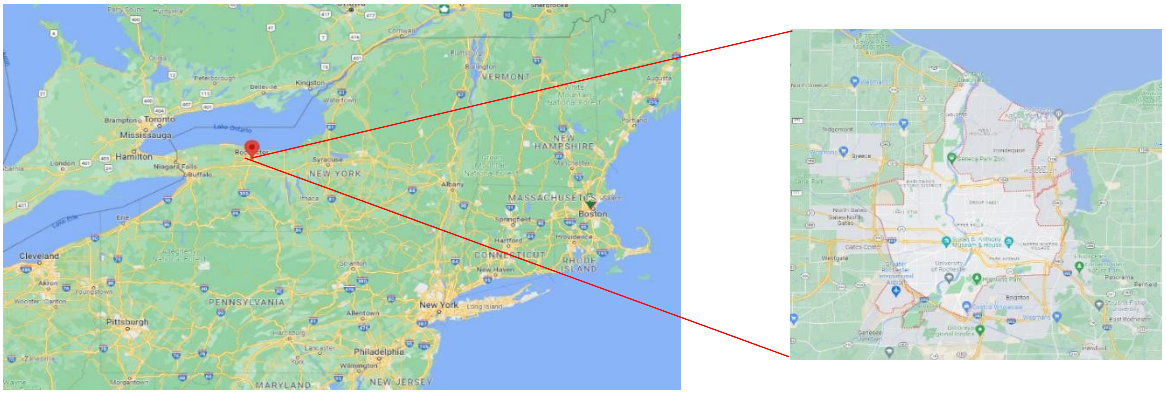
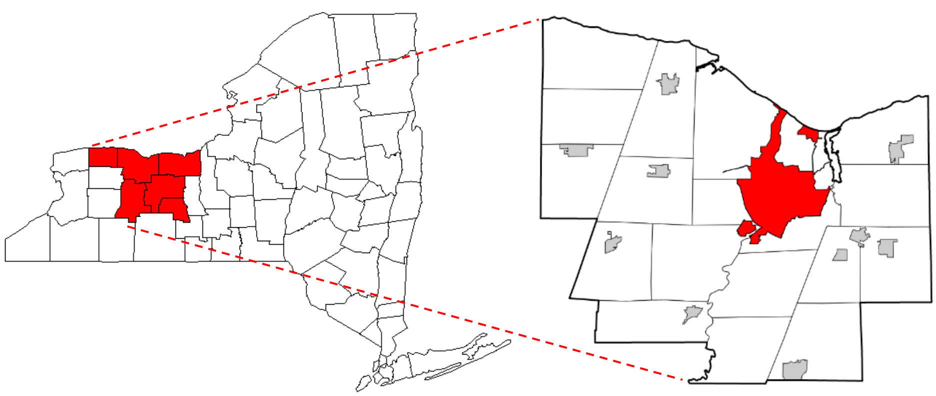
## General Information



The city of Rochester is located in Monroe County, New York State, on the shore of Lake Ontario, with the Genesee River flowing through the city from south to north. The northeast part of Rochester is surrounded by Irondequoit Town and Lake Ontario, linking to the main part of Rochester by a road. Rochester, NY Metropolitan Statistical Area (MSA) is the metropolitan area with the third-largest population in the state of New York, with a total area of 3266 square miles. Livingston, Monroe, Ontario, Orleans, Wayne, and Yates are the six counties in this region. TheCity of Rochester is the largest city within the Rochester, NY MSA and comes in at number 79 on the list of the largest cities in the United States. Within a radius of 400 miles from Rochester are 14 US states in the northeast, two of the most populous provinces in Canada, the capital city of New York, which is Albany, and the capital city of the United States, which is Washington, District of Columbia (Visit Rochester n.d.).



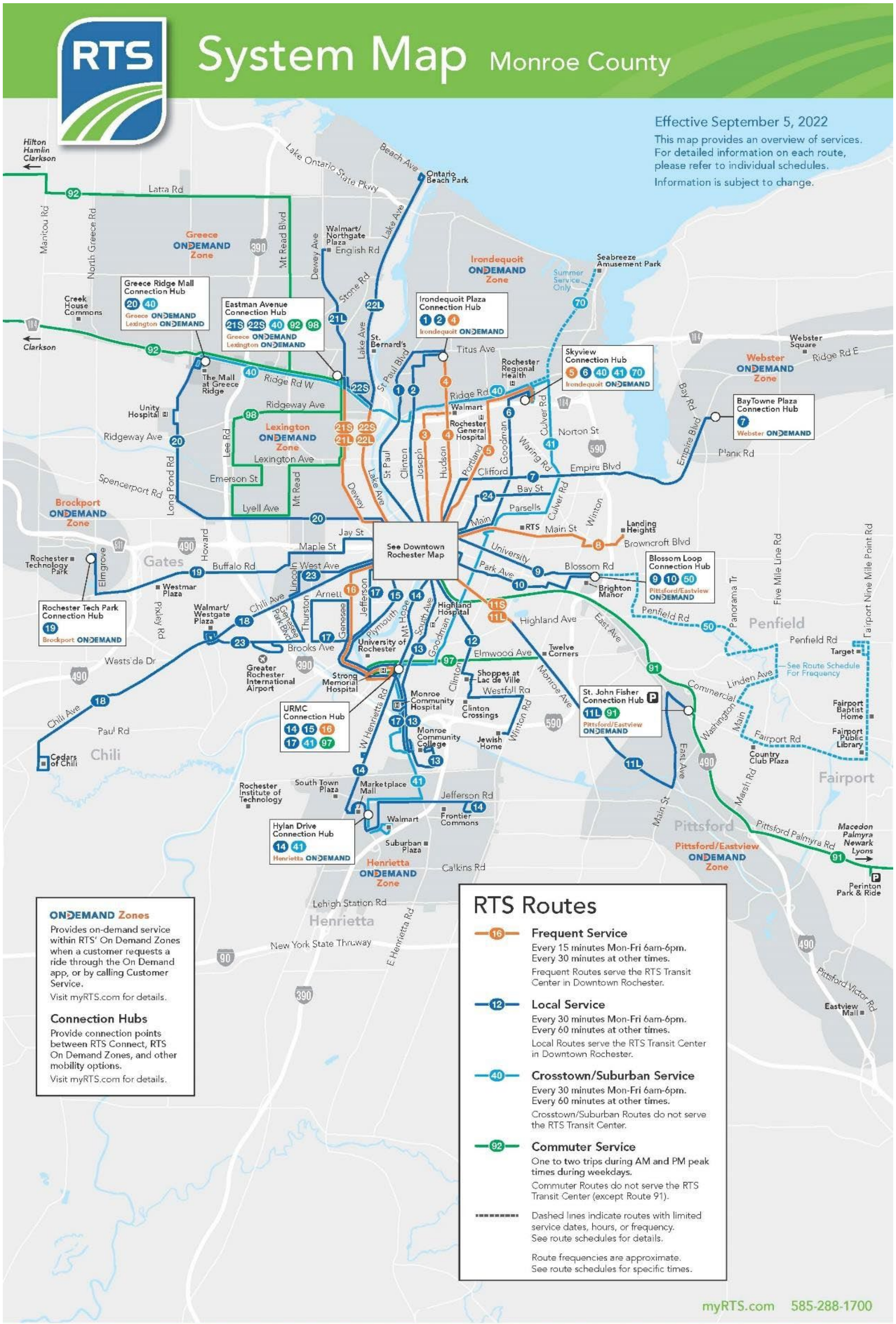
Rochester, NY MSA within New York State (left) and City of Rochester within Monroe County(right)

An abundant supply of fresh water, a central location among the population centers of the northeastern United States, and the presence of global corporate headquarters such as Kodak, Xerox, and Bausch and Lomb all contribute to Rochester's thriving economy. In 2015, the White House made the announcement that the new Integrated Photonics Institute for Manufacturing Innovation would be located in Rochester. Rochester is currently on its way to becoming the world's capital for imaging, optics, and photonics. The Rochester Institute of Technology and the University of Rochester contribute to developing a highly educated labor force in addition to the regional research industry. Manufacturing of food and beverages, biotechnology, and environmentally conscious innovation are a few examples of other expanding industries ("ROCHESTER, N.Y. COMMUNITY PROFILE", n.d.).

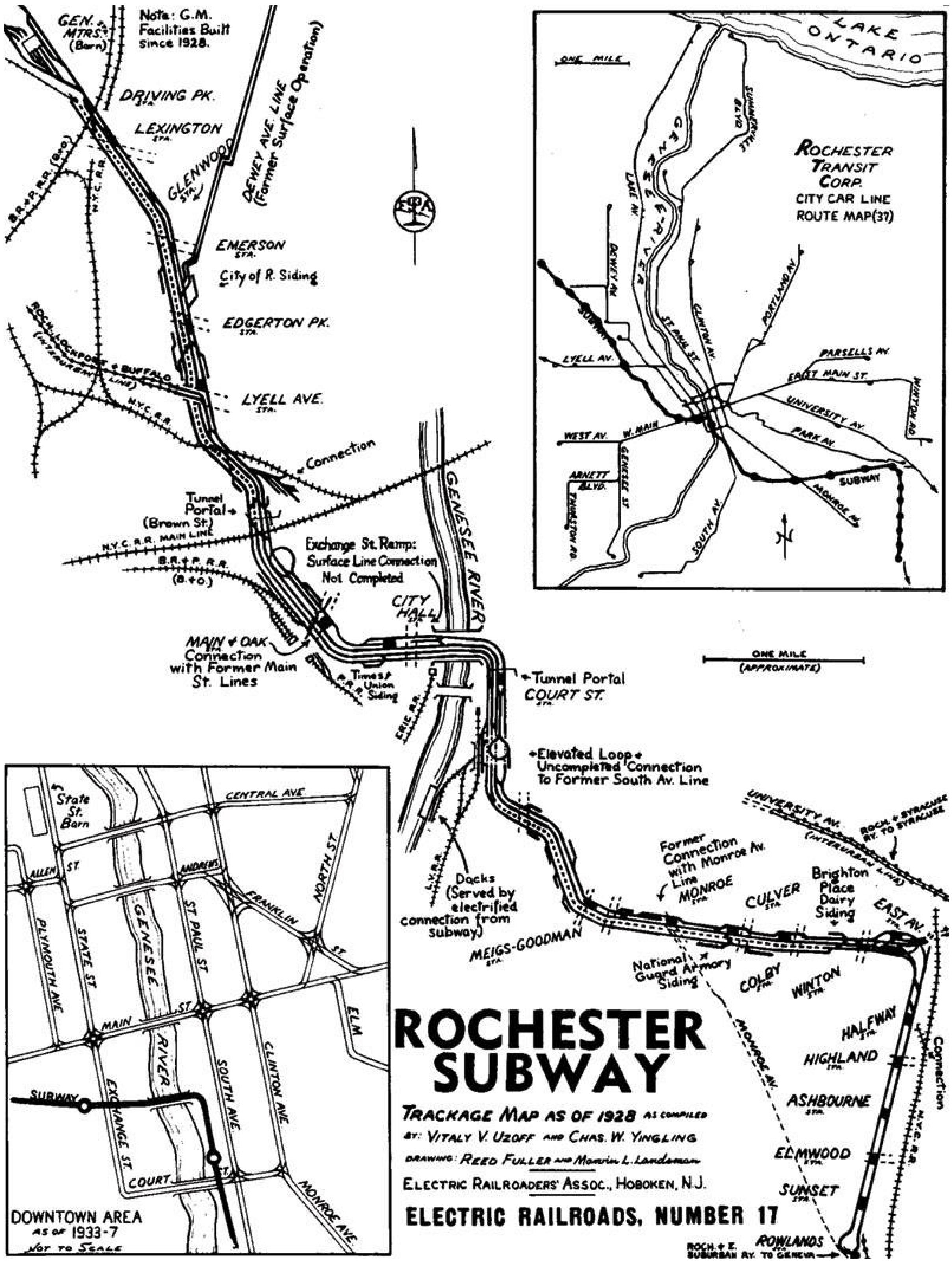
According to the census completed in the year 2021 by the United States, Rochester City had a populationof 210,606 people, making it the fourth most populous city in the state after New York City, Buffalo, and Yonkers. The city of Rochester is expanding at a rate of 0.04% each year, and its population has grown by 0.11% since the most recent census, which recorded a population of 211,328 in the year 2020. Rochester has a population density of 5,915 people per square mile despite its sprawling size of 37 miles in length. White people make up 37.1% of the city's population, followed by people of African American (36.3%) and Hispanic (18.7%) descent in that order (United States Census Bureau 2022).

The 2021 census data from U.S. Census Bureau shows that Rochester Metropolitan Statistical Area has a population of 1,088,383 people and 445,082 households, with an average population density of 333 people per square mile. About 76% of the population is white, 10% is black, and 8% is Hispanic. Over 93% of the population is native to the US. The median household income for the MSA is $65,812, with a Gini coefficient of 0.46. The Gini coefficient measures the inequality of health with the range of zero, indicating perfect equality, and one, representing maximal inequality. On average, people spend 21 minutes commuting to work, with more than 77% of people driving along to work ("Rochester, NY Metro Area" n.d.).

Regional Transit Service (RTS) is serving the public transit for the City of Rochester, actively running over thirty bus routes, commuter connections, and seven on-demand zones around Rochester (Regional Transit Service, 2023). Rochester once operated its underground rapid transit system, Rochester Subway, from 1927 to 1956 for passenger service, and some parts were protected for historical landmarks ("Abandoned Subway", n.d.). According to Next-Generation National Household Travel Survey, Rochester MSA had about 952 million totaltrips within the city in 2020, with about 796 million trips by vehicle and 156 million by active transportation orferries (ATF). There were about 989 million trips with origin or destination in Rochester MSA in 2020, within which440 thousand were in air mode, 29 thousand in rail mode, 832 million in vehicle mode, and 156 million in ATFmode. For trips inside Rochester MSA, only about 16.4% is for work purpose, and over 82.1% of trips are within 10miles (Federal Highway Administration (FHWA), 2022).




Map of RTS Routes, Image Source: https://www.myrts.com/Portals/0/RTS%20System%20Map%20layout.pdf

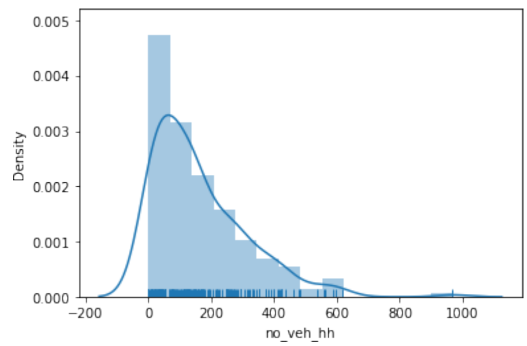



Rochester Subway Historic Map, Image Source:
https://rocwiki.org/Abandoned_Subway?action=Files&do=view&target=map.jpg

## Descriptive Statistics

The Number of Total Households

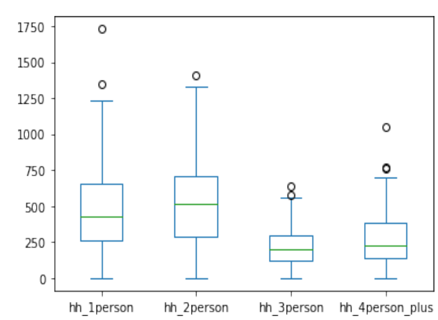
| | total_hhs | no_veh_hh |
|---|---|---|
| count | 211 | 211 |
| mean | 1478.46 | 163.20 |
| std | 657.22 | 151.64 |
| min | 0 | 0 |
| 25% | 1042.5 | 43.5 |
| 50% | 1468 | 125 |
| 75% | 1973 | 250.5 |
| max | 3263 | 968 |




- Among 211 census tracts in the Rochester area, the one with the largest number of households is 3263, while the smallest number of households is 0.
- Among 211 census tracts in the Rochester area, the one with the largest number of car-less/car-free households is 968, while the smallest number of households is 0.
- The number of no vehicle owning households is skewed to left :
  The left tail (smaller values) is much longer than the right tail (larger values). In a skewed left distribution, the bulk of the car-less/ car-free households per census tract is medium/large, with a few observations that are much smaller than the rest.

Family members per Households

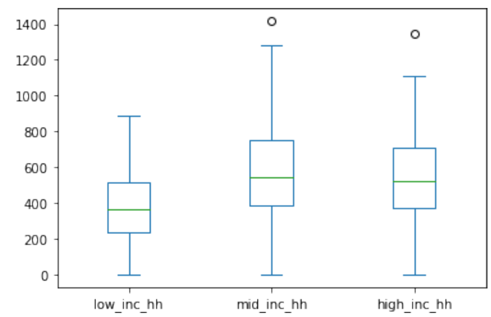
| | hh_1person | hh_2person | hh_3person | hh_4person |
|---|---|---|---|---|
| count | 211 | 211 | 211 | 211 |
| mean | 477.53 | 519.74 | 214.50 | 266.69 |
| std | 281.31 | 282.68 | 126.86 | 175.15 |
| min | 0 | 0 | 0 | 0 |
| 25% | 265 | 293 | 120 | 136 |
| 50% | 430 | 518 | 202 | 231 |
| 75% | 657.5 | 712 | 298.5 | 385.5 |
| max | 1730 | 1405 | 642 | 1052 |




- Among 211 census tracts in the Rochester area, the one with the largest number of single-person households is 1730, while the smallest number of households is 0.
- Among 211 census tracts in the Rochester area, the one with the largest number of 2-people households is 1405, while the smallest number of households is 0.
- Among 211 census tracts in the Rochester area, the one with the largest number of 3-people households is 642, while the smallest number of households is 0.
- Among 211 census tracts in the Rochester area, the one with the largest number of 4-people households is 1052, while the smallest number of households is 0.
- 3 and 4 people household shows less devoiatin than a single-person family or 2-people households, which means those are more clustered around the mean value.

Income level

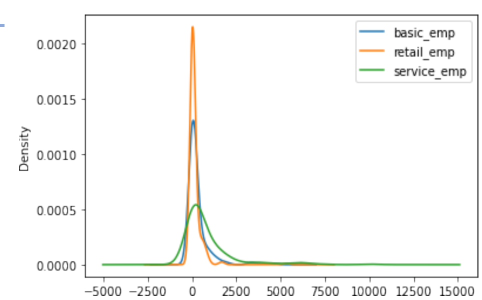
| | low_inc_hh | mid_inc_hh | high_inc_hh |
|---|---|---|---|
| count | 211 | 211 | 211 |
| mean | 374.83 | 568.58 | 535.05 |
| std | 185.48 | 267.24 | 248.20 |
| min | 0 | 0 | 0 |
| 25% | 234.5 | 386.5 | 373 |
| 50% | 364 | 547 | 522 |
| 75% | 518 | 755.5 | 709 |
| max | 885 | 1416 | 1347 |




- Among 211 census tracts in the Rochester area, the one with the largest number of low-income households is 885, while the smallest number of households is 0.
  In this criteria, households with less than 30 percentile were considered a low-income group within each census tract.
- Among 211 census tracts in the Rochester area, the one with the largest number of middle-income households is 1416, while the smallest number of households is 0.
  In this criteria, households with less than 70 percentile/ more than 30 percentile were considered a low-income group within each census tract.
- Among 211 census tracts in the Rochester area, the one with the largest number of high-income households is 1347, while the smallest number of households is 0.
- In this criteria, households with more than 70 percentile were considered a low-income group within each census tract.

The Number of Employee

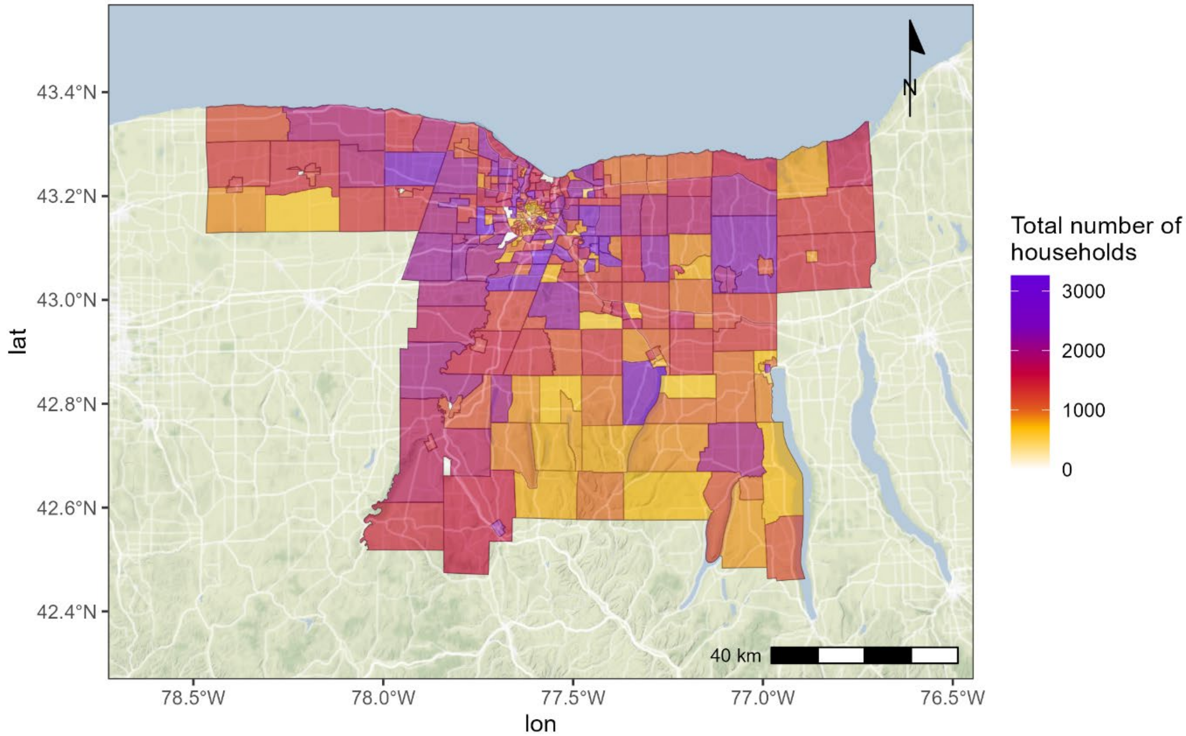
| | total_emp | basic_emp | retail_emp | service_emp |
|---|---|---|---|---|
| count | 211 | 211 | 211 | 211 |
| mean | 1292.92 | 307.34 | 153.11 | 832.47 |
| std | 2145.03 | 678.11 | 437.67 | 1447.73 |
| min | 0 | 0 | 0 | 0 |
| 25% | 80 | 6.5 | 2.5 | 28.5 |
| 50% | 550 | 51 | 30 | 263 |
| 75% | 1568.5 | 274.5 | 101 | 940 |
| max | 16186 | 4664 | 5345 | 10071 |



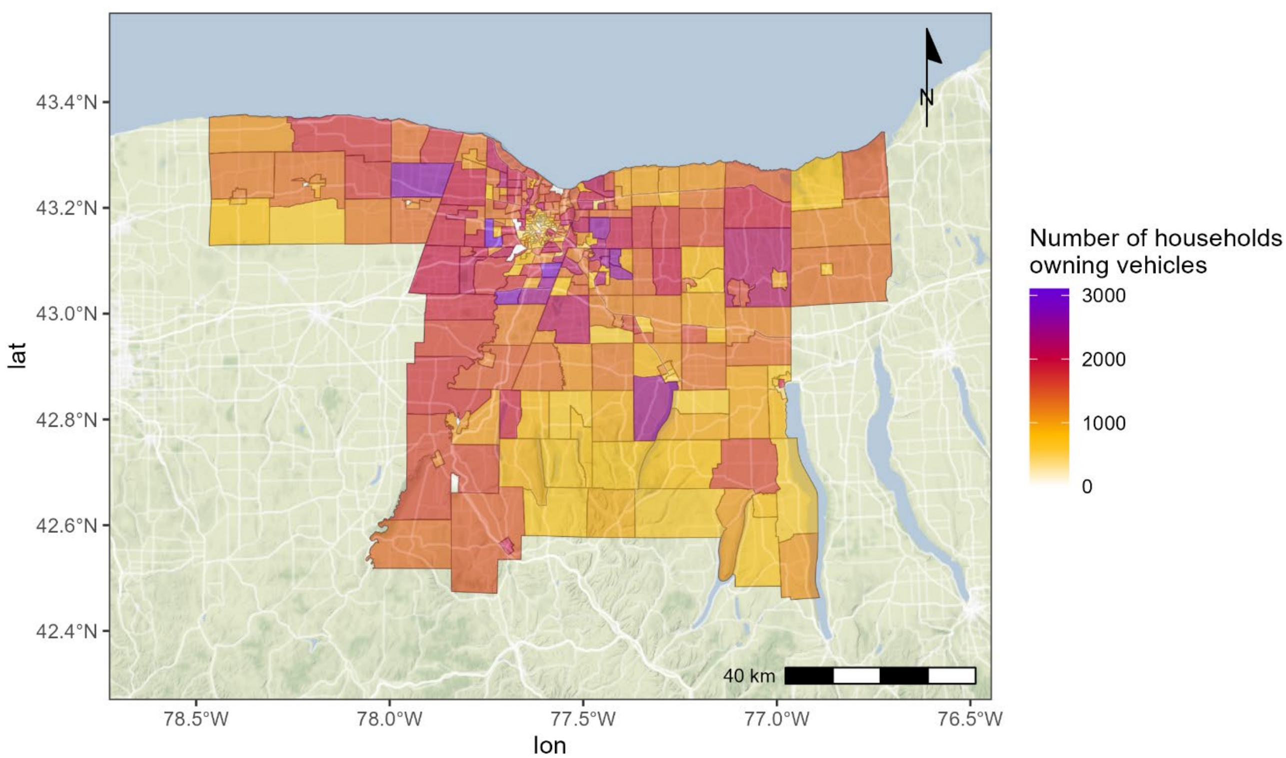

- Among 211 census tracts in the Rochester area, the one with the largest number of employment is 16186, while the smallest number of households is 0.
- Among 211 census tracts in the Rochester area, the one with the largest mean of employment is the service sector, followed by basic and retail.
- As shown in the kernel density plot, kernel density estimates are calculated by adding all row values; here, the number of employees for each sector is normalized by the number of data points. The bandwidth of employment is highest in retail sector, followed by basic and service.

## Spatial Distribution

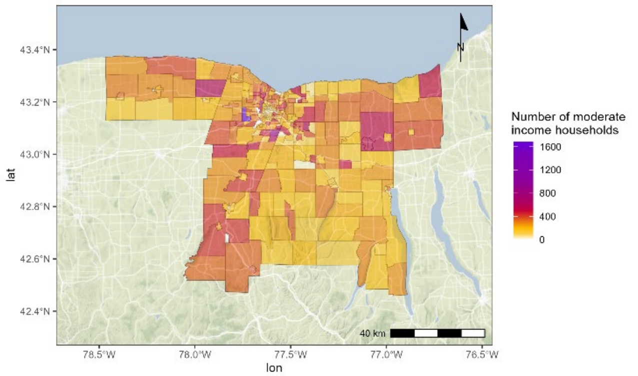
Total number of households:

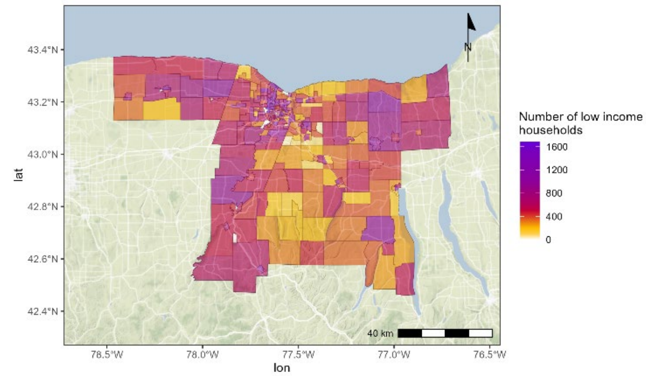


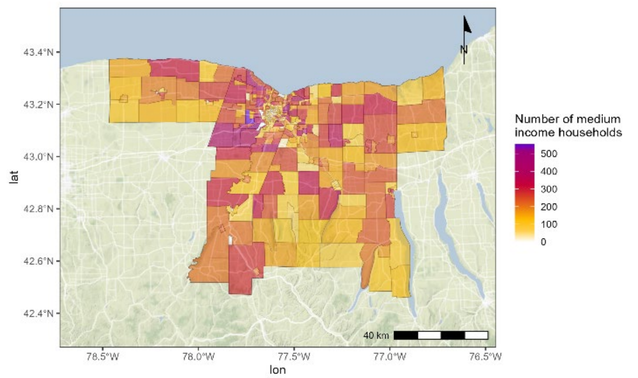

Household vehicle availability:

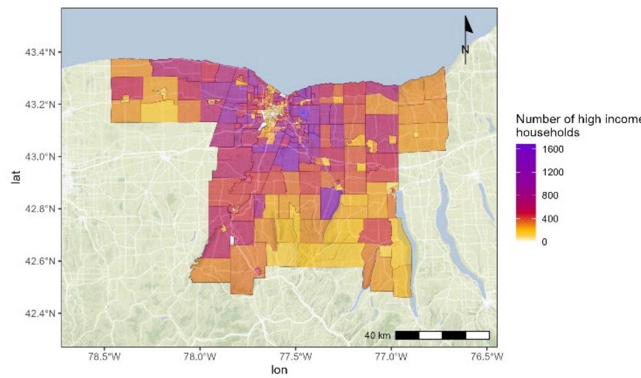


Household income:

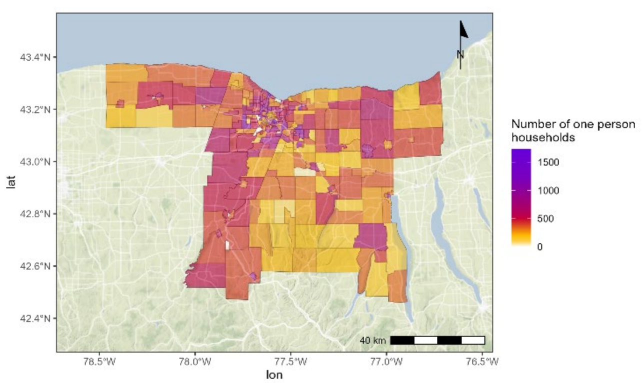


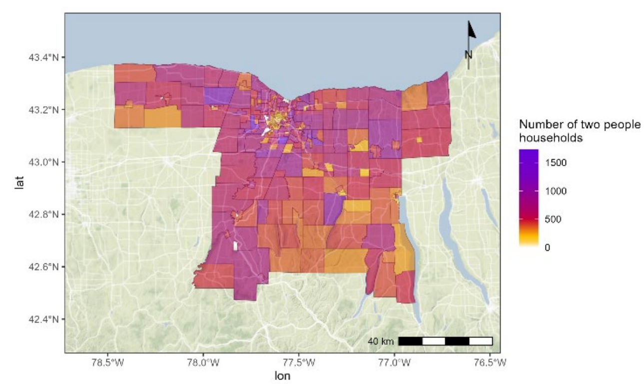



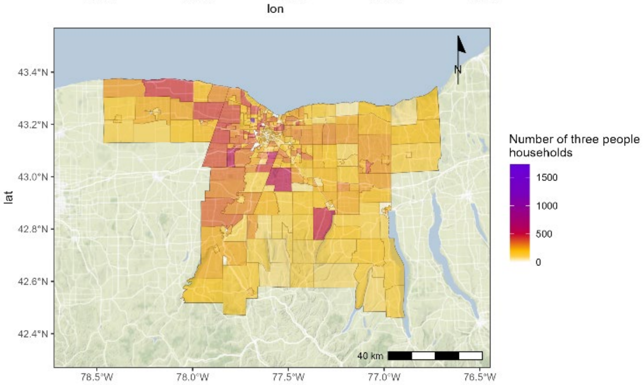



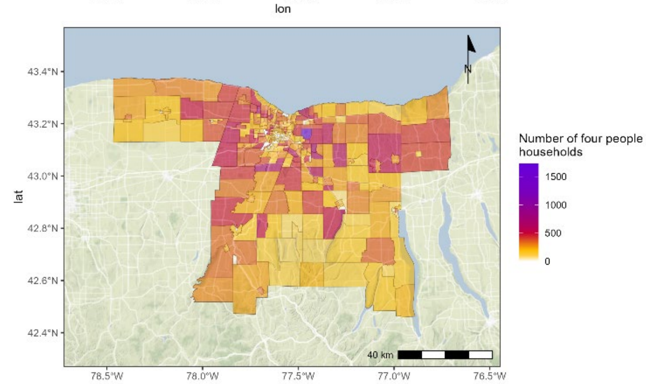




Household size:

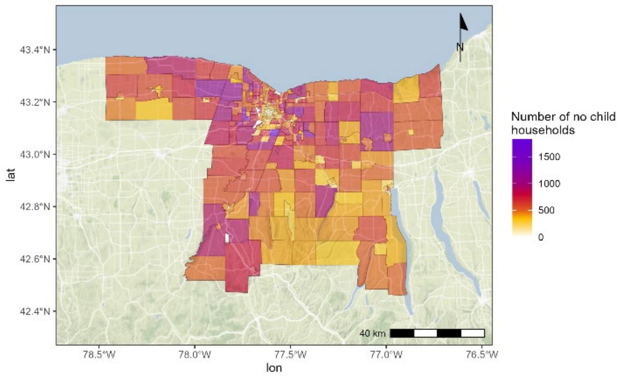


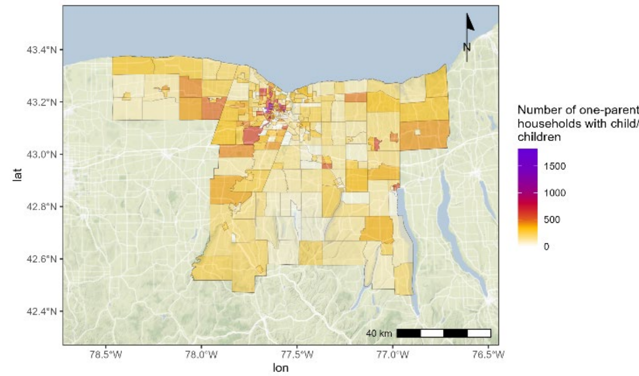



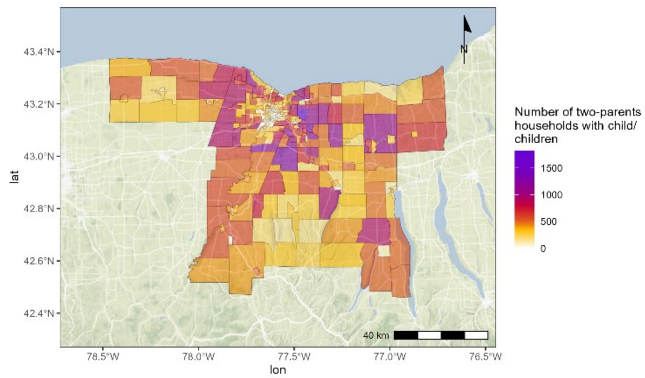



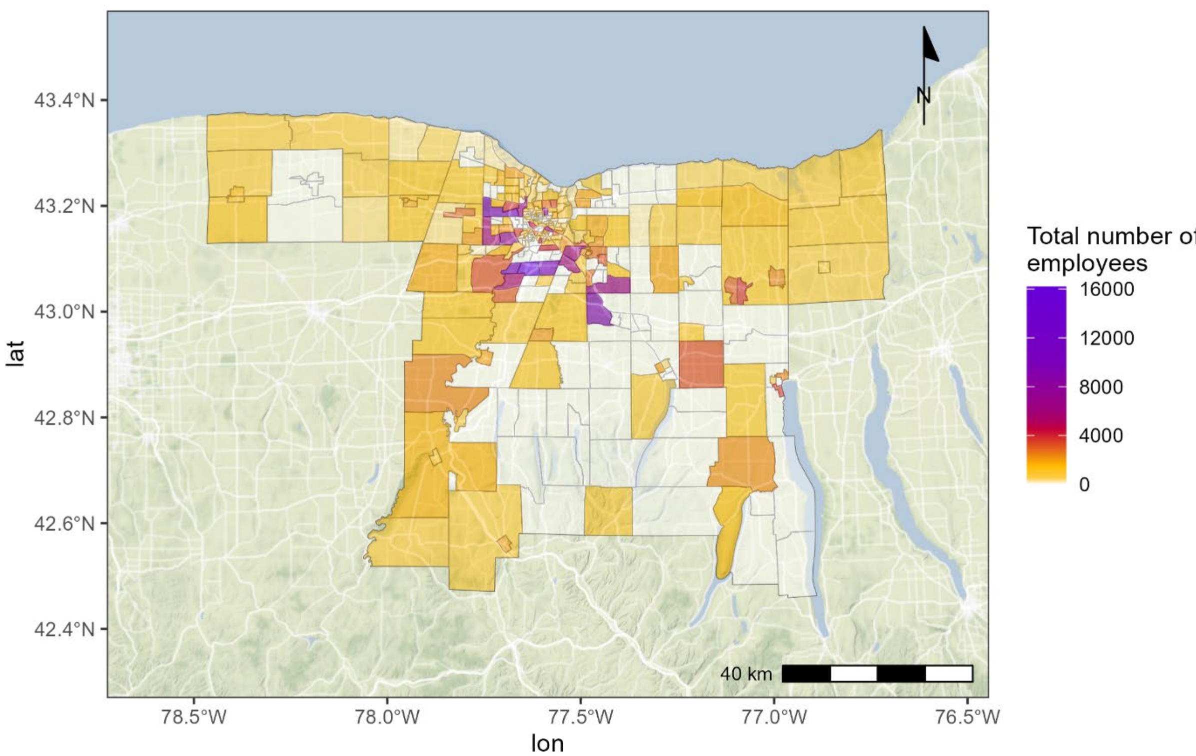
Household structure:



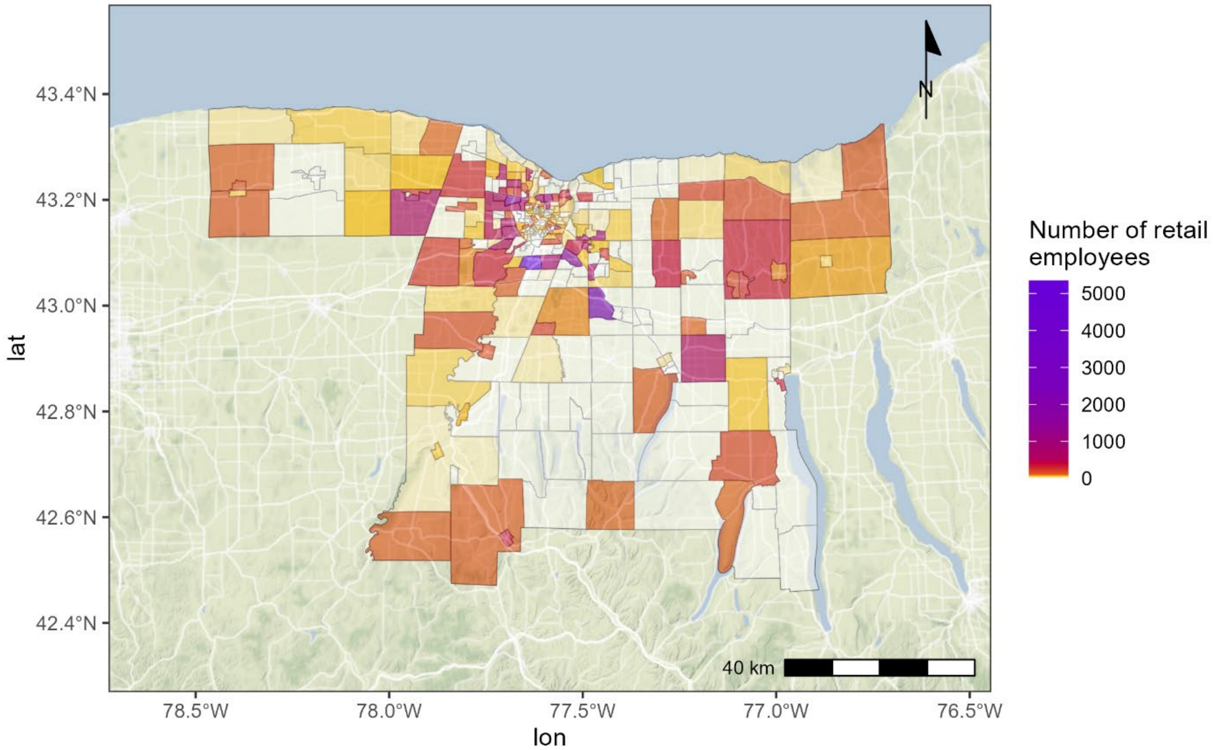



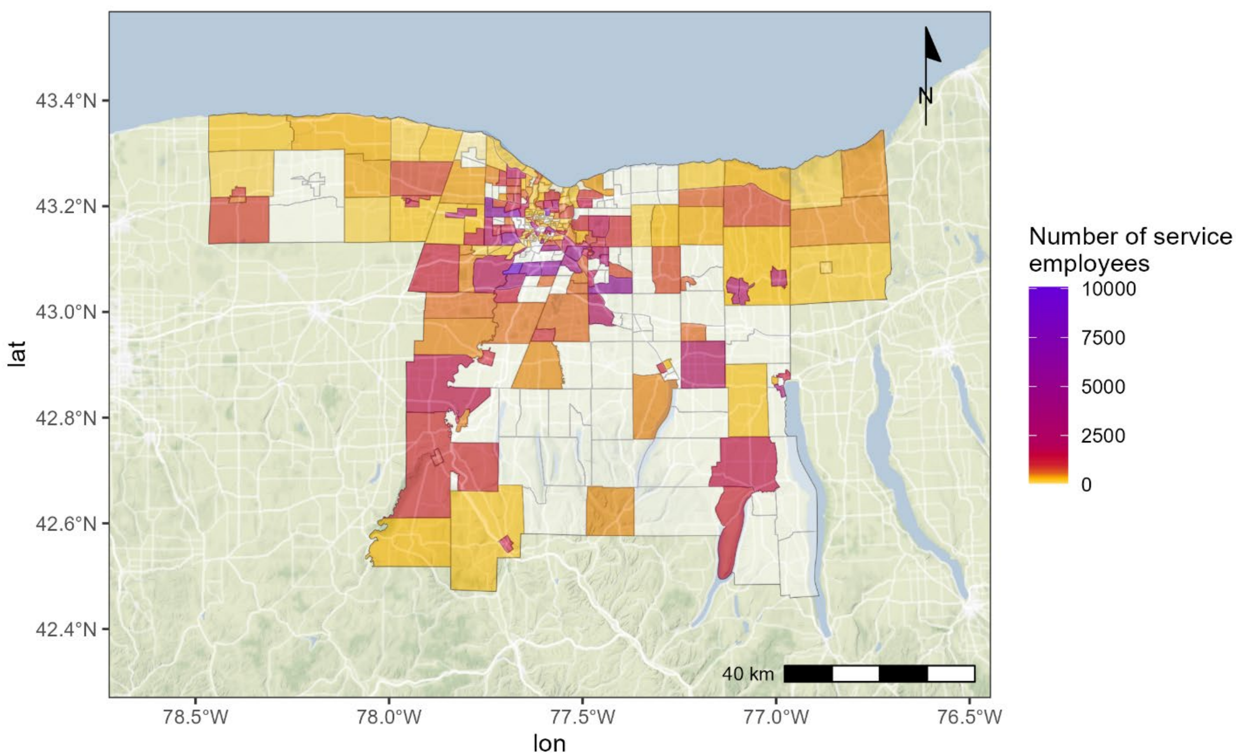

Total number of employees:



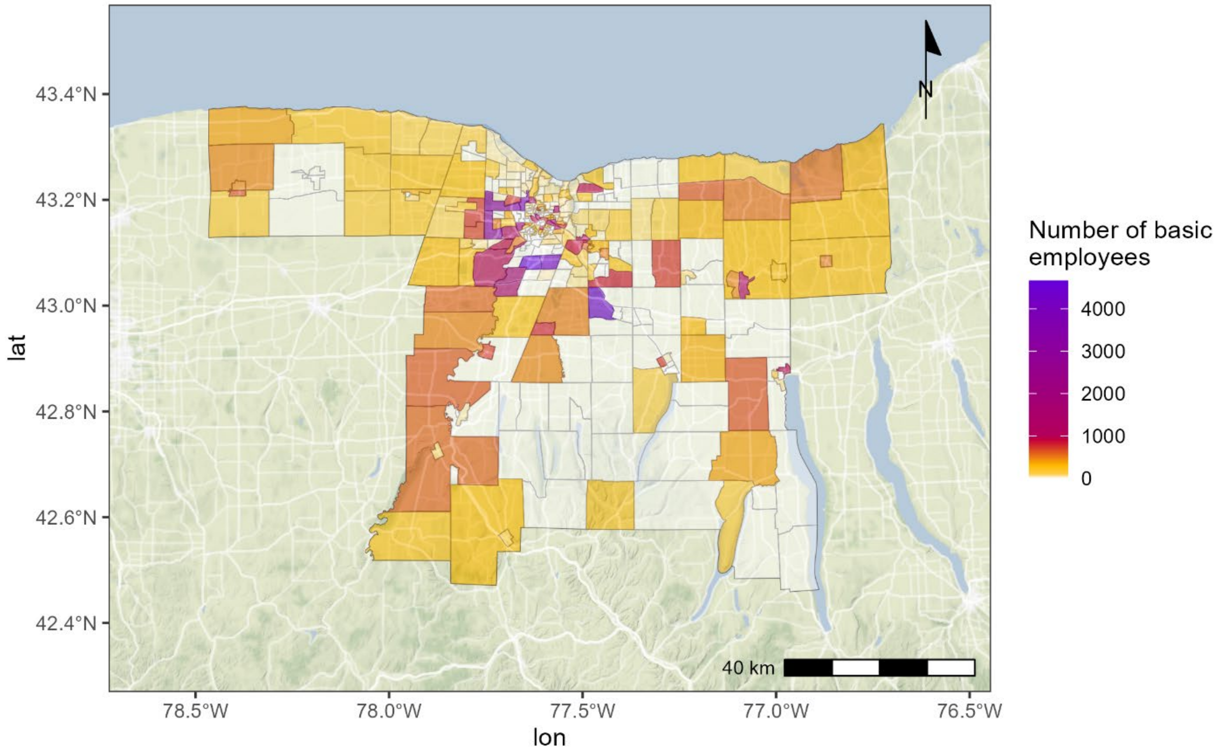
Number of retail employees:



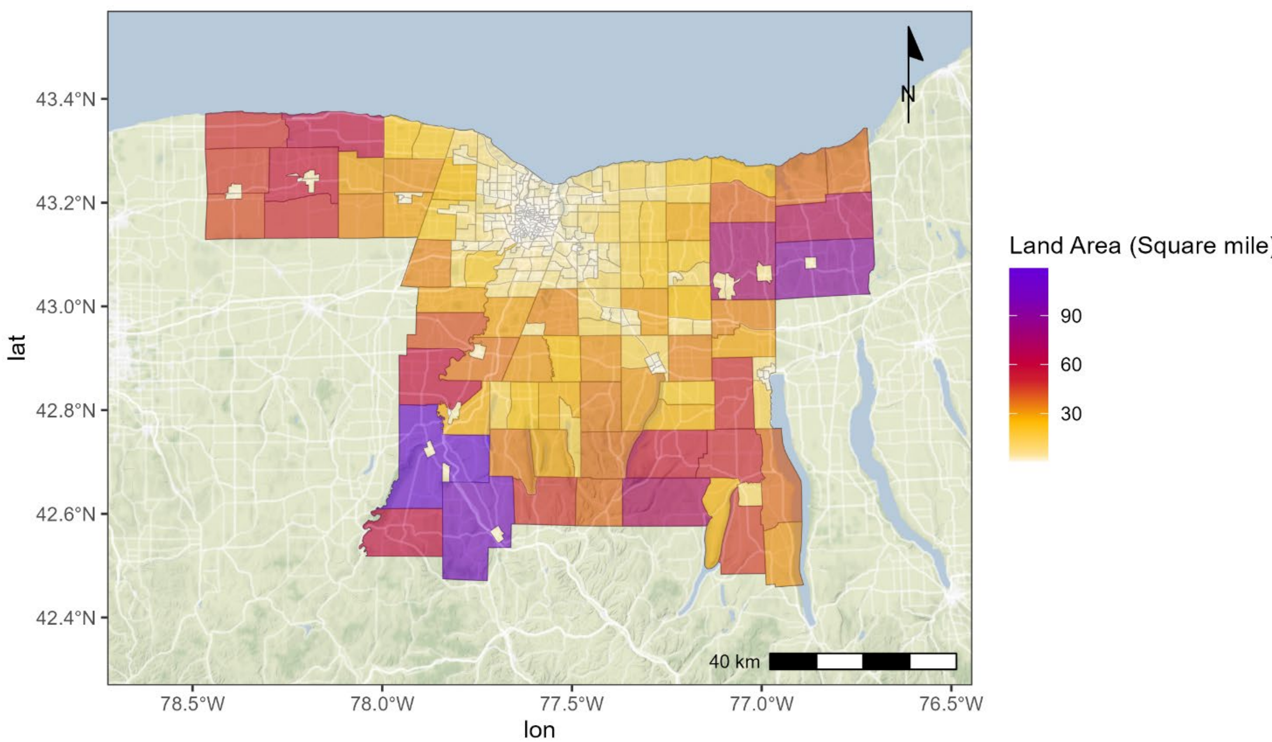

Number of service employees:



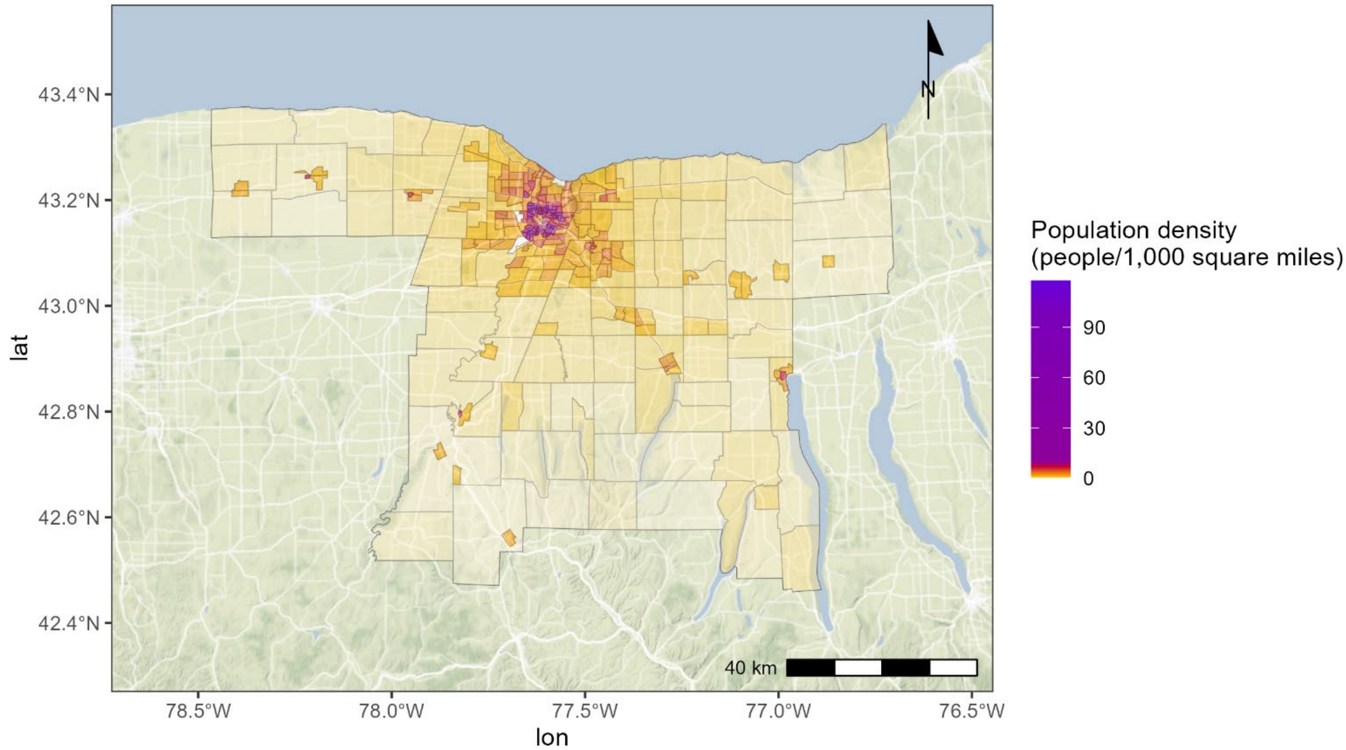
Number of basic employees:



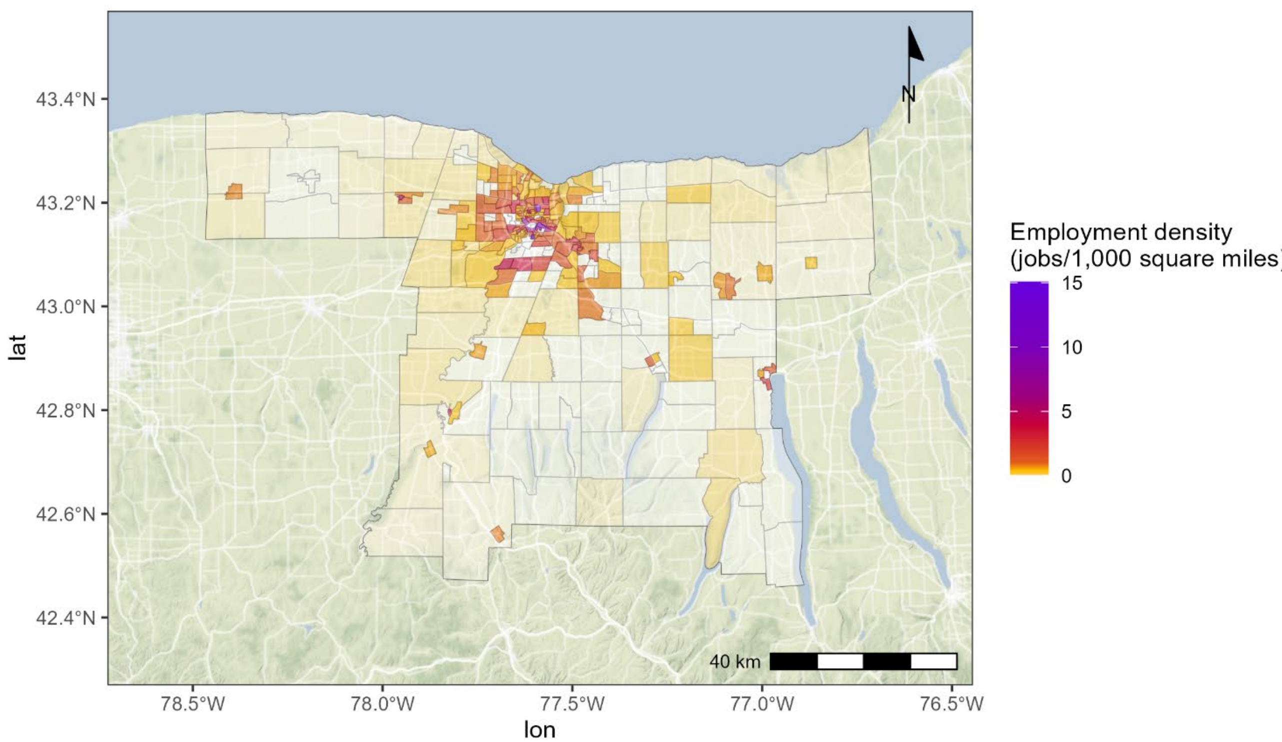

Land area:



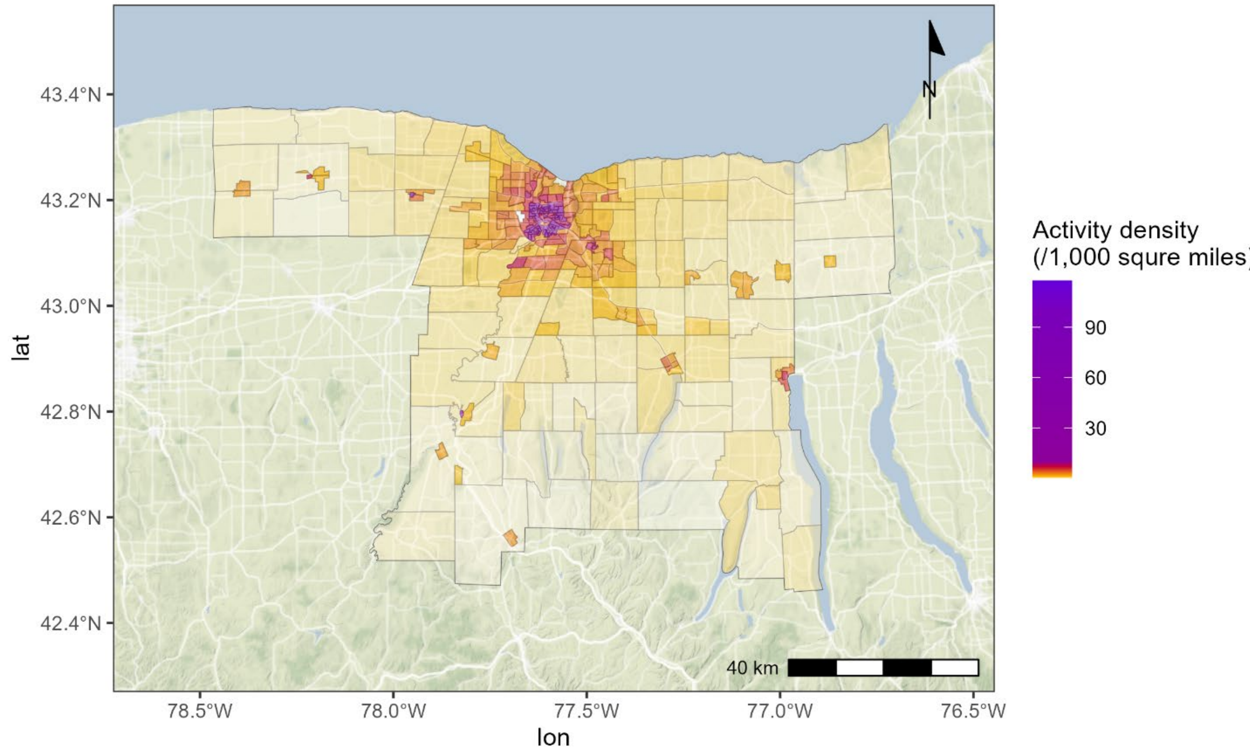
Population density:




Employment density:



Activity (population + employment) density:




## Road Network Skim

The network model for the vehicle includes road network under the classes of motorway, trunk, primary, secondary, tertiary, motorway_link, trunk_link, primary_link, secondary_link, and tertiary_link roads, with data gathered from OpenStreetMap. The following table shows the total milage and total lane milage of each class of road network in the model within the Rochester, NY MSA.

| Type of Road | Total milage (mile) | Total lane milage (mile) |
|---|---|---|
| Motorway | 366 | 836 |
| Trunk | 254 | 526 |
| Primary | 858 | 1780 |
| Secondary | 512 | 1104 |
| Tertiary | 1962 | 4070 |
| Total (Including Link Roads) | 5106 | 8508 |

We made the assumptions for the vehicle speed for road network as: motorway for 65 miles per hour, trunk for 55 miles per hour, primary for 50 miles per hour, secondary for 40 miles per hour, tertiary for 30 miles per hour, motorway_link for 40 miles per hour, trunk_link for 40 miles per hour, primary_link for 30 miles per hour, secondary_link for 30 miles per hour, tertiary_link for 25 miles per hour, and centroid connectors for 15 miles per hour.

**AMONG ONE CENSUS TRACT GENERATED TRIPS**

| **MAX** | MIN |
|---|---|
| **131.447281** | 0.690213 |

The longest travel time is one way trip from census tracts with GEOID 36073401200 to 36123150101.

The shortest travel time is one way trip from census tracts with GEOID 36055006900 to 36055006600 and from 36055006900 to 36055006600.

**SUM OF TOTAL TRIPS GENERATED AT A CENSUS TRACT**

| **MAX** | MIN |
|---|---|
| **23465.63774** | 5695.3497 |

The census tract has the largest sum of total travel time to the other zone is census tract with GEOID 36123150101. The census tract has the smallest sum of total travel time to the other zone is census tract with GEOID 36055009403.

**TRAVEL TIMES BETWEEN THE O-D PAIRS**

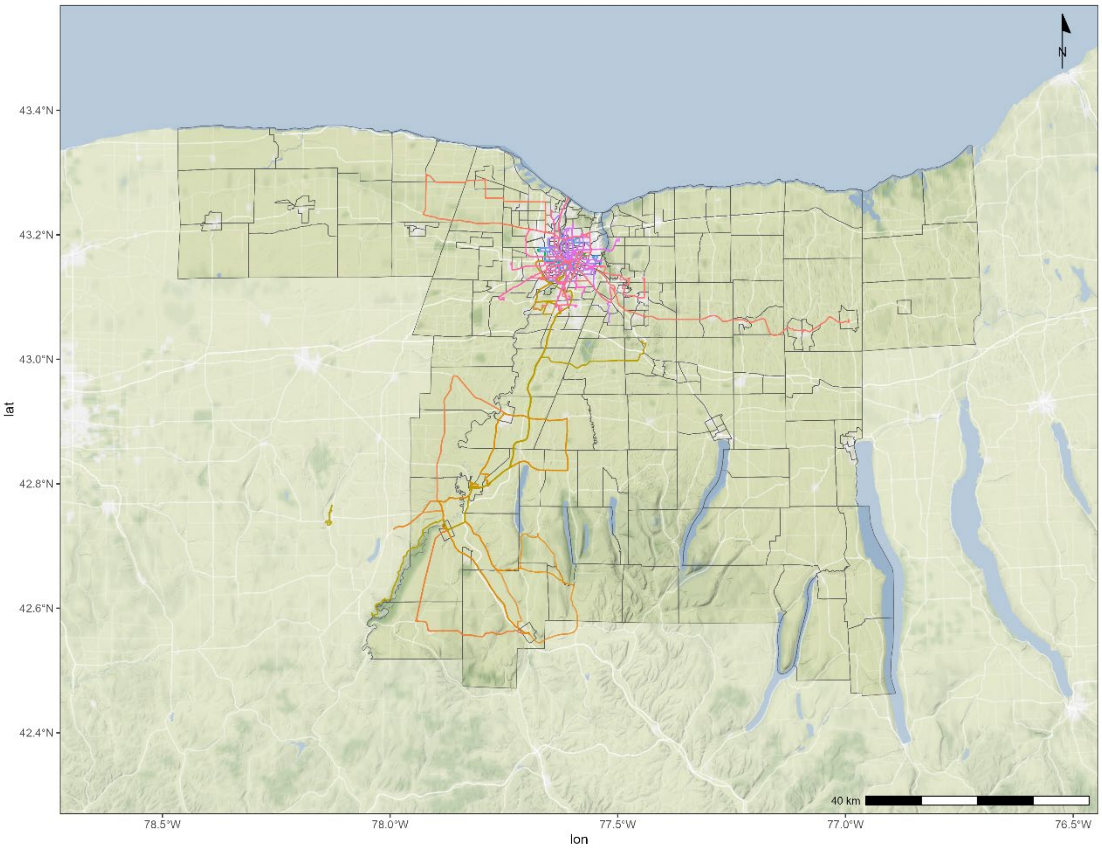
| **MIN.** | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|---|---|---|---|---|---|
| **0.6902** | 12.7828 | 25.4514 | 29.503 | 42.6054 | 131.4473 |

The shortest travel time between a Origin-Destination round trip is the one between census tracts with GEOID 36055006900 and 36055006600.

The longest travel time between a Origin-Destination round trip is the one between 131.4473 is census tracts with GEOID 36123150101 and 36073401200.

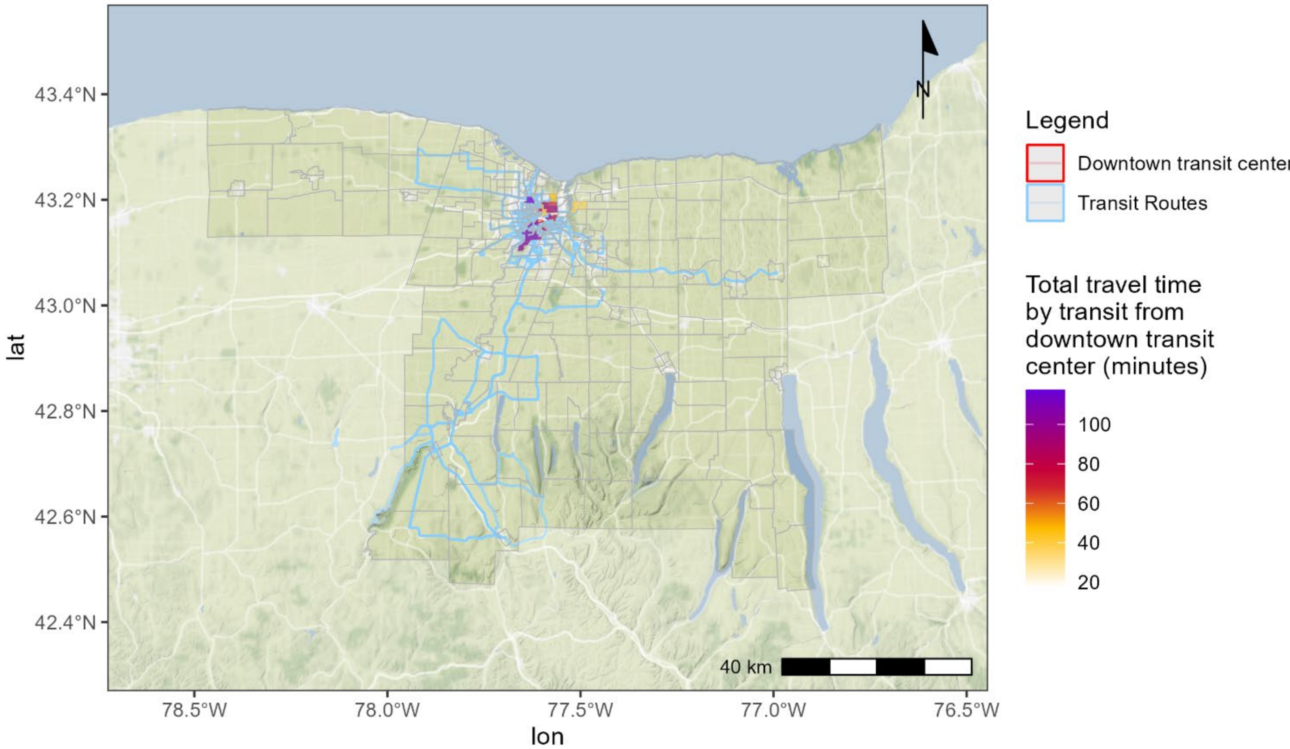
## Transit Network Skim

In this analysis, we imported 135 transit routes in Rochester, NY, Metropolitan Statistical Area from Regional Transit Services (RTS), which operates at weekday evening peak hours between 4:00 pm and 7:00 pm. The transit routes in the region are shown in the below image.



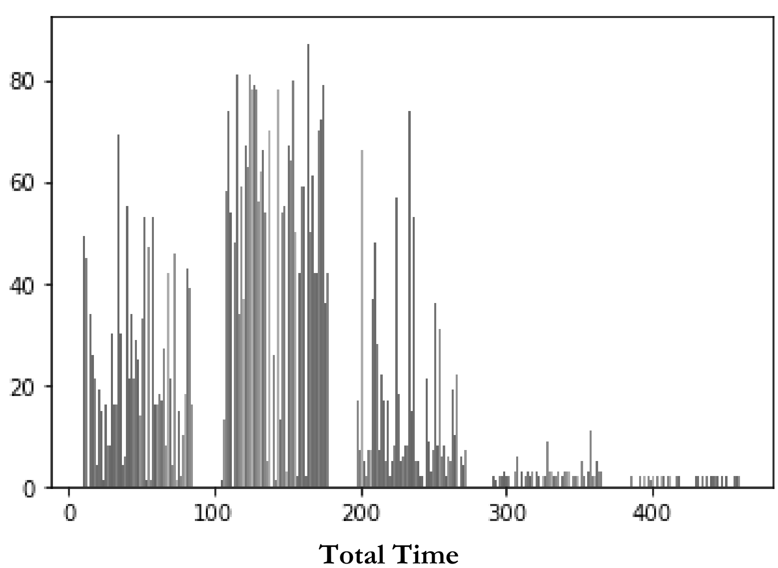

Transit Routes in Rochester, NY MSA

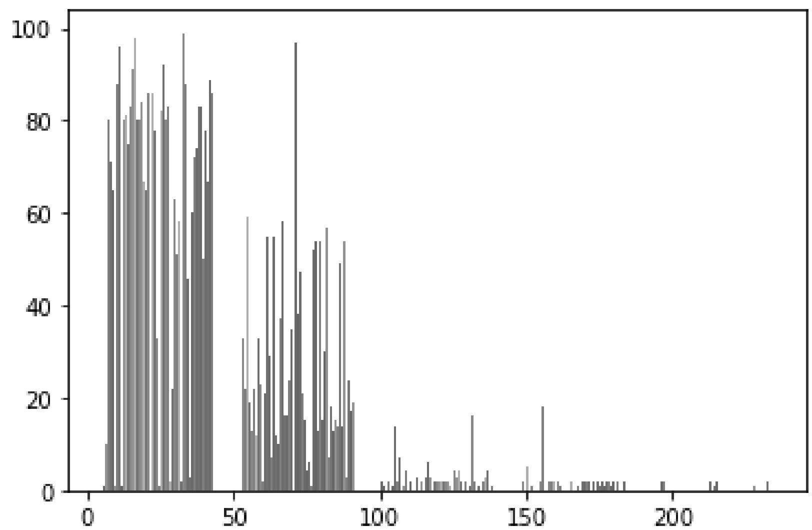
We made some assumptions and simplifications in building the network based on some empirical knowledge. Since we do not have underground in the region, we assumed the vehicles moving in the transit network with a speed of 17 miles per hour. When building the network, we set a maximum transfer time of five times. We also assume that people in the census tract start their journey in the centroids and walk at the speed of 2.8 miles per hour to the transit stations, adjusted for people walking for longer routes than the centroid connectors in real life. The transit fee is set as a flat fee of one dollar without a transfer fee according to the actual full fee for adults in the region. The interarrival parameter is set to be 0.5, and the maximum initial wait time is 15 minutes, which means that for headway less than or equal to 30 minutes, we assume that people wait at the station on average for half of the headway, without caring too much about the arrival times. For headway larger than 30 minutes, we assume that people get to the stations 15 minutes before the transit leaves the station, accounting for the information about the arrival time and the consideration of the cost of missing a bus. The maximum transfer wait time is set to be sixty minutes, and the transfer penalty is three minutes. The minimum wait time for both the initial ride and transfer is two minutes. The maximum access and egress walk time are twenty minutes.



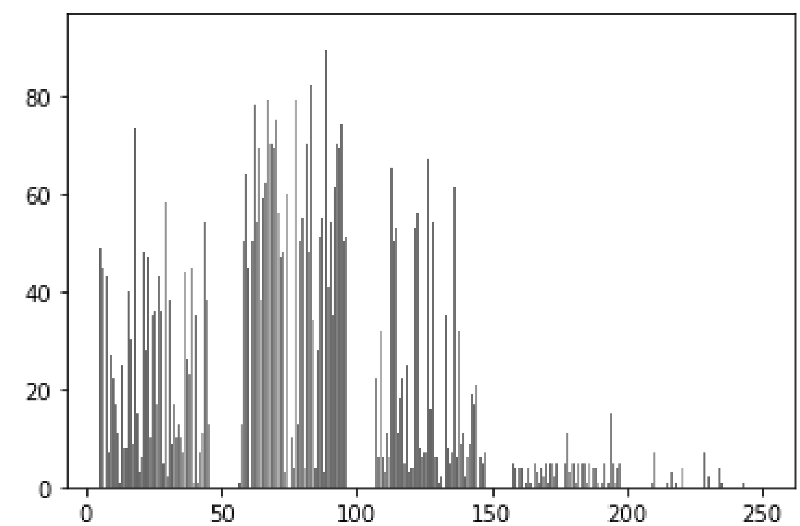

Total travel time by transit from Rochester downtown transit center within two hours with red area showing the census tract downtown transit center falls in

Moreover, it might be derived using the data obtained from the transit skim, as is illustrated below. The values that are not included in the large clusters of the histogram are likely to be an outlier due to the fact that the amount of time consumed is excessive.






**In Vehicle Time**




**Transfer Wait Time**

The model for building the transit skim has some limitations, as listed below.

First, we should have manually drawn the links between transit stations for better simulation so that transfers could happen not only to transit routes that share the same transit stations. In real scenarios, people may walk for a while if it makes them transfer for less time or get to places they cannot access without these walking transfers. It underestimates the accessibility of the transit system in the area.

Second, we calculate the walking time from the centroids of census tracts to the transit stations based on the centroid connectors rather than the actual road networks. Although we downgraded a bit for the walking speed, it would still cause some mismatch from reality.

Third, we allowed at most five times for the transfer and a maximum waiting time of an hour for the transfer. Therefore, some results show that the transfer wait time for some travel is higher than three hours, which is unreasonable. People may be less willing to transfer so many times and wait for such a long time for a transfer in real life. In this case, the model overestimates the accessibility of the transit system.

## Accessibility

In this analysis, accessibility is measured by the ease with which a person can fully participate in mostly the economic life of their society. The accessibility is affected by both the mobility and the proximity. The accessibility increases when people can access larger areas with the same amount of time. It also increases when their destinations for activities are closer to people's origin. We calculate the number of total employment accessible by the households within each census tract by car and transit using the gravity-based decay function, which weighs easier-to-reach destinations more than the harder-to-reach ones instead of a binary cumulation with a fixed threshold. Further study can include broader aspects like the civil and social life by calculating the accessible facilities, like the schools and parks.

Based on Santana Palacios and El-geneidy's article, we chose the logistic function for the measurement for better model fit than the cumulative opportunities-based measurement (Santana Palacios and El-geneidy 2022). As shown in the 2022 data from US Census Bureau, the average commute time to work in Rochester, NY MSA is 21 minutes with 85.2% driving alone or carpooling and 1.8% taking public transit. We consider people can accept a slightly longer travel time for transit when they compare the two modes based on total cost of travel. Therefore, we adjust for the decay function slightly for car and transit using 20 minutes as inflection and 12 minutes as standard deviation for car and 25 minutes as inflection and 12 minutes as standard deviation for transit. The monetary cost of taking transit is lower than driving.

$$Accessibility\ Weight_{car} = \frac{1}{1 + e^{\frac{(Travel\ Time_{car} - 20)}{12}}}$$

$$Accessibility\ Weight_{transit} = \frac{1}{1 + e^{\frac{(Perceived\ Travel\ Time_{transit} - 25)}{12}}}$$

During the calculation process, we use the perceived travel time for transit as studies reveal that transit riders perceive out-of-vehicle travel time (OVTT) more than in-vehicle travel time (IVTT). In the review of travel demand modeling studies in the U.S., the U.S. Environmental Protection Agency (2000), walking time, waiting time, combined walking and waiting time are considered twice as much as in-vehicle travel time for large urban areas over 750,000 population, and Rochester MSA falls within this category (Iseki, Taylor, and Miller 2006, 25). Therefore, the perceived travel time for transit is calculated as below. With further investigation on how people perceived waiting and walking time when taking transit compared to travel time in the transit based on latest data of survey, the study may improve the model of calculating perceived travel time for transit.

$$Perceived\ Travel\ Time_{transit} = IVTT + 2 \times OVTT$$

For a more straightforward interpretation of the accessibility calculated based on the gravity-based decay function, we calculate the accessibility index for both cars and transit within the Rochester MSA, NY. After summing up the product of the number of jobs and the weights from each census tract, the accessibility index is calculated by dividing the value by the maximum accessibility within the Rochester MSA, NY, then multiplying by 100. A census tract with the value of 50 of the accessibility index indicates the census tract is accessible to about half number of total jobs compared to the census tract with the maximum accessibility by the respective transit mode.

There are two ways to measure transport accessibility when discussing it in a specific region. The first is to measure car accessibility and transit accessibility separately, whereas the second is to measure overall accessibility as the weighted sum of car accessibility and transit accessibility.

It should be clear enough to show the accessibility of cars and transit separately, as any method adopted to calculate the overall accessibility for cars and transit is mainly subjective and controversial. By separating two accessibility categories, we can examine travel behavior in greater detail.

The accessibility for travel by car with average travel time and travel by transit during the weekday evening peak hours show different patterns within Rochester, MSA. The proximity is the same for the two transit modes, while the road network determines the mobility of cars, and the mobility of transit is largely affected by frequency and coverage.

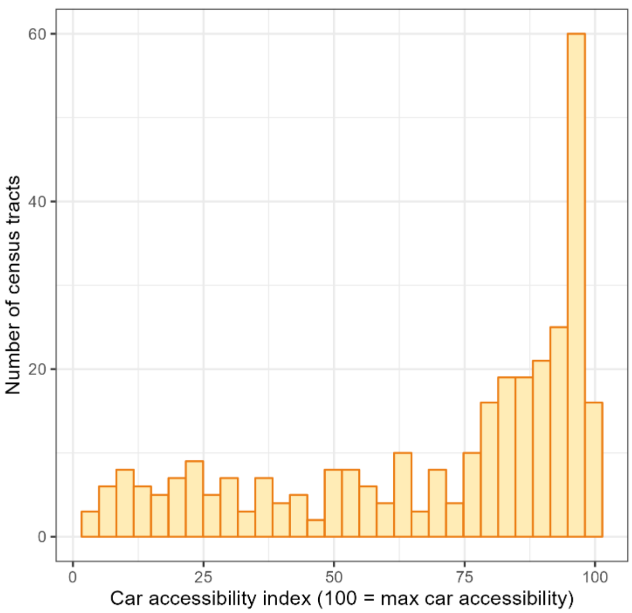
We can comprehend modal preferences between two modes when we separate car accessibility and transit accessibility. Measuring car and transit accessibility separately enables a more thorough understanding of how people in a region prefer to travel. Some people prefer to drive, while others prefer to take public transportation. By measuring accessibility separately, we can better understand which areas are more accessible to drivers and which are more accessible to transit users.

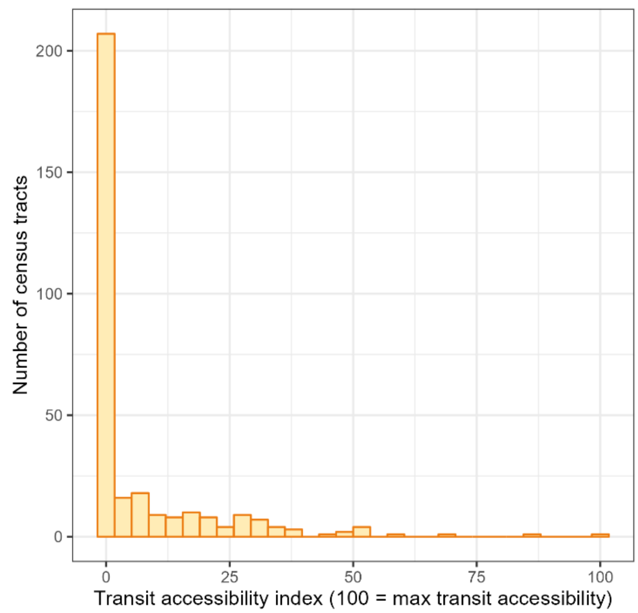
Moreover, it is crucial to identify mobility barriers. For instance, a region may be easily accessible by car but have few public transportation options, making it difficult for those without a car to get around. In contrast, a region may have good transit accessibility but be difficult to navigate by car, making it difficult for those who rely on driving to get around. Barriers to mobility differ slightly from modal preferences because the barrier eliminates options where the barrier exists, which is a more potent factor in determining travel demands.

Furthermore, measuring car and transit accessibility separately can also assist in targeting transportation investments more effectively. For instance, if a region has good transit accessibility but poor car accessibility, it may make sense to invest in road improvements or the construction of new highways to improve car accessibility. In contrast, if a region has good car accessibility but poor transit accessibility, it may be prudent to invest in public transit infrastructure to increase transit accessibility.

Descriptive statistics of car and transit accessibility index

| Mode | Mean | Min | 1st Quantile | Medium | 3rd Quantile | Max |
|---|---|---|---|---|---|---|
| **Car** | 69 | 4 | 49 | 82 | 95 | 100 |
| **Transit** | 7 | 0 | 0 | 0 | 7 | 100 |

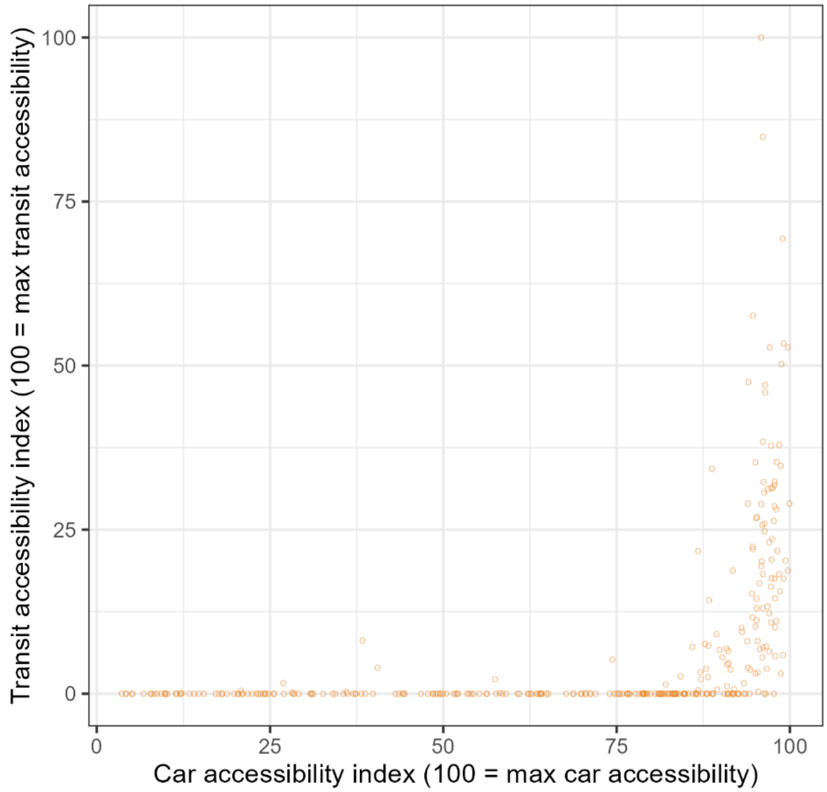


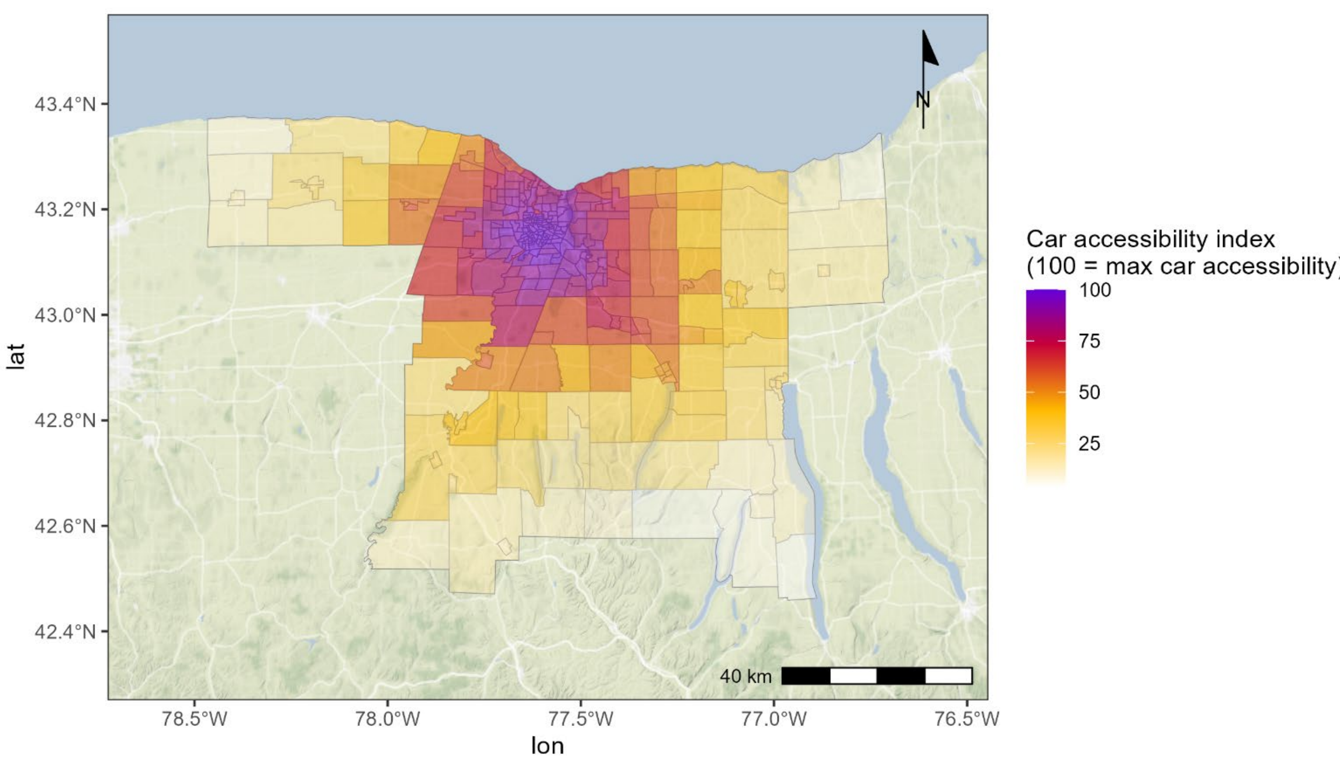

Distribution of car (left) and transit (right) accessibility index

There are many census tracts with high car accessibility, near the maximum accessible tract in the MSA. However, there are many census tracts without transit accessibility due to the limit of coverage of transit during the weekday evening peak hours. There are much more census tracts with much lower transit accessibility than the most transit accessible tracts than the ones with relatively high transit accessibility.

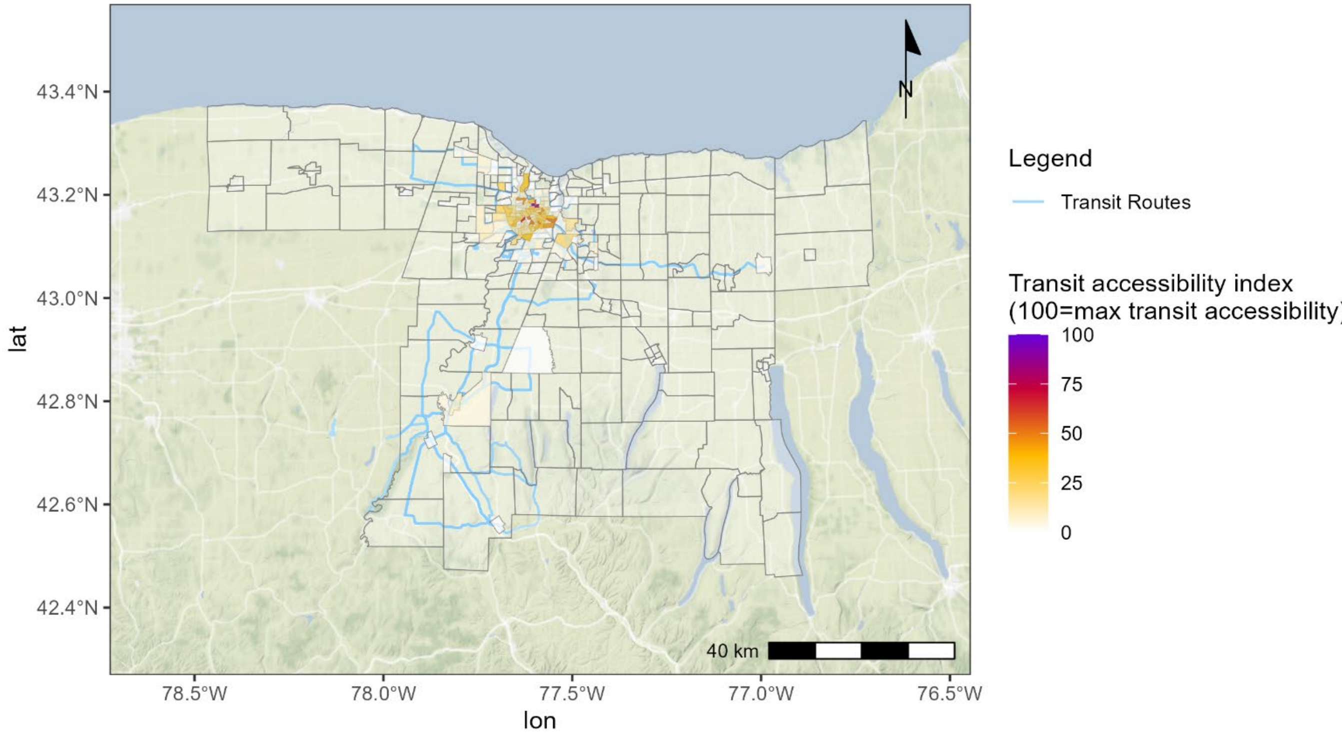
Census tracts that are transit accessible tend to be more accessible by car, mainly with a car accessibility index higher than 80. It indicates that transit primarily operates within the areas with more development opportunities and density. For tracts accessible by transit during weekday evening peak hours, tracts with higher car accessibility tend to have higher transit accessibility. No census tracts are accessible by transit for tracts with a car accessibility index lower than 26.




Relation of car and transit accessibility index




Spatial distribution of car accessibility index




Spatial distribution of transit accessibility index

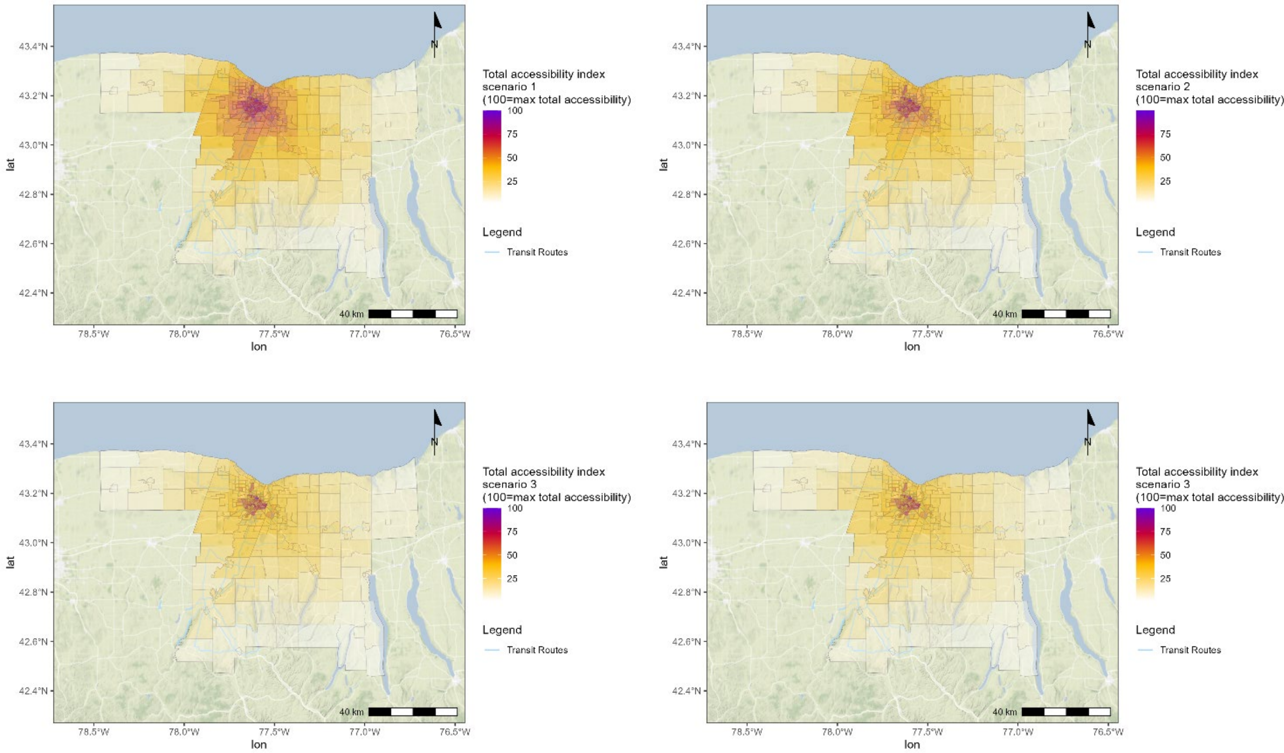
One possible way to calculate the overall accessibility is to weigh car and transit accessibility based on mode share. In this case, transit accessibility would mean little to the overall accessibility, and it raises the equity issue and environmental concerns. As we outweigh car accessibility to transit accessibility, fewer opportunities would exist for improving and even maintaining the transit system. People without the privilege of driving cars would find it harder to travel, and people with cars could drive more and increase greenhouse gas and pollutant emissions based on current technologies. If we outweigh transit accessibility to car accessibility, we need more research to support the choice of different weights for cars and transit. The following graphs show how four different scenarios for weighing car and transit accessibility affect the total accessibility measurement.

Scenario 1: $Total\ Accessibility\ = 1.5 \times Car\ Accessibility + Transit\ Accessibility$

Scenario 2: $Total\ Accessibility = Car\ Accessibility + Transit\ Accessibility$

Scenario 3: $Total\ Accessibility = Car\ Accessibility + 1.5 \times Transit\ Accessibility$

Scenario 4: $Total\ Accessibility = Car\ Accessibility + 3 \times Transit\ Accessibility$




Four scenarios of calculating total accessibility index

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