ASSIGNMENT 10

PEDESTRIANIZATION IN SALT LAKE MSA

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ABOUT THE PROJECT

Our study area is the Salt Lake Metropolitan Statistical Area which includes Salt Lake and Tooele counties. In this project, we will be modelling the pedestrianization of Main Street and closure of the street for cars, to explore how impactful the plan for a permanent pedestrian zone may be. This topic is especially relevant since Open Streets have been implemented all across the country, post-pandemic, and many other cities are also considering similar pedestrianization projects with the success of outdoor dining and retail activities.

Existing Scenario

Main Street is one of the key commercial streets in Salt Lake City with banks, major retailers and a high pedestrian footfall. In a few weeks in September and October 2020, a block on the Main Street was shut down for cars from Thursday to Saturday from 6-10 p.m. Referred to as the Downtown SLC Open Streets program, this was done in an attempt to revitalize the downtown area and encourage patrons. The new spaces created, and outdoor dining and retail services initiated as a result of social distancing requirements due to the pandemic, were leveraged to "expand options for pedestrians" and benefit on-street businesses.

In response to the success of this initiative, it was repeated the next year in April for an expanded stretch from South Temple to 400 South. As before, this aimed to invite pedestrians and support local businesses. This news article reports that Downtown Alliance, the group leading this, is considering asking city to make it a permanent, year-round "pedestrian zone."

Alternative Scenario

In response to the success of a pedestrianization initiative on this street, creation of a permanent pedestrian zone is being considered in the South Temple to 400 South stretch.

We aim to model this alternative scenario where we will close Main Street from South Temple to 400 South i.e., we will model the deletion of this roadway segment for cars. Additionally, to complement the street closure, we will increase the frequency of bus route 200 on a parallel road towards its east, from 15 minutes to 5 minutes headway. Through these transportation network changes, we wish to see the impact of street closure on travel demand and behavior and also if the increased frequency of bus route 200 in this scenario can further support the impact of the closure of Main Street.

Assumptions and Limitations

In our alternative scenario we are not proposing any changes to the population and employment characteristics. We recognize that the transportation network changes described in the alternative scenario above could impact the population and economy in the area as well. For instance, by closing the street to cars, and promoting on-street activities, there may be an increase in commercial activities/services on the street and therefore more jobs and employees. Similarly, the further increase in the frequency of the existing rapid transit line may further impact land use, households, and jobs in the census tracts. However, for the purposes of this modelling assignment/project, we have only considered changes in the inputs identified above and would be treating all other inputs such as land use, population and economic characteristics as constant in the area, to isolate and truly understand the potential impacts of the proposed transportation changes, irrespective of surrounding conditions.

Analysis methodology

In Assignments 2 and 3, we describe the distribution of population and employment across traffic analysis zones within our study area using R. We use census tracts in Salt Lake and Tooele counties as our traffic analysis zones. We start this exercise by isolating the zone boundaries for this MSA and retrieving existing population and employment data (ACS 2019) for census tracts in these two counties for the following variables:

- Total number of households
- Household size composition
- Total number of zero-vehicle households
- Total number of households in multiple income categories
- Total number of employees
- Number of retail employees
- Number of service employees
- Number of basic employees

In Assignment 4, we describe the variations in travel times between the existing and the alternative scenario based on the proposed street and transit network changes by generating travel time skims for four modes - walking, biking, transit and car trips.

In Assignments 5 and 6, we describe and compare the accessibility to employment opportunities through different modes (cars and transit), for every census tract in Salt Lake MSA. We then estimate zero vehicle households in the alternative scenario.

Assignment 7 onwards we begin the four step travel demand modelling process. In Assignments 7 & 8, we detail out trip generation and trip distribution models, the first two steps in the travel demand model. This involves an estimate of the number of trips produced by or attracted to each TAZ, as a function of its socioeconomic characteristics and the number of generated trips travelled between the geographic units or the TAZs in Salt Lake MSA. In Assignment 9, we estimate the mode choice of the distributed trips for our alternative condition based on the existing modeshare model. In Assignment 10, we conclude with an estimate of transit ridership and regional VMT.

HOUSEHOLD ATTRIBUTES

This chapter details out three key household/population attributes and employment characteristics of tracts for the existing scenario in the Salt Lake Metropolitan Statistical Area based on data from ACS 2019.

Household Sizes

The first section is about the data on household sizes, which is a key factor in understanding the population characteristics of any area. There are 395,298 households in Salt Lake MSA. The tree map in Fig.1 below represents the household size composition of the community in Salt Lake MSA. The MSA has about 47% households with 3 or more persons, which could mean that there are significant number of families within the community. Both 2 person and over 4-persons households dominate the composition.

Fig. 1: Household size composition in Salt Lake MSA (ACS 2019)

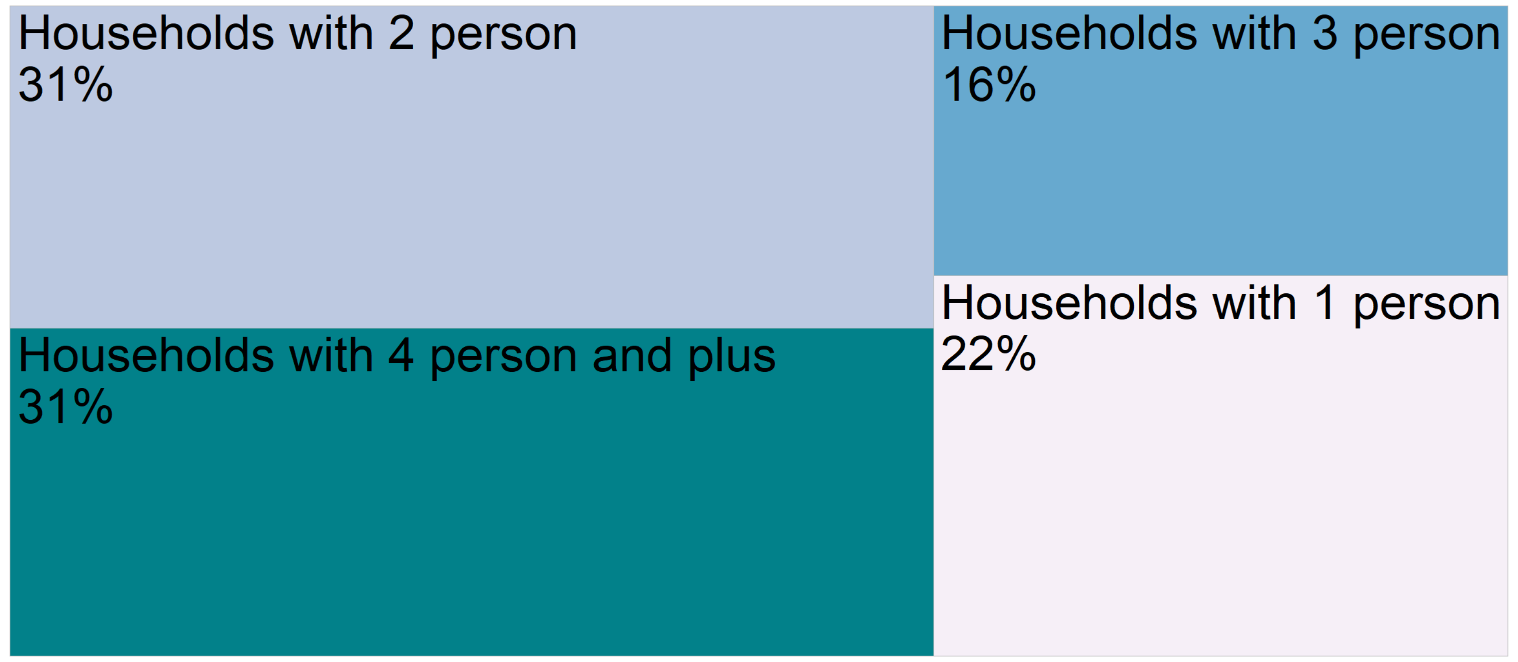
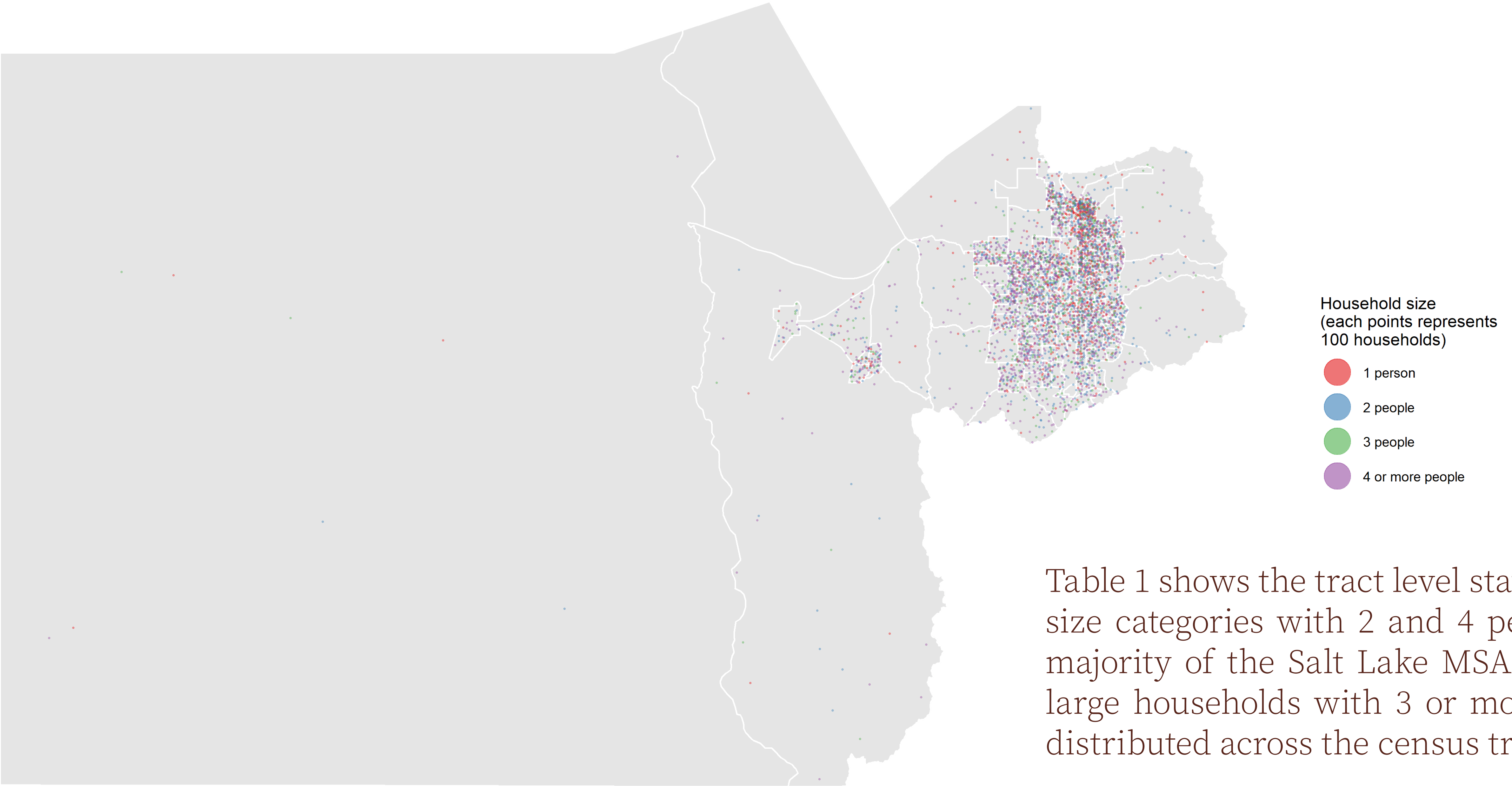


Fig. 2: Distribution of total number of households by household size in Salt Lake MSA (ACS 2019)



The dot density map in Fig.2 above shows the distribution of the number of households at the census tract level. A significant disparity can be seen in terms of the household distribution between the Salt Lake and Tooele counties. The majority of the households in this metropolitan statistical area are concentrated in Salt Lake county.

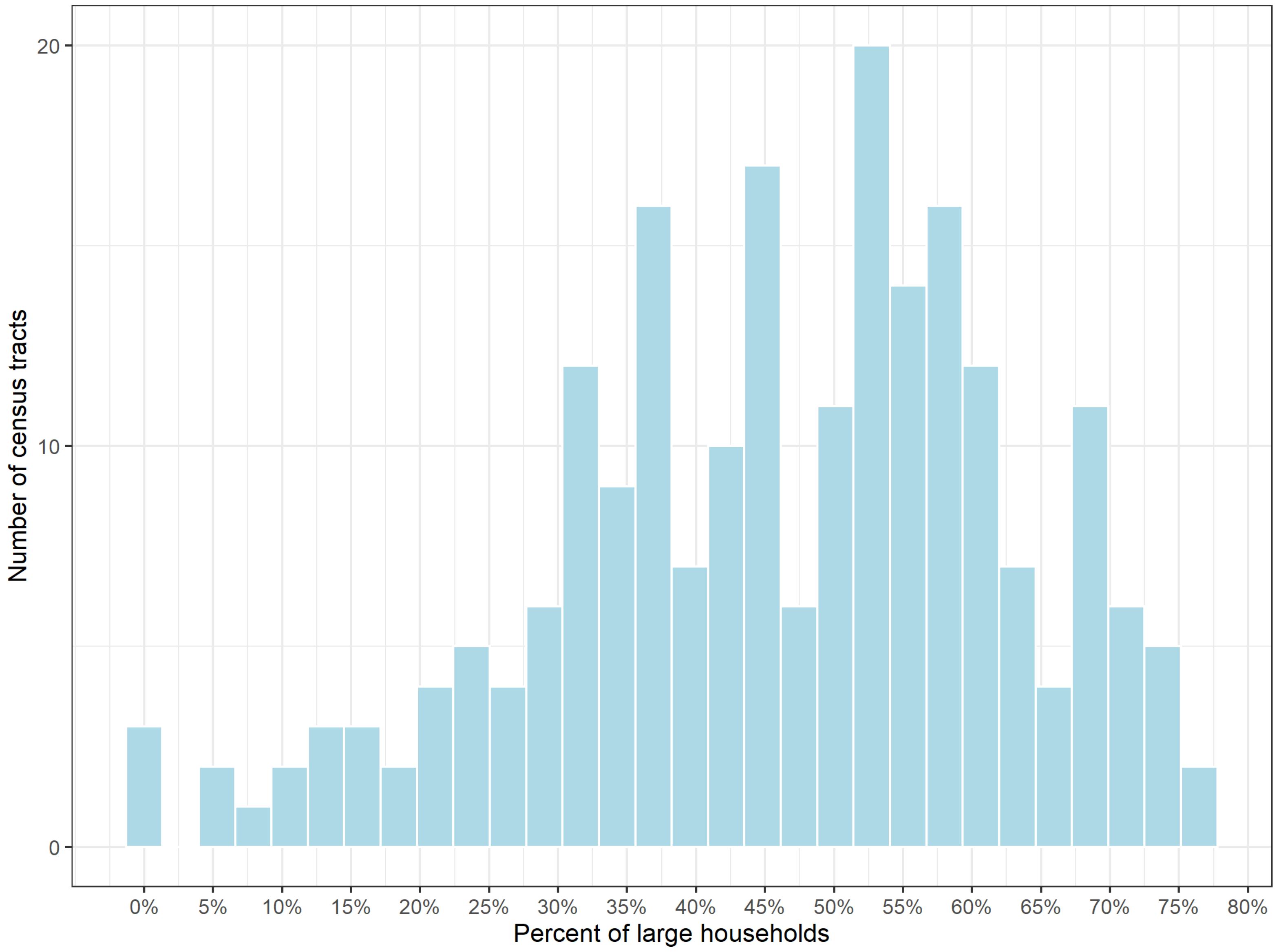
The mean number of total households per census tract is 1773, the median is 1665. However the standard deviation is significant at 878 indicative of the fact that they are probably not a fair representation of the distribution of households across the MSA.

Table 1: Household size distribution - tract level statistics

Household Size	Mean	Standard Deviation	Median
1 person	398	282	317
2 people	541	253	507
3 people	282	162	259
4 or more people	552	461	487

Table 1 shows the tract level statistics for the different household size categories with 2 and 4 peopl households constituting the majority of the Salt Lake MSA community. Fig. 2.1 shows that large households with 3 or more members are fairly normally distributed across the census tracts.

Fig. 2.1: Distribution of large households in Salt Lake MSA



Income Distribution

Another critical population characteristic is household income. The tree map in Fig. 3 represents the household income composition for the overall community in Salt Lake MSA. We created five income categories based on the quintiles obtained from the regional-level data for the MSA. The majority of households i.e., 61 % of the households in the MSA have a household income of over $60,000 (ACS 2019). There is also a significant section of the population in MSA that earns below $ 60,000 which is below the national median income in USA. The dot density map in Fig. 4 shows the spatial distribution of households under different income categories across the MSA. We find a greater concentration of households with higher incomes in the northern region of Salt Lake County.

Table 2: Household income - tract level statistics

Income Category	Mean	Standard Deviation	Median
< $ 35,000	346	242	292
$ 35,000 - $ 60,000	342	196	307
$60,000 - $ 100,000	469	283	421
$100,000 - $ 150,000	341	273	285
$150,000 - $ 200,000	275	257	181

Fig. 3: Household income composition in Salt Lake MSA)

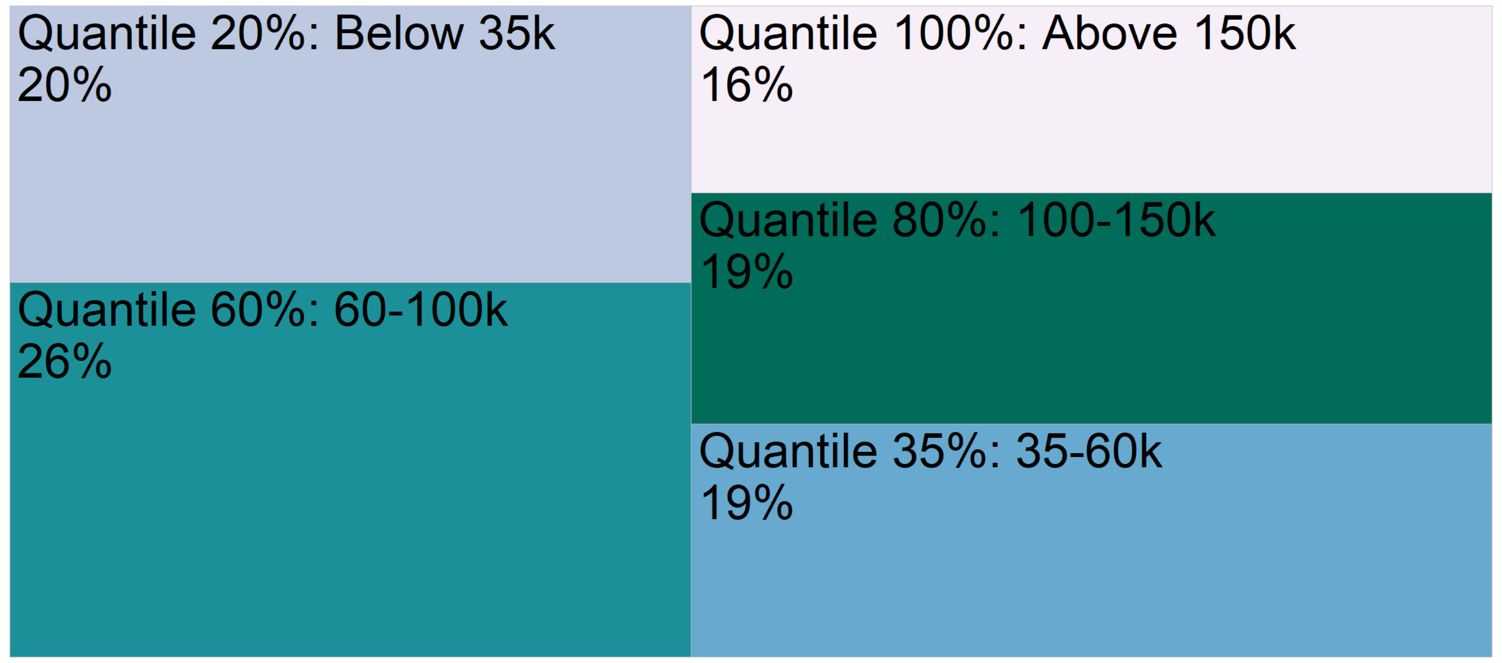


Fig. 4: Distribution of total number of households by household income in Salt Lake MSA (ACS 2019)

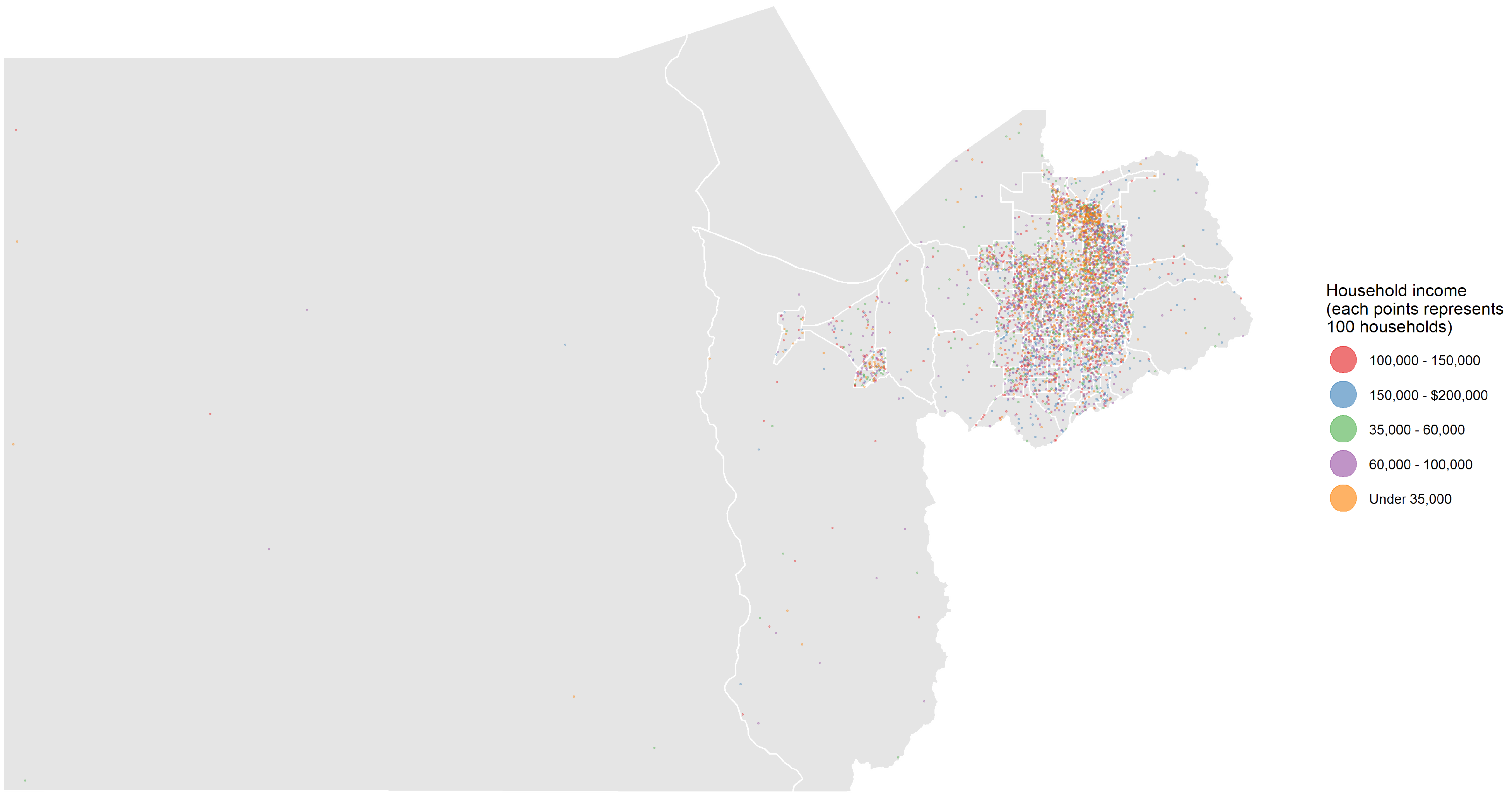


Table 2 represents tract statistics for the household income data and on an average majority of the households were earning $60,000 - $100,000 with an average 469 households per tract and a little under 350 households for the lower two income categories. The standard deviation is significant and so the mean may not be truly representative of the distribution.

In Fig. 3.1 and 3.2, we have visualized the existing data for low and high icome brackets through histograms to better understand their existing distribution. e socioeconomic variables at the household level are fairly normally distributed. It can be seen that they are both fairly normally distributed across the census tracts with majority of the census tracts having 5-10% high income households (those in the fifth income quintile) and 10-15% low income households (those in the first income quintile).

Fig. 3.1: Distribution of high-income households in Salt Lake MSA

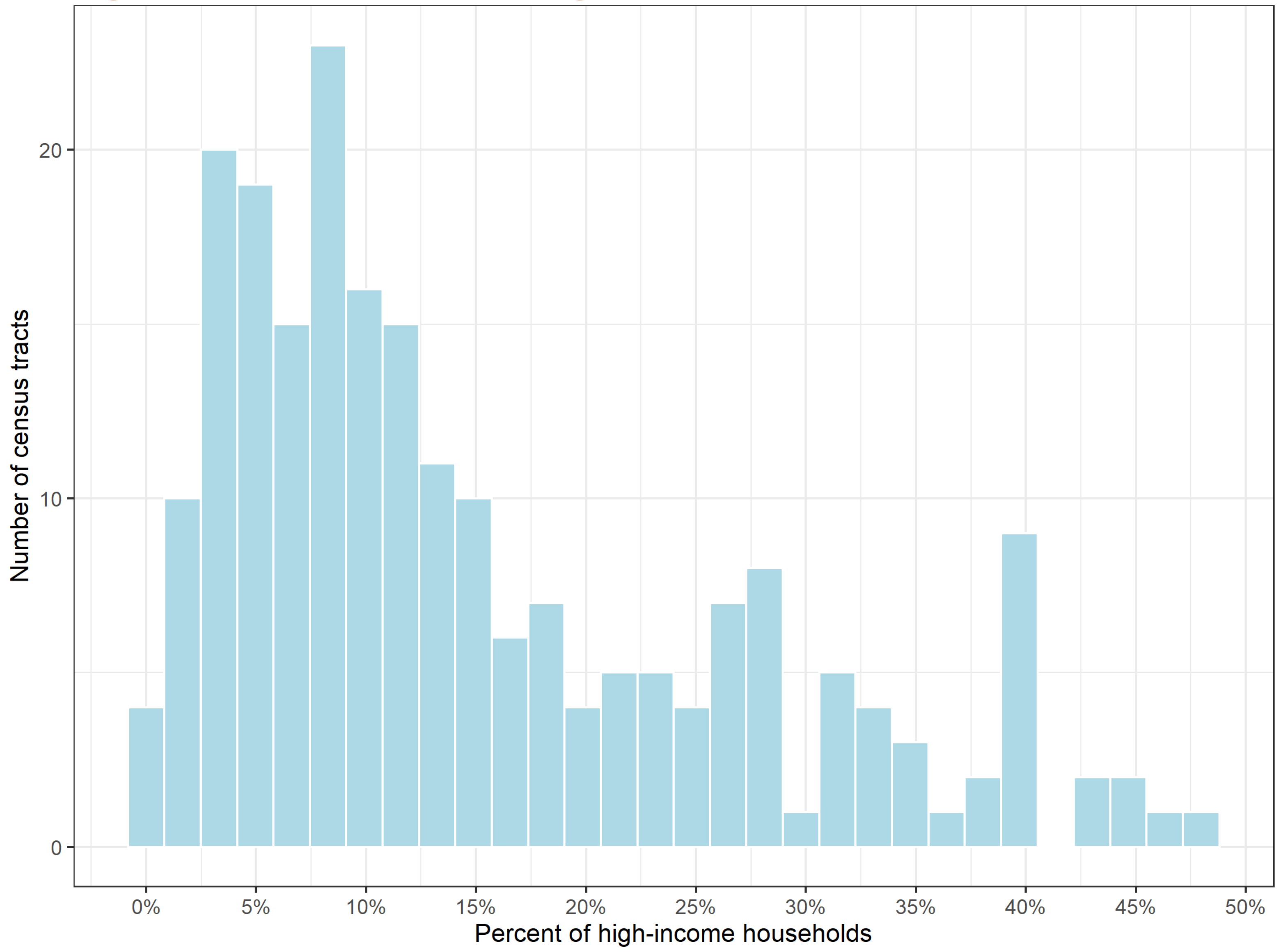


Fig. 3.2: Distribution of low-income households in Salt Lake MSA

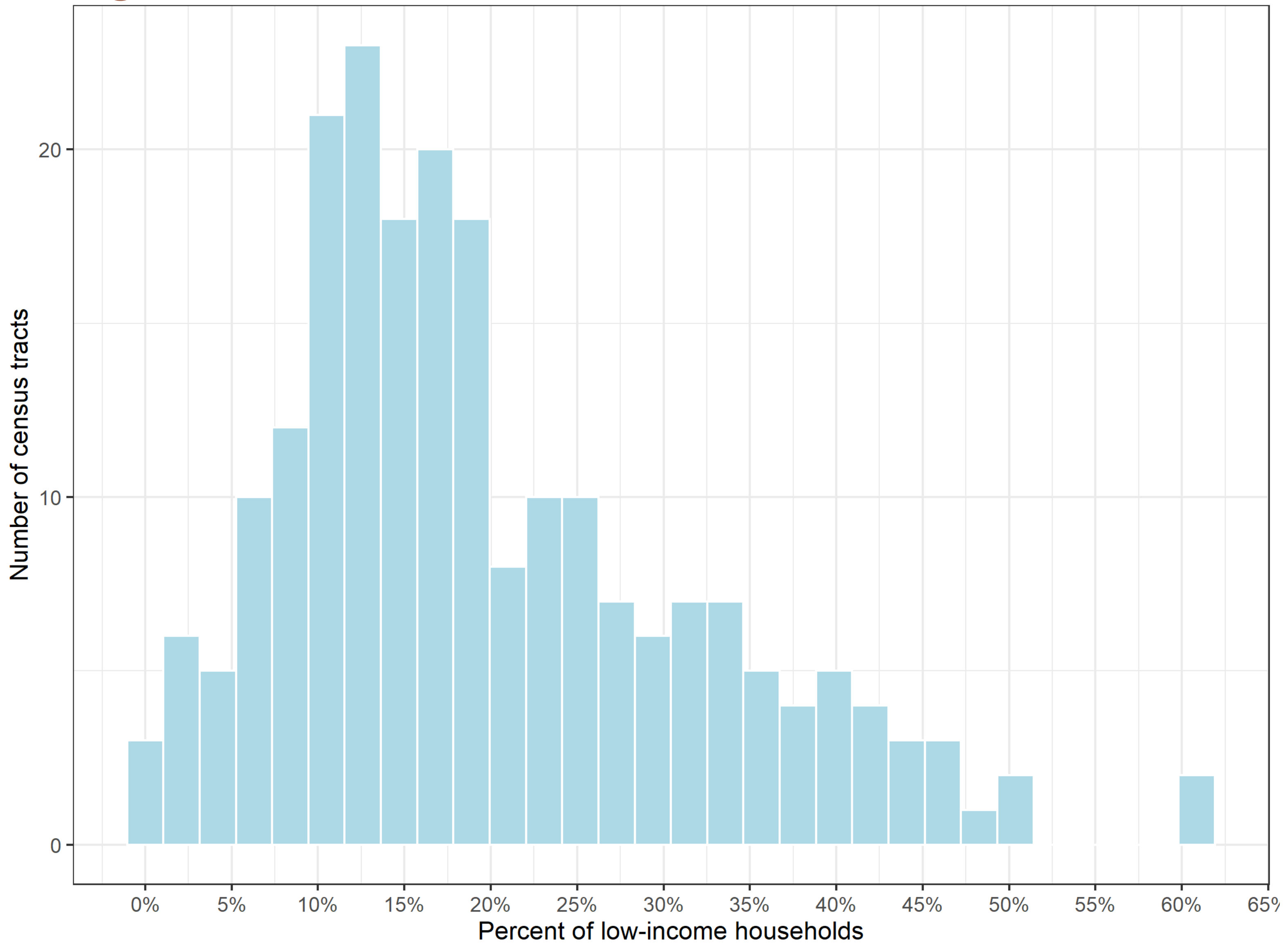
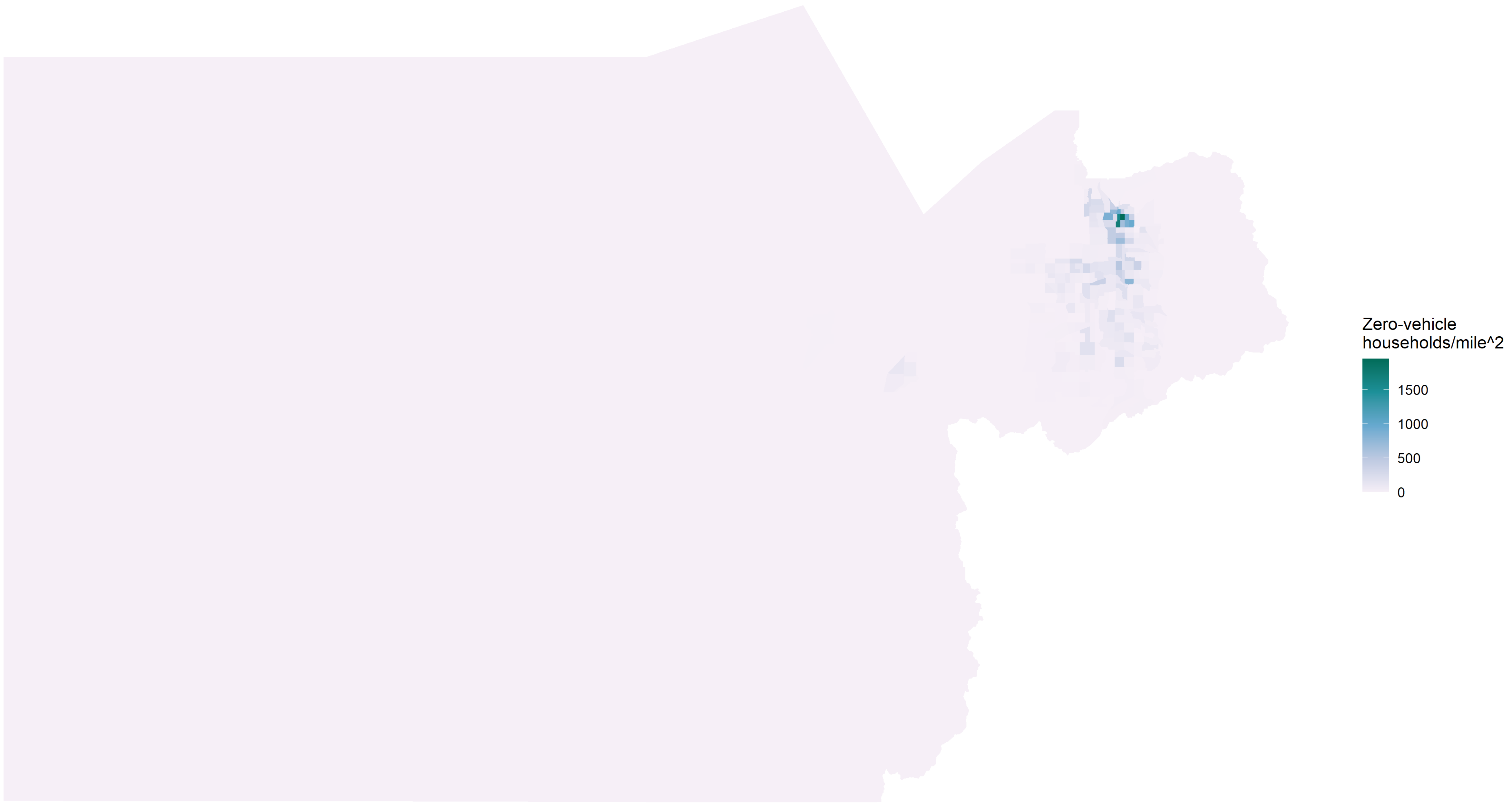


Fig. 5: Density of zero-vehicle households per square mile in census tracts in Salt Lake MSA (ACS 2019)



Vehicle Ownership

The chloropleth map in Fig. 5 alongside represents the distribution of the households at the census tract level with zero-vehicle ownership and shows the density of such householdds per square mile. This is an interesting and relevant variable to consider in our model since we would be pedestrianizing a road section, so we can see the impact on this.

The greatest concentration of zero-vehicle households is in Salt Lake County, specifically in and around the Salt Lake city area which speaks to the land use, activities and kind of development in the area - it could be due to the higher walkability in certain streets/neighborhoods such as downtown. Alternatively, it could be reflective of the income levels of the community in those tracts.

Based on the tract level statistics, the mean number of zero-vehicle households per census tract is 90, the median is 52 and it has a high standard deviation of 106 households.

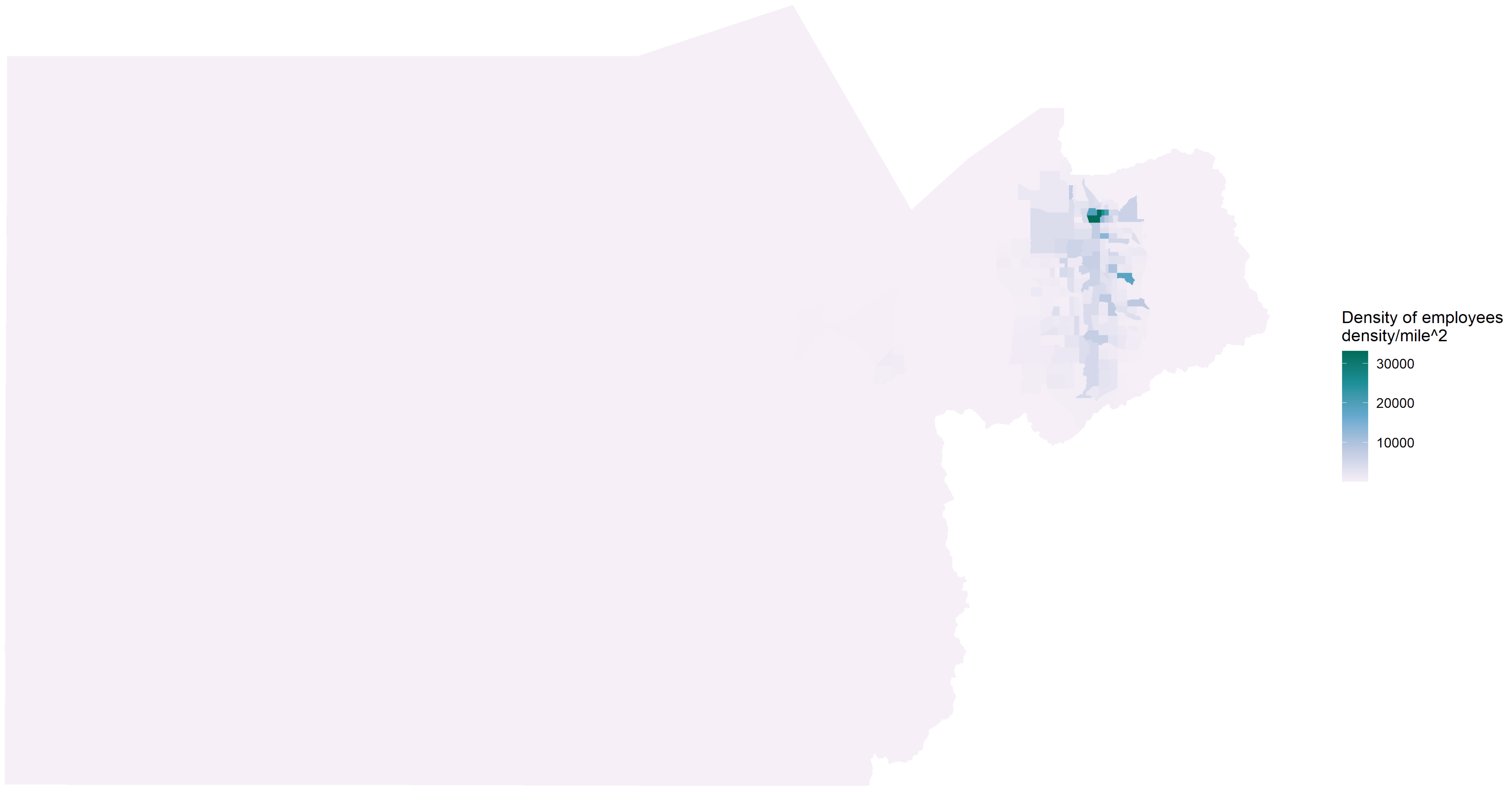
EMPLOYMENT DISTRIBUTION

Employment variables are important for any travel demand model since they result in a majority of trips. For our project focused on pedestrianization of a commercial street, total employment as well employment in retail and service categories would be relevant variables to consider when determining variations in other aspects in our model scenario.

The figures ahead represent employment data from the Workplace Characteristics section in the Longitudinal Employer-Household Dynamics (LEHD) dataset for 2019, and includes information about total employment as well as its constituent categories:

- Basic employment (Agriculture, Forestry, Fishing, and Hunting, Mining and extraction, Utilities, Construction, Manufacturing, Wholesale trade and Transportation and warehousing)
- Retail employment
- Service employment (all the remaining employment figures are included in this)

Fig. 6: Density of total workers/employees in Salt Lake MSA (LEHD, WAC, 2019)



There are 733,400 workers in total in Salt Lake MSA spread across the two counties, largely in Salt Lake County. Service employment is the major employment category with 456,451 workers, i.e., almost 62 percent of total employment. The chloropleth map in Fig. 6 above shows the distribution of the total number of workers at the census tract level in the MSA.

A significant disparity can be seen in terms of the employment distribution between the Salt Lake and Tooele counties, and also within the Salt Lake County, where the employment is concentrated. Maximum employment density is present in the census tracts in the regions in and around West Valley City (approx. 63,500 workers) and Salt Lake City, with densities over 30,000 workers per square mile.

EMPLOYMENT DISTRIBUTION

The chloropleth maps in Fig. 7, Fig. 8, and Fig. 9 below display the density of basic, retail and service employees per square mile in every census tract in Salt Lake MSA. These maps are helpful to show the spatial distribution of number of employees under different employment categories and some variation can be noticed between these three employment types.

There is a higher concentration of service and basic (potentially manufacturing) employment in the northern tracts of Salt Lake County, likely in Salt Lake and West Valley cities, seen in Fig 10 and Fig.8 respectively. On the other hand, a relatively greater density of retail employment is observed in a southern tract in the County in Fig. 8.

Table 3: Household income - tract level statistics

Employment Category	Mean	Standard Deviation	Median
Basic workers	891	3054	142
Retail workers	350	751	139
Service workers	2047	3927	829

We determined tract statistics for the household income data shown in Table 3 below. On an average, there were about 2047 service workers per tract, with this being the major employment type. The standard deviation is significant and so the mean may not be truly representative of the distribution.

Fig. 7: Density of Basic Employees

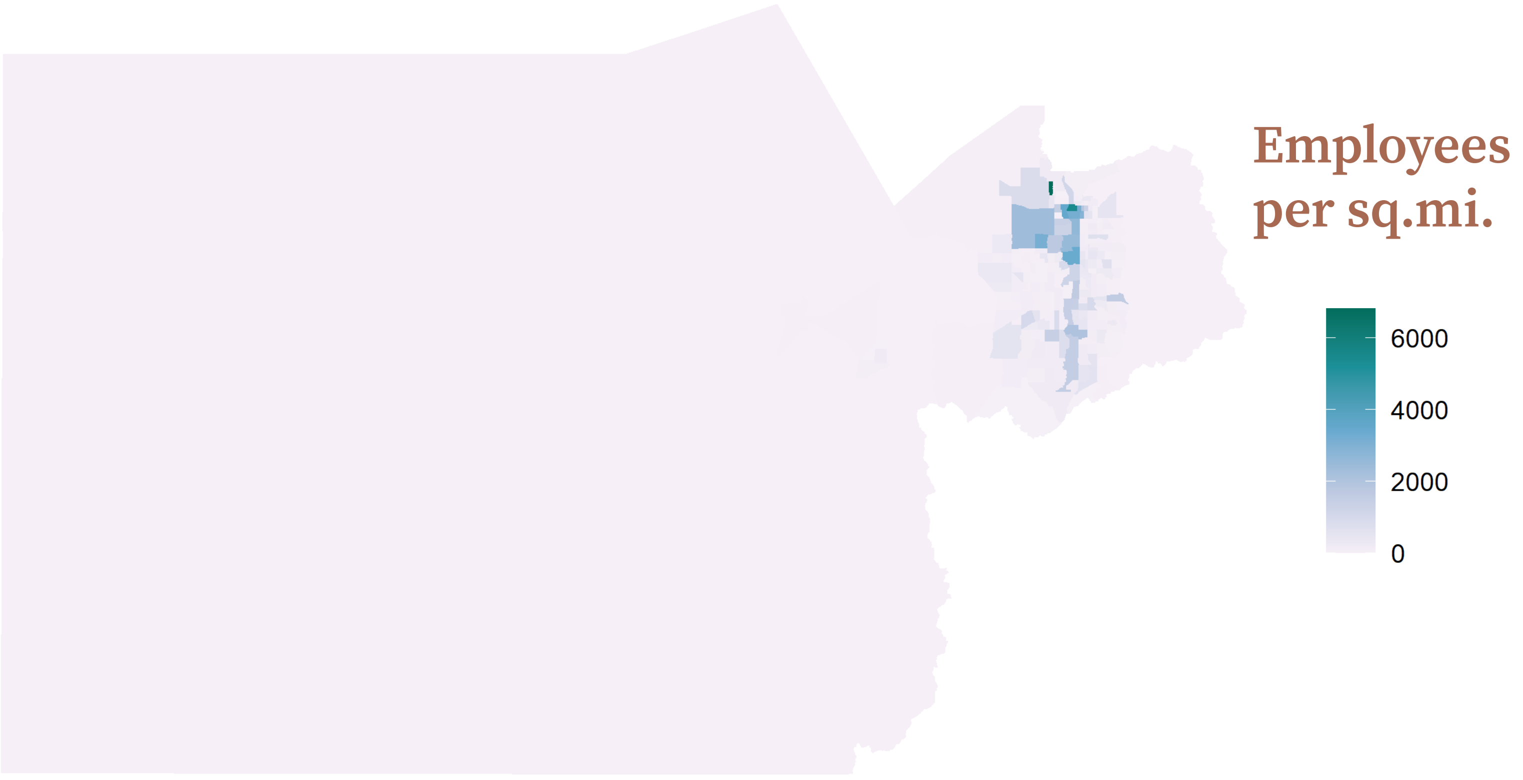


Fig. 8: Density of Retail Employees

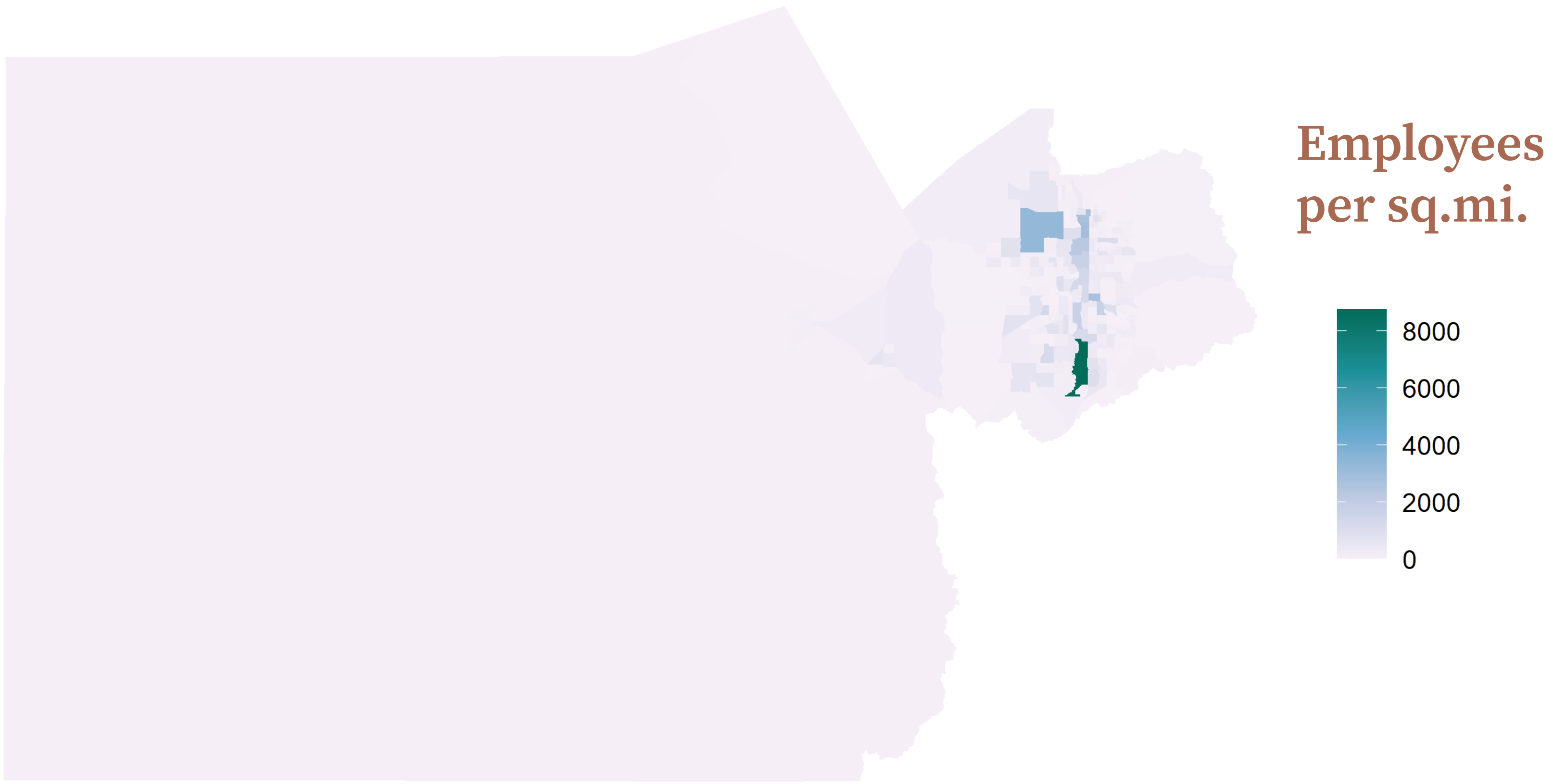
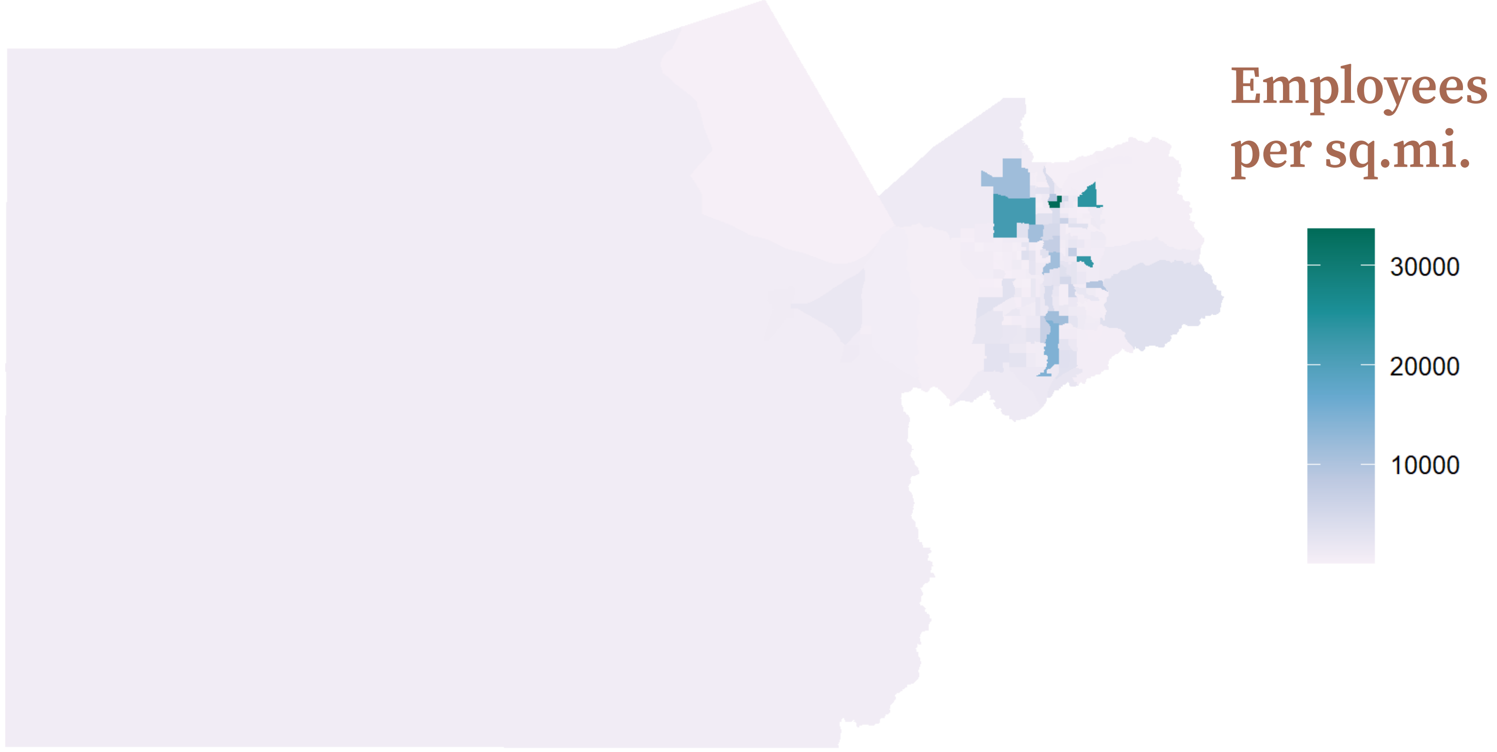


Fig. 9: Density of Service Employees



NETWORK CHANGES

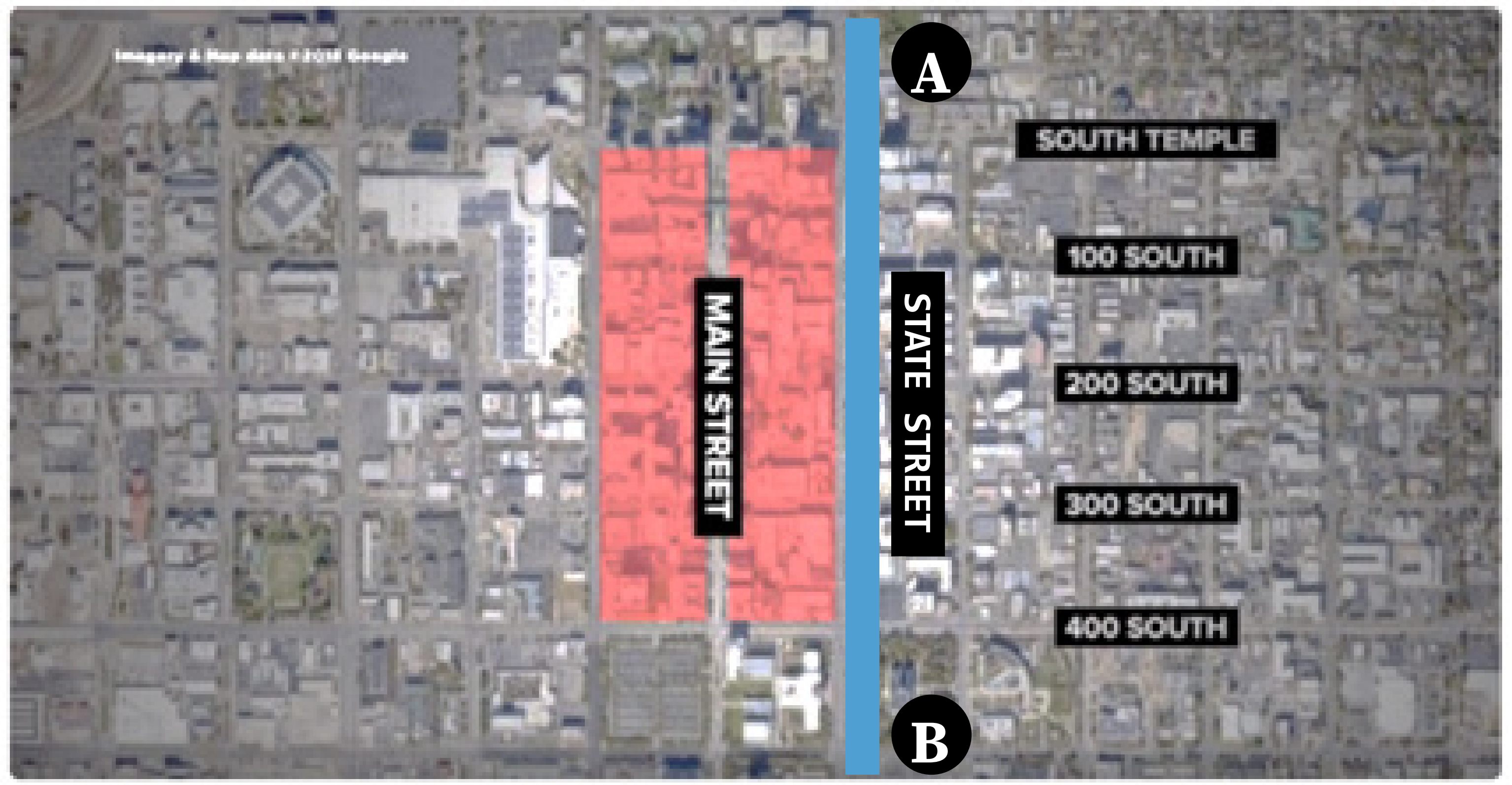
This chapter details out the existing travel times within the Salt Lake MSA and discusses the network changes we propose in the existing street and transit networks and its potential impact on the travel times for all origin-destinations within the MSA.

Existing Scenario

Main Street is an important commercial street in Salt Lake City with major retailers, banks and a high pedestrian footfall. State Street on the other hand, is an automobile-oriented road running one block east to Main Street, and is designated as a highway. Utah Transit Authority operates the bus route 200 i.e., State Street North, along this everyday from 4:08 AM - 11:38 PM. The route has 54 stops departing from North Temple Station and ending in Murray Central Station with a trip duration of about 49 minutes.

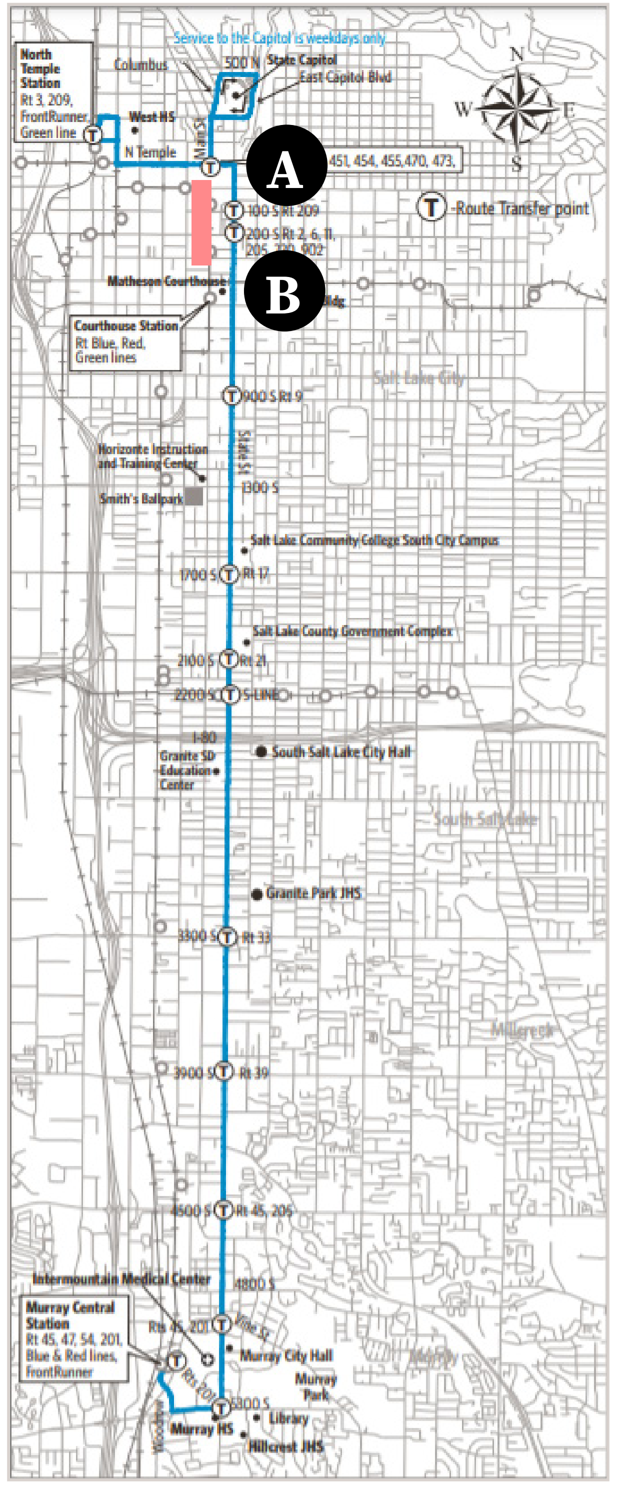
We generated travel time skims for four modes - cars, transit, walking and bikes for the existing scenario for all origin-destinations across the 223 tracts in the Salt Lake MSA. We then performed some network changes aligned with our proposal of pedestrianizing a section of Main Street in Salt Lake City and increasing the frequency of a transit route on the parallel road State Street shown and described alongside.

Fig. 10: Main Street section to be pedestrianized



Keith Kramer, FOX 13 News

Fig. 11: Bus Route 200



Alternative Scenario

We converted the section from 400 South Main Street to South Temple shown in Fig 10 into a pedestrianized road that is closed for all motor vehicles, but open for walking and bicycle modes. We modified this section using an available OpenstreetMap network dataset.

For this model, we also increased the frequency of the bus Route 200 - State Street North, running from North Temple Station to Murray Central Station via State Street, shown in Fig. 11. For this, we reduced the minimum headway along the route from 14 minutes to 5 minutes for a typical weekday (Wednesday) in March 2022. This reduced our headway range for the route from 14-30 minutes to 5-15 minutes, with variations occuring across the day.

Travel Times

Tables 4 and 5 below show the summarized statistics for travel times across the four modes in the existing and alternative scenarios.

Table 4: Tract level travel times - Existing scenario

Mode	Mean	Standard Deviation	Median
Bike	73.63	30.51	77
Car	22.59	13.52	19
Transit	81.92	21.03	83
Walk	77.18	30.13	82

Table 5: Tract level travel times - Alternative scenario

Mode	Mean	Standard Deviation	Median
Bike	73.63	30.51	77
Car	22.59	13.52	19
Transit	81.75	21.08	83
Walk	77.18	30.13	82

There is very little variation in the mean travel times and no observed variation in the median travel times between the existing and proposed scenarios in this model, for all four modes. The greatest variation is seen in mean travel times for transit trips - however that too signifies only a marginal decrease in the travel time from 81.92 minutes to 81.75 minutes, and an increase in standard deviation from 21.03 to 21.08. The mean travel time for cars is approximately 22.6 minutes in both the scenarios. No variation is observed in the mean travel times of car and walking trips. A tiny increase is observed in the mean travel time of bike trips but that when rounded off, it is the same for both scenarios.

TRANSIT TRAVEL TIMES

We performed the street and transit network changes mentioned on the previous page and determined the travel times for cars for both the existing and alternative scenarios. Based on this travel time skim analysis we determined that the census tract representing South Salt Lake city had the highest difference in travel times for transit.

The chloropleth maps in Fig. 12 and Fig. 13 below display the spatial variation in travel times for the existing and altenative scenario with respect to trips from the identified tract shown in red, to all other tracts in the MSA. Some variation is observed between these scenarios in the northern tracts in Salt Lake County, which is probably as a result of the change in transit frequency. The chloropleth map in Fig. 14 shows the difference in travel times for cars to the identified census tract, between the two scenarios ranging from a reduction of 5 minutes to an increase by 10 minutes. This finding shows that the pedestrianization of a section of Main Street and increasing transit frequency of route 200 in Salt Lake marginally impacted travel times for transit trips across the County.

Fig. 12: Spatial variation in transit travel times: Existing

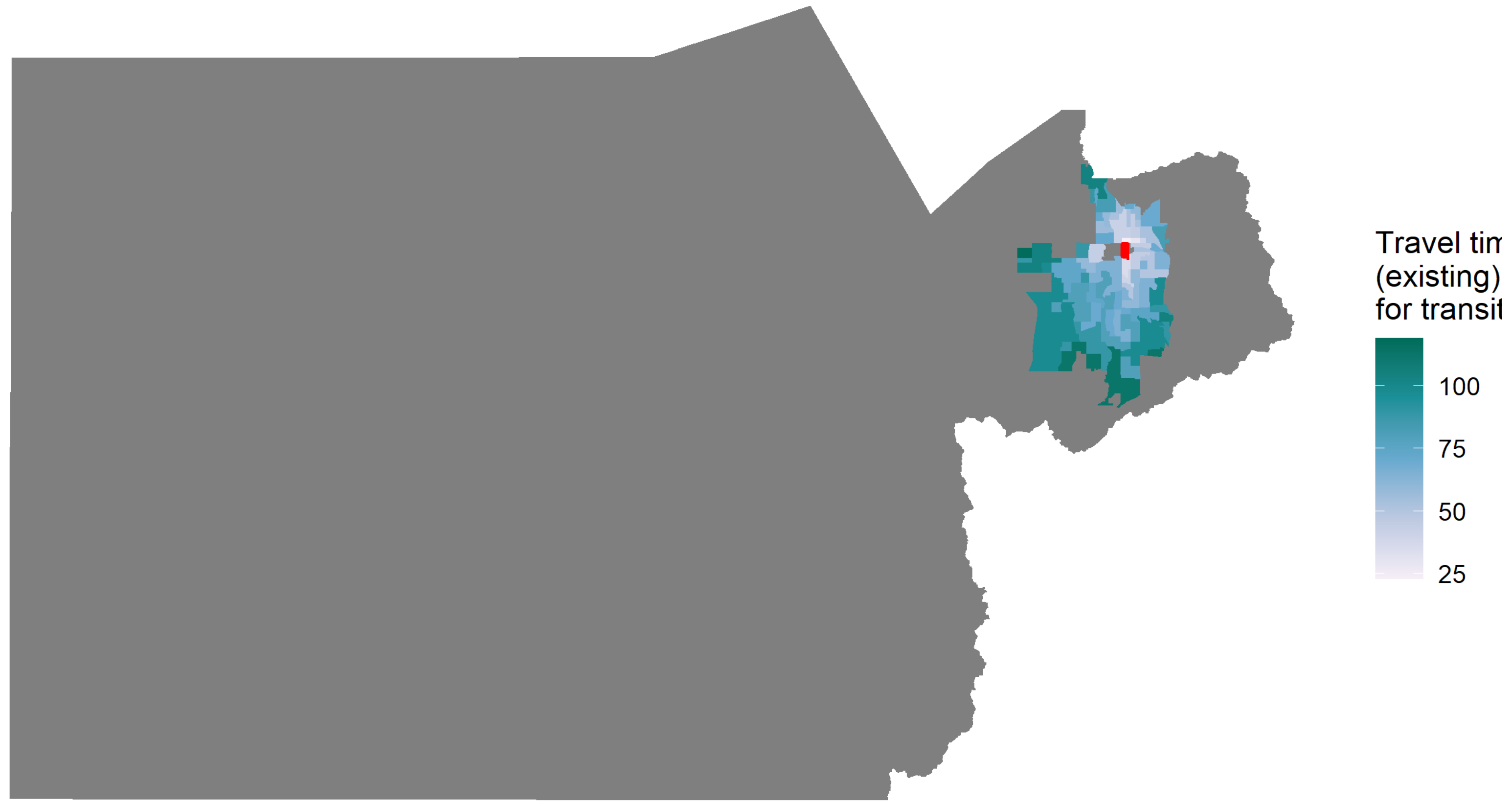


Fig. 13: Spatial variation in transit travel times: Alternative

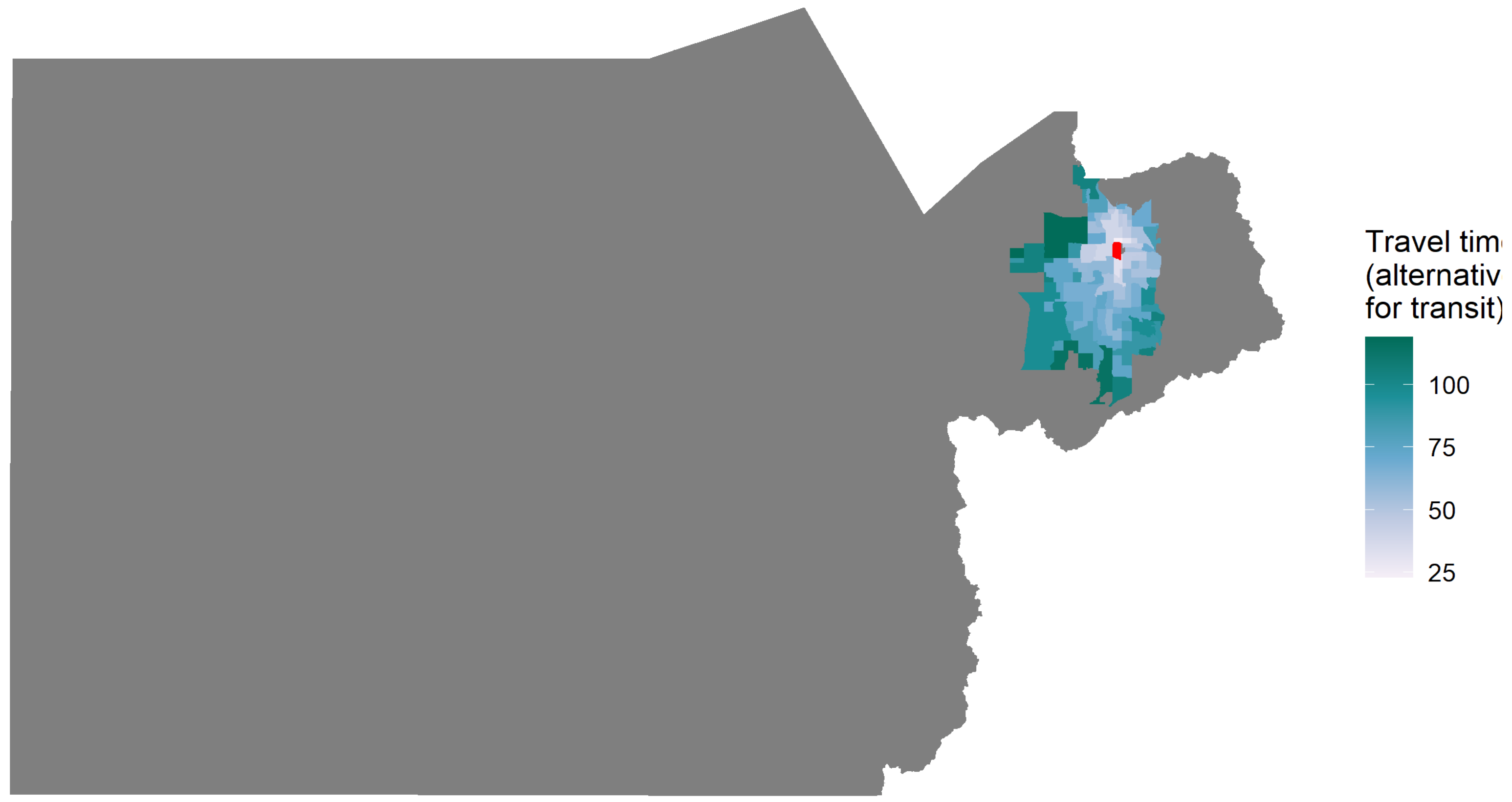
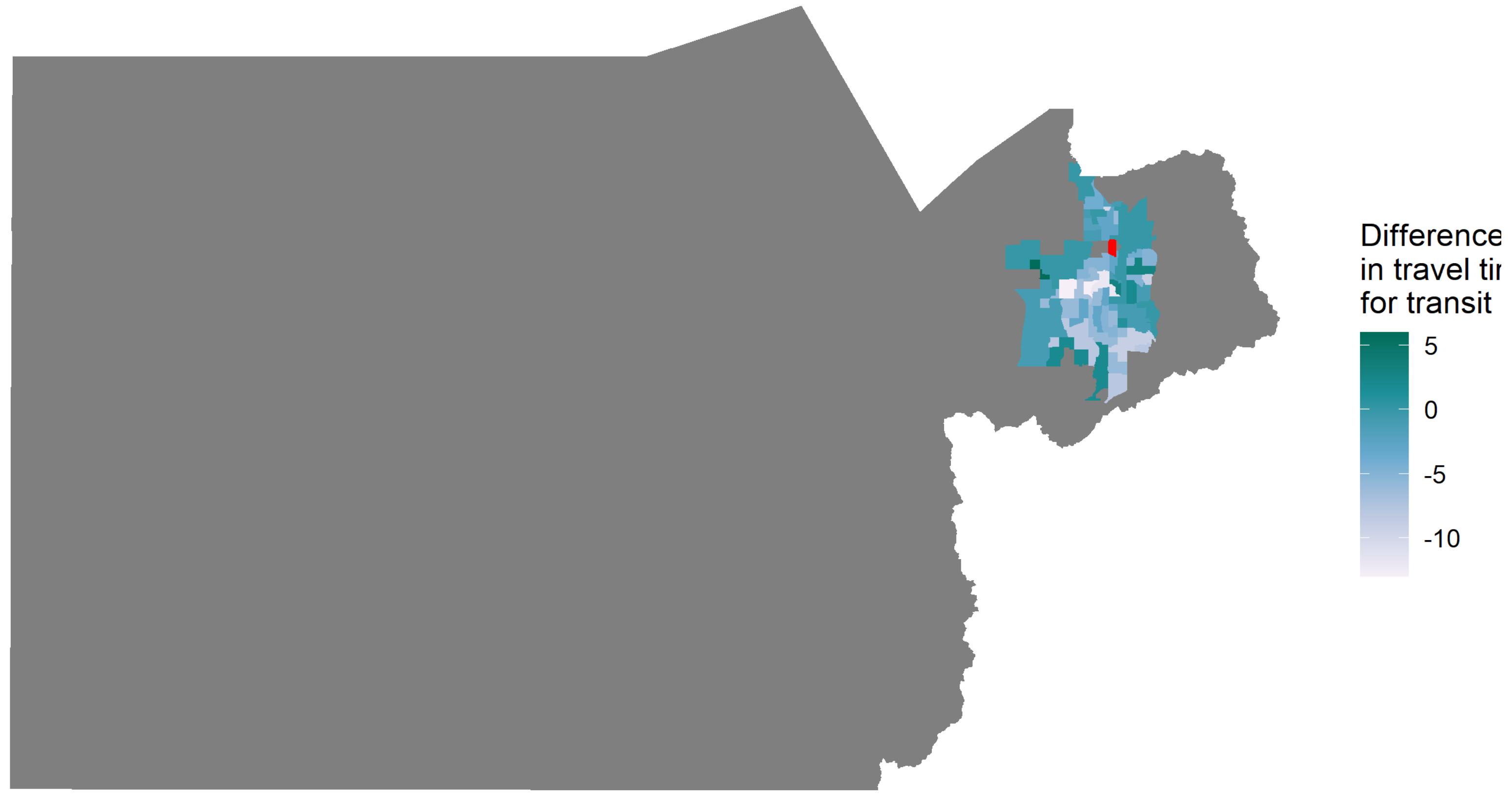


Fig. 14: Difference in transit travel times



CAR TRAVEL TIMES

We performed the street and transit network changes mentioned previously and determined the travel times for cars for both the existing and alternative scenarios. Based on this travel time skim analysis we determined that a census tract near Draper (49035112822) had the highest difference in travel times for cars.

The chloropleth maps in Fig. 15 and Fig. 16 below display the spatial variation in travel times for the existing and altenative scenario with respect to trips from the identified tract shown in red, to all other tracts in the MSA. These figures do not show any variation between the two scenarios.

The chloropleth map in Fig. 17 shows the difference in travel times for cars to the identified census tract, between the two scenarios. No variation is observed between these scenarios. This finding shows that the pedestrianization of a section of Main Street and increasing transit frequency of route 200 in Salt Lake city did not have any impact on travel times for car trips across the county.

Fig. 15: Spatial variation in car travel times: Existing

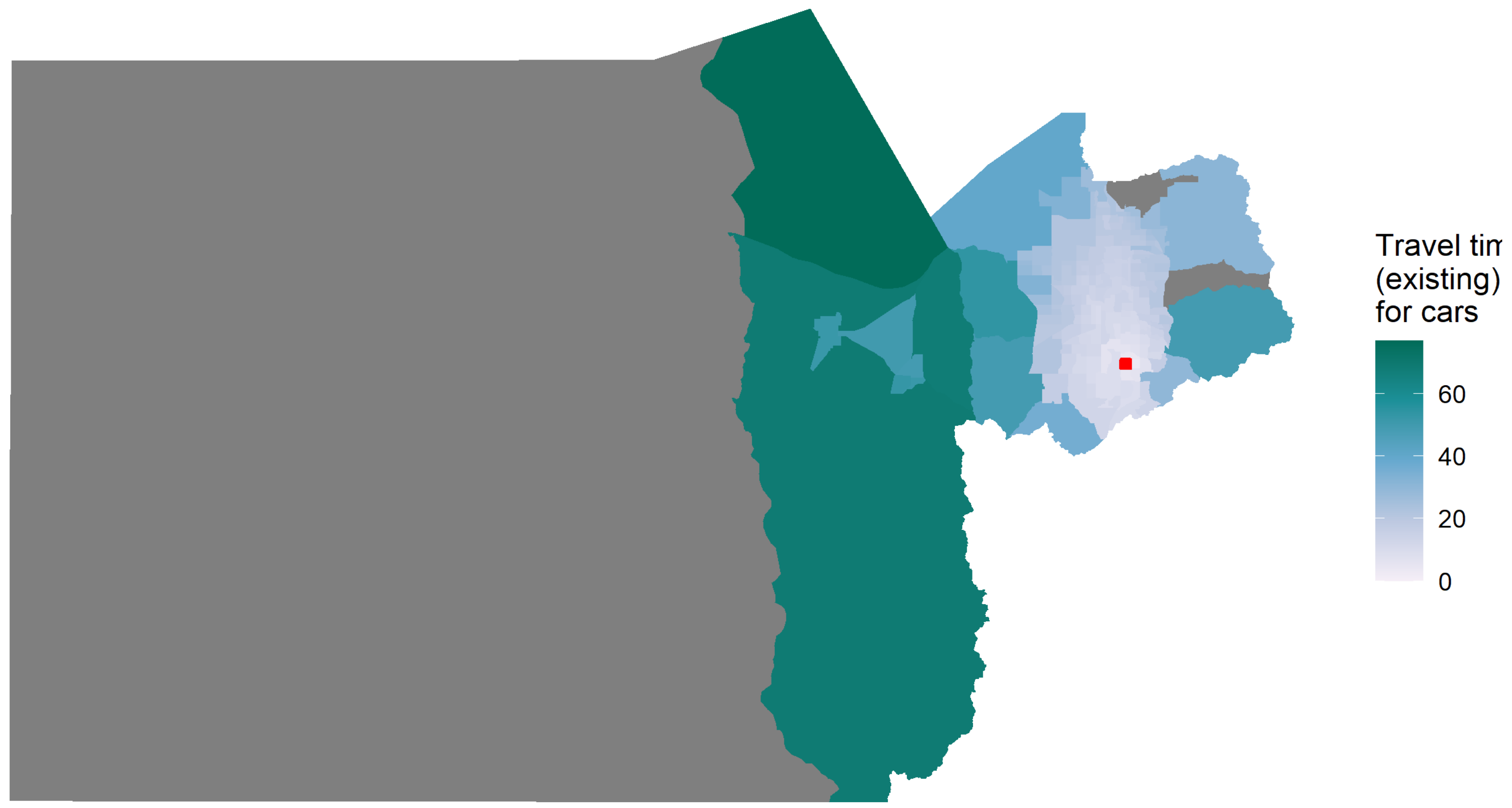


Fig. 16: Spatial variation in car travel times: Alternative

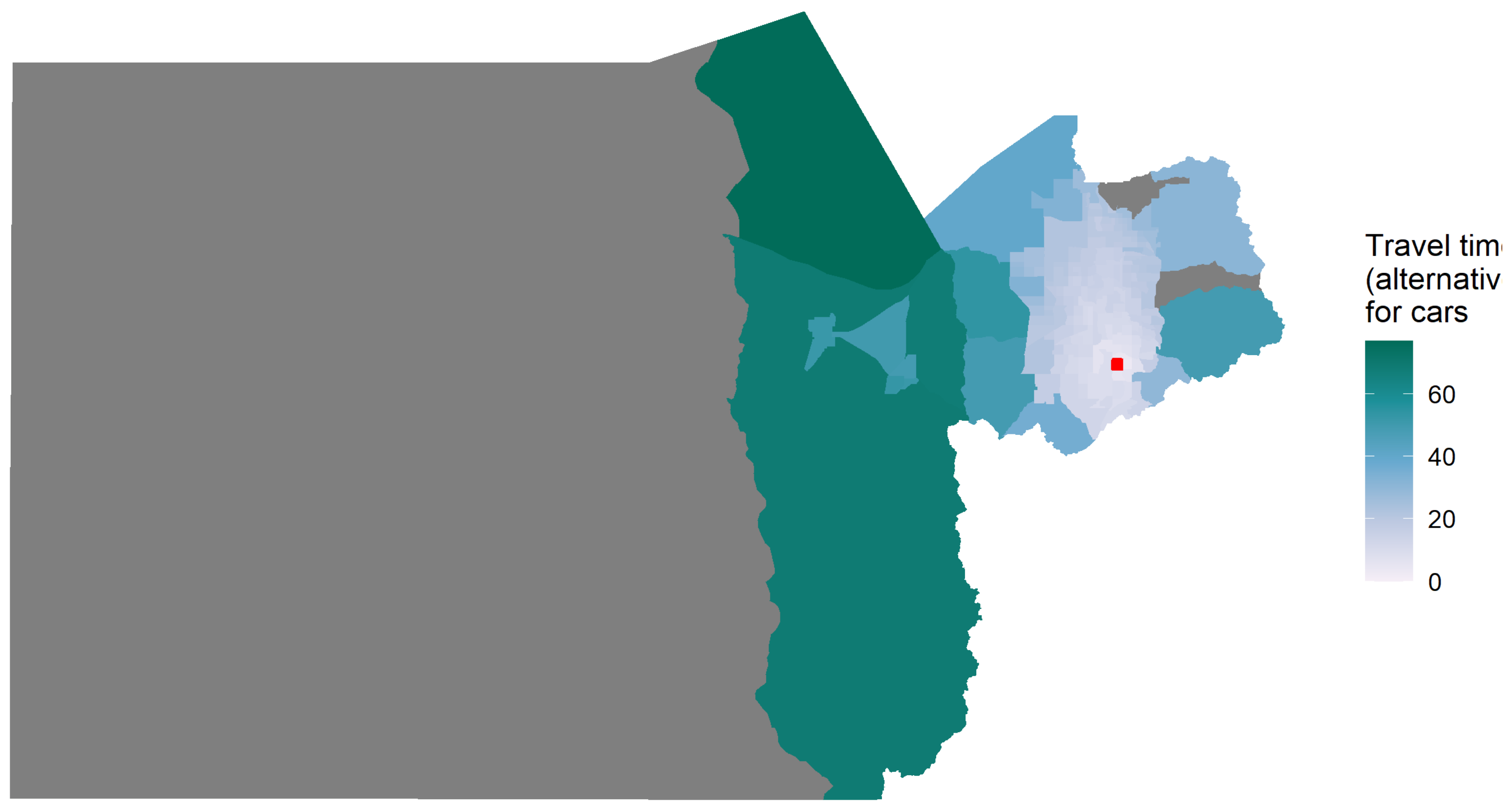
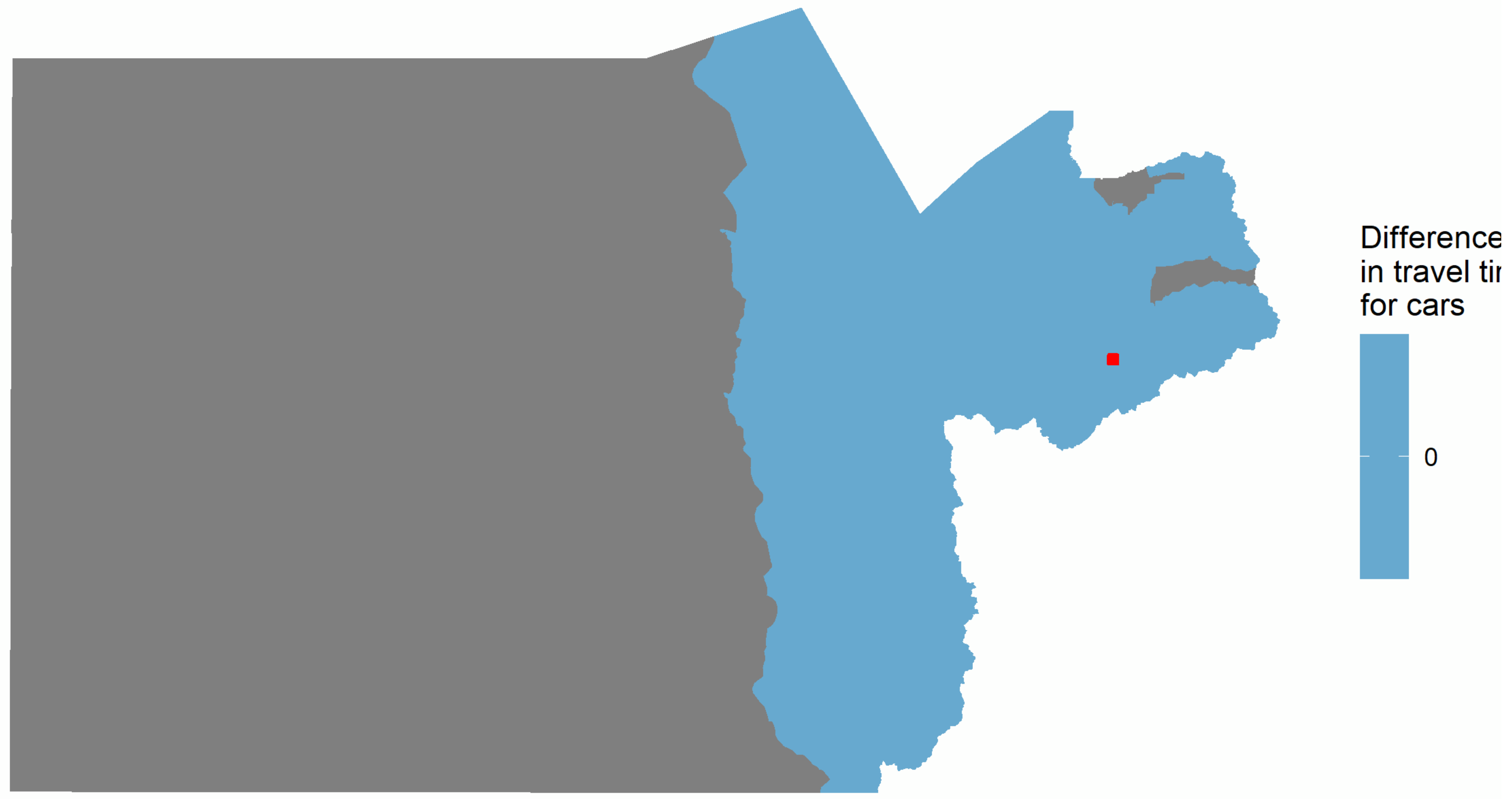


Fig. 17: Difference in car travel times



WALKING TRAVEL TIMES

We performed the street and transit network changes mentioned previously and determined the travel times for pedestrians for both the existing and alternative scenarios. Based on this travel time skim analysis we determined that a census tract near Draper (49035112822) had the highest difference in travel times for walking trips.

The chloropleth maps in Fig. 18 and Fig. 19 below display the spatial variation in travel times for the existing and alternative scenario with respect to trips from the identified tract shown in red, to all other tracts in the MSA. These figures do not show any variation between the two scenarios. The chloropleth map in Fig. 20 shows the difference in travel times for pedestrian to the identified census tract, between the two scenarios. No variation is observed between these scenarios. This finding shows that the pedestrianization of the section of Main Street and increasing transit frequency of route 200 in Salt Lake city did not have a significant impact on travel times for pedestrians across the County.

Fig. 18: Spatial variation in walking travel times: Existing

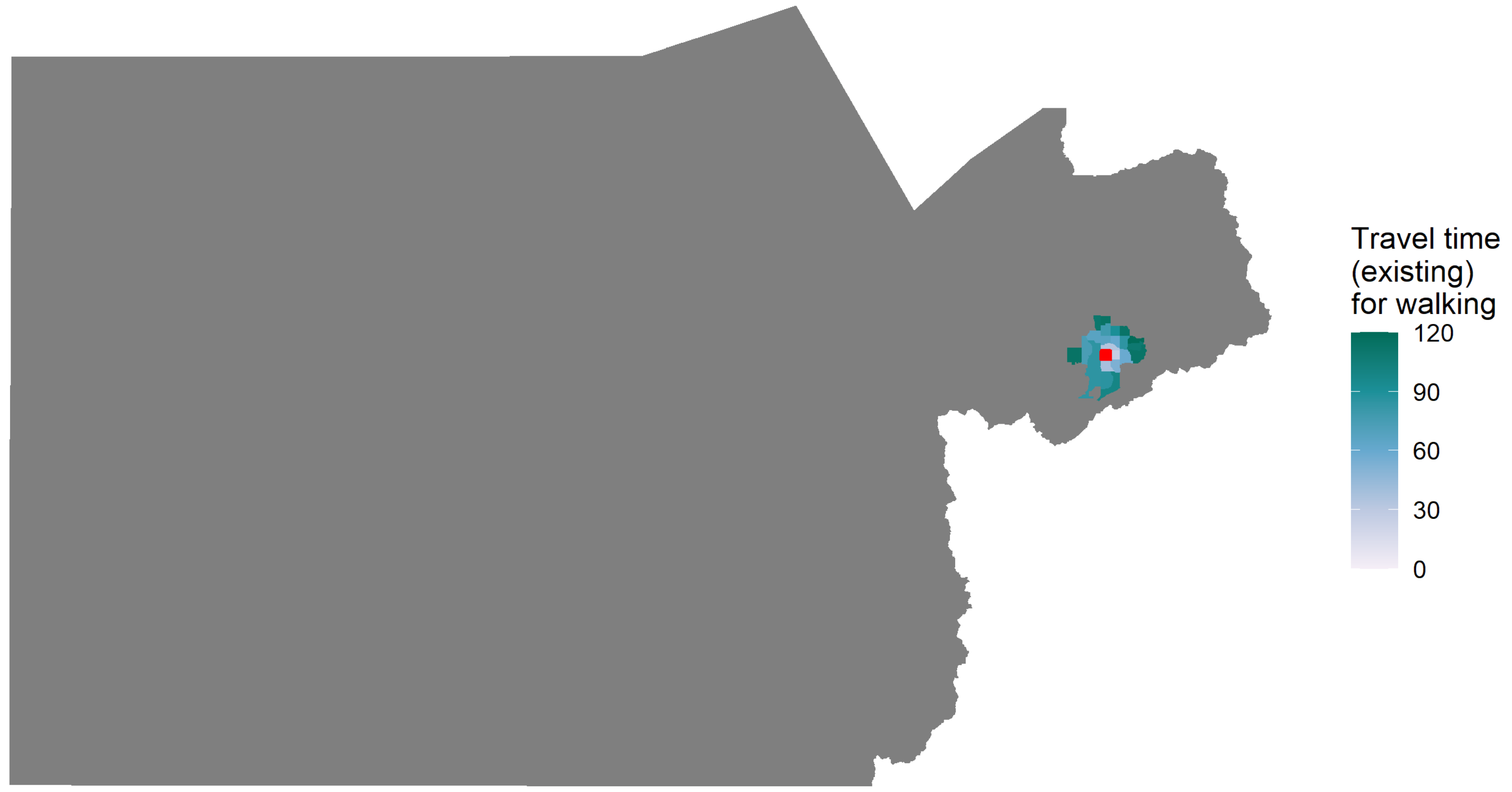


Fig. 19: Spatial variation in walking travel times: Alternative

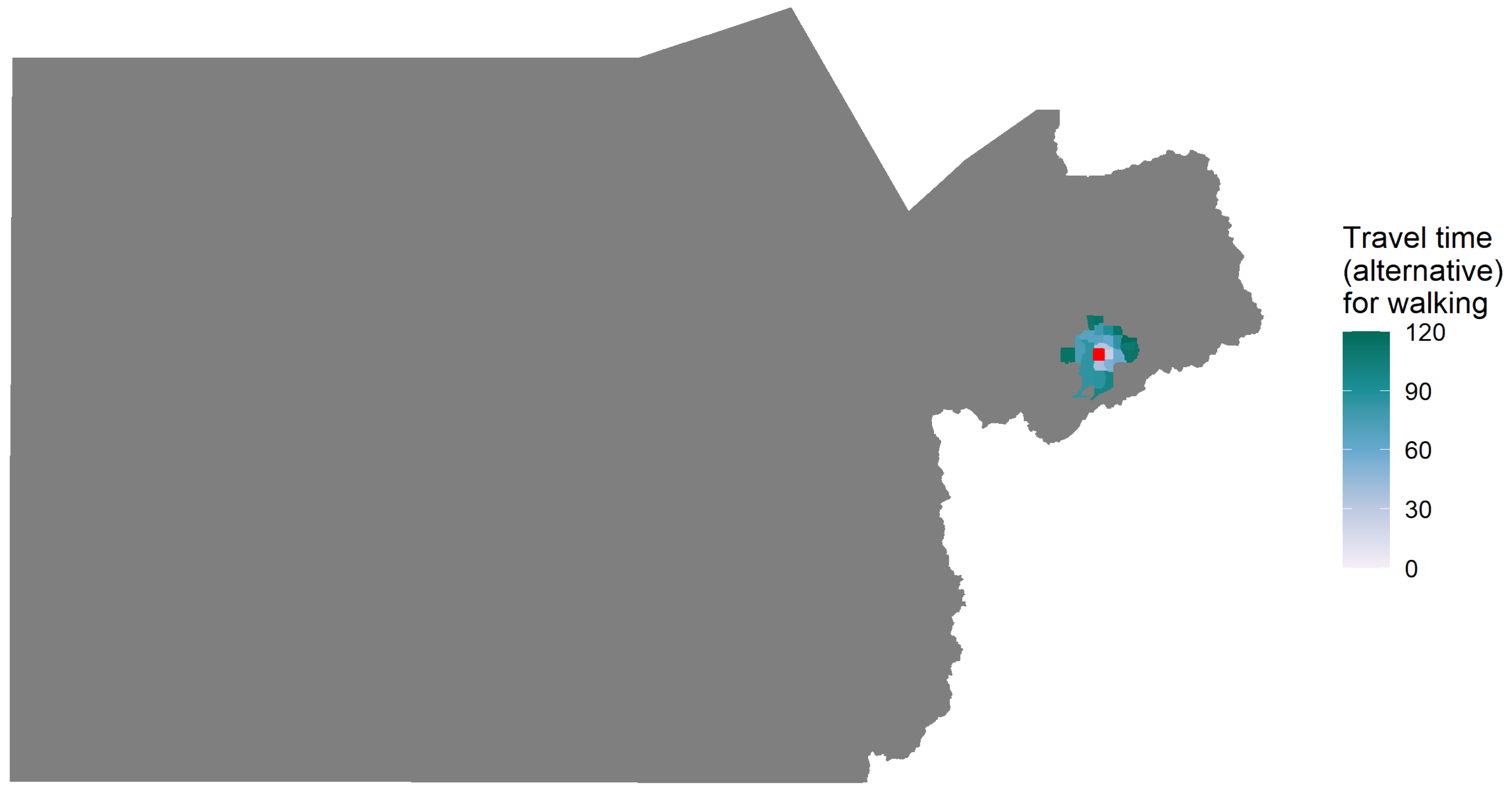
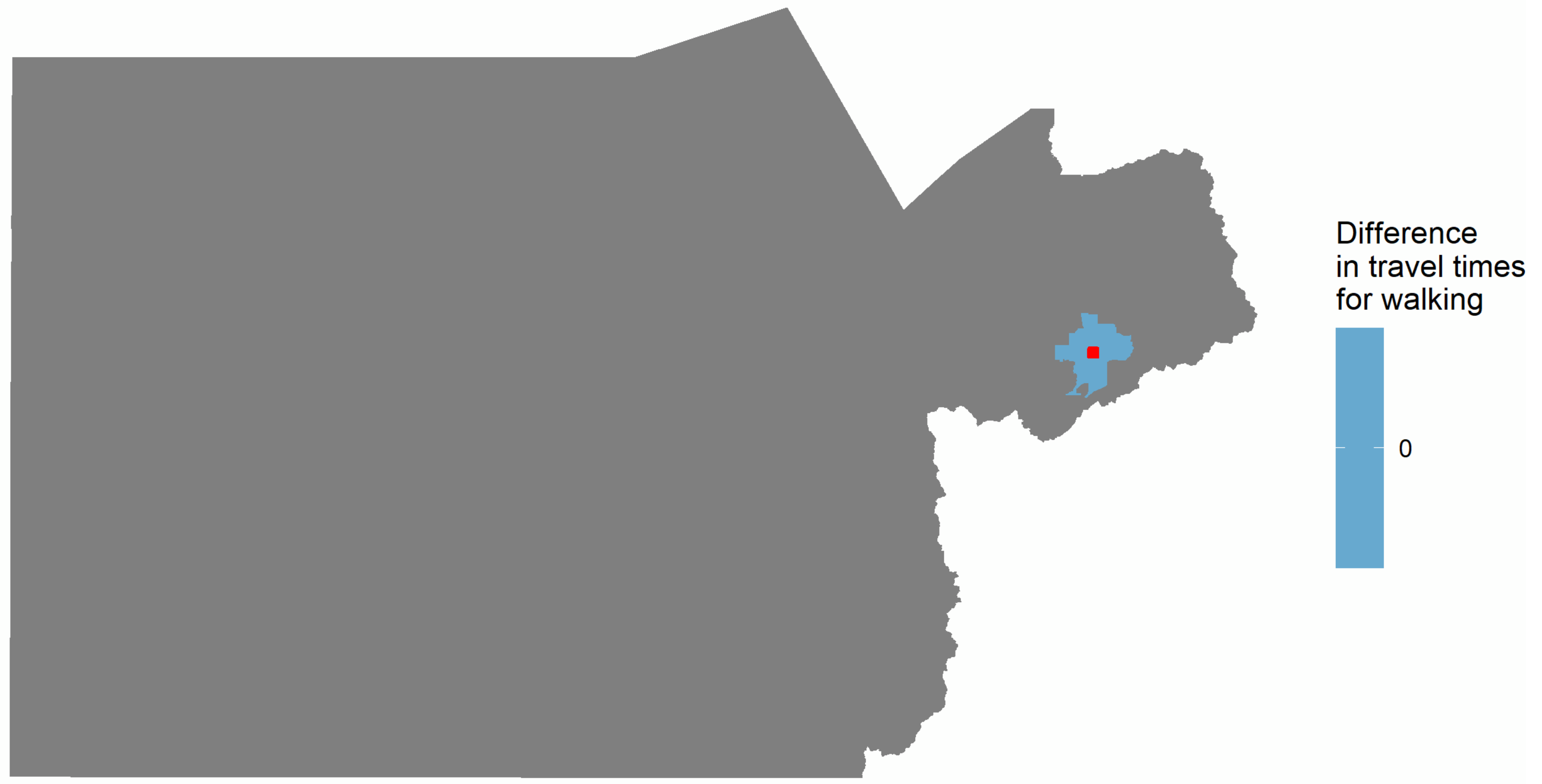


Fig. 20: Difference in walking travel times



BICYCLE TRAVEL TIMES

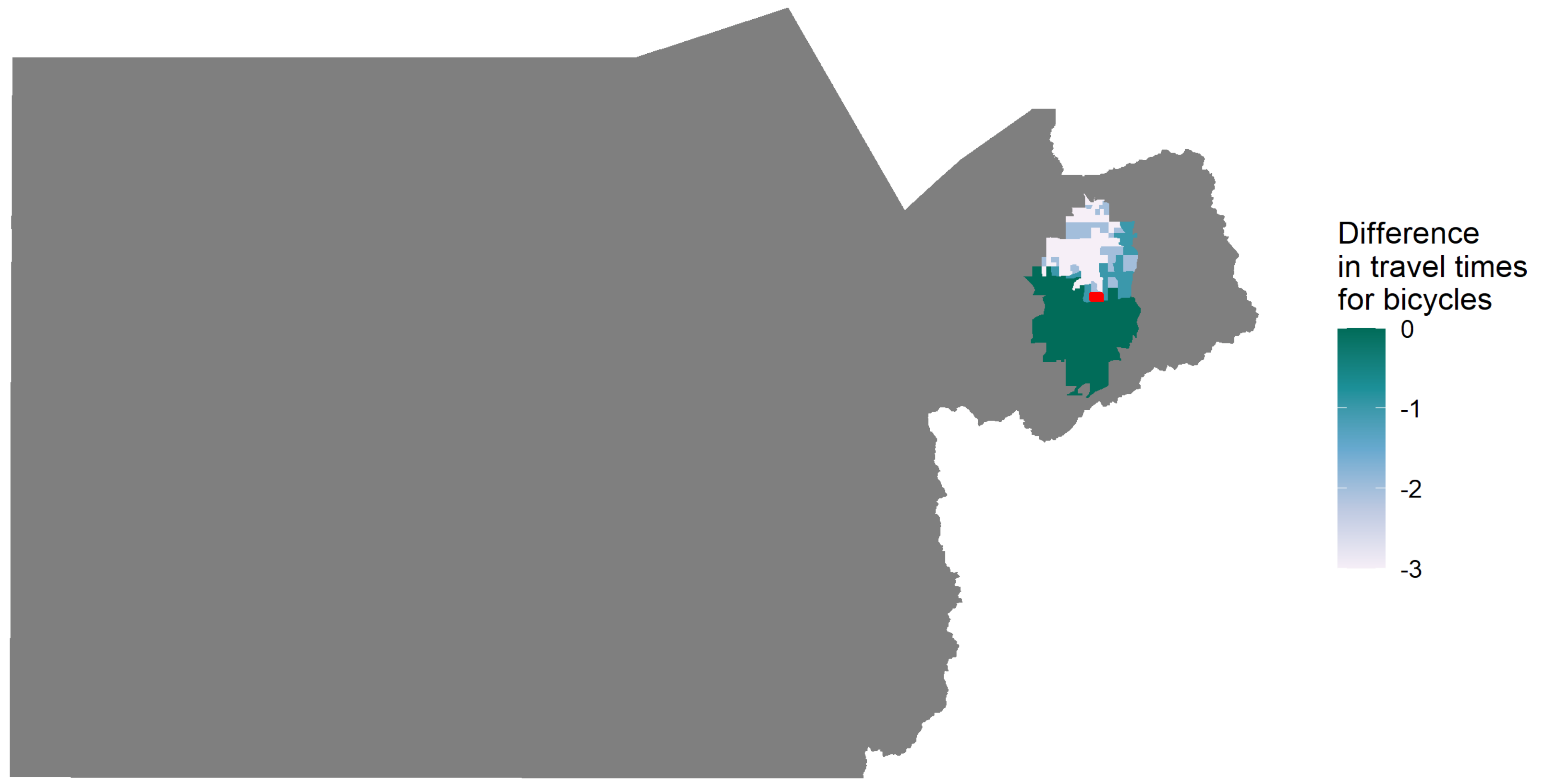
We performed the street and transit network changes mentioned previously and determined the travel times for cycling trips for both the existing and alternative scenarios. Based on this travel time skim analysis we determined that a census tract towards the south of Murray (49035112302) had the highest difference (increase) in travel times for cycling trips.

The chloropleth maps in Fig. 21 and Fig. 22 below display the spatial variation in travel times for the existing and altenative scenario with respect to trips from the identified tract shown in red, to all other tracts in the MSA. Not much variation is observed between these scenarios in these two figures. The chloropleth map in Fig. 23 shows the difference in travel times for cyclists to the identified census tract, between the two scenarios. Minor changes in cycling time by up to 3 minutes are observed in the tracts north to the identified tract. This finding shows that the pedestrianization of the section of Main Street and increasing the transit frequency of route 200 in Salt Lake city had a small impact on travel times for cycling trips across the County.

Fig. 21: Spatial variation in bicycle travel times: Existing

Fig. 22: Spatial variation in bicycle travel times: Alternative

Fig. 23: Difference in bicycle travel times



EXISTING ACCESSIBILITY

This chapter details out the accessibility to employment opportunities through different modes, for every census tract in Salt Lake MSA. For purposes of this assignment, the logistic funtion is used to determine access to jobs within 45 minutes when traveling by cars and public transit, with a standard deviation of 5 minutes.

The chloropleth maps in Fig 24 and Fig.25 represent the spatial variation in the existing accessibility to employment opportunities within a 45-minute travel distance by cars and public transit. While there are census tracts that allow access to over 600,000 jobs when travelling by a car for 45 minutes, a maximum of about 163,000 jobs can be accessed within 45 minutes by public transit from any census tract. Fig. 25 shows greater transit accessibility in the northern and central tracts in Salt Lake County in and around Salt Lake City. The chloropleth map in Fig. 26 shows the spatial variation in the ratio of transit accessibility to car accessibility. Four tracts had no car and transit accessibility due to presence of natural features such as mountains and lakes and are visible as anomalies in Fig. 26. These include the tracts in the eastern part of the MSA colored in grey as well as Tooele County on the west. These values were omitted from the statistical summary of access to employment opportunities presented in Table 6.

Through Table 6 and Fig. 26, it is evident that majority of the census tracts in Salt Lake MSA have low transit to car accessibility ratios, i.e., under 0.25, indicating limited transit accessibility and implying a greater reliance on cars as the primary mode of travel when accessing employment opportunities.

Table 6: Existing tract-level accessibility to employment

Mode	Car Access	Transit Access	Transit : Car Access Ratio
Minimum	576	26	0.0004389
1st Quartile	706880	3836	0.0070710
Median	712093	14829	0.0221237
Mean	678900	31036	0.0450367
3rd Quartile	715535	45062	0.0669163
Maximum	719151	163152	0.2278328

Fig. 24: Existing Car Accessibility

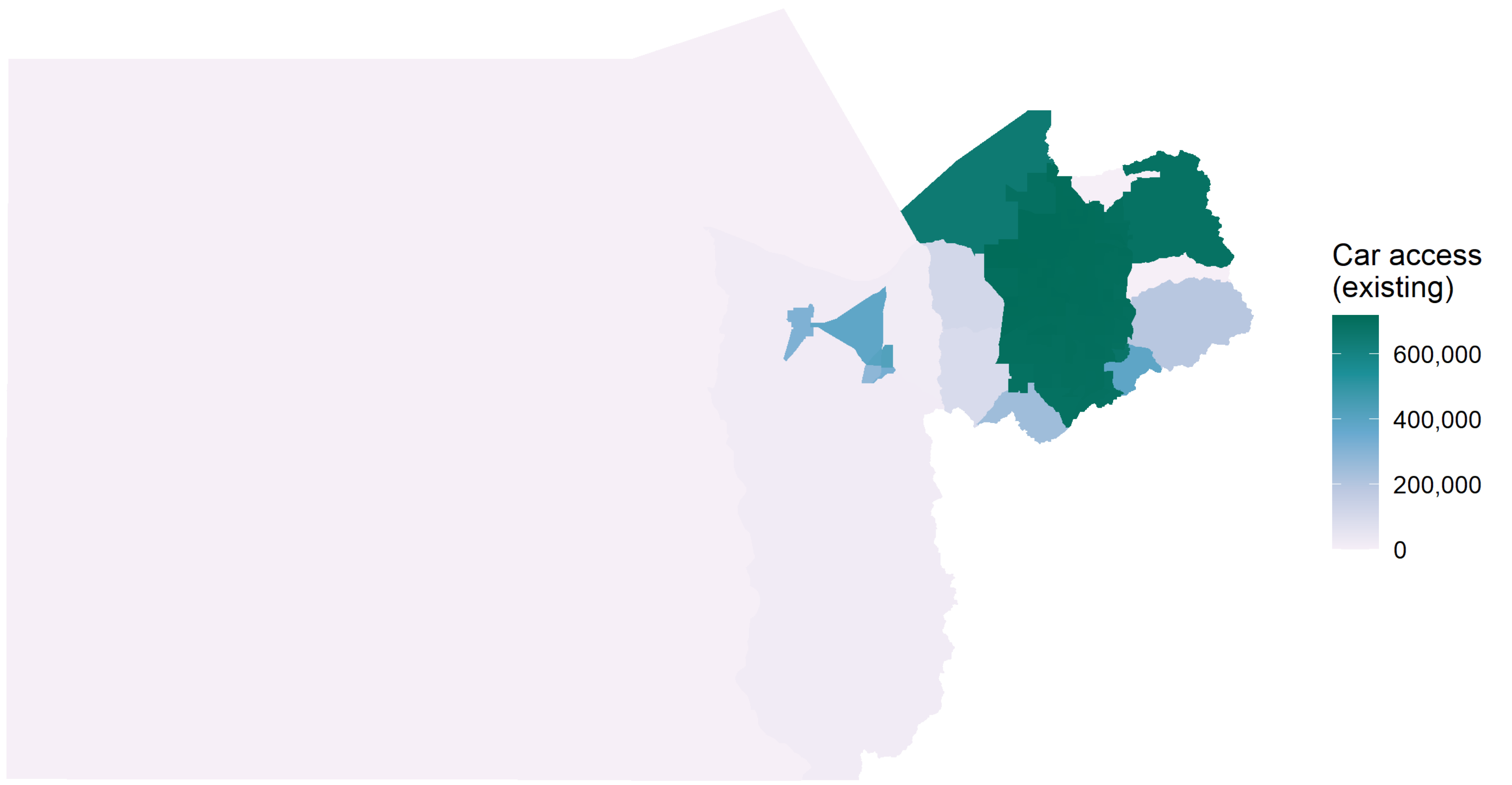


Fig. 25: Existing Transit Accessibility

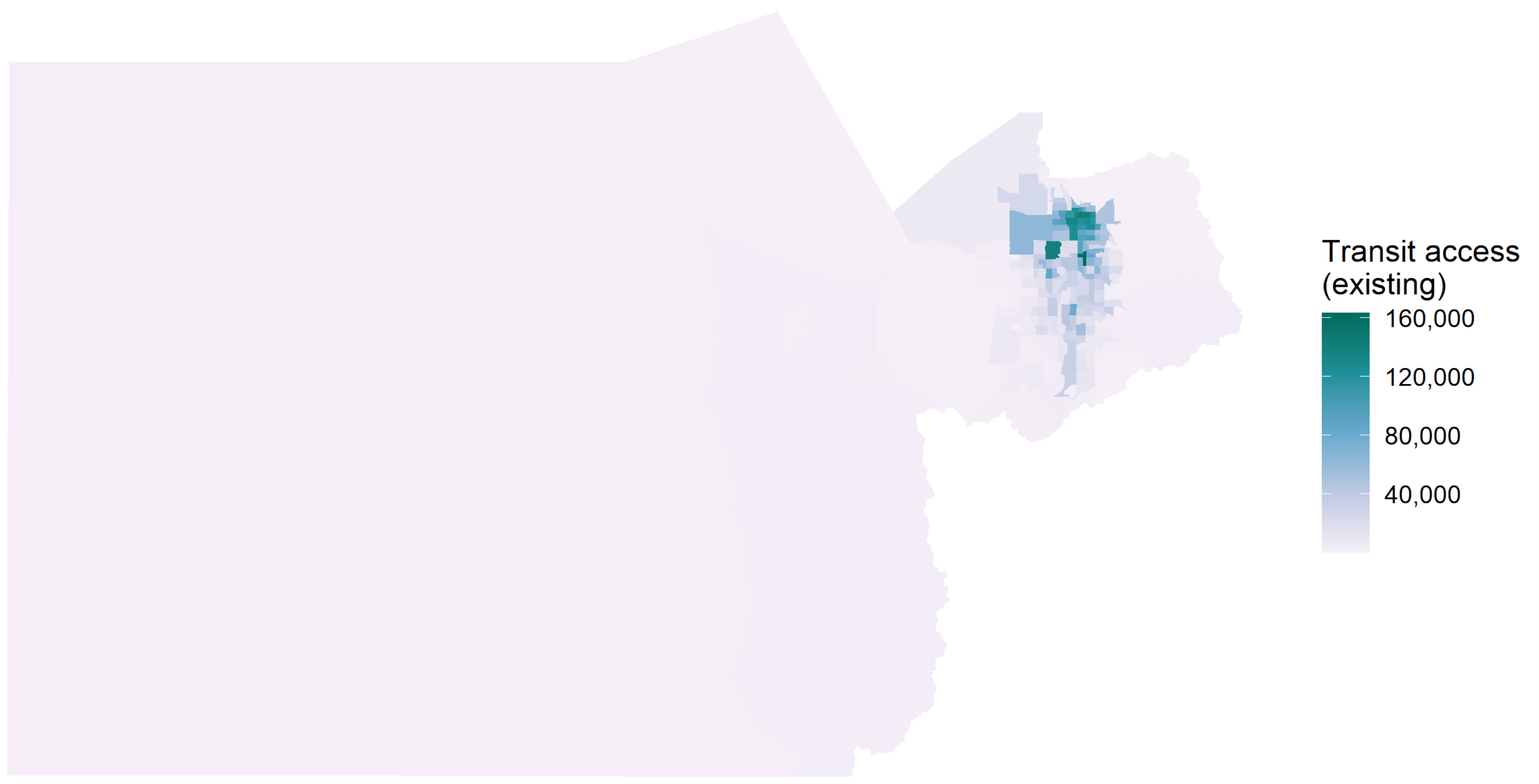
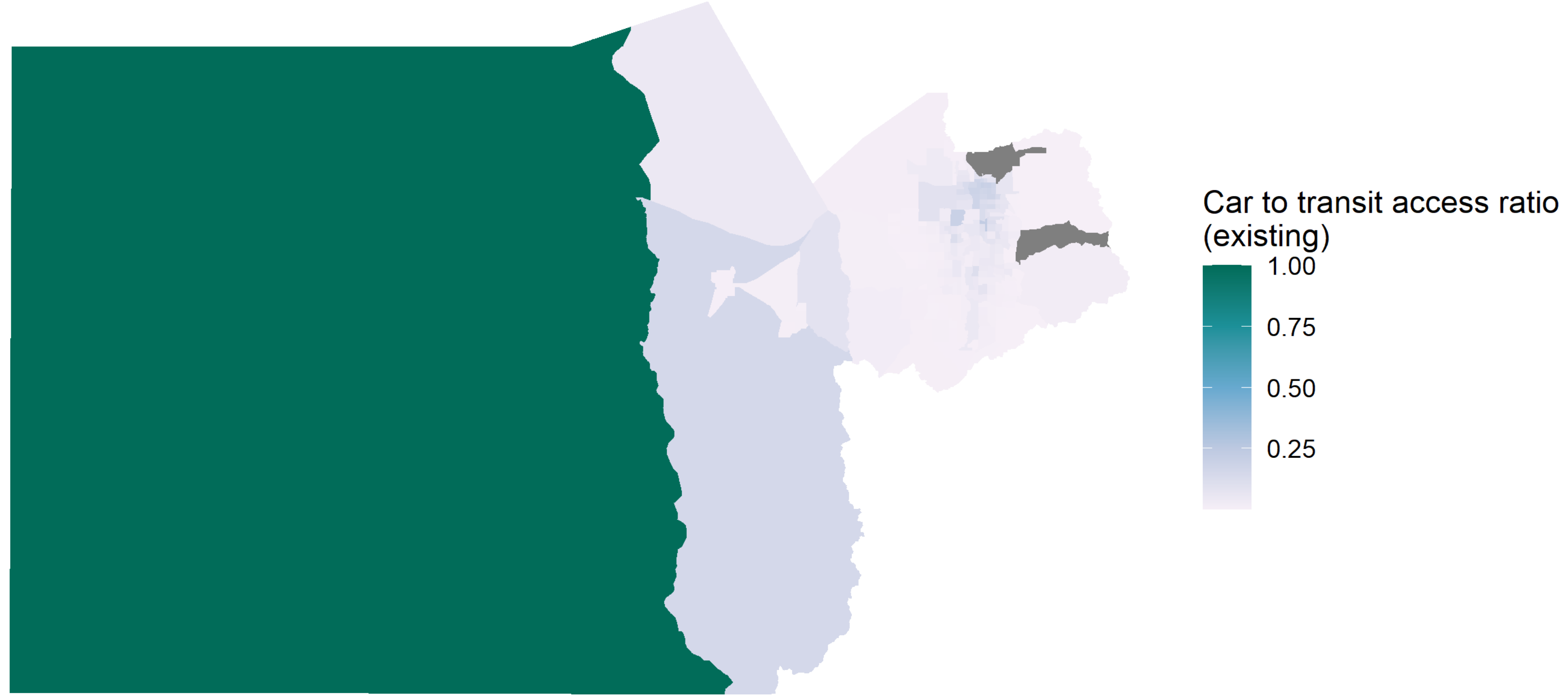


Fig. 26: Existing Transit-Car Accessibility Ratio



ALTERNATIVE ACCESSIBILITY

This section discusses the accessibility to employment opportunities in the proposed scenario with the pedestrianization road section and increased frequency on bus Route 200. The maps in Fig 27 and Fig.28 represent the spatial variation in the accessibility to employment opportunities in the alternative scenario within a 45-minute travel distance by cars and transit. While there are census tracts that allow access to over 710,000 jobs when travelling by a car for 45 minutes, a maximum of around 167,000 jobs can be accessed within 45 minutes by transit, higher than that in the existing scenario by about 4000 jobs. Fig. 28 shows that greater transit accessibility is observed in the northern and central tracts in Salt Lake County in and around Salt Lake City. The chloropleth map in Fig. 29 shows the spatial variation in the ratio of transit accessibility to car accessibility. Four tracts had no car and transit accessibility due to presence of natural features and are visible as anomalies in Fig. 29. These include the tracts in the eastern part of the MSA colored in grey as well as Tooele County on the west. These values were omitted from the statistical summary of access to employment opportunities presented in Table 7. In Table 7 and Fig. 29, it is evident that the alternative scenario is similar to the existing one. Here too, most census tracts in Salt Lake MSA have low transit to car accessibility ratios, i.e., under 0.25, indicating limited transit accessibility and implying a greater reliance on cars as the primary mode when accessing employment opportunities. The highlighted cells in Table 7 represent a slight increase from the existing values in Table 6 and imply a small improvement in transit accessibility - the mean transit accessibility increases by 721 and transit to car accessibility ratio increases by 0.001 for every census tract.

Table 7: Alternative tract-level accessibility to employment

Mode	Car Access	Transit Access	Transit : Car Access Ratio
Minimum	576	26	0.0004389
1st Quartile	706880	3836	0.0070710
Median	712093	14829	0.0221321
Mean	678900	31757	0.0460459
3rd Quartile	715535	45132	0.0669566
Maximum	719151	167422	0.2337956

Fig. 27: Alternative Car Accessibility

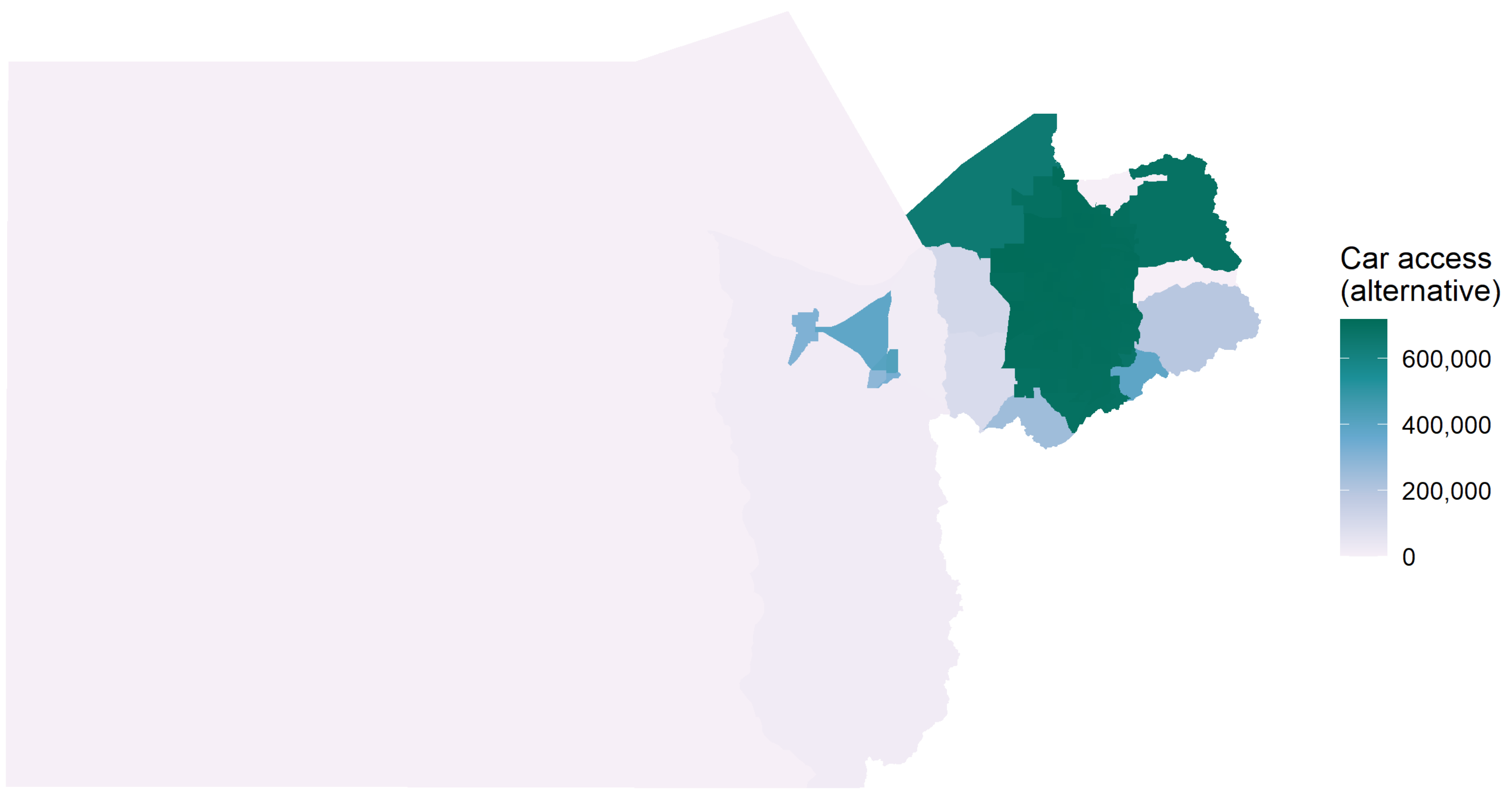


Fig. 28: Alternative Transit Accessibility

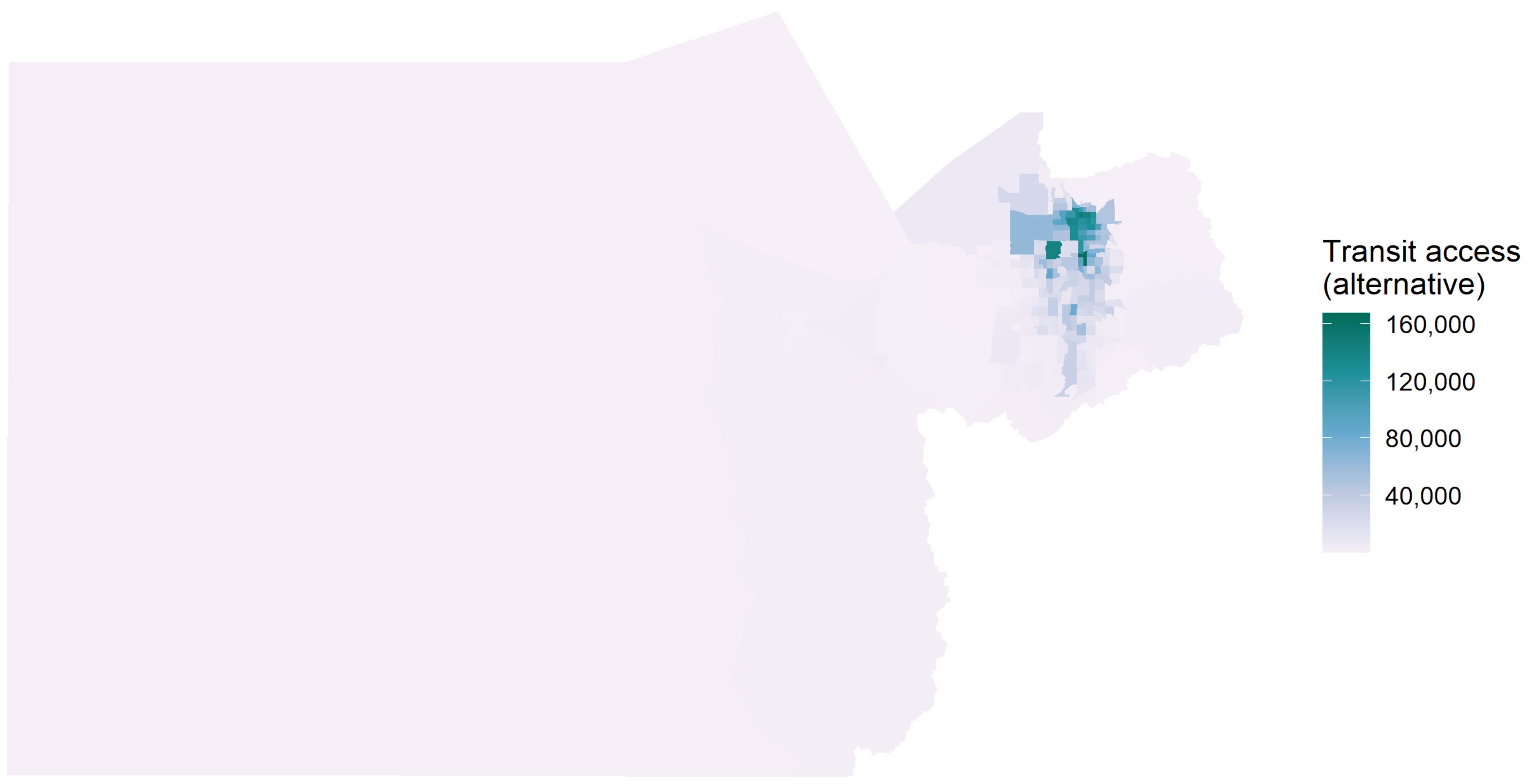
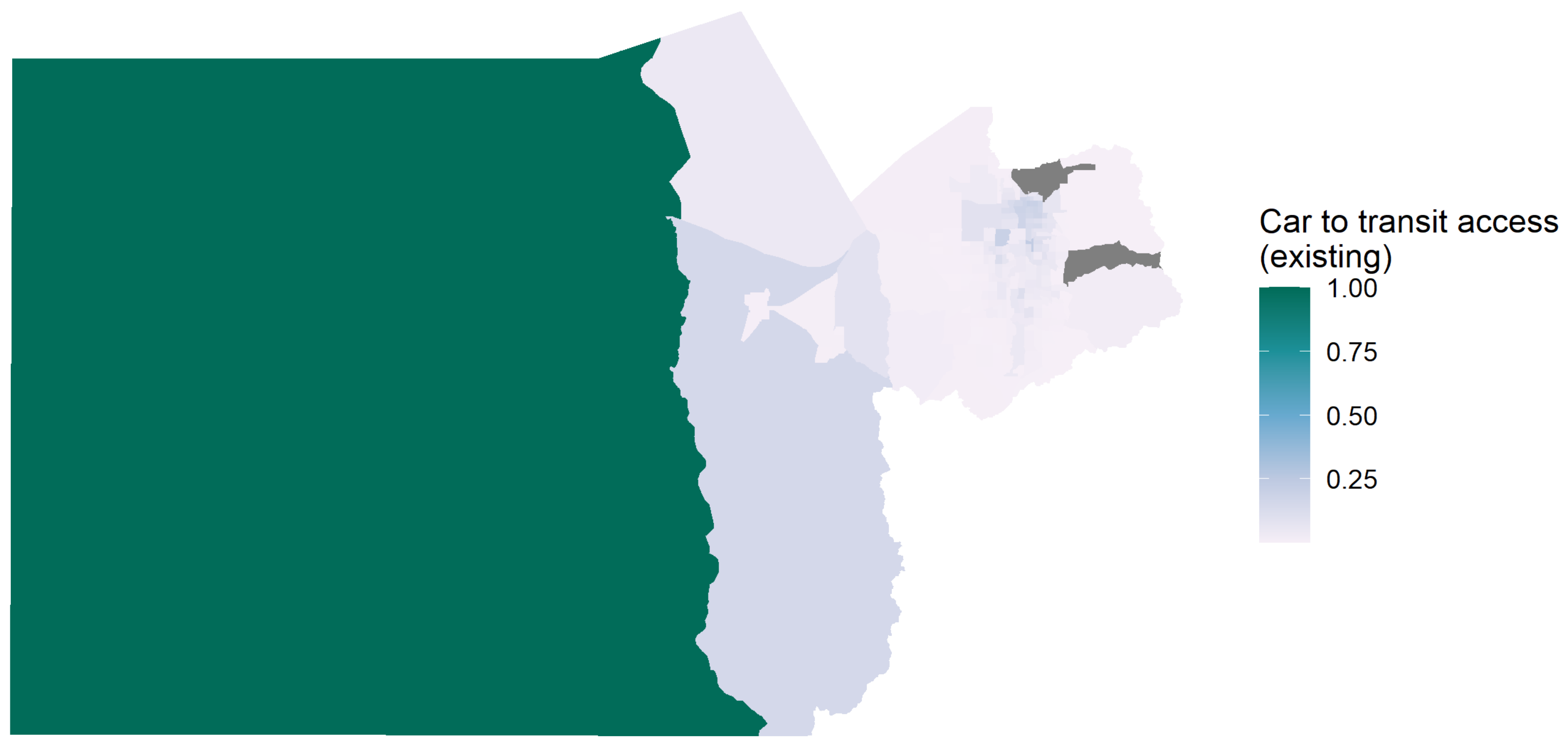


Fig. 29: Alternative Transit-Car Accessibility Ratio



CHAPTER 5

ESTIMATING VEHICLE OWNERSHIP

This chapter discusses the next step of estimating a model to predict the number of zero-vehicle households in each census tract in the alternative scenario in Salt Lake MSA.

For this model, we consider four independent variables that might predict vehicle ownership which is the dependent variable:

a) The ratio of transit accessibility to car accessibility that we determined in the previous chapter

b) The percentage of big households i.e., those with three or more people

c) The percentage of low-income households i.e., those in the first income quintile

d) The percentage of high-income housholds, i.e, those in the fifth income quintile

The three scatterplot diagrams below visualize the relationships between our dependent variables i.e., the percentage of zero-vehicle households, and each independent variable mentioned above for the existing scenario. Fig. 30 shows the relationship between the percentage of large households in a tract and the percentage of zero-vehicle households.

Since there is a downward sloping trend line from left to right, it indicates a negative correlation between two and implies that with tracts with a higher percentage of large households with 3 or more members correlate with a lower perecentage of zero-income households. Therefore a higher share of larger households in a tract implies potentially greater vehicle ownership shares.

Fig. 31 and Fig. 32 show the relationship between the percentage of low-income and high-income households in census tract that represent the first and fifth income quantiles in existing household incomes in the region, respectively, and the percentage of zero-vehicle households. Fig. 31 suggests through its upward sloping trend that with higher shares of low-income households in a census tract, the shares of zero-vehicle households increase, while Fig. 32 suggests an opposite trend in zero-vehicle households with respect to high-income households. As shares of high-income households in a tract increase, the percentage of zero-vehicle households fall.

Fig. 30: Percentage of big and zero-vehicle households

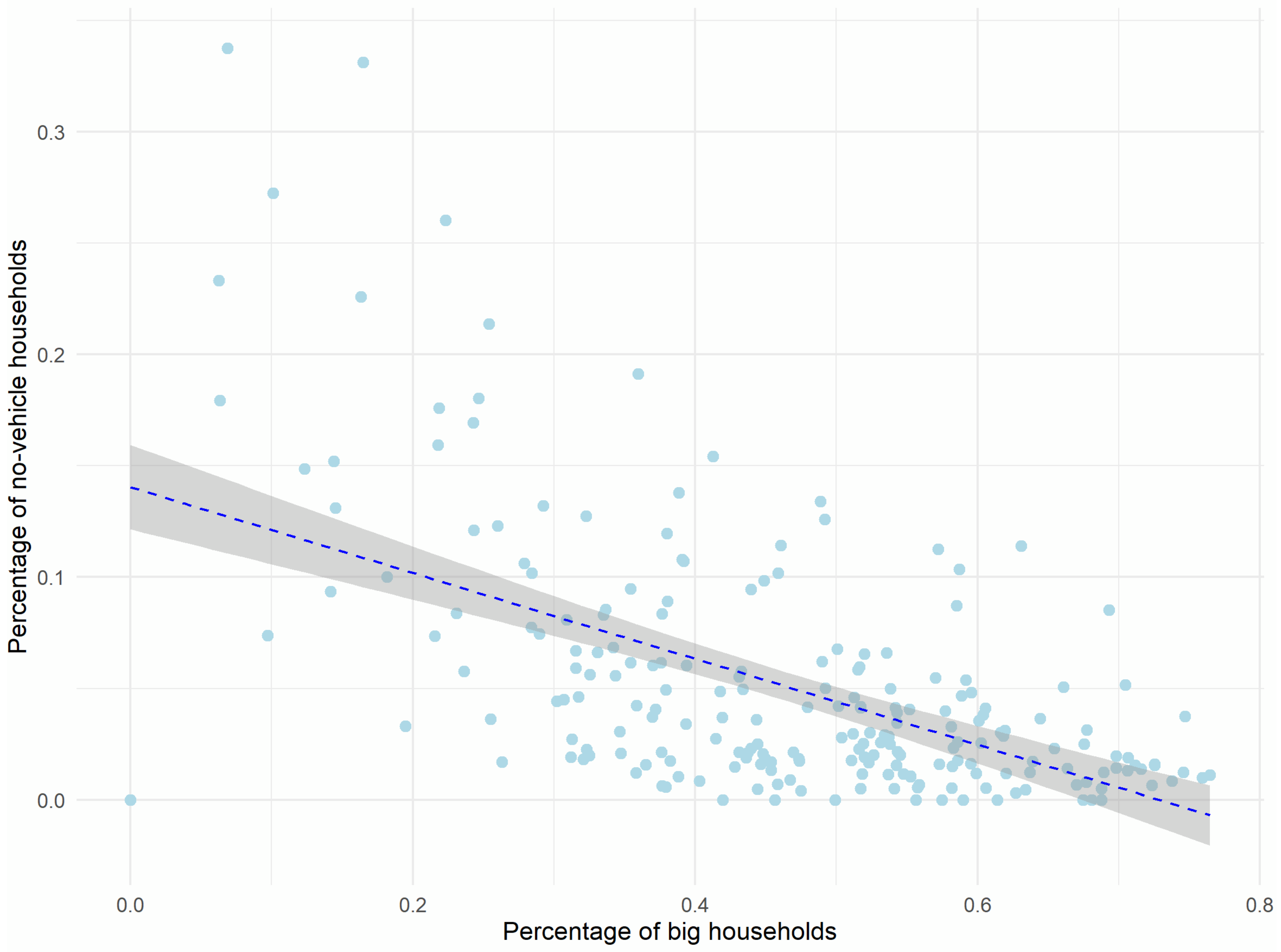


Fig. 31: Percentage of low-income and zero-vehicle households

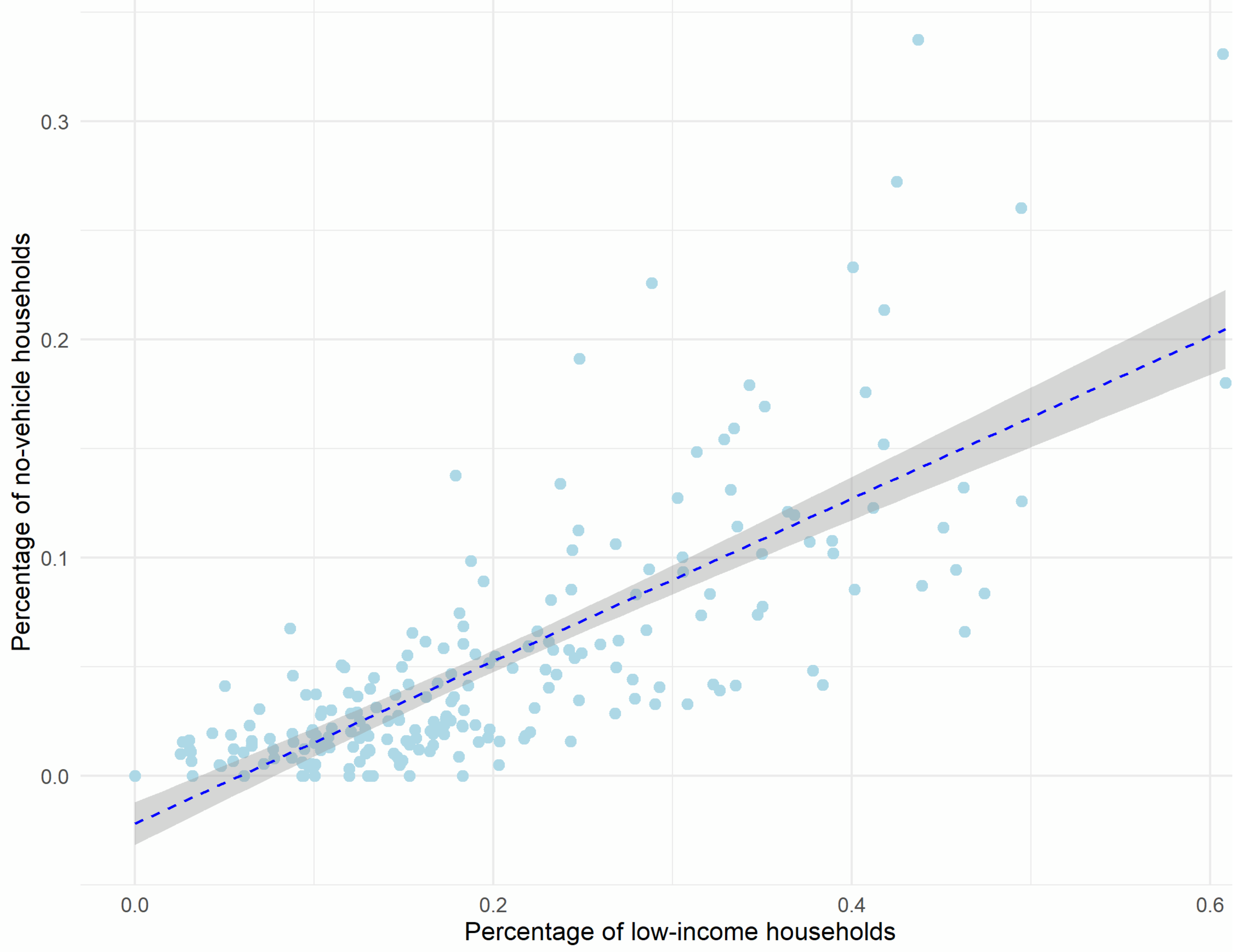


Fig. 32: Percentage of high-income and zero-vehicle households

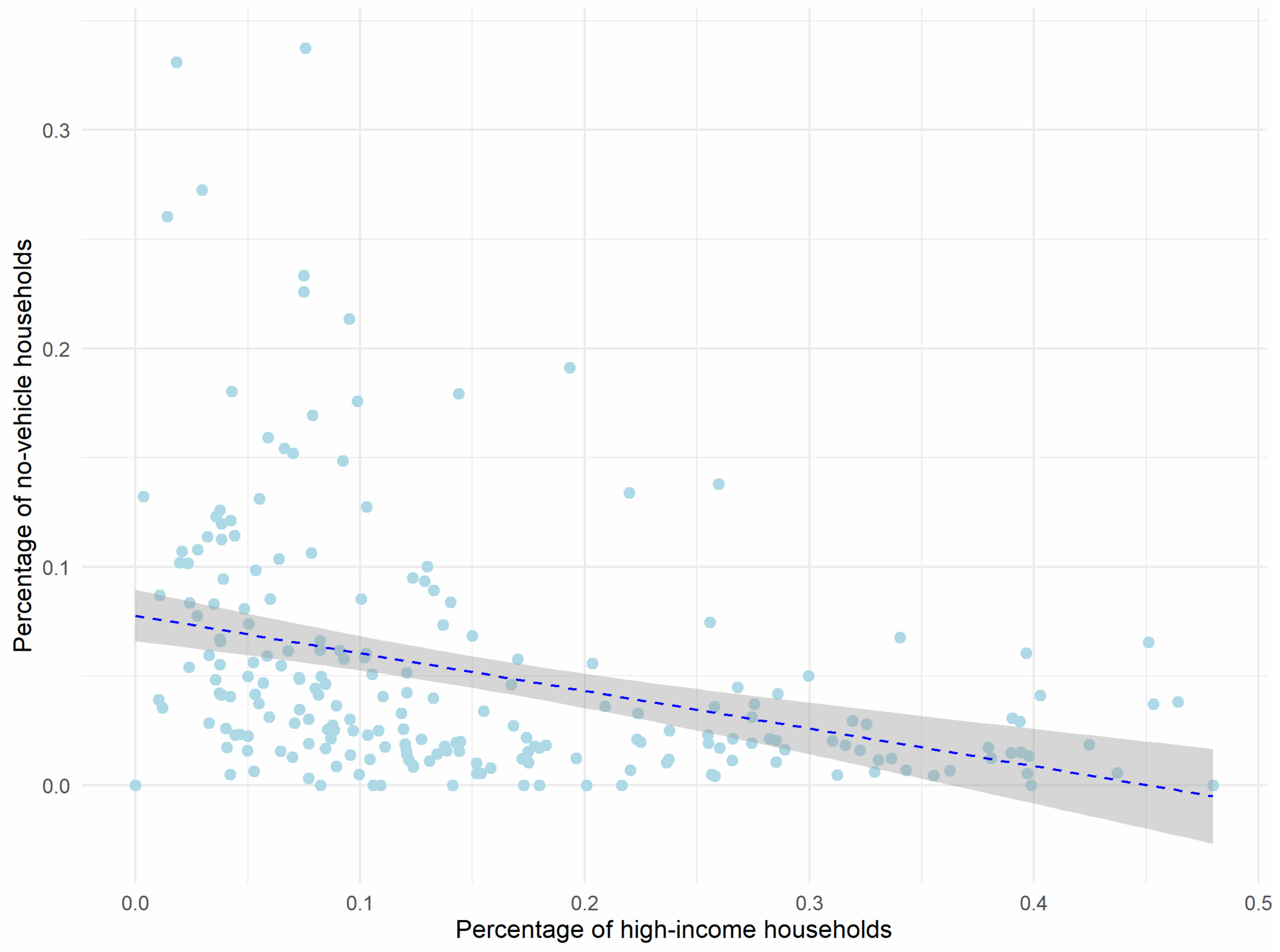


Fig. 33 shows an upward sloping trend reflecting a positive correlation although the correlation strenth seems lower since the points are not tightly clustered. It suggests that with higher ratios of transit accessibility to car accessibility in a census tract, the shares of zero-vehicle households increase. In Fig. 34, we have visualized the existing data the accessibility ratio at the household level are fairly normally distributed. The other three selected independent variables have been described in Chapter 2.

We then estimated regression models for our existing data with results shown in Fig. 33. In the first model we noticed that one of our independent variables (the percentage of high-income households) did not have a significant coefficient. We then tried a second version of the model that excludes that variables and noticed the same model fit reflected by the R squared value of 0.64.

Since fewer variables may lead to a more effective and cleaner regional travel demand model, we also wanted to explore further

Fig. 33: Transit-car accessibility ratio and zero-vehicle households

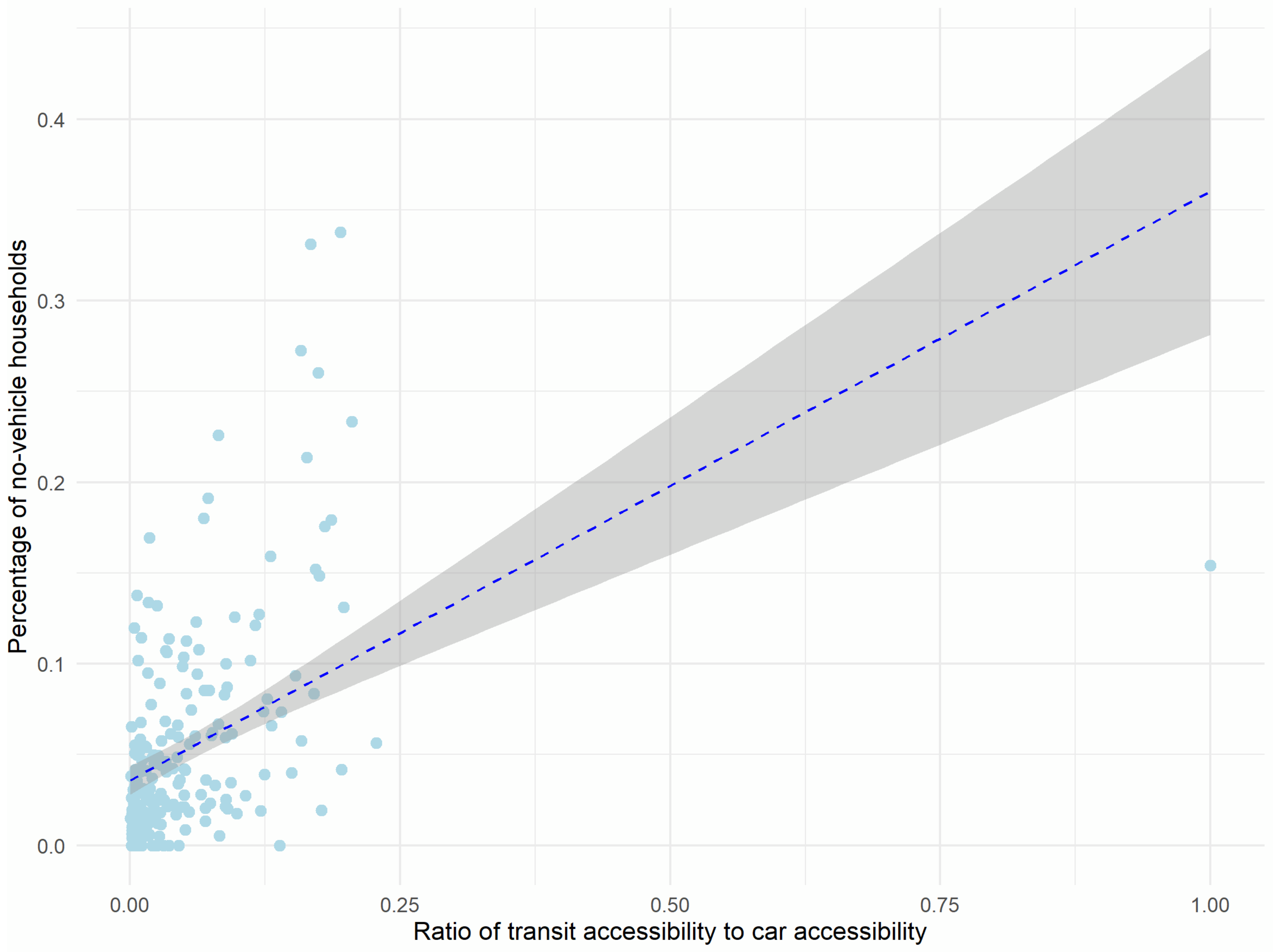
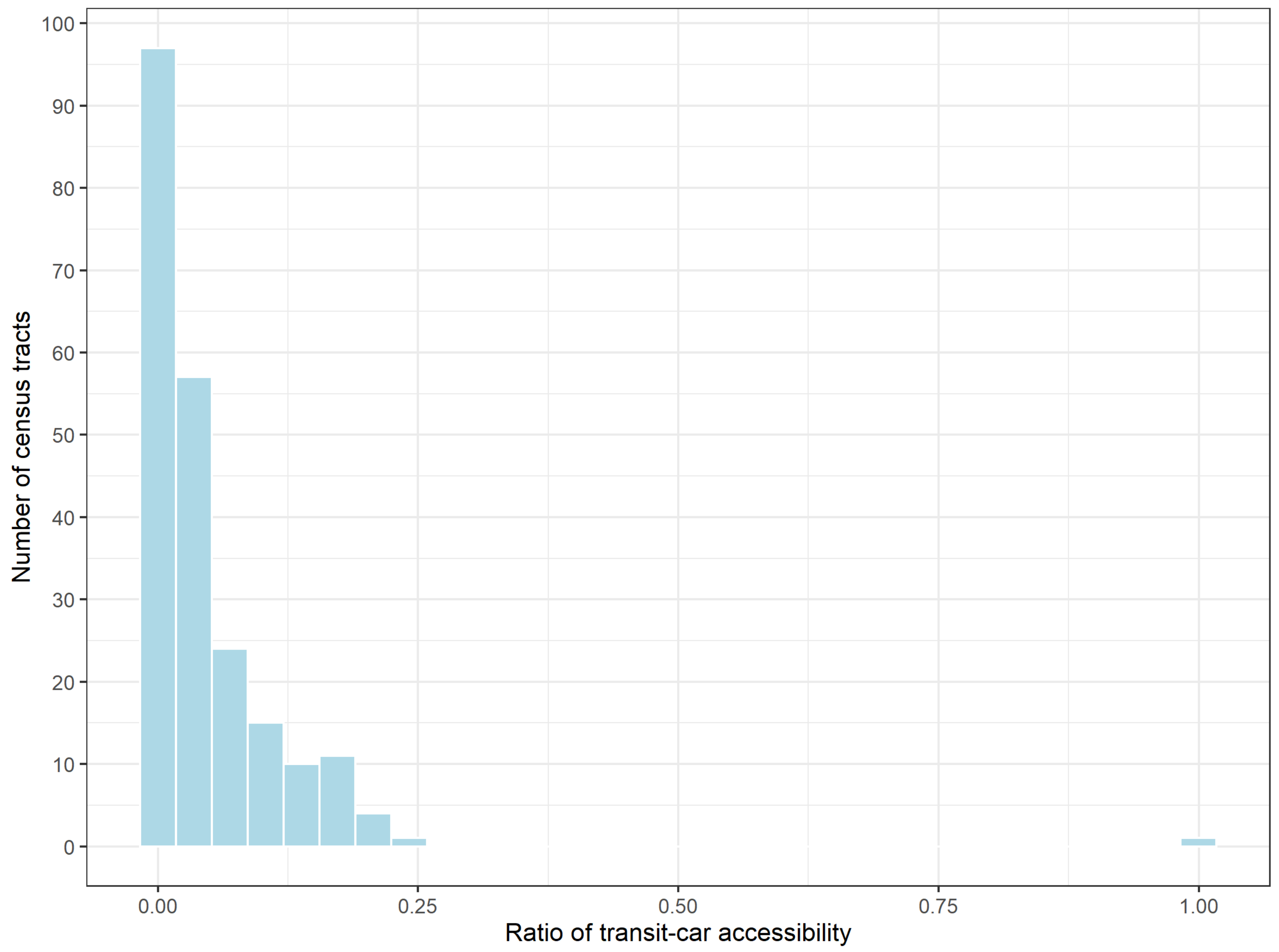


Fig. 34: Distribution of transit to car accessibilility ratios



and tried a third version of our model where we eliminated the variable on car and transit accesibility ratio which had a less significant coefficient. We noticed a slight reduction in the R squared value. We therefore decided to move forward with the second model that considers three independent variables. Fig 34 represents a visual summary of our regression models. We used the results of the second regression model to predict vehicle ownership in our alternative scenario by estimating the number of zero vehicle households.

The chloropleth map in Fig. 35 represents the distribution of the estimated number of zero-vehicle households. We found no significant change in the percentage of zero-vehicle ownership in the census tracts between the existing and alternative scenarios, and is represented in the summary table below that has a standard deviation of 0.058. To explore further, we also tried to estimate the number of zero-vehicles in Model 3 and we found no change reflected in that either. This insignificant difference could be because our alternative scenario does not involve any change in the socioeconomic variables of income and household size, and previously the difference in our accesibililty ratios for our two scenarios was also very marginal.

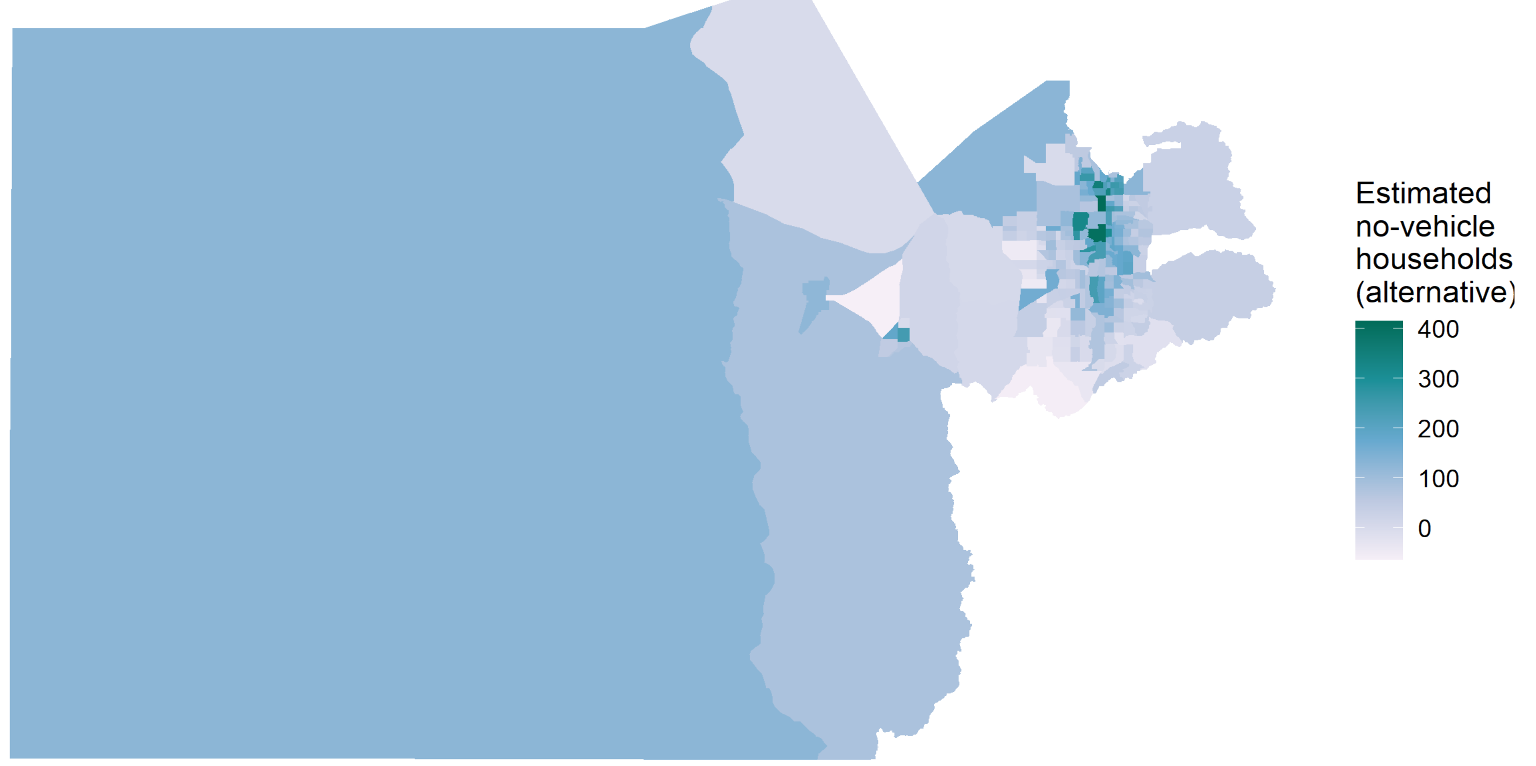
Fig. 33: Regression models

	Model 1	Model 2	Model 3
(Intercept)	0.01	0.02 *	0.03 **
	(0.01)	(0.01)	(0.01)
pct_big_hh	-0.07 ***	-0.08 ***	-0.09 ***
	(0.02)	(0.02)	(0.02)
pct_lo_inc	0.32 ***	0.30 ***	0.32 ***
	(0.03)	(0.02)	(0.02)
pct_hi_inc	0.04		
	(0.02)		
ratio	0.08 *	0.08 *	
	(0.03)	(0.03)	
N	220	220	220
R2	0.64	0.64	0.63

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

	Percentage change in zero vehicle households
Minimum	0.01555
1st Quartile	0.01555
Median	0.03093
Mean	0.05179
3rd Quartile	0.06608
Maximum	0.33760

Fig. 35: Distribution of estimated zero vehicle households



C H A P T E R 6

ESTIMATE TRIP GENERATION

This chapter details out the trip generation model, which is the first and basic step in the travel demand model, and estimates the number of trips produced by or attracted to each TAZ, as a function of its socioeconomic characteristics.

Trip Productions

We first estimate three regression models that predict the number of trips produced per household. We picked three variables from the NHTS 2017 data for our region that have a reasonable tract-level analog in the American Community Survey, to estimate the household-level trip production model, shown in Table 8.

Zone level ACS variables	Household level NHTS variables
Number of people in income categories*: 1st category is under \$35k per annum 2nd category is \$35k to \$75k per annum 3rd category is \$75k to \$100k per annum 4th category is \$100k to \$150k per annum 5th category is over \$150k per annum	Household income
Number of zero-vehicle households	Number of household vehicles

*The income categories are based on the regional income quintiles but have been slightly adjusted to match the income brackets in NHTS data.

Table 8: Trip production model variables

Household size: Number of 1-person households Number of 2-person households Number of 3-person households Number of 4-or-more-person households	Number of household members

We determine productions and attractions for three trip purposes:

- Home-based Work (HBW) trips: These have the home and the place of work for a household member as the two trip ends.
- Home-based Other (HBO) trips: The home is one of the trip ends, and another place like shopping areas, restaurants, amenities, etc. that is not the home or workplace, is the other trip end.
- Non-home based (NHB) trips: These do not have the household's home on either end of the trip, i.e., neither the origin or destination.

Fig. 38 - 40 represent the Household-level Regression models for the three trip purposes that include all the selected variables in the first model. We test out alternative models by reducing insignificant variables. If the R2 does not change much after dropping insignificant variables, we opt for the alternative models. For all the trip purposes, we find that only household size is the significant variable. However, we kept income quintiles for NHB trip generation model because otherwise the R2 would be reduced to 0.08 from 0.11. After testing alternative models, we apply the coefficients from the preferred model for all three purposes to estimate the zone-level trip productions across Salt Lake MSA.

Fig. 41 - 43 on the next page show the number of trips for each purpose for all the census tracts in the MSA. Maximum trips are for HBO purpose at about 2.13 million trips. This is followed by 1.09 NHB trips. HBW trips constitute the least number of trips with only about 0.43 million trips annually. The chloropleth maps in Fig. 44 -46 show the spatial distribution of trip productions and highlight that highest trip productions are in the southern tracts in Salt Lake County.

Fig. 38: Household-based regression models for HBW trips

	Full model		Reduced model	
(Intercept)	1.17 *	(p = 0.01)	1.24 **	(p = 0.01)
zero_veh_TRUE	0.66	(p = 0.13)		
size_one	-1.13 **	(p = 0.01)	-1.03 *	(p = 0.02)
size_three	-0.44	(p = 0.36)	-0.45	(p = 0.35)
size_two	-0.44	(p = 0.29)	-0.40	(p = 0.34)
inc_quint_2nd	0.61	(p = 0.19)	0.51	(p = 0.24)
inc_quint_3rd	0.02	(p = 0.96)	-0.10	(p = 0.82)
inc_quint_4th	0.63	(p = 0.14)	0.55	(p = 0.18)
inc_quint_5th	0.53	(p = 0.30)	0.43	(p = 0.39)
N	119		119	
R2	0.12		0.12	

*** p < 0.001; ** p < 0.01; * p < 0.05.

Fig. 39: Household-based regression models for HBO trips

	Full model		Reduced model	
(Intercept)	7.73 ***	(p = 0.00)	7.74 ***	(p = 0.00)
zero_veh_TRUE	-0.82	(p = 0.43)		
size_one	-5.72 ***	(p = 0.00)	-5.95 ***	(p = 0.00)
size_three	-1.31	(p = 0.31)	-1.20	(p = 0.37)
size_two	-2.80 *	(p = 0.03)	-2.67 *	(p = 0.03)
inc_quint_2nd	0.52	(p = 0.62)		
inc_quint_3rd	-1.71	(p = 0.15)		
inc_quint_4th	-0.32	(p = 0.82)		
inc_quint_5th	1.79	(p = 0.41)		
N	119		124	
R2	0.25		0.22	

*** p < 0.001; ** p < 0.01; * p < 0.05.

Fig. 40: Household-based regression models for NHB trips

	Full model		Reduced model	
(Intercept)	2.31 **	(p = 0.00)	2.30 **	(p = 0.00)
zero_veh_TRUE	-0.15	(p = 0.87)		
size_one	-1.95 *	(p = 0.05)	-1.97 *	(p = 0.03)
size_three	0.22	(p = 0.82)	0.22	(p = 0.82)
size_two	-0.87	(p = 0.35)	-0.87	(p = 0.34)
inc_quint_2nd	1.44	(p = 0.11)	1.46	(p = 0.08)
inc_quint_3rd	1.87	(p = 0.08)	1.89	(p = 0.06)
inc_quint_4th	-0.12	(p = 0.86)	-0.11	(p = 0.88)
inc_quint_5th	2.69	(p = 0.10)	2.71	(p = 0.09)
N	119		119	
R2	0.11		0.11	

*** p < 0.001; ** p < 0.01; * p < 0.05.

Trip Attractions

The next step after determining trip production is to estimate trip attraction for the zones. For this assignment, we do not estimate our own trip attraction model. Instead, we apply the one from Table 4-4 of the National Cooperative Highway Research Program (NCHRP) Report 716, to predict the the number of trips attracted to each zone for each trip purposes. We compare the estimated trip attraction with the trip production values. Overall, we find that the trip attraction model is estimating more trips than trip production model for all three purposes. We scale the trip attractions so the regional total matches the total number of trip productions, and the trip attraction values for each purpose equals the number of trips produced through the estimated model.

Fig. 41: Number of HBW trip production in Salt Lake MSA

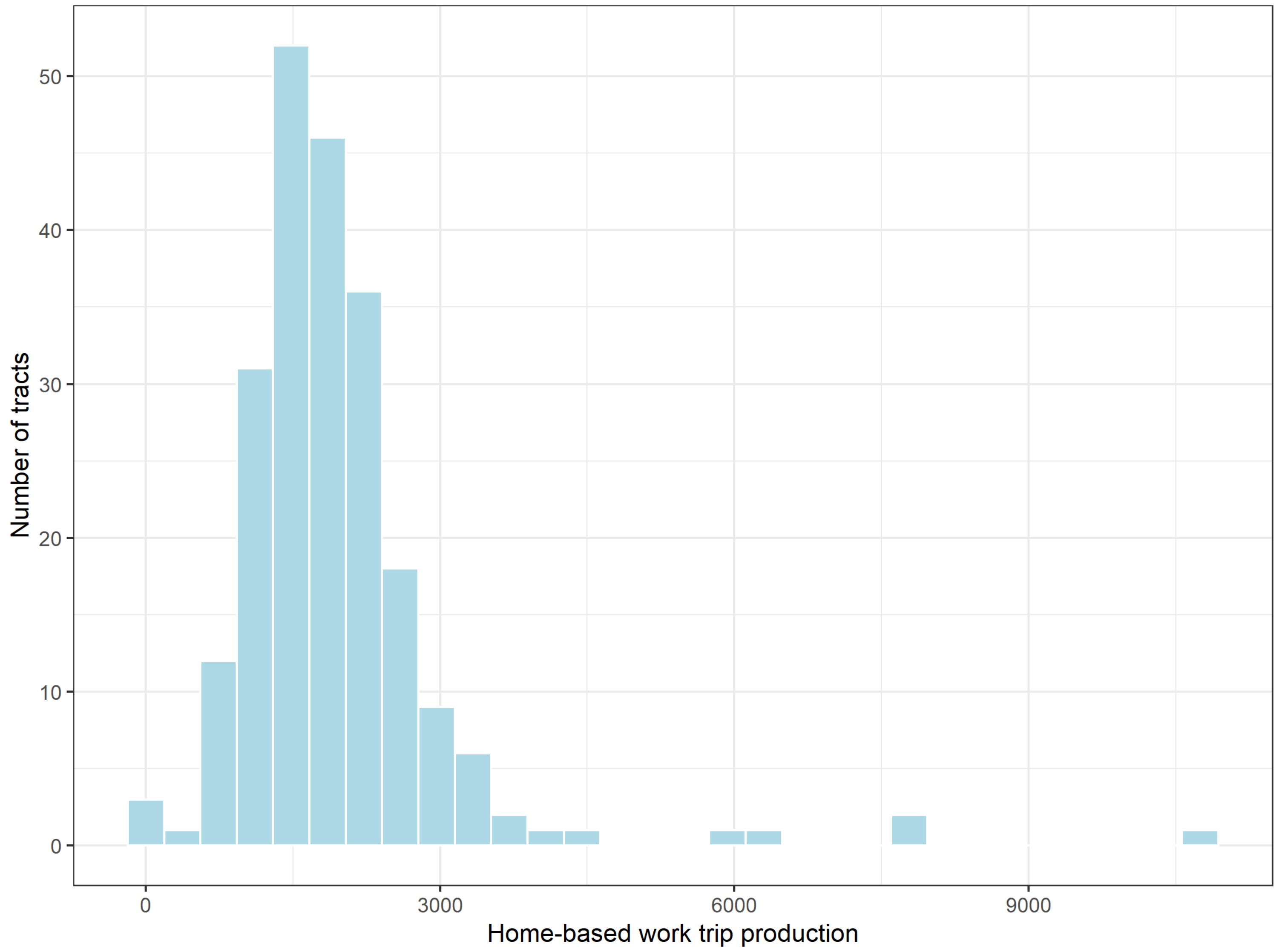


Fig. 42: Number of HBO trip production in Salt Lake MSA

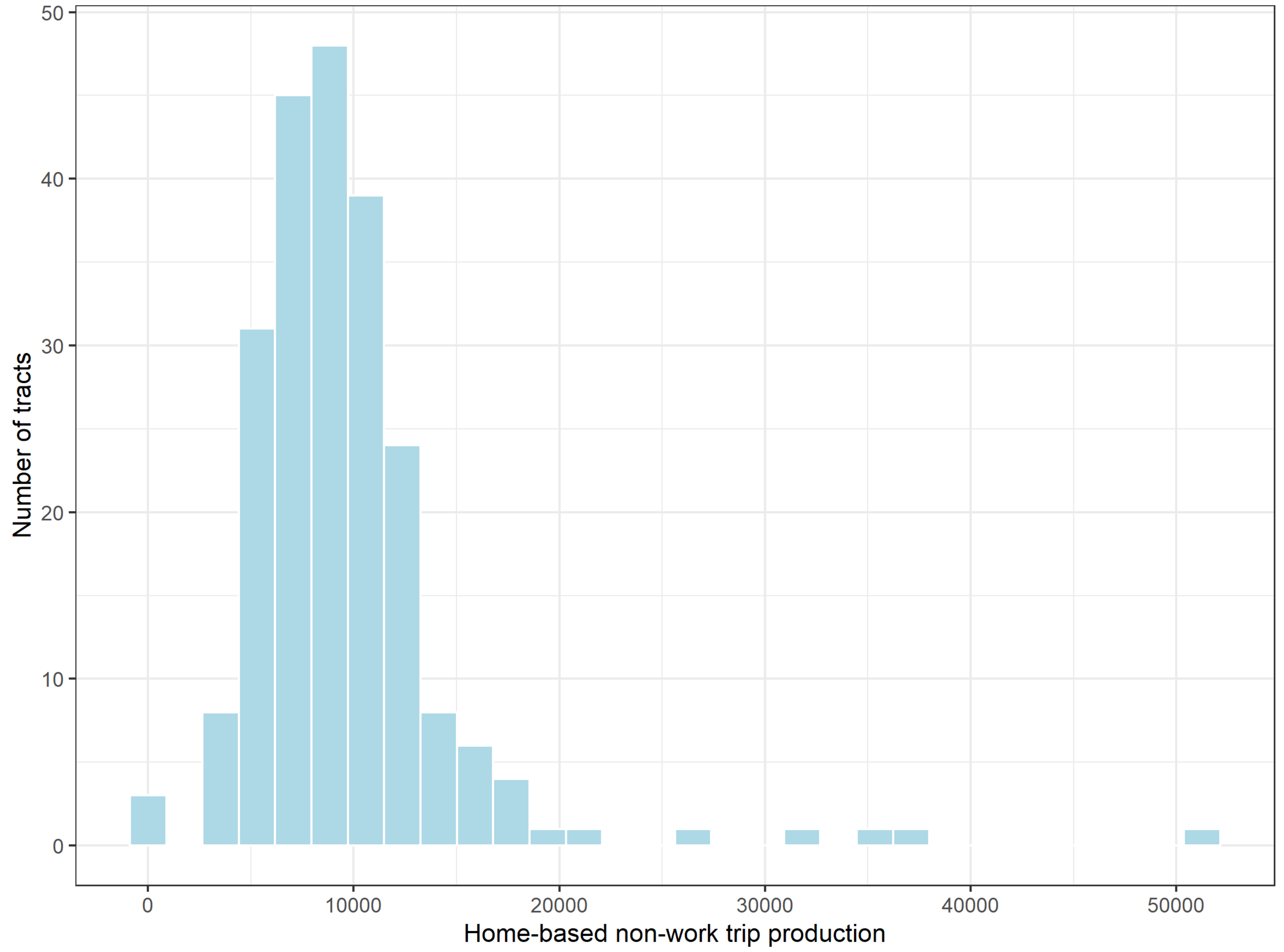


Fig. 43: Number of NHB trip production in Salt Lake MSA

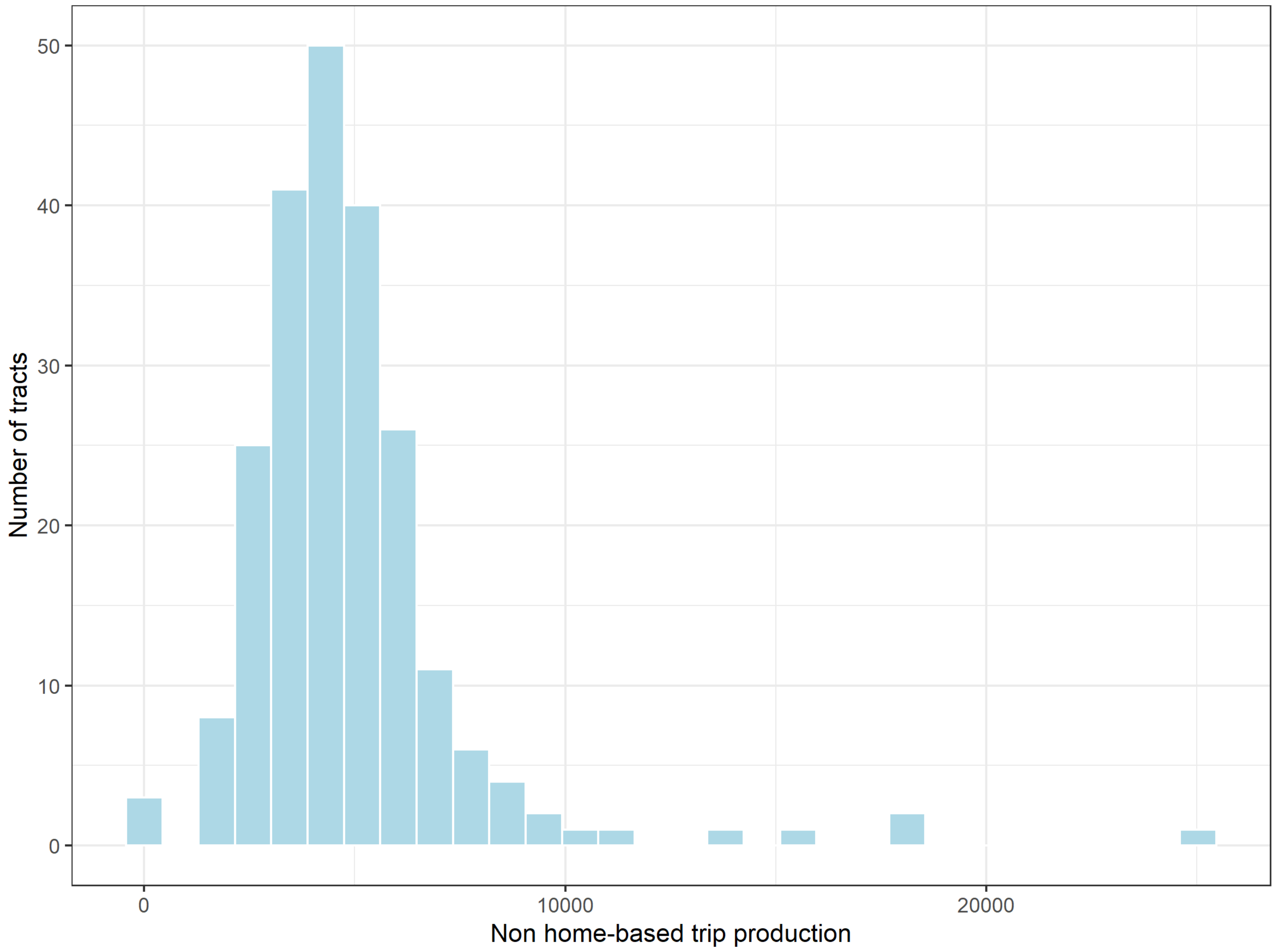


Fig. 44: Distribution of HBW trip productions in Salt Lake MSA

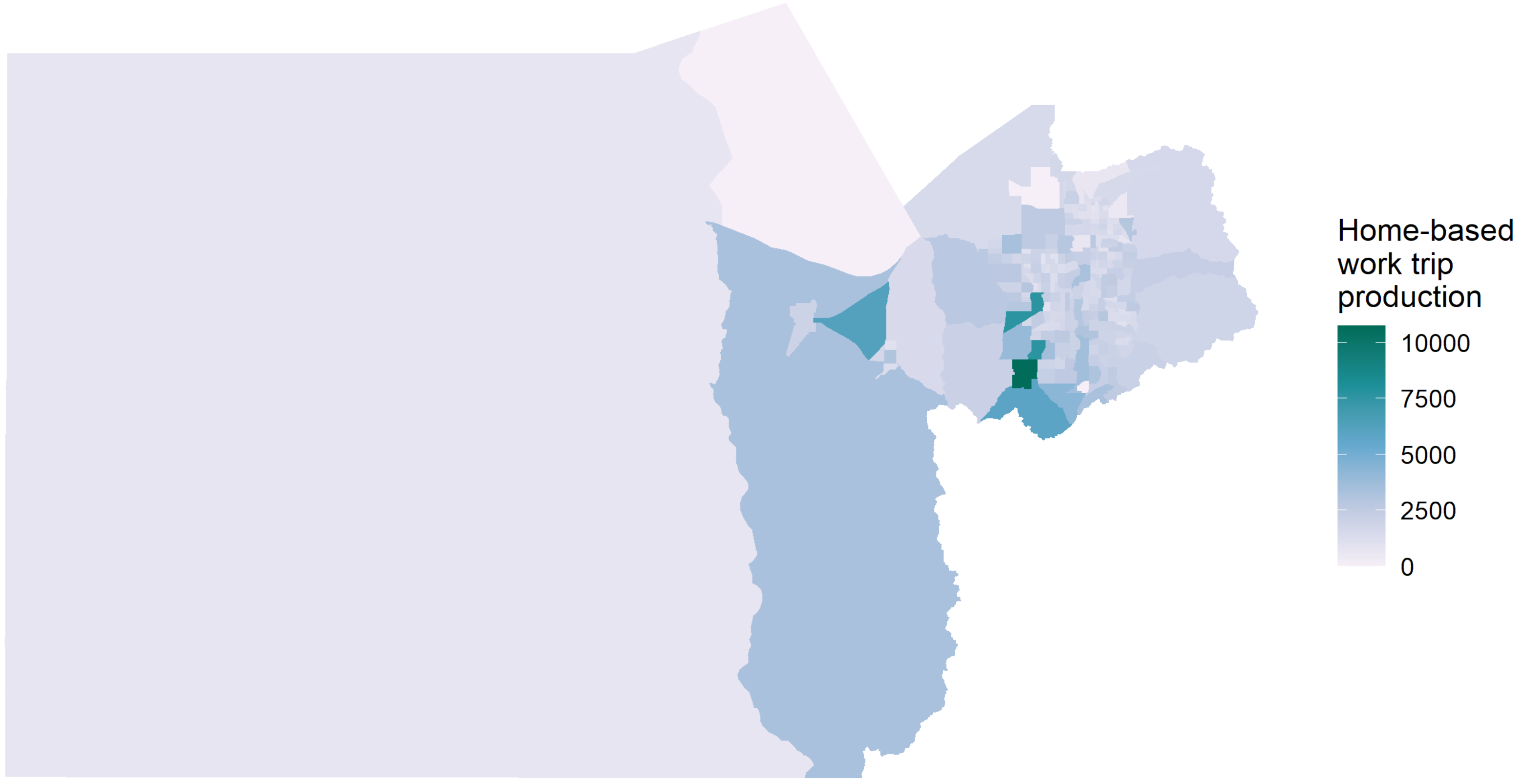


Fig. 45: Distribution of HBO trip productions in Salt Lake MSA

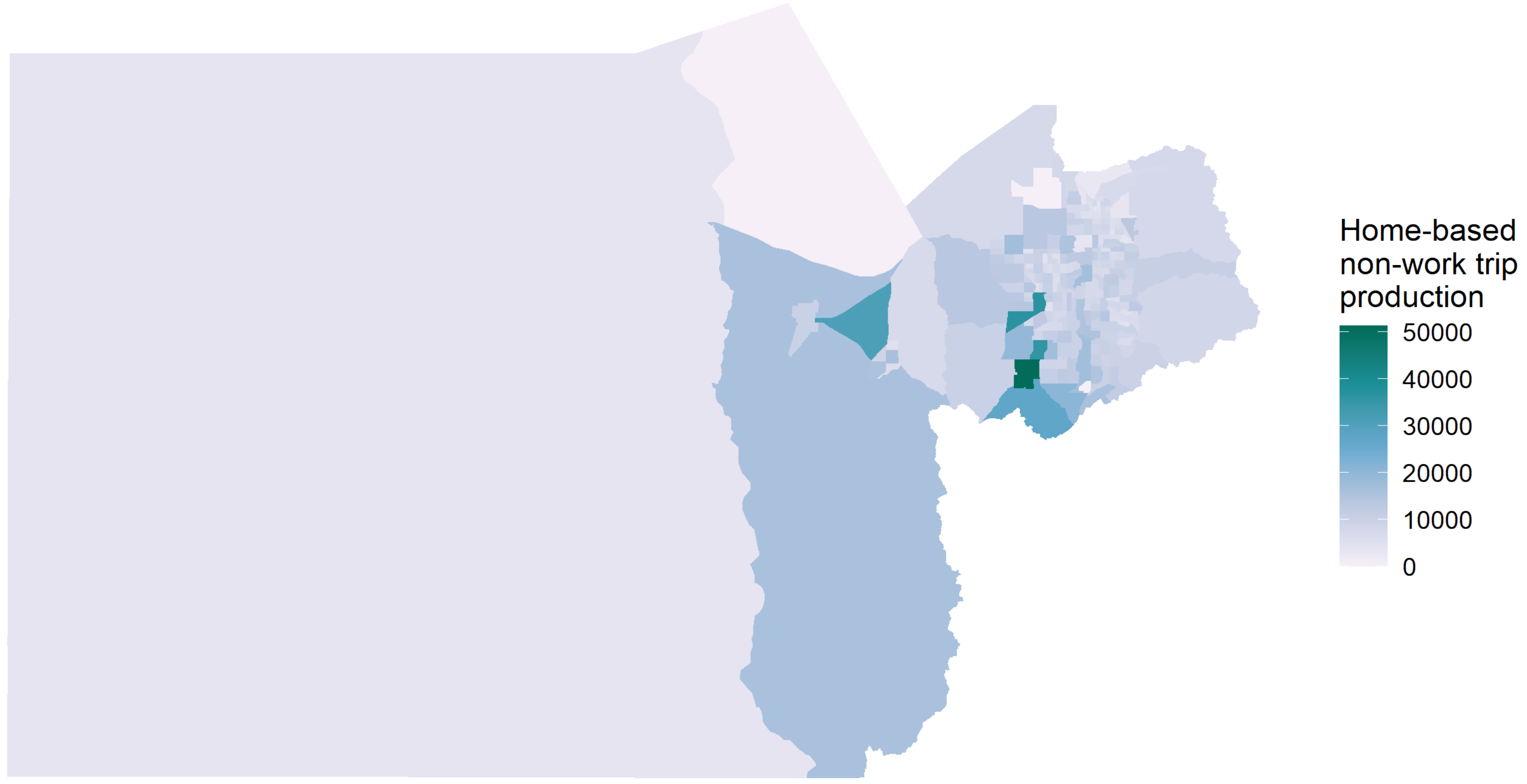


Fig. 46: Distribution of NHB trip productions in Salt Lake MSA

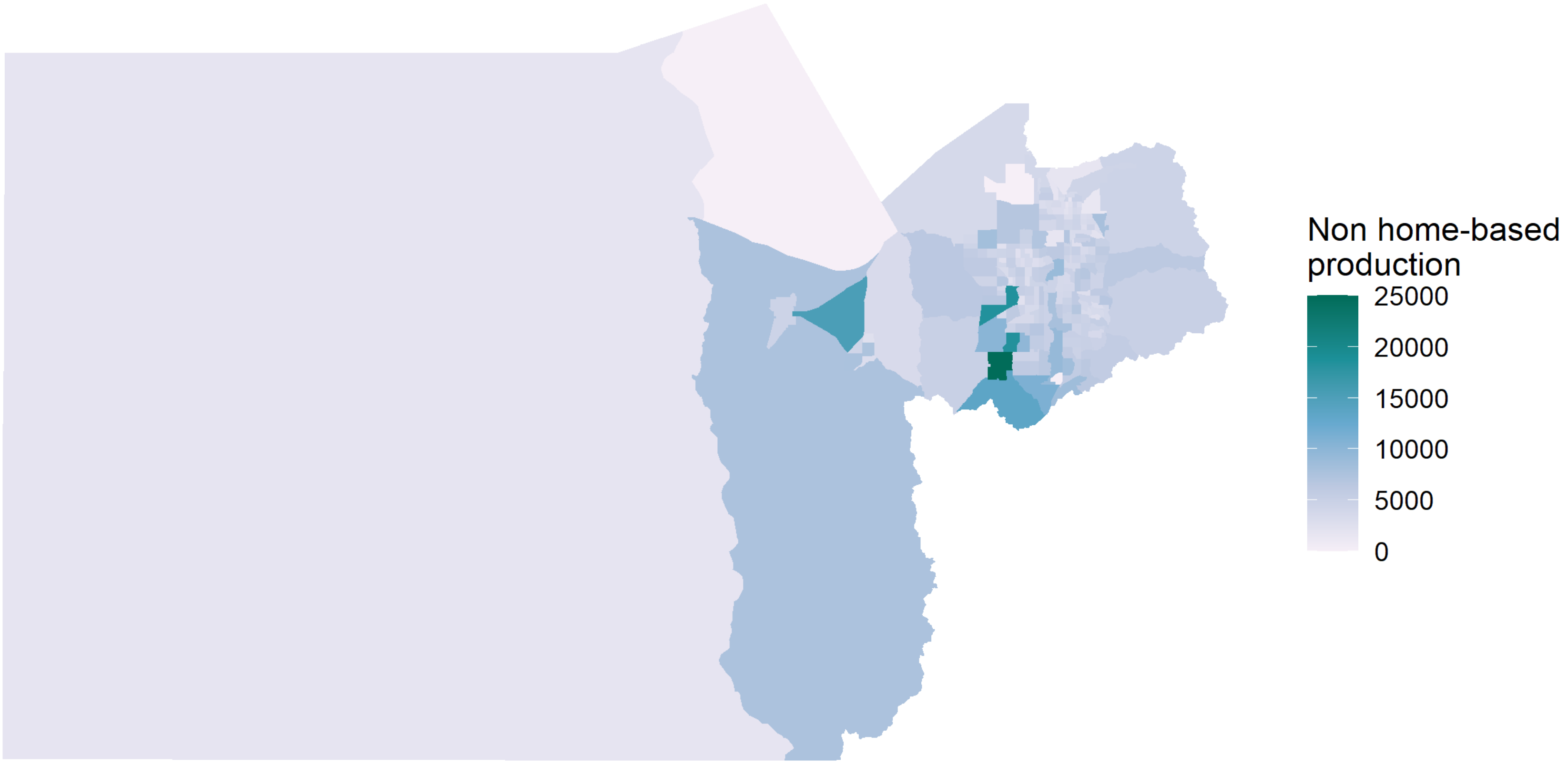


Fig.48, 49 and 50 show that all adjusted trip attractions have a right-skewed distribution. Most tracts attract less than 10,000 HBW trips. As shown in Fig. 51, HBW attractions are concentrated on the north side (over 30,000 trip attractions) and the south side (over 20,000 trip attractions) of Salt Lake City. Some HBW attractions are scattered along the central corridor of Salt Lake City. Fig.50 shows that most tracts attract less than 30,000 HBO trips. As shown in Fig. 52, HBW attractions are concentrated on the north side (over 150,000 trip attractions) and the south side (over 90,000 trip attractions) of Salt Lake City. Some HBW attractions are scattered along the central corridor of Salt Lake City. Fig. 50 shows that most tracts attract less than 20,000 HBO trips. As shown in Fig.53, HBW attractions are concentrated on the north side (over 70,000 trip attractions) and the south side (over 50,000 trip attractions) of Salt Lake City. Some HBW attractions are scattered along the central corridor of Salt Lake City.

Fig. 48: Number of HBW trip attractions in Salt Lake MSA

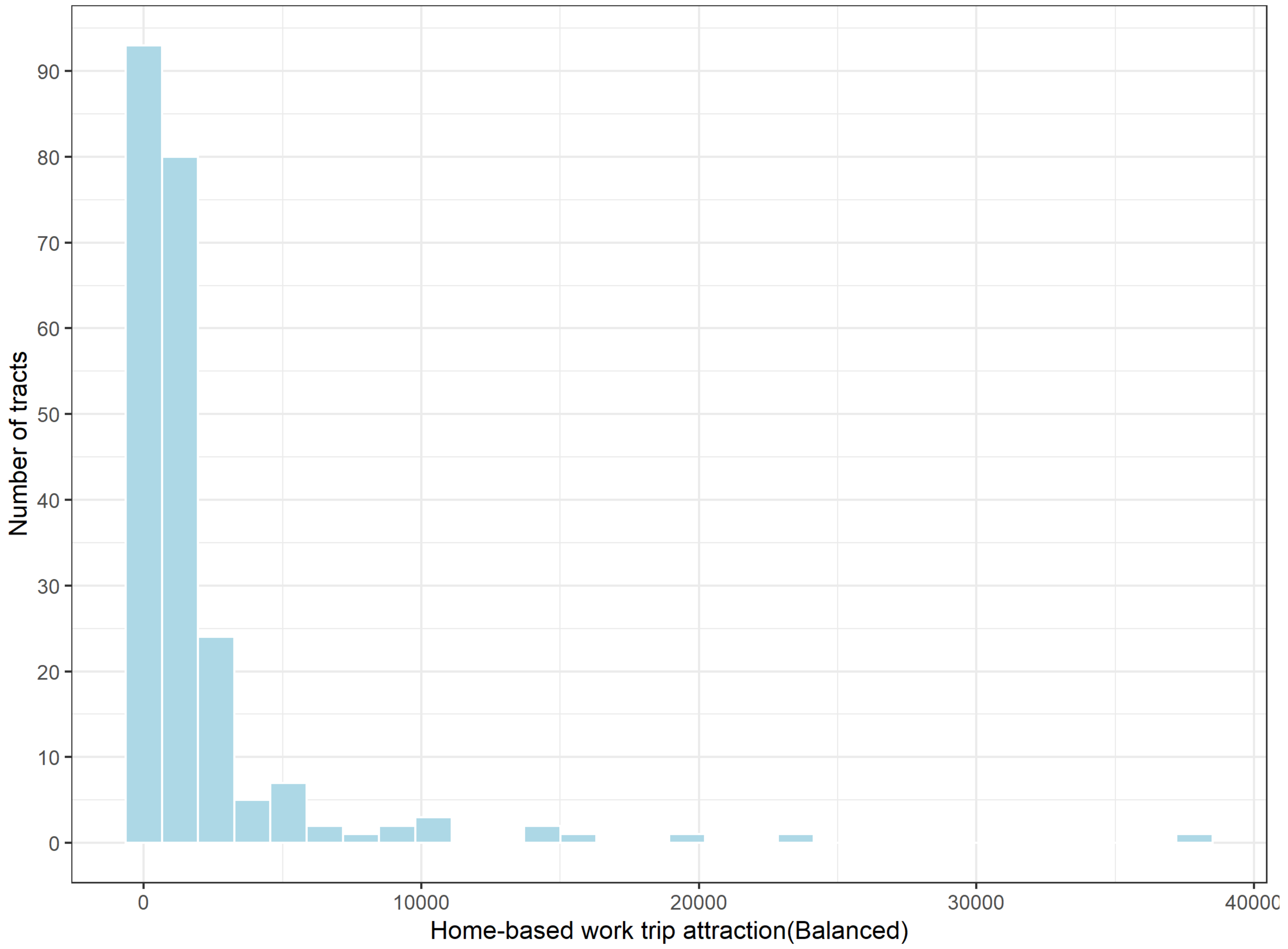


Fig. 51: Distribution of HBW trip attraction in Salt Lake MSA

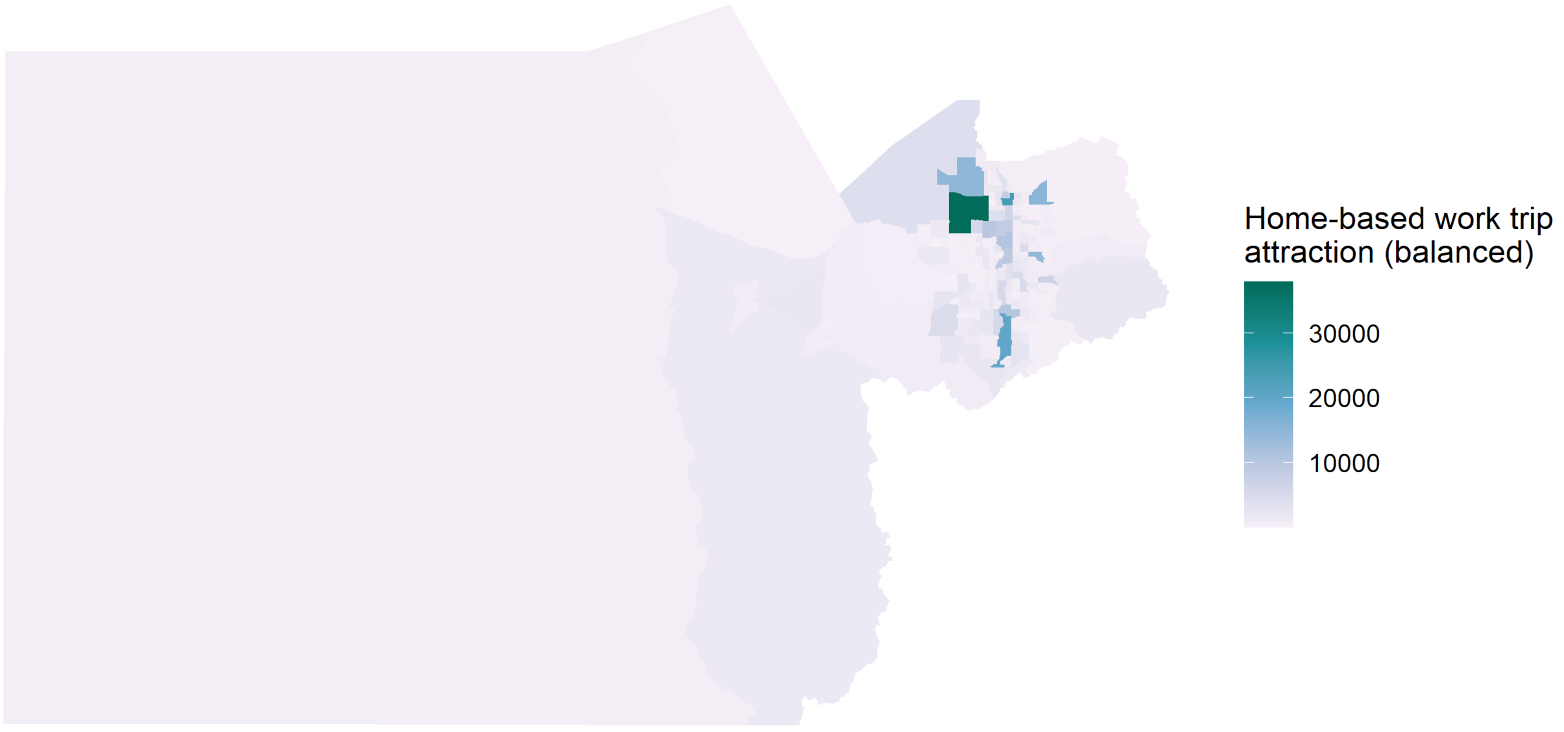


Fig. 49: Number of HBO trip attractions in Salt Lake MSA

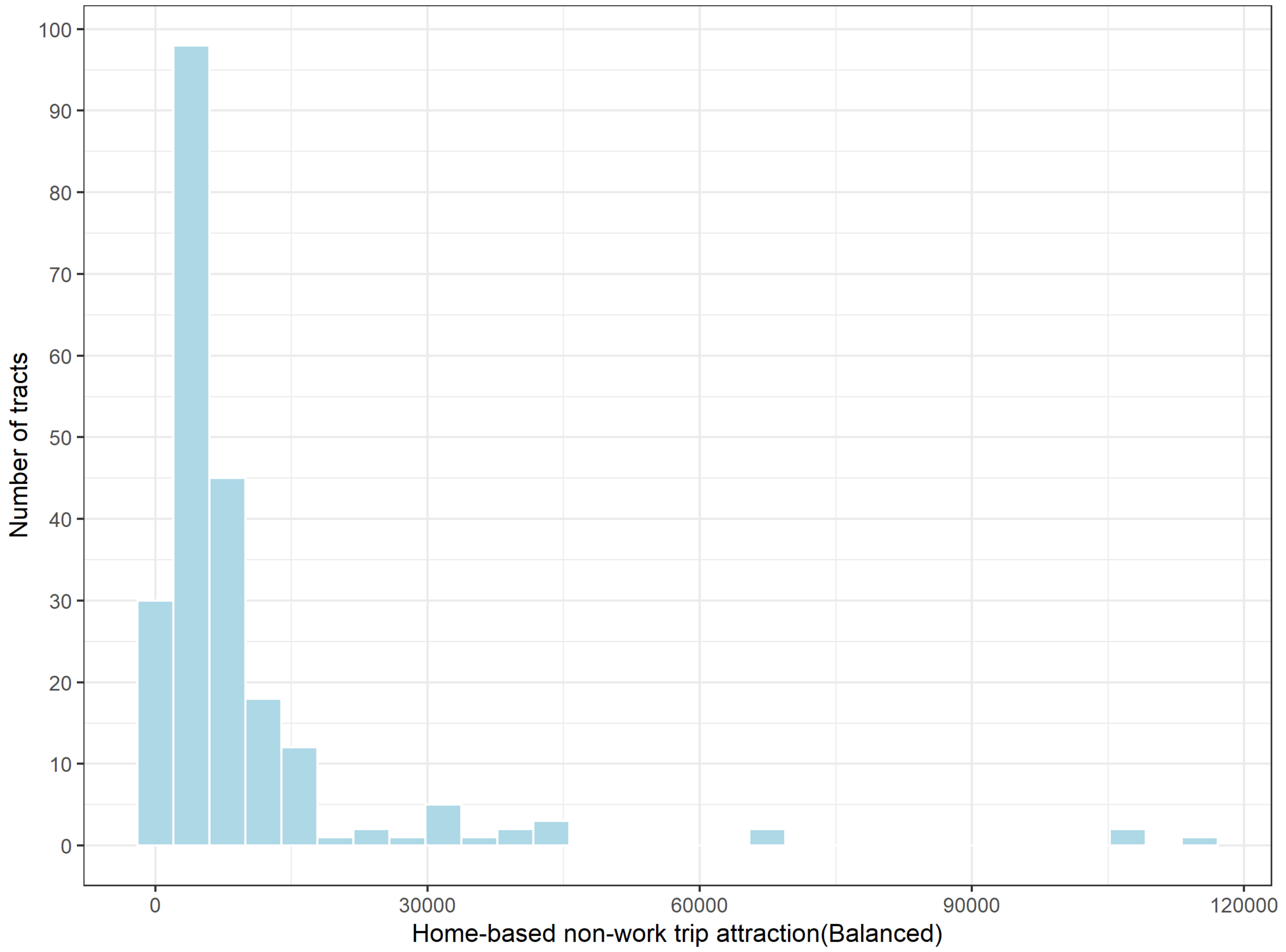


Fig. 52: Distribution of HBO trip attraction in Salt Lake MSA

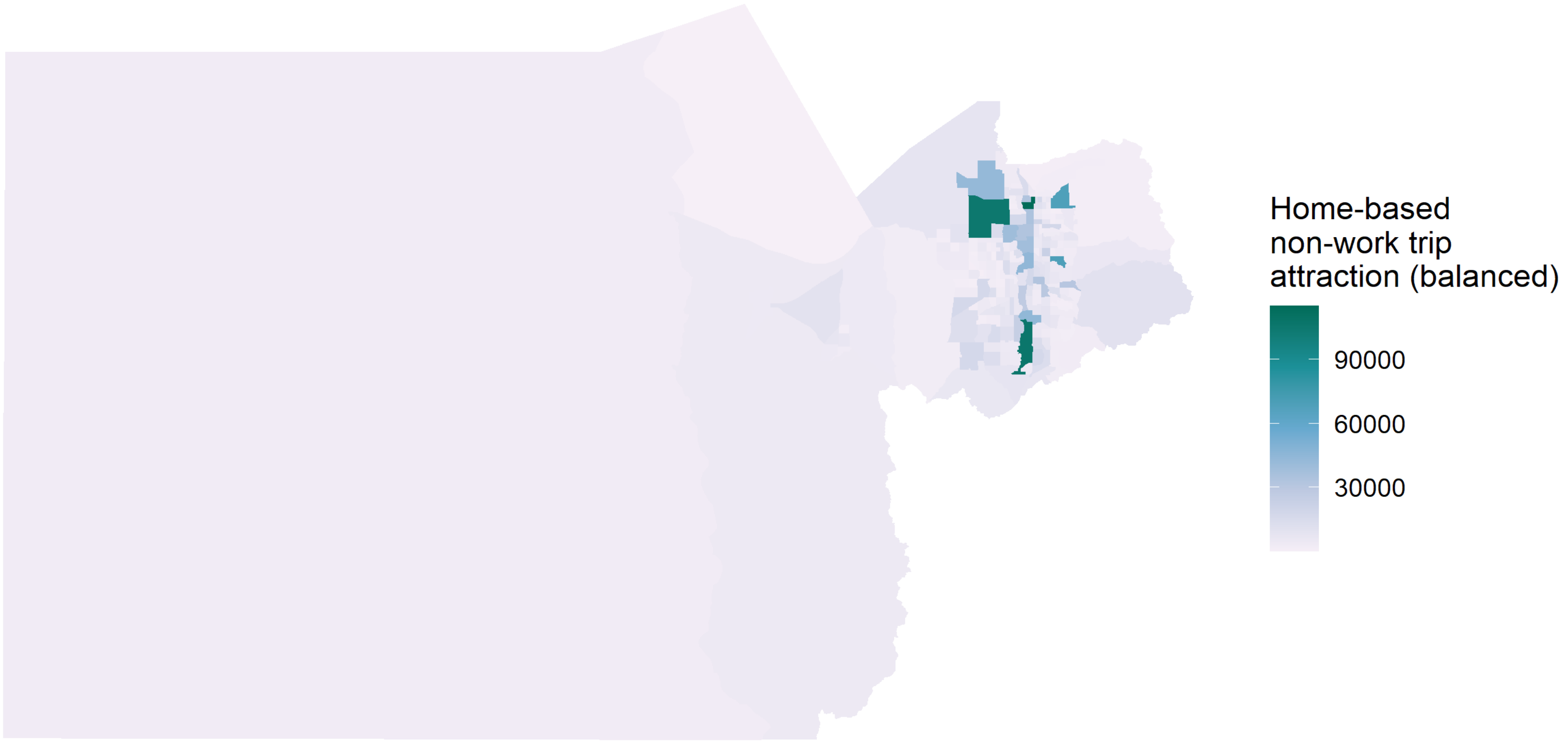


Fig. 50: Number of NHB trip attractions in Salt Lake MSA

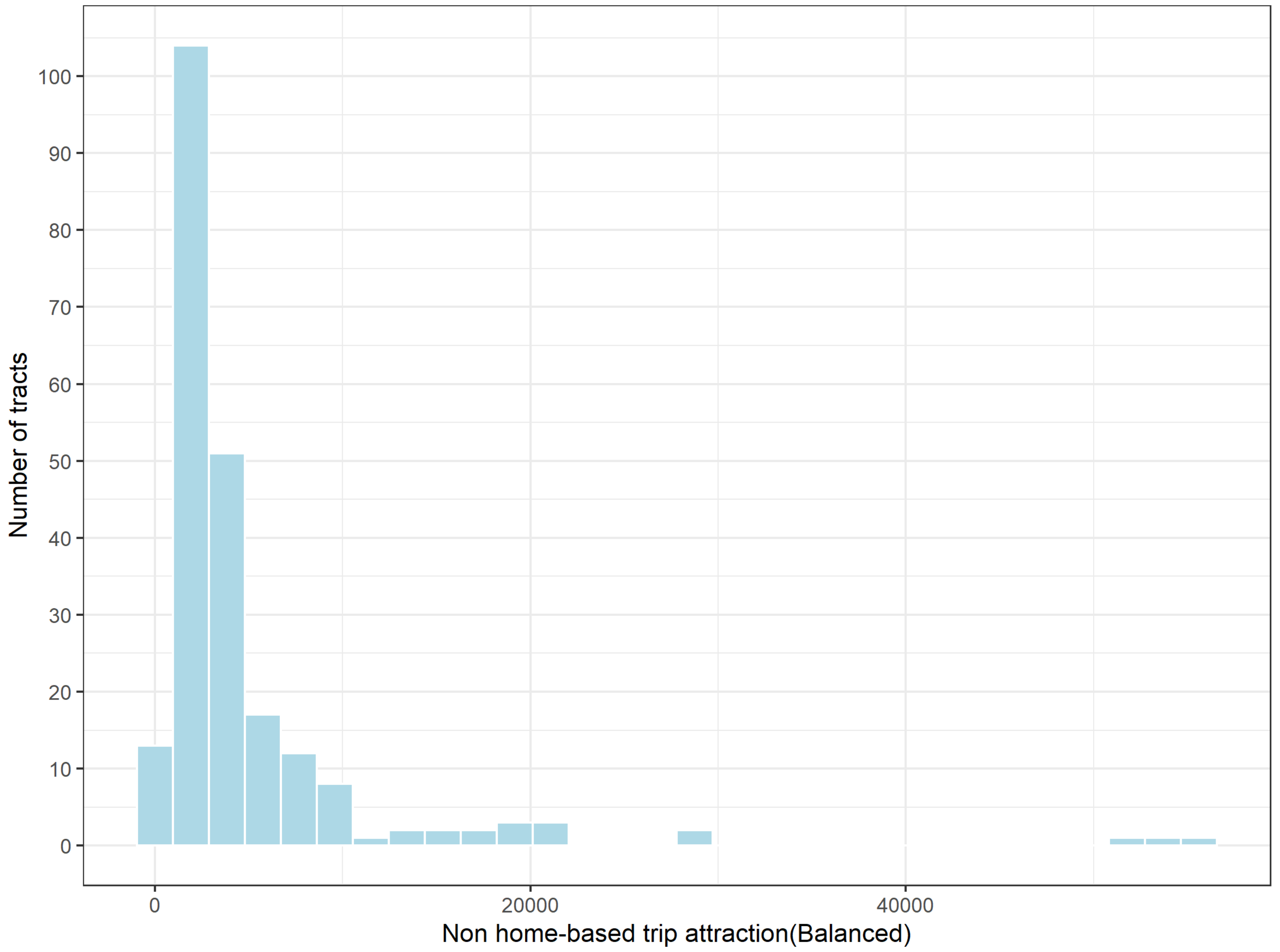
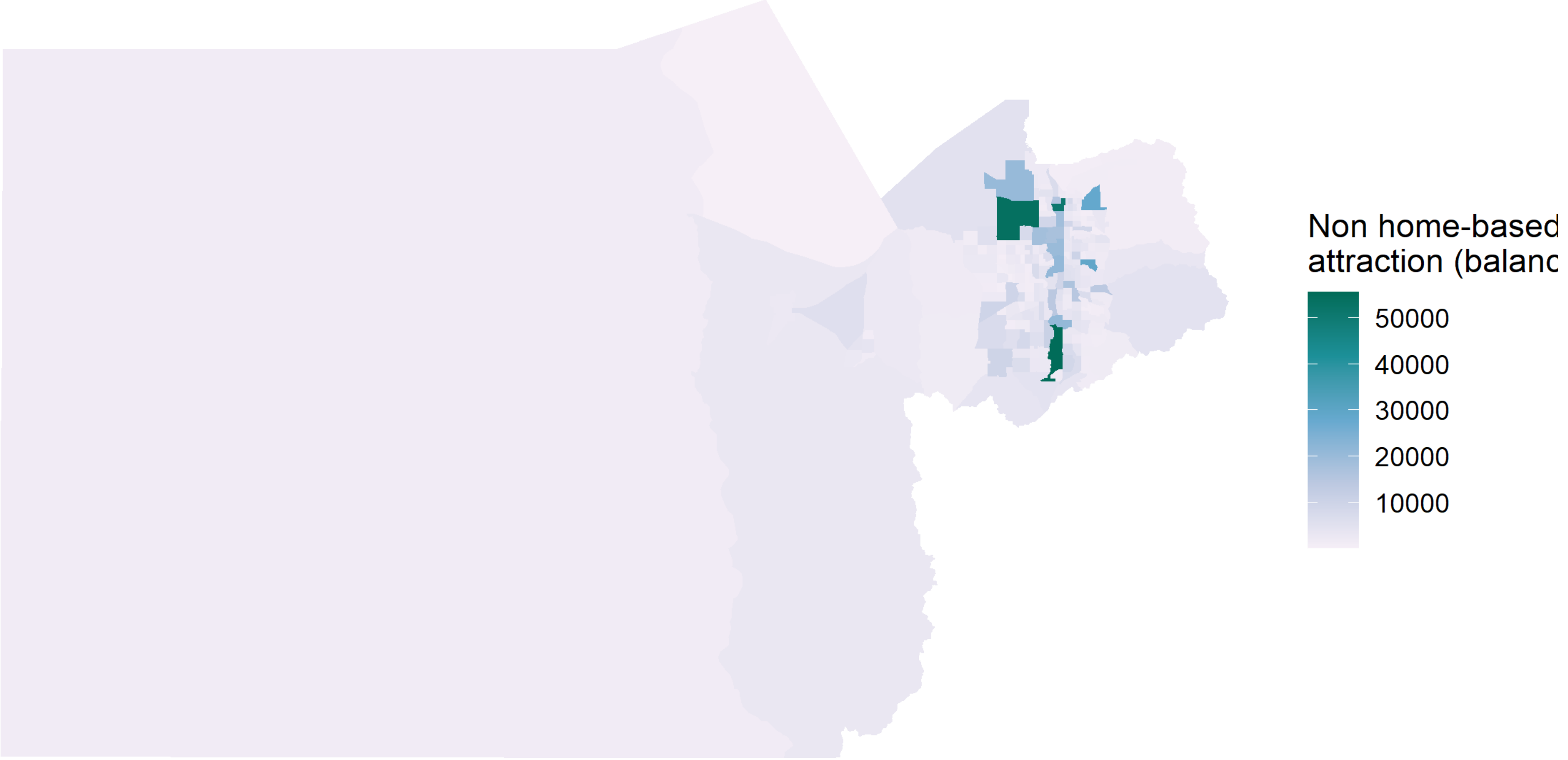


Fig. 53: Distribution of NHB trip attraction in Salt Lake MSA



To be revised based on change to percentage values of tolerance

CHAPTER 7

ESTIMATE TRIP DISTRIBUTION

This chapter details out the trip distribution model, which is the second step in the travel demand model determining how many of the trips generated travel between units of geography, e.g., traffic analysis zones. We use the gravity model to distribute trips for each trip purpose throughout Salt Lake MSA.

We first calculate the average travel times by trip purpose from the NHTS 2017 data for our region, shown in Table 10. We calculate the friction factors using the Gamma function, which is the product of the power function and the exponential function and can be written as: $F_{ijp} = t_{ij}^{b} e^{ct_{ij}}$ where F_{ij} is the friction factor for trips with purpose p between zone i and zone j, t_{ij} is the the travel time from zone i to zone j, and b and c are calibration parameters. NCHRP 716 offers example values for b and c used by seven MPOs that use a gamma function for the trip distribution step of their regional travel demand model. We selected parameters from the Large models since Salt Lake MSA has a population of over 1 million. We used parameters from MPO 1 for HBO & NHB and MPO 3 for HBW which had the smallest gap with estimated travel time. In estimating travel flows, we observe that out of 48012 zonal pairs, 34571 pairs have non-zero HBO trips, 44022 pairs have non-zero HBW trips and 38665 pairs have non-zero NHB trips between them. Figures 54 - 56 represent the origin-destination data for each trip purpose through desire lines connecting origins to destinations in one specific zone which attracts the maximum number of trips for each purpose. Fig. 54 shows the desire lines for a census tract in Salt Lake City that attracts the maximum number of HBO trips. Fig. 55 shows the desire lines for a census tract in western Salt Lake City that attracts the maximum number of HBW trips. Fig. 56 shows them for a tract near Draper city that attracts the maximum number of NHB trips. Table 10 below compares the average travel time calculated using NHTS data, and that estimated by our gravity model that generated P-A matrices for the different trip purposes, and shows only a small gap between the predicted and observed average travel times.

Table 9: Average Travel Times by trip purpose

Trip Purpose	Average Travel Time (NHTS)	Standard Error	Average Travel Time (gravity estimate)
HBO	16.193	1.020	14.311
HBW	24.275	1.622	21.691
NHB	17.179	1.201	15.262

Fig. 54: Desire line diagram for HBO trips

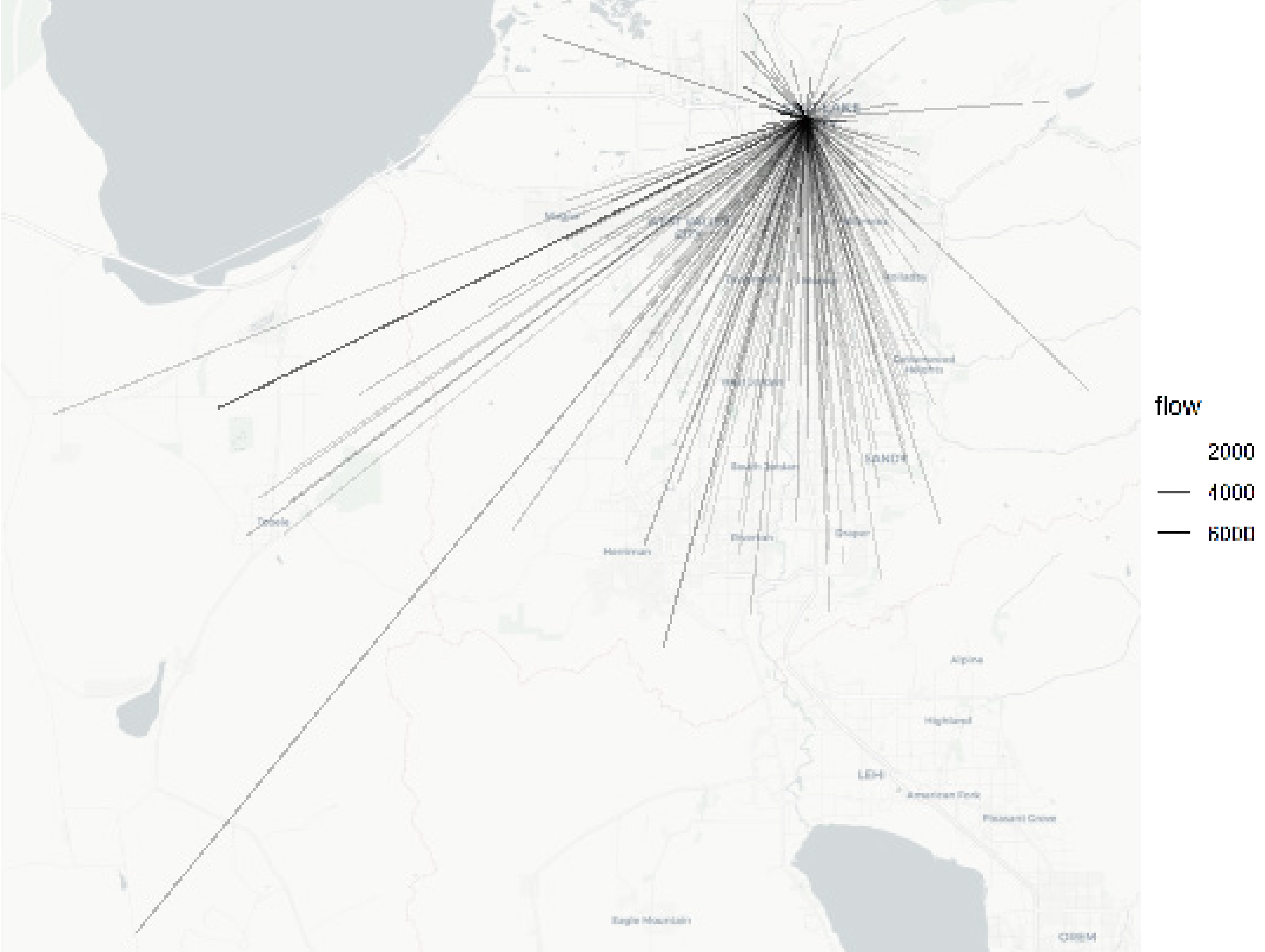


Fig. 55: Desire line diagram for HBW trips

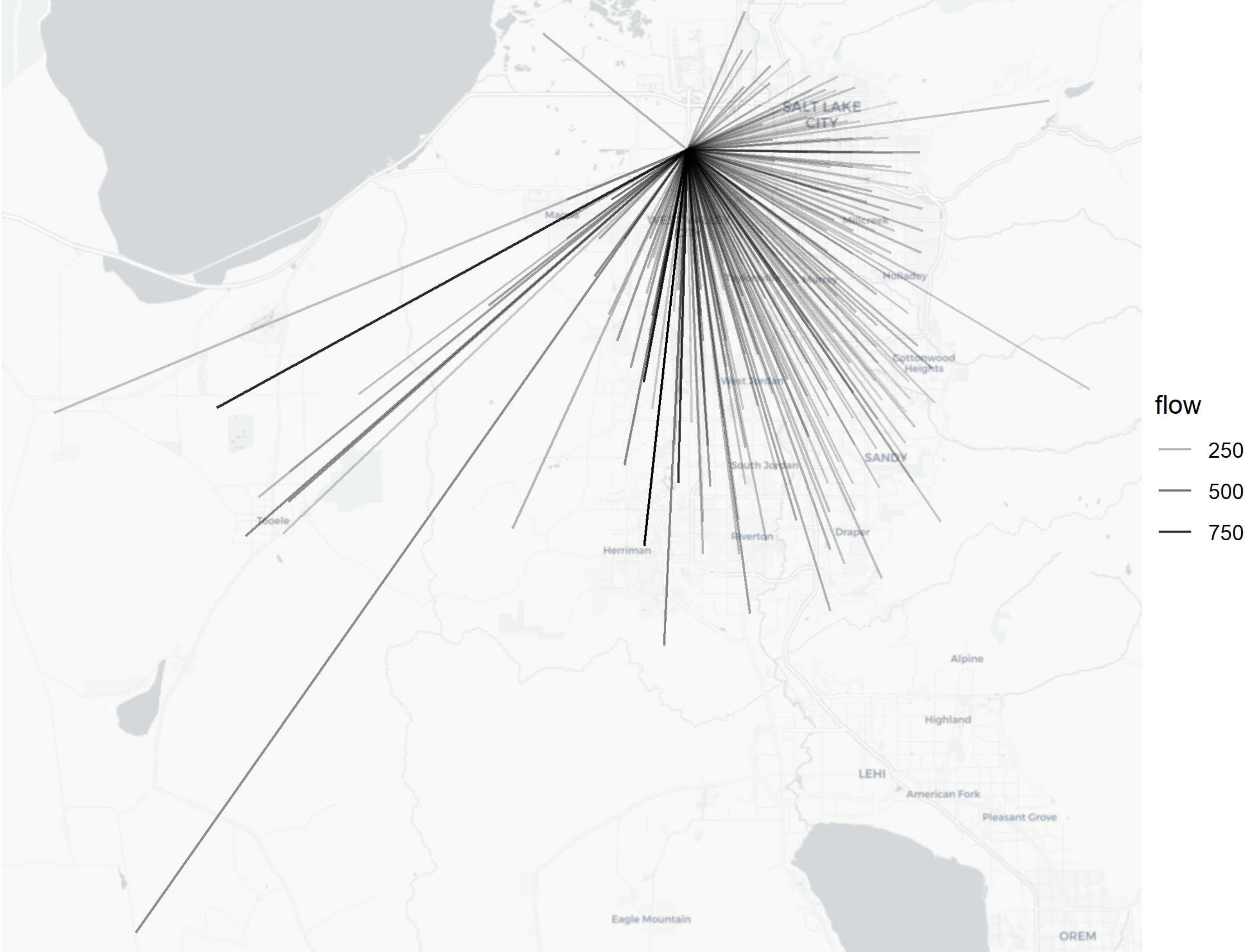
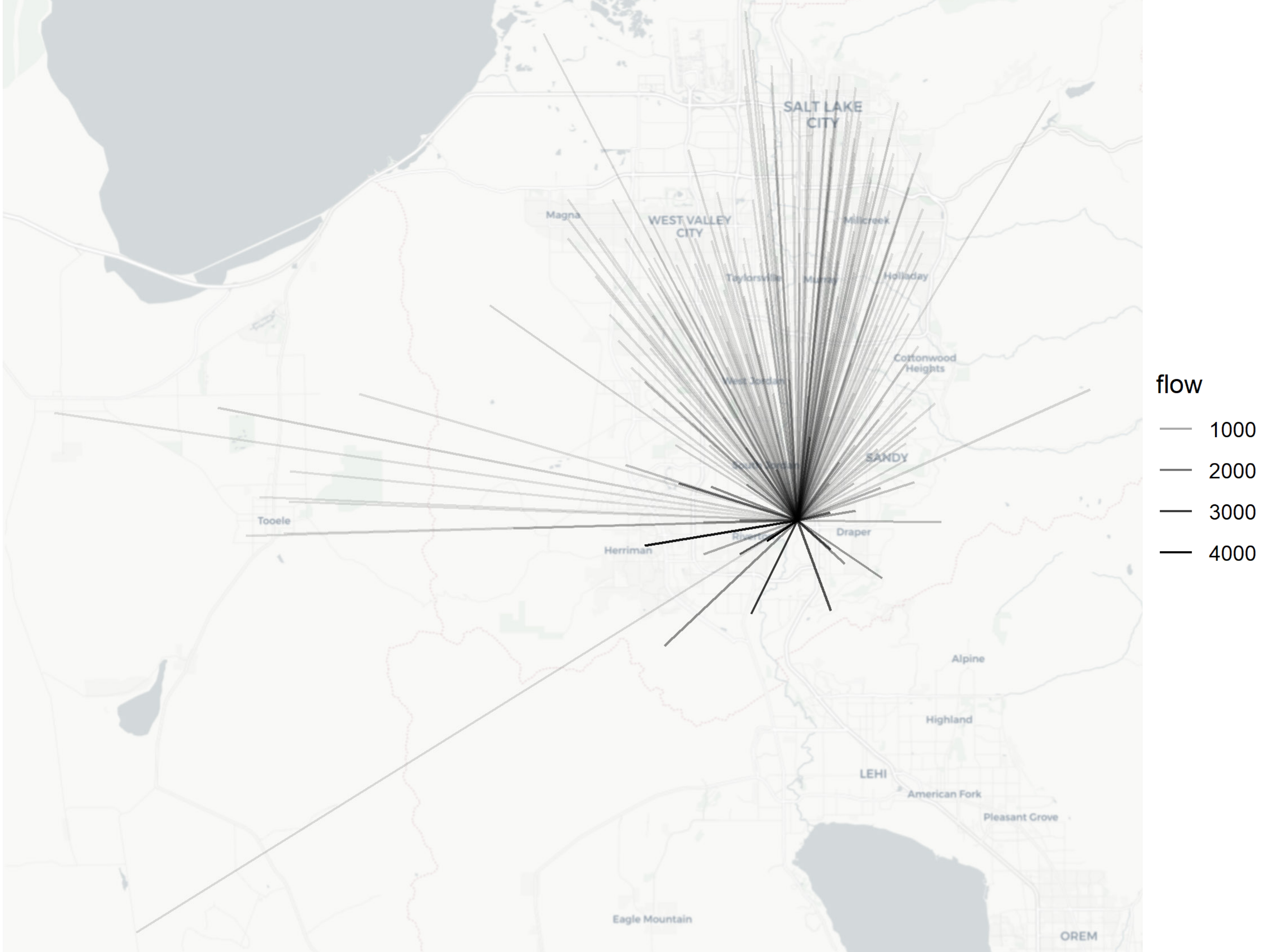


Fig. 56: Desire line diagram for NHB trips



ESTIMATE MODE CHOICE

This chapter details out the third step in the travel demand model i.e., estimating mode choice for the trips we previously estimated.

We first calculated the regional mode shares for each of the three trip purposes based on NHTS data shown in the first three rows of Table 10. Using these values, we generated mode-specific constants and used mode choice model parameters such as in-vehicle time, walk time, transfer time and cost from selected models in NCHRP 716 to estimate the existing mode split for each trip purpose throughout our study area Salt Lake MSA. We adjusted our mode specific constants and calibrated the existing gravity models to match the NHTS modeshares, the results for which are shown as model 2 results in Table 10. Figures 57 to 59 show the existing regional mode shares. While SOV trips dominate the modeshare for home-based work trips in Fig. 58, HOV trips command the highest share for existing home-based other and non-home based trips in Fig.57 and Fig. 59. For this assignment, we have included cars, trucks, vans, SUVs, golfcart/segways, RV, and motorcycle/mopeds under the SOV and HOV car categories. Either way, car trips dominate. Transit trips comprise a low share, with maximum being 3% in HBW trips, which have an insiginificant number of walking trips. Walking interestingly comprises 7% in NHB/non-home based trips.

Table 10: Existing & alternative modeshares by trip purpose (%)

Model	Trip Purpose	Bike	SOV	HOV	Transit	Walk
NHTS	HBO	0.04	27.71	53.81	1.70	16.74
NHTS	HBW	1.33	80.91	11.57	3.28	2.91
NHTS	NHB	0.35	34.90	56.29	0.65	7.80
Existing	HBO	0.81	26.98	68.76	1.69	1.69
Existing	HBW	1.25	80.89	13.74	3.03	0.35
Existing	NHB	0.96	34.16	56.81	0.63	7.22
Alternative	HBO	0.81	26.98	68.75	1.70	1.69
Alternative	HBW	1.24	80.88	13.74	3.05	0.35
Alternative	NHB	0.96	34.16	56.81	0.63	7.22

We then applied the adjusted mode specific constants to the previously generated travel skims for our alternative condition to determine the alternative mode shares. The results for these are shown in the last three rows of Table 10 and on rounding up, the percentage values are the same as shown in Fig. 57 - Fig. 59. There are only some very minor changes in the modeshare percentages.

The transit share increases by 0.01% in HBO trips and by 0.02% in HBW trips. The share of HOV drops by 0.01% in HBO trips while SOV and bike trips decreases by the same magnitude in HBW trips. No difference in modeshare is observed in NHB trips in the alternative condition. This shows that our proposed increase in transit freequency and road segment pedestrianization does not have much of an impact on the regional modeshare values.

Fig. 57: Mode share for HBO trips: Alternative

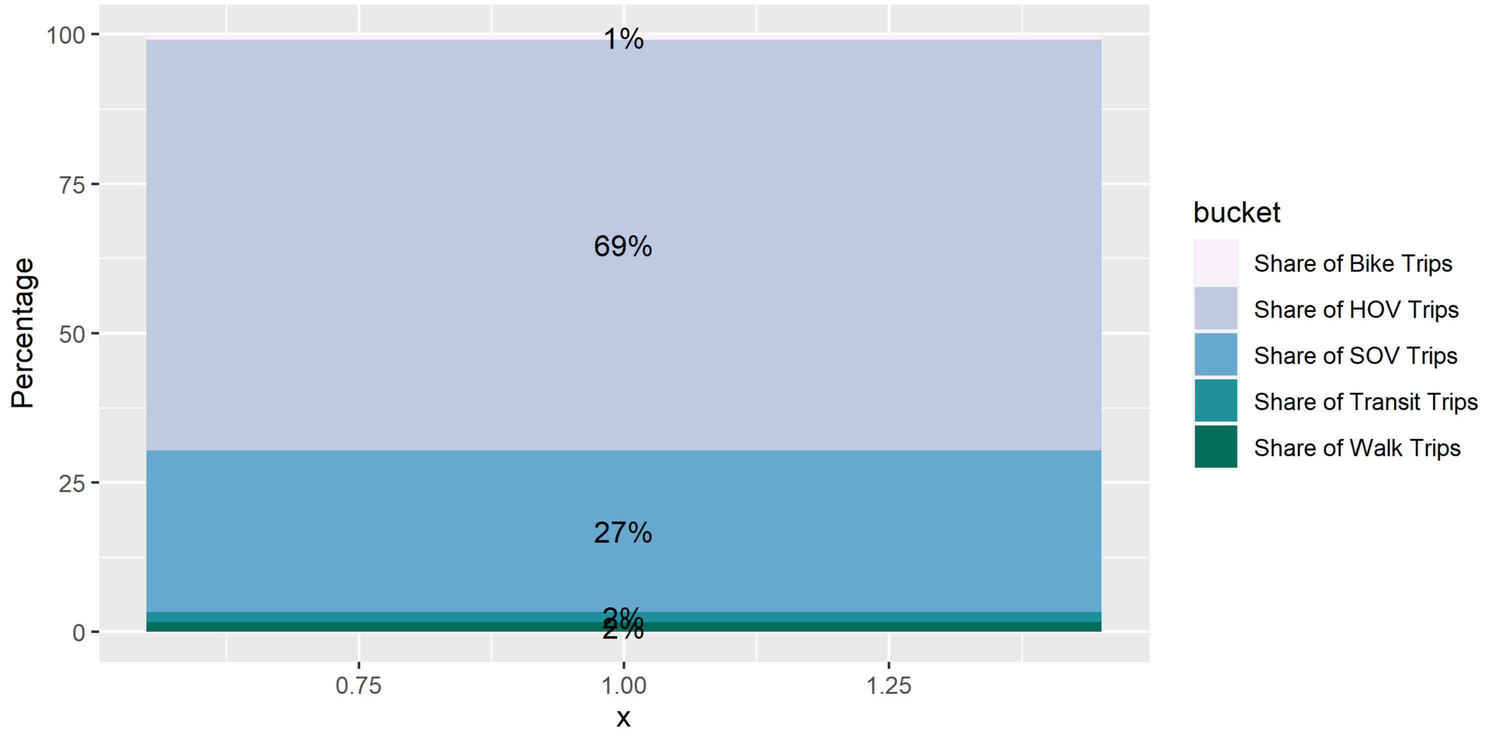


Fig. 58: Mode share for HBW trips: Alternative

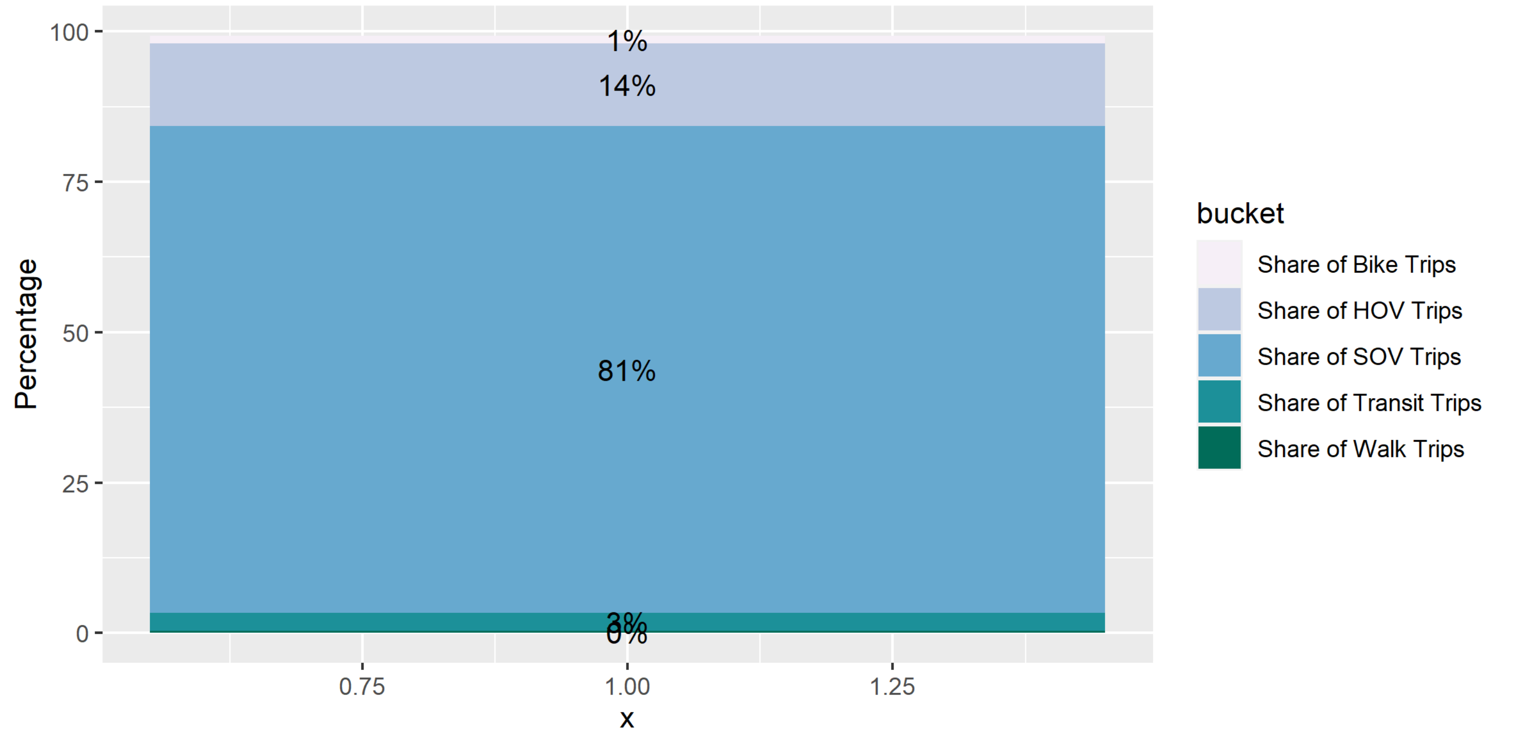


Fig. 59: Mode share for NHB trips: Alternative

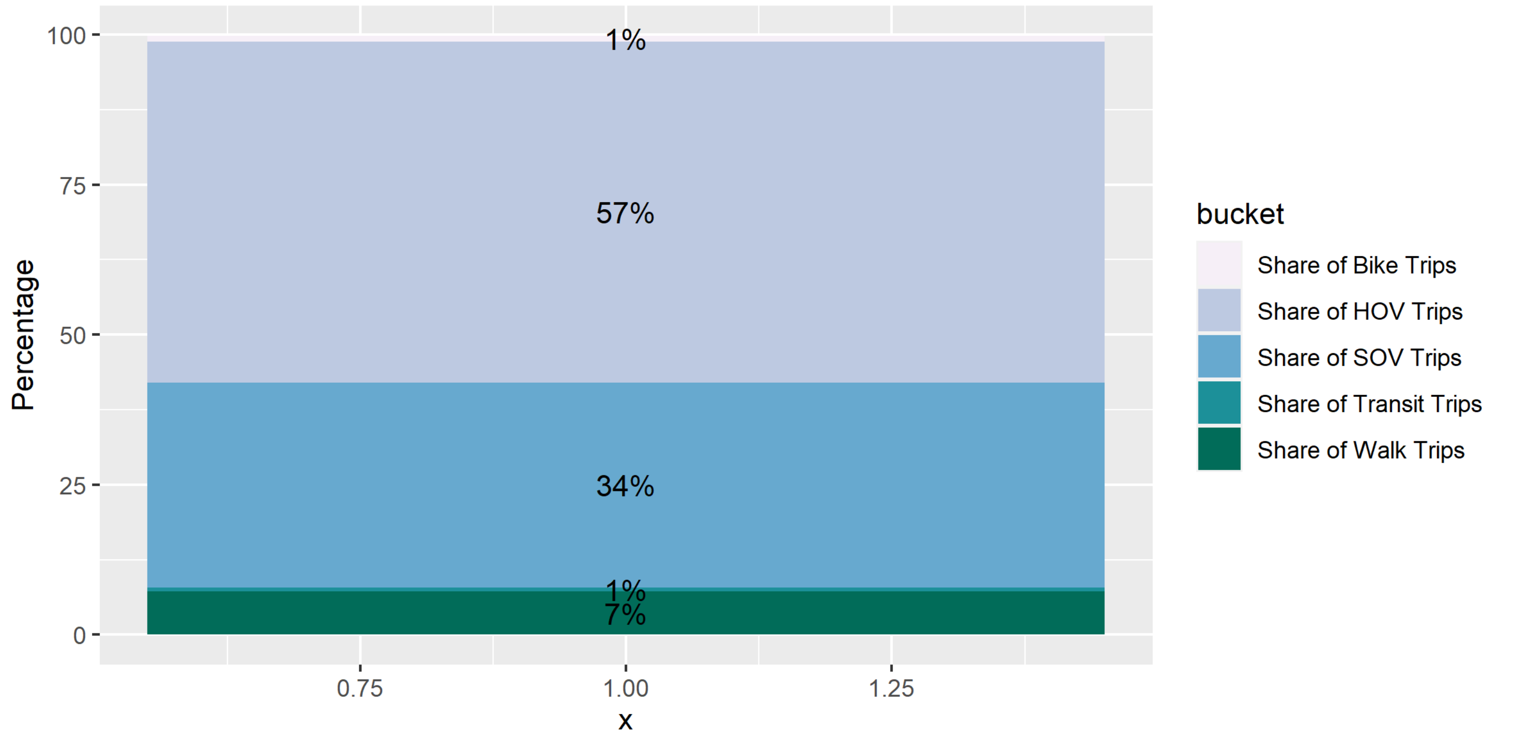


Fig 60-64 shows the percentage of each mode in all HBW trips in the alternative condition. In the analysis, we left out tracts 49035114800, 49035100200, and 49035110104 as they are either inaccessible by car or have no population, and thus were anomolies in terms of the modeshare values. Excluding such tracts allows the spatial patterns to be more prominent. Most tracts have SOV taking up more than 80% of their HBW trips. Walking is particularly popular in the north part of the central downtown area. Transit mode has a more even distribution along the central downtown area. And biking mode is concentrated in a few tracts in the north in Salt LAke MSA.

Fig. 60: HBW trips from tract: SOV

Fig. 61: HBW trips from tract: HOV

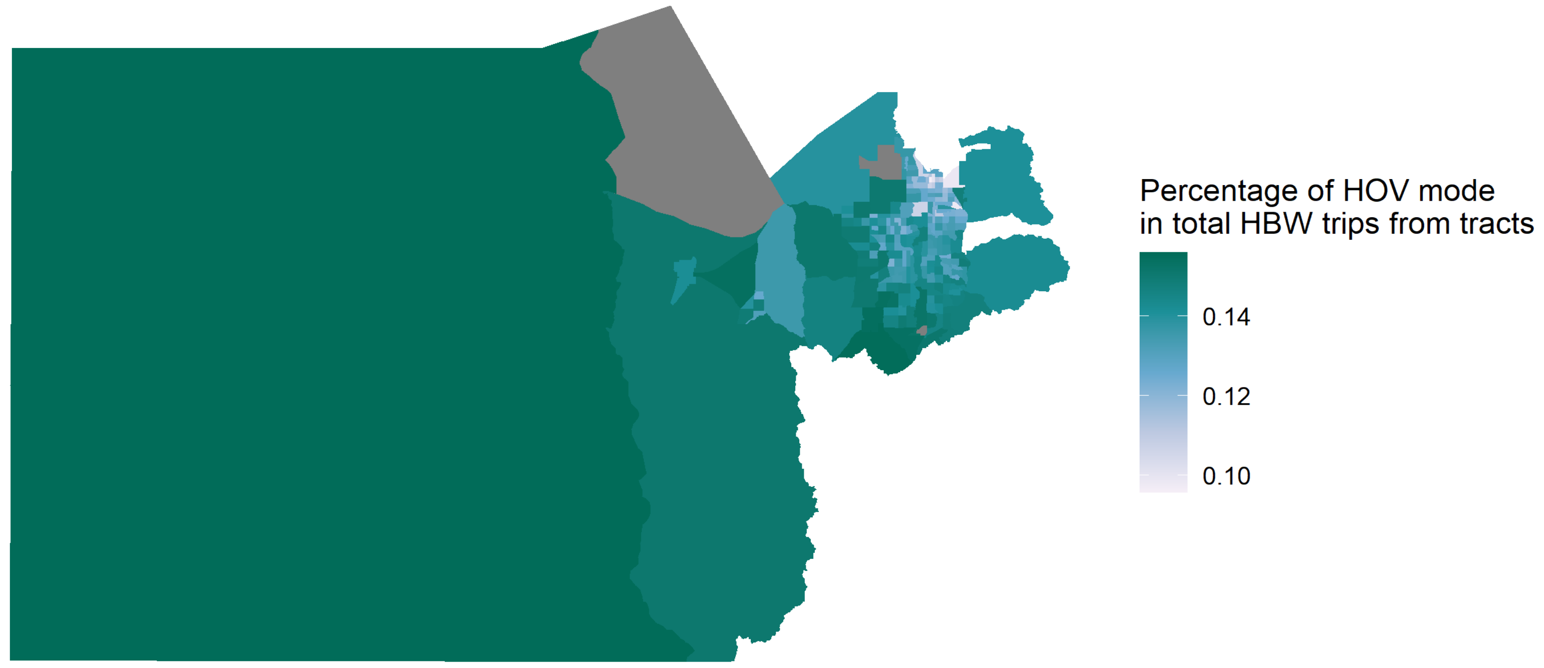


Fig. 62: HBW trips from tract: Transit

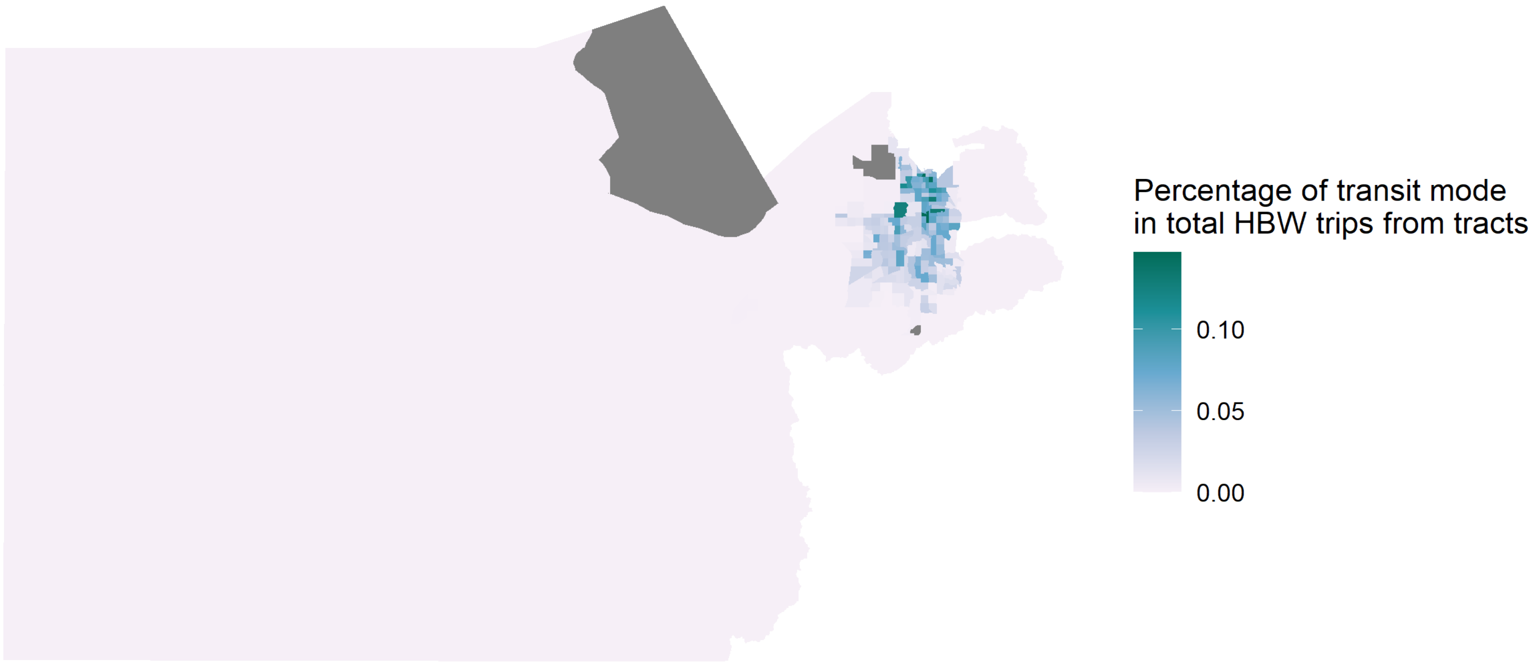


Fig. 63: HBW trips from tract: Walk

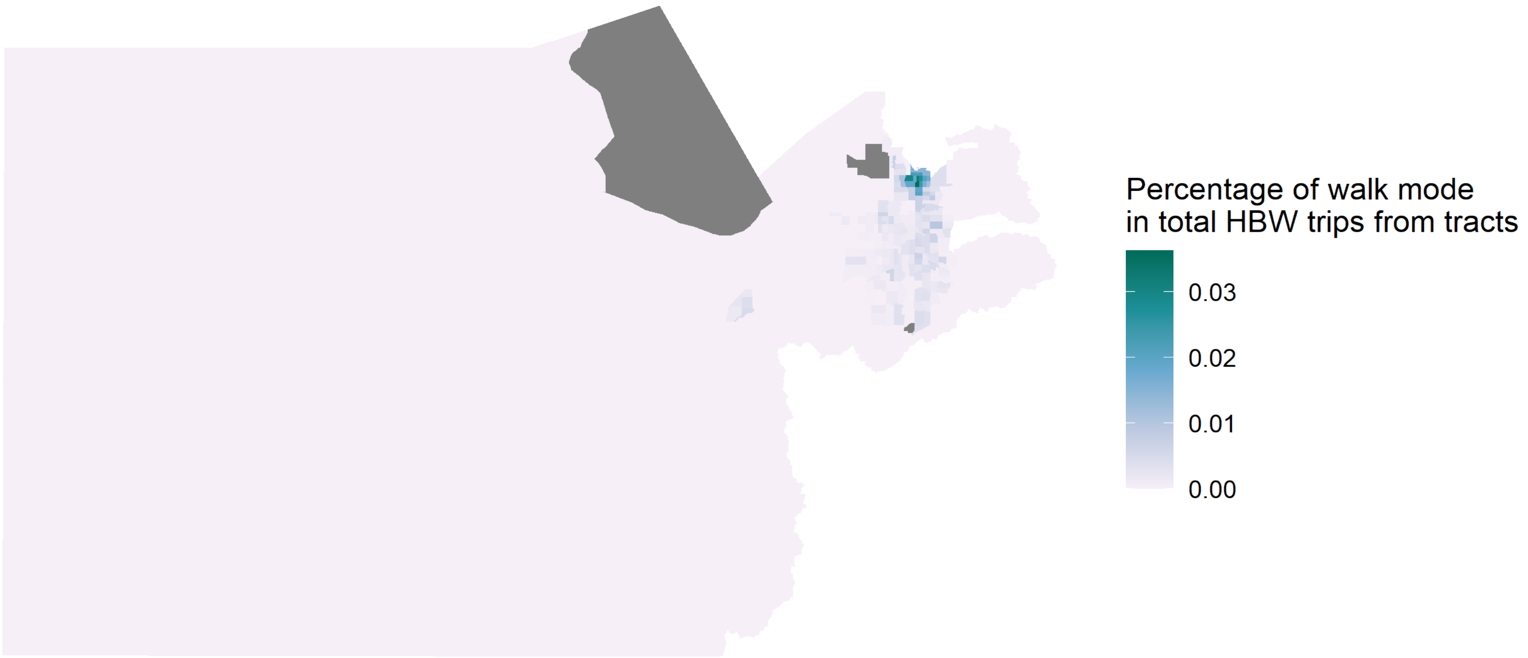


Fig. 64: HBW trips from tract: Bike

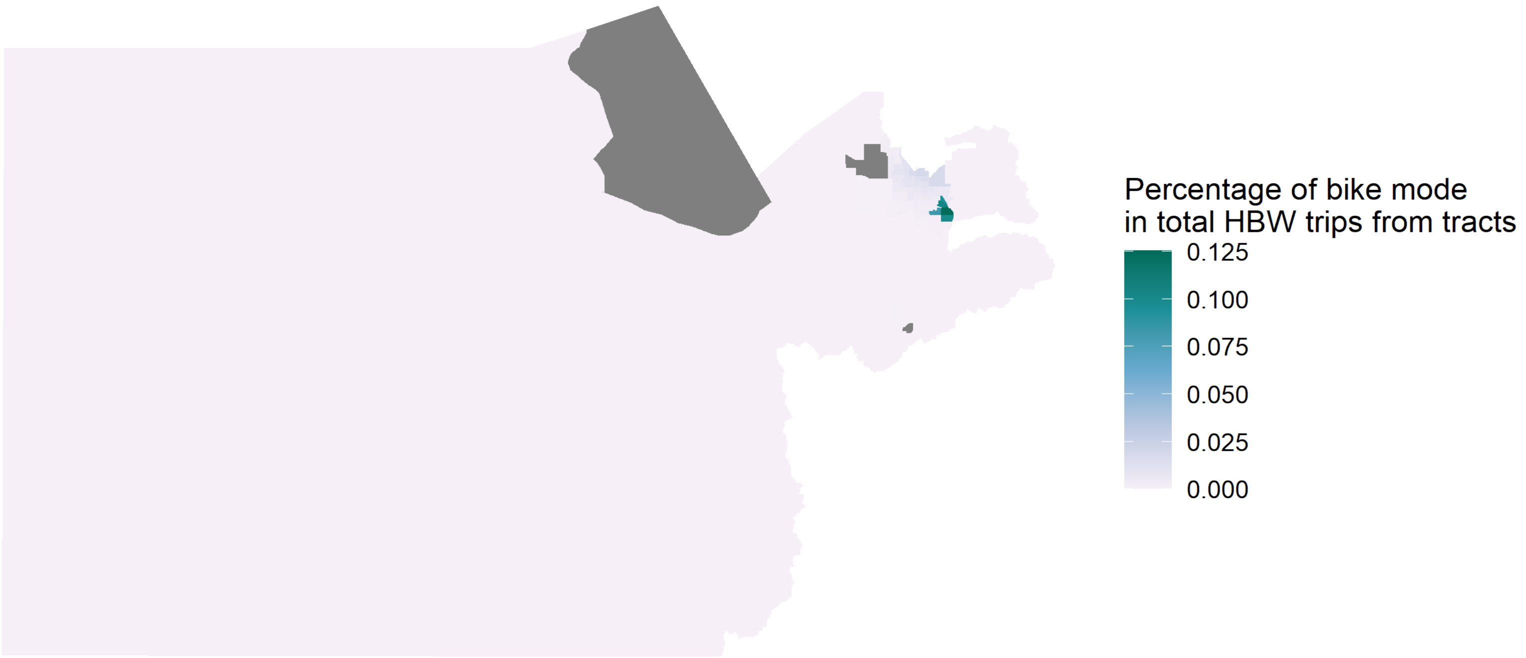


Fig 65-70 shows the percentage of three predominant modes - cars (combined SOV and HOV), transit and walking in all HBO and NHB trips in alternative condition. We have not shown bike trips below as the distribution is fairly minimal and similar to the one for HBW trips in the previous page. Additionally, in our model, even after adjustment, the bike share was not close enough to the existing regional modeshare from NHTS due to lack of appropriate bike-related coefficients, and therefore may not be as accurate. In the analysis, we left out tracts 49035114800, 49035100200, and 49035110104 for the same reasons as above. Most tracts have SOV taking up 95% of their HBO trips, particularly in western tracts and Tooele County. Walking is somewhat popular in the north part and secondly along the central part of the downtown area. Transit mode has a more even distribution along the entire downtown area, with popularity decreasing moving away from the center. And biking mode is concentrated in a few tracts in the north. Overall, walking and biking are more popular for HBO and NHB trips than HBW trips.

Fig. 65: HBO trips from tract: Car

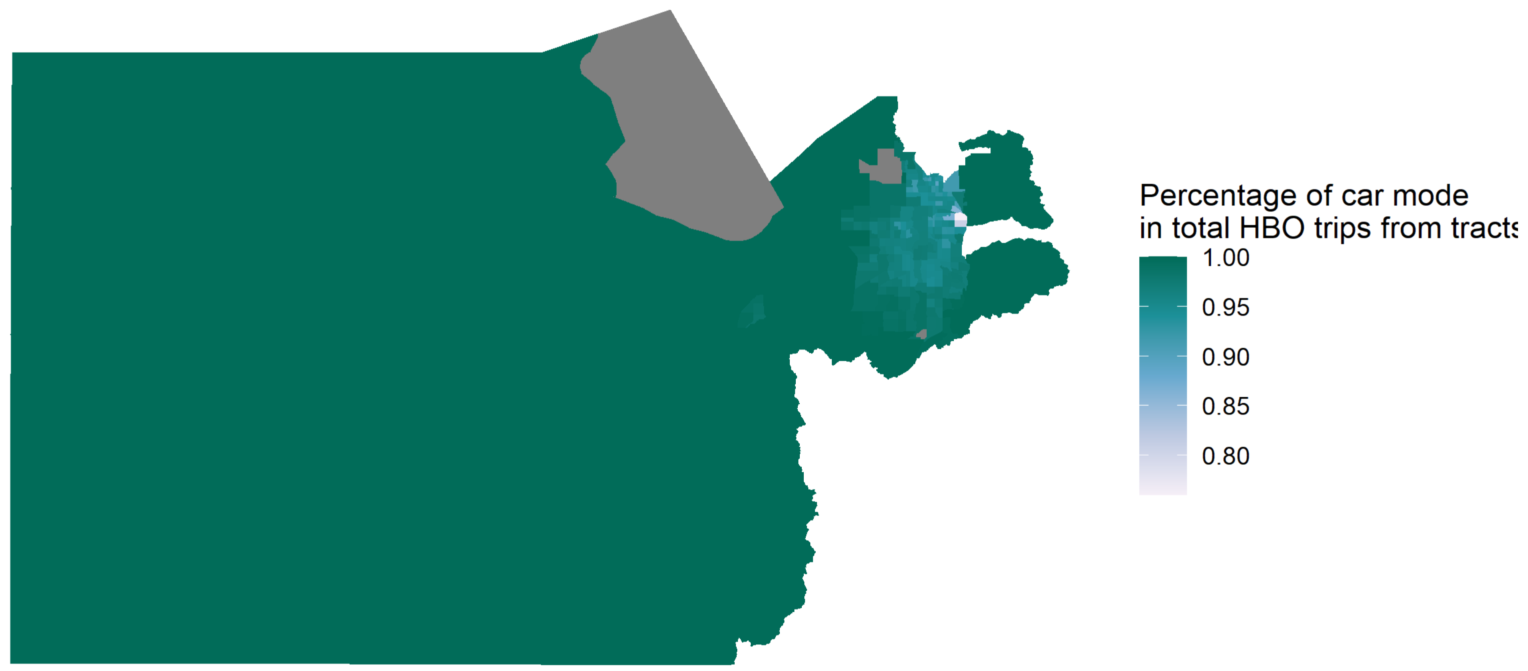


Fig. 66: HBO trips from tract: Transit

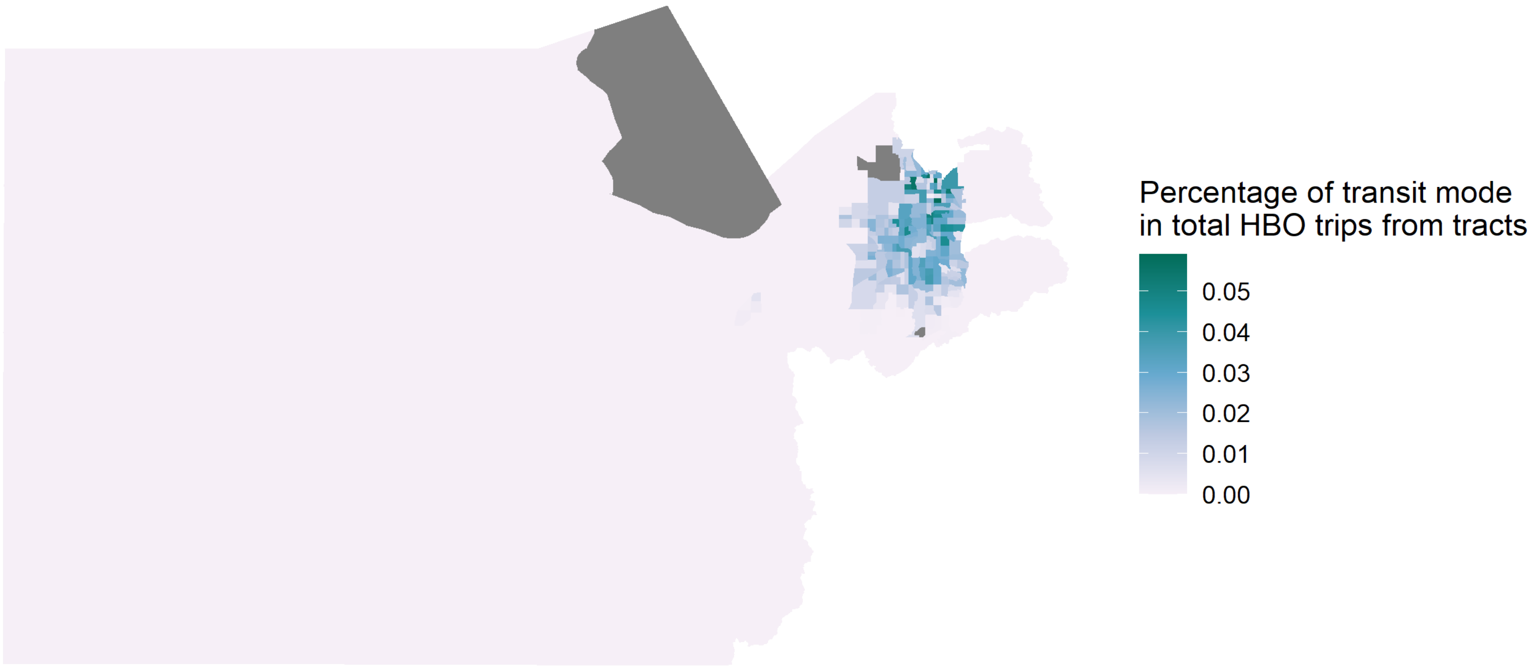


Fig. 67: HBO trips from tract: Walk

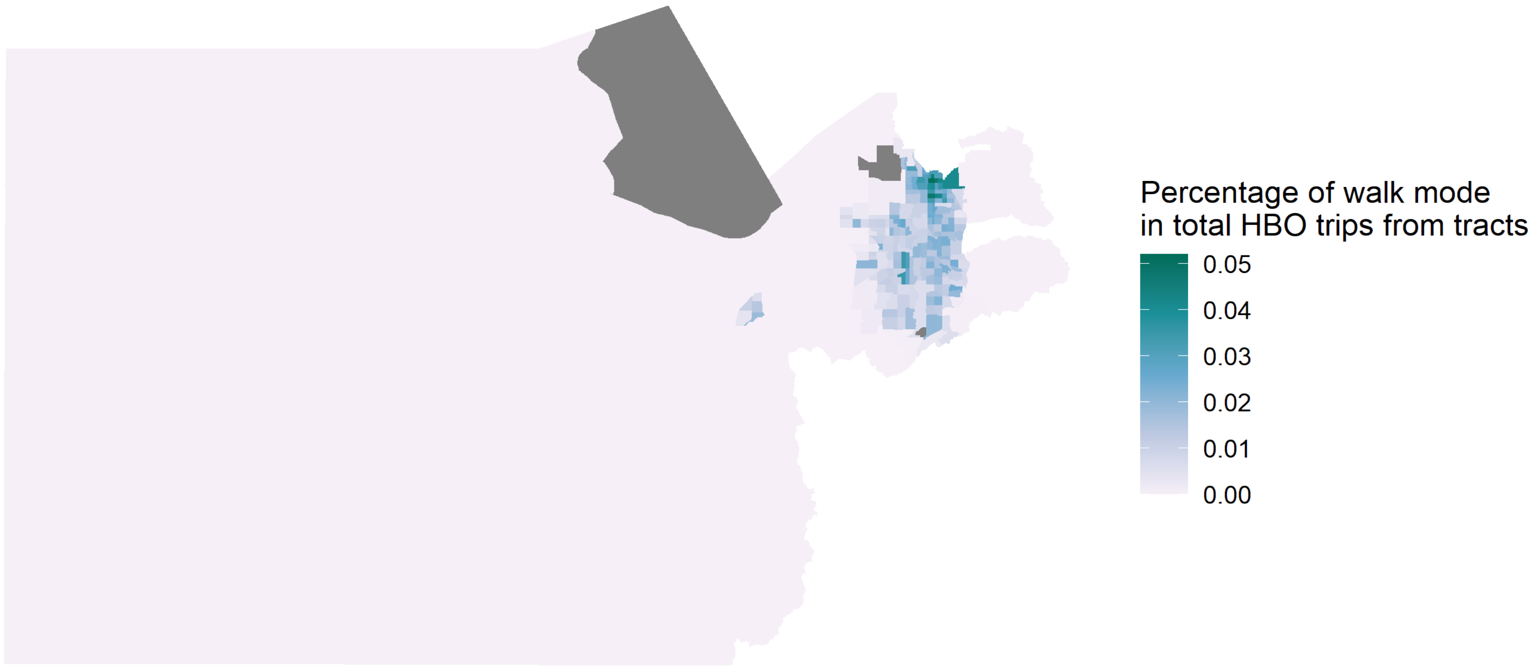


Fig. 68: NHB trips from tract: Car

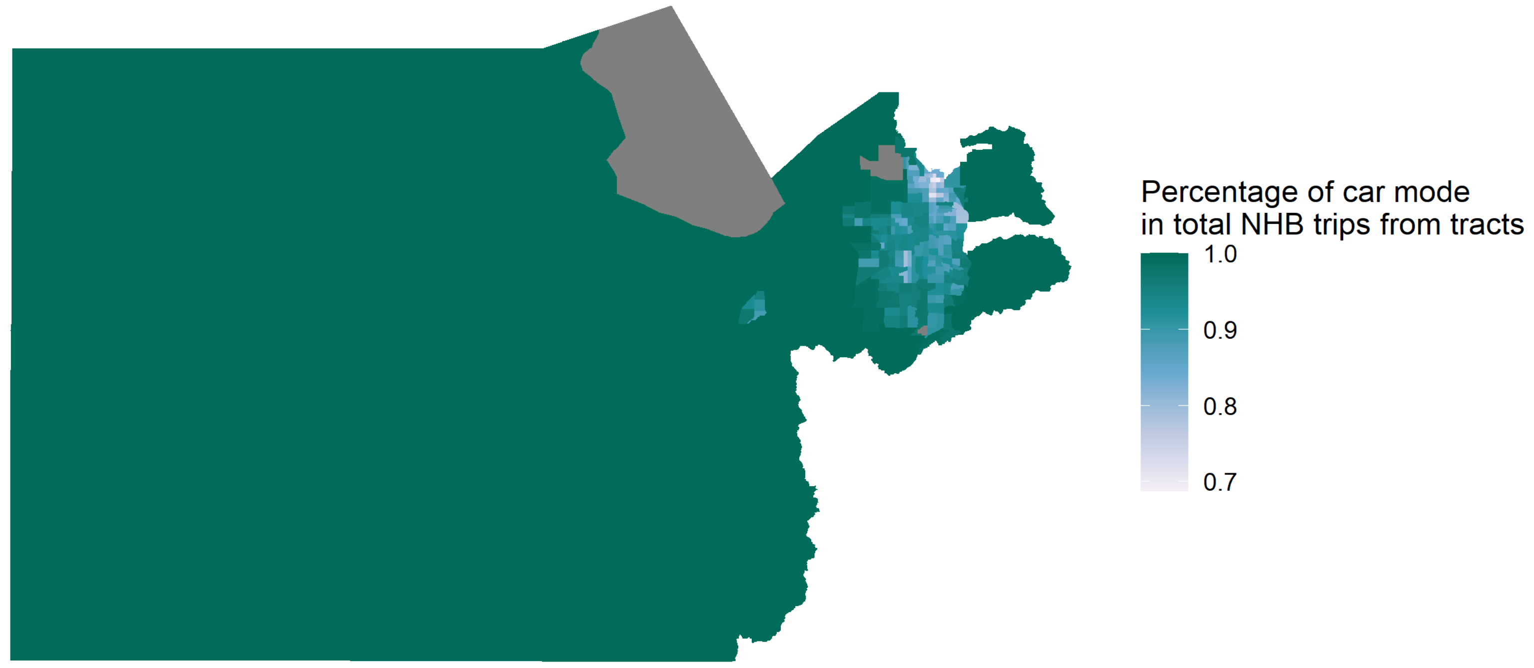


Fig. 69: NHB trips from tract: Transit

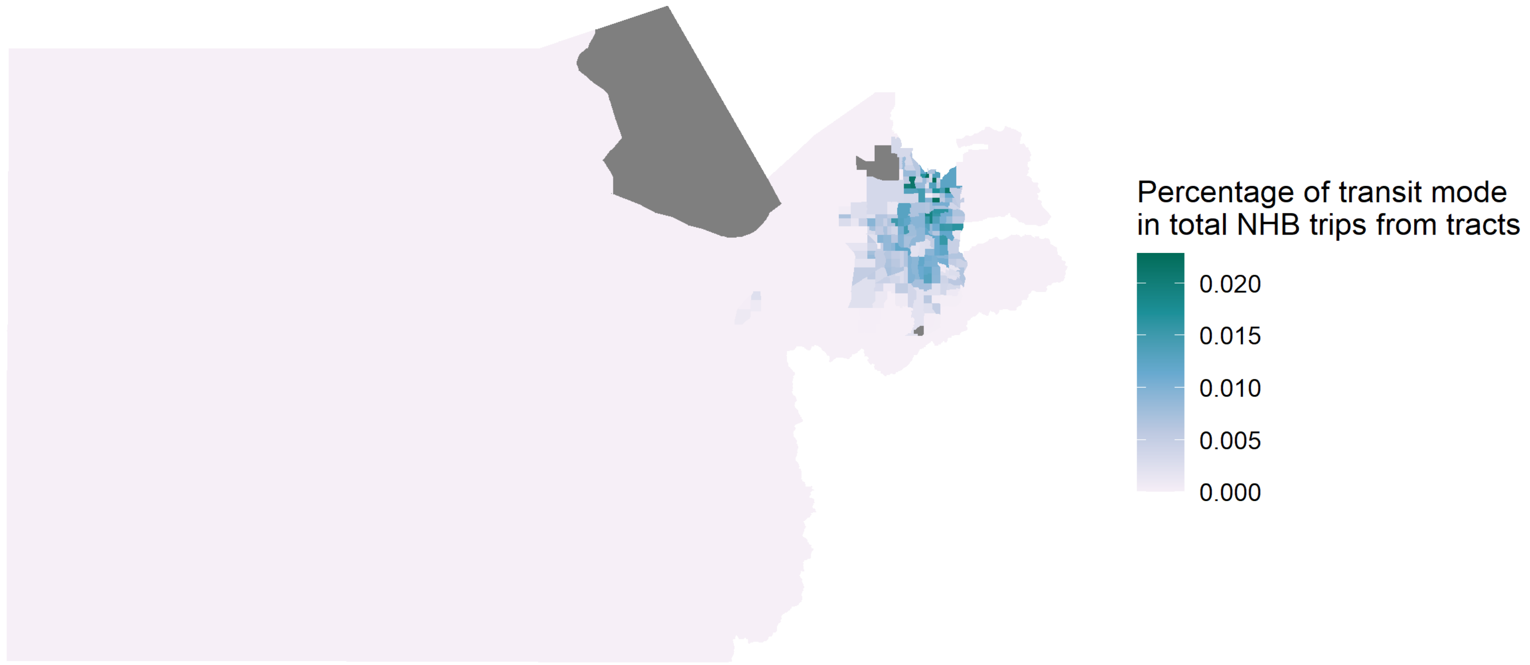
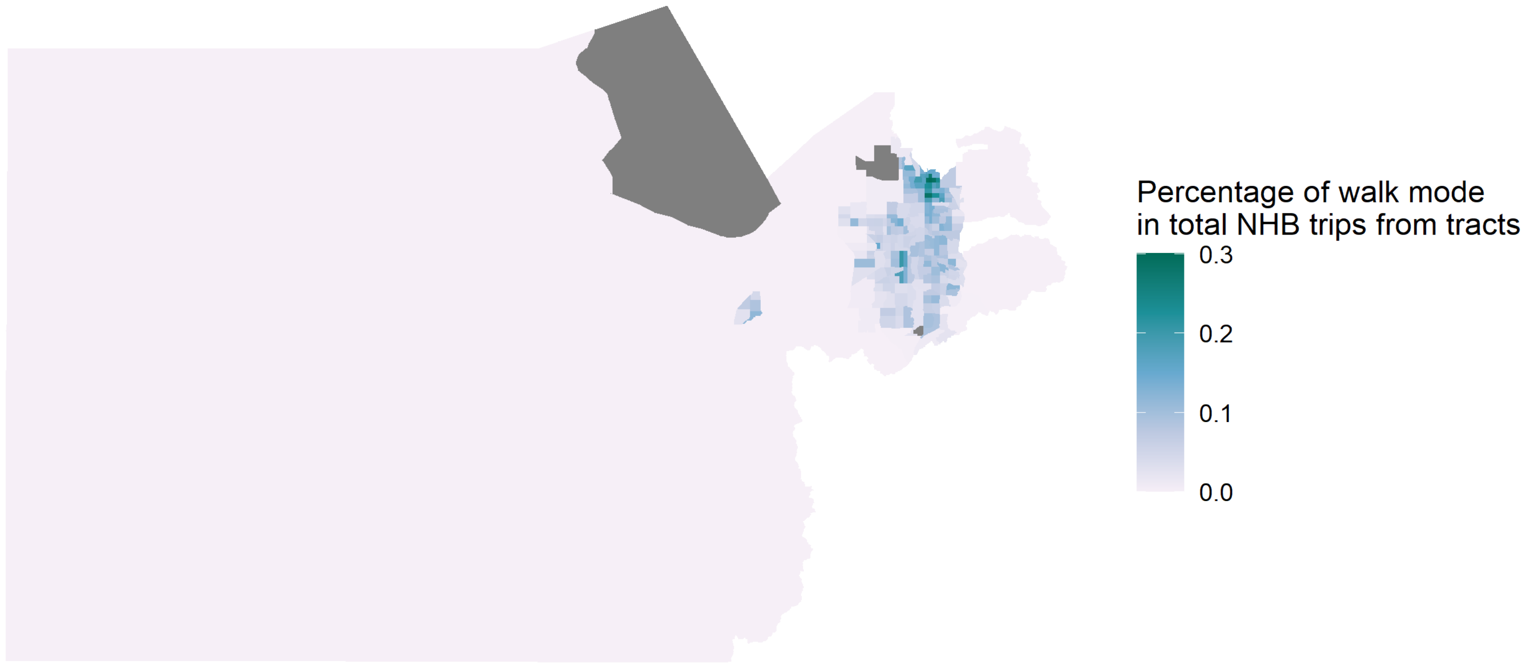


Fig. 70: NHB trips from tract: Walk



ESTIMATE RIDERSHIP AND VMT

This chapter details out one component of trip assignment, the fourth and final step in the travel demand model. We perform transit assignment to estimate transit ridership on all routes, but have not done highway assignment in this particular academic exercise. We instead estimate overall regional vehicle miles traveled (VMT) from driving and person miles traveled (PMT) from active modes of commuting - walking and biking.

Transit Assignment

For transit assignment, we first generated Origin-Destination (OD) matrices using Production-Attraction data generated previously and by averaging the PA matrix with its transpose. Through this, we estimated transit ridership for all transit routes in our region in the existing scenario as well as the alternative scenario which has increased frequency along bus route 200. Table 11 shows the ridership values for both scenarios for ten out of fifty-seven routes with the greatest magnitude of change in ridership by trip purpose along with their overall ridership values.A summary of our key transit ridership findings are as follows:

• Route 27610 (bus route 200, State Street North) in which we modified its frequency for the alternative scenario naturally has the greatest change in transit ridership with the existing ridership of 2057 adding another 862, for an increased alternative ridership of 2919. Within this, maximum ridership is for HBO trips with 1714 trips which also sees the highest increase of 533. This is followed by a ridership of 770 for HBW purpose with an increase of 233 HBO trips from the existing scenario. It also includes a ridership of 435 for NHB trips which increases the least from the existing scenario, i.e., by 99 trips.

• Two routes show the maximum decrease in ridership - i.e., 27614 (bus route 205, 500 East) and 39020 (704, Green Line). The former is located close to Route 200 on a parallel road running towards its East and so we could assume that the increase in frequency in route 200 led to some of the transit ridership transferring to that from route 205. The latter - Green Line - runs in the western part of Salt Lake City and sees a fall in ridership from 4007 trips in the existing scenario to 3959. For both of them, maximum ridership reduction is observed for HBO trips.

• Route 5907 (701, Blue Line) is the light rail line near and towards the west of State Street, which has the highest existing ridership of 7216 amongst all the other routes, and continues to have the greatest assigned trips in the alternative scenario too, even though ridership falls by 58 to 7518. Route 45418 (bus route 220, Highland Drive) to the east of route 200, has the second highest overall ridership for both scenarios but it sees a slight increase by 48 to give the alternative ridership value of 4762. Maximum increase in this route is observed for HBW trips.

• Ridership values for all other routes change by less than 100, with 12 routes having no change at all and 27 other routes with a relatively insignificant change of less than 10.

Table 11: Existing and alternative ridership on selected transit routes with greatest ridership change:

Transit Route	HBO trips		HBW trips		NHB trips		Total ridership		Change in ridership
	Existing	Alternative	Existing	Alternative	Existing	Alternative	Existing	Alternative	
27610	1181	1714	540	770	336	435	**2057**	**2919**	**862**
27614	822	719	624	604	156	141	**1602**	**1464**	**-138**
39020	1985	1914	1730	1698	362	347	**4077**	**3959**	**-118**
5907	3858	3806	2697	2698	661	654	**7216**	**7158**	**-58**
45389	333	364	314	330	66	72	**713**	**766**	**53**
45418	2888	2902	1332	1363	494	497	**4714**	**4762**	**48**
2332	1181	1150	342	336	194	189	**1717**	**1675**	**-42**
19930	168	150	54	39	28	20	**250**	**209**	**-41**
2328	1340	1358	557	567	252	256	**2149**	**2181**	**32**
2053	1616	1632	484	497	224	226	**2324**	**2355**	**31**

Fig. 71: Frequency of routes for different ridership values

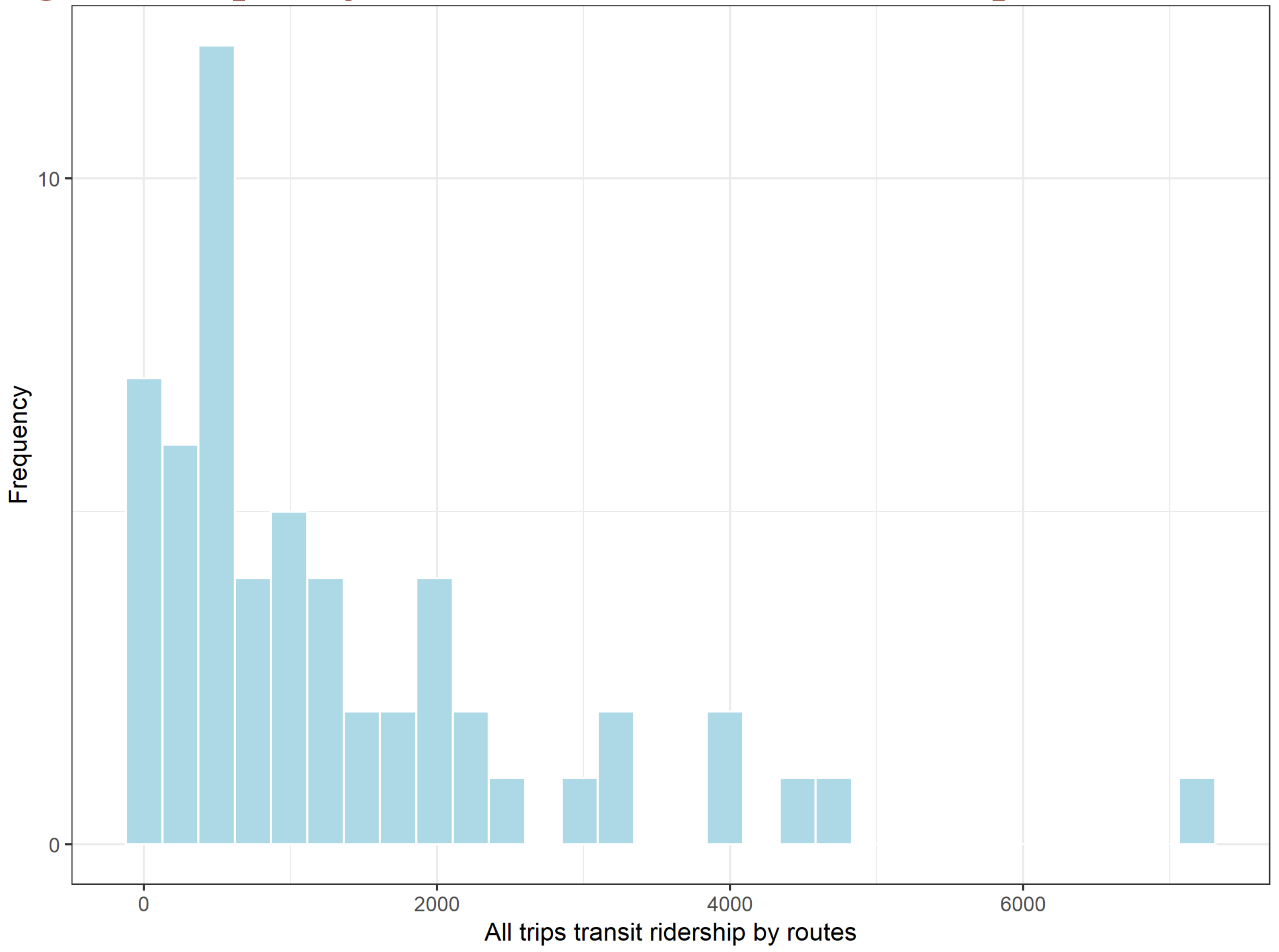


Figure 71 shows that majority of the routes have ridership less than 1000 with a few routes having over 4000 ridership, some of which are listed Table 11 and have been described on the previous page.

PMT for walking and biking trips

Table 12 summarizes the overall PMT generated from walking and biking trips. Biking trips results in an overall PMT of 298,872 miles in the alternative scenario with the over 50% of the biking PMT generated by HBO trips. The overall PMT is lower than the existing PMT by 221 miles. Within this we observe the greatest reduction in NHB trip miles.

Walking trips have a lower overall PMT than biking. Here the PMT is 212,207 miles in the alternative scenario, which is almost the same as the existing PMT, with only a very marginal decrease by 2 miles. We observe that NHB trips account for the greatest share in walking PMT, and in contrast to biking trips which saw a consistent reduction across all trip purposes, walking trip miles increases slightly for HBO trips, but falls marginally for HBW and NHB trips.

We therefore conclude that pedestrianizing the small section of Main Street and doubling transit frequency along one route in Salt Lake city has little impact on the overall regional walking PMT and results in a slight reduction in overall bike PMT.

Overall regional VMT

We then calculated VMT for cars including both SOV and HOV using PMT values shown in Table 12. We observe a reduction in larger reduction in PMT in SOV trips with the maximum reduction of 779 miles in HBW trips.

The VMT values per mode and overall are given in Table 13. To determine VMT, we assumed the HOV vehicle occupancy using different daily occupancy values for carpools with 2+ occupants for each trip purpose, from NCHRP 716, Table 4-16. We find that

Table 12: Existing and alternative regional VMT by mode and trip purpose:

Mode	Scenario	HBO	HBW	NHB	Overall PMT
Bike	Existing	159,057	43,797	96,239	**299,093**
	Alternative	158,977	43,779	96,116	**298,872**
Walk	Existing	74,207	2,832	135,170	**212,209**
	Alternative	74,216	2,830	135,161	**212,207**
SOV	Existing	4,351,930	4,753,787	3,124,806	**12,230,522**
	Alternative	4,351,771	4,753,008	3,124,625	**12,229,404**
HOV	Existing	11,167,665	797,374	5,232,248	**17,197,286**
	Alternative	11,167,291	797,286	5,232,186	**17,196,763**

Table 13: Existing and alternative regional VMT

	HBO	HBW	NHB	Overall VMT
Existing	8,472,839	5,083,280	6,276,762	**19,832,882**
Alternative	8,472,542	5,082,465	6,276,544	**19,831,551**
Change	-297	-815	-218	**-1330**

our proposed modifications lead to an overall VMT reduction of 1330 miles with overall alternative VMT being 19.831 million miles. VMT reduces for all three trip purposes but maximum reduction is seen for HBW trips with a drop by 815 miles.

Fig. 72 and Fig. 73 show the alternative regional VMT from all census tracts and the PMT from walking trips for all trip purposes respectively. Maximum VMT is generated by tracts in the Southern and western part of Salt Lake County and Tooele County. Walking PMT is highest naturally in Salt Lake city. Tracts in the central region of Salt Lake County have fewer than 10,000 miles of PMT.

Fig. 72: Overall regional VMT for for all trip purposes

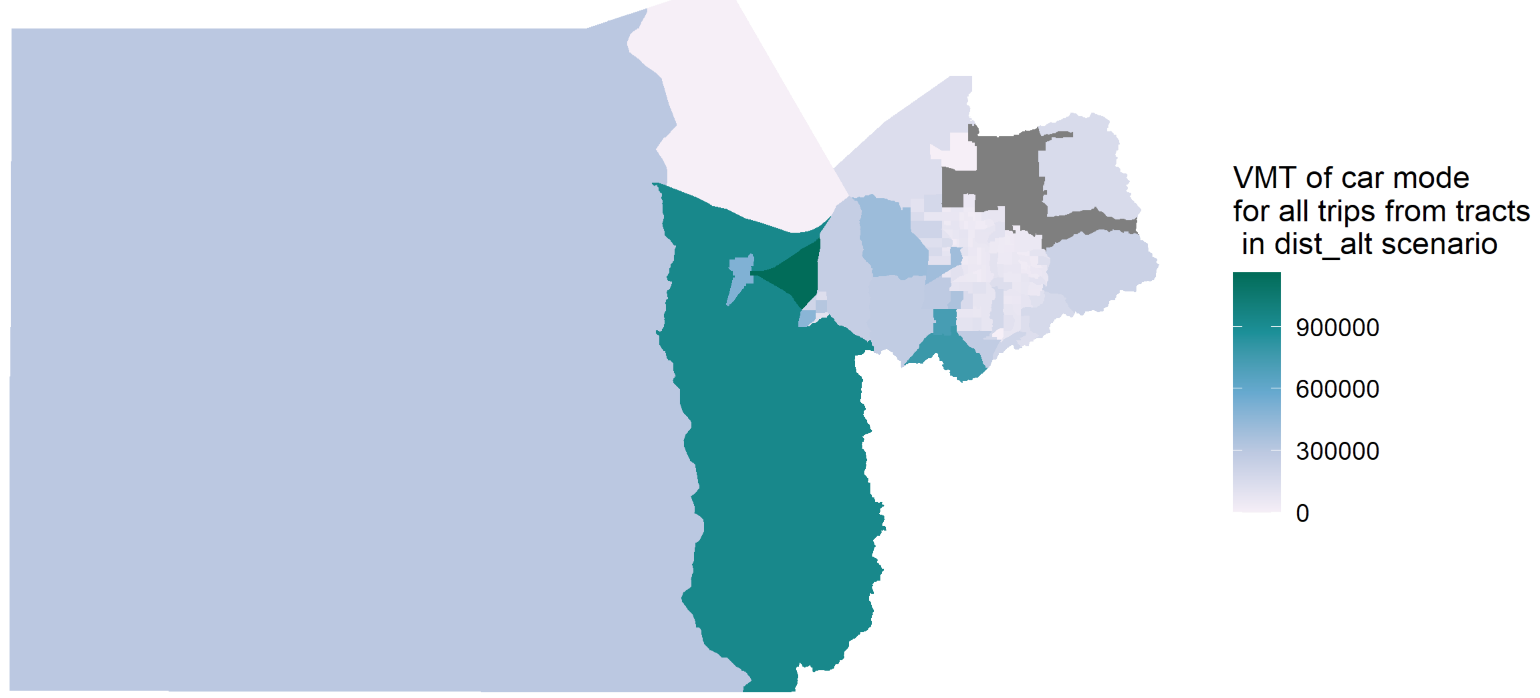
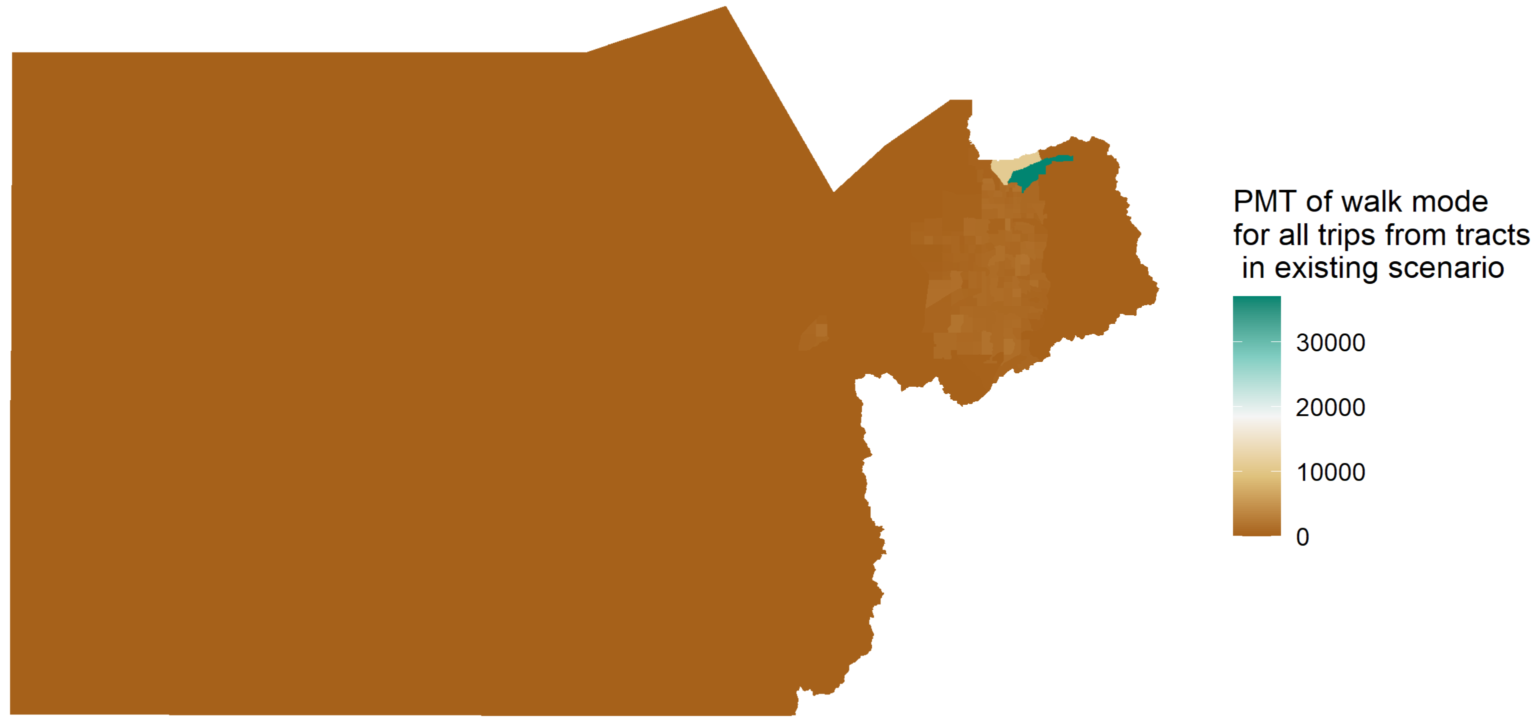


Fig. 73: PMT for walking for all trip purposes



THANK YOU

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AIJING LI