure highlights that the before dates have the largest values, but that the dates from after the PBL was installed follow closely behind. This is a product of the overall increase in bicycle traffic, and therefore I decided to control for this by using a counts index.

Figure 53: Basic Output for 15th Street Total Traffic Violation Analysis

Oneway Analysis of Count By Date/Treatment



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
A - 06/05/13 – Before – Wednesday (R)	13	13.9	20	23	29.75	34.2	36
B - 07/11/13 – Before – Thursday	24	24.6	26.75	34	47.5	55.8	57
C - 11/13/13 – Buffered Lane – Wednesday (R)	4	4.3	8.75	14.5	19.75	24	24
D - 04/15/14 – Buffered Lane – Thursday	13	13.3	15	17	20.5	25.8	27
E - 08/06/14 – PBL – Wednesday	17	17.6	19	21	22.75	33.7	37
F - 08/27/14 – PBL – Wednesday	12	13.5	17.25	22	23.75	31.3	34
G - 09/10/14 – PBL – Wednesday	7	9.1	14	23	28	32.1	33
H - 09/17/14 – PBL – Wednesday	15	16.2	22	23	28.75	36.9	39
I - 11/19/14 – PBL – Wednesday	6	6.9	9.25	13.5	19.25	24.7	25
J - 09/14/14 – PBL – Sunday	8	8	10.25	11.5	16.5	23.1	24
K - 09/21/14 – PBL – Sunday	3	4.5	10.75	13.5	15.75	19	19

Figure 54: Connecting Letters Report from Tukey-Kramer HSD for 15th Street Total Traffic Violation Analysis

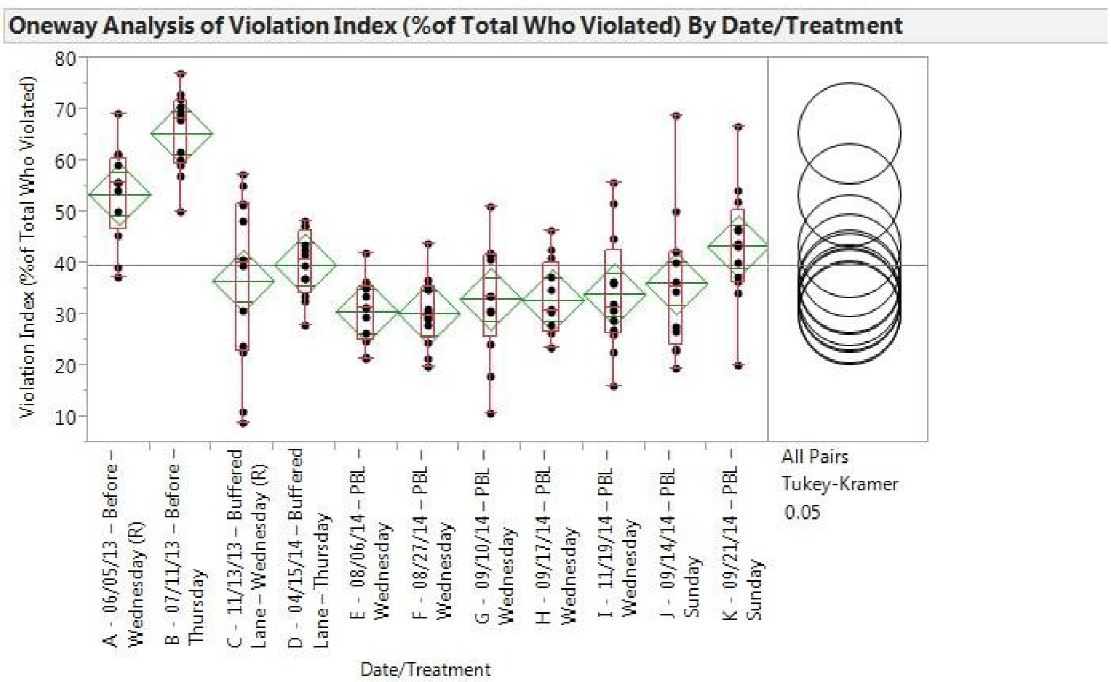
Connecting Letters Report

Level				Mean
B - 07/11/13 – Before – Thursday	A			37.166667
H - 09/17/14 – PBL – Wednesday	B			25.083333
A - 06/05/13 – Before – Wednesday (R)	B			24.000000
E - 08/06/14 – PBL – Wednesday	B	C		22.083333
F - 08/27/14 – PBL – Wednesday	B	C	D	21.333333
G - 09/10/14 – PBL – Wednesday	B	C	D	21.083333
D - 04/15/14 – Buffered Lane – Thursday	B	C	D	17.916667
I - 11/19/14 – PBL – Wednesday		C	D	14.666667
C - 11/13/13 – Buffered Lane – Wednesday (R)		C	D	14.500000
J - 09/14/14 – PBL – Sunday		C	D	13.500000
K - 09/21/14 – PBL – Sunday			D	13.083333

Levels not connected by same letter are significantly different.

My counts index is similar to the sales tax index, but it differs slightly in that it provides the value as a percentage of the whole rather than a percentage of the selected starting value. An ANOVA of the total traffic violation counts index revealed interesting findings about how the traffic violations relate to the daily count. Figure 55 displays the ANOVA for the traffic violations indices**,** which shows there to be a significant difference in means across the 15th Street study area sites, $F(10, 121) = 12.85$, $p = .0001$. This highlights the statistically significant difference between the means of my observation days. A Tukey-Kramer HSD test with an $\alpha = .05$, provided in Figure 56, corresponds with the circles on the far right of Figure 55. This display visualizes the statistically significant differences within the data by letter, and the hierarchy appears to follow the facility type and general weather patterns. The connecting letters report highlights how the before days, buffered lane days, and Sundays have the largest traffic violation averages, with the before days displaying a majority of bicyclists disobeying traffic signals. The after PBL weekdays have the lowest averages and are all significantly different than the before day total traffic violation counts. I also performed an ANOVA on the disobeying traffic signals data which returned similar results as the aforementioned analysis.

Figure 55: Basic Output for 15th Street Total Traffic Violation Indices Analysis



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
A - 06/05/13 – Before – Wednesday (R)	37.04	37.634	46.5875	55.56	60.4075	66.701	69.05
B - 07/11/13 – Before – Thursday	50	52.07	59.385	68.185	71.5225	75.797	77.03
C - 11/13/13 – Buffered Lane – Wednesday (R)	8.7	9.351	22.775	40.04	51.41	56.498	57.14
D - 04/15/14 – Buffered Lane – Thursday	27.94	29.326	34.18	40.57	46.1275	47.913	48.21
E - 08/06/14 – PBL – Wednesday	21.36	21.447	25.09	31.255	35.35	40.137	41.82
F - 08/27/14 – PBL – Wednesday	19.67	20.159	25.3675	29.835	35.1625	41.578	43.75
G - 09/10/14 – PBL – Wednesday	10.77	12.924	25.7125	33.33	41.49	48.126	50.85
H - 09/17/14 – PBL – Wednesday	23.4	23.412	26.585	30.775	40.135	45.183	46.38
I - 11/19/14 – PBL – Wednesday	16.07	17.999	26.325	31.26	42.645	54.348	55.56
J - 09/14/14 – PBL – Sunday	19.23	20.319	23.9775	35.37	42.26	63.125	68.75
K - 09/21/14 – PBL – Sunday	20	24.263	36.3425	43.465	50.4575	62.92	66.67

Figure 56: Connecting Letters Report from Tukey-Kramer HSD for 15th Street Total Traffic Violation Indices Analysis

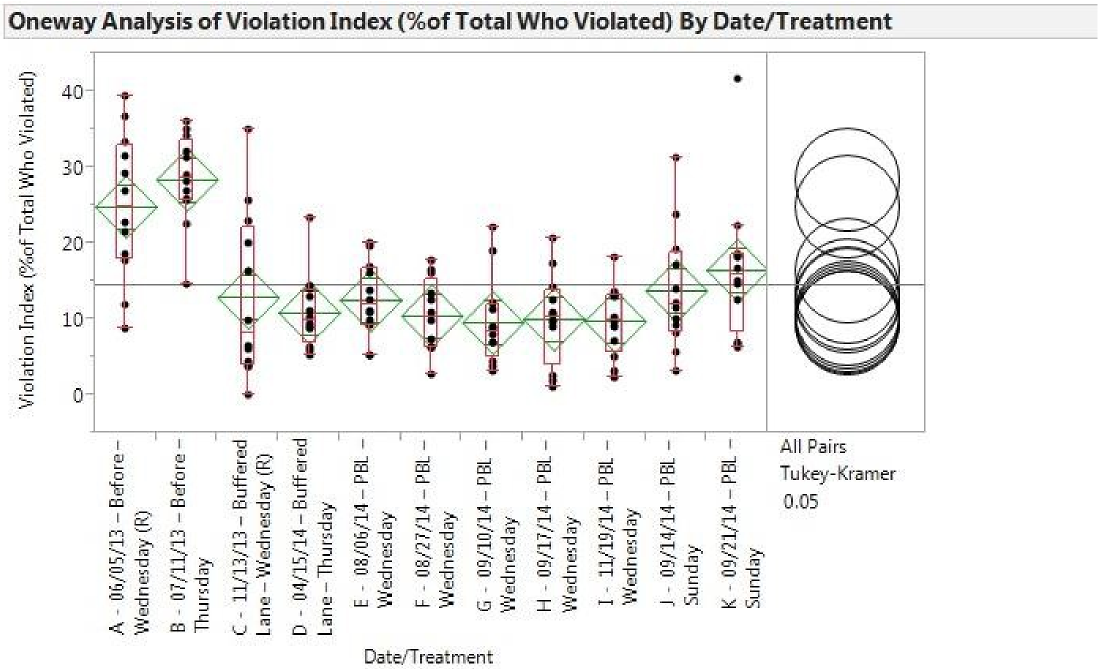
Connecting Letters Report

Level				Mean
B - 07/11/13 – Before – Thursday	A			65.446667
A - 06/05/13 – Before – Wednesday (R)	A	B		53.543333
K - 09/21/14 – PBL – Sunday		B	C	43.321667
D - 04/15/14 – Buffered Lane – Thursday		B	C	39.755833
C - 11/13/13 – Buffered Lane – Wednesday (R)			C	36.628333
J - 09/14/14 – PBL – Sunday			C	36.097500
I - 11/19/14 – PBL – Wednesday			C	33.931667
G - 09/10/14 – PBL – Wednesday			C	33.080000
H - 09/17/14 – PBL – Wednesday			C	32.853333
E - 08/06/14 – PBL – Wednesday			C	30.639167
F - 08/27/14 – PBL – Wednesday			C	30.286667

Levels not connected by same letter are significantly different.

Sidewalk riding is a major topic of concern in bicycle discussions and a topic that resonates with business owners because it puts their patrons in conflict. I conducted an analysis of sidewalk riding to see if there were any interesting findings, and the results were similar to the analysis of total traffic violations I conducted earlier. Sidewalk counts are a component of traffic violations, and therefore this was not a major surprise. Figure 57 displays the ANOVA for the traffic violation indices**,** which shows there to be a significant difference in means across the 15th Street study area sites, $F(10, 121) = 9.5$, $p = .0001$. This highlights the statistically significant difference between the means of my observations days. A Tukey-Kramer HSD test with an $\alpha = .05$, provided in Figure 58, corresponds with the circles on the far right of Figure 57. This display visualizes the statistically significant differences within the data by letter, and the hierarchy appears to follow the facility type and general weather patterns. The order of this connecting letters report is nearly identical to the one for total traffic violations. This highlights how the before days, buffered lane days, and Sundays have the largest sidewalk riding averages, with the before days having nearly a third of all bicyclists riding on the sidewalk. Next, I performed ANOVAs for the individual sidewalk riding counts, which I did not include because they were nearly identical to the total sidewalk riding findings. The similarities between total traffic violations and the sidewalk riding counts are noteworthy and highlight how sidewalk riding has a major influence on traffic violations after the PBL was installed, which causes them to trend together.

Figure 57: Basic Output for 15th Street Total Sidewalk Riding Indices Analysis



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
A - 06/05/13 – Before – Wednesday (R)	8.7	9.66	17.965	24.78	32.8675	38.557	39.34
B - 07/11/13 – Before – Thursday	14.55	16.92	25.725	28.58	33.58	35.658	35.94
C - 11/13/13 – Buffered Lane – Wednesday (R)	0	1.11	3.975	8.18	22.145	32.213	35
D - 04/15/14 – Buffered Lane – Thursday	5.26	5.446	6.9375	9.795	13.6575	20.618	23.33
E - 08/06/14 – PBL – Wednesday	5.15	5.183	9.245	11.805	16.715	19.901	20
F - 08/27/14 – PBL – Wednesday	2.78	3.821	6.335	10.31	15.265	17.269	17.65
G - 09/10/14 – PBL – Wednesday	3.08	3.311	4.9125	8.27	11.83	21.118	22.03
H - 09/17/14 – PBL – Wednesday	1.04	1.31	4.04	10.195	13.685	19.672	20.65
I - 11/19/14 – PBL – Wednesday	2.22	2.463	5.535	9.89	13.13	16.779	18.18
J - 09/14/14 – PBL – Sunday	3.13	3.904	8.3525	11.83	18.7075	29.018	31.25
K - 09/21/14 – PBL – Sunday	6.25	6.376	8.3	15.835	18.495	35.835	41.67

Figure 58: Connecting Letters Report from Tukey-Kramer HSD for 15th Street Total Sidewalk Riding Indices Analysis

Connecting Letters Report

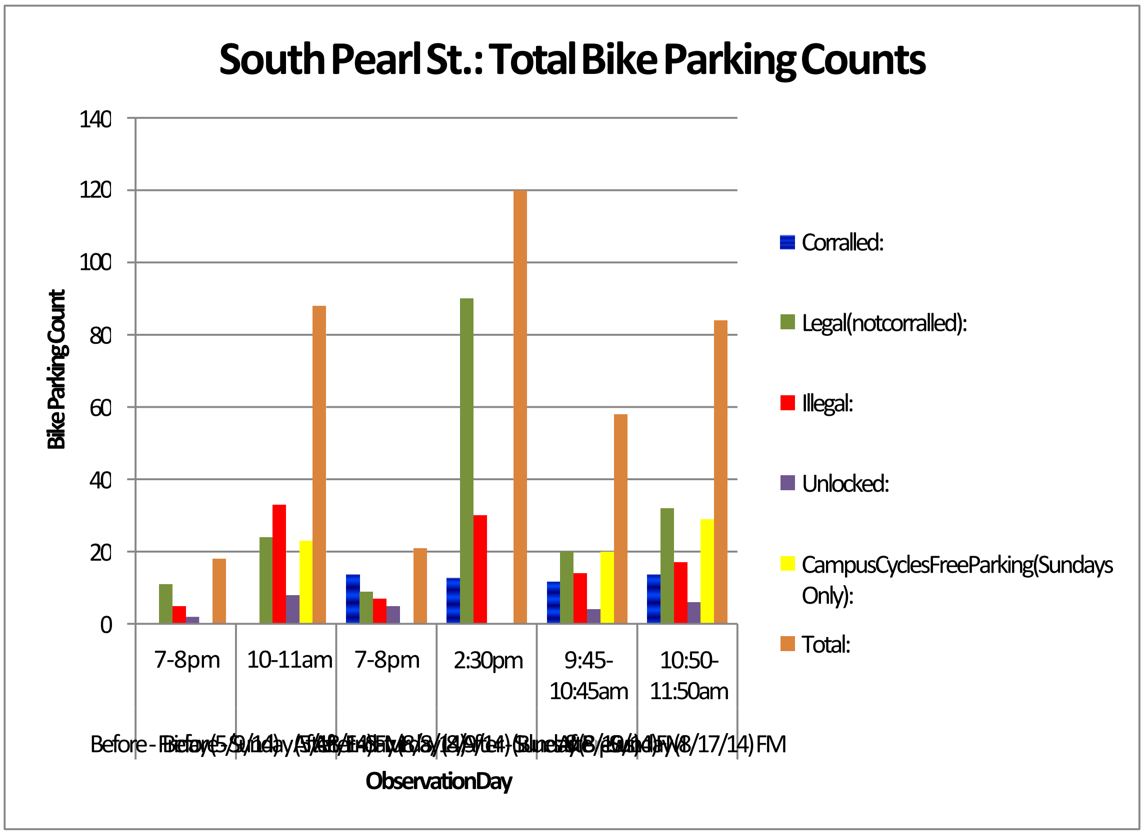
Level				Mean
B - 07/11/13 – Before – Thursday	A			28.412500
A - 06/05/13 – Before – Wednesday (R)	A	B		24.828333
K - 09/21/14 – PBL – Sunday		B	C	16.469167
J - 09/14/14 – PBL – Sunday			C	13.771667
C - 11/13/13 – Buffered Lane – Wednesday (R)			C	12.847500
E - 08/06/14 – PBL – Wednesday			C	12.509167
D - 04/15/14 – Buffered Lane – Thursday			C	10.857500
F - 08/27/14 – PBL – Wednesday			C	10.442500
H - 09/17/14 – PBL – Wednesday			C	9.984167
I - 11/19/14 – PBL – Wednesday			C	9.730833
G - 09/10/14 – PBL – Wednesday			C	9.562500

Levels not connected by same letter are significantly different.

South Pearl Street: Quantitative Observations and Simple Statistics

The analysis of South Pearl Street's world-class bike corrals is admittedly limited, yet a brief discussion of my findings from this unique street segment is still relevant to my broader research on the impacts of improved bicycle facilities. Figure 59 reveals an increasing trend for the total bike parking counts that was coupled with decreasing trends for illegally parked bikes, following the new on-street bike corrals. The qualitative notes from my observational research highlighted South Pearl Street as a unique corridor that experiences varying demand for bike parking, especially during events such as the Farmer's Market. There appear to be "all types" of cyclists accessing the shops on South Pearl (Dill and McNeil 2013). My final observation was how the bike corral utilization varied between corrals. I often found the corral in front of Stella's Coffee to be overflowing with bikes, while the one in front of Black Pearl was often empty. This puzzling observation revealed a major connection between bicycle facility location and overall utilization. I debated the reasoning for Stella's corral's improved performance and anecdotally believe it is due to the corral placement being closer to the corner, as opposed to the Black Pearl corral's mid-block placement, and the higher density of destinations that result from corner placement, as opposed to mid-block across from a surface parking lot. Despite the lack of other on-street bicycle facilities, the South Pearl Street bike corrals have added to the fabric of the business district and showcase how unique funding mechanisms can be employed for local-scale street improvements.

Figure 59: South Pearl Street: Total Bike Parking Counts



Discussion

"Bicycles are almost as good as guitars for meeting girls."

Bob Weir, Grateful Dead

The results illustrate the importance of mixed-methods analysis in bicycle research. Bicycles are an inherently human mode of transportation, and therefore research must simultaneously focus on quantitative and qualitative data to understand the impacts of bicycle facilities. Four broad conclusions can be garnered from this research. First, Denver exhibits untapped potential for increasing the bicycle mode share, especially when bike trips are combined with transit trips. Second, bicycle facilities are correlated with statistically significant positive economic impacts for local businesses and do not have negative impacts. Third, PBLs improve overall safety for all users and encourage more "types" of bicyclists to use the facility. Lastly, PBLs increase overall bicycle traffic, while simultaneously decreasing the number of traffic violations and sidewalk riding counts.

Denver exhibits untapped potential for increasing the bicycle mode share, especially when bike trips are combined with transit trips

Denver has many local environmental factors that combine to make it an excellent bicycle city from a natural and built environment perspective. The infrequent rain, relatively flat topography, nearly 300 days of sunshine, and isolated storm patterns highlight the environmentally favorable conditions. Denver's urban layout with a gridded street pattern, comprehensive transit system, and relatively wide streets are also very favorable for increasing the bicycle mode share.

RTD's data highlight the potential for increasing the number of people who use a bicycle to access transit and showed that 2,500 patrons drove less than two miles to access transit facilities across the entire RTD district. A pedestrian scale analysis of only Denver's transit access showcased that 1,200 patrons drove less than 3 miles to access transit, which is FTA's standard bikeable distance. While there is some overlap between these two figures, they highlight the potential benefits of encouraging patrons to access transit by bike and can eliminate thousands of gas intensive cold starts, thousands of vehicles stuck in traffic, and thousands of vehicles that RTD needs to accommodate at Park-n-Rides. The Park-n-Ride license plate survey data combine with Denver's environmental factors to showcase the potential for increasing the bicycle mode share by picking the cost effective, low hanging fruit.

Bicycle facilities are correlated with statistically significant positive economic impacts for local businesses and do not have negative impacts

Sales tax analysis illustrates that the installation of new bicycle facilities is closely tied to positive economic impacts for local businesses. The sales tax indices for both study sites show that the Larimer Street and 15th Street improvement sites outperformed their respective comparison sites after new bicycle facilities were installed. Figure 23 and Figure 22 highlight how the positive economic impacts often have similar timing as the street improvement, and the Larimer Street improvement site exhibited economic growth immediately following the addition of new bicycle facilities. An ANOVA revealed that the difference in positive economic impacts between the improvement and comparison sites was statistically significant, especially for the Larimer Street study site. It highlighted that the new bicycle facilities certainly did not hurt business along the corridor and may have contributed to the economic boost. The Larimer Street study site also exhibited a potential spillover effect, when Blake Street saw a boost in total sales tax nearly two years after the new bicycle facilities were added on Larimer Street.

While it is difficult to imply direct causality for the positive economic impacts, it is reasonable to conclude that the increase in sales can, at least in part, be attributed to changes stemming from the new bicycle facilities. Larimer Street's improvement site experienced a $1,570,440 increase in gross sales, a $36,129 increase in food and beverage tax, and a $29,937 increase in other tax following the installation of new bicycle facilities. 15th Street's improvement site also experienced increases after the buffered bike lane and PBL were installed, but they were not as pronounced as the Larimer Street site. This suggests that 15th Street is too new to notice discernible trends and must be studied again at a later date.

Larimer Street represents a successful case study of positive economic impacts following the installation of new bicycle facilities. The timing and magnitude of Larimer Street's sales boosts highlight how bicycle facilities are a part of complete and economically successful streets. New bicycle facilities are closely correlated with increasing economic performance, especially in stagnant districts, and also have interesting interplay with the pedestrian-oriented land uses in this area. It seems that the economic boosts for local businesses are due to new bicycle facilities funneling more customers by their establishment. Many of Denver's business districts/corridors do not have bicycle facilities, which forces potential customers to ride on a parallel street and use cross streets to cut over and access their destination on Broadway, Colfax Avenue, Evans Avenue, University Boulevard, or any other exemplary street. Not only is this an inefficient use of time, but it discourages bicyclists from making impromptu "stop in" purchases along the way, purchases which could add to economic benefits for local businesses.

The preceding discussion asserts that bike lanes are correlated with statistically significant positive economic impacts for local businesses, and that they most certainly do not have negative impacts. Factors, including timing, magnitude, and comparative increases in economic performance, suggest that the bicycle facility played a role in the positive economic impact. The sales tax analysis also suggests that bicycle facilities have increased business benefits when they are installed in dense and destination rich corridors. Denver's historical streetcar suburbs are great places to add bicycle facilities because they have flatter grades, wider streets, more businesses, and the residential densities to support local businesses and bicycle transport.

To address the challenges of revealing causality, researchers conducting future studies may want to pair this type of sales tax analysis with a customer and/or business owner survey to see if the local residents noticed any differences following the street improvement. Pairing this method with a survey, or advanced statistical model, would help to pinpoint exact causality. However, even in the absence of a survey, this is still an excellent method to assert that bicycle facilities are correlated with statistically significant positive economic impacts for local businesses, and they most certainly do not have negative impacts.

PBLs improve overall safety for all users and encourage more "types" of bicyclists to use the facility

PBLs add vertical separation between bicyclists and cars, which help to avoid collisions and greatly improves safety for bicyclists and car drivers. The new PBL on 15th Street funneled the majority of bicycle traffic from the right side of 15th Street to the new left-sided facility, which greatly increased the predictability of bicycle traffic within the corridor. Prior to 15th Street having bicycle facilities, the area represented a free-for-all with bicyclists everywhere. Thankfully this changed following the street improvement, and many bicyclists began to use the PBL after installation. The new PBL on 15th Street helped to reduce the types of bike-car encounters down to several key conflicts, namely in mixing zones and for turning bicyclists, that are more manageable for city planners to remedy.

The new bicycle facility also encouraged a wider variety of "types" of bicyclists to use the PBL (Dill and McNeil 2013). Bicycling down 15th Street used to require high speed riding and a fearless attitude, but now any individual can bike along at their own pace and only need to worry about car encounters in the mixing zones. This encouraged more members of underserved groups, including need-based, female, juvenile, and elderly cyclists, to use the 15th Street PBL. While the PBL increased safety and encouraged more types of users to access 15th Street, it is still a pilot project with considerable room for further improvements. The large number of mixing zones and minimal separation from car traffic often force bicyclists to interact with cars. It does not feel completely protected. This was revealed on a ride with colleagues from the department, who noted how the mixing zone interactions did not make for a low-stress bicycling experience on PBL. Efforts to reduce mixing zone conflicts, protect bicyclists at intersections, improve signal timing, and improve the vertical separation are necessary to take 15th Street from a successful pilot project to a world-class PBL, however the current facility is still a vast improvement over having no facility.

PBLs increase overall bicycle traffic, while simultaneously decreasing the number of traffic violations and sidewalk riding counts

Statistical analyses reveal that PBLs display numerous traffic benefits as well. The 15th Street PBL increased overall bicycle traffic through the corridor by 37%, which aligns with the "if you build it they will come" argument for constructing new bicycle facilities. More impressively, this 37% increase in total bicycle traffic was paired with a 33% decrease in traffic violations and a 54% reduction in sidewalk riding. This major increase in ridership, coupled with equally large decreases in law breaking and sidewalk riding, asserts that PBLs encourage larger numbers of bicyclists to ride on 15th Street in a more law abiding way, which significantly improves bicycle, pedestrian, and car safety thanks to fewer collisions.

Figure 50, Figure 51, and Figure 52 display the differences between the pre-improvement, post-improvement, and Sunday bicycle traffic counts. The decoupling of total counts and traffic violations between the pre- and post-improvement figures highlights how bicyclists tend to follow more laws after the PBL was installed. ANOVA tests on total count, total traffic violations, and sidewalk riding data reveal statistically significant differences between the pre- and post-improvement bicycle traffic counts. PBLs draw out larger numbers of bicyclists, while also encouraging them to follow more laws. The aforementioned findings showcase the PBL as an excellent bicycle facility type for business districts, within busy traffic corridors, to attract more customers.

Weather was also a major factor in bicycle counting efforts, which suggested that counts should be taken on days with comparable weather. The November observation days had very similar counts, but closer inspection revealed that the November 2013 observation displayed a high temperature of 67^{0}F, while there was snow on the ground for the November 2014 observation date. This showcased a relative increase in ridership from 2013-2014, and displays the importance of using comparable observation days, while also explaining why the counts from the buffered bike lane observation days are lower than the pre-installation counts.

The bicycle traffic counts along 15th Street tell an excellent story of increased bicycle counts and safety, combined with decreased law breaking. Despite the aforementioned win-win-win for 15th Street's PBL, it is still far from a perfect facility. An unfortunately large number of mixing zone conflicts, unprotected intersections, lack of signal timing, and skimpy vertical separation suggest that 15th Street's PBL is a successful pilot project with considerable room for improvement. The shortcomings of the 15th Street PBL provide interesting parallels to Denver's incomplete bicycle network shown in Figure 5 above. 15th Street's PBL begins on a random sidewalk and abruptly ends at Larimer Square with a forced merge over to sharrows, which is not overly intuitive. This is analogous to Denver's disconnected bicycle network that has a few blocks of bike lane in one area, with a trail connection in another, and it all feels very piecemeal. While 15th Street's PBL falls short of a low-stress bicycle facility, it is still far better than no facility. This point underscores how research on 15th Street can help planners, policymakers, and other relevant stakeholders build low-stress bicycle facilities and sculpt the resulting network to encourage increased bicycle use by everyone.

Conclusion

"Cycle tracks will abound in Utopia."

H.G. Wells

The preceding study sought to answer the following three research questions:

1. Based on a multiscalar analysis of sales tax and other relevant data, what are the local-scale economic impacts of bicycle facility improvements, and what are the implications for similar corridors in the region and planners across the US?
2. Based on observational research and counts, how does bicycle use change within the corridor before and after the implementation of new bicycle facilities?
3. Based on a GIS and statistical analysis of transit access data, how far do most RTD transit patrons drive to access transit facilities, in Denver, and the entire RTD district?

These questions were answered using quantitative analyses of geographic sales tax, bicycle count, transit access, land use, and census data, in addition to qualitative observational research analyses. This approach revealed the specifics of how improved bicycle facilities impact local scale economic performance and bicycle traffic, while also suggesting how other cities within the region, and across the country, can make beneficial improvements to their alternative transportation networks. The aforementioned methods uncovered the economic trends and overall traffic changes following the installation of improved bicycle facilities, while also showcasing the importance of mixed methods research for bicycling topics.

This research revealed four central findings that contribute to the current transportation and bicycle literature and to future studies. First, Denver exhibits untapped potential for increasing the bicycle mode share, especially when bike trips are combined with transit trips. Many Denver residents live in close proximity to transit, which suggests that they can replace car trips with bike and transit trips. There is also considerable room to improve Denver's on-street bicycle network to encourage people to ride bicycle for transport.

Second, bicycle facilities are correlated with statistically significant positive economic impacts for local businesses and do not have negative impacts. This research uncovers that new bicycle facilities do not hurt local businesses. In fact, the findings from the Larimer Street study area suggest that the new bicycle facilities significantly increased economic performance within the corridor, when compared to similar local streets. Modeling, time, and other constraints limited the ability to claim that the new bicycle facilities directly caused the economic increases. However, the analysis certainly suggests that the new bicycle facilities were a key component, and potentially the impetus, behind the improved economic performance. While this research was unable to claim direct causality, future studies can combine these methods with interviews or a more robust statistical model to assign causality.

Third, PBLs improve overall safety for all users and encourage more “types” of bicyclists to use the facility. The current lack of bicycle facilities represents the main barrier to increasing ridership levels. This research makes the case that new bicycle facilities can improve the overall safety and equity of the US’ bicycling transportation system. One cannot undervalue the importance of human safety, and this research highlights the key role of bicycle facilities in making US streets safer for all.

Lastly, PBLs increase overall bicycle traffic, while simultaneously decreasing the number of traffic violations and sidewalk riding counts. 15^{th} Street experienced a 37% increase in bicycle traffic at the same time as a 33% decrease in traffic violations and a 54% decrease in sidewalk riding. The impressive increase in ridership, coupled with drastic decreases in sidewalk riding and traffic violation counts, point to new bicycle facilities as a win-win-win that attract more usurers to a space, while also encouraging many of the new users to obey the traffic laws at higher rates than before.

The preceding findings from this research highlight how the bicycle is an underutilized mobility tool with major room for growth in the current US transportation system. New bicycle facilities are tied to increased safety and use, and also appear to provide major economic benefits for the businesses located along the street improvement.

A mixed methods analysis of geographic sales tax, bicycle count, transit access, land use, and census data, paired with qualitative observational research, suggests how planners, policy makers, and other relevant stakeholders can build the best transportation network for Denver's future.

The peak travel context informs this study on the economic and traffic impacts following the installation of new bicycle facilities. Emerging trends suggest that policymakers and transportation planners need to reconsider the belief that VMT levels will perpetually continue to increase. This study helps to address the need to understand how new bicycle facilities impact local neighborhoods, businesses, and the people who use them to get around the city. These findings speak to the logical reasons why Denver should build more bicycle facilities, but the intrinsic benefits of the bicycle as an inexpensive, efficient, cost-effective, healthy, low impact, local, sustainable, equitable, accessible, and enjoyable transportation mode, represent the true reasons why US cities must improve their bicycles networks and encourage more residents to have fun riding their bicycle for transportation (Rosen et al. 2007; Mapes 2009; Byrne 2010; Birk and Kurmaskie 2012; Pucher and Buehler 2012; Henderson 2013).

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