Bicycles and Transit: Weather or Not: A Study on the Effect of Weather and Air Quality on Bicycle-Transit, Bicycle, Rail Transit Counts in Denver

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Bicycles and Transit: Weather or Not

A Study on the Effect of Weather and Air Quality on Bicycle-Transit, Bicycle, Rail Transit Counts in Denver

A Thesis
Presented to
the Faculty of the College of Natural Sciences and Mathematics
University of Denver

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by
Christiana M. Fairfield
June 2022
Advisor: Dr. Andrew R. Goetz
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The movement of people and goods within metropolitan areas is critically important to the operational efficiency and functionality of cities. This study explores the influence of local weather conditions and the air quality index on bicycle-transit user in Denver, Colorado. Based on bicycle-transit having two key components, bicycle and transit, the effect of local weather conditions and the air quality index is also explored with bicycle use and rail-transit usage. Key findings include: (1) the most significant variable across all three modes is temperature, (2) for bicycle-transit and bicycle use, there is a steady increase in ridership as temperatures increase to about 85-degrees Fahrenheit before decreasing, (3) bicycle-transit users at the University of Denver Station are more likely to park their bike at the station when the temperature is lower and less of a chance of precipitation, and (4) college students are more affected by rain in the morning than in the afternoon. The use of multimodal transit systems has been increasing because of the congestion and negative impacts on the environment the automobile has created. This research explores the effects that weather and air quality have on the number of bicycle-transit users, bicycle users, and rail-transit users in the City and County of Denver.
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Chapter One: Introduction

Problem Statement

Since the mid-19th century, the United States has dedicated a substantial amount of resources to creating transportation systems connecting major population and economic centers with second order effects of increased urban population. Since 1960, the urbanized population in the United States has more than doubled, reaching just over 249 million in 2010, representing nearly 80 percent of the United States population (US Census 2012). The enormous economic prosperity post-World War II led to an increase in automobile ownership as well as an increase in suburbanization, shift of population from central cities to suburbs. With urban design being catered to the automobile, most suburbs are poorly-connected to the central city or other suburbs by public transportation which has led to increased congestion, especially during peak hours, on the highway as suburban residents travel to the central city or suburbs for jobs and entertainment by private car.

The transportation stress and congestion urban areas are facing today is why it is imperative to improve the efficiency of urban transportation networks. Congestion caused by the automobile requires diversifying from its majority dedicated usage and promoting other means of transportation, such as bicycle-transit, the combination of using a bicycle and public transit to get to the destination.
In an automobile culture, it can be difficult to sell the idea of public transportation over the use of a private automobile as public transportation limits the freedom of movement that an automobile provides and creates the additional challenge of not being able to get from Point A to Point B in one single flow. It may require rail line or bus line changes which can be an obstacle. If one bus is late getting to a station, the rider trying to switch to another bus line might miss their next bus, potentially making them late to their destination. A practical difference between use of bicycle-transit as a means for travel compared to the automobile is protection from the elements such as rain, wind, and temperature. Amiri and Sadeghpour (2015) conducted a study in Calgary, Canada finding that despite nearly freezing temperatures, 96 percent of frequent winter cyclists continued commuting to work by bicycle with 71 percent continuing to cycle in temperatures colder than -20 degrees Celsius (Meng et al. 2016). There has been a continued growth of cycling and rail transit usage after decades of being overshadowed by automobiles and as policies and practices are put into place, growth will continue (Krizek and Stonebraker 2010). While growth overall continues, this research is focused on the daily counts of bicycle-transit taking into the relationship between weather, air quality, and seasonal employment.

**Intellectual Merit**

The rates of active transportation, in this research bicycle use, have increased nationally in recent years. Much of this has been driven by a steady increase in bicycle infrastructure. However, much to the frustration of transportation professionals, there is a lack of bicycle count data when utilizing bicycle-transit. There is a lack of research on the effect of daily weather changes and air quality on bicycle, rail transit, and bicycle-transit
counts. This is a problem because in addition the bikeability of a city is being severely diminished by the urban sprawl of a built environment, if infrastructure and policies are not put in place to assist with weather and air quality then urban planners and city officials cannot cater to those cyclists affected by weather changes. This research will enhance the knowledge of the relationship between the effect weather has on bicycle-transit and its impact on the number of cyclists per day by providing thorough analysis on the daily bicycle-transit counts considering temperature and chance of precipitation. Additionally, the literature is thin when it comes to studying the effects of air quality and bicycle, rail transit, and bicycle-transit usage. This research will add to the literature by analyzing the daily changes in bicycle counts compared to the measure of air quality.

This research will contribute to: 1) the increasing amount of geographic literature on the relationship between bicycles and weather, 2) the current body of literature analyzing the relationship between cycling and high employment concentrations, and 3) thicken the little amount of literature on air quality and cycling. Research studies, such as this one, focus on creating a more sustainable transportation network and are an effort to silence the “siren song” of Americans’ love affair with the automobile (Schroth 2014).

**Broader Impacts**

The implementation of a connected bicycle-transit network is imperative to building sustainable transportation in urban areas. The data collected are a picture of bicycle, rail transit, and bicycle-transit usage that will contribute to the overall picture of multimodal transportation in Denver. This analysis could be useful in assisting with the Active Transportation Plan and will be made available for planning and analysis efforts for transportation planning in Denver. It increases the health of its users and can aid efforts to
create a positive change in the air quality with the decreased use of automobiles. Efforts that are now coming from Governor Polis’ office after Summer 2021 resulted in 12 air monitoring sites across the Front Range recording a three-year average above 70 parts per billion of ozone, the federal health standard (Brasch and Minor 2021). This analysis, particularly the light rail, will potentially serve to assist Governor Polis’ budget request to make public transit free during the ozone season (31 May-31 August) and to “serve to save riders money, help rebuild ridership [due to COVID-19], and reduce driving” (Brasch and Minor 2021). In addition to making public transit free during the ozone season, the budget would also be used to purchase electric school buses and replace old diesel trucks with a more fuel-efficient fleet (Phillips 2022).

Analyzing the effect weather has on bicycle-transit will increase the understanding of bicycle-transit performance to city planners, policy developers, and transit agencies. Given the current need to decrease automobile traffic congestion and impacts to the environment, developing an effective method of evaluating bicycle-transit networks is essential.
Chapter Two: Literature Review

Cycling is viewed as a flexible transportation mode with good adaptability to provide mobility alternatives and decrease the congestion seen on urban roads (Buehler and Handy 2008). Initiatives to increase bicycle usage, such as bicycle-transit integration, have been increasing in recent years in the United States. These initiatives have the overarching goal of decreasing the amount of vehicular traffic on the road thereby decreasing the commuter time and decreasing the amount of pollution from car emissions (Buehler and Handy 2008). However, many studies have found that the relationship between bicycle-transit and weather is complex. Some studies have found decreased automobile traffic and increased ridership during poor weather conditions while others have found increased automobile traffic in similar conditions (Kienteka et al. 2017, Meng et al. 2016, Kalkstein et al. 2009, de Palma and Rochat 1999, Changnon 1995). Due to these mixed results, this paper aims to find the relationship between bicycle-transit and weather as well as bicycle-transit and air quality, and seasonal employment in Denver.

Bicycle-Transit

The promotion of cycling as an alternative option of daily travel has garnered significant attention from urban planners since the early 2000s. There has been a substantial growth in cycling and a slight growth in the use of public transit in US cities which may be partly attributable to bicycle-transit integration, however, the attribution is hard to measure. This may be due to an inadequacy in academic literature, although, the
literature seems to have increased in the last fifteen years. Evident throughout the literature is that increasing bicycle infrastructure, to include safer bicycle lanes, is not enough. Clayton and Musselwhite (2013) explored various changes to cycle infrastructure that would improve the experience of cycling and acknowledge that while an increase in infrastructure developments will lead to an increase in cyclists, the infrastructure is not enough to make as large of an impact as it would if integrated with public transit.

The distance between the origin and destination affects the probability of a commuter choosing cycling over use of their automobile (Zhao and Li 2017, Krizek and Stonebraker 2011, Krizek et al. 2007). When the distance between the trip origin and a bicycle trail is over 2.5 km, the probability of cycling decreases dramatically (Krizek et al. 2007). However, when bicycle-transit is available, the probability for cycling slightly increases (Zhao and Li 2017). In 2011, Krizek and Stonebraker assessed various options to enhance bicycle-transit integration and found that transit with the ability to bring your bicycle on board was most preferred for cyclists. The ability to bring their bicycle on board, for example on front-mounted bicycle racks on busses, allows cyclists to travel the last mile or so to their destination encouraging the use of cycling as a transfer mode. Additionally, on boarding a bicycle also provides a safe option in the case of inclement weather.

Coordinating cycling with rail transit enhances the benefits of both travel modes by encouraging more cycling and more rail transit use (Pucher and Buehler 2012; Brons et al. 2009; Givoni and Rietveld 2007; Hegger 2007; Martens 2004 and 2007). Cyclists
support public transportation by extending the reach of rail stations and bus stops much further than the ability to walk and public transit increases the distance of trips for cyclists. Rail transit networks can also provide opportune alternatives when cyclists encounter bad weather, difficult terrain, gaps in the cycling infrastructure network, and maintenance issues (Pucher and Buehler 2012). As with all choices, there is a threshold. Krizek and Stonebraker (2011) found that transit services traveling long distances, 30 miles, with relatively few stops, such as express routes, tend to draw a larger number of bicycle-transit users than short distance routes with more stops. Shorter distances with more stops can slow a cyclist down as it is accepted that with the increased number of stops, a cyclist may be able to cycle the short distance more quickly than by the local rail or bus line (Krizek and Stonebraker 2010). A study of three European countries showed that most bicycle-transit users ride between one and three miles to access faster transit options, but for the unfavorable slower transit options, bicycle-transit users typically do not ride more than one to two miles (Martens 2004). The larger number of bicycle-transit users associated with rail routes may be justified by frequent transit users who are willing to undertake a longer access trip in return for a shorter overall commute time (Krizek and Stonebraker 2010).

If the ability to bring the bicycle on board is unavailable or the capacity has reached its maximum, the availability and design of bicycle parking sites is an important factor to not deter cyclists (Krizek and Stonebraker 2011, Martens 2004). Exclusive and safe parking sites designed for bicycles at transit stations contribute to a higher rate of bicycle-transit trips, however, unsafe parking near transit stations is an obstacle that urban
planners need to account for with bicycle-transit integration (La Paix and Geurs 2015, Advani and Tiwari 2006). Enhancing parking at a transit stop gives cyclists the potential to increase the security and weather protection for their bike. In the United States, the aspect of bike-and-ride was limited due to lack of usage of cycling and public transportation, the opposite of what is seen throughout Western Europe (Pucher and Buehler 2009).

While there is little empirical evidence for the factors of people’s decision to use bicycle-transit integration, it is commonly believed to be an important element of increasing the efficiency and use of urban transportation systems (Zhao and Li 2017).

**Bicycle-Transit and Weather**

Urban planners and transit agencies have recognized that weather affects human contentment which in turn affects bicycle usage as well as public transit usage. Studies on the effect of weather on cycling have been conducted in a few countries to include Austria, Canada, Australia, and the United States (Nosal and Miranda-Moreno 2014, Thomas et al. 2013, Flynn et al. 2011, Rose et al. 2011, Nankervis 1999, Hanson and Hanson 1975), however, quantitative studies about the relationship are uncommon. A study in Geneva found that over 50 percent of respondents specified that weather was an important factor in determining what mode of transportation to use with 73 percent identifying that it affects their departure time (Kalkstein et al. 2009). For many, weather can have an impact on bicycle usage. Unfavorable weather conditions, such as humidity, temperature, and precipitation, affect cycling usage. A study in Uppsala, Sweden found that leisurely travel was impacted by weather more than commuter travel (Nankervis 1999, Hanson and Hanson 1975). Leisure activities are optional in nature whereas
commuter travel is required due to work. Helbich et al. (2014) found similar results 39 years later in Rotterdam, Netherlands finding that people are much more sensitive to weather when the trip is leisurely instead of a commuter trip. These results were again echoed by Wei in a 2022 study arguing that the weather variables are negligible influencing adult ridership because trips to work are typically on a fixed schedule that cannot be changed due to weather. However, Wei (2022) only found the similar results for the AM peak (6:30-8:30). As for the PM peak (4:00-6:30), Wei (2022) found that precipitation had a negative influence on adult ridership for those in suburban areas but positive influence for those in the inner city.

In 1999, Nankervis studied the effect of weather on people commuting to work by bicycle in Melbourne, Australia. His assumption was confirmed that adverse weather conditions had a negative effect on commuting by bicycle. He found that the number of cyclists was higher in the summer than in the winter due to the cold weather (Nankervis 1999). In 2011, Flynn et al. conducted a study in five counties across Vermont with 163 participants and found that the likelihood of bicycle commuting increased in the absence of rain and snow and with higher temperatures. In 2007, Winters et al. found that when a year had more days of precipitation and freezing temperature, there were lower levels of cycling in 53 selected Canadian cities.

Rose et al. (2011) studied the bicycle travel data and weather in Portland, Oregon and Melbourne, Australia with the same results as previous studies – warmer temperatures and less rainfall created an environment for increased bicycle traffic in both cities studied. The study did find that the extent of the effect of temperature has on cycling can
differ in each city with the coefficients of the temperature calculated at 0.3 to 0.6 in one city and 0.2 in the other (Meng et al. 2016). In 2012, Tin et al. found a similar result in Auckland, New Zealand with the hourly volume of cyclists being over 26 percent higher on sunny days than less than sunny days. The previous studies mentioned all found similar results – temperature and precipitation impact bicycle usage. Meng et al. (2016) found that in Singapore, approximately 30 percent of participating cyclists checked the weather forecast before beginning a trip and they preferred temperatures between 85-87° Fahrenheit with humidity between 52 and 62 percent and no rain the last 60 minutes. In 2021, Bean et al. found similar results. They found in most of the cities analyzed, usage increases up to between 27- and 28-degrees Celsius (80-82-degrees Fahrenheit) (Bean et al. 2021). Bean et al. (2021) found that, while the effects will be small, that global warming is likely to lead to an increase in active transportation in colder climates but decline in warmer climates.

Disregarding cycling, studies have found that public transit ridership decreases due to unfavorable weather conditions as well (Kalkstein et al. 2009, de Palma and Rochat 1999, Changnon 1996). Therefore, it is not surprising that bicycle-transit also decreases during poor weather conditions as the bicycle adds additional time in the elements. A study in Chicago conducted in 2007 also found that decreased temperature and increased precipitation caused decreases in transit usage, however, it was most notable on weekends rather than weekdays (Kalkstein et al. 2009, Guo et al. 2007).

This research will be most similar to the research conducted by Thomas et al. (2013) where they explored the daily cycling count changes based on the daily weather
fluctuations in the Netherlands (Meng et al. 2016). The study used data gathered by the Wageningen University using pneumatic tubes in the Netherlands, cities of Gouda and Ede, from 1987 to 2003 (Thomas et al. 2013). As with previous studies, (Helbich et al. 2014, Guo et al. 2007, Hanson and Hanson 1975), this group of researchers also found leisurely trips to be more affected by weather than commuter trips.

**Bicycle-Transit and Air Quality**

Cycling is a great source of exercise for many people, however, air quality can deter cyclists because the health benefits from cycling are negated when the air quality is so poor that the health benefits are diminishing. Pollutants can linger in the lungs and enter the bloodstream which may lead to heart or lung problems (Gustke 2017). A few studies show that cycling during rush hour, when automobile usage is at its peak during the day and the highest number of pollutants are being emitted into the air, puts cyclists at more risk because they are breathing in more air as they breathe more heavily while cycling (Apparicio et al. 2021, Schiffman 2017). In New York City, health officials estimate that particulate matter contributes to over 2,000 early deaths and more than 6,000 hospital visits per year (Sidder 2016).

Conversely, a study in the Journal of the American Heart Association found that while physical activity does increase the inhalation of air pollutants, the physical benefits were not reduced when cyclists were exposed to high levels of air pollution (Kubesch 2018). The study does recommend for cyclists, or any active transportation users, when cycling for leisure to do so during off-peak hours to avoid the highest level of pollutants. Another study conducted by the BBC found that cyclists inhaled fewer pollutants than automobile users. The study found that automobile users inhaled particulate matter at 44
percent more than what the World Health Organization has set as the baseline with cyclists inhaling particulate matter at 28 percent over the baseline (Short 2019). A study conducted at Leeds University also found that cyclists are the least exposed to air pollution in a congested city, where automobiles were sitting in stop-and-go traffic, citing automobiles as “boxes collecting toxic gases” (Carrington 2018).

**Bicycle-Transit and Employment**

The daily commute from people’s residence to workplace is an important component to everyday life. In 2015, Schrank et al. found that about 19 percent of commuting time in the United States is spent in traffic congestion and the time stuck in traffic congestion is growing with the average automobile commuter spending 54 hours in traffic congestion in 2019. Promoting the use of bicycle-transit is an important step in reducing automobile usage – public transit is often not available for door-to-door service but bicycle-transit allows for the first and last mile to facilitate the gaps.

As for seasonal employment, Wei (2022) found that college students are more likely to use public transit when it is a rainy morning between the hours of 7:00-9:00 which Wei defines as the AM peak and this again seen during the PM peak (2:30-6:30). This is due to most students have the travel mode options of walking, cycling, or public transit. Wei (2022) determined that students are more likely to use public transit instead of active transport to avoid getting rained on prior to classes.

Overall, there is very little literature on bicycle-transit and employment concentrations. There is a large amount of research in regards to the working poor, transit-oriented developments, and employment locations (Oviedo 2019, Legrain et al. 2016, Boschmann 2011, Sanchez et al. 2004, Holzer et al. 2003). There is also plenty of
research on the spatial distancing of jobs and residences but many of these studies focus on racial inequalities, commuting time and distance using an automobile (Sanchez 1999). Few studies have considered the impact of employment concentrations on bicycle-transit. Urban public transit networks operate efficiently in densely developed urban areas and tend to be oriented to the downtown. Although Denver is expanding and upgrading its bicycle network, its focus has been in the location of high employment concentrations, especially downtown. The University of Denver has a high-seasonal employment concentration. Denver is focusing on three areas to address multi-modal transit, Central, South Central, and Northwest. The University of Denver Light Rail station falls within the South Central area.
Chapter Three: Research Questions and Hypotheses

Research Questions

This research developed from the overarching goals of Denver to reduce the amount of congested traffic and emissions footprint and from the researcher to analyze the way weather and air quality impact bicycle-transit usage. Other goals were to see if bicycle-transit usage could promote environmental urban sustainability, encourage a healthier lifestyle, and, despite the urban sprawl, make Denver more bicycle-friendly. Infrastructure is essential for supporting safe and increasing bicycle use, thereby reducing the emissions put into the atmosphere by fossil-fuel transport choices and vehicle-miles traveled (VMT). In 1982, Denver had 484,000 auto commuters with 8.9 million freeway daily VMT and by 2010, there were 1.27 million auto commuters with 21.8 million freeway daily VMT (Texas A&M Transportation Institute 2021). In 2019, the number of auto commuters increased to 1.34 million auto commuters, however, even though there was not a large increase in auto commuters, the freeway daily VMT increased to 27.9 million VMT (Texas A&M Transportation Institute 2021). The amount of urban sprawl that has developed over the last half-century does not always make it feasible to use a bicycle as a mode of transportation. There are physical limitations and time constraints to make it from a suburb to the central city for a job or even from a suburb to a suburb. The integration of bicycle and the rail transit network in Denver decreases these limitation and time constraints. In bicycle-transit integration, the bicycle is a desirable feeder mode
of travel because it is quicker than walking but offers more flexibility than just using public transit (Rietveld 2000; Keijer and Rietveld 2000). Before exploring the various topics listed above in future research, I want to see how the factor of weather affects bicycle-transit usage. This is important because cyclists are a vulnerable population, not just to automobiles, but to weather as well (Zhao and Li 2017, Buehler and Pucher 2012, Bergström and Magnusson 2003).

Given this information, the following research question is posed:

1. Is there a relationship between weather, air quality, and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?

I am also interested in analyzing weather separately from air quality. Therefore, the following questions are posed:

2. Is there a relationship between weather (temperature and precipitation) and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?
   a. Is there a relationship between temperature and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?
   b. Is there a relationship between precipitation and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?

Denver has many air quality alerts due to wildfires and emissions. During these alerts, it is advised to the public to exercise indoors and limit the number of outside trips which could decrease the number of cyclists if someone is taking the recommendation into account. Given this information, another question is posed:
3. Is there a relationship between air quality and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage?

The DU Light Rail Station is located at a seasonal employment location and therefore a final question is posed:

4. Is there a relationship between bicycle-transit usage, weather, and seasonal employment?

**Hypotheses**

For each of the analyses that will be explored, the null hypothesis (H₀) is \( H₀ = \mu = 0 \) and the alternative hypothesis (Hₐ) is \( Hₐ = \mu \neq 0 \). The analyses will be explored at 95 percent confidence level by examining the test statistic. A 95 percent confidence interval is widely accepted by researchers as an acceptable level of risk (MacFarland 2013). A test statistic is used to determine if there is a significant difference between the data being analyzed. In this research, the test statistic will be used to determine if there is a significant difference between the number of bicycle-transit users, bicycle users, and rail users and temperature, precipitation, air quality, and employment.
Chapter Four: Research Design and Methods

For this research, a quantitative data analysis will be conducted. The data will be collected by conducting basic counts of bicycle-transit users at the DU Light Rail Station. The counts conducted up until the official start of classes will be used as data towards out-of-session, July 12th – September 10th, and the counts conducted from the official start of classes to November 11th will be used as data toward in-session, September 13th – November 11th.

Location Background

Denver is a hot spot today for people looking for relocation opportunities. Since 2010, the city and county of Denver’s population has increased by nearly 130,000 and is projected to continue to increase at a similar rate. The focus of this research is not the entirety of Denver but specifically at the DU Light Rail Station. The DU Light Rail Station not only provides data for weather and air quality but also adds an element of a seasonal employment concentration due to its proximity to the University of Denver. The DU Light Rail Station has three lines – E, F, and H. The F-line is currently suspended due to COVID-19. DU encourages its community to shift from a vehicle mindset to more sustainable options by using part of the student fees to provide a College Pass which allows students regional travel on the rail network. DU also promotes bicycle use as an
active, fun, and sustainable mode of transportation. The DU Parking and Mobility Services provides Denver Bicycle Network maps as well as information about how to on-board a bicycle on the rail network.

As previously noted, cyclists are vulnerable to weather. Denver weather is influenced by its proximity to the Rocky Mountains and at times can be unpredictable. On 5 September 2020, the record high temperature in Denver was set at 101-degrees Fahrenheit and three days later Denver received an inch of snow (NOAA 2020). Safer cycling encourages more people to use bicycle-transit because risk-averse people are deterred from cycling for fear and injury and unpredictable weather can influence this decision (Jacobsen and Rutter 2012). Urban planners and city policy makers cannot control the weather, however, ensuring information about how to safely cycle during hazardous weather has the potential to increase the confidence of users. Urban planners and city policy makers can impact the amenities provided at the light rail stations to encourage, not only cyclists but people over all, to use transit during poor weather conditions by providing shade/rain shelters, cooling towers, and heated lamps to protect the users from the weather while waiting for the train.

Denver cyclists not only have to be aware of the weather but also the air quality. This research will analyze the effect the air quality index has on cycling. The air quality index is

“a measurement of air pollutant concentrations in ambient air pollution and their associated health risks…An [air quality index] number is assigned based on the air pollutant with the highest [air quality index] number at the moment the air quality is measured” (IQ Air 2021).
Table 1 shows the air quality index chart widely used throughout the United States.

As the air quality index increases, the quality of air decreases.

<table>
<thead>
<tr>
<th>US AQI Level</th>
<th>Health Recommendation (for 24 hour exposure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Air quality is satisfactory and poses little or no risk.</td>
</tr>
<tr>
<td>Moderate</td>
<td>Sensitive individuals should avoid outdoor activity as they may experience respiratory</td>
</tr>
<tr>
<td></td>
<td>symptoms.</td>
</tr>
<tr>
<td>Unhealthy for Sensitive Groups</td>
<td>General public and sensitive individuals in particular are at risk to experience</td>
</tr>
<tr>
<td></td>
<td>irritation and respiratory problems.</td>
</tr>
<tr>
<td>Unhealthy</td>
<td>Increased likelihood of adverse effects and aggravation to the heart and lungs among</td>
</tr>
<tr>
<td></td>
<td>general public.</td>
</tr>
<tr>
<td>Very Unhealthy</td>
<td>General public will be noticeably affected. Sensitive groups should restrict outdoor</td>
</tr>
<tr>
<td></td>
<td>activities.</td>
</tr>
<tr>
<td>Hazardous</td>
<td>General public at high risk of experiencing strong irritations and adverse health</td>
</tr>
<tr>
<td></td>
<td>effects. Should avoid outdoor activities.</td>
</tr>
</tbody>
</table>

*Table 1. Air Quality Index Chart (IQ Air 2021)*

While Colorado is known for its pure mountain air, frequent wildfires during the summer months in recent years detract from that pure air to the point that it is recommended to exercise indoors and not travel on somedays. On 7 August 2021, Denver’s air quality was ranked one of the worst cities in the United States due to the wildfires in the West, mainly from California, Oregon, and Washington (AP 2021). The Colorado Department of Public Health and Environment (CDPHE) issued a health advisory stating that those with respiratory illnesses should avoid outdoor activities and keep windows closed through 8 August 2021 (AP 2021). This was not the only day an advisory was issued. Action Day Alerts are issued throughout the summer (ozone) season (May 31 – August 31) (Colorado Department of Public Health and Environment 2021).
During this period in 2021, there were 65 Action Day Alerts with 41 consecutive alerts from July 5 – August 14) (Colorado Department of Public Health and Environment 2021). Depending on the air quality conditions at the time the alert is issued, which is 1600 daily, an alert can expire after 8-hours or 24-hours. While data for the number of Action Day Alerts are available dating back to 2011, 2021 had the highest number of Action Day Alerts with the next highest being 52 in 2018 (Colorado Department of Public Health and Environment 2021). To try and lessen the decreasing air quality, the CDPHE has implemented Action Days. If the CDPHE determines the need for an

“Action Day for fine particulate matter, carbon monoxide, ozone or other pollutants that indicates that either current air quality is unhealthy or conditions are expected to worsen later in the day or on the next day. This also indicates that the air quality will be in the Unhealthy or Unhealthy-for-Sensitive-Groups categories according to the Air Quality Index. Action Days always convey overarching public health recommendations, and, according to season, trigger a variety of mandatory and voluntary pollution prevention measures.” (Colorado Department of Public Health and Environment 2021).

In 2019, the Environmental Protection Agency (EPA) gave Denver the designation of “serious” air quality violator (Phillips 2022). Due to the severity of air quality in Denver and after years of failing to improve air quality, the EPA will be downgrading Denver from “serious” to “severe” and in response Denver residents will see an increase in gas prices and more strict emissions standards (Phillips 2022).

With 300 days of sunshine, there has been a bicycle resurgence in Denver and the number of bicyclists has increased for mode of transportation since they are inexpensive, environmentally friendly, and a healthy mode of transport. Bicycle-transit is a commuting option aimed to reduce traffic congestion, improve air quality, and improving the quality of life for the residents of the Denver region. The goal of the increase in gas prices is to
reduce the pollution, particularly ozone, that is seen in the Denver skyline as a brown haze, which would improve the air quality for Denver residents (Phillips 2022). Despite this resurgence, most people in Denver do not feel comfortable about cycling in the built environment. Additionally, with the amount of urban sprawl in Denver, cycling is not an option due to physical distance. To help promote the use of bicycle-transit, the Regional Transportation District (RTD) has implemented a Bike-n-Ride program that has two bike zones on some light rail vehicles with room for two bikes in each zone and commuter rail vehicles have level boarding to allow for rolling the bike on and off the cars with vertical racks available for bike storage (Regional Transportation District 2021). It is also possible for bicyclists to use the space reserved for riders needing mobility devices if they are not already being used. Availability to onboard a bicycle also provides cyclists an option in case the weather takes a turn – a sunny day becomes a stormy, windy, and/or rainy day. Policies and practices that ensure transit capabilities to onboard bicycles will encourage people to leave their cars at home and decrease automobile congestion.

**Bicycle-Transit User Counts**

With the interest to determine the effect of weather, air quality, and seasonal employment on bicycle counts, quantifying active transportation data is crucial to analyzing favorable weather for bicycle-transit use and the change over time, in-season compared to out-of-season employment, in order to plan and design for active transportation such as bicycle-transit. The DU Light Rail Station was selected due to the availability of bike racks, the proximity to current and future bicycle lane infrastructure, seasonal employment concentrations, and the University of Denver is located within the service area of the Lyft and Uber Bicycle Share programs. Additionally, this station is
located in a Transit Oriented Development (TOD) area and is located on three lines, with two currently in use – E and H line. The third line, F, is currently suspended due to COVID-19. TOD is a strategic urban development approach that maximizes residential, business, and leisure areas within an active transportation distance of public transit.

The counts will be used to gauge ridership on weekdays during rush hour and daily changes. Counts will be conducted Monday-Friday between 0730-0930 and 1600-1800 from July-November at the University of Denver (DU) Light Rail Station. These two time periods also coincide with high bicycle usage found in the 2017 Colorado Department of Transportation Bicycle Count Study (Colorado Department of Transportation 2018). Counts will be conducted on those who carried their bike onboard, those who departed with a bike, those who transferred from one line to another with their bike (not likely at the DU Station but possible so will be potentially captured), those who parked their bike, those who arrived to the station using a bike share bicycle, and those who departed the station using a bike share bicycle. For the 2021-2022 Academic Year, over 12,000 graduate and undergraduate students and over nearly 3,000 faculty will be in session from 11 September 2021 – 10 June 2022. The daily data for in-session was conducted Monday-Friday from 13 September – 9 November 2021. The daily weekday data for out-of-session data was collected from 11 July – 10 September 2021. Table 2 shows the descriptive statistics of the bicycle-transit count data and the independent variables associated with this transit mode.
Counts data could be useful to improving services and infrastructure in the area of the DU Light Rail Station. This data will provide some preliminary insights to improve bicycle-transit use but a more exhaustive, long term monitoring would be idyllic to select and implement the best strategies. Bicycle count data are important for Denver because the Denver Moves 2050 and Comprehensive Plan 2040 both pledge bicycle improvements. Bicycle-transit count data can help support this initiative as it can justify the installation of bicycle racks or lockers or an increase in weather structures and bicycle lanes in the vicinity of the rail station. The temperature and chance of precipitation source for bicycle-transit counts is the National Oceanic and Atmospheric Administration (NOAA). NOAA provides historical weather data for the Denver Area dating back to 1872. The Air Quality Index data will be pulled from IQ Air.

**Bicycle User Counts**

With the interest to determine the effect of weather and air quality on bicycle user counts, separate counts on just bicycle users will be analyzed. The data provided is a collection of counts conducted by the City and County of Denver’s Department of Transportation and Infrastructure: Parks and Recreation. The counts are calculated based on a 24-hour period. The counts available are from the Cherry Creek and South Platte

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle-Transit Count</td>
<td>60</td>
<td>14</td>
<td>37</td>
<td>25.22</td>
<td>6.383</td>
</tr>
<tr>
<td>Temperature</td>
<td>60</td>
<td>46</td>
<td>97</td>
<td>79.63</td>
<td>14.333</td>
</tr>
<tr>
<td>Precipitation</td>
<td>60</td>
<td>0</td>
<td>60</td>
<td>12.58</td>
<td>17.086</td>
</tr>
<tr>
<td>AQI</td>
<td>60</td>
<td>20</td>
<td>192</td>
<td>89.47</td>
<td>40.411</td>
</tr>
<tr>
<td>SchoolINS</td>
<td>60</td>
<td>0</td>
<td>1</td>
<td>0.50</td>
<td>0.504</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 2. Bicycle-Transit Descriptive Statistics*
Trails and the counts were gathered through automated counts. The counts are available approximate two weeks post the end of the collection period (i.e. On 15 October the counts were available for September 2021). The daily weekday data for the bicycle user counts was collected from July 2021 through November 2021. Table 3 shows the descriptive statistics of the bicycle user count data and the independent variables associated with this transit mode.

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC &amp; SF Bicycle Total</td>
<td>107</td>
<td>1275</td>
<td>9192</td>
<td>5374.68</td>
<td>1759.311</td>
</tr>
<tr>
<td>Temperature</td>
<td>107</td>
<td>37</td>
<td>99</td>
<td>78.72</td>
<td>15.206</td>
</tr>
<tr>
<td>Precipitation</td>
<td>107</td>
<td>0</td>
<td>60</td>
<td>9.30</td>
<td>14.233</td>
</tr>
<tr>
<td>Air Quality</td>
<td>107</td>
<td>20</td>
<td>192</td>
<td>84.22</td>
<td>41.589</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>107</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 3. Bicycle Users Descriptive Statistics*

The temperature and chance of precipitation data used for these counts will be the same data collected for the bicycle-transit counts. For the dates that capture bicycle users but not bicycle-transit users, the air quality data is available on Air Now. I hypothesize for the bicycle user counts to have a positive relationship with temperature and an inverse relationship with the chance of precipitation and air quality index.

**Rail Transit User Counts**

With the interest to determine the effect of weather and air quality on rail transit user counts, separate counts on just rail transit users will be analyzed. The rail transit user data are provided by RTD. Unfortunately, daily transit data are unavailable and the data RTD has available to share are monthly. RTD has over 200 light rail vehicles and 65 percent of the vehicles are equipped with the Automated Passenger Counters (APC) (Regional
Transportation District 2022). When the rail cars return to the rail yard at the end of the day, the information collected on the vehicle is downloaded to a server located in the yard using a WiFi access point (Regional Transportation District 2022). An issue that RTD has encountered is that with the large rail yards, the rail cars are not always close enough to the WiFi access point to download the information collected by the vehicle, however, RTD has determined that on average each vehicle gets close enough to a WiFi access point to download the data within every seven days (Regional Transportation District 2022). This is why daily data counts are not available.

While these data will not provide analysis for daily rail transit users compared to air quality changes, it will provide analysis for monthly changes for temperature and average air quality. About 10 years of data are available from RTD and I plan to analyze 2017, 2018, and 2019. Each year provides 12 points of data and I would like to have more than 30 points so that I can either prove or disprove a statistical relationship with the expectation that this analysis is based upon the normal distribution to be valid. I have selected 2017, 2018, and 2019 as they are the most recent years that have not been impacted by COVID-19. I believe that analyzing these years will give a better idea of temperature and air quality because comparing 2020 and 2021 to 2019, the data would be skewed due to the lower ridership caused by the pandemic. The temperature and chance of precipitation source, NOAA, used for the bicycle-transit counts and bicycle user counts will also be used for the rail transit user counts. Since the rail transit user counts are based on the total monthly users, the total precipitation for each month between January 2017 – December 2019 was used as the precipitation data. For the air quality index source, the U.S. Environmental Protection Agency provides archived daily air
quality reports. I will pull the daily air quality reports for 2017-2019 and then calculate the average of each month to compare to the monthly rail transit user counts. The monthly counts are from January 2017 through December 2019. There were three outlier months that have been removed: February 2018, July 2018, and July 2019. Table 4 shows the descriptive statistics of the rail transit count data and the independent variables associated with this transit mode.

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail Transit Count</td>
<td>33</td>
<td>1764818</td>
<td>2392923</td>
<td>2092017.61</td>
<td>169411.695</td>
</tr>
<tr>
<td>Precipitation</td>
<td>33</td>
<td>.03</td>
<td>3.66</td>
<td>.9639</td>
<td>.82974</td>
</tr>
<tr>
<td>Temperature</td>
<td>33</td>
<td>28.3</td>
<td>75.4</td>
<td>49.370</td>
<td>15.0127</td>
</tr>
<tr>
<td>Air Quality</td>
<td>33</td>
<td>42.39</td>
<td>99.10</td>
<td>59.7142</td>
<td>16.97501</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 4. Rail Transit Users Descriptive Statistics*

I hypothesize that rail transit user counts will be the lowest in the winter months, show growth in the spring months, peak in the summer months, and begin to decrease in the fall months. This will analyze average temperature differences between months as well as air quality. I do believe temperature will have a better analysis conducted rather than air quality because air quality changes would be better analyzed at the daily time period.
## Summary of Data Sources

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Source</th>
<th>Time Period</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle-Transit Counts</td>
<td>Counts conducted by researcher</td>
<td>July-November 2021</td>
<td>Daily/Weekday</td>
</tr>
<tr>
<td>Bicycle User Counts</td>
<td>Denver Parks and Recreation</td>
<td>July-November 2021</td>
<td>Daily/Weekday</td>
</tr>
<tr>
<td>Rail Transit Counts</td>
<td>RTD</td>
<td>January 2017-December 2019</td>
<td>Monthly</td>
</tr>
<tr>
<td>Temperature</td>
<td>Bicycle-Transit: NOAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bicycle Users: NOAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rail Transit: NOAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td>Bicycle-Transit: NOAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bicycle Users: NOAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rail Transit: NOAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Quality</td>
<td>Bicycle-Transit: IQ Air</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bicycle Users: IQ Air and Air Now</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rail Transit: US EPA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5. Data Source Summary*
Chapter Five: Methods of Data Analysis

Analyzing geographic information involves seeking patterns, relationships, and connections. Data analysis for this research will be conducted using Bivariate Regression Analysis and Multivariate Regression Analysis.

Bivariate Regression Analysis

Bivariate Regression Analysis is a statistical technique for analyzing the relationship between a dependent variable and an independent variable. For this research, a few regression analyses will be conducted. The first set of analyses will be analyzing weather. While I hypothesize the two factors, temperature and chance of precipitation are interdependent, I am interested in analyzing the variables independently to see the individual relationships. Chance of precipitation is being analyzed instead of the actual precipitation observed because theoretically bicycle-transit users, bicycle users, and rail transit users are checking the weather report prior to making the decision on the type of mode to use that day based on the chance of precipitation as it is a potential make-or-break factor. To complete this, two regression analyses will be conducted: 1) The relationship between temperature and bicycle-transit counts and 2) The relationship between chance of precipitation and bicycle-transit counts. The dependent variable will be the daily count number and the independent variable will be the temperature high or the chance of precipitation predicted in the morning.
The predicted temperature high and chance of precipitation for the day will be pulled from The National Oceanic and Atmospheric Administration (NOAA) to keep the source consistent. The results have the potential to help urban planners make future decisions on bicycle infrastructure implementation to encourage bicycle-transit use based on temperature and precipitation. (RQ2a: Is there a relationship between temperature and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?; RQ2b: Is there a relationship between precipitation and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?)

The second set of regression analyses will be conducted on the relationship between bicycle-transit counts, bicycle user counts, and rail transit users and air quality. While I understand that air quality and weather both potentially affect the choice of one of these three users, I am interested in seeing a separate analysis of all factors. The overall air quality index data will be pulled from the CDPHE. There are 18 real-time monitoring sites throughout the Denver Metro Area. The air quality index reported is the maximum air quality index for Ozone, Particulate Matter (PM) 2.5, PM10, Carbon Monoxide, Nitrogen Dioxide, and Sulfur Dioxide currently being reported by the sites. (RQ3: Is there a relationship between air quality and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage?)

**Multivariate Regression Analysis**

Multivariate Regression Analysis is a statistical technique that measures the relationship between the dependent variable and other predictor variables. Multivariate Regression Analysis can also eliminate variables it recognizes as not being statistically significant by identifying the importance of each of the predictor variables to the
relationship. For the three multivariate regression analyses, the dependent variable will be daily count. The predictor variables for the first multivariate regression analysis will be the overall air quality index, temperature, and chance of precipitation. This analysis will add to the original regression analysis to determine if there is a significant relationship amongst the group of variables not only with the individual variables. The bivariate regression analysis will provide isolated analyses; however, this is real life and multiple factors affect the choices of transit users each day so a multivariate regression analysis will provide a more accurate assessment of the relationships. 

(RQ1: Is there a relationship between weather, air quality, and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?)

The predictor variables for the second multivariate regression analysis will be weather factors, temperature and chance of precipitation. The importance of this analysis is that not everyone checks air quality so this explores the relationship between bicycle-transit users, bicycler users, and rail transit users and weather. This analysis is separate from RQ2a and RQ2b because it explores these factors together instead of separately. 

(RQ2: Is there a relationship between weather (temperature and precipitation) and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?)

A third, and final, set of multivariate regression analyses will be conducted on the seasonal employment using a dummy variable. In-session (school is in-session) will equal 1 and out-of-session (school is out-of-session) will equal 0. The dependent variable will be the daily count and the independent variables will be the dummy variable, temperature, and precipitation. Data collected between 11 July – 10 September will represent the out-of-session analysis and data collected between 13 September – 11
November will represent the in-session analysis. *(RQ4: Is there a relationship between bicycle-transit counts, weather, and seasonal employment?)*

**Interpretation of Analysis**

The interpretation of these results for the regression results will primarily be analyzed looking at the correlation matrix, the regression equation, Pearson’s Correlation Coefficient (*r*), the coefficient of determination (*r*²), test statistic, and probability value (p-value). For the multivariate regression analysis, the results will primarily be analyzed looking at *r*, *r*², p-values, and multicollinearity.

A correlation matrix is a symmetrical table that displays the correlation coefficients for the variables being analyzed. The individual cells in the correlation matrix show the correlation coefficient between the row and column variables (Burt et al. 2009). One aspect of the table is that the correlation between a variable and itself is always 1. Looking at the principal diagonal of the matrix, it will always contain the value of *r* = 1 (Burt et al. 2009). Another aspect of the matrix is that the correlation between the *x* – *variable* and *y* – *variable* is the same as the *y* – *variable* and the *x* – *variable*.

The regression equation describes how the values of a dependent variable, *y*, depend on the values of an independent variable, *x*. The regression equation has the simplistic form of *Y* = *a* + *bX*. *a* is the intercept of the regression line, where the line crosses over the *y* – *axis*, and *b* is the slope of the line, displaying the association of the dependent variable based on the change in value of the independent variable (Burt et al. 2009). The interpretation of the regression equations explains how the dependent variable varies with changes in the independent variable. It is important to understand that the intercept cannot be readily interpreted in most cases because it can only be interpreted when the
independent variable can take the value of zero and when the regression line has been fit over a range of x-values that include zero (Burt et al. 2009). For this research, the only x-values that include zero is the chance of precipitation variable, therefore the intercept can be reasonably interpreted. Zero was not observed for temperature, air quality, and school/no school therefore the intercept will not be able to be reasonably interpreted. While the intercept may not be reasonably interpreted, the value of the slope coefficient is always meaningful. The regression equation for this research will be used to draw initial interpretations based on the sign of the slope coefficient. The sign of the slope coefficient will indicate if there is a positive or negative correlation between the two variables being analyzed.

The correlation coefficient, \( r \), will always fall between \(-1\) and \(+1\) (Burt et al. 2009). If \( r = 1 \) there is a perfect positive correlation. If \( r = -1 \) there is a perfect negative correlation. If \( r = 0 \) there is almost no correlation. \( r \) is calculated using the following equation where \( X_i \) and \( Y_i \) are the observed values and \( \bar{X} \) and \( \bar{Y} \) are the mean values of the observed data:

\[
r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}
\]

The correlation coefficient will be interpreted using Table 6.
| $|r|$ | Interpretation                        |
|----|--------------------------------------|
| < 0.2 | Weak correlation, almost no relationship |
| 0.2 − 0.39 | Low correlation, definite but small relationship |
| 0.4 − 0.69 | Moderate correlation, substantial relationship |
| 0.7 − 0.89 | High correlation, strong relationship |
| 0.9 − 1.0 | Very high correlation, very dependable relationship |

Table 6. Pearson’s Correlation Coefficient ($r$) and Interpretation of $r$ (Schober et al. 2018)

The coefficient of determination, $r^2$, assesses the ability of a linear regression model to explain the outcome. The predicted value is typically different than the observed value and this called a residual (Burt et al. 2009). For each observation, there is one residual. The coefficient of determination is calculated by squaring the correlation coefficient. It indicates the relationship of the variance in the dependent variable that is explained by the independent variable. For example, if $r^2 = 0.5$ it indicates that the $x$ − variable explains 50 percent of the variance in the $y$ − variable. A higher $r^2$ value means there is a good fit and a low value means there is a poor fit.

The test statistic will be analyzed to determine if there is a significant difference between the data being analyzed. The test statistic value and significance will be calculated using Microsoft Excel and the software Statistical Package for Social Sciences (SPSS). The test statistic is analyzed against the critical value. If the test statistic value is greater than the critical value, then the null hypothesis is rejected and the test indicates statistical significance. If the test statistic value is less than the critical value then the null hypothesis fails to be rejected and the test is not statistically significant. The p-value
represents the probability of the occurrence of a given event (Burt et al. 2009). If the p-value is less than $\alpha$, the test is statistically significant and if the p-value is greater than $\alpha$, the test is not statistically significant. The confidence interval is the probability that the data being analyzed will fall between a set of values, the upper and lower bounds. Figure 1 shows the relationship between the confidence interval and hypothesis testing. The confidence interval determines the chance of potentially being incorrect. The upper and lower bounds for a 95 percent confidence interval are calculated using the following equation where $\bar{x}$ is the sample mean, $z_{0.025}$ is the critical value, $\sigma$ is the standard deviation, and $n$ is the total number of observations:

$$
\bar{x} \pm z_{0.025} \frac{\sigma}{\sqrt{n}}
$$

Recall, the hypothesis is $H_0 = \mu = 0$ and the alternate hypothesis is $H_A = \mu \neq 0$. If zero falls within the confidence interval then the hypothesis is not rejected but if zero falls outside of the confidence interval the hypothesis is rejected. A 95 percent confidence interval indicates there is a five-percent chance of being incorrect.

![Figure 1. Relationship between the Confidence Interval and Hypothesis Testing (Burt et al. 2009)](image)

Multicollinearity is when there is intercorrelation between the independent variables which means that the independent variables are moving together and not independently.
Multicollinearity will be analyzed by looking at the tolerance and the variance inflation factor (VIF) for the multivariate regression analyses. Tolerance is the amount of variability of the selected independent variables that are not explained by the other independent variables (Burt et al. 2009). VIF measures the correlation and the strength of the correlation between the independent variables (Burt et al. 2009). The higher the intercorrelation of the independent variables, the more the tolerance will approach zero (Burt et al. 2009). Multicollinearity is an issue when tolerance is < 0.10 (Burt et al. 2009). Hair et al. (2018) argue that a VIF < 10 is acceptable and will be used in this research to determine if multicollinearity is present. Multicollinearity is not required when analyzing bivariate regression analysis because the tolerance and VIF will always be 1.0 because there is only one predictor variable and therefore no collinearity to analyze as there are no remaining predictor variables.
Chapter Six: Results and Discussion

The following section contains a detailed discussion of the findings from this research. Tables 7, 8, 9, and 10 summarize the results of each research question. The rows are the statistical factors and the columns are the independent variables. Temperature is shortened to Temp, Chance of Precipitation is abbreviated as CoP, and Air Quality Index is abbreviated as AQI. The significance for the multivariate regression research questions is shown by the mode of transit. The significance for the bivariate regression research questions is shown by the independent variable. Followed by the tables, the first section is focused on Bicycle-Transit use, the second section analyzes Bicycle use, and the third section looks at Rail Transit use. Each of the research questions is addressed within each of these sections. This chapter concludes with a check of model validity for each of the models and then a discussion of the overall findings and recommendations.

<table>
<thead>
<tr>
<th></th>
<th>Bicycle-Transit</th>
<th>Bicycle Users</th>
<th>Rail Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp CoP AQI</td>
<td>Temp CoP AQI</td>
<td>Temp CoP AQI</td>
</tr>
<tr>
<td><strong>r</strong></td>
<td>0.68</td>
<td>0.86</td>
<td>0.61</td>
</tr>
<tr>
<td><strong>r^2</strong></td>
<td>0.41</td>
<td>0.72</td>
<td>0.38</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td>0.00 0.04 0.19</td>
<td>0.00 0.58 0.62</td>
<td>0.00 0.96 0.01</td>
</tr>
<tr>
<td><strong>Confidence Interval Lower Bound</strong></td>
<td>0.17 -0.21 -0.19</td>
<td>84.59 -16.11 -7.89</td>
<td>5927.17 -59099.27 -11595.18</td>
</tr>
<tr>
<td><strong>Confidence Interval Upper Bound</strong></td>
<td>0.54 -0.01 0.04</td>
<td>119.11 -8.99 4.73</td>
<td>18012.93 56063.36 -1821.64</td>
</tr>
<tr>
<td><strong>Collinearity</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 7. Research Question 1 Summary of Results

** Significant at 99% Confidence Level
* Significant at 95% Confidence Level
### Table 8. Research Question 2 Summary of Results

<table>
<thead>
<tr>
<th></th>
<th>Bicycle-Transit</th>
<th>Bicycle Users</th>
<th>Rail Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Temp</strong></td>
<td><strong>CoP</strong></td>
<td><strong>Temp</strong></td>
</tr>
<tr>
<td><strong>r</strong></td>
<td>0.66</td>
<td>0.85</td>
<td>0.47</td>
</tr>
<tr>
<td><strong>r²</strong></td>
<td>0.39</td>
<td>0.73</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Confidence Interval</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Bound</td>
<td>0.13</td>
<td>-0.22</td>
<td>-16.12</td>
</tr>
<tr>
<td>Upper Bound</td>
<td>0.45</td>
<td>-0.03</td>
<td>8.89</td>
</tr>
<tr>
<td><strong>Collinearity</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

** Significant at 99% Confidence Level  
* Significant at 95% Confidence Level

### Table 9. Research Questions 2a, 2b, & 3 Summary of Results

<table>
<thead>
<tr>
<th></th>
<th>Bicycle-Transit</th>
<th>Bicycle Users</th>
<th>Rail Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Temp</strong></td>
<td><strong>CoP</strong></td>
<td><strong>Temp</strong></td>
</tr>
<tr>
<td><strong>r</strong></td>
<td>0.54</td>
<td>0.40</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>r²</strong></td>
<td>0.27</td>
<td>0.13</td>
<td>-0.03</td>
</tr>
<tr>
<td><strong>Test Statistic (AbsValue)</strong></td>
<td>3.57 &gt; 2.74</td>
<td>2.43 &gt; 2.04</td>
<td>0.97 &gt; 2.00</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td>0.00</td>
<td>0.02</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>Confidence Interval</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Bound</td>
<td>0.13</td>
<td>-0.25</td>
<td>-0.11</td>
</tr>
<tr>
<td>Upper Bound</td>
<td>0.47</td>
<td>-0.02</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>Temp</strong></td>
<td></td>
<td></td>
<td>7.85 &gt; 1.98</td>
</tr>
<tr>
<td><strong>CoP</strong></td>
<td></td>
<td></td>
<td>0.54 &lt; 1.98</td>
</tr>
<tr>
<td><strong>AQL</strong></td>
<td></td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td><strong>AQL</strong>**</td>
<td></td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td><strong>AQL</strong></td>
<td></td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td><strong>AQL</strong>**</td>
<td></td>
<td></td>
<td>0.19</td>
</tr>
<tr>
<td><strong>Confidence Interval</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Bound</td>
<td>16.8 &gt; 1.98</td>
<td>-30.38</td>
<td>-19.23</td>
</tr>
<tr>
<td>Upper Bound</td>
<td>110.43</td>
<td>17.39</td>
<td>32.23</td>
</tr>
<tr>
<td><strong>Temp</strong></td>
<td></td>
<td></td>
<td>1656.16</td>
</tr>
<tr>
<td><strong>CoP</strong></td>
<td></td>
<td></td>
<td>42928.29</td>
</tr>
<tr>
<td><strong>AQL</strong></td>
<td></td>
<td></td>
<td>32.23</td>
</tr>
<tr>
<td><strong>AQL</strong>**</td>
<td></td>
<td></td>
<td>7852.07</td>
</tr>
</tbody>
</table>

** Significant at 99% Confidence Level  
* Significant at 95% Confidence Level
Bicycle-Transit

The first mode of transportation analyzed was bicycle-transit. Prior to analysis, a correlation matrix was generated in SPSS. This analysis showed that there was a weak correlation between temperature and bicycle-transit users. After further data analysis, it was found that the assumption that as temperatures increase the number of bicycle-transit users increases was correct but only to a certain threshold. When the temperature gets over a certain degree Fahrenheit the number of bicycle-transit users begins to decrease because it is now too hot. Due to this, further analysis was conducted after removing data points with a temperature greater than 85-degrees Fahrenheit. 85-degrees Fahrenheit was selected based on the noticeable decrease in users and the findings from the study conducted by Meng et al. in 2016 who concluded that the preferred temperature for cyclists is between 85-87-degrees Fahrenheit. Now with the data scrubbed, another correlation matrix was generated in SPSS, Figure 2.

**Table 10. Research Question 4 Summary of Results**

<table>
<thead>
<tr>
<th></th>
<th>Bicycle-Transit**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>r</strong></td>
<td>0.81</td>
</tr>
<tr>
<td><strong>r^2</strong></td>
<td>0.62</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td>0.00</td>
</tr>
<tr>
<td>Confidence Interval</td>
<td></td>
</tr>
<tr>
<td>Lower Bound</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>CoP</strong></td>
<td>-0.18</td>
</tr>
<tr>
<td><strong>Upper Bound</strong></td>
<td>0.58</td>
</tr>
<tr>
<td><strong>School vs. No School</strong></td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Collinearity</strong></td>
<td>No</td>
</tr>
<tr>
<td><strong>Confidence Interval</strong></td>
<td>5.09</td>
</tr>
<tr>
<td><strong>Confidence Interval</strong></td>
<td>13.88</td>
</tr>
</tbody>
</table>

** Significant at 99% Confidence Level
* Significant at 95% Confidence Level
Figure 2. Correlation Matrix: Bicycle-Transit and Independent Variables

Initial analysis of the correlation matrix indicates that there is a moderate positive relationship between temperature and bicycle-transit users, a moderate negative relationship between chance of precipitation and bicycle-transit users, a weak positive relationship between school vs. no school and bicycle-transit users, and almost no relationship between the air quality index and bicycle-transit users. The p-value, the Sig (2-tailed) in Figure 2, shows that temperature is statistically significant with the number of bicycle-transit users at a 99 percent confidence level, the chance of precipitation is statistically significant with the number of bicycle-transit users at a 95 percent confidence level, and not statistically significant with school vs. no school and the air quality index.

This indicates that the number of bicycle-transit users tend to increase as temperature...
increases, decreases as the chance of precipitation increases, and that there is almost no relationship with air quality index or school vs. no school.

Additional analysis shows that there is a moderate negative relationship between temperature and school vs. no school and a moderate positive relationship between temperature and the air quality index and that both are statistically significant at the 99 percent confidence level. Additionally, school vs. no school has a moderate negative relationship with the air quality index and is statistically significant at the 99 percent confidence level.

**Discussion of Research Question 1**

Linear regression analysis was run in SPSS to analyze the regression and relationship between weather (temperature and chance of precipitation), air quality index, and bicycle-transit counts. For this analysis, multivariate regression analysis was conducted with the dependent variable being the bicycle-transit counts and the three independent variables were air quality index, temperature, and chance of precipitation.

The Stepwise method was run in SPSS to analyze the model. The Stepwise method evaluates each independent variable’s relative contribution to the model. The variable that makes an insignificant contribution to the model is eliminated. Figure 3 shows the variables included in the model. The first model ran just the temperature variable and the second model ran both the temperature and chance of precipitation variables. Figure 4 shows that the air quality index variable was not included in either model confirming the initial analysis of the correlation matrix that it is not significant.
Since the model finds that there is no statistical relationship between the number of bicycle-transit users and air quality index, the model fails to reject the null hypothesis at a confidence level of 95 percent.

**Discussion of Research Question 2**

Linear regression analysis was run in SPSS to analyze the regression and relationship between weather (temperature and chance of precipitation) and bicycle-transit users. For this analysis, the dependent variable was the bicycle-transit counts and the two independent variables were the temperature and chance of precipitation.
**Multivariate Regression Equation**

The multivariate regression equation is $y = 0.289x_1 - 0.127x_2 + 7.849$. In this case, there are two slopes. The slope of $x_1$ indicates that the number of bicycle-transit users increases by 0.289 per degree Fahrenheit increase in temperature. The slope of $x_2$ indicates that the number of bicycle-transit users decreases by 0.127 per percent chance increase in precipitation. The intercept indicates if the value of $x$ is zero for both independent variables, it can be expected for the number of bicycle-transit users to equal 7.849. Zero was not observed for the temperature variable therefore this information is being extrapolated because the number of expected bicycle-transit users is being predicted for a value of temperature that is beyond the range of the observed data. Based on the hypothesis, a positive slope was expected for temperature because theory suggests the relationship between temperature and the number of bicycle-transit users is positive and a negative slope was expected for chance of precipitation because theory suggests that the relationship between chance of precipitation and the number of bicycle-transit users is negative.

**Correlation of Determination ($r^2$)**

The coefficient of determination, $r^2$, is 0.391, Figure 5. The value indicates that the independent variables explain approximately 40 percent of the variance in the number of bicycle users. An $r^2$ value of 0.391 is a low-moderate coefficient of determination indicating that this model has a moderate fit and a moderate association.
Significance Testing and Analysis

The correlation coefficient, $r$, is 0.655, indicating a moderate-high correlation, Figure 5. This model indicates that both variables are statistically significant. This is shown in four ways: 1) The correlation coefficient indicates a moderate-high correlation, Figure 5, 2) The $p$-value for the temperature variable is <0.001 and the chance of precipitation variable is 0.011 indicating that both are significant because the $p$-value is less than $\alpha$, 0.05, Figure 6, 3) Zero falls outside of the confidence intervals for both variables, again, indicating that it is statistically significant, Figure 6, and 4) Looking at the multicollinearity, Figure 6, the tolerance is greater than 0.10 and the VIF factors are all well under 10 indicating that multicollinearity is not an issue and adding to the significance of the model. The model has found a statistical relationship between the number of bicycle-transit users and weather and therefore the null hypothesis is rejected at a confidence level of 95 percent.
Discussion of Research Question 2a

Bivariate Regression Equation

The bivariate regression equation is $y = 0.011x + 24.97$. The slope indicates that for every degree increase in temperature, the expected number of bicycle-transit users increases by 0.011. Zero is not the smallest value of temperature observed therefore this information is being extrapolated because the number of expected bicycle-transit users is being predicted for a value of temperature that is beyond the range of the observed data. Based on the hypothesis, a positive slope was expected because theory suggests that the relationship between temperature and bicycle-transit users is positive.

Correlation of Determination ($r^2$)

The coefficient of determination, $r^2$, is 0.268, Figure 7. The value indicates that the temperature variable explains approximately 27 percent of the variance in the number of bicycle-transit users. An $r^2$ value of 0.268 is a low coefficient of determination indicating that this model has a poor fit and a low association.

![Model Summary: Temperature vs. Bicycle-Transit Counts](Figure 7. Model Summary - Temperature vs. Bicycle-Transit Counts)

Significance Testing and Analysis

The correlation coefficient, $r$, is 0.539, indicating a moderate correlation, Figure 7. This model indicates that there is statistical significance with the temperature variable. The statistical significance for the temperature variable is shown in four ways: 1) The
correlation coefficient is 0.539 indicating a moderate positive relationship, Figure 7, 2) The p-value is 0.001 which is less than \( \alpha \), 0.05, indicating a statistical relationship, Figure 8, 3) Zero does not fall between the confidence intervals indicating a statistical relationship, Figure 8, and 4) Looking at the test statistic and the critical value, this method also shows that the model is statistically significant.

![Figure 8. Model Coefficients - Temperature vs. Bicycle-Transit Counts](image)

The test statistic is 3.57 and the critical values associated with degrees of freedom of 33 at a confidence level of 0.05 is 2.74, \(|3.57| > 2.74\), therefore, the null hypothesis is rejected at a significance level of \( \alpha = 0.05 \). Table 11 summarizes these calculations. The model has found a statistical relationship between the number of bicycle-transit users and temperature and therefore the null hypothesis is rejected at a confidence level of 95 percent.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Means</th>
<th>99% Bounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H_0: \mu = 0 )</td>
<td>( \bar{x} ) = 69.76</td>
<td>( \bar{y} ) = 25.94</td>
</tr>
<tr>
<td>( H_1: \mu \neq 0 )</td>
<td>( \bar{x} ) = 69.76</td>
<td>( \bar{y} ) = 25.94</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STD</th>
<th>Calculated Values</th>
<th>Critical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} ) = 12.09</td>
<td>( r ) = 0.54</td>
<td>2.74</td>
</tr>
<tr>
<td>( \bar{y} ) = 6.72</td>
<td>( t ) = 3.57</td>
<td>0.00</td>
</tr>
</tbody>
</table>

\( \rho \) associated with \( t \) 0.00

\( 99\% \) Bounds 0.128 0.471

Table 11. Test Statistic Calculations for Temperature vs. Bicycle-Transit Counts
Discussion of Research Question 2b

Bivariate Regression Equation

The bivariate regression equation is \( y = 46.667 - 1.174x \). The slope indicates that for every percent chance increase in precipitation, the expected number of bicycle-transit users decreases by approximately one. Based on the hypothesis, a negative slope was expected because theory suggests that the relationship between the chance of precipitation and bicycle-transit users is negative.

Correlation of Determination (\( r^2 \))

The coefficient of determination, \( r^2 \), is 0.133, Figure 9. The value indicates that the chance of precipitation variable explains approximately 13 percent of the variance in the number of bicycle-transit users. An \( r^2 \) value of 0.133 is a low coefficient of determination indicating that this model has a poor fit and a low association.

Significance Testing and Analysis

The correlation coefficient, \( r \), is 0.400, indicating a moderate positive correlation, Figure 9. This model indicates that there is a statistical significance with the chance of precipitation variable and bicycle-transit users. The statistical significance for the variable is shown in four ways: 1) The correlation coefficient is 0.400 indicating a moderate positive correlation, Figure 9, 2) The p-value is 0.021 which is less than \( \alpha \),
0.05, indicating a statistical relationship, Figure 10, 3) Zero does not fall between the confidence intervals indicating a statistical relationship, Figure 10, and 4) Looking at the test statistic and the critical value, this method also shows that the model is statistically significant.

The test statistic is 2.43 and the critical values associated with degrees of freedom of 33 at a confidence level of 0.05 is 2.04. $|2.43| > 2.04$, therefore, the model rejects the null hypothesis at a significance level of $\alpha = 0.05$. Table 12 summarizes these calculations. The model has found a statistical relationship between the number of bicycle-transit users and chance of precipitation and therefore the null hypothesis is rejected at a confidence level of 95 percent.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Means</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_0$: $\mu = 0$</td>
<td>$x: 25.94$</td>
<td>$y: 16.21$</td>
</tr>
<tr>
<td>$H_A$: $\mu \neq 0$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Calculated Values</strong></td>
<td><strong>95% Bounds</strong></td>
<td></td>
</tr>
<tr>
<td>$r$</td>
<td>$-0.19$</td>
<td>n: 33</td>
</tr>
<tr>
<td>$t$</td>
<td>-2.16</td>
<td></td>
</tr>
<tr>
<td>$p$ associated with t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>$0.02$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12. Test Statistic Calculations for Chance of Precipitation vs. Bicycle-Transit Counts
Discussion of Research Question 3

The correlation matrix, Figure 2, indicated that there is no statistical relationship between the air quality index and the number of bicycle-transit users. The model was run in SPSS and confirmed that there is no relationship. The statistical insignificance for the air quality index variable is shown in three ways: 1) The p-value is greater than \( \alpha \), 2) Zero falls between the confidence intervals, and 3) The test statistic is greater than the critical value. The model fails to find a statistical relationship between the number of bicycle-transit users and the air quality index variable and therefore fails to reject the null hypothesis at a confidence level of 95 percent.

Discussion of Research Question 4

Multivariate Regression Equation

The multivariate regression equation is \( y = 0.440x_1 - 0.105x_2 + 9.485x_3 - 10.803 \). In this case, there are three slopes. The slope of \( x_1 \) indicates that the number of bicycle-transit users increases by 0.440 per degree Fahrenheit increase in temperature. The slope of \( x_2 \) indicates that the number of bicycle-transit users decreases by 0.105 per percent chance increase in precipitation and the slope of \( x_3 \) indicates that the number of bicycle-transit users increases by 9.485 if school is in-session. The intercept indicates if the value of \( x \) is zero for all three independent variables, it can be expected for the number of bicycle-transit users to equal -10.803. Zero was not observed for the temperature variable therefore this information is being extrapolated because the number of expected bicycle-transit users is being predicted for a value of temperature that is beyond the range of the observed data. Based on the hypothesis, a positive slope was
expected for temperature and school vs. no school variables because theory suggests the relationship between these variables and the number of bicycle-transit users is positive and a negative slope was expected for chance of precipitation because theory suggests that the relationship between chance of precipitation and the number of bicycle-transit users is negative.

**Correlation of Determination ($r^2$)**

The coefficient of determination, $r^2$, is 0.623, Figure 11. The value indicates that the weather and seasonal employment variables explain approximately 62 percent of the variance in the number of bicycle-transit users. An $r^2$ value of 0.623 is a moderate-high coefficient of determination indicating that this model has a moderately-high fit and a strong association.

![Model Summary](image)

**Significance Testing and Analysis**

The correlation coefficient, $r$, is 0.811, indicating a high correlation, Figure 11. This indicates that there is a positive relationship between the independent variables, weather and school vs. no school, because the correlation coefficient increased from 0.655 (RQ2: Bicycle-Transit Users) to 0.811. This model indicates there is a statistical significance between the variables.
As seen in the correlation matrix and now the coefficients table, Figure 12, the temperature and chance of precipitation variables are significant and while the school vs. no school variable is not highly correlated with the dependent variable, it is statistically significant in the model. This significance is shown in four ways: 1) The correlation coefficient is 0.811 indicating a high correlation, Figure 11, 2) The p-value for temperature is <0.001, 0.009 for precipitation, and <0.001 for school vs. no school, all of which are less than \( \alpha \), 0.05, indicating that these variables are statistically significant, Figure 12, 3) Zero does not fall within the confidence intervals of each of the variables, Figure 12, and 4) Looking at the multicollinearity, Figure 12, the tolerance is greater than 0.10 and the VIF factors are all well under 10 indicating that multicollinearity is not an issue and adding to the significance of the model. The model has found a statistical relationship between the number of bicycle-transit users, school vs. no school, and weather and therefore the null hypothesis is rejected at a confidence level of 95 percent.

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig</th>
<th>95% Confidence Interval for ( B )</th>
<th>Correlations</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td>Tolerance</td>
</tr>
<tr>
<td>1</td>
<td>(Constant) -10.803</td>
<td>6.065</td>
<td>-1.781</td>
<td>.085</td>
<td>-23.207</td>
<td>1.601</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature .440</td>
<td>.069</td>
<td>.791</td>
<td>6.333</td>
<td>&lt;0.001</td>
<td>.289</td>
<td>.592</td>
</tr>
<tr>
<td></td>
<td>Precipitation -1.05</td>
<td>.037</td>
<td>-.307</td>
<td>2.787</td>
<td>.009</td>
<td>-.181</td>
<td>-.028</td>
</tr>
<tr>
<td></td>
<td>Bicycle Usage 9.485</td>
<td>.149</td>
<td>-.553</td>
<td>4.413</td>
<td>&lt;0.001</td>
<td>5.099</td>
<td>13.891</td>
</tr>
</tbody>
</table>

*Dependent Variable: Bicycle-Transit Count

![Figure 12. Model Coefficients - Weather and Seasonal Employment vs. Bicycle-Transit Users](image)

**Bicycle Usage**

The second mode of transportation analyzed was bicycle usage along the Cherry Creek and South Platte trails. Prior to analysis, a correlation matrix was generated in SPSS, Figure 13.
Initial analysis of the correlation matrix indicates that there is a high positive relationship between temperature and bicycle users, almost no relationship between chance of precipitation and bicycle users, and a moderate positive relationship between the air quality index and bicycle users. The p-value, the Sig (2-tailed) in Figure 13, shows that temperature and air quality index are statistically significant with the number of bicycle users at a 99 percent confidence level and not statistically significant with chance of precipitation. This indicates that the number of bicycle users tend to increase as temperature increases, increase as the air quality index increases, and that there is almost no relationship with chance of precipitation.

Additional analysis shows that there is a high positive relationship between temperature and the air quality index and that it is statistically significant at the 99 percent confidence level. This is why the opposite relationship between the air quality index variable and the number of bicycle users is indicated by the correlation matrix. It
was expected that as the air quality index increases, the number of bicycle users would decrease however the opposite is indicated in the correlation matrix which may signify collinearity between the temperature and air quality index variable.

**Discussion of Research Question 1**

Linear regression analysis was run in SPSS to analyze the regression and relationship between weather (temperature and chance of precipitation), air quality index, and bicycle user counts. For this analysis, multivariate regression analysis was conducted with the dependent variable being the bicycle user counts and the three independent variables were air quality index, temperature, and chance of precipitation.

The Stepwise method was run in SPSS to analyze the model. Figure 14 shows the variables included in the model. The model ran just the temperature variable. Figure 15 shows that the chance of precipitation and air quality index variable were not included in the model indicating that neither are statistically significant in this model. Although the air quality index variable showed a moderate correlation with the number of bicycle users, in the overall model it is excluded due to its collinearity with the temperature variable. The temperature and air quality index variables show a greater correlation with each other than the air quality index shows with the number of bicycle users which is why the program removed it from the model.
Since the model finds that there is no statistical relationship between the number of bicycle users and two of the independent variables, the model fails to reject the null hypothesis at a confidence level of 95 percent.

**Discussion of Research Question 2**

Linear regression analysis was run in SPSS to analyze the regression and relationship between weather (temperature and chance of precipitation) and bicycle users. For this analysis, the dependent variable was the bicycle counts and the two independent variables were the temperature and chance of precipitation.

**Multivariate Regression Equation**

The multivariate regression equation is \( y = 98.683x_1 - 3.616x_2 - 2359.956 \). In this case, there are two slopes because there are two independent variables. The slope of
\( x_1 \) indicates that the number of bicycle users increases by 98.683 per degree Fahrenheit increase in temperature. The slope of \( x_2 \) indicates that the number of bicycle users decreases by 3.616 per percent chance increase in precipitation. The intercept indicates if the value of \( x \) is zero for both independent variables, it can be expected for the number of bicycle users to equal 2359.956. Zero was not observed for the temperature variable therefore this information is being extrapolated because the number of expected bicycle users is being predicted for a value of temperature that is beyond the range of the observed data. Based on the hypothesis, a positive slope was expected for temperature because theory suggests the relationship between temperature and the number of bicycle users is positive and a negative slope was expected for chance of precipitation because theory suggests that the relationship between chance of precipitation and the number of bicycle users is negative.

**Correlation of Determination (\( r^2 \))**

The coefficient of determination, \( r^2 \), is 0.725, Figure 16. The value indicates that the independent variables explain approximately 73 percent of the variance in the number of bicycle users. An \( r^2 \) value of 0.725 is a high coefficient of determination indicating that this model has a good fit and a strong association.

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>R Square Change</th>
<th>( F ) Change</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.854*</td>
<td>.730</td>
<td>.725</td>
<td>923.410</td>
<td>.730</td>
<td>140.385</td>
<td>2</td>
<td>104</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*Predictors: (Constant), Precipitation, Temperature

*Figure 16. Model Summary - Weather vs. Bicycle User Counts*
Significance Testing and Analysis

The correlation coefficient, \( r \), is 0.854, indicating a high correlation, Figure 16. This model indicates that there is a statistical significance with the temperature variable and no statistical significance with the chance of precipitation variable. Although there is a high correlation, the model is not statistically significant because the chance of the precipitation variable is not statistically significant. The statistical insignificance for the chance of precipitation variable is shown in two ways: 1) The p-value is 0.567 which is greater than \( \alpha \), 0.05, indicating no statistical relationship, Figure 17, and 2) Zero falls between the confidence intervals indicating no statistical relationship, Figure 17. As shown in Figure 17, the temperature variable is statistically significant. The statistical significance of the temperature variable and bicycle users is further analyzed in Research Question 2a: Bicycle Users. The model fails to find a statistical relationship between the number of bicycle users and weather and therefore fails to reject the null hypothesis at a confidence level of 95 percent.

### Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>Beta</th>
<th>t</th>
<th>Sig.</th>
<th>95% Confidence Interval for ( \beta )</th>
<th>Correlations</th>
<th>Collinearity Statistics</th>
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</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td>Partial</td>
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<tr>
<td></td>
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<td></td>
<td>476.161</td>
<td>-4.405</td>
<td>&lt;0.001</td>
<td>-506.167</td>
<td>-111.745</td>
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<td></td>
<td>Temperature</td>
<td></td>
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<td>0.853</td>
<td>16.724</td>
<td>&lt;0.001</td>
<td>88.982</td>
<td>110.384</td>
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<td></td>
<td>Precipitation</td>
<td></td>
<td>6.304</td>
<td>-0.029</td>
<td>-2.574</td>
<td>0.012</td>
<td>-16.117</td>
<td>8.885</td>
</tr>
</tbody>
</table>

a. Dependent Variable: CC & BP Bicycle Total

Discussion of Research Question 2a

**Bivariate Regression Equation**

The bivariate regression equation is \( y = 98.78x - 2400.8 \). The slope indicates that for every degree increase in temperature, the expected number of bicycle users increases
by almost 99. Zero is not the smallest value of temperature observed therefore this information is being extrapolated because the number of expected bicycle users is being predicted for a value of temperature that is beyond the range of the observed data. Based on the hypothesis, a positive slope was expected because theory suggests that the relationship between temperature and bicycle users is positive.

**Correlation of Determination ($r^2$)**

The coefficient of determination, $r^2$, is 0.726, Figure 18. The value indicates that the temperature variable explains approximately 73 percent of the variance in the number of bicycle users. An $r^2$ value of 0.726 is a high coefficient of determination indicating that this model has a good fit and a strong association.

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std Error of the Estimate</th>
<th>R Square Change</th>
<th>F Change</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>.854</td>
<td>.729</td>
<td>.726</td>
<td>.920</td>
<td>.729</td>
<td>282.245</td>
<td>1</td>
<td>105</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

*a. Predictors: (Constant), Temperature

*Figure 18. Model Summary - Temperature vs. Bicycle User Counts*

**Significance Testing and Analysis**

The correlation coefficient, $r$, is 0.854, indicating a high positive correlation, Figure 18. This model indicates that there is a statistical significance with the temperature variable and the number of cyclists. The statistical significance for the temperature variable is shown in four ways: 1) The correlation coefficient is 0.854 indicating a high positive relationship, Figure 18, 2) The p-value is <0.001 which is less than $\alpha$, 0.05, indicating a statistical relationship, Figure 19, 3) Zero does not fall between the confidence intervals indicating a statistical relationship, Figure 19 and 4) Looking at the
test statistic and the critical value, this method also shows that this model is statistically significant.

![Figure 19. Model Coefficients - Temperature vs. Bicycle User Counts](image)

The test statistic is 16.8 and the critical value associated with degrees of freedom of 107 at a confidence level of 0.05 is 1.98. $|16.8| > 1.98$, therefore, the null hypothesis is rejected at a significance level of $\alpha = 0.05$. Table 13 summarizes these calculations. The model has found a statistical relationship between the number of bicycle users and temperature and therefore the null hypothesis is rejected at a confidence level of 95 percent.

![Table 13. Test Statistic Calculations for Temperature vs. Bicycle Users Count](image)


**Discussion of Research Question 2b**

The correlation matrix, Figure 13, indicated that there is no statistical relationship between the chance of precipitation and the number of bicycle users. The model was run in SPSS and confirmed that there is no relationship. The statistical insignificance for the chance of precipitation variable is shown in three ways: 1) The p-value is greater than $\alpha$, 2) Zero falls between the confidence intervals, and 3) The test statistic is greater than the critical value. The model fails to find a statistical relationship between the number of bicycle users and the chance of precipitation variable and therefore fails to reject the null hypothesis at a confidence level of 95 percent.

**Discussion of Research Question 3**

**Bivariate Regression Equation**

The bivariate regression equation is $y = 25.73x + 3207.7$. The slope indicates that for every unit increase in the air quality index, the expected number of bicycle users increases by 25.73. Zero is not the smallest value of the air quality index observed therefore this information is being extrapolated because the number of expected cyclists is being predicted for a value of the air quality index that is beyond the range of the observed data. Based on the hypothesis, a negative slope was expected because theory suggests that the relationship between air quality index and bicycle users is negative. The outcome of this regression equation can be explained by the fact that the air quality index and temperature have a high correlation (as temperature increases, the air quality index increases) and temperature and bicycle user counts are highly correlated (as temperature
increases, bicycle user counts increase). This suggests that the temperature affects a cyclist’s decision more than the air quality index.

**Correlation of Determination ($r^2$)**

The coefficient of determination, $r^2$, is 0.364, Figure 20. The value indicates that the air quality index variable explains approximately 36 percent of the variance in the number of bicycle users. An $r^2$ value of 0.364 is a low-moderate coefficient of determination indicating that this model has a low-moderate fit and a low-moderate association.

![Model Summary](image)

**Significance Testing and Analysis**

The correlation coefficient, $r$, is 0.608, indicating a moderate correlation, Figure 20. This model indicates that the air quality index variable and the number of cyclists is statistically significant. The statistical significance for the air quality index variable is shown in four ways: 1) The correlation coefficient is 0.608 indicating a moderate correlation, Figure 20, 2) The p-value is <0.001 which is less than $\alpha$, 0.05, indicating a statistical relationship, Figure 21, 3) Zero does not fall between the confidence intervals indicating a statistical relationship, Figure 21, and 4) Looking at the test statistic and the critical value, this method also shows that the model is statistically significant.

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The test statistic is 7.85 and the critical value associated with degrees of freedom of 107 at a confidence level of 0.05 is 1.98. $|7.85| > 1.98$, therefore, the null hypothesis is rejected at a significance level of $\alpha = 0.05$. Table 14 summarizes these calculations. The model has found a statistical relationship between the number of cyclists and the air quality index variable and therefore the null hypothesis is rejected at a confidence level of 95 percent.

![Table 14. Test Statistic Calculations for Air Quality Index vs. Bicycle Users Count](image)

### Rail Transit Usage

The third mode of transportation analyzed was light rail transit usage. Prior to analysis, a correlation matrix was generated in SPSS, Figure 22.
Initial analysis of the correlation matrix indicates that there is a moderate positive relationship between temperature and rail transit users, a weak positive relationship between chance of precipitation and rail transit users, and a low positive relationship between the air quality index and rail transit users. This indicates that the number of rail transit users tend to increase when the temperature increases, increases as the air quality index increases, and increases as the chance of precipitation increases. The p-value, the Sig (2-tailed) in Figure 22, shows that temperature is statistically significant with the number of rail transit users at a 99 percent confidence level and not statistically significant with chance of precipitation or the air quality index variables. This analysis indicates that chance of precipitation and the air quality index variables are not significant on the number of rail transit users. The correlation matrix also indicates a high correlation between temperature and air quality index at the 99 percent confidence level.
The final analyses drawn from this correlation matrix is that the other independent variables do not have any significant correlation to each other.

**Discussion of Research Question 1**

Linear regression analysis was run in SPSS to analyze the regression and relationship between weather (temperature and chance of precipitation), air quality index, and rail transit user counts. For this analysis, multivariate regression analysis was conducted with the dependent variable being the rail transit user counts and the three independent variables were air quality index, temperature and chance of precipitation.

The Stepwise method was run in SPSS to analyze the model. Figure 23 shows the variables included in the model. The first model ran just the temperature variable and the second model ran both the temperature and air quality index variables. Figure 24 shows that the chance of precipitation variable was not included in either model confirming the initial analysis of the correlation matrix that it is not significant.

<table>
<thead>
<tr>
<th>Variables Entered/Removed&lt;sup&gt;a&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>Model</td>
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<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

<sup>a</sup> Dependent Variable: Rail-Transit Count

*Figure 23. Variables Entered/Removed*
It appears that there is collinearity between the air quality index and temperature variables as the VIF is approaching five. While 10 is the red flag for collinearity, as the VIF approaches or surpasses five, it does show cause for concern (Burt et al. 2009). Since the model finds that there is no statistical relationship between the number of rail transit users and chance of precipitation, the model fails to reject the null hypothesis at a confidence level of 95 percent.

**Discussion of Research Question 2**

The correlation matrix, Figure 22, indicated that there is no statistical relationship between the chance of precipitation and the number of rail transit users. The model was run in SPSS and confirmed that there is no relationship. The statistical insignificance for the chance of precipitation variable is shown in three ways: 1) The p-value is greater than $\alpha$, 2) Zero falls between the confidence intervals, and 3) The test statistic is greater than the critical value. The model fails to find a statistical relationship between the number of rail transit users and the chance of precipitation variable and therefore fails to reject the null hypothesis at a confidence level of 95 percent. The model did find a statistically significant relationship between the number of rail transit users and temperature. The
relationship between temperature and rail transit users is explored in Regression Analysis and Discussion of Research Question 2a: Temperature.

**Discussion of Research Question 2a**

**Bivariate Regression Equation**

The bivariate regression equation is $y = 4754.1x + 0.00002$. The slope indicates that for every degree increase in temperature, the expected number of rail transit users increases by about 4754. Zero is not the smallest value of temperature observed therefore this information is being extrapolated because the number of expected cyclists is being predicted for a value of temperature that is beyond the range of the observed data. Based on the hypothesis, a positive slope was expected because theory suggests that the relationship between temperature and rail transit users is positive.

**Correlation of Determination ($r^2$)**

The coefficient of determination, $r^2$, is 0.200, Figure 25. The value indicates that the temperature variable explains approximately 20 percent of the variance in the number of rail transit users. An $r^2$ value of 0.200 is a low coefficient of determination indicating that this model has a poor fit and a low association.

**Significance Testing and Analysis**

The correlation coefficient, $r$, is 0.472, indicating a moderate correlation, Figure 25. This model indicates that there is a statistical significance with the temperature variable.
and rail transit users. The statistical significance for the temperature variable is shown in four ways: 1) The correlation coefficient is 0.472 indicating a moderate positive correlation, Figure 25, 2) The p-value is 0.004 which is less than $\alpha$, 0.05, indicating a statistical relationship, Figure 26, 3) Zero does not fall between the confidence intervals indicating a statistical relationship, Figure 26, and 4) Looking at the test statistic and the critical value, this method also shows that the model is significant.

The test statistic is 3.12 and the critical value associated with degrees of freedom of 36 at a confidence level of 0.05 is 2.03. $|3.12| > 2.03$, therefore, the null hypothesis is rejected at a significance level of $\alpha = 0.05$. Table 15 summarizes these calculations. The model has found a statistical relationship between the number of rail transit users and temperature and therefore the null hypothesis is rejected at a confidence level of 95 percent.

---

**Figure 26. Model Coefficients - Temperature vs. Rail Transit Counts**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig</th>
<th>95% Confidence Interval for $B$</th>
<th>Zero-order</th>
<th>Correlations</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>1891872.701</td>
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<td>22.265</td>
<td>&lt;.001</td>
<td>1684717.425</td>
<td>1999017.977</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Temperature</td>
<td>4756.114</td>
<td>1524.400</td>
<td>3.119</td>
<td>.004</td>
<td>1856.161</td>
<td>7852.968</td>
<td>0.472</td>
<td>0.472</td>
</tr>
</tbody>
</table>

*a Dependent Variable Rail Transit Count*
Table 15. Test Statistic Calculations for Temperature vs. Rail Transit Users

Discussion of Research Question 2b

The correlation matrix, Figure 13, indicated that there is no statistical relationship between the chance of precipitation and the number of rail transit users. The model was run in SPSS and confirmed that there is no relationship. The statistical insignificance for the chance of precipitation variable is shown in three ways: 1) The p-value is greater than $\alpha$, 2) Zero falls between the confidence intervals, and 3) The test statistic is greater than the critical value. The model fails to find a statistical relationship between the number of rail transit users and the chance of precipitation variable and therefore fails to reject the null hypothesis at a confidence level of 95 percent.

Discussion of Research Question 3

The correlation matrix, Figure 22, indicated that there is no statistical relationship between the air quality index and the number of rail transit users. The model was run in SPSS and confirmed that there is no relationship. Although, the air quality index was included in the model for Research Question 1: Rail Transit Users, on its own it does not
have a statistical significance. The statistical insignificance for the air quality index variable is shown in three ways: 1) The p-value is greater than \( \alpha \), 2) Zero falls between the confidence intervals, and 3) The test statistic is greater than the critical value. The model fails to find a statistical relationship between the number of rail transit users and the air quality index variable and therefore fails to reject the null hypothesis at a confidence level of 95 percent.
Summary of Findings

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Statistically Significant?</th>
<th>Why/How?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RQ1</strong>: Is there a relationship between weather, air quality, and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle-Transit</td>
<td>1. No</td>
<td>$\propto &lt; p$ (Air Quality), multicollinearity</td>
</tr>
<tr>
<td>Bicycle Usage</td>
<td>2. No</td>
<td>$\propto &lt; p$ (Air Quality &amp; Chance of Precipitation), multicollinearity</td>
</tr>
<tr>
<td>Rail Transit Usage</td>
<td>3. No</td>
<td>$\propto &lt; p$ (Chance of Precipitation), multicollinearity</td>
</tr>
<tr>
<td><strong>RQ2</strong>: Is there a relationship between weather (temperature and precipitation) and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?</td>
<td></td>
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<tr>
<td>Bicycle-Transit</td>
<td>1. Yes*</td>
<td>$\propto &gt; p$, confidence intervals, no multicollinearity</td>
</tr>
<tr>
<td>Bicycle Usage</td>
<td>2. No</td>
<td>$\propto &lt; p$ (Chance of Precipitation)</td>
</tr>
<tr>
<td>Rail Transit Usage</td>
<td>3. No</td>
<td>$\propto &lt; p$ (Chance of Precipitation)</td>
</tr>
<tr>
<td><strong>RQ2a</strong>: Is there a relationship between temperature and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle-Transit</td>
<td>1. Yes**</td>
<td>$\propto &gt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td>Bicycle Usage</td>
<td>2. Yes**</td>
<td>$\propto &gt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td>Rail Transit Usage</td>
<td>3. Yes**</td>
<td>$\propto &gt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td><strong>RQ2b</strong>: Is there a relationship between chance of precipitation and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage in Denver?</td>
<td></td>
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</tr>
<tr>
<td>Bicycle-Transit</td>
<td>1. Yes*</td>
<td>$\propto &gt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td>Bicycle Usage</td>
<td>2. No</td>
<td>$\propto &lt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td>Rail Transit Usage</td>
<td>3. No</td>
<td>$\propto &lt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td><strong>RQ3</strong>: Is there a relationship between air quality and 1) bicycle-transit usage, 2) bicycle usage, and 3) rail transit usage?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle-Transit</td>
<td>1. No</td>
<td>$\propto &lt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td>Bicycle Usage</td>
<td>2. Yes**</td>
<td>$\propto &gt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td>Rail Transit Usage</td>
<td>3. No</td>
<td>$\propto &lt; p$, confidence intervals, test statistic</td>
</tr>
<tr>
<td><strong>RQ4</strong>: Is there a relationship between bicycle-transit counts, weather, and seasonal employment?</td>
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<td></td>
</tr>
<tr>
<td>Bicycle-Transit</td>
<td>Yes**</td>
<td>$\propto &gt; p$, confidence intervals, no multicollinearity</td>
</tr>
</tbody>
</table>

Table 16. Summary of Findings

** Significant at 99% Confidence Level
* Significant at 95% Confidence Level
Model Validity

The residual plots can be used to check for the validity of a linear model. If a residual plot looks like a pattern of points instead of a scattering of points, then the model is considered to be suspicious for the validity of the linear model (Burt et al. 2009). The validity of each model is analyzed below based on Figure 27. Only models that showed a statistical significance will be checked for validity.

Bicycle-Transit Model Validity

Model Validity for Research Question 2

The shape of this residual plot aligns with Figure 27a and indicates the assumptions of the linear regression hold, Figure 28. This means that the residuals have a similar or equal variance compared to the predicted y-values and validates the model.
Model Validity for Research Question 2a

The shape of this residual plot aligns with Figure 27a and indicates the assumptions of the linear regression hold, Figure 29. This means that the residuals have a similar or equal variance compared to the predicted y-values and validates the model.
**Model Validity for Research Question 2b**

The shape of this residual plot aligns with Figure 27a and indicates the assumptions of the linear regression hold, Figure 30. This means that the residuals have a similar or equal variance compared to the predicted y-values and validates the model.

![Figure 30. RQ2b: Bicycle-Transit Users Residual Plot](image)

**Model Validity for Research Question 4**

The shape of this residual plot aligns with Figure 27a and indicates the assumptions of the linear regression hold, Figure 31. This means that the residuals have a similar or equal variance compared to the predicted y-values and validates the model.
Bicycle Users Model Validity

Model Validity for Research Question 2a

The shape of this residual plot aligns Figure 27c which indicates that the wrong functional form was used, Figure 32. This means that the positive residuals have moderate values of the predicted y-values and negative residuals for high and low values of predicted y-values (Burt et al. 2009).
The scatterplot for this data, shows that there is a decrease in the number of cyclists as the temperature increases. This was the same idea explored with bicycle-transit users and temperature. This shows that there is a linear relationship to a certain threshold but then that linearity is disrupted. After removing the data points with temperatures greater than 85, the correlation coefficient increases to \( r = 0.90 \), the t-statistic becomes even greater than the critical value, and the p-value remains less than alpha. Additionally, the new residual plot, shown in Figure 33 aligns with Figure 27a. This means that after removing the points greater than 85-degrees Fahrenheit, the positive residuals now have moderate values of the predicted y-values and negative residuals for high and low values of predicted y-values (Burt et al. 2009).
Another way to analyze model validity is to use the same model with a different set of data. The validity of this model was also tested using bicycle counts along the Butler Trail in Austin, Texas. This model was found to also be statistically significant at the 99 percent confidence level and valid. Table 17 shows that the model is statistically significant in Austin based on the correlation coefficient, p-value, the confidence interval, and the test statistic. Figure 34 shows that the shape of this residual plot aligns with Figure 27a indicating that the model is valid.
Hypothesis

\[ H_0: \mu = 0 \]
\[ H_A: \mu \neq 0 \]

Means

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STD

<table>
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Critical Value 2.05

95% Bounds

<p>| | |</p>
<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>30</td>
</tr>
</tbody>
</table>

52.59 86.27

Table 17. Test Statistic Calculations Temperature vs. Bicycle User Counts in Austin, Texas

Figure 34. Austin Bicycle Users & Temperature Residual Plot

Model Validity for Research Question 3

The shape of this residual plot aligns with Figure 27c which indicates that the wrong functional form was used, Figure 35. This means that the positive residuals have moderate values of the predicted y-values and negative residuals for high and low values of predicted y-values (Burt et al. 2009).
Due to the moderate correlation between temperature and the air quality index, $r = 0.73$, the air quality index for the days where the temperature was greater than 85-degrees Fahrenheit were removed based on the temperature threshold determined previously.

Figure 36 shows that by doing so the residual plot reflects Figure 27a, however, it does appear there could be room for improvement in the model.
Another way to analyze model validity is to use the same model with a different set of data. The validity of this model was also tested using bicycle counts along the Butler Trail in Austin, Texas. This model was found to also be statistically significant at the 99 percent confidence level and valid. Table 18 shows that the model is statistically significant in Austin based on the correlation coefficient, p-value, the confidence interval, and the test statistic. Figure 37 shows that the shape of this residual plot aligns with Figure 27a indicating that the model is valid.
Table 18. Test Statistic Calculations Air Quality Index vs. Bicycle User Counts in Austin, Texas

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Means</th>
<th>STD</th>
<th>99% Bounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_0: \mu = 0$</td>
<td>$x$</td>
<td>34.40</td>
<td>$\sum_{i=1}^{n} (y_i - \bar{y})(y_i - \bar{y})$</td>
</tr>
<tr>
<td>$H_A: \mu \neq 0$</td>
<td>$y$</td>
<td>1478.13</td>
<td>$\alpha$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$r$</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.36</td>
<td>$\beta$</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Critical Value: 2.76

40.87 103.72

Figure 37. Austin Air Quality Index & Bicycle Users Residual Plot

Rail Transit Users Model Validity

Model Validity for Research Question 2a

The shape of this residual plot aligns with Figure 27a and indicates the assumptions of the linear regression hold, Figure 38. This means that the residuals have a similar or equal variance compared to the predicted y-values and validates the model.
Overall Findings and Recommendations

This section will provide an analysis of the overall findings as well as recommendations on how this research could be furthered. This initial research has identified the statistical relationships between these transit modes and a few variables and lays the initial foundation to now analyze what further research could be done to potentially increase the number of bicycle-transit users, bicycle users, and rail transit users.

Temperature

This research found that temperature has a statistical relationship with the number of bicycle-transit users, bicycle users, and rail transit users. One conclusion determined is there is a threshold when it comes to bicycle-transit users and bicycle users with temperature. If it gets too hot then there tends to be a decrease in users of both modes. Based on the data collected, this temperature was determined to be 85-degree Fahrenheit. This determination is in line with the findings of many other studies analyzing the effects
of temperature on bicycle usage (Bean et al. 2021, Lepage and Morency 2021, Böcker et al. 2019, Heaney et al. 2019, Kim 2018, Meng et al. 2016, Miranda-Moreno and Nosal 2011). In order to further this research in Denver, a survey could be conducted to determine the preferred temperature and what amenities, such as drinking fountains, could be added to potentially increase the number of users when temperatures get over the threshold, currently perceived at 85-degrees Fahrenheit.

This research found that there is a linear relationship between the number of bicycle and bicycle-transit users but the relationship is linear only to a certain point, the threshold of 85-degrees Fahrenheit. Based on the shape of the residual plot, a temperature dummy variable and interaction term were introduced to the model. The temperature dummy variable was created using zero for data with temperatures greater than 85-degrees Fahrenheit and using one for data with temperatures equal to or less than 85-degrees Fahrenheit. By entering these terms into the model for bicycle users, the correlation coefficient increased to 0.914 with a coefficient of determination of 0.831. Figures 39, 40 and 41 summarize the values showing its significance. Figure 42 shows the shape of the residual plot for this model aligns with Figure 27a and indicates the assumptions of the linear regression hold. This means that the residuals have a similar or equal variance compared to the predicted y-values and validates the model.
### Correlations

<table>
<thead>
<tr>
<th></th>
<th>CC &amp; SP Bicycle Total</th>
<th>Temperature</th>
<th>TempDummy</th>
<th>TempTempDummy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td></td>
<td>1.000</td>
<td>.962</td>
<td>-.373</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>1.000</td>
<td>1.000</td>
<td>-.773</td>
</tr>
<tr>
<td></td>
<td>TempDummy</td>
<td>-.560</td>
<td>-.773</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>TempTempDummy</td>
<td>-.373</td>
<td>-.582</td>
<td>.964</td>
</tr>
<tr>
<td>Sig. (1-tailed)</td>
<td>CC &amp; SP Bicycle Total</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>TempDummy</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>TempTempDummy</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>N</td>
<td>CC &amp; SP Bicycle Total</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>TempDummy</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>TempTempDummy</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
</tbody>
</table>

**Figure 39. Correlation Matrix: Bicycle Users and Temperatures Using Temperature Dummy Variable and Interaction Variable**

### Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>R Square Change</th>
<th>F Change</th>
<th>df1</th>
<th>df2</th>
<th>Sig F Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.914*</td>
<td>.835</td>
<td>.718.243</td>
<td>.035</td>
<td>.735</td>
<td>3</td>
<td>102</td>
<td></td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

* a Predictors: (Constant), TempTempDummy, Temperature, TempDummy
  b Dependent Variable: CC & SP Bicycle Total

**Figure 40. Model Summary: Bicycle Users and Temperatures Using Temperature Dummy Variable and Interaction Variable**

### Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>95.0% Confidence Interval for B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>t</td>
<td>Lower Bound</td>
</tr>
<tr>
<td>1</td>
<td>(Constant)</td>
<td>13599.523</td>
<td>2735.395</td>
<td>4.968</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>-74.951</td>
<td>29.398</td>
<td>-.656</td>
<td>.512</td>
</tr>
<tr>
<td></td>
<td>TempDummy</td>
<td>-17992.919</td>
<td>2784.981</td>
<td>-6.461</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>TempTempDummy</td>
<td>204.935</td>
<td>30.330</td>
<td>6.767</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

* a Dependent Variable: CC & SP Bicycle Total

**Figure 41. Coefficients: Bicycle Users and Temperatures Using Temperature Dummy Variable and Interaction Variable**
Based on the findings for bicycle users, this model was also run with bicycle-transit users. The temperature dummy variable was created using zero for data with temperatures greater than 85-degrees Fahrenheit and using one for data with temperatures equal to or less than 85-degrees Fahrenheit. By entering these terms into the model for bicycle users, the correlation coefficient increased to 0.598 with a coefficient of determination of 0.317. Figures 43, 44, and 45 summarize the values showing its significance. Figure 46 shows the shape of the residual plot for this model aligns with Figure 27a and indicates the assumptions of the linear regression hold. This means that the residuals have a similar or equal variance compared to the predicted y-values and validates the model.
Figure 43. Correlation Matrix: Bicycle-Transit Users and Temperatures Using Temperature Dummy Variable and Interaction Variable

<table>
<thead>
<tr>
<th>Correlations</th>
<th>Bicycle-Transit Count</th>
<th>Temperature</th>
<th>TempDummy</th>
<th>TempTempDummy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td>Bicycle-Transit Count</td>
<td>1.000</td>
<td>.205</td>
<td>.085</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>.205</td>
<td>1.000</td>
<td>-.744</td>
</tr>
<tr>
<td></td>
<td>TempDummy</td>
<td>.085</td>
<td>-.744</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>TempTempDummy</td>
<td>.206</td>
<td>-.532</td>
<td>.961</td>
</tr>
<tr>
<td>Sig (1-tailed)</td>
<td>Bicycle-Transit Count</td>
<td>.574</td>
<td>.277</td>
<td>.071</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>.974</td>
<td>.000</td>
<td>.030</td>
</tr>
<tr>
<td></td>
<td>TempDummy</td>
<td>.277</td>
<td>.000</td>
<td>.030</td>
</tr>
<tr>
<td></td>
<td>TempTempDummy</td>
<td>.971</td>
<td>.000</td>
<td>.030</td>
</tr>
<tr>
<td>N</td>
<td>Bicycle-Transit Count</td>
<td>51</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>51</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>TempDummy</td>
<td>51</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>TempTempDummy</td>
<td>51</td>
<td>51</td>
<td>51</td>
</tr>
</tbody>
</table>

Figure 44. Model Summary: Bicycle-Transit Users and Temperatures Using Temperature Dummy Variable and Interaction Variable

<table>
<thead>
<tr>
<th>Model Summary</th>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>R Square Change</th>
<th>F Change</th>
<th>df1</th>
<th>df2</th>
<th>Sig F Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>.598*</td>
<td>.358</td>
<td>.317</td>
<td>5.204</td>
<td>.359</td>
<td>8.729</td>
<td>3</td>
<td>47</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), TempTempDummy, Temperature, TempDummy  
b. Dependent Variable: Bicycle-Transit Count

Figure 45. Coefficients: Bicycle-Transit Users and Temperatures Using Temperature Dummy Variable and Interaction Variable

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>1</th>
<th>Sig</th>
<th>95.0% Confidence Interval for B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>(Constant)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>176.645</td>
<td>47.652</td>
<td></td>
<td></td>
<td>3.707 &lt;.001 80.791 272.509</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temperature</td>
<td>-1.645</td>
<td>-3.819 -3.187</td>
<td>.003 -2.884 - .867</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TempDummy</td>
<td>-171.629</td>
<td>47.968 -13.165 -3.679</td>
<td>&lt;.001 -268.103 -75.154</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TempTempDummy</td>
<td>1.945</td>
<td>522 10.826 3.728</td>
<td>&lt;.001 .895 2.995</td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: Bicycle-Transit Count
An additional interesting finding was the statistical relationship between bicycle-transit users parking their bike at the station compared to temperature. As the temperature increases, the number of bicycle-transit users parking their bike at the station decreases. This is statistically shown with a Pearson’s Correlation Coefficient of 0.37 and a p-value of 0.01. The morning data collection period (7:30-9:30) is when this is found more so than during the afternoon data collection period (4:00-6:00). This indicates that when a higher temperature is predicated for the day, bicycle-transit users are more likely to onboard their bicycles instead of parking it at the station.

Residents of Denver bike year-round because it might be their only mode of transportation, their age might restrict them from driving, it can be used to live a healthier lifestyle, and/or to reduce their carbon footprint that is caused by other modes of transportation. It is important for planners to ensure that all cyclists can bicycle
comfortably regardless of temperature. Another identification made is that on 6 September 2021, although the temperature was very hot, 94-degrees Fahrenheit, the highest number of cyclists in September were recorded on this day. This day coincides with Labor Day 2021 so the assumption can be drawn that with the day off, more cyclists took to the trails despite the temperature. During federal holidays, different organizations should use this peak as a potential day to perform extra outreach and education services along the bicycle trails as a way to promote cycling as a mode of transportation and not just a form of recreation. Outreach and education services should also be utilized on Denver’s Bike to Work Day, if it is not being done so already. With a temperature of 79-degrees Fahrenheit, 22 September 2021 was Denver’s Bike to Work Day and the second highest number of cyclists in September was recorded on that day, another potential opportunity to change the mindset that cycling is only or mostly a form of recreation.

**Chance of Precipitation**

It was found that the chance of precipitation only had a correlation with the number of bicycle-transit users and no correlation with the number of bicycle users and rail transit users. The climate in Denver is a semi-arid climate which means that there is not much rainfall and when rainfall does occur, it does not last for long. There is a saying in Colorado that “if you do not like the weather, wait 20 minutes.” This insignificance of the chance of precipitation indicates that bicycle users and rail transit users obey this common phrase. Additionally, rail transit users are sheltered during their commute on the transit lines which is why there could be no correlation. These findings support the results of Wei (2022) in that adult public transit commuters are “immune to weather conditions
during the morning and afternoon peaks of traffic due to work commute trips usually have a fixed schedule that cannot be adjusted in response to weather condition.”

A finding that is also supported by the findings of Wei (2022) is that college students are more affected by rain in the morning than in the afternoon. This research found that there is a negative correlation between the chance of precipitation and bicycle-transit users in the morning with a Pearson’s Correlation Coefficient of 0.47 and a p-value of 0.008. This research also found that there is no statistical relationship between the chance of precipitation and bicycle-transit users in the afternoon which also supports the findings of Wei (2022).

An interesting finding was that bicycle-transit users at the University of Denver Station are more likely to park their bicycles at the station in the afternoon data collection period when there is less of a chance of precipitation. This was found to be statistically significant at the 95% confidence level with a Pearson’s Correlation Coefficient of 0.29 and a p-value of 0.03. Further analysis indicates that this is particularly true when school is in-session. When school is in-session, using both morning and afternoon data, Pearson’s Correlation Coefficient is 0.64 and has a p-value of 0.002. This indicates that when there is a higher chance of precipitation, bicycle-transit users are less likely to park their bike at the station. However, this analysis requires further analysis because after removing outliers, there were only 22 observations to come to this conclusion, eight short of the standard 30.

Finally, the number of bicycle-transit users tends to decrease when there is a higher chance of precipitation. On average, there are approximately 26 bicycle-transit users
when the chance of precipitation is 30 percent or lower and there are approximately 21 bicycle-transit users when the chance of precipitation is greater than 30 percent. Further research should be conducted to determine the what, why, and how the bicycle-transit users who do not use bicycle-transit when the chance of precipitation is greater than 30 percent in order to determine what mode the user chooses when the chance of precipitation increases. This could help uncover if they rely more on rail transit, driving to a rail station, or decide to use an automobile and could potentially help find solutions to use bicycle-transit or other solutions that do not involve driving alone in their automobile.

Much of the literature when it comes to cycling and precipitation, shows the effects during the precipitation period and the hour to the left and right of the precipitation period (Bean et al. 2021, Lepage and Morency 2021, Rose et al. 2011, Winters et al. 2007, Pucher and Buehler 2006). This study adds the variable chance of precipitation to the literature and concludes that there is not much of a deterrence or correlation between the chance of precipitation with bicycle usage and rail transit usage during the commute to work peak travel hours.

**Air Quality Index**

The third independent variable explored was the Air Quality Index and it was found to only have a correlational relationship with bicycle users. Although a correlational relationship was determined, the sign of the correlation was the opposite of the expected sign. A positive correlation was calculated; however, a negative correlation was expected. It was expected that as the air quality index value increased, the number of cyclists would
decrease. One theory is that the relationship between temperature and air quality index has a strong correlation. A large component of poor air quality is ozone pollution which increases in warmer months. As the temperature increases so does the air quality index. This assumes that temperature plays a greater role in the choice of a bicycle user. This assumption could be further explored by using surveys to learn about what and why bicycle users make their decision.

No correlational relationship between the number of bicycle-transit users and rail transit users was expected based on the theory that the users of these two modes have the rail cars to act as a barrier between their lungs and the quality of the air. Air quality index was found to be statistically significant when all factors were analyzed with bicycle-transit but this significance was found to be attributed to the relationship between temperature and air quality and not air quality and the number of bicycle-transit users.

**Seasonal Employment: In-Session vs. Out-of-Session**

The final independent variable explored was the effect on bicycle-transit when school is in-session and when school is out-of-session which was found to be statistically significant. Much of this could be due to the negative moderate correlation between the temperature variable and seasonal employment. There is a negative relationship between these two variables because as temperature decreases, school is in-session and the number of bicycle-transit users increases. Dummy variables cannot have regression analysis conducted without another independent variable being present. However, when analyzing the raw data, when school is in-session it is evident that the number of bicycle-transit users increases. The data also shows that there is a wider range in the number of
bicycle-transit users when school is in-session. This could be due to varying student schedules whereas the out-of-session data could be more indicative of a fixed job schedule. Further research, such as a survey, could be conducted to determine the cause for the variance – it could be different class times, different class schedules, different sports practice schedules, college students do not typically have a fixed work schedule, etc. Due to the significance of school being in-session or out-of-session on the number of bicycle-transit users, future research should assess how employment affects other rail transit stations near high employment centers or near employment centers with more shift work than fixed job schedules to determine if there is any significance with other employment locations.

**Recommendations**

As I explored Denver using bicycle-transit, I noticed that there are no trees and very few shelters around the rail stations. With temperatures increasing globally, increasing temperatures could threaten public transit ridership. Trees have proven to reduce the effect of extreme heat and while shelters do not have that same effect with temperature, shelters have been proven to reduce the effect of precipitation on public transit (Lanza and Durand 2021). While sitting at the University of Denver Light Rail Station, I could not escape the heat. Sitting under the structures situated between the two tracks helped a little but, depending on the angle of the sun, it did not always protect me from the sun. Trees can help with this issue, as well as providing a little more protection when raining as leafy trees can reduce the number of droplets landing on people.
Most of the stations have some sort of structure but it is open on all sides which does not protect users waiting for the trains if it is raining and windy. I experienced this first hand as I sat through some rainy days. I could not manage to keep dry because although I had shelter above me, I was not protected from the rain when the wind was whipping through the area. For people who are transit dependent, more protection needs to be provided in order to improve their journey to work and would add to the equity of a transportation system. Additionally, as personally experienced, when precipitation is present the number of people driving alone in their automobile increases so in order to not lose transit patrons to the convenience and comforts of an automobile, more protection needs to be provided. Studies have found that amenities with weather-protection located at public transport stations have the potential to retain ridership despite inclement weather days (Lanza and Durand 2021, Miao et al. 2019, Böcker et al. 2013).

The air quality index did not have a correlation with two of the independent variables and the correlation calculated with the third independent variable is suspect due to the relationship between the air quality index and temperature. Although no correlation was found, it is still important to reduce emissions into the air to avoid air quality values found in China and Los Angeles. Further research could explore the relationship between the air quality index in China and Los Angeles to see if there is more of a correlational relationship as these locations were often in the “Hazardous (301+)” air quality classification, Table 1, whereas Denver’s worst air quality classification was “Unhealthy (151-200).
The University of Denver has many programs to encourage bicycle and public transit usage for its students. The University of Denver should continue its programs and potentially increase the advertisements of the benefits of using transit. Benefits such as time to focus on decompressing after a long day or using the time to catch up on reading or homework or the environment impact students’ choices. There are also the intrinsic benefits such as the fact that familiarizing students to the benefits of transit can translate into a better appreciation for transit systems with the potential of creating a habit of transit usage that could last into their adult life. Other ways to encourage bicycle and public transit use is to make free parking scarce and ticket those who do not comply, promote the free campus shuttle, develop an app to show where the campus shuttles are located at a given period in order to increase transparency of a shuttle being delayed or late, and increase the number of micromobility vehicles available on the campus. Through the University of Denver’s Center for Sustainability many of these aspects are already in place, however, an increase in ticketing, a refinement of the TripShot app for the campus shuttle, and an increase in the number of micromobility vehicles available on campus would advance the mission and push towards a more sustainable University of Denver.
Chapter Seven: Conclusion

With continued urban growth, modes other than the automobile, such as bicycle-transit, will continue to be a major focus in urban transportation research. Accurate weather information is important for bicycle-transit users to make decisions, with temperature being the most influential factor. Being prepared for changes in weather can promote bicycle-transit usage.

This research offers undeniable evidence that weather influences the number of bicycle-transit users but it does not explain why users make their decision. The research on weather and air quality index are only a few of the factors to analyze the impacts on bicycle-transit usage. Future research should also include safety, such as traffic reports and night safety implementations, equity, gender, age, income, and accessibility to bicycle-infrastructure around the transit stations. These factors, coupled with weather and air quality index, would contribute to the bicycle-transit decisions made by users.

Additionally, it is important to note that much of what has influenced the number of bicycle-transit users or lack thereof is public policy, particularly that in automobile infrastructure. Bicycle-transit or public transit in general may be better for the environment but it is not faster. Post-World War II, there was a clear shift in the dominant mode of transportation with the number of automobiles increasing by 1000 percent and the number of public transit users decreasing by 75 percent from 1945 through 1973. Much of this was due to the Federal Aid Highway Act of 1956 which
began the interstate system whereby the state or local governments only had to cover 10 percent of the funding for highways while the federal government would provide the remaining 90 percent. The amount of urban sprawl and quick growth of roads and amenities catered to the automobile took off and by 1964, the federal government was trying to correct the issue and wanted to focus more on multimodal transportation systems than just the highway. Unfortunately, the seed had been planted and the American public had a love affair for the automobile. The amount of infrastructure dedicated to the automobile, especially the road networks connecting the suburbs to the central city, made and continues to make the journey from the suburb to the central city much easier by automobile than public transit.

For those who have the choice of how to commute, commuters who have other options for getting around and do not have to rely on public transit, the decisions they make are often weighted based on time. As discussed in the Literature Review, the distance between the origin and destination affects the probability of a commuter choosing cycling or public transit over use of their automobile. Transit services traveling long distances, with relatively few stops, such as express routes, tend to draw a larger number of bicycle-transit users than short distance routes with more stops (Krizek and Stonebraker 2011). Unfortunately, due to the required amount of track required for express routes and shortage of open spaces in urban areas, it is not widely available to add express lanes on rail lines. This means that not only do the short distance routes have more stops, so do the longer distance routes. Most American cities, with the exception of a few like New York City, were built to be traveled by car not for public transit systems.
While there is not much room available to add public transit infrastructure, there are other options like during peak hour travel, creating dedicated lanes for public transit which would prevent busses from getting stuck in traffic. This change in public policy would make public transit more appealing than sitting in an automobile and decrease the amount of time a trip takes using public transit versus that of the automobile. Integrating cycling with public transportation is mutually advantageous as it enhances the benefits of cycling and public transportation (Brons et al. 2009, Givoni and Rietveld 2007, Hegger 2007, Martens 2007).

As seen with the latest the Federal Bipartisan Infrastructure Law and the recent Colorado Infrastructure Bill (SB21-260), there is much more emphasis being put on the development and improvement of public transit systems. The Federal Bipartisan Infrastructure Law created the largest federal investment in public transit, the largest federal investment in passenger rail since the establishment of Amtrak, and helps fight the climate crisis by investing in clean energy transmission to include the electrification of transit buses across the country (The White House 2021). Here in Colorado, Governor Polis signed SB21-260 which has many sustainability components, including a focus on multimodal transit and the Revitalizing Main Street Program. These are just two components of the bill but show Colorado’s dedication to improving the air quality through sustainable transportation initiatives. The multimodal transit initiative is to improve access to transit, biking, and walking and increased frequency and reliability of the network and the Revitalizing Main Street Program initiative is to improve pedestrian and bicycle infrastructure with new bike lanes, sidewalks and crosswalks, road diets, and,
traffic calming elements (Colorado General Assembly 2021). Continued public policy promoting the use of public transit, increasing the accessibility of public transit networks, and an increase in bicycle infrastructure is required to encourage automobile users to use a multimodal network. An effective urban transportation system would better integrate transportation and land use planning which would require updated policies, such as, zoning, housing, and parking policies to increase multimodal access in return reducing vehicle travel.

Expanding this research is needed to determine the tradeoffs involved in the decision-making process of bicycle-transit users, bicycle users, and rail transit users. Ultimately, analyzing these factors will assist transit agencies in the advancement of system performance and help focus in on where enhancements to the overall system or amenities in and around the stations and along bicycle infrastructure corridors could be implemented not only based on statistical analysis but also through public involvement with surveys, focus groups, or town halls. The success of increasing bicycle-transit or any multimodal network in Denver will depend on the cooperation and coordination of many agencies and key players, including public participation.
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