# EVALUATING PUBLIC TRANSIT ACCESSIBILITY IN ALBUQUERQUE, NEW MEXICO: A FIXED-ROUTE BUS SERVICE ANALYSIS

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**BY**

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**B.S., Civil Engineering, Gonzaga University, May 2019**

THESIS

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## ABSTRACT

This research analyzed how residential accessibility to fixed-route bus service in Albuquerque, New Mexico varies by distance, income level, and headway. A literature review investigated components of travel that might deter people from using public transit such as travel distance, sidewalk condition or availability, bus headway, lack of active travel in today's society, personal and traffic safety, and access equity. Geographic Information System (GIS) mapping was used to determine if low-income neighborhoods have better or worse access to ABQ Ride bus stops relative to medium- or high-income neighborhoods. Residential land use was divided into three economic classes based on 2018 median household income. A random point for every 100 people was generated and connected with the closest bus stop through a spatial network analysis. Statistical analysis was performed to determine if there is any statistical significance between distance to bus stop and economic class. A bivariate choropleth map was produced to compare proximity to bus stop and bus headway in an attempt to reveal areas of improvement for the Albuquerque fixed-route bus network. Next steps for this research include an investigation of the following factors: trip destination, number of boardings, bus transfers, paratransit service, ADA compliance, and overall transit equity.

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# 1. BACKGROUND

Public transportation is an important asset to any community, including Albuquerque, New Mexico with a population of about 560,500 (United States Census Bureau, 2019). Well-designed and managed public transportation systems are capable of efficiently moving large numbers of people from one place to another. Benefits of public transit include reducing air pollution, increasing fuel efficiency, reducing traffic congestion, and providing affordable mobility for low-income populations (Federal Transit Administration, 2015). Public transportation is cheaper out-of-pocket in relation to a personal vehicle mode choice *(Litman, 2020)*. However, when incorporating travel time into the mode comparison, the out-of-pocket advantage of transit may be overshadowed in favor of faster travel times of personal vehicles. According to the U.S. Department of Transportation, public transportation has substantially lower crash rates and lower crash severity than personal automobile travel (U.S. Department of Transportation , 2015). According to a 2014 study in Victoria, Canada, public transportation passengers have about one-tenth the fatality rate per mile as compared to automobile passengers *(Litman, 2019)*. Public transit boosts healthier habits by encouraging people to walk or bike to bus stops, as well as to their final destinations. Public transportation station area planning is key to ensure integration with infrastructure such as bike-share stations and transit-oriented development (U.S. Department of Transportation , 2015).

Accessibility differs based on mode of travel, type of traveler, type of trip, and travel context. A person's ability to reach an activity site depends on physical proximity, but it also depends heavily on mobility. Mobility in our auto-oriented transportation systems usually requires the use of an automobile. However, in some cases people do not have access to a personal automobile. This brings forth an equity issue present within our transportation system.

As transportation engineers and planners, we need to closely consider who is gaining accessibility and who is losing it based on transportation design and development. Are people choosing a mode based on a choice or based on a constraint? Immobility can create a sense of isolation for households that do not have access to automobiles (Giuliano & Hanson, 2017). Social equity and urban transportation lean on public transportation to provide opportunities to all.

Bus service in Albuquerque is provided for public benefit by the City of Albuquerque under the brand name "ABQ Ride". According to the National Transit Database, there were over 9.9 million unlinked trips for ABQ Ride in 2018 (Federal Transit Administration, 2018). An unlinked trip is defined as, "the number of passengers who board public transportation vehicles and are counted each time they board no matter how many vehicles they used to travel from their origin to their destination" (Federal Transit Administration , 2020). This large number of boardings demonstrates the need for transit-accessibility in Albuquerque. Transit-accessibility "refers to the ease, in terms of proximity in distance or time, with which residents and workers can reach transit-facilities or services" (Manout, Bonnel, & Bouzouina, 2018).

### 1.1. Goal and Objectives

The goal of this analysis is to determine the relative accessibility of the fixed-route bus service in Albuquerque, NM according to the following factors: distance to bus stop, equity among income classes, and peak hour bus headway. The first objective is to determine the physical proximity of bus stops to residential housing which will be categorized by median household income. The main question we seek to answer is: do low-income areas have better or worse accessibility to ABQ Ride bus stops than medium- or high-income areas? The second

objective is to determine areas in need of improvement within the Albuquerque fixed-bus network by comparing distance to bus stop with bus headway.

## 2. LITERATURE REVIEW

Amidst all the benefits to public transit, people still hesitate to use this mode choice. There are countless reasons why someone might not want to walk to a bus stop such as travel distance, sidewalk condition or availability, headway of bus service, lack of active travel in today's society, personal and traffic safety, and access equity. Those barriers will be explored below through existing research as a basis for analyzing accessibility in Albuquerque. Other notable deterrances include weather, climate and topography. Although these topics will not be covered in the literature review, there is existing research to support the assumption that weather and climate can negatively impact bus ridership *(Stover & McCormack, 2012; Guo, Wilson, & Rahbee, 2007; Arana, Cabezudo, & Penalba, 2014; Singhal, Kamga, & Yazici, 2014).*

### 2.1. Travel Distance

Recent research suggests that there is a correlation between travel distance and transit ridership *(Ryan & Frank, 2009).* A recent Australian-based analysis performed a cross-sectional survey (n = 944) and an independent interview study (n = 22) to examine reasons why people walked to a more distant bus stop *(Ragaini, et al., 2020).* Factors for this study included demographic variables, past week bus use, bus stop accessibility, and physical activity. Less than 15% of the survey participants used distant bus stops every or most times and over half claimed they did this for physical activity gain. Co-benefits included avoiding crowded bus stops and minimizing time spent on the crowded bus. Not surprisingly, there was statistical significance (P = 0.003) between median walking time and total physical activity of participants. These data results support the claim that public transportation is tied to healthier

living *(Lachapelle & Frank, 2009).* It is important to note that 83% of the sample lived within a 10-minute walk of a bus stop, indicating that travel distance was not an issue. Transportation planning typically places an emphasis on quantitative impacts such as travel speed *(Sun, Zhou, & Wang, 2008; Jang, 2010).* Efficiency is important however, travelers place a high value on convenience, comfort, security, and prestige *(Goodwin, 1976; Litman, 2017).*

### 2.2. Sidewalk Condition and Availability

Although travel distance is an important contributing factor to ridership, adequate pedestrian infrastructure should also be included in the transit user conversation. The built environment is significant in modal decision making. Sidewalk quality, availability, and street network connectivity are key access factors in reaching public transit stations *(Woldeamanuel & Kent, 2016).* An analysis of the Orange Line bus rapid transit (BRT) in the San Fernando Valley, Los Angeles concluded that there is a significant positive relationship between both sidewalk connectivity ($P = 0.01$) and sidewalk availability ($P = 0.04$) with public transit ridership *(Woldeamanuel & Kent, 2016).* Walking protection, comfort, enjoyment and directedness are all factors that contribute to a walk-access cost *(Jiang, Zegras, & Mehndiratta, 2012).* A walking level of service analysis in Sapporo, Japan showed that pedestrians will sacrifice short distance routes for routes with higher quality sidewalks and crosswalks *(Muraleetharan & Hagiwara, 2002).* Transportation engineers and planners can encourage public transit through environmental design such as providing sidewalks that are in good condition and lead to desirable destinations.

## 2.3. Bus Headway

The departure and arrival of buses within a transportation network directly affect the service quality, mode attraction, and economic benefits of the system *(HanYinJiangKinkai, 2011; Sun, Zhou, & Wang, 2008).* If the bus travels too quick, resources will be wasted. If it travels too slow, passengers will be waiting for a long time which might deter them from using the service again. Headway should be determined based on the demand of passengers for a given area *(HanYinJiangKinkai, 2011).* When mode choice is an option (rather than necessity), public transit must become competitive and attractive to people by providing a greater headway of service, a longer span of service throughout the day, and a more direct coverage with important origin and destination locations *(Vermont Agency of Transportation, 2020).* According to the National Transit Database, New York bus ridership declined 16% from 2002-2016, while the city's population increased by 6% and subway ridership increased by 25% *(NYC Bus Coalition, 2016).* The New York City Bus Coalition created an action plan that included how to improve service headway and reengage ridership. This plan included redesigning indirect routes, breaking up routes that were too long, implementing tap-and-go onboard fare collection, intervening when buses get off track, and instituting a headway-based control for frequent buses. A few of their other ideas included creating dedicated bus lanes, installing bus bulbs and boarding islands, and introducing queue-jump lanes for buses. These initiatives are a great way to improve bus service headway in any city, not just NYC, especially when schedule reliability and passenger wait times are key factors in public transit ridership *(Bowman & Turnquist, 1981; Mallett, 2018).*

### 2.4. Active Travel

According to the U.S. Department of Transportation, about one in every four adults in the United States report that they do not engage in any physical activity outside their jobs *(U.S. Department of Transportation, 2015).* Given this statistic, it might not be surprising that two of every three adults in the United States are overweight or obese *(U.S. Department of Transportation, 2015).* Transportation engineers can create opportunities for people to be active, whether it is for recreation or utilitarian purposes. Active travel can be encouraged by reducing distances between desirable destinations and providing suitable bicycle and pedestrian facilities *(Iacono, Krizek, & El-Geneidy, 2010; Rowangould & Tayarani, 2016).* Active travel facilities and public transit access are especially important in low-income neighborhoods because low-income populations are less likely to own vehicles and unsafe streets might deter pedestrians from active travel *(Paulley, et al., 2006; Pont, Ziviani, Wadley, Bennett, & Abbott, 2009).*

Another form of active travel that has recently gained popularity is shared micromobility, which consists of station-based bike share, dockless bike share and scooter share. According to the National Association of City Transportation Officials (NACTO), people took 84 million trips using shared micromobility devices in the United States in 2018, which was more than double the number of trips taken in 2017 *(NACTO, 2018).* While mass transit remains the most efficient choice for longer-distance travel, transporting people to and from transit stations remains a common difficulty. This is typically referred to as the first-mile/last-mile challenge *(Zarif, Pankratz, & Kelman, 2019).* People are more likely to opt into public transit if there is a convenient and affordable way to access the transit services.

Micromobility provides environmental, social and economic benefits for a community and might be an answer to the first-mile/last-mile challenge *(Tice, 2019)*.

Travel can be subdivided into three linked components: the person, the vehicle and the built environment *(Lavery, Davey, Woodside, & Ewart, 1996)*. Travel is only successful if these three links are effectively joined. Mobility-impaired people typically have a barrier between themselves and their built environment. Engineers and planners must work towards breaking down those barriers to increase mobility for all users. Accessible busses are increasing the travel availability for the elderly and other mobility-impaired community members. Sun Van, ABQ Ride's paratransit service provides accessible transportation to persons residing in or visiting the metro area whose impairment makes it difficult, if not impossible, to use the fixed-route service *(City of Albuquerque, 2019)*. Paratransit routes were not included in this spatial and statistical analysis however, they should be noted as important aspects to the accessibility of public transit as a whole.

### 2.5. Personal Safety and Crime

Another deterrence of using public transit is the perception of lower personal safety and higher crime threat when walking or biking from your home to a bus station. Fear can be present early in the morning or late at night when it is dark outside. Studies have shown that improved street lighting can lead to improved perceptions of crime and lower crime rates, although results are mixed *(Farrington & Welsh, 2002; Pease, 1999)*. The overall reduction in crime for thirteen British studies was estimated at 20% compared to control areas *(Farrington & Welsh, 2002)*. Targeted lighting improvements were found to decrease crime occurrences while general lighting improvements were able to improve perceptions of crime *(Pease, 1999)*.

Interestingly, lighting improvements have been found to reduce crime both at night and in the daytime *(Pease, 1999; Farrington & Welsh, 2002)*.

A research study was conducted by Cambridge University to determine the influence of street lighting improvements on crime, fear, and pedestrian street use, after dark *(Painter, 1996)*. Street lighting was upgraded in three urban streets and a pedestrian footpath, in the north, east and west areas of London. Attitudinal and behavioral measures were assessed by a before and after survey of pedestrians. Pedestrians were asked about their experience of crime in the area within the previous 12 months. The number of pedestrians were counted and on-site incidents of crime and disorder were noted. The after surveys showed that incidents of crime and disorder were significantly reduced in two of the three study streets. There was also data to support a significant drop in crime and disorder occurring in adjacent streets. This suggests that lighting has a positive impact on the area as a whole. The study area also saw an overall increase in pedestrian use after dark. It should be noted that not all lighting is implemented correctly. Poorly designed lighting can have a negative impact on the migration of birds and other wildlife *(Dudley, Erkintalo, & Genty, 2015; Bhardwaj, Soanes, Lahoz-Monfort, Lumsden, & van der Ree, 2020)*. Lighting design should be thoughtfully implemented and all impacts should be taken into consideration (*Isebrands, et al., 2006; Murray & Feng, 2016)*. If people feel safe walking and biking in their neighborhoods, transit ridership will increase *(Delbosc & Currie, 2012)*.

### 2.6. Traffic Safety

In continuing the topic of personal safety, this section will describe traffic safety as it relates to traveling from residential land use to the closest transit facility. As previously

mentioned, people must feel safe walking to and from the bus stop if they are to rely on public transit as a viable mode of transportation. One deterrence to walking to a public transit station is the presence of high-speed vehicles. Travel speed is an important component in residential traffic safety that can be influenced through design. Speed increases the possibility and severity of a crash by increasing braking distance and decreasing driver perception-reaction time. According to the Federal Highway Administration, about half of speeding-related fatalities occur on lower speed collector and local roads *(U.S. Department of Transportation, 2019).* Setting appropriate speed limits and providing designs that enforce them are key for the safety of all roadway users.

A few miles per hour can be the difference between life and death of a pedestrian or cyclist. Danny Dorling, a professor of geography at the University of Oxford, suggests the implementation of 20 mph speed limits in residential areas. Dorling explains that introducing 20 mph zones would save lives, prevent injuries and reduce health inequalities in the process. Slowing down cars would reduce inequalities within cities because people in poorer parts of cities are most at risk of being hurt or killed by cars *(Dorling, 2014).* From the years 2005-2007, Sheffield, UK experienced a noteworthy contrast of child deaths under the age of 10 in two constituencies with different socio-economics, indicating equity issues *(Thomas, Pritchard, Vickers, & Dorling, 2009).* The risk of pedestrian fatality was calculated in the UK by Danny Dorling in 2014. The results indicated that there is a 50 percent chance of a fatality when hit by a vehicle traveling 40 mph *(Dorling, 2014).* As speed increases, so does risk. A speed limit of 20 mph on residential streets would give the best protection to the most vulnerable street users.

Bus stop data obtained from the City of Albuquerque was one of the main components for this accessibility analysis. This will be discussed further in the methods section, but it is important to note specific facts about the data with regards to traffic speed. There are currently 2,786 active bus stops in Albuquerque. Table 1 details the functional classification and corresponding speed to the number of bus stops located along different types of streets. As you can see, the majority of Albuquerque bus stops are located on minor and principal arterials. This suggests that traffic speed should be considered as a possible barrier for safe access to transit stops since you will have to cross these high-speed streets at some point. Even if the bus stop is on your side of the street when you board, you will return on the other side of the street and be required to cross.

**TABLE 1**. Number of Bus Stops Located on Each Functional Classification (GIS Data from City of Albuquerque)

| ***Local (25 mph)*** | ***Minor & Major Collector (35-40 mph)*** | ***Minor Arterial (40 mph)*** | ***Principal Arterial (45 mph)*** |
|---|---|---|---|
| 272 bus stops | 503 bus stops | 700 bus stops | 1311 bus stops |

One way in which transportation engineers around the world are working towards safer roads is the implementation of Vision Zero. Vision Zero is a commitment to create safer streets for all people whether they are walking, biking, driving or taking transit, regardless of age or ability *(Vision Zero Network , n.d.).* Vision Zero plans to eliminate all traffic fatalities and severe injuries, while increasing safe, healthy, equitable mobility for all. In May 2019, Albuquerque's Mayor Tim Keller signed an executive order committing the city to Vision

Zero. The administration is currently forming an action plan to eliminate all traffic fatalities and injuries in the city. The Albuquerque City Council unanimously passed a Complete Streets Ordinance in August 2019 giving the Vision Zero pledge some legislative backing and specific design criteria. Improving traffic safety for all road users is currently an important policy priority in Albuquerque and across the country; one that directly translates to alternative modes of transportation such as public transit.

### 2.7. Transit Access Equity

Access to public transportation is critical for mobility and job opportunities to many minority and low-income populations *(Welch, 2013; Blumenburg & Ong, 2001).* Research in transportation equity has shown that developers and planners need to work together to find affordable housing locations that provide access to transit locations with high connectivity rather than simply reducing distance to any transit *(Welch, 2013).* Allocating public transportation resources in an equitable manner can create an accessibility barrier to many disadvantaged groups *(El-Geneidy, Levinson, Boisjoly, & Verbich, 2016).* A case study in Montreal, Canada proposed a set of accessibility measures that incorporated both travel time and transit fare and then applied the measures to determine whether people in socially disadvantaged neighborhoods experience better or worse accessibility *(El-Geneidy, Levinson, Boisjoly, & Verbich, 2016).* Results showed that residents of the socially disadvantaged areas had more equitable accessibility to jobs using transit with a small decrease in accessibility when fare costs were included. This supports the importance of public transit in providing both mobility and economic means.

## 3. METHODS

According to the *Transit Capacity and Quality of Service Manual*, the majority of bus riders (75-80%) will walk 0.25 miles or less to access a bus stop (Kittelson & Assoc, Inc., Parsons Brinckerhoff, Inc., KFH Group, Inc., Texam A&M Transportation Institute, & Arup, 2013). The manual projected that almost 0% of riders will commit to a walk greater than 0.50 miles. Other research produced similar walking distance thresholds of 0.25 and 0.50 miles (Yang & Diez-Roux, 2012; Pulugurtha & Agurla, 2012; Federal Highway Administration , 2013; Gleason, 1975). A distance of less than or equal to 0.25 miles will be considered "reasonable proximity" for the purpose of this analysis. Distances between 0.25 and 0.50 miles will be identified as "moderate proximity".

To determine whether residential areas in Albuquerque have reasonable or moderate proximity to transit bus stops, the student edition of ArcMap 10.7 was used to conduct a spatial analysis of the area. Two main data sources were used for the GIS analysis. As briefly mentioned above, the first source was the City of Albuquerque (CABQ) maps open data portal, obtained from the CABQ website (City of Albuquerque, 2020). The shapefiles downloaded from this site were "Land Use", "Streets", "Transit Bus Routes and Stops", and "Annexations". The second data source used was the New Mexico Resource Geographic Information (RGIS) database run by the Earth Data Analysis Center at The University of New Mexico (Earth Data Analysis Center-UNM, 2020). The main shapefile layer downloaded from this site was "Income and Earnings by Tracts 2018". A table of values titled "Population by Tracts 2018" was also downloaded and joined to the income shapefile.

FIGURE 1 displays a map of Albuquerque, highlighting the residential land use as well as the location of active ABQ Ride bus stops. This will be the study area for determining public transportation accessibility.

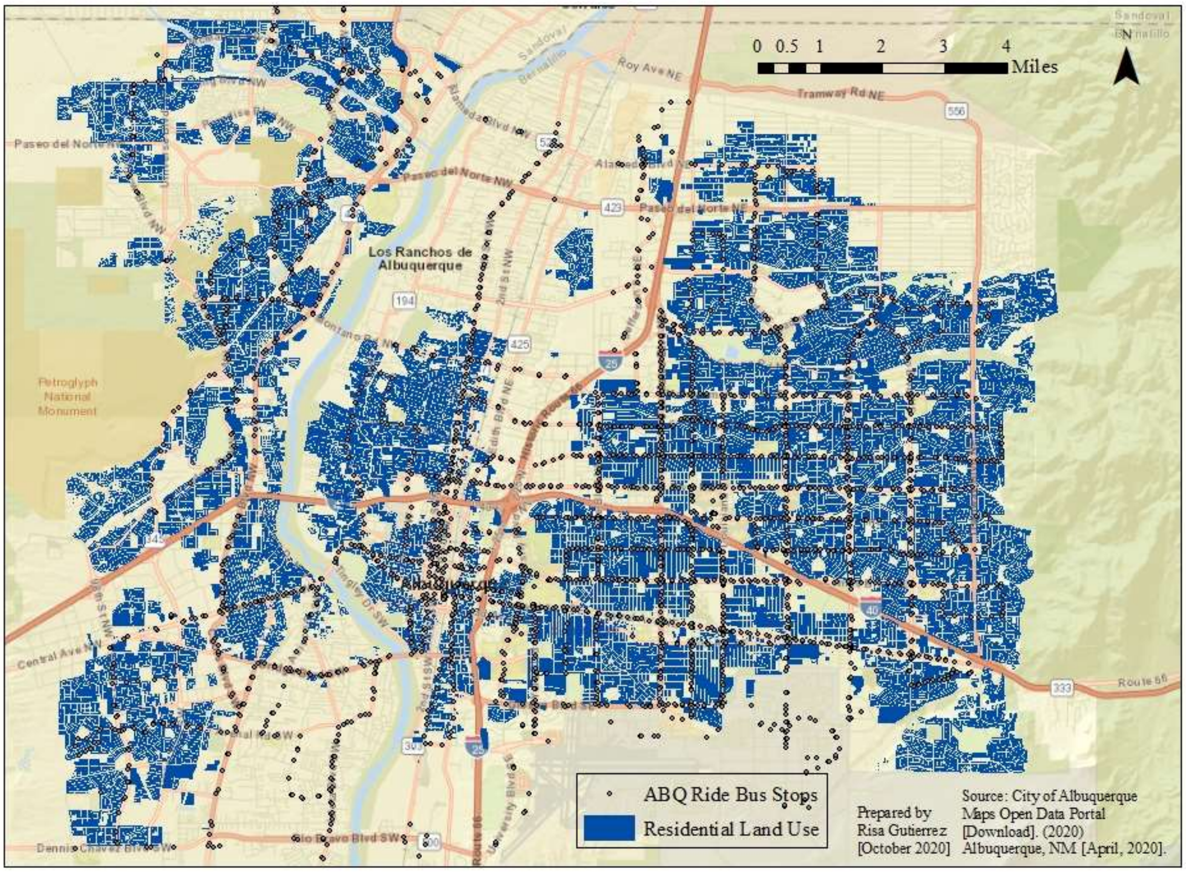


**FIGURE 1.** Residential Land Use in Albuquerque, NM and ABQ Ride Bus Stops

Network analysis, also known as network models, “are used to represent and analyze the cost, time, delivery, and accumulation of resources along network links and between the connected features or centers” (Bolstad, 2016). Networks can be found all around us such as roads, powerlines, telephone and television cables, and water distribution systems (Bolstad, 2016). Spatial analysis tools, such as a “network analysis”, help us to use and maintain these intricate networks. The main goal for this accessibility analysis is to find the closest street

network path from a randomly generated residential location to the nearest ABQ Ride bus stop. These routes will represent typical paths taken by Albuquerque residents on their way to the closest transit facility entry point.

A bit of data preparation was required before running the network analysis tool. In addition to assessing bus stop accessibility as a city network, Albuquerque will be grouped into three separate income levels in order to compare distance to bus stop by median household income. As previously mentioned, 2018 income and earnings data for each Albuquerque census tract was obtained through the RGIS database. The first step was to determine what is considered middle-income in Albuquerque and designate the census tracts accordingly.

The Pew Research Center considers a household income to be middle class if it is between 67% and 200% of the median household income (Kochhar, 2018). According to the U.S. Census Bureau, the median household income in 2018 in Albuquerque, New Mexico was $51,128 (United States Census Bureau, 2019). Using this value as the base, the Pew definition of middle-class income would equate to households earning between $34,085 and $102,256. For the initial GIS analysis, those numbers were rounded to the nearest $5,000 to create a range of $35,000 to $105,000. Lower-class income was considered less than $35,000 and higher-class income was considered greater than $105,000. This breakdown of income was clipped to include only residential land use and a graduated colors map was generated (not shown). The map produced disproportionately favored the middle-income category with 107 census tracts (77%). The low-income category contained 25 census tracts (18%) and the high-income category contained only 7 census tracts (5%). The groups were vastly disproportionate to each other and to Albuquerque as a whole.

A decision was made to group the income brackets into approximate equal thirds according to the total population of the Albuquerque data obtained. Although Albuquerque alone has a population of about 560,500 people (United States Census Bureau, 2019), after clipping the income layer with the COA annexation layer, 138 tracts remained with a population of 613,571 people. This annexed part of the city is included in this analysis. The population of 613,571 split into three equal parts equates to approximately 204,500 people per income layer. The median household income field was sorted by ascending value. The separation of tracts was determined and a summary of the distribution is shown in Table 2.

**TABLE 2.** 2018 Total Median Household Income Bracket Distribution

| | ***Median Household Income Range*** | ***Total Population*** | ***Total Census Tracts*** |
|---|---|---|---|
| ***Low-Income Bracket*** | \$18,000-42,000 | 203,773 | 46 |
| ***Medium-Income Bracket*** | \$42,000-63,000 | 208,012 | 48 |
| ***High-Income Bracket*** | \$63,000-140,000 | 204,241 | 44 |

Three new polygon shapefiles were created containing each grouping of census tracts for the three income levels (Figure 2).

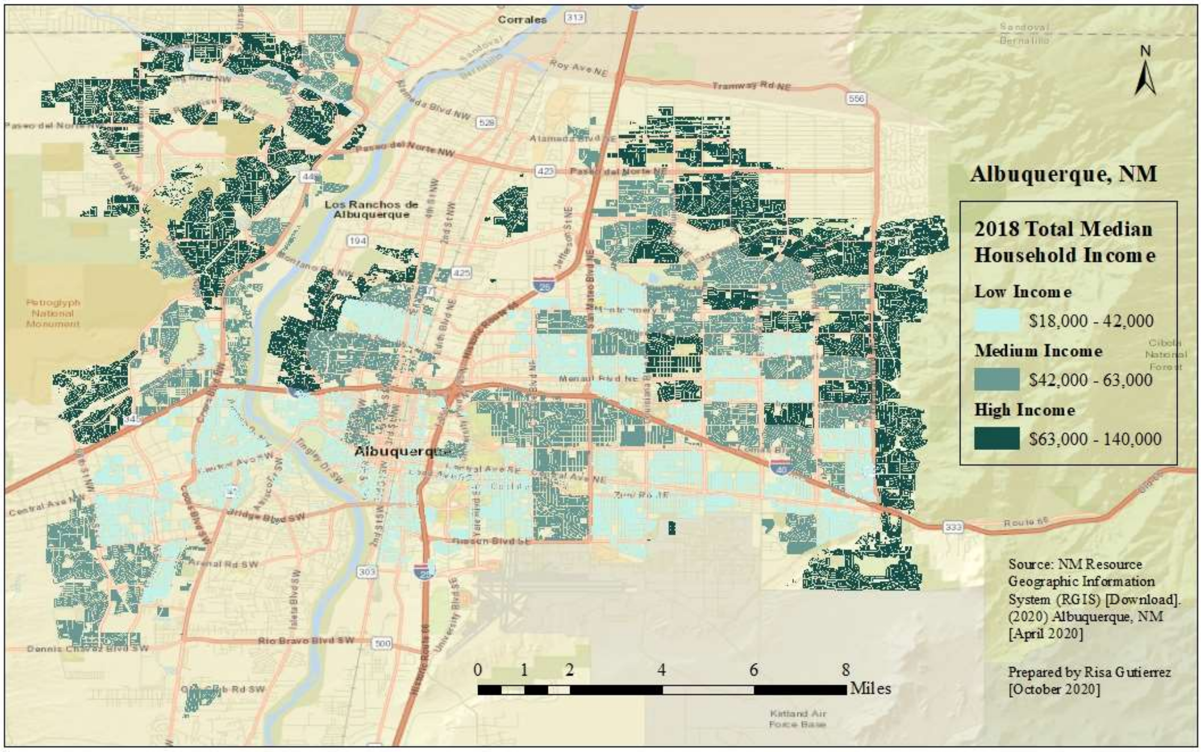


**FIGURE 2.** Median Household Income Distribution for Albuquerque Census Tracts in 2018

The boundaries between the census tracts that comprise each of the three income layers were dissolved to create a single polygon for each income level. The polygons were then used as a constraining feature class. A random sample of points was generated within each polygon, with the selection occurring at a rate of one point per 100 people. Population density is relatively consistent across the city which is why random points were not added to each census tract individually. The low-, medium-, and high-income layers generated 2,056, 2,036, and 2,043 sample points, respectively. These points do not represent specific addresses, but rather geographical coordinates in residential land use. Each point was spatially joined with the original income and population layer for later analysis. Figure 3 displays all 6,131 sample points with their associated income categories.

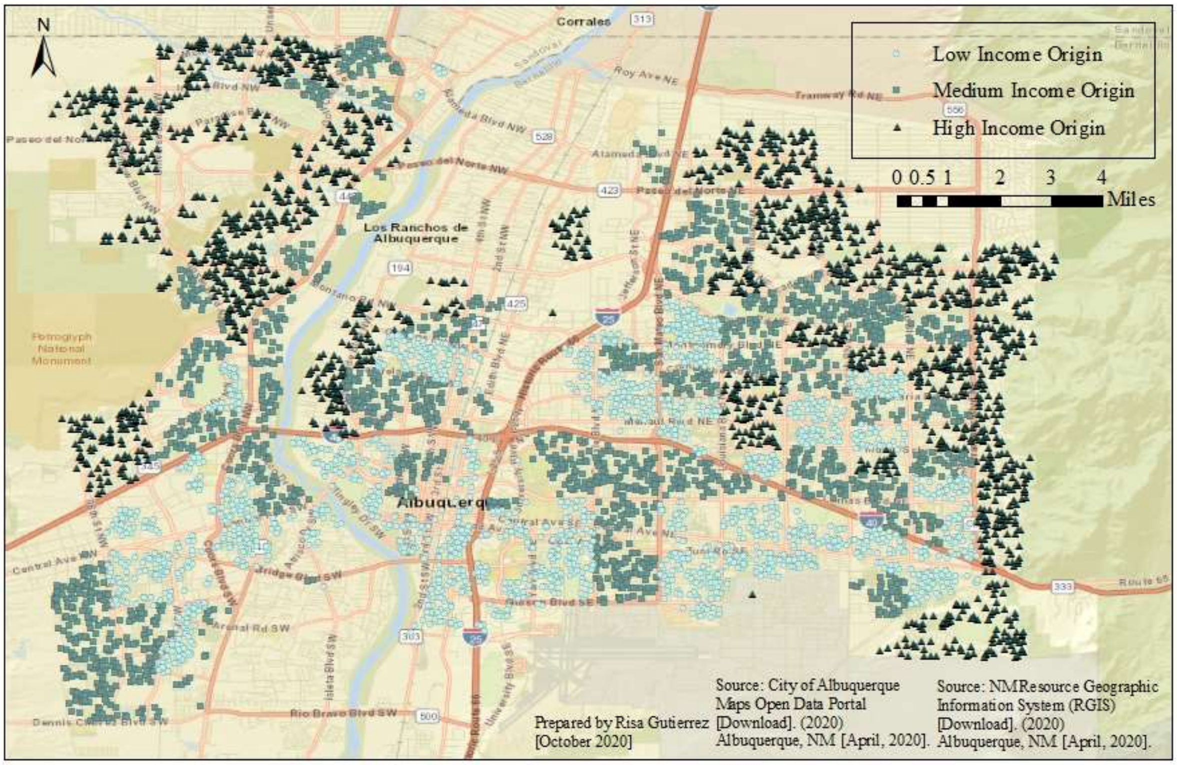


**FIGURE 3.** Low-, Medium-, and High-Income Origin Points Used for Network Analysis

The first step for the network analysis was to create a new network dataset for the streets layer, with each street broken apart at every point of intersection. The ability of the network to model turns was enabled. Elevation was not incorporated into the network analysis command. However, it should be considered as a possible deterrence once areas of concern are identified. The attribute for the network dataset was set to length in miles. A new closest facility command was initiated in order to solve for pedestrian travel paths based on proximity. The "Facilities", also known as destinations, were assigned to the ABQ Ride bus stop layer. The "Incidents", also known as origins, were assigned to the newly created low-income residential points layer. The solve command was activated and GIS routes were generated from each origin to each destination. The routes were exported and saved as a new layer. Although the

GIS software refers to these distances as “routes”, for the remainder of this analysis they will be referred to as “paths” to provide distinction between existing ABQ Ride bus routes. This process was repeated two more times to obtain the pedestrian travel paths for the medium- and high-income residential point layers. A graduated colors map was created using all 6,131 paths, shown in Figure 4. This map displays accessibility in Albuquerque for residential land use as a whole.

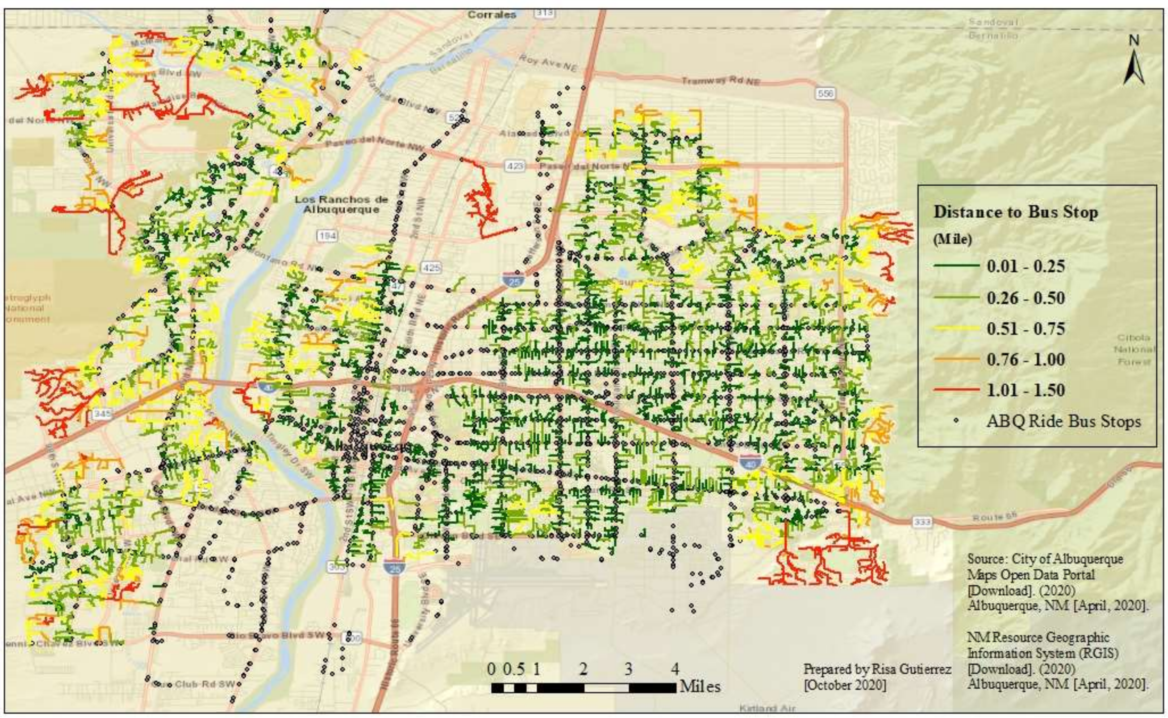


**FIGURE 4.** Proximity from Residential Land Use to ABQ Ride Bus Stops

A linear regression was conducted to determine if there is a statistically significant relationship between median household income and route length. In ArcMap, the “Feature Vertices to Points” tool was used to create a new origin point for each path. This origin point is spatially the same as the random residential point generated earlier. However, these points

now contain the path data. The new sample points were then spatially joined with the census tract data through the income polygon layers. Once each origin point contained a length value and an income value, the data was exported as a comma separated excel file. The software R was used for this statistical analysis and the results will be explained in the next section.

A bivariate choropleth map was generated to simultaneously analyze distance to bus stop and bus headway. To provide a bit of background on this term, a univariate choropleth map uses color to show quantities for one variable within geographic areas such as counties, states, or countries (Stevens, 2015). Choropleth derives from the Greek word "choro" meaning area and "plethos" meaning multitude (Stevens, 2015). A bivariate choropleth map follows the same concept except it shows two variables at once and determines their agreement and disagreement between each other.

The first variable for the map was distance to bus stop. The "Feature Vertices to Point" tool was used again on the 6,131 paths to obtain a point layer containing the end point of the path. A new field titled "variable 1" was created for the end point layer with the following reclassification: "1" = 0.01-0.25 mile, "2" = 0.26-0.75 mile, and "3" = greater than 0.75 mile. The second variable for the map was peak bus headway. The ABQ Ride bus stop layer was spatially joined with the COA ABQ Ride routes layer, which contained the bus headway data. A new field titled "variable 2" was created for the new bus stop layer with the following reclassification: "A" = less than or equal to 15 minutes, "B" = 16-30 minutes, and "C" = greater than 30 minutes. The headway categories were chosen based on the data statistics for the ABQ Ride routes layer. The median headway for all routes was 30 minutes. This became the upper and lower threshold for the medium and long headway ranges. Since the standard deviation was 16 minutes, I subtracted 16 from 30 to obtain a lower threshold value of 14 minutes. After

inspection of the data, I decided to include 15 minutes values in the lower headway category to create a more even distribution.

The reclassified bus stop layer was spatially joined with the reclassified end of path distance layer. A new field was created in the attribute table in order to combine variable 1 with variable 2. This calculation produced nine possible results: A1, A2, A3, B1, B2, B3, C1, C2, and C3. Figure 5 visually displays this process and indicates what each output represents. The darker the pink, the farther the distance. The darker the green, the longer the bus headway. White represents short distance and short wait time. Dark blue represents long distance and long wait time. The finished map will be shown in the results section.

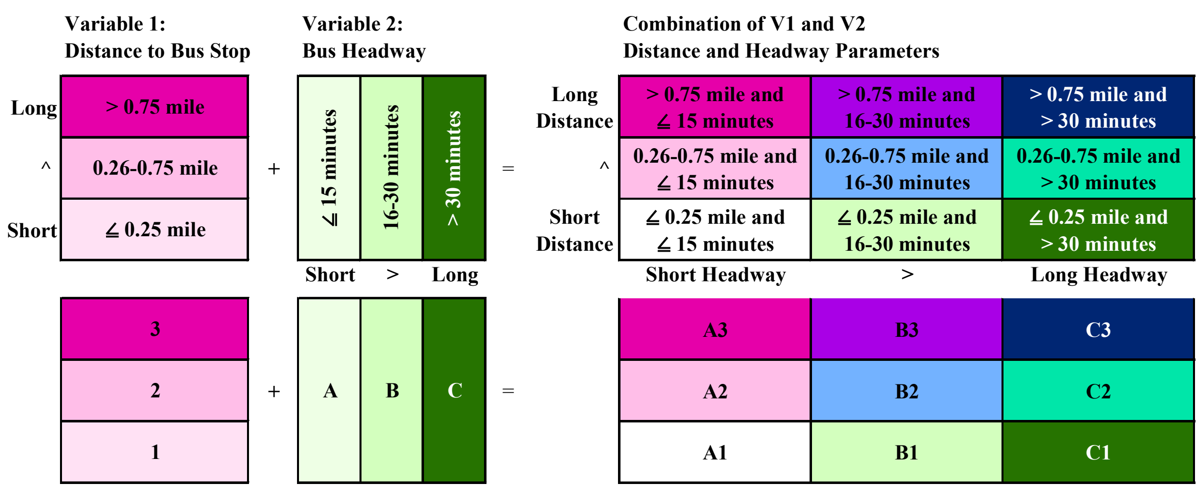


**FIGURE 5.** Bivariate Choropleth Process (Stevens, 2015)

## 4. RESULTS

Figure 4 displays the network analysis results classified into five color-coded categories. Distances less than or equal to 0.50 miles are shown in dark and light green, while distance between 0.51 and 0.75 miles are shown in yellow. The orange and red categories indicate the farthest distance to bus stop at a range of 0.76 to 2.5 miles. Transit ridership typically declines as distance to bus stop increases. Therefore, green paths are more desirable than yellow, orange or red paths. The overwhelming amount of light and dark green displayed in Figure 4 suggests that the sample produced a large number of paths equal to or less than 0.50 miles from ABQ Ride bus stops. The dark green areas are concentrated primarily east of I-25, between Montgomery Blvd and Central Ave, as well as downtown Albuquerque. As expected, paths greater than 1.0 mile are mostly located along the perimeter of the city. Table 3 and Figure 6 detail the summary statistics for each distance category based on number of paths.

**TABLE 3.** Summary Statistics for Distance to Closest Bus Stop

| *Distance to Closest Bus Stop (Miles)* | *Number of Paths* | *Percentage of Total* |
|---|---|---|
| ***0.01-0.25*** | 2,882 | 47.0% |
| ***0.25-0.50*** | 1,956 | 31.9% |
| ***0.51-0.75*** | 717 | 11.7% |
| ***0.76-1.00*** | 276 | 4.5% |
| ***1.01-2.50*** | 300 | 4.9% |
| ***TOTAL*** | 6,131 | 100.0% |

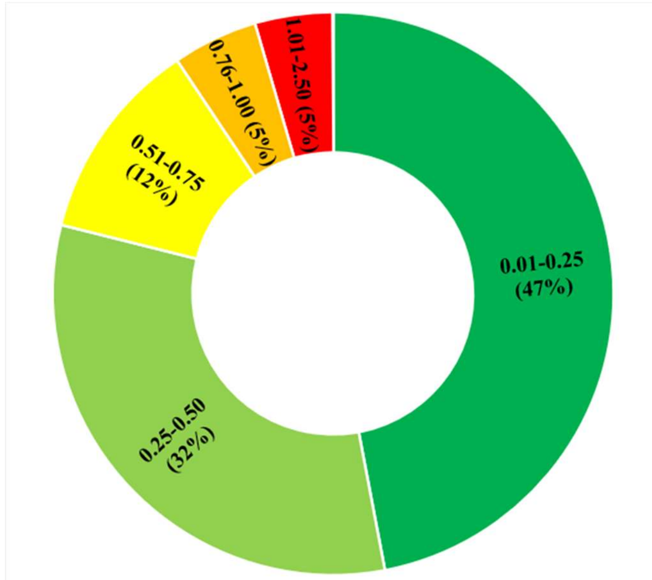


**FIGURE 6.** Percentage of Total Paths by Mile Category

Based on the 6,131 sample points, 47% of paths generated are less than or equal to 0.25 miles of a bus stop, 79% are less than or equal to 0.50 miles, and 22% are greater than 0.50 miles. The results indicate that over half of the sample points (53%) are not reasonably located near a bus stop (> 0.25 miles). When assessing moderate proximity (≦ 0.50 miles), the sample points reach just over three quarters.

As previously mentioned, a statistical analysis was conducted to compare the relationship between distance to bus stop and median household income. Based solely on the points in the scatterplot, low-income values are heavily concentrated with short trips as shown in the left half of Figure 7. As income increases, variability in the data and average distance also increases as shown in the right half of Figure 7.

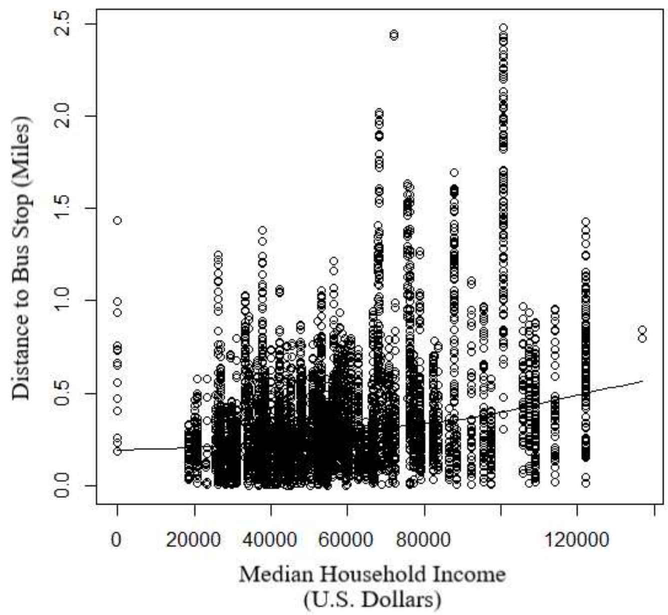


**FIGURE 7.** R Scatterplot for Length in Miles (Dependent Variable Y) and Total Median Household Income (Independent Variable X)

The p-value for the linear regression is $2.2 \times 10^{(-16)}$, indicating that the relationship between the variables has a high level of statistical significance. The regression equation is shown in Equation 1.

$$Distance\ to\ Bus\ Stop = 4.93x10^{-6}(Median\ Household\ Income) + 0.0793 \qquad (1)$$

The adjusted R-squared value for this data is 0.13. About 13% of the change in length of miles is explained by median household income and 87% of the change is due to other variables. Based on the statistical results, it can be stated that distance from residential land use to closest bus stops has a statistically significant relationship to median household income. However, other factors should be explored to determine the other 87% correlation.

Now that all paths have been explored, it is time to separate them by income level (Figures 8-10). As denoted in the legend, green paths indicate close proximity and red paths indicate low proximity to bus stops. Based on visual analysis, high-income areas (Figure 10) contain the most red/dark orange paths. This suggests that high-income areas are less accessible than low- and medium-income areas. The low- and medium-income maps display similar color distribution with mostly green and yellow values and only a few red/orange outliers. Low-income areas (Figure 8) seem to have the most dark/light green areas indicating highest accessibility. However, actual data values should be analyzed before making any definite conclusions.

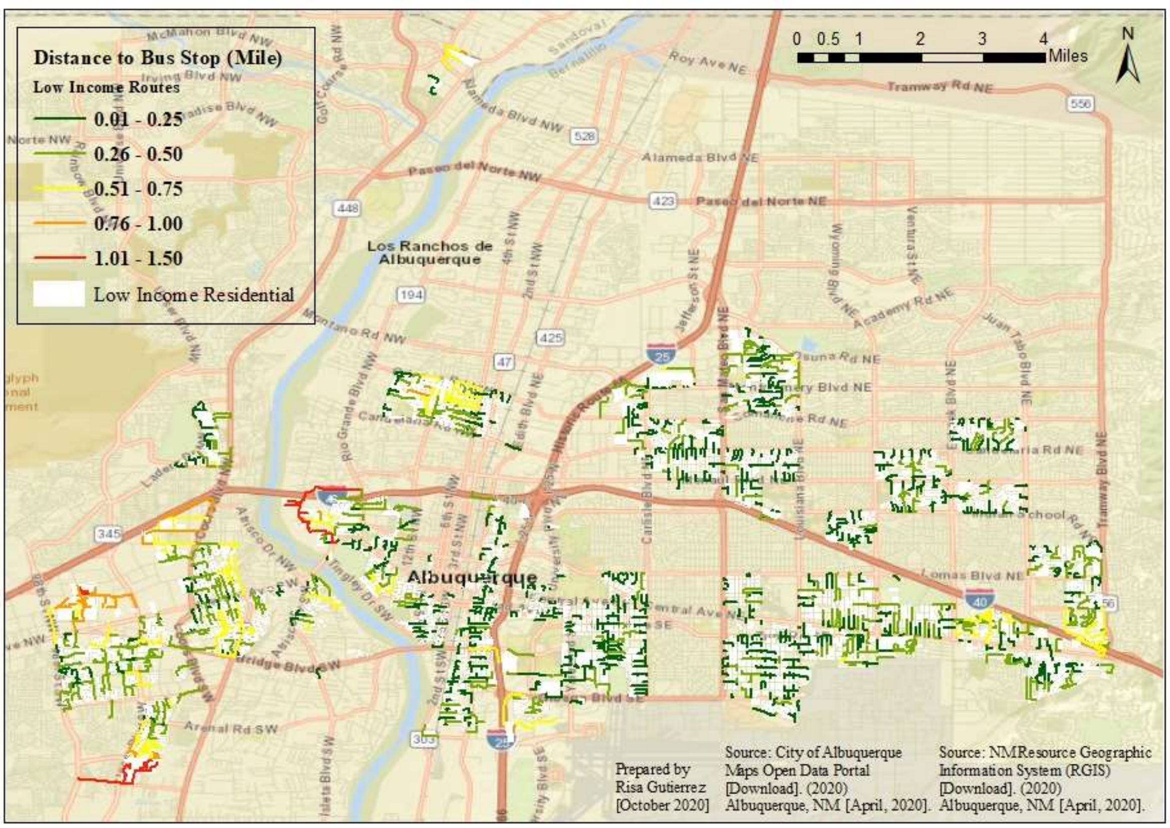


**FIGURE 8.** Low-Income Areas ($18,000-42,000) Proximity to ABQ Ride Bus Stops

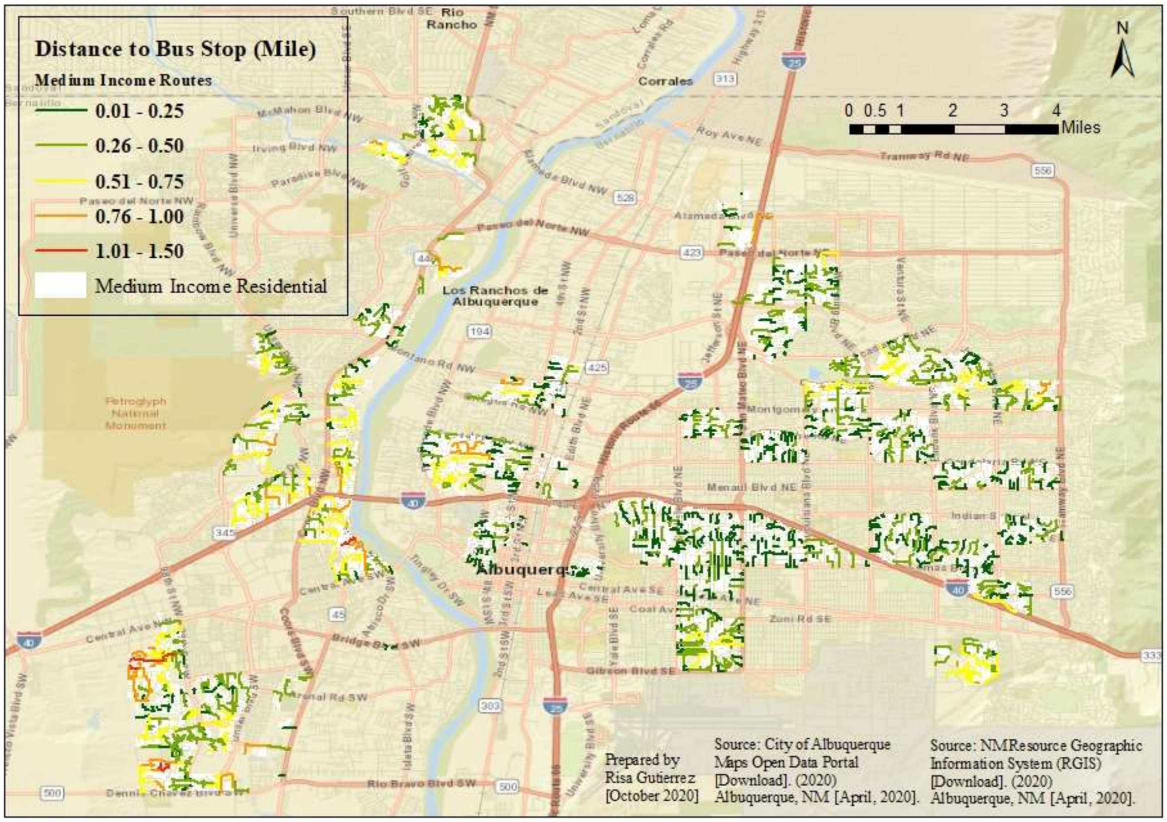


**FIGURE 9.** Medium-Income Areas ($42,000-63,000) Proximity to ABQ Ride Bus Stops

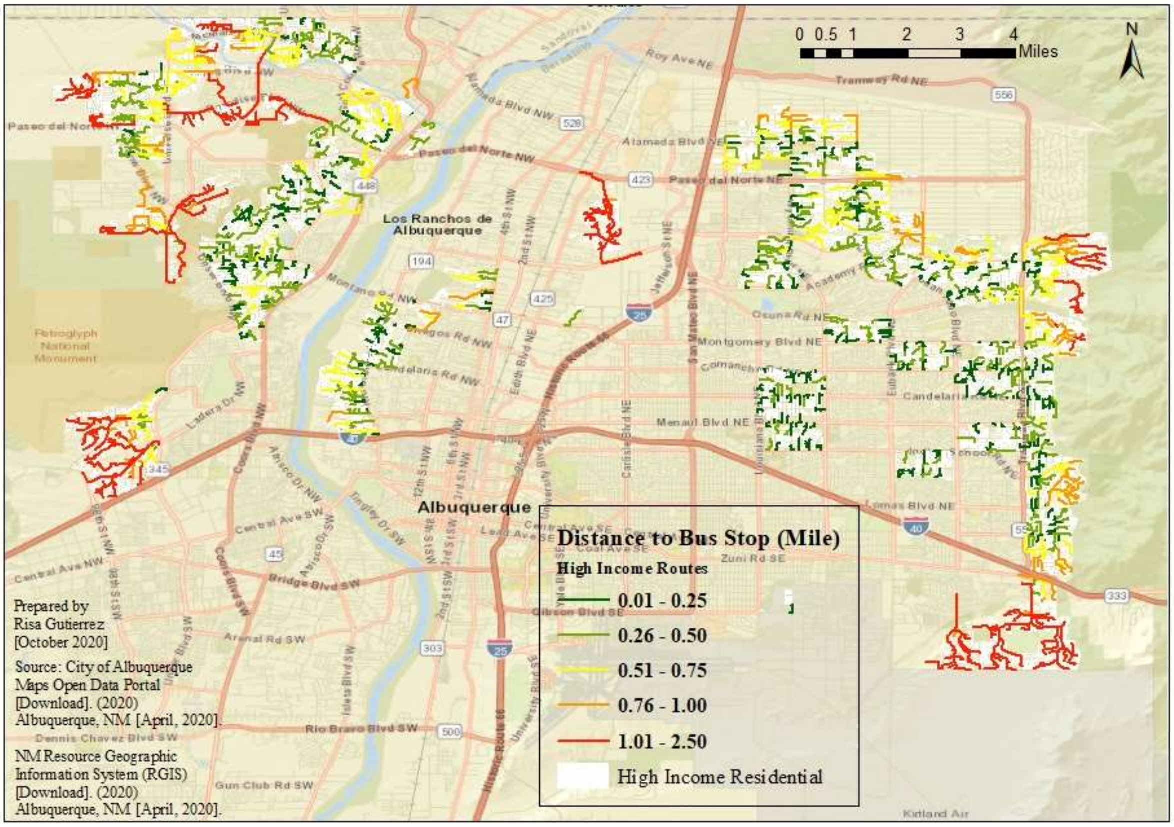


**FIGURE 10.** High-Income Areas ($63,000-140,000) Proximity to ABQ Ride Bus Stops

To better compare the network analyses, the summary statistics for each map were combined into Table 4. The maximum distance is greatest for high-income at 2.48 miles, followed by low-income at 1.38 miles and then medium-income at 1.22 miles. Low-income and medium-income have similar mean values at 0.26 miles and 0.31 miles. High-income however, has a much higher mean with 0.51 miles. High-income has a large standard deviation of 0.45 miles, indicating there is large variation between data points. Coefficient of variation percentage values were calculated by dividing the standard deviation by the mean to compare the differences in data spread between the three income categories. High values indicate more dispersal among data points. High-income has the highest coefficient of variation at 88%.

**TABLE 4.** Summary Statistics for the Three Income Distance to Bus Stop Layers

| *(Miles)* | *Low-Income ($18,000-42,000)* | *Medium-Income ($42,000-63,000)* | *High-Income ($63,000-140,000)* |
|---|---|---|---|
| ***Minimum*** | 0.00 | 0.00 | 0.01 |
| ***Maximum*** | 1.38 | 1.22 | 2.48 |
| ***Mean*** | 0.26 | 0.31 | 0.51 |
| ***Standard Deviation*** | 0.20 | 0.20 | 0.45 |
| ***Coefficient of Variation*** | 77% | 65% | 88% |

Figure 11 compares the percentage of low-, medium-, and high-income paths for the distance range 0.01 to 0.50 miles. 61% of low-income paths, 46% of medium-income paths, and 34% of high-income paths are within the 0.01 to 0.25 miles range. These distance ranges are the most valuable to inspect because they define reasonable and moderate proximity. As previously discussed, people are not likely to use a bus stop that is located greater than 0.50 miles. Figure 11 illustrates much more accessible the low-income paths are in comparison to the medium- and high-income paths.

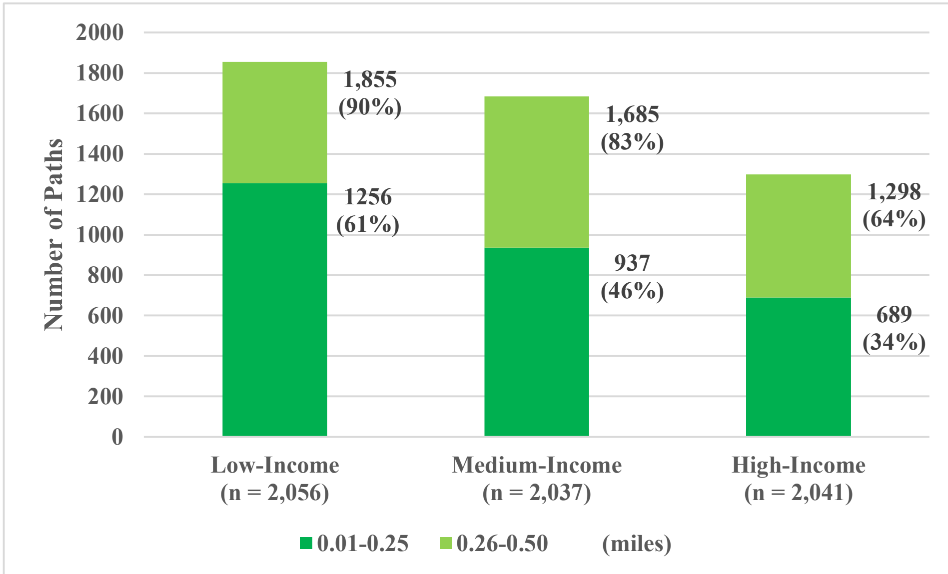


**FIGURE 11.** Low-, Medium-, and High-Income Paths ≦ 0.50 Miles

The path data was once again manipulated for visual analysis, this time into three histograms (Figure 12). The x-axis was formatted to display intervals of 0.15 miles for equal comparison of income class. Low-income has the highest count for any category with approximately 800 points for the distance range 0.15-0.30 miles. The high-income bars are shorter than the low- and medium-income bars which again, indicates high variability in the data with a greater standard deviation. Results from Figure 11 and Figure 12 suggest that low-income areas are the most accessible based on our sample size, but are closely followed by medium-income origins.

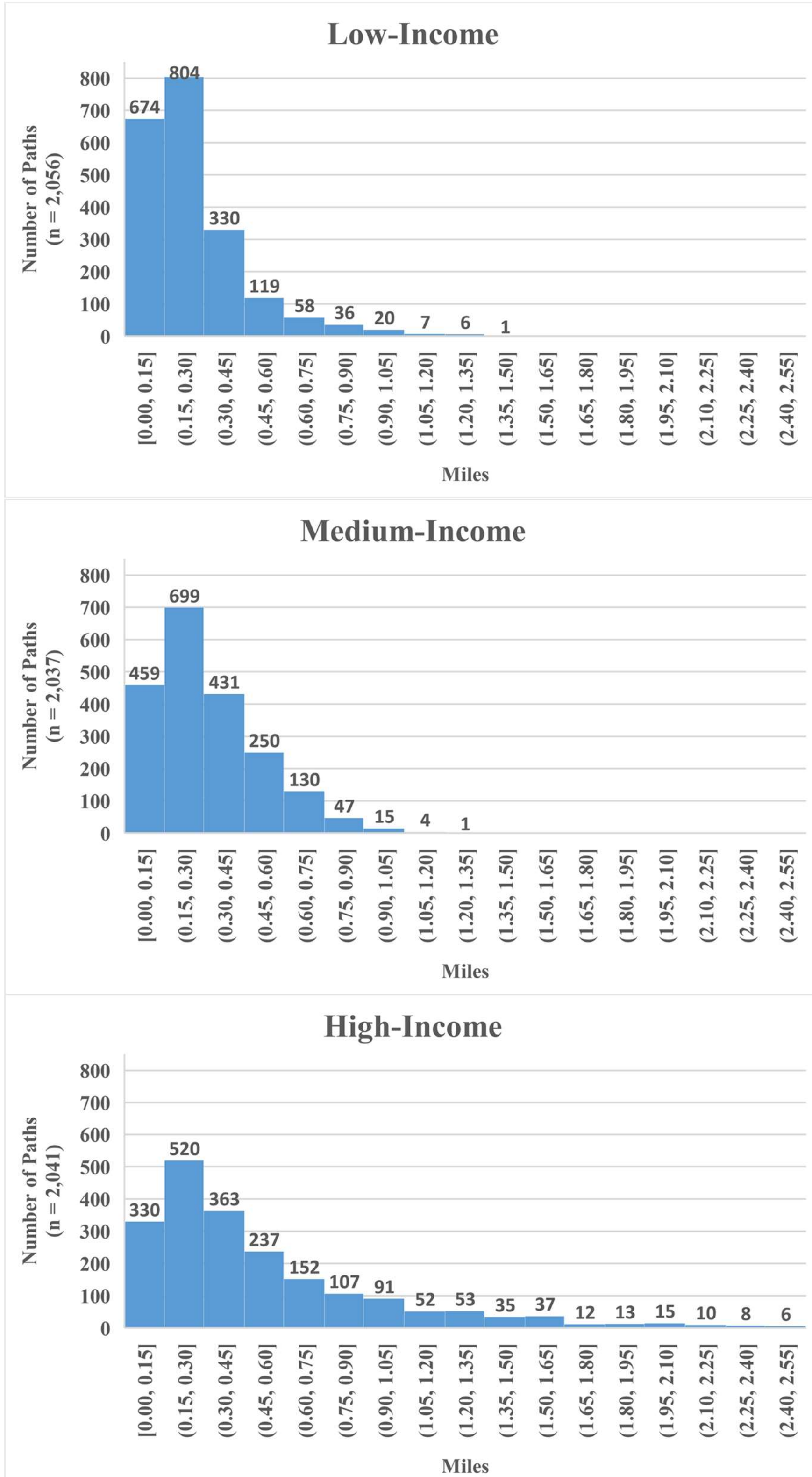


**FIGURE 12.** Histograms Displaying Path Distribution for Each Income Class

The bivariate choropleth analysis compares the relationship between distance to bus stop and bus headway (Figure 13). As indicated in the legend, the left column represents a high bus headway (short wait time) but varies up and down based on distance. The right column represents a low bus headway (long wait time) and again, varies up and down by distance. The top row represents a long distance from origin to bus stop and varies left to right by bus headway. The bottom row represents a short distance from origin to bus stop and again, varies left to right by bus headway. Pink values mean the data strongly reflects variable 1, distance to bus stop. Green values mean the data strongly reflects variable 2, bus headway.

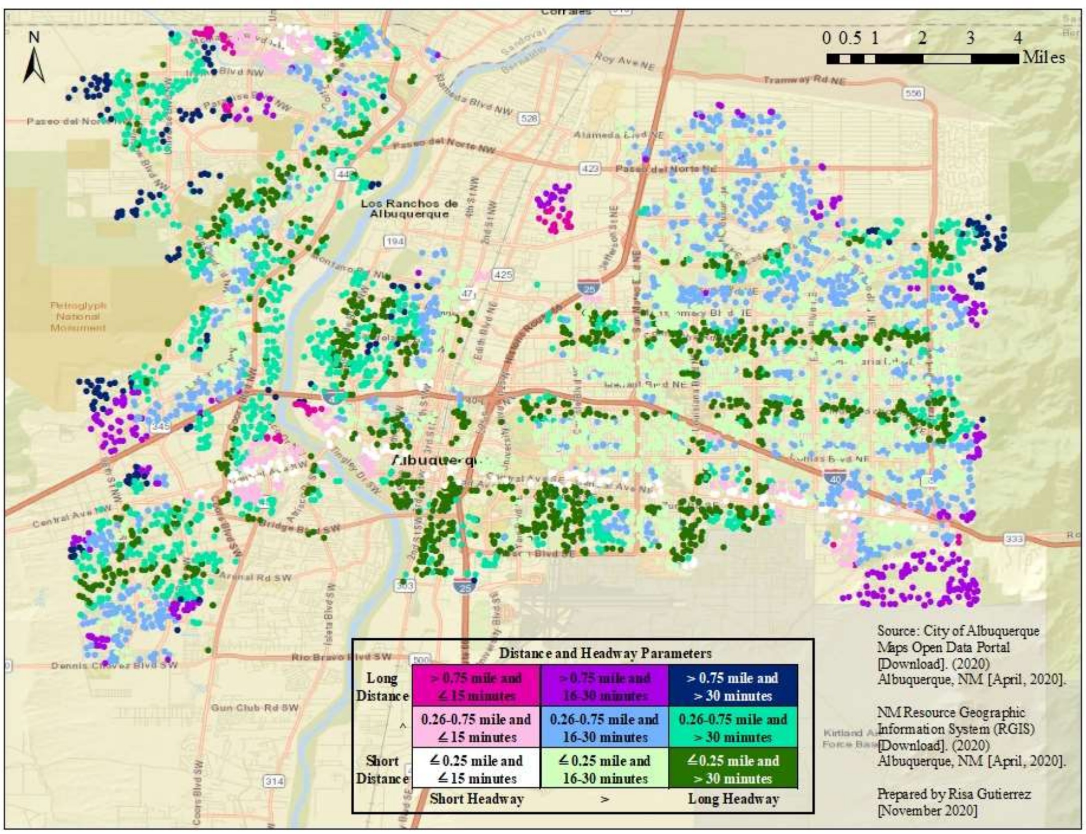


**FIGURE 13.** Bivariate Choropleth Comparing Distance to Bus Stop and Bus Headway

The white dots are primarily located along Central Avenue, as well as the residential housing north of Mc Mahon Blvd and east of Unser Blvd. People living in these areas are in close proximity to bus stops and the buses arrives frequently. The dark blue dots are primarily present in High Desert (NE heights), Ventana Ranch (NW corner), Vista Vieja (west of Unser Blvd.), and Del Webb at Mirehaven retirement community (south of Petroglyph National Monument). These residential locations are farther from bus stops and have a longer bus headway. Figure 14 details the bivariate choropleth results, first grouped by distance to bus stop and then by bus headway.

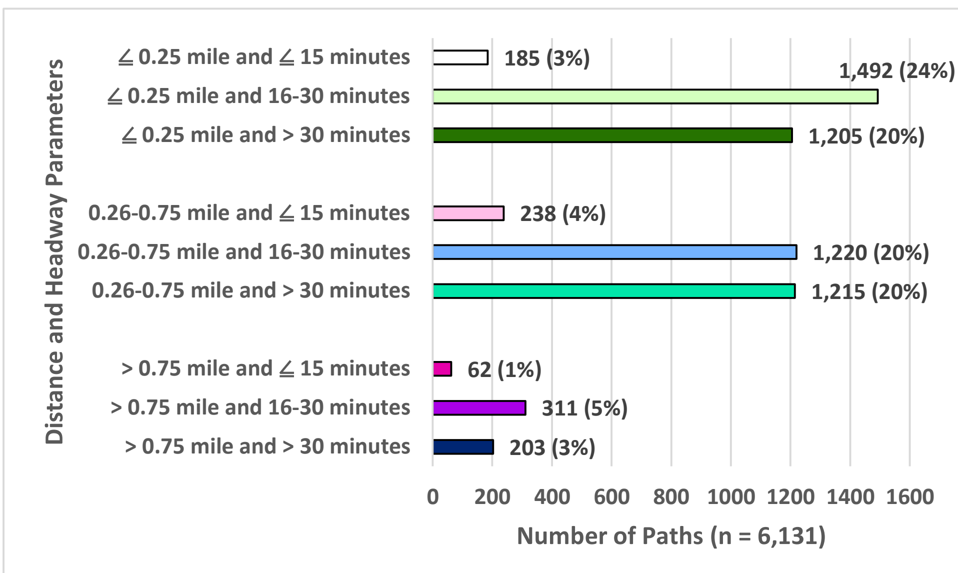


**FIGURE 14.** Bivariate Choropleth Results

Light green dots, representing short travel distance and medium bus headway, dominate the map with 1,492 paths (24%). Light blue dots, representing medium travel distance and medium bus headway, are also vastly represented with 1,220 paths (20%). It makes sense that the majority of paths would be located in the middle range parameters with a headway of 16-

30 minutes and a distance of 0.75 miles or less. The next highest classifications were teal with 20% and dark green with 20%. These colors represent wait times longer than 30 minutes and distances less than or equal to 0.75 miles. The smallest grouping of paths belonged to dark pink, representing long distances and short wait time, with 1% of the total number of paths.

## 5. DISCUSSION

The network analysis revealed that the worst bus stop distance and bus headway combination appears along the edges of the city. In general, there are more challenges connecting housing developments as they sprawl outwards. Newer medium- to high-income residential areas are commonly comprised of cul-de-sacs and dead-end streets. This contributes to a less connected street network and longer paths to the nearest bus stop. Lower-income areas are typically closer to transit facilities, to downtown, and to original city development.

A bus is not a viable mode option unless you can access the bus stop with relative ease, the bus arrives when you need it to, and it takes you to where you need to go. The bivariate choropleth map is helpful for assessing bus stop accessibility because it incorporates two variables of travel time simultaneously. Additional travel time will correlate with poor accessibility, whether that additional time comes from walking to a farther bus stop or waiting longer for a bus to arrive. Figure 13 provides guidance as to where Albuquerque should allocate transit improvement resources. It is clear that dark blue areas are the worst in terms of distance and wait time. The next categories of concern are purple with long distance and medium weight time and teal with a long weight time and medium distance. However, do these areas of town necessarily need better transit infrastructure? The dark blue and purple areas are located primarily in higher-income neighborhoods. High-income residents can mostly likely afford to own personal vehicles. Auto-centric neighborhoods will have a lesser need for improved public transportation facilities than low-income neighborhoods who solely rely on public transit for mobility. Figure 15 displays a bivariate choropleth map comparing distance to bus stop and bus headway for only low- and medium-income residential areas. This provides a narrowed focused for where improvement resources should be allocated.

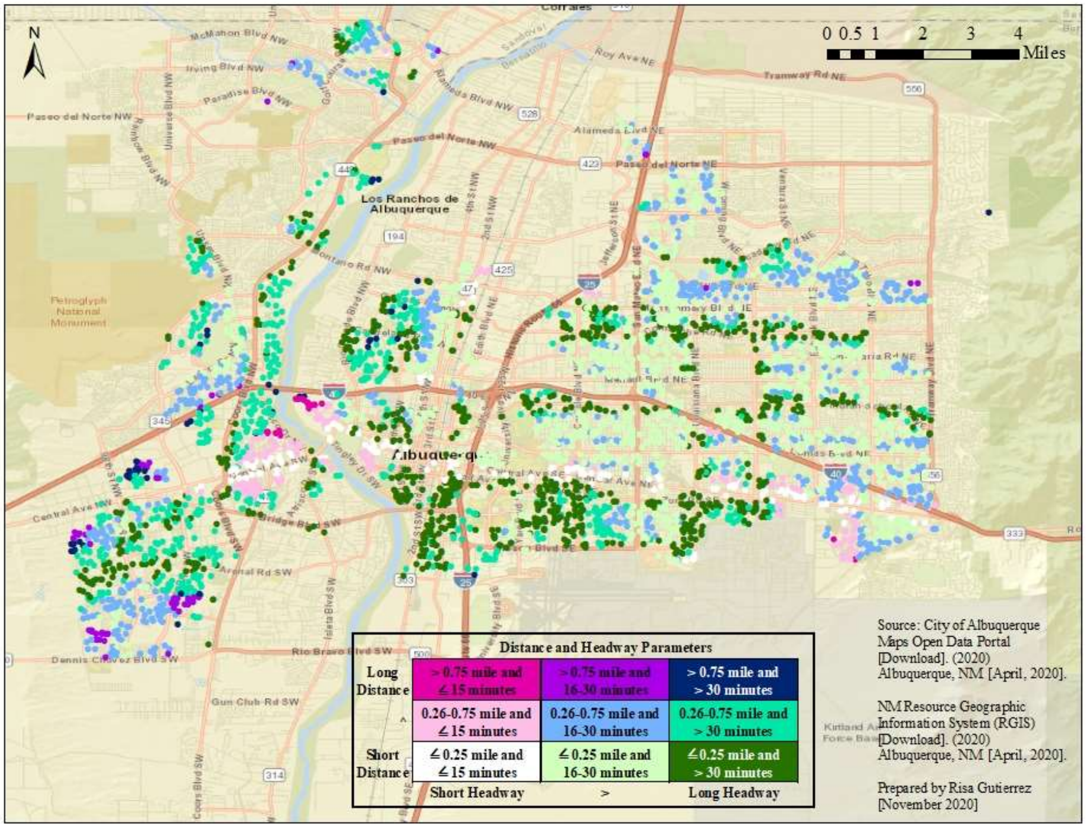


**FIGURE 15.** Bivariate Choropleth Comparing Distance to Bus Stop and Bus Headway For Only Low- and Medium- Income Areas

Dark pink areas have short wait times but their distance to the nearest bus stop could be improved. One solution is to add more bus stops near dark pink residential areas. Dark pink areas include the West Mesa and West Old Town neighborhoods, which are south of I-40 near Coors Boulevard (Figure 15). There are also two dark pink data points located on the southeast side of the city near Central Avenue and Eubank Boulevard (Figure 15). Dark green areas on the other hand, provide a short commute to the bus stop (< 0.25 miles) but the wait time exceeds 30 minutes. One solution to improve headway issues is adding more busses along the paths near dark green areas. Dark green areas represent 22% of the residential points shown in Figure

15, for analyzing only low- and medium-income households. There are large groupings of dark green in the following areas:

- Along Comanche Road
- Along Indian School Road
- In between Central Avenue and Gibson Boulevard
- The South Broadway neighborhood near I-25 and Bridge Boulevard
- The Westgate Heights neighborhood in the southwest corner of Albuquerque
- Neighborhoods east of Rio Grande Boulevard on the N/S side of Griegos Road

With such a large range of locations, additional factors such as population and ridership should be taken into considerations to further narrow the locations based on need. Light pink, light green, and light blue areas are less of a concern because they have average lengths and average wait times. As previously mentioned, white areas are the best locations in terms of proximity to bus stop and bus headway meaning they will not need distance or headway improvements.

Housing and public transportation policy can continuously be improved to meet the equity goals of a city. Among the benefits previously mentioned, public transit can be essential for connecting people with job opportunities. Efficient and reliable transit services in low-income land use can significantly improve the economic condition of many residents *(Welch, 2013)*. Albuquerque policies should put a large emphasis on high connectivity and accessibility to bus stop in low-income neighborhoods. Transit stops should also ensure connection to meaningful destinations. In addition to enhancing transit facilities, Albuquerque should reconsider the value of transit-oriented development. Rather than moving bus routes or adding more busses in the outskirts of town, we should move people back into the city to create a rich,

diverse, and dense atmosphere. More affordable housing should be built near existing transit routes. With the implementation of quality public transportation programs, and the engagement of local neighborhoods, access and mobility can improve for the benefit of all transportation users.

## 5.1. Assumptions and Future Work

A few key assumptions were included in this analysis and can be the basis for future work. The first main assumption is that once you reach the closest bus stop, that you are easily able to reach your destination. This research only focused on the home to facility segment of a trip. Destination was not factored into the analysis due to its complexity and unpredictability. More data is needed to determine if people can adequately reach their desired destinations.

Another assumption made is that the entire city is using the fixed-route bus service at the same necessity. Future research can investigate how many boardings are occurring in low-income neighborhoods versus medium- and high-income neighborhoods. Is there a statistical relationship between ridership and distance to bus stop or ridership and bus headway? As previously mentioned, low-income areas are typically located closer to historical development, which was based on transit as a main mode of transportation. Number of passenger boardings in relation to spatial location within Albuquerque would be a path for future work.

As mentioned in the literature review, ABQ Ride's paratransit service was not included in this analysis. Future work should incorporate an assessment of Sun Van's service to determine if it is adequately serving the community's needs. Paratransit capabilities should be noted as important aspects to the accessibility of public transit as a whole.

In addition to assessing Sun Van's service, future work should incorporate how Albuquerque's transit accessibility relates to Americans with Disabilities Act (ADA). Is Albuquerque's infrastructure in low-income areas more or less ADA compliant than infrastructure in medium- to high-income areas? If any ADA deficiencies exist in low-income areas, do they negatively affect the accessibility to bus stops? According to the COA bus stop data layer, 11% of active bus stops do not have a sidewalk, 7% do not have a curb extension, 11% do not have a brail pad, 56% do not have a bench, 77% do not have a shelter, and 67% are positioned in the traffic lane. Future work should extend to these types of factors to discover inadequacy among Albuquerque's transit infrastructure. Being in close proximity to a bus stop with frequent buses is beneficial, unless you cannot get to the bus stop due to physical barriers in the sidewalk. Maybe there is low lighting, 3' sidewalks, 9% slope ramp, and no pedestrian button. Low-income neighborhoods may be accessible according to distance and headway, but not in terms of feasibility. The higher income neighborhoods might have better maintained and newer ADA compliant facilities. These types of transportation equity issues should be addressed and accounted for when allocating city resources.

## 6. CONCLUSION

Based on the network analysis with a sample size of 6,131 residential origins, it can be concluded that low-income areas have better access to ABQ Ride bus stops than medium- or high-income areas. The high-income paths produced a high maximum value (2.48 miles), a high mean value (0.51 miles), and a large coefficient of variation (88%) in comparison to the low- and medium- income paths. Albuquerque does not have reasonable proximity to fixed-route bus service because only 47% of sample paths were located between 0.01 to 0.25 miles from the closest bus stop. The linear regression concluded that there is a statistical significance between distance to bus stop and median household income with a p-value of $2.2\text{x}10^{(-16)}$. According to the adjusted R-squared value, about 13% of the change in length of miles is explained by median household income and 87% of the change is due to other variables.

The bivariate choropleth map provided a valuable comparison of distance to bus stop and bus headway. The map illustrated that only 3% of the sample paths were located between 0.01 to 0.25 miles and had a bus headway less than or equal to 15 minutes. By incorporating the next best option, only 24% of sample paths were located between 0.01 to 0.25 miles and had a bus headway less than or equal to 30 minutes. This suggests a huge area of improvement for the ABQ Ride fixed-route bus service with regards to proximity and headway. The edges of the city produced longer bus wait times and longer distances to bus stops. Those areas are highly contrasted with historic corridors, such as Central Avenue, which produced the shortest bus wait times and the shortest distance to bus stops. According to this network analysis, fixed-route bus service is not very accessible in Albuquerque. This accessibility analysis could be enhanced by factoring in destination, number of boardings, bus transfers, paratransit, ADA compliance issues, and overall transit equity.

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